Book of Abstracts for the 4:th CEAS Conference, 2013.

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of the 4:th CEAS conference, Linköping 2013

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Welcome

We welcome you to the fourth CEAS (Council of European Aerospace Societies) Air and Space Conference. We have chosen the theme 'Innovative Europe' for the gathering of Europe's most qualified professionals in air and space technologies.

Europe has a leading role in research, engineering and manufacture of aerospace systems. Today, development of new concepts and systems are increasingly dependent on cooperation and mutually beneficial relationships, such that meetings and networking between professionals become even more important. Those are the basics for this conference, and the necessary elements for the air and space industries of Europe to take innovative and leading steps into the future. We are very happy to have received so many high quality contributions in such a wide range of topics. We are also proud to have a number of very high profile keynote speakers and thematic sessions with invited speakers, to reflect

the overall theme of the conference. There are contributions from more than twenty countries, also from outside of Europe. Integrated in this conference are also a great number of national contributions in line with our regular national conference on aviation and space technologies. We feel confident that this range of presentations will firmly establish the CEAS Air & Space conference as one of the most important events among the community of air and space professionals.

The city of Linköping has a background of more than one hundred years in aviation, and is the locus of many emerging companies in the air and space arenas. Additionally, Linköping is situated in a beautiful rural district with many lakes, channels and rivers. The city was founded in the 12th century and is the fifth largest city in Sweden, where you can find many places and buildings of historical interest.

We wish you a fruitful meeting and a pleasant stay in Linköping.

Petter Krus
Chairman of programme committee
Professor in Fluid and Mechatronic
Systems, Linköping University

Roland Karlsson
Chairman of the organizing committee
Chairman of the Swedish Society of
Aeronautics and Astronautics

Some words from the program secretary

This document is the collection of abstracts of papers and presentations held at the CEAS2013 conference. They are a mix of academic papers and industrial presentations, joining the 4:th CEAS air and space conference with Flygtekniska föreningens Flygteknik Congress 2013.

At the submitting to press the final presentation program was not yet fixed, meaning no index of presentation slots could be given. However, the abstracts herein are ordered after topic. Papers numbers of papers that have been withdrawn after printing will be posted at the conference.

Abstracts are listed in the index section, sorted on page number, paper number and first author name.

Full papers for the academic contributions will be available in the proceedings after the conference.

I would personally like to thank all authors who have worked hard and submitted their work to this conference, thereby helped making CEAS2013 an endeavour of the highest quality.

Dr. Tomas Melin, program secretary

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4:th CEAS Air & Space Conference
FTF Congress: Flygteknik 2013

Navier-Stokes Simulations of Store Separation

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FOI, Sweden

Lars Tysell
FOI, Sweden

Keywords: *unsteady aerodynamics, store separation*

Abstract

CFD has become increasingly important in the design of systems for store separation. It offers opportunities to investigate complex flow physics interacting with the separated store, which is a basis for the design of the store release unit (ERU). An integrated system for numerical simulation of store separation by solving, quasi-steady or unsteady, Euler or Navier-Stokes equations is presented. The flow computations are coupled to a 6-DOF rigid body motion module. The grid is deformed in order to conform to the moving boundaries and remeshed when the grid deformation module fails to achieve sufficient grid quality. The computational method is assessed against experimental data for an AGARD test case, separation of a generic finned-store shape at transonic speed from a wing-sting-pylon configuration. The computational results compares well with wind tunnel measurements.

1 Introduction

In the last decades, computational fluid dynamics coupled to 6-DOF simulation have been applied to analyze store separation scenarios. The three main components of the computational model consists of flow solver, grid system and flight mechanics model.

Quasi-steady Euler computations have been successfully applied to simulate separation of external weapons Ref. [1-3]. If stores are separated from weapons bays, the flow around the weapons is unsteady and the computations must be time accurate viscous simulations in order to capture relevant flow physics, Ref. [4-5].

1.1 Flow solver

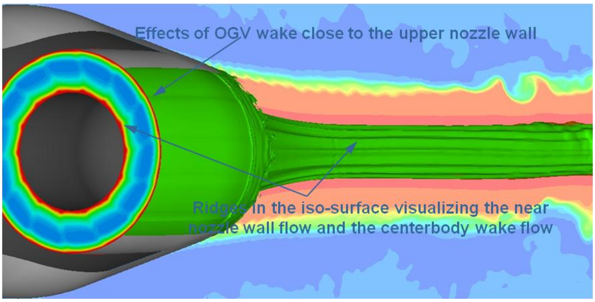
The CFD computations are carried out with FOI in-house tool Edge, Ref. [6]. The Navier-Stokes equations in integral form are solved with convective fluxes approximated with a second-order central scheme. Explicit artificial scalar dissipation is added, using combined second and fourth order differences. The time-dependent simulation is advanced using dual-time stepping, where a global physical time step is employed and the local time step is used in the sub-iterations based on explicit three stage Runge-Kutta scheme.

In this study both URANS and hybrid RANS-LES approaches are applied to model time accurate flow. The RANS-LES approach is the HYB0 model, Ref. [8], the turbulent stress tensor, is modeled using the eddy viscosity

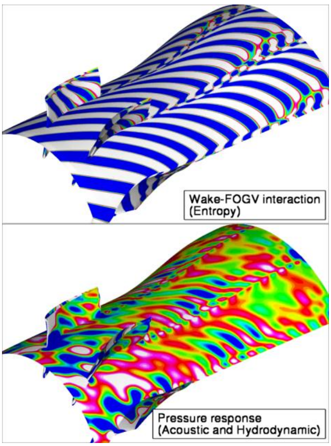
Aeroacoustic research at GKN Aerospace Engine Systems

Mattias Billson, GKN Aerospace Engine Systems

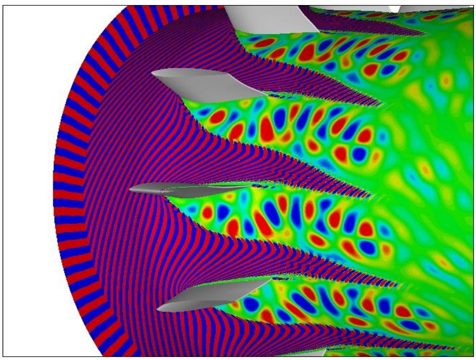
GKN Aerospace Engine Systems has been contributing to the Swedish and European research in aeroacoustics since 1999 by participating in a number of national and European research projects. The research at GKN has covered jet noise, aerothermal instabilities, turbomachinery noise and acoustic liners focusing on numerical predictions to increase the understanding and to reduce the effect of the acoustic phenomena. The presentation will show an overview of the research done at GKN Aerospace Engine Systems with highlights on the most interesting types of problems which have been studied. The presentation will include the most important concepts regarding noise generation and propagation as well as the main challenges in the area of acoustic predictions in turbo machinery. Finally the current aeroacoustic research going on at GKN Aerospace Engine Systems & partners will be presented.



Co-Axial jet noise prediction



Fan-OGV interaction



Separated turbine outlet guide vane

Abstract for Flygteknik 2013
(For presentation only)

TITLE: The role of optimization tools in a real-life wing design with aeroelastic contraints

AUTHORS: Torsten Bråmå, Martin C. Leijonhufvud and Emma Holst
Saab AB, Linköping, Sweden

During the early design studies of the next version of the Gripen fighter aircraft it was proposed to introduce a new improved wing tip pylon with increased mass. From a flutter point of view this was considered as a structural design challenge. A significantly increased mass moment of inertia at the wing tip pylon would usually require a corresponding increase of the torsional stiffness and hence also the weight of the wing.

To investigate the need for a wing redesign, a design team was put together including participants from several disciplines such as structural design, aeroelasticity, structural dynamics, loads, stress, aerodynamics, systems engineering and production.

A first conceptual phase of the work resulted in an agreement on a maximum allowed value of the moment of inertia of a new wing tip pylon. This agreement was a compromise between the desire to be able to have heavier equipment stored in the pylon and an estimate of what was possible to achieve in terms of designing a stiffer wing. The agreement made it also possible to separate the redesign of the pylon from the redesign of the wing.

In the following preliminary design stage the goal was to achieve appropriate flutter margins with a minimal mass penalty. Only small changes to the outer shape were allowed and the design should still be attractive from a manufacturing point of view. Structural integrity and control surface effectiveness had to be maintained.

It was early on recognized that it was the outer wing tip that needed to be stiffened. A local wing model could be used instead of a complete aircraft model. The flutter criteria could be replaced by a requirement of separating the bending and torsion frequency. These simplifications made it possible to have fast design iterations.

The design team of 5-10 engineers had regular meetings where design decisions were made based on results from the latest calculations. Several structural optimization problems were solved minimizing mass while separating frequencies. Gradient plots were produced to find interesting areas for stiffening. 'Pareto-front'-plots illustrating the relation between structural mass and flutter margin were used to select interesting design points. Finally, an optimized and stiffer wing design could be presented that was capable of carrying the new improved wing tip pylon with minimum weight penalty.

This paper will briefly describe the actual work that was performed, focusing on how numerical optimization tools were used in the overall design process.

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CFD sensitivity analysis on bumped airfoil characteristics for inflatable winglet

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Keywords: CFD, Winglet, Inflatable, Pollution Reduction, Bumped Airfoil

Abstract

The new aerospace technological milestone is aimed to reducing direct operating costs and pollution. In order to obtain pollution reductions via high aerodynamic efficiency, a performance analysis for bumped airfoil based winglet has been proposed. Most conventional aircrafts are equipped with fixed winglets to decrease the induced drag; thus, saving more fuel. New projects point towards advanced smart materials and telescopic wing tip devices to obtain an adaptive morphing shape that gives, through performance improvement, a fuel consumption reduction resulting in less pollutants. The focus of this paper is to evaluate the aerodynamic performance, in terms of lift, drag and moment coefficient for a bumped airfoil in climb/descent flight condition at 5000 meters altitude. The performance analysis has been conducted via a numerical investigation of the effects of bumps number, height and width for inflatable winglet airfoil, a system that would guarantee a more comfortable arrangement of extraction system and just minor surplus of weight compared to classical winglet solutions, with all the subsequent advantages.

Mission adaptive wing-let optimization for reducing vortex drag

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Álvaro Martins Abdalla

Renato Cosin

This work addresses a proposal for a Variable camber wing-let which can adapt for optimum wing tip vortex flowfield incidence in order to reduce induced drag. As it is well known, induced drag can be reduced by increasing wing aspect ratio, optimizing wing loading or placing wing tip devices such wing-lets in order to modify the tip flow field to produce a thrust.

The efficiency of such fixed devices is a compromise of aircraft mission stage. Induced drag is a function of CL^2 and therefore will be greater at climb and at the first heavy cruise leg. Also a parasitic drag will occur at the lighter cruise leg as the wing-let is out of design.

Mission adaptive wing or, as it is called today, morphing wing is a future option for an efficient wing as it can be optimized for each phase of the flight. However, such systems and material for accomplish all safety and certification requirements still to be proven and most of the studies stacked at TRL3-4 [1 to 3]. A morphing wing let may be easier to reach higher TRL as it could be tested in both wind tunnel and flight in a shorter time.

Morphing wing let model: The wing-let is a blended type one with a leading and trailing edge camber variation. The variable camber mechanism proposed is presented in Fig. 2. As in previous VCW proposals {1], the mechanism assumes a central load carrying fixed section of the wing and two geometrically variable sections attached to it. Here the variable sections extend from the LE to 27.6% of the chord and from 64.5% of the chord to the TE (Fig. 2a). The main idealisation assumption for the mechanism is that shape variation could be entirely achieved by elastic deformation and length extension of the upper and lower surfaces of the variable sections. For this, two regions on the variable sections are considered to be “plugs”, fixed in geometric shape to a certain extent of the chord from the LE and TE (Fig. 2a). It has been verified that the original airfoil could be closely reproduced by a single parametric cubic spline function, interpolating only the points on the fixed central section and on the LE and TE plugs. Arbitrary shape variation is then obtained through the following procedure:

(a) arbitrary displacement (δX, δZ) of LE and TE plugs, measured from an assumed reference point on each of them (“RP”, Fig.2b);
(b) rotation of the plugs around the reference points. To keep minimum structural feasibility of the shape obtained, the rotation is assumed to be the slope of natural cubic spline curves, attached to the mean camber line of the central fixed section, and passing through each plug reference point (Fig. 2b);
resampled airfoil representation by a single parametric cubic spline function, interpolating only the points on the LE and TE plugs and on the central fixed section. Fig. 2c shows an example resulting airfoil, discretized in 65 points and ready for aerodynamic analysis (Fig. 2c). The cubic spline representation is considered to closely reproduce the possible shape the flexible variable sections would assume, given a certain plug displacement and rotation configuration.

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FLUID-STRUCTURE INTERACTION ANALYSES OF WINGS WITH CURVED PLANFORM: PRELIMINARY AEROELASTIC RESULTS

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Keywords: Curved Wing, CFD Analyses, Wave Drag, FSI Analyses, Stall of Wings

Abstract. The paper shows preliminary results of aeroelastic analyses of two half-wing models, having curved and swept planform, carried out at the Aerospace Unit of the Department of Civil and Industrial Engineering of Pisa University. In the transonic regime the curved planform, as demonstrated in previous papers regarding rigid models of wings, reduce the wave drag effects. The present numerical comparison, between curved and traditional swept wing, includes the effects of structure's deformability (the wings have the same aspect ratio). The effects of the planform shape on drag polar curves are confirmed (for fixed values of Lift Coefficient (CL=0.4, Figure 1) the reduction of Drag Coefficient (CD) reaches 7%). The curved planform configuration improves the wing's aeroelastic behavior: as an example, adopting similar wing box metallic structures for the two half-wing models, for a fixed value of CL the reaction moments and stress values at the root of the curved wing are reduced by about 5%-8% with respect the data obtained for the traditional swept wing at the same flight conditions. Finally, preliminary numerical analyses carried out at high angles of attack show that, as expected, the centers of pressure of the wings move forward with a percentage variation of their longitudinal positions that are quite similar. These results indicate that the curved planform shape does not change in a drastic fashion the performances of a wing when the stall condition are reached.

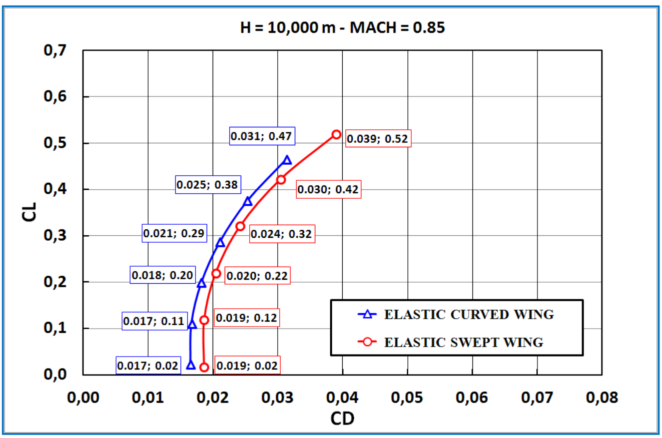

Fig. 1 Drag Polar Curves of the Two Elastic Wings.

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Autofocus and adaptivity for wavelength-resolution airborne SAR systems

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Keywords: *SAR, autofocus, adaptivity, time-domain processing*

Abstract

Synthetic aperture radar, SAR, is a technique which is used to generate long-range high-resolution images of ground scenes with small antennas. A critical part of a SAR system is its ability to generate the high resolution radar image from the radar echoes. During recent years (primarily within NFFP4/5 projects at Saab EDS and Chalmers), extensive development has been performed in order to include autofocus and adaptivity in the framework of modern and efficient time-domain SAR processing methods for airborne platforms.

There is a wide plethora of published autofocus methods but traditional methods are not suited to handle wavelength-resolution SAR. In a new autofocus method, addressing the core issue for the autofocus problem, i.e. the incomplete geometrical knowledge of the SAR path, the underlying cause is measured and corrected. Using a multi-stage time-domain SAR processing method where data is available at several different subaperture lengths, the new autofocus method estimates and corrects the SAR path before merging to larger subapertures. This ensures that a fully focused SAR image will be produced. In contrast to traditional autofocus methods which are applied after a first general SAR processing, i.e. essentially a two-step approach, this new autofocus method is included within the actual SAR processing (i.e. a one-step approach).

The new autofocus method has been tested with simulated and real SAR data for wavelength-resolution SAR systems. Results show that it can handle and correct defocusing effects, i.e. fully addressing the problem of incomplete knowledge of the SAR path geometry. The results are also bench-marked against widely used traditional autofocus methods and it is clear that these methods fail for the tested cases.

The new autofocus method is one important step to cheaper and more compact SAR systems. For many SAR systems, a large cost is an inertial navigation system (which can also be export-restricted) and the aim is to use smaller and cheaper navigation systems for SAR systems.

Other important adaptivities have also been studied in the NFFP projects. Results show that adaptivity for long integration of slow moving ground targets and for wave propagation into the ground can be included in the new processing method. Using the same framework as above, the processing also becomes efficient in terms of processing time and memory usage. Results have also been obtained for three-dimensional imaging within the ground.

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Experimental Study on Aerodynamic Characteristics of Ornithopter

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Keywords: *Ornithopter ,UAV flapping, feathering, lead-lag*

Abstract

Fundamental aerodynamic characteristics are studied for the ornithopter model as shown in this paper. Three types of movement of a wing are examined including 1) flapping motion to move the wing into the vertical direction, 2) feathering motion to change the angle of attack in the flapping motion, and 3) lead-lag motion to move the wing into the horizontal direction. The wing model in two dimensional motion in vertical plane is analyzed numerically in these motions. These numerical results show the importance of the method of combination between the Tri-motion. Result of the numerical analysis shows the possibility of producing the thrust and lift for a wing moving with an appropriate combination of tri-motion. An experimental device representing these motions is constructed in order to compare with results of numerical simulation. In summary, lift and thrust is proven numerically and experimentally to be able to be produced for a two-dimensional wing moving with appropriate motion.

1. Introduction

This Ornithopter is aircraft that imitate the flapping-wing flight of birds, bats, and ,insects, from Greek *ornithos* "bird" and *pteron* "wing", that is a "flap target," "flapping wing" as an alias.

While there have been from time immemorial challenge to manned flight, but the person who has not yet succeeded. Icarus in Greek mythology in Fig.1[14)], Emperor Shun of China has challenged, in medieval Europe Leonardo da Vinci has been a challenge in Fig.2 .

Recently, an ornithopter is tested by the University of Toronto Institute for Aerospace Studies (UTIAS) of Canada which flew about 300 m in 2006, but that of the auxiliary jet engine was used at the time of takeoff, the flight by ornithopter was not proven. [3]

Today, the mainstream of ornithopter research is a small machine about 5 ~ 50cm in Fig.3.

A model of bird flight is constructed by Nakazato and the model has flown successfully in 2006 in Fig.4. The model has its wingspan 3.3m with an engine 31,000rpm to flapping the wing and flew in average flight velocity 6m/s and ascending velocity 1m/s. The model is able to realize three movement, flapping, feathering, and lead-lag motion, and furthermore the flapping motion is synchronized to change its frequency increasing in the upward motion and decreasing in the downward motion, in other words, asymmetric flapping motion. The change of frequency in the flapping motion is a key idea to increase the efficiency in producing lift and thrust also increasing the performance of maneuverability in the flight of ornithopter and is designed in the model of Nakazato. The present paper is devoted to study the effect on the production of lift and thrust of such motion characteristics as flapping, feathering, and lead-lag. The present paper, based on this fact, to

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Wind Tunnel Tests of a New Commuter Aircraft

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Keywords: *wind tunnel tests, commuter aircraft, longitudinal and lateral-directional stability*

Abstract

Tecnam Aircraft Industries and the Department of Industrial Engineering (DII) of the University of Naples "Federico II" are deeply involved in the design of a new commuter aircraft. The wind tunnel tests campaign of the so called "P2012 Traveller" aircraft has been performed in the wind tunnel facility of the DII. Tests of a 1:8.75 scaled model have been performed on different configurations through a 3-component longitudinal and lateral directional internal strain gage balance, in order to estimate both longitudinal and lateral directional stability and control derivatives of the aircraft under investigation. Reynolds number during tests was about 0.55 million. Tests have been performed with transition strip placed on the all lifting surfaces(wing and tail-planes) at about 5% of the local chord. Many tests have been performed for different aircraft configurations with the aim to estimate the effects of the different components on the aerodynamic characteristics of the aircraft, (i.e. flaps rudder deflection, fuselage, nacelles, landing gear and winglets). Have been tested also 3 different positions of the horizontal plane, in order to evaluate its right positioning respect to the wing and ensure a good value of longitudinal static margin. Finally the complete aircraft lateral-directional stability and control derivatives have been evaluated, and the winglets effect on aircraft lateral stability has been highlighted.

1 Introduction

Commuter aircraft market is today related to old model. The major airlines in this segment have been demanding a replacement for many hundreds of "heritage" airplanes in the FAR23/CS23 category currently in service around the world - as many are now coming to the end of their useful commercial life. GAMA (General Aviation Manufacturer Association) 2011 Statistical Databook & Industry Outlook [1], which is usually a very useful and impressive source of data and statistics for general aviation, reports that the average age of general aviation registered aircraft is 46 years for single-engine piston powered aircraft and 15 years for single-engine turboprop aircraft. The average age for twin-engine 8-12 seats aircraft is 42 years for piston powered models and about 29 years for twin-engine turboprop commuter aircraft. These impressive data dramatically show the need of new aircraft model which will be characterized also by the application of new technologies like composite, light structures, new engines (with lower weight and lower fuel consumption) and new avionics and flight control systems. The main idea behind the

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Effects of Roll Maneuver on Unrestrained Aircraft Wing/stores Flutter

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Keywords: *flutter, unrestrained aircraft, external stores, roll maneuver*

Abstract

The flutter of an aircraft wing carrying a fuselage at its semispan and arbitrary placed external stores under roll maneuver is studied. Maneuver terms are combined in the governing equations which are obtained using the Hamilton's principle. The wing is represented by a classical beam and incorporates bending-torsion flexibility. Theodorsen unsteady aerodynamic pressure loadings are considered to simulate the aeroelastic loads. The Galerkin method is subsequently applied to convert the partial differential equations into a set of ordinary differential equations. Numerical simulations are validated against several previous published results and good agreement is observed. In addition, simulation results are presented to show the effects of the roll angular velocity, fuselage mass, external stores mass and their locations on the wing flutter of an aircraft in free-flight condition. Parametric studies show that the predicted stability boundaries are very sensitive to the aircraft rigid body roll angular velocity, fuselage mass and external stores mass and locations.

1 Introduction

The flutter prediction of an unrestrained aircraft wing with stores as shown in Fig. 1 is of paramount importance for the analysis and design of an aircraft. Clearly, estimating the aeroelastic instabilities of such wing configurations is critical to establish the flight envelope of newly design aircrafts. One of the first works devoted to the aeroelasticity of aircraft wings with external store is the paper by Goland and Luke on the determination of the flutter speed of a uniform cantilever wing with tip mass[1]. Lottati considered the aeroelastic stability of a swept wing with tip weights for an unrestrained vehicle [2]. In his work a composite wing has been studied and it was observed that flutter occurs at a lower speed as compared with a clean wing configuration. Also, Edwards and Wieseman [3] studied the flutter and divergence of three check cases includes unrestrained airfoils and wing models.

Although these works and several others addressed the problem of the wing-store aeroelasticity, the effect of the aircraft maneuvers on the unrestrained aircraft wing instability has not received much attention in the

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Experimental aircraft system identification from flight data: Procedures and Results

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Keywords: *Identification, aerodynamic derivatives, flight data.*

Abstract

This paper presents the results obtained by system identification from flight data of an experimental ultra-light aircraft called FLARE (Flying Laboratory for Aeronautical Research).

The method used is based on the Maximum Likelihood estimation principle, which permits to obtain the stability and control derivatives estimation by minimizing a cost function through suitable numerical procedure.

To perform aerodynamic derivatives estimation, two decoupled linearized model (for longitudinal dynamics and lateral-directional dynamics, respectively) were introduced. The estimation of the two models was performed independently by choosing suitable manoeuvres which in each test only excite the dynamic of interest. The identified parameters were finally included, together with the thrust coefficient also estimated from experimental data, in a nonlinear 6 degrees of freedom simulation model of the vehicle.

The validation of the identified model on data set not used in the identification process enhanced good capability of the model to reproduce the dynamics of interest and to match actual flight data, confirming that the identification technique was successfully applied to flight data.

Finally it is worthy to remark that the identified aerodynamic model was used to design a flight control system that successfully performed many autonomous take-off and landings.

The present work was carried out in the framework of the Italian funded project TECVOL, executed by the Italian Aerospace Research Centre (CIRA), with the aim of developing innovative technologies for flight autonomy and collision avoidance.

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Datainsamling i ett distribuerat avioniksystem

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Keywords: *datainsamling, registrering, distribuerat, avionik*

Abstract

Dagens stridsflygplan har mer likheter med informationssystem än med tidigare generationers flygplan. Den stora mängden sensorer ger möjlighet till att registrera data i en tidigare ej hanterbar utsträckning. Registreringsfunktionerna är centrala för förmågan att spela upp/utvärdera uppdrag, underhålla och felsöka samt inte minst för att verifiera funktionalitet och prestanda för nya flygplan.

Det finns flera typer av arkitekturer för att samla in data. Allt ifrån att spela in allt som skickas på bussar och nätverk till att selektivt plocka ut de parametrar som behövs för olika syften.

Gemensamt för dessa är att de kräver kraftfulla stödsystem under utveckling för att klara av att hålla data konsistenta mellan ombordsystemets olika applikationer samt användarens utvärderingsverktyg.

Krav på sekretess och separation av viss typ av information bidrar dessutom till att öka komplexiteten.

Vår presentation kommer att belysa uppgiften att bygga ett datainsamlings- och registreringssystem som klarar av att hantera stora datamängder och där informationen till stor del är inkapslad i lokala applikationer. Vidare presenteras en jämförelse mellan olika designansatser utifrån syfte med datainsamlingen och vald arkitektur.

Presentationen kommer att definiera registreringsbegreppet i ett distribuerat och integrerat modulärt avioniksystem. Den kommer också att visa vilken roll ombordsystemet har i kedjan från planering av uppdrag och underhåll, via flygning till utvärdering av registrerad information. Huvudsaliga avgränsningar och designval presenteras.

Presentationen kommer också att behandla principerna för avioniksystemet och vilka utmaningar arkitekturen ställer upp för datainsamlingen.

Flight Control Research Laboratory Unmanned Aerial System flying in turbulent air: an algorithm for parameter identification from flight data

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Keywords: *system identification, EKF, UAS, flight data.*

This work addresses the identification of the dynamics of the research aircraft FCRL (Flight Control Research Laboratory) used for the Italian National Research Project PRIN2008 accounting for atmospheric turbulence.

The subject vehicle is an unpressurized 2 seats, 427 kg maximum take of weight aircraft. It features a non retractable, tailwheel, landing gear and a powerplant made up of reciprocating engine capable of developing 60 HP, with a 60 inches diameter, two bladed, fixed pitch., tractor propeller. The aircraft stall speed is 41.6 kts, therefore it is capable of speeds up to about 115 kts (Sea level) and it will be cleared for altitudes up to 10.000 ft. The studied aircraft is equipped with a research avionic system composed by sensors and computers and their relative power supply subsystem. In particular the Sensors subsystem consists of :

- Inertial Measurement Unit (three axis accelerometers and gyros)
- Magnetometer (three axis)
- Air Data Boom (static and total pressure port, vane sense for angle of attack and sideslip)
- GPS Receiver and Antenna
- Linear Potentiometers (Aileron, Elevator, Rudder and Throttle Command)
- RPM (Hall Effect Gear Tooth Sensor)
- Outside air temperature Sensor

A nonlinear mathematical model of the subject aircraft longitudinal dynamics, has been tuned up through semi empirical methods, numerical simulations and ground tests.

To taking into account the atmospheric turbulence the identification problem addressed in this work is solved by using the Filter error method approach .In this case, the mathematical model is given by the stochastic equations:

$$\begin{aligned} \dot{x}(t) &= f\left(x(t),u(t),w(t),\theta\right) \\ y(t) &= h\left(x(t),u(t),\theta\right) \\ z(k) &= y(k)+v(k) \\ x(t_0) &= x_0 \end{aligned} \tag{1}$$

where x is the state vector, u is the control input vector, f and h are dimensional general nonlinear vector functions, θ contains the unknown system parameters, z is the measurement vector ,w is the process noise and $v(k)$ is the measurement noise. The presence of nonmeasurable process noise requires a suitable state estimator to propagate the states. To take into account model nonlinearities in the present paper an Extended Kalman Filter has been implemented as the estimation algorithm.

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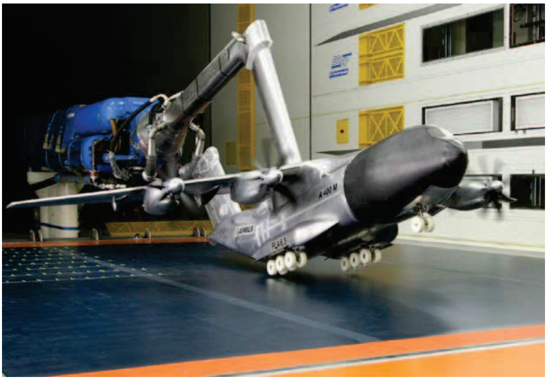
German-Dutch Wind Tunnels

Innovations in wind tunnel testing to ensure competitiveness at DNW

by Christophe Hermans (deputy director DNW) christophe.hermans@dnw.aero

Abstract for Flygteknik, FT 2013 track

The German Dutch Wind tunnels DNW is one of Europe's most advanced and specialized organizations for wind tunnel testing. DNW's eleven wind tunnels include subsonic, transonic and supersonic facilities, and provide experimental aerodynamic simulation capabilities to a global user community at large. DNW provides techniques for aerodynamic, aero acoustic or aero elastic simulations and tests of scale models in a controlled environment. Its experimental simulation techniques capture the essence of the issues to be investigated.



A400M model test in ground proximity

The Large Low-speed Facility (LLF) in Marknesse (the Netherlands) is an industrial wind tunnel for the low-speed domain. It is a closed circuit, atmospheric, continuous low-speed wind tunnel with one closed wall and one configurable (slotted) wall test section and an open jet. Low speed means testing of aircraft in take-off and landing flight configurations and therefor DNW focusses its investments for the LLF on safety (ground proximity) and environmental issues (acoustics) related testing capabilities.

Current DNW-LLF upgrade programs focus on ground proximity simulation (procurement of a new moving belt system) and significant reduction of background noise levels to improve its capabilities and market attractiveness. The main driver for the latter initiatives is a clear trend i.e. continuous reduction of aircraft noise levels.

High-Lift and Radar Cross Section Characteristics of Unmanned Combat Air Vehicles Employing Serrated Leading-Edge Strakes

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Abstract

The radar cross section (RCS) characteristics of two Uninhabited Combat Air Vehicle (UCAV) demonstrators, the Northrop Grumman X-47B and the Dassault nEUROn, are contrasted with those of the Boeing F-18E Super Hornet manned naval strike aircraft, Figure 1. The comparison emphasises the advantages of an edge-aligned, all-wing planform when designing for reduced detectability by radar. Figure 2(a) shows a generic 40^o edge-aligned UCAV configuration, incorporating 60^o leading-edge strakes, with high subsonic cruise Mach number performance characteristics similar to those of the X-47B. The RCS for head-on X-band radar illumination at 9 GHz is predicted using a finite-difference, time-domain solution method for Maxwell's Equations. High-lift aerodynamic performance is assessed by low-speed wind tunnel testing of a $1/20^{th}$ scale model. As expected, the maximum-lift performance of the UCAV planform is enhanced by the incorporation of leading-edge strakes, exploiting the additional lift generated by the leading-edge separated vortex flow. However, the presence of the leading-edge strakes results in additional RCS spikes being generated in the forward viewing direction. These RCS spikes can be attenuated by use of edge-aligned, serrated strakes rather than the more conventional simple-swept strakes, Figures 2(b) and (c). Wind tunnel testing indicates that the triple-serrated strakes retain the enhanced high-lift characteristics of the conventional strakes. Figure 3 compares the experimental low-speed, high-lift aerodynamic performance of the triple-serrated strake UCAV configuration with inviscid-flow predictions using an unstructured-grid Euler flow solver. These indicate encouraging agreement in terms of maximum-lift performance and details of the pitching-moment characteristics. Figure 4 compares predicted upper surface static-pressure contours with experimental flow visualisations. The paper will discuss in more detail the aerodynamic and RCS performance characteristics of the serrated-strake configurations, suggesting that they should be seriously considered for application to the next generation of high-performance UCAV vehicles.

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Numerical Investigation of Aerodynamic Interaction for a Quad-Rotor UAV Configuration

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Keywords: *Quad-rotor, UAV Configuration, Aerodynamic Interaction, CFD, Unstructured Mesh*

Abstract

In the present study, numerical investigation about the mutual aerodynamic interaction of the rotors of a multi-rotor UAV (Unmanned Aerial Vehicle) configuration was conducted. For this purpose, time-accurate unsteady flow calculations were performed using a three-dimensional unstructured mesh CFD flow solver. The fluid motion was assumed to be governed by the three-dimensional, incompressible, inviscid, Euler equations. To handle the relative motion of the rotors, an overset mesh technique was adopted. To reduce the large computational time, the flow solver was parallelized based on a domain decomposition technique. As an application of the present method, simulations were made for a quad-rotor UAV in hover and in forward flight. It was observed that in the case of hovering flight, the mutual aerodynamic interaction of the rotors induces slightly higher inflow than an isolated rotor, and invokes unsteady fluctuating thrust variation. In forward flight, the tip vortices from the upstream rotors affect those at further downstream by reducing the effective angle of attack at the rotor blades and form a complex interactional wake structure. It was found that the mutual aerodynamic interaction leads to a deterioration of the attitude stability of the UAV in forward flight, and this aerodynamic interaction should be considered seriously in designing accurate attitude control algorithms for multi-rotor UAV configurations.

1 Introduction

For the past few decades, active researches have been conducted for Unmanned Aerial Vehicles (UAVs) as demanded by the practical usefulness for both civilian and military application purposes. Among the several UAV configurations, rotary-wing type vehicles have received quite an attention due to the unique capability of vertical take-off and landing (VTOL) [1]. The research and development have been performed particularly for multi-rotor UAVs, because of the simplicity of the flight mechanism which does not require any anti-torque system and swash plate for flight control [2-5].

Recently, quad-rotor UAVs became one of the standard platforms in the development and also in the practical field application of multi-rotor UAVs. With the four rotors, the two pairs are designed to rotate clockwise and counter-clockwise, respectively, to negate the production of torque on the vehicle. Because the rotors are set at a fixed pitch, the attitude of the vehicle is controlled by the difference of the individual rotor thrust attained by the rotational speed control [1].

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Experimental Analysis on Dynamic Characteristics of an Ornithopter

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Keywords: *Ornithopter, dynamic behavior, flapping, feathering, lead-lag*

Abstract

Ornithopter is an aircraft that moves its wings to fly like a bird. A flight model of an ornithopter is constructed and analyzed its flight characteristics experimentally in the present study. Size of the model for the experimental demonstration is wingspan 3.3m and, length 1.4m. The present flight model is constructed to enable the following three movements in the main wing: 1) flapping motion to move the wing into the vertical direction, 2) feathering motion to change the angle of attack in the flapping motion, and 3) lead-lag motion to move the wing into the horizontal direction.The flapping mechanism is implemented in the model employed with the ornithopter concept and feathering and lead-lag motions are realized in order to let the model produce both lift and thrust. Results of the experiment show sufficient lift to suspend the body with about 4kg and thrust with controllability.

1 Introduction

A model of the ornithopter has flown but not completely by Prof. Delawrier at the Institute of Aeronautics Study of University of Toronto in 2006 employed with jet engine as an auxiliary propulsion device.[1]

Aerodynamics of the ornithopter is studied by many researchers [2]-[12] and the importance of the three kinds of motion is understood in order to produce lift and thrust by the wing. These three kinds of motion includes, 1) flapping motion to move the wing into the vertical direction, 2) feathering motion to change the angle of attack in the flapping motion, and 3) lead-lag motion to move the wing into the horizontal direction. Wing motion is also studied rather than bird including insects, butterfly, mosquito, cicada, and some mechanisms are reported in their performance in order to simulate the motion of small air vehicles.

A model of bird flight is constructed by Nakazato and the model has flown successfully in 2007 [13]. The model has its wing span 3.3m with an engine 31,000rpm to flapping the wing and flew in average flight velocity 6m/s and ascending velocity 1m/s. The model is able to realize three movement, flapping, feathering, and lead-lag motion, and furthermore the flapping motion is synchronized to change its frequency increasing in the upward motion and decreasing in the downward motion, in other words, asymmetric flapping motion. The change of frequency in the flapping motion is a key idea

The Influence of Ground Proximity on the Aerodynamics of a Wheel

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Keywords: *Aerodynamics, CFD, Ground Proximity, Landing Gear, Wheel*

Abstract

The landing gear is known to be one of the main contributors to the noise generated from an aircraft. The scope of this work is to carry out an exploratory investigation as a first step to understanding the aerodynamics around the wheels of a landing gear. The wheel was modelled and simulated in free air and with the effect of decreasing ground proximity. The effect of Yaw and varying Turbulence Intensity (Tu) with decreasing ground proximity is also modelled to see how these variables affect the aerodynamics around the wheel. Fackrell [1] had carried out an experimental investigation for an isolated wheel in contact with the ground; therefore the same wheel was used for this study so comparisons can be made. In this study, the flow structures are explained with detailed explanations regarding the pressure, velocity, lift and drag forces with comparisons to previous literature.

1 Introduction

The effect of ground proximity on the aerodynamics of an aircraft's landing gear is a complex problem which has received little attention in the aircraft industry. The landing gear is a major contributor to the noise levels generated from an aircraft. Aircraft noise is produced because of the variations in the flow field as the air interacts with the exposed components of an aircraft. These noise levels produce disruption and discomfort to millions of people in the vicinity of an airport.

Fackrell [1] had conducted an experimental investigation for an isolated wheel in contact with the ground. A moving floor was used to analyze the flow on a range of treads and wheel profiles. Similarly, based on that study, McManus and Zhang [2] carried out a computational study for a wheel in contact with the ground. This study was focused on the same wheel geometry in [1]. Lift and drag force coefficients had been obtained from the simulations corresponding to C_D=0.48 and C_L=0.35 for a stationary wheel in contact with the ground. Areas of separation have been seen behind the wheel on the top shoulders. Counter rotating vortices are also experienced behind the wheel on the lower half. More recently an experimental study was carried out by Zhang, Smith and Sanderson [3] regarding the aerodynamics on a single wheel. This study discovered that lines of separation exist around the tread as the air from the hub area interacts with the air around the wheel. The flow then passes around the edges of the wheel and meets at the rear causing four vortices to appear.

This paper analyses the effect of decreasing ground proximity of a single wheel with the effect of yaw and TI.

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An Experimental Study of a Separation Control on the Wing Flap Controlled by Close Loop System

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Keywords: *applied aerodynamics*

Abstract

Flow control by using an additional blowing has been a subject of many experimental and computational works. The main task of an additional blowing is to increase the flow velocity in the airfoil boundary layer to delay the flow separation phenomenon and in result to improve the airfoil aerodynamic performance. This paper presents the results of wind tunnel tests of flow control using an additional blowing on the airfoil segment equipped with the movable flap. Blowing was realized through the set of nozzles located on the trailing edge of the main body of the airfoil. Air flow through the nozzles was controlled by a set of the electromagnetic valves located inside the model. Pressures, measured by sensors mounted on the flap surface, created a control signal for a feedback system, regulating flow through the nozzles. The work was performed under the European project "ESTERA".

1 Introduction

Active flow control became widely used in many fields of science and technology and continues to be the subject of intense experimental and numerical studies in a number of research centers [1-7]. Improvement of the efficiency of currently used aircraft control systems or replace them by unconventional flow control methods, can be a source of measurable benefits. These benefits can still be significantly enhanced by the use of flow control operating in the Close Loop Control (CLC) System .

The literature describes a number of different flow control methods [1], One of the methods of active flow control is an additional blowing on a wetted surface. In this method, properly targeted additional air jets increase energy of the flow. Boundary layer supplied with additional energy becomes less susceptible to separation, even at angles of attack higher than the critical (for the condition without blowing). Postponed flow separation contributed to the increase of maximum lift and simultaneously to drag decrease. This in turn, can improve the airplane aerodynamic performance.

In flow control process important issue is to minimize air mass flow rate necessary to use. So air mass flow rate blown to keep flow attached, should be changed respectively to the actual flow conditions. These conditions may change due to deflection of the airplane control surfaces, as well as due to change in external flow conditions. To avoid flow separation during changes in flow conditions it is required

Study on the influence of deflected strake on the rocket plane aerodynamic characteristics.

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Warsaw University of Technology

Abstract

Due to a market demand on a vehicle to space suborbital human flights, WUT team beginning working on an airplane system to space tourism. The concept is inspire by White Knight & Space Ship One but consists of some interesting improvements. WUT concept assumes that both vehicles are design as a tailless airplane but bonded together create a conventional plane where the rocket plane is use as a tail of the whole system. This system is called Modular Aeroplane System – MAS.

The concept of MAS mission profile assumes that during the re-entry the rocket plane glide and vortex lift is generated by the strake. This phenomenon supports aerobraking which prevents excessive accelerating of the rocket plane.

Generation of vortex flow by the strake is very important issue for the proper flight condition of the rocket plane. It was assumed that, it allows generating an additional component of the lift force and to control descending speed of the vehicle. Therefore to improve aerodynamic characteristics of the rocket plane the conception of deflected strake (hinged strake) and Strake Forward Flaps were applied (Figure 1).

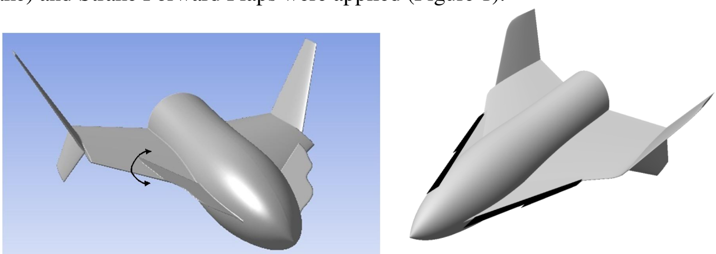

Figure 1 Concept of the strake deflection (on the left) and Strake Forward Flaps (on the right)

Presented paper includes numerical and experimental investigation of hinged strake and a few configuration of Strake Forward Flap. The study focused on impact of the strake configuration on the basic aerodynamic characteristic of aircraft in tailless configuration.

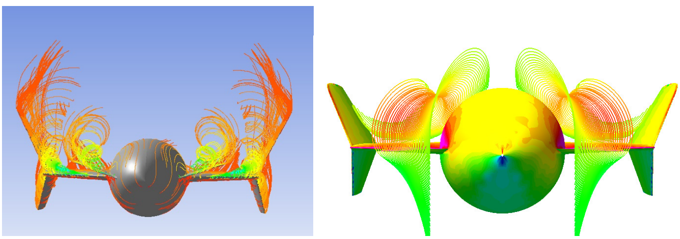

Figure 2 Flow visualization for hinged strake (on the left) and Strake Forward Flap (on the right)

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Wingtip Vortices in the Near-field – A Numerical and Experimental Investigation

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Keywords: *vortex, wingtip, near-field, turbulent, vorticity confinement*

Abstract

The near-field (up to 3 chord lengths) development of a wing-tip vortex was investigated numerically and experimentally. The research was conducted in a medium speed wind tunnel on a NACA 0012 square tip half-wing at a Reynolds number of 3.2 × 10^5 at two angles of attack (10° and 5°). The objective of the research was to evaluate the capability of a Reynolds stress turbulence model coupled with a vorticity confinement method in accurately computing mean flow and turbulent characteristics of a vortex. The need to evaluate such a model stems from the obvious advantages Reynolds Averaged Navier Stokes (RANS) models have in terms of computational cost and complexity. Experimental measurements were taken with a five-hole probe and x-wire anemometer and used as a method for judging numerical accuracy. The trajectory and mean flow of the computed vortex was in very good agreement with experiment as the circulation parameter and peak crossflow velocity were within 3% and 1% of the experiment at the trailing edge (10°) and one chord length downstream (5°) respectively. The axial velocity excess and deficit was slightly under predicted for both angles of attack while the numerical Reynolds stress component ‹u'v'› was in very good agreement at the trailing edge for α = 5°, but an order of magnitude smaller further downstream. The computed vortex shows some promising results in terms of both mean flow and vortex trajectory and vortex size. Both the experimental and numerical vortices had moved inboard by the same amount by three chord lengths downstream and the core diameters of both were also in very good agreement. The agreement between the magnitudes of Reynolds shear stress ‹u'v'› at the trailing edge for an angle of attack of 5° also bodes well for the modelling approach taken. Future modelling work will look at adaptive grid refinement and perhaps comparison with LES.

An Investigation into Shock Oscillation Noise Reduction

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Keywords: *shock-oscillation countermeasures, flow-induced sound, numerical simulation*

Abstract

Self-sustained shock-oscillations were investigated in this work, with a view to implementing countermeasures to stop the motion of the shock and, therefore, to reduce the associated noise. The transonic flow past a symmetric airfoil was computed using computational fluid dynamics. A number of potential countermeasures were also included in the simulations in order to identify the relative importance of their physical parameters in reducing the shock motion.

Self-sustained shock wave oscillations on airfoils at transonic flow conditions are of importance to many applications, as it is associated with flow phenomena such as buffeting, unsteady boundary layer separation and vortex shedding in the trailing-edge region, which are major causes of noise.

The objective of this work was to investigate the onset and behavior of self-sustained shock-oscillations on a strut, typically used for mounting objects to the exterior of aircraft, in order to implement countermeasures to stop the shock motion and to reduce the associated sound generation.

The transonic flow past an *18%* thick circular-arc airfoil was computed using unsteady-RANS and DES, and with different turbulence models. Free-stream Mach number between $M_\infty=0.76$ and $M_\infty=0.8$ were examined at a Reynolds number of $Re=10^7$. The acoustic sources in the separated flow downstream of the shock were quantified using Howe's acoustic analogy. Countermeasures, including shock-fixators and a splitter plate, were also included in the simulations with the aim of reducing the shock motion and reducing the noise sources.

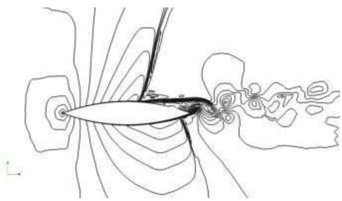

Fig. 1 Velocity contours from the DES solution.

2D URANS simulations, with the Spalart-Allmaras turbulence model predicted the onset of shock oscillation at $M_\infty=0.77$; with the k-ω-SST model at $M_\infty=0.77$, and the k-ε model at $M_\infty=0.79$. The reduced frequency for shock oscillation at $M_\infty=0.77$ was predicted at *0.44* for the 2D URANS simulation and at *0.47* for the quasi-3D DES. Both the use of shock-fixators and a splitter plate proved to be effective in reducing the strength of shock oscillations. Both the length of the splitter plate and the position of the shock-fixators were important parameters for the effectiveness of these countermeasures.

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Improving the performance of the CFD code Edge using LU-SGS and line-implicit methods

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Keywords: convergence acceleration, LU-SGS, parallelization, ordering techniques, implicit time-stepping, line-implicit.

Abstract

The implicit LU-SGS solver has been implemented in the code Edge to accelerate the convergence to steady state. Edge is a flow solver for unstructured grids based on a dual grid and edge-based formulation. LU-SGS has been combined with the line-implicit technique to improve convergence on the very anisotropic grids necessary for the boundary layers. LU-SGS works in parallel and gives better linear scaling with respect to the number of processors, than the explicit scheme. The ordering techniques investigated have shown that node numbering does influence the convergence and that the native orderings from Delaunay and advancing front generation were among the best tested. LU-SGS for 2D Euler and line-implicit LU-SGS for 2D RANS are two to three times faster than the explicit and line-implicit Runge-Kutta respectively. 3D cases show less acceleration and need a deeper study.

1 Introduction

Computational fluid dynamics (CFD) has become a significant tool routinely used in the aerodynamic design and optimization of aircraft. CFD tools are used from the conception phase to the production as preliminary tests of a specific aircraft design. CFD simulations have largely replaced experiments to provide aerodynamic data. However, computing time can become very costly, thus convergence acceleration techniques are needed to speed up CFD solvers.

Edge [1] is a flow solver for unstructured grids based on a dual grid and edge-based formulation on node-centered finite-volume discretization. Edge uses an explicit multistage Runge-Kutta time integration solver [1] . Agglomeration multigrid (MG) acceleration speeds up the convergence rate based on the Full Approximation Scheme/Storage (FAS) [2] for nonlinear problems. This is combined with the line-implicit method [3] for RANS stretched meshes and integrates implicitly in time along lines in regions where the computational grid is highly stretched.

Implicit schemes which mitigate the CFL time-step limit of explicit schemes are becoming more and more spread in the CFD field, for reducing simulation time. The use of an explicit or implicit scheme is considered when dealing with problems solved by time- (or pseudo-time-)stepping. The time-step will have an influence either on the accuracy of the solution for time-dependent problems or on the convergence to steady-state for non-linear problems. This paper considers computation of steady states and focuses on the speed of convergence to steady-state.

An Implicit Lower-Upper Symmetric Gauss-Seidel (LU-SGS) [4, 5, 6] solver has been im-

Design and Construction of a Silent Wind Tunnel for Aeroacoustic Research

R. Putzu, D. Greco, D. Craquelin, F. Crisinel

Abstract

The anechoic chamber of ``hepia - Genève" was modified with the purpose to host a removable wind tunnel for aeroacoustic research. Special attention is given to a detailed description of the technical challenges faced.

Due to the growing interest in aeroacoustics from the side of ``hepia - Genève", its pre-existing anechoic chamber was modified in order to host a wind tunnel which can be used for aeroacoustic research. The anechoic chamber, still having to be used for classical acoustic measurements, could not host a permanent facility. A choice has been made to design and construct a removable wind tunnel inside the anechoic chamber. This paper describes in detail the design and construction of this small scale, low Mach number, silent wind tunnel.

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Gas-kinetic schemes for compressible turbulent flow

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Keywords: turbulence modelling, compressible flow, gas-kinetic scheme, gas kinetic theory, shock - boundary layer interaction

1 Abstract

Gas-kinetic schemes are an alternative to schemes derived directly from the Navier-Stokes equations. In this study a gas-kinetic scheme is applied to the simulation of turbulent compressible flow, by replacing the molecular relaxation time with a turbulent relaxation time in the BGK model. The turbulence dynamics is modelled on the basis of a standard, linear two-equation turbulence model. The resulting turbulence stress tensor is linear in smooth flow and non-linear in the presence of stronger flow gradients. The non-linear correction terms in the numerical flux are activated depending on the ratio between turbulent and mean length scales, or in other words, of "rarefaction" - referred to turbulence dynamics and not to molecular dynamics. No assumptions on the nature of the turbulence have been made and a linear two-equation turbulence model is used, however, the turbulence gas-kinetic scheme corrects the turbulence stress tensor effectively; on the basis of a number of benchmark flow cases, characterized by strong shock - boundary layer interactions, the turbulent gas-kinetic scheme provides more accurate results than Navier-Stokes schemes using the same turbulence model.

2 Introduction and Motivation

Gas-kinetic schemes (GKS) model the numerical fluxes on the basis of the gas kinetic theory - in other words, not using the Navier-Stokes equations but the Boltzmann equation or the BGK model [1]. GKS are consistent with traditional schemes as the Euler and the Navier-Stokes equations can be derived both from the Boltzmann equation and from the BGK model, for instance by means of the Chapman-Enskog expansion [2, 15]. GKS are nevertheless suitable for the continuum regime; they have been developed in order to achieve a better accuracy and stability than traditional numerical schemes based on the Navier-Stokes equations (NSS). Several GKS were developed over the past twenty years [5, 9, 10, 16, 18]. Among them, the scheme developed by Xu in 2001 [16] emerges as one of the most successful, it has been successfully employed to simulated a number of laminar flow cases in the continuum regime, ranging from low-Reynolds subsonic to hypersonics [8, 10, 13, 17]. The numerical simulations obtained with this GKS show that it disposes of mechanisms able to recover the gas-kinetics physics whenever the Navier-Stokes equations are insufficient for a particular flow or grid resolution, such as inside shock-layers.

The higher accuracy of the GKS is attributed to the underlying gas-kinetics which generates a time-space coupled gas-evolution, whereas the numerical fluxes in NSS are time-independent. Moreover, gas-kinetics generates coupled advective and viscous fluxes, whereas NSS calculate the two fluxes separately with the consequence that the generation of advective fluxes is independent from the viscosity of the fluid or the effects of the particle collisions. In laminar flow, the effects of collisions on the advective fluxes are only significant in shock layers, where the

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A Simple Laboratory Approach to Investigate Boundary Layer Transition due to Free Stream Particles

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Keywords: *laminar flow technology, ice crystals, particle wake, turbulent contamination*

Abstract

Application of drag reduction technology based on laminar flow in a commercial environment is still being hindered by unanswered questions regarding its operational reliability. A malfunction of a laminar flow system, even if temporary, could have a considerable effect (depending on the extent of its application) on the overall fuel planning; and, for more ambitious designs, possibly even on the handling characteristics of a correspondingly equipped aircraft. Nevertheless, a first small scale application has recently been introduced into routine commercial airline service. The encounter of ice crystals, as occurring in cirrus cloud, is known to result in performance degradations or even a temporary complete loss of laminar flow. Actually occurring mechanisms are not well understood and previously proposed critical parameters have not yet been verified experimentally. Difficulties encountered while attempting to recreate conditions in the laboratory that are representative of the real occurrences have led to several alternative experimental methods. This study presents results from a relatively simple method, in terms of its complexity, providing for further insight into the phenomenon that a small particle is capable of producing a turbulent event while travelling through an initially laminar boundary layer. Using this method, for a smooth spherical particle, a critical Reynolds number in the order of 300 has been determined above which the generation of a turbulent-spot-like disturbance will occur.

1 Introduction

The depletion of cheap fossil fuel reserves has focused research attention on improving aircraft efficiencies within a short time frame, and this has revived the interest in laminar flow technology due to its great potential to reduce fuel consumption. If applied to all aircraft components that are currently rated as being practical, namely the wings' upper surfaces, the empennage and the engine nacelles, overall drag reductions of approximately 16% [1] are thought to be realistic. This would translate into a reduction of fuel consumption in the order of 10% [2].

The principles to achieve such benefits are Natural Laminar Flow (NLF), a passive technique based on extended regions of accelerated flow over specifically designed contours, and the active method of Laminar Flow Control (LFC) based on suction through a perforated or slotted surface, which prevents the

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Abstract: Aero-Thermal Behaviour of Actively Cooled Porous C/C Structures by Means of Transpiration Cooling

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Markus Selzer and Hermann Hald
Institute of Structure and Design (IBK), German Aerospace Center (DLR), Stuttgart, Germany

Introduction

One of the key technologies of today's aerospace applications is the effective protection of thermally heavy loaded components like the inner walls of combustion chambers or the heat shields of re-entry vehicles. This issue will become even more important for perspective missions were considerably increased energy densities are expected. In this respect, porous high-temperature fibre ceramics (CMC: Ceramic Matrix Composites), which can be actively cooled by means of transpiration cooling, are promising candidates to serve the arising demand for powerful thermal protection systems of future aerospace applications.

Designed and manufactured at DLR's Institute of Structure and Design (IBK), porous C/C (carbon/carbon) samples are investigated as reference material for the certain material class of CMCs. Detailed studies to identify the involved transport mechanisms of transpiration cooled C/C segments are conducted in close cooperation with the Institute of Aerospace Thermodynamics (ITLR) at the University of Stuttgart.

The projected paper is going to report of these studies and their findings with respect to the thermal behaviour of C/C wall segments under heat loads. Particular the wall internal temperature distribution as well as the pressure drop over the material thickness when actively cooling the porous segment are focused. The applied heat loads are established by convective- or radiative-heating using two independent test benches. To guarantee extensive as well as accurate measurements, the thermal conditions are selected to be rather moderate compared to the aero-thermal loads of thinkable applications.

The planned contribution attempts to support the general understanding of the involved thermodynamic mechanisms of transpiration cooled porous high-temperature ceramics.

Investigated Material

The studies are focused on the porous high-temperature fiber ceramic C/C. At DLR in Stuttgart this material is manufactured via resin transfer molding (RTM) and pyrolysis in which the resin matrix is changed into carbon. This process leads to a shrinking of the matrix volume which creates micro dimensional cracks within the fabric. These cracks are interconnected and establish the porosity as well as the permeability which is essential for active through flows. The small size of these passages form a huge internal surface which is the basis for the significant heat transferring characteristics of this material. Depending on the resins and the fibers, material intrinsic properties like porosity, permeability as well as thermal conductivity can be triggered during the manufacturing process.

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Micro T-strips to save cost and fuel

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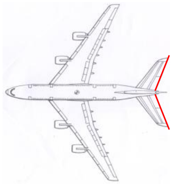
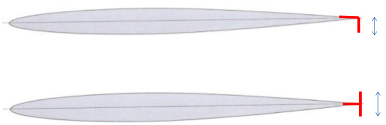
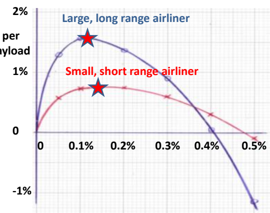
Formerly with BAE Systems, UK

The T-strip, applied to the trailing edge of an aerofoil, is a double-sided version of the well-known L-strip which was originally called a Zaparka flap, but is now more commonly called a Gurney flap. The key advantage of the T-strip is that it is effective in increasing the lift slope, maximum lift and control power of aerofoils at both positive and negative angles of attack.
The T-strip was used on many old aircraft to improve stability and control characteristics and it is still seen on a few new aircraft types.







The limited test data available for T-strips has been augmented, analysed and correlated to allow interpolation down to very small sizes……the Micro T-strip

An example is shown of how Micro T-strips might be used on a new airliner design to allow smaller tail surfaces and so reduce operating costs and fuel burn. Two classes of airliner were studied, a large, long-range type and a small, short-range type.

The potential to save about 1% cost and fuel may seem to be rather small. However, based on forecasts for future airliner production and jet fuel usage, there would be an industry-wide operating cost saving of over $4Bn per year, together with a jet fuel saving of over 2 million tonnes per year.

It is suggested that the Micro T-strip would be a suitable research topic for both CFD and wind tunnel testing at high speed….perhaps as part of the EU Clean Sky programme?

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Acoustic Probes for Pressure Pulsation Measurement In Gas Turbine Flow Duct and Combustor

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Keywords: *gas turbine, dynamic pressure probe, frequency response, compensator*

Abstract

Instabilities in flow duct of aircraft and industrial gas turbines can produce intolerably large pressure waves, which lead to fatigue, detachment of components, and costly outages and repair. The measurement of dynamic pressure amplitudes within the combustion chamber and characteristic points of compressor and turbine may be used in condition monitoring analyses to detect and correct instabilities before they cause serious damage. However, the technical challenge in physically measuring dynamic pressure placing the sensor directly at the pick-up point is a significant one, especially within the high temperature environment of the gas turbine combustion chamber. The article considers indirect measurement that involves fitting small bleed tubes (or conduits) from the pick-up point to a pressure sensor placed at a less extreme temperature location. This permits the use of freely available industrial pressure transducers instead of expensive piezoelectric crystal devices. Proposed measurement techniques provide minimal distortion of the signal over a wide frequency range at small dimension of the probe and high reliability. The transmission line method is used for sizing the correcting device of the probe. The developed probes were implemented for dynamic pressure monitoring in aircraft engines.

1 Introduction

Pressure pulsations in a flow duct of the gas turbine engine provide key information on dynamic behavior and stability of the compressor and the combustor. Therefore measurements of pressure pulsations in characteristic points of low and high pressure are usually carrying out at the engine development (Fig. 1).

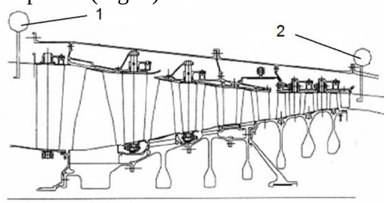

Fig.1 Pressure gauges at the input (1) and output (2) of the compressor

High temperature and a lack of space make it difficult to place the pressure sensor directly at the point of measurement. The typical decision is an application of special acoustic probes consisting of the inlet pipe, the pressure pulsations sensor and correcting element (Fig. 2).

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Optimal Control for Flight Control Law Design

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February 15, 2013

Keywords: Flight Control, Optimal Control, Model Predictive Control

Abstract

Unlike the ideal systems which are usually studied, real aircrafts are dynamic systems that naturally contain a variety of constraints and nonlinearities such as maximum load factor, angle of attack and control surface limitations. Taking these limitations into account in the design of control systems becomes increasingly important as performance and complexity of the controlled systems is steadily increasing. However input and state constrained optimal control problems are in most cases impossible to solve with an explicit feedback policy.

There are however one optimal control method that offers a way to solve these problems and that is Model Predictive Control (MPC). MPC is one of the most popular advanced control techniques and it is widely used in the process industry. It solves the constrained optimal control problem through the solution of a finite horizon optimization problem iteratively solved online in a receding horizon fashion, using the current state of the system as initial condition. Due to the iterative nature of MPC one must take special measures to ensure that the optimization problem remains feasible and that the controller stabilize the system. A big drawback with MPC is that it is fairly computationally expensive and this has so far limited its practical use for aeronautical applications.

As the name, Model Predictive Control, suggests it is based on predictions of the system's future behavior, and based on that it decides on the best possible control. The performance of the MPC method is based on the availability of good models to describe the dynamics of the system but all models contain uncertainties and all systems are subject to disturbancies, and this greatly affects the ability of the MPC methodology to deal with constraints in the systems.

In this presentation we will present the MPC methodology and show how it can be applied within the aeronautical industry. We will discuss around possibilities and limitations, alternate formulations and adjustments to the standard algorithms to make MCP more suitable for aeronautical use. We also present open research areas which the author thinks need to be adressed to make MPC applicable for flight control design.

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Computational Design and Investigations of Closed-Loop, Active Flow Control Systems Based on Fluidic Devices, Improving a Performance of Wing High-Lift Systems

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Keywords: *CLC, active flow control, blowing-suction devices, wing high-lift system*

Abstract

The overall concept of Closed-Loop Control (CLC) system utilising fluidic devices for an active control of air flow on an aircraft wing has been presented. The main purpose of the system is to control autonomously the flow on the wing flap so as to protect it against strong separation and to improve this way the wing high-lift-system performance.

The developed concept of CLC-system is based on the row of nozzles located at the main-wing trailing edge. Air jets blown through the nozzles amplify stability of boundary layer on the flap protecting this way the flow against strong separation. The system works fully autonomously. This means that the air jets are activated automatically and only in such situations when there is the threat of strong flow separation on the flap.

When designing the CLC-system, several problems were solved, including design of the wing high-lift system, design of high-efficiency system of blowing mini-nozzles and development of the CLC-algorithm, which controls a fully autonomous work of the system.

The whole study was conducted using computational technique, and the results of the research were the base for development of the technology demonstrator tested in wind tunnel. Examples of CFD simulations using developed CLC algorithms have been presented.

1 Introduction

Advanced aeronautical-engineering design is increasingly based on the technology of smart structures, i.e. structures which are able to sense their environment, self-diagnose their condition and adapt in such a way so as to make the design more useful and efficient. One of the important directions of development of smart structures in the aeronautical engineering is their application to control the flow on the lifting surfaces of an aircraft. The research presented in this paper concerns this subject.

Considerable part of the presented study was conducted within the EU 7th FWP Project ESTERA, titled: Multi-level Embedded Closed-Loop Control System for Fluidic Active Flow Control Actuation Applied in High-Lift and High-Speed Aircraft Operations. Generally, the research aimed at development of the overall concept of Closed-Loop Control (CLC) system utilising fluidic devices for active control of the flow on the aircraft wing, so as to improve the

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Steps Towards Automated Robust RANS Meshing

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Keywords: Hybrid mesh generation, Automatic mesh generation, Computational Fluid Dynamics

Introduction The creation of high-quality discretizations for use in viscous flow simulations remains a challenging task. Even with modern software tools and substantial human effort, the application of state-of-the-art mesh generation algorithms in the presence of geometric features such as concave corners may still result in inadequate local mesh configurations, which can severely affect the resolution of important flow features. To address such issues, mesh generation tools for hybrid unstructured grids often expose a considerable number of algorithm configuration parameter. The resulting flexibility does indeed enable the creation of sufficiently resolved hybrid meshes, although the process often requires a very considerable amount of time even for an experienced user. In a production environment where a large number of detailed simulations of single aircraft configuration are performed, the cost in terms of man-hours may be acceptable. For other applications with requirements for short turn-around time, a more automated approach is desirable. Since an automatic mesh generation procedure cannot rely on user intervention for the resolution of geometric complications or edge cases, a robust strategy for the handling of the surface geometry encountered in realistic aircraft configurations must be implemented.

The approach presented here is based on a segregated prismatic/tetrahedral mesh generation procedure, and aims to achieve robustness by means of local geometric modifications. Criteria chosen and algorithmic modifications make use of similar principles as in earlier work, but are adapted for the specific requirements of mesh generation for aircraft configurations. An existing set of open-source tools is exploited for mesh data structures, file format support, surface mesh generation and tetrahedral volume meshes.

Method The mesh generation strategy present is based on four phases, starting with the creation of a sufficiently resolved surface mesh. In a second step, the envelope mesh of the prismatic boundary layer mesh is determined; the robustness of this stage is the primary contribution of the present work. Thirdly, tetrahedral elements are generated to fill the volume between the envelope of the prismatic layer and the farfield boundaries, and finally, pentahedral elements are grown between adapted wall and envelope mesh.

Preliminary Results The algorithm implemented into existing open source libraries was applied to two applications presented in this study, a fairly simple wing-body-stabilizer configuration typical for a transonic transport aircraft (CRM) and a rather complex, detailed geometry of a delta wing fighter prototype (F-16XL). RANS solutions converged to engineering accuracy are found to yield solutions in close agreement with meshes produced by a well established grid generator for the `EDGE` flow solver provided that comparable resolutions are used for both the prismatic layer and the tetrahedral domain.

Conclusions When comparing mesh generation timings, an interesting observation was made. For the common situation where parallel CFD solutions are performed on a compute cluster, the analyst may be evaluating post-processed results of a simulation based on a mesh created with the method presented in this paper before a serial advancing front mesh generation has even been completed.

Obviously, this does not mean that there is no need for high-quality advancing-front mesh generation tools. A substantial proportion of relevant geometries and flight conditions likely require detailed control over mesh generation parameters which is available in a hybrid Delaunay method. However, for routine solutions where serial mesh generation time is a bottleneck, the libraries including the method can be used to accelerate the turnaround time considerably.

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Aerodynamic Optimization of Control Surface Schedules for Trim on the New Gripen Aircraft

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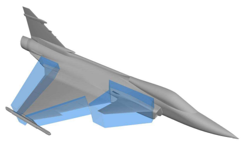
Keywords: *Aerodynamics, CFD, Optimization, Drag, Trim*

Abstract

The new Gripen fighter aircraft features three control surfaces that influence the longitudinal trim – canard, leading edge flap and elevons. In order to achieve the best possible performance of the aircraft it is essential to always use the best combination of control surface settings for each flight condition. The objective of the study is to identify the control surface deflections for each combination of lift and Mach that gives the lowest drag when the aircraft is trimmed for zero pitching moment.



Layout of the different box regions

The approach is to calculate the aerodynamic forces and moments with the FOI Edge Navier-Stokes solver. The grid around the aircraft is divided in to four different regions. The main region covers all fixed part of the aircraft and the major part of the outer grid extending to the farfield. Three grid boxes have been defined around each movable control surface. Several grids have been generated for different discrete deflections for each box as a preparation for the optimization. In order to be able to calculate an arbitrary combination of deflections a tool has been developed that picks the grid box that has the closes match of deflection angle. An automatic surface modification is carried out in order to obtain the exact deflection angle combined with an advanced grid stretching method that adjust the volume grid to the new surface within the actual box. By using this technique together with the functionality to combine different regions in Edge it is possible to calculate any combination of control surface deflections in a fully automatic manner.

The optimization is performed with the control surface deflections and angle of attack as free parameters, totally 4 design parameters. The constraints are lift and pitching moment. The objective function is to minimize drag. Approximative gradients, which drive the optimization towards the optimum, are computed by means of finite differences. The complete optimization procedure with geometry/grid modification, CFD calculations and optimization is integrated and controlled by the optimization program **cadsos** *developed at Saab Aeronautics.*

Final results are new optimized control surface schedules, which improves aircraft performance compared to the initial schedules.

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Development of an unsteady wind tunnel experiment for vortex dominated flow at a Lambda – wing

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Keywords: *vortex, lambda wing, round leading edge, high sweep angle, unsteady experiment*

A half wing model, a test rig and new wind tunnel walls were designed to study the vortex development at a lambda wing. It has a sweep angle of 53° and round leading edges. It is designed for pitching oscillations around a mean angle of attack of up to 20°, up to a free stream Mach number of 0.7. Unsteady aerodynamic load data shall be delivered for aeroelastic calculations of Unmanned Combat Aerial Vehicles (UCAV). The new wind tunnel walls for the Transonic Wind Tunnel Goettingen were designed to increase the optical access. A peniche was optimized to reduce wing – wall interference effects. The opening in the wall for the mounting to the test rig is sealed by a turnable disk.

The model was designed in two stages. First, the feasibility of a model with eigenfrequencies, well above the test frequencies, was checked. To determine the basic structural setup, finite element models mainly consisting of shell elements were created by a parametric model generator. For the detailed design, solid elements were used. The load cases for the design and the sizing were generated by superimposing aerodynamic loads and the inertia forces caused by the rotational acceleration of the pitching motion. The stiffness of the mounting of the model was tuned to experimental results.

Due to the highly nonlinear aerodynamic character, the design of the model had to take into account load cases with beginning and fully developed vortices. Furthermore, the different character at subsonic and transonic speeds had to be included. The inboard movement of the main vortex with increasing angle of attack was analyzed especially regarding its impact on the variation of the load distribution. All design loads were scaled to a maximum global normal force that hereby can be used as main monitoring value for the wind tunnel test. Coupled fluid/structure simulations with a modal representation of the structural model were performed to ensure the dynamic stability. They were started based on jig- or flight shape to assess the unsteady behavior at different flow conditions i.e. Mach number, mean angle of attack and pitch amplitude. The unsteady characteristics of the developing vortex at a pitch motion were determined by a frequency variation.

The aerodynamic coefficients and deformations of the coupled simulations were analyzed in the time and frequency domain and displayed e.g. as spanwise distributions. Therefor an interpolation to a structured grid was performed. The superposition of inertial and steady aerodynamic loads of the design was compared to the coupled computations.

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Transonic Wing Design for a Regional Jetliner

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Keywords: wing design, airfoils, transonic, wave drag, Euler

Abstract

Aerodynamic shape optimization on a 3D laminar wing at transonic speed is studied, with three redesigns come out. The inviscid drag is improved and its pressure distribution has been refined. The wing root bending moment is also reduced a bit. The desired pressure at one cross section is specified and one redesign is obtained by Direct Iterative Surface Curvature method.

1 Introduction

The design of aircraft involves multi-disciplinary approach. The optimization needs to include aerodynamics and structural properties. It helps therefore to be able to parametrize and reduce the order of optimization effort. Within the FP7 NOVEMOR project, a Regional airliner (based on Embraer reference) is being studied. The ideas is to incorporate a fully parameterized wing including morphing LE / TE. A timely specific goal is to compare with other aircraft (e.g. Boeing Business Jet based on 737 series). An important aspect for transonic aircraft concerns wave drag estimation and its reduction.

1.1 Goals/challenges for efficient wing design

The authors will establish a computational design framework for a fully parametric virtual aircraft of the reference design with morphing surfaces. Our specific goal here is to explore the conceptual design space of the reference model to see if equal or superior aerodynamic performance can be achieved with respect to a conventional regional airplane, e.g., the A-320. The reference design (RD0) is mounted with a preliminary designed wingtip device which is about 10% (or 1.5 m) of the main wing semi-span, by reducing the inviscid drag 5%. The reference aircraft is designed as a regional jetliner cruising at transonic speed, with the designed requirements raised by EMBRAER. The MTOW is 58034 kg, with fuselage length 36.86 m, and wing span 34.46 m. It cruises at 11 km, with Mach 0.78, and C_L 0.47.

However, the winglet on the reference wing has some unfavorable aerodynamics. Figure 1 shows that the pressure distribution C_p from Euler solution for the spanwise stations near the wingtip inboard and outboard. It can be seen that all of the C_p distributions have a “cross-over” behavior that we should try to avoid.

1.2 Design algorithms

The design is carried out in two-folded. The whole wing is re-designed using the traditional gradient-based optimization method with some reasonable constrains on pitching moment, wing loading and bending moment [7], with the inviscid drag as objective function that to be minimized. This is a straightforward method and we trust the numerically computed gradient is correct. To ensure that the gradient indicates the correct search direction which leads conver-

In-flight emergency flight planning using a decoupled trajectory optimization technique

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Abstract

In a response to an emergency situation during flight, the initial focus of the pilots is to stabilize and regain control of the aircraft. Then, they switch their focus into finding the shortest (and safest) way to land the aircraft, with assistance from the FMS, flight manuals and air traffic controllers whenever it is possible. The decision on where to land can be a difficult one, as it might be affected by the new maneuver envelope after the emergency situation is identified, the distance to the available landing fields, the length of their runways (and thus the maximum allowed landing weight for a non-crashing landing), terrain avoidance, and the risk to population and properties on the ground, among other factors. In this work, we present the use of a trajectory optimization tool developed for on-board use, in the problematic of finding optimal emergency trajectories that take into consideration the described factors, offering the pilot a set of feasible trajectories that minimizes the estimated risk. As a demonstration of its capabilities, landing trajectories for a precautionary landing scenario and two emergency scenarios (one-engine inoperative and fuel starvation) are obtained for a hypothetical flight emergency situation.

1. Introduction

In the event of an emergency situation, being it critical or not, the pilot has to evaluate the status of the aircraft, and decide if the aircraft safety is compromised, meaning that the flight must be interrupted.

In this case, the decision to be made focus on where to land the aircraft safely. When the aircraft has just took-off, the decision is simple, with the normal procedure of just returning to the same airport. This might be complicated by the fact that the aircraft might be too heavy to land, as the maximum takeoff weight is usually higher than the maximum landing weight. For example, an Airbus A321 has a MTOW of about 93 tons, while the MLW is significant lower, at 77.8 tons. This means that the pilot has to decide either to reduce the weight by dumping unburned fuel (but the ability of jettison fuel is not available for every aircraft), or by spending fuel flying in a high thrust configuration. Of course, if the emergency is critical, the pilot might prefer to land the aircraft above MLW, and risk some structural damages.

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Process for Evaluation and Validation of Non-Original Components for Aircraft Hydraulic Systems

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Keywords: *Supplementary type certificate, Hydraulic system, Hydraulic Pump, Simulation*

Abstract

This paper presents an efficient evaluation and validation process which can be used to determine suitability of non-original components for aircraft systems in order to apply for the supplementary type certificate (STC).

In the process a non-original component is compared against the original one. Goal in the comparison is to prove that the non-original component has at least equal performance and safety and reliability characteristics than the original component has.

Key performance characteristics are usually well defined in aircraft's documentation or can otherwise be defined relatively easily. Also the testing of them is usually relatively straight forward process and can be carried out with test equipment used depot level maintenance. Usually also component testing procedures specified in depot level maintenance documentation can be applied.

Comparing safety and reliability characteristics of non-original and original component is however less straight forward task. There can be general component specifications available (such as MIL-specifications for military equipment of US origin) which define baseline requirements for these characteristics. Baseline however is definition of absolute minimum and there usually is no data available how much above it the original component lays. Comparison is most cost effectively made by comparing the safety and reliability performance of components in a life test which replicates the load spectrum of the real application as closely as possible or accelerated life test of some kind.

The complete evaluation and validation process is presented and discussed using the case of a twin engine aircraft hydraulic pump as an example. In this case the load spectrum of hydraulic pump is generated by extracting flight control system command data from real mission data and converting it to pump load spectrum using combined flight simulation and system simulation model. This load spectrum is then used as load spectrum in life testing of both original and non-original hydraulic pumps in a test rig.

1 Introduction

Components of aircraft systems go through long and thorough evaluation and validation procedures before they are approved and included in the initial aircraft design [1]. The type certificate, issued by the aviation regulating body to manufacture certifies that the initial

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Modeling of backlash in drivetrains

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Keywords: *drivetrain, backlash, inertia, elasticity, damping*

Abstract

The presence of backlash in drivetrains is a major source of limitations as it introduces nonlinearities that reduce their efficiency in speed and position control. Existing models in backlash assume massless shaft, and use only elasticity and damping properties to describe the transmitted torque. This assumption makes them inaccurate since it does not account for the contribution of the body's inertia. Thus, a new and simple model that takes into account the rotational inertia, elasticity and damping properties is proposed. The importance and validity of this approach is shown analytically, graphically and with an example of a simple failure case of shaft rupture. Preliminary analysis shows that real system behavior is predicted more closely than in previous model. Thus, the new model can be used for better prediction of system behavior for definition and optimization.

Abbreviations and terms

θ: Angular displacement
α: Half of backlash angle
k: Elasticity
c: Internal damping
j: Inertia
T: Torque
SDOF: Single Degree of Freedom
PPM: Phase plane model
JCK: Inertia Damping Elasticity
Backlash: Clearance between mating gear teeth

1 Introduction

The presence of backlash in drivetrains is a major source of limitations that introduces nonlinearities in system behavior, a consequence of which might be problems with safety and/or reliability, which are crucial in the design of aerospace systems. This paper focuses on the analysis of existing backlash models followed by the proposal of a new modeling approach. In this study, some commonly used backlash models are examined. As an example a shaft model with backlash is considered. Many alternatives for estimating the effect of backlash in drivetrains exist. Some of these include the dead-zone model and the modified dead-zone model [1, 2]. On the other hand, there are limitations of the accuracy level of these models. Since existing backlash models differ in their results and do not predict system behavior

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Aircraft Hydraulic Fluid On-Line Condition Monitoring System for Maintenance and Troubleshooting Purposes

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Keywords: *Aircraft, Hydraulic Fluid, Condition Monitoring*

Abstract

Perfect overall condition of the aircraft's hydraulic system is essential to ensure the airworthiness of the aircraft. Usually indications of upcoming faults in hydraulic systems are visible as increased amount of particles in the hydraulic fluid. During the recent years the real-time on-line particle counters have developed to be reliable and accurate measuring instruments for particle quantity. The benefits when compared to the more traditional off-line measurement methods have been studied and proven in recent researches. However, free air commonly present in the hydraulic fluid of the aircraft usually causes measurement error when using on-line particle counters.

This paper presents an on-line condition monitoring system which can reliably measure fluid quality and monitor the condition of the aircraft hydraulic system. Methods to remove the measurement disturbances caused by free air are discussed and their implementation to the condition monitoring unit is presented. The functionality of the condition monitoring unit is verified with measurements made in real working conditions while unit was connected to an aircraft.

1 Introduction

Recent development of on-line capable hydraulic fluid condition monitoring sensors and applicable data analysis methods have made fluid on-line condition monitoring to become more relevant option in condition monitoring of hydraulic systems. Particle quantity and fluid chemical quality can be measured by online sensors which can directly be installed in the system to continuously monitor the parameters describing the condition of the fluid and the system itself. Online sensors give possibility to monitor hydraulic systems in real-time and thereby to react faster in upcoming maintenance needs and failures.

During recent years there has been increasing number of online condition monitoring applications in aircrafts. However these applications have mostly relied on prognosis based on indirect measurements rather than direct measurement of particle quantity or fluid quality. Direct online measurement of fluid quality involves many challenges in aircraft hydraulic systems because of flight safety issues, complex structure of hydraulic systems,

Propulsion integration and flight performance estimation for a low observable flying wing demonstrator

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Keywords*: propulsion integration, flight performance, UAV, flying wing*

Abstract
Within the consortium of the Sagitta project, aiming to develop technologies for Unmanned Aerial Vehicles (UAVs), the Institute of Aircraft Design is contributing with the areas of propulsion integration, novel control concepts and overall configuration integration. Major in-house research topics are the development of novel flight control effectors as well as reliable propulsion integration solutions, including thrust vectoring. In order to complement the research activities a scaled flying demonstrator has been selected as an airborne test bed. The overall project, joining multiple universities and research organizations, has been initiated and supported by Cassidian. The configuration of the flying demonstrator is a low observable, low aspect ratio diamond shaped flying wing system. In this paper the primary characteristics of the configuration will be summarized as well as the principal driving requirements for the design and integration of the propulsion system and the major aspects of his initial layout will be presented. Furthermore a performance estimation will conclude the present work, which is considering also data from other Sagitta partners.

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RAPID – Robust Aircraft Parametric Interactive Design (A Knowledge Based Aircraft Conceptual Design Tool)

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Keywords: _Aircraft Conceptual Design, Knowledge Based, XML Data_

Abstract

Conceptual design is the early stage of aircraft design process where results are needed faster both analytically and visually so that the design can be modified or changed at the earliest stages. Although there is no necessity for a CAD model from the very beginning of the design process it can be an added advantage to have the model, to get the impression and appearance.

Tango and RAPID (Robust Aircraft Parametric Interactive Design) are knowledge based aircraft conceptual design tools being developed in CATIA and Matlab respectively. The user can work in parallel with both programs and exchange the data between them via XML. This paper describes the knowledge based design automated methodology of RAPID and its application in the courses "Aircraft conceptual design" and "Aircraft project course" at Linköping University. A multifaceted user interface is developed to assist in the whole design processes.

1 Introduction

Conceptual design tools always need to be refined and improved. There is no end to it and this is how it should be. One such much needed refinement is to be able to communicate between the analytical design tool and the 3D environment, i.e. CATIA. Data communication between conceptual design programs has always been a major obstacle which now has found a solution through this work, presently being done at Linköping University. A seamless connection appeals to the designer, but it has to work both ways. There are a handful of existing software tools in the industry, at universities and research centers. Some have connections to CAD programs, but the connection is usually not seamless and even more rarely they work both ways [11].

Existing aircraft conceptual design tools:

- RDS [2]
- ADS [8]
- Desktop Aero [10]
- J2 Universal Tool Kit [7]
- Piano [9]
- CEASIOM [3]
- PADLab [4]
- VSP [5]
- Bauhaus Luftfahrt: Conceptual Design Tool (CDT) [6]

2 Knowledge Based Engineering Design

Knowledge Based Engineering can be explained as reusable information that exists in the specific method or form; this knowledge is reused either manually or automatically and the whole process of using existing knowledge such

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Integrated Aircraft Design Network

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Keywords: *aircraft conceptual design, parametric modeling, Knowledge based, sizing, XML database*

Abstract

This paper describes the XML based multidisciplinary tool integration in a conceptual aircraft design framework, developed by the Division of Fluid and Mechatronic Systems (FluMeS), Linköping University. Based on a parametric data definition in XML, this approach allows for a full 3D CAD integration. One-database approach currently conducted by many research organizations, enables the flexible and efficient integration of the different multidisciplinary processes during the whole conceptual design phase. A central XML database approach with a detailed explanation of the developed geometry description and the data processing, focusing on the CAD integration is presented. A case study is presented in showing the data build up and data handling.

1 Introduction

Information is generated by tools, normally coupled towards intern/proprietary data structures. In a multidisciplinary design process this information/data has to be propagated among tools and has to be fully accessible to any tool at any time. This dilemma leads either to a central “one-tool” or a “one-database” approach.

The One-tool approach cannot solve the problem since it is not a practical and justifiable solution as different applications need different tools for different needs. Hence the best and optimal solution would be one-database approach. RAPID and Tango are tools being developed in CATIA® and Matlab® respectively [9], to address one-database approach. In order to maintain flexibility and allow the developer to choose preferred work method, both programs should be implemented in parallel. Switching between the two should be possible at any time [9].

1.1 Related Work

In the field of aircraft conceptual design, a great many programs from research institutes and universities and also commercial products can be found. Some, like the RDS software from D. Raymer [1] of a direct implementation from classical aircraft design handbook methods, as described for example in [2], [3] or [4]. Here follows a short list of related university/research projects and programs:

- CEASIOM [5]
- PADLab: Preliminary Aircraft Design Lab [6]
- Vehicle sketch pad [7]
- Bauhaus Luftfahrt: Conceptual Design Tool (CDT) [8].

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About Feasibility of a 5th generation Light Fighter Aircraft

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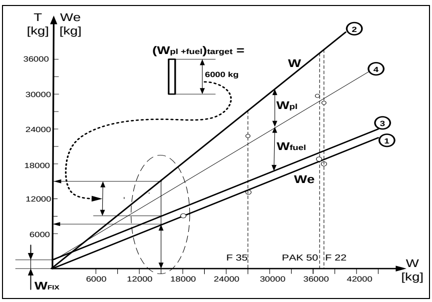
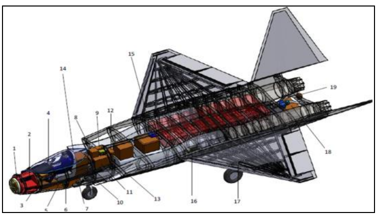
Keywords; *Light Fighter, 5th Generation Fighter, Fighter Conceptual Design, Fighter Layout*

Abstract

The paper is aimed to illustrate an idea about the feasibility of a peculiar aircraft, i.e. a 5th Generation Light Fighter. At first a short description of previous technological generations of Jet Fighter is given, introducing the interest that has always been originated by the concept of "Light Fighter" for every of the first four Fighter Generations. Henkel He 162, Fiat G91-R, Northrop F-5 and Saab JAS 39 Gripen are examples of Light Fighter, respectively, of the first to the fourth fighter generation. They are aircraft with size, performances and capabilities reduced in comparison with other fighters of the same generation, but generally still appreciable. Their advantage and what makes them interesting is the reduced size which means reduced costs. So the Light Fighters can have a good Efficacy to Cost ratio and they can be the only solution for Operators with limited financial resources.



The derivation of the first idea of a new 5th Generation Light Fighter is then described. A first feasibility study is carried out through a statistical plot (previous figure) showing Empty Weight (We) and W_{pl} plus W_{fuel} related to Maximum Take-Off Weight (W), that by the way, is also their sum. So, by hypothesizing a minimum value of W_{pl} plus W_{fuel} it is possible to individuate the size of the wanted light fighter. Then to further investigate the feasibility of idea, a Conceptual Design Study has been driven up by utilizing peculiar tools, both for quantitative and qualitative (i.e. the aircraft layout definition) evaluations. The aircraft layout has been performed through CAD software (see figure below) which is considered essential, by the authors, since it tends to operate as validation tool of the numerical results. Finally the authors further investigate the feasibility of the concept by means of preliminary studies of the main aircraft Subsystems in terms of architecture, weight, volume and power required. Then the implementation of the aircraft dynamic model in X-PLANE context validates flight qualities and performances of the 5th Generation Light Fighter.



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Preliminary Design for Flexible Aircraft in a Collaborative Environment

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Keywords: *CPACS, Collaborative Design, DEE Initiator, Aeroelastic Engine, OAD*

Abstract

The work presents a collaborative design approach, developed to account for flexible effects in the pre-design stages of generic aircraft configurations. A streamlined design process is developed between DLR and TU Delft, to support the transition from an initial aircraft conceptual solution, to physics based simulations. The TU Delft DEE initiator is the conceptual tool providing the initial design, which is used to instantiate further analysis tool. An Aeroelastic Engine module is responsible for the abstraction of the aircraft structural properties, and the generation of the fluid-structure disciplinary couplings, necessary to account for the flexibility effects. Multiple distributed disciplinary solvers are available, and accessible via a decentralized architecture. All the analysis modules are integrated in the design workflow by means of the open source distributed framework RCE, and the DLR's central data model CPACS. The approach is tested for the pre-design of conventional and unconventional configurations, designed for the a set of top level aircraft requirements. Hence, the flexibility effects for both cases are presented.

1 Introduction

The current visions and technology roadmaps on the future of the air transportation systems pose ambitious challenges for the design of the next generations' air vehicles [1, 2]. However, the assessment of game-changing technologies cannot rely on the conventional pre-design methodologies, which are primarily based on statistical data, and on the application of technology factors to account potential benefits. Thus, in order to correctly assess the vehicles' behavior and performance, and to minimize the risks associated with the development of unconventional aircraft configurations, physics based simulations have to be included in the early stages of the design process.

Nevertheless, the sophisticated physics based analysis codes currently available in every aeronautical discipline, can be effectively used at the early stages, only if highly automated in the model pre-processing, analysis execution and post-processing of the results.

As identified in Ref.3 automated analysis capabilities, relief the designer from allocating most of the time of the development cycle to repetitive and non-creative tasks, and enable the large design space exploration required by unconventional designs.

Aeroelastic Tailoring Through Combined Sizing and Shape Optimization Considering Induced Drag

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Multidisciplinary design optimization (MDO) is more and more being applied during the entire aircraft development process solving strongly interrelated problems. In this context a multidisciplinary design optimization framework is being developed at Cassidian that enables combined shape and sizing optimization to improve aircraft performance taking into account aeroelastic effects. The framework allows fully coupled aeroelastic shape optimization based on the vortex lattice method together with linear finite element analysis using gradient based optimization methods. Three components form the shape optimization framework: A parametric geometry kernel, a multidisciplinary optimization program and an aerodynamic solver. The architecture of this framework and its components are described briefly before demonstrating its capabilities using the example of a full generic transport aircraft configuration. The aeroelastic induced drag during cruise flight is minimized modifying shape and sizing variables while considering aerodynamic and structural aspects. Two different approaches of addressing structural and aerodynamic requirements during the optimization are examined and discussed. First, a sequential treatment of the aerodynamic properties and the structural criteria is performed minimizing induced drag through shape with a subsequent structural sizing optimization. The second approach combines the shape and sizing optimization while simultaneously considering structural as well as aerodynamic requirements.

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The Concept of the Joined Wing Scaled Demonstrator Programme

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Keywords: *joined-wing, UAV, optimization, flight testing*

Abstract

Joined wing is an unconventional aeroplane configuration considered as a candidate for future airplanes. It consists of two lifting surfaces similar in terms of area and span. One of them is located at the top or above the fuselage, whereas the second is located at the bottom. Moreover one of lifting surfaces is attached in front of an aeroplane Centre of Gravity, whereas the second is attached significantly behind it. Both lifting surfaces join each other either directly or with application of wing tip plates (box wing). Application of this concept was proposed for the first time by Prandtl in 1924. It has many possible advantages like induced drag reduction and weight reduction due to the closed wing concept. Unfortunately it is much more complicated to design than conventional aeroplane due to the strong aerodynamic coupling and static indeterminacy. Therefore it was not possible to build successful aeroplane in this configuration before computer aided design systems became available and even its early versions were not powerful enough.

This paper presents the concept of the project dedicated to design and build scaled demonstrator in joined wing configuration. Particular attention is put on various approaches to the aeroplane optimisation. Also flight characteristics of the small flying model are discussed. It was designed and built as a part of preparatory phase of the project. It is currently flight tested to investigate various control concepts predicted for large UAV demonstrator which will be built later in the project.

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Aircraft Conceptual Design Optimization Based on Direct Simulation

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Keywords: *Aircraftconceptual design, MDO, Simulation,*

Abstract

Aircraft design is an inherently multidisciplinary activity that requires different models and tools for various aspects of the design. At Linköping University a novel design framework is being developed to support the initial conceptual design phase of new aircraft. By linking together various modules via a user-friendly interface, the framework allows multidisciplinary analysis and optimizations to be carried out. The test case is a mission simulation is performed on a UAV-type aircraft. The flight simulation is carried out in order to realized an early design optimization of the UAV involving weight data, aerodynamic, simple structure analyses and full hydraulic system characteristics. Different aerodynamic model have been used in order to see the impact when flying the mission.

1 Introduction

Todays aircraft development have become more challenging than ever, with emergent competitor and high pressure on cost reduction. As a consequences higher efficiency during product development is needed. The product development process is continuously challenged by demands of increased efficiency. Both with respect to development time as well as development cost, without loosing product quality. At the same time as products become more and more technically advanced, the demands for customized variants increase as well as for new product generations and updates. These increasing challenges can typically not be addressed by adding more development engineers to the project. Instead, it must be addressed with more efficient development tools, methods and processes. Often, fundamental changes in product development process are required to meet these challenges.

This means that they need to iteratively cycle through sketching a concept, analyze it, evaluate and compare its performances. A framework aimed at the automation of this loop is currently being developed at Linköping University [11] [13] [14]. The framework is intended to be a multidisciplinary optimization tool for defining and refining aircraft designs, with respect to its aerodynamic, stability, weight, stability and control. **Error! Reference source not found.** below describes how the complete framework will look like once all modules will be ready and connected.

Different studies have already been carried out for method and framework validation [12]

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Multidisciplinary Aircraft Design Software in Aeronautical Education

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Keywords: *aircraft design, education, multidisciplinary optimization*

Abstract

In the introduction section the role of preliminary aircraft design software in aeronautical education process is discussed. A program WINGOPT developed at Samara State Aerospace University (SSAU) is described.

Aircraft design is mutually multidisciplinary task, incorporating areas as aerodynamics, flight dynamics, structure, strength of materials, and many others. Students studying the aeronautical engineering should not only be qualified in separate disciplines, but also clearly understand connections between disciplines and influence of these connections on integrated design process. Often it is very difficult for students to understand the importance and place of separate disciplines in the aircraft design process while studying the specific course. A software tool WINGOPT developed at Aeronautical Engineering department of Samara State Aerospace University is aimed to integrate specific courses and help to understand the multidisciplinary nature of aircraft design process.

In the next section a features and capabilities of WINGOPT are described. The program is aimed to be used for multidisciplinary optimization of unconventional aircraft configurations at preliminary design stage. The algorithm is based on integration of two numerical models – aerodynamic model based on simple panel code for aerodynamic characteristics and loads calculation and special finite element model for mass estimation.

The mass model is relying on variable-density body method. The basic idea of the method is described: an admissible design domain, defined by external and internal boundaries of a structure is filled with hypothetic material with variable density, aerodynamic and structural loads are applied. Starting with uniform density distribution an iterative optimization routine is run to find the density distribution delivering the minimum mass of the structure while satisfying the strength constraint. The optimization algorithm is based on fully-stressed design principles. Resulting variable density structure is used to estimate the minimum mass of the structure that could be design inside the given domain.

The total mass is then estimated based on statistical relation between load-bearing and total mass.

The results obtained on variable density model can be used as stand-alone for topology

Abstract for Flygteknik 2013
(For presentation only)

TITLE: Confident aircraft design and development using robust aeroelastic analysis

AUTHORS: Martin Carlsson Leijonhufvud and Anders Karlsson, Saab AB, Linköping, Sweden

There are several sources of model uncertainties involved in aeroelastic analysis. During the early design and development of a new aircraft the computational model uncertainties are often of special concern. In particular, this is the case before the structural and aerodynamic models have been validated and updated based on ground vibration testing (GVT) and wind tunnel tests. Furthermore, when developing a new fighter aircraft numerous future external stores with a large variation in structural and aerodynamic properties have to be accounted for early in the design phase. The access to aerodynamic and structural data may be limited and often preliminary models associated with large model uncertainties have to be used.

The so-called μ-p approach for robust aeroelastic stability analysis extends the standard industrial tools for flutter analysis to include physical uncertainties and model variations. At Saab, the μ-p method was used for confident aeroelastic analysis during the early investigations for a future version of the Gripen fighter aircraft. The method was found to be a very useful tool and a superior alternative to time-consuming parameter variation type of analyses. The purpose of the paper is to describe some of the robust aeroelastic investigations that were performed during the preliminary studies for a new version of the Gripen aircraft. The paper also describes some recent development with respect to the uncertainty model description. Except for pressure variations, the uncertainty model can now also be directly related to physical properties such as aerodynamic derivatives.

The general design study involved investigation of a large number of store configurations of which the most critical ones were selected for further robust aeroelastic analysis and hereby accounting for the model uncertainties. First, the aeroelastic investigations with respect to a new wing tip pylon are described. Since no wind-tunnel data were available for validation the new aerodynamic model was validated and adjusted with respect to preliminary steady CFD computations. The amount of uncertainty involved in the new aerodynamic representation was however considered to be significant. Robust aeroelastic analysis using the μ-p method was therefore performed to ensure that the aircraft would be free from flutter instabilities when considering the uncertainty for the aerodynamic properties of the new pylon. (Corresponding structural uncertainties were included in a more traditional manner outside the robust frame work).

Investigations focusing on uncertainties in the aerodynamic properties of new under-wing external stores, will also be included in the paper. Robust aeroelastic analyses were applied using uncertainty descriptions that allowed fairly large variations of the aerodynamic coefficients of the external stores. Initial results here showed a relatively insensitive behavior to the external store aerodynamics. The preliminary models could hence be used confidently during the subsequent design phase.

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Challenges with the Transfer of Aircraft Production in an Offset Business

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Keywords: *Transfer, Aircraft Production, Offset Business, Tacit Knowledge, Communication*

Offset or industrial collaboration is a key aspect in practically all large international agreement in defense-related industries, such as the aircraft industry. The buyer generally wants this collaboration to support long term local industrial development, with for example the transfer of some production from the selling organization. This is a growing trend and it will become increasingly important to reduce the risks of transferring production in defence related sales.

Transfer of production can be divided into two key elements, transfer of knowledge and transfer of technology. It is often more challenging to transfer knowledge than technology. Technology transfer is easier to break-down to measurable milestones within a process. Knowledge can be divided into two categories; explicit and tacit, there is no distinct difference between the two terms. Explicit knowledge refers to knowledge about facts and can often be divided into smaller pieces and documented. Tacit knowledge is knowledge "ingrained in the walls" and difficult to identify and document. Engineers often have ambitions to standardize, formalize and generalize their work into categories. Few engineers focus their work on the non formalized part of engineering, such as tacit knowledge. This is interesting, because many requirements cannot be documented; usability and easy maintenance are two examples of this. This indicates that costs could be reduced through working with the non formalized part (tacit knowledge).

A company that fails to keep track of components needed in a manufacturing process will probably not function when the production is transferred. The same is true for companies that do not keep track of their knowledge components. It is of great importance to know where the knowledge is, to categorize it (tacit or explicit) and to find means of transferring it when required.

At a study performed at Saab Aeronautics, a Swedish company with long experience and holistic knowledge of manufacturing aircrafts, some problems were identified.

Problems within the transfer of aircraft production

- Full-scale production is not reached as planned
- Production documentation is incorrect
- Quality issues with the product
- Additional costs and delays due to insufficient configuration management
- Cultural differences

A root-cause analysis was performed and several challenges were identified:

Future challenges with the transfer of aircraft production

- Transfer of knowledge
- Communication and relations

Historically, focus has been on the symptoms instead of the root cause; however the challenge lies with the transfer of soft values. Aeronautics has good technicians with experience of technology transfers, when a transfer process is created; the technical details are often included. However it is harder to include knowledge, communication and relations. The challenge is to combine the transfer of explicit and tacit knowledge in a "technical" transfer process.

Modeling for Physics Based Aircraft Predesign in a Collaborative Environment

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Keywords: *CPACS, Collaborative Design, CPACScreator, CEASIOM, RCE*

Abstract

The work presents a collaborative design environment, developed to account high fidelity analysis in the aircraft pre-design stage for conventional and unconventional configurations. The approach build up on centralized model architecture, based on the DLR developed namespace CPACS, and on available CPACS compatible aircraft design competences, distributed among DLR and KTH, communicating each other via a distributed architecture. In the presented approach, the centralized model is generated by the CPACScreator, a management system under development at KTH, capable to instantiate in a time efficient manner CPACS models, which are suitable for high fidelity analysis. A design process is setup between DLR and KTH, to support the designer towards an all-physics based design, already at the early stages of the development. The multiple disciplinary solvers available are accessible via a decentralized architecture, and integrated in a collaborative workflow by means of the open source framework RCE. The approach is tested for the pre-design analysis of conventional and unconventional configurations. Results for both cases are presented.

1 Introduction

The current visions on the future of the air transportation systems pose ambitious challenges for the design of the next generations' air vehicles [1, 2]. Therefore unconventional aircraft configurations are currently investigated by the research and the industry communities. However, the assessment of novel aircraft technologies cannot exclusively rely on the conventional pre-design methodologies, which are primarily based on statistical data, and on the simple application of technology factors to account for the potential benefits. Thus, in order to minimize the development risks associated with unconventional aircraft designs, physics based simulations have to be included in the early stages of the design process.

The recent advancement in computational performance and simulation capabilities provide accessibility to sophisticated, and at the same time efficient analysis module, in all the aeronautical disciplines. Nevertheless, these codes are often not included in the aircraft pre-design activities, due to the complexity, and the time demand, faced by the designer's team to pre-process and to instantiate the multiple

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An Application of AHP, TOPSIS-Fuzzy and Genetic Algorithm in Conceptual Aircraft Design

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Keywords: *conceptual design, AHP, TOPSIS, genetic algorithm, aircraft design*

Abstract

This work approaches the conceptual design of an aircraft using a combination of three innovative tools. Genetic Algorithm is used in order to find the optimum solution inside the search space. Generated conceptual aircrafts are evaluated by AHP and TOPSIS in fuzzy environment. These tools allowed the creation of a complete system for multidisciplinary optimization that was tested in an aircraft conceptual design and achieved good performance. The main limitation of the method is the need of creating a good model to determine operational performance from general characteristics.

1 Introduction

One of the most challenging parts in the design of an airplane is determining the optimal balance of general characteristics. Although being one of the fastest phases in the whole aircraft design, the conceptual design plays an important role in achieving the best operational performance and fulfillment of the market's requirements.

One of the difficulties in this job is to estimate several interdependent characteristics that will only be known when the whole design phase is complete. Generally, previous knowledge based on experience is used in order to predetermine these values, but when new technologies are applied this information and statistics are rare or nonexistent. The solution for this problem is the evaluation supplied by the combination of Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution in fuzzy environment (TOPSIS-Fuzzy).

2 Theory

This work proposes the combination of three different methods in order to create an optimization tool where establishing the importance of each performance characteristics and estimating parameters are difficult processes. AHP is used along TOPSIS-Fuzzy in order to give a rational and efficient way to evaluate the different choices while GA allows creating different combinations of project characteristics without having the direct estimation of unknown parameters.

3 Discussion

The results obtained by the method were satisfactory as the optimized aircraft presented good performance parameters. The method has proven to be effective for the optimization of complex problems with multiple goals such as the conceptual design of a general aviation bi-place aircraft.

Future works will be made in order to refine performance calculations and implement cost analysis in the system. Moreover, the AHP TOPSIS-fuzzy method can be tested with other optimization techniques.

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Parametric Design Studies for Propulsive Fuselage Aircraft Concepts

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Keywords: *Distributed propulsion, propulsive fuselage, wake filling, boundary layer ingestion*

Abstract

Breaking with the classical separation of airframe and powerplant system, new synergy effects may be rooted in close design coupling and the approach of distributing the production of thrust along the main components of the airframe. Beside greater configurational flexibility, airframe structural relief, improved noise shielding, and, the potential for control power augmentation, distributed propulsion is particularly interesting due to the reduced propulsive power demands expected from the notion of aircraft wake filling. In previous work, the concept of a propulsor encircling the aft-fuselage with intent to entrain the fuselage boundary layer was identified to be one of the most promising concepts for aircraft wake filling. In this paper, the analytical basis for the quantification of efficiency benefits connected to the propulsive fuselage concept is discussed. Appropriate control volume and consistent efficiency chain definitions are introduced. A simplified boundary layer model is derived from axisymmetric fuselage CFD simulation and used to determine the momentum deficit ingested by the fuselage propulsor. Based on a novel figure-of-merit for vehicular efficiency, the Energy Specific Air Range, ESAR, the dependency of aircraft cruise efficiency on basic propulsion system and aircraft design changes is parametrically investigated. Specifically, the sensitivities of vehicular efficiency w.r.t. wing aspect ratio and flow transition characteristics, propulsor size, and aircraft design cruise Mach number are studied.

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Conceptual design of aerospace plane the next decade

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Keywords: *aerospace plane, crew transport vehicle*

Abstract

Looking back on the tragic event on 1 February 2003, when the crash of aero-space plane (ASP) "Columbia" occurred, there should be a special flight vehicle which would prevent from the tragedy. After that, there appeared a new term in the classification of ASP – Crew Transport Vehicle.

In this work is made the analysis of parameters of a conceptual ASP, intended for delivery in low orbit 6-7 people or 4.5 tons of cargo. One of the main questions is concerned of the thermal protection system.

1 Conceptual design of ASP

Now days the need of ASP loading much more easily and quickly than "Space Shuttle" is obvious, and this is clearly seen in the regular delivery of cargo and crew between the International Space Station and the Earth. But perhaps one of the most pressing problems of this prospective ASP is involved in exceptional circumstances, i.e., rescue operations.

The students of Nanjing University of Aeronautics and Astronautics have developed a conceptual design of ASP "Orbiter Salvor" systems using CATIA, ANSYS, and FLUENT. Figure 1 shows its 3D model.

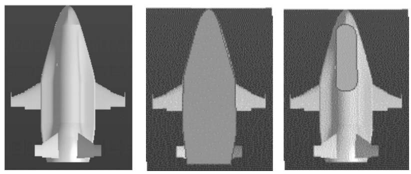

Fig. 1 ASP "Orbiter Salvor".

2 Conclusion

The main features of this project include:

1. Use of heat-resistant power screen, which is the structural basis to store all the components of ASP;
2. Modular design of aircraft, allowing a minimal cost to rebuild the ASP in different ways: unmanned freight, manned transportation, lifesaving, travel;
3. Telescopic pull-out aerodynamic bearing surface, resulting in a working state at speed to appropriate M <2…3;
4. Use of a turbojet engine RD-33 with turning vectored thrust;
5. The versatility of this ASP will allow also to use it for space tourism.

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Weight Analysis of Hot Structures

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Keywords: *thin-walled construction, heating, weight formula*

Abstract

In this presentation the weight formula for heated constructions is considered. Numerical calculations that show the effect of heating on the weight of full stress designs are conducted and weight estimation of aero-space plane wing is made.

1 About weight formulas

The weight of a flight vehicle (FV) at all stages of design is one of the most important design parameters and it's used as one of the main criteria. For the estimation of weight in the early stages of design, there are hundreds of so-called "weight formulas", which are usually obtained from a statistical analysis of existing aircraft and on the basis of simplified calculation models. The question of analyzing the mass of structures, working with a considerable heating is a very relevant one.

For the analysis we use the universal weight formula of V.Komarov [1], which is recorded in the form

$$m = \varphi\, G/(\bar{\sigma}) = \varphi\, C\, P\, l/(\bar{\sigma}) \qquad (1)$$

where φ is the coefficient taking into account the mass of additional non-load-carrying part of the construction and deviations from the optimal (theoretical) option in favor of manufacturability; $\bar{\sigma}$ is the specific strength of a construction material, $\bar{\sigma} = \sigma_u/\rho$; $G = C\, P$ – load-carrying factor, including: C is the load-carrying factor coefficient; P, l – the reference load and size of the projected design.

The coefficient φ is obtained on the basis of statistical processing of the already existing structures. The groundwork for the φ and C allow us to estimate the mass of the construction of the completely new project, including the most original circuit solutions.

2 Calculation of the panels

There are two rods working together without bending, which can be heated and loaded longitudinal force P. Such a model task allows you to approximately assess the impact of warming up to the height of the load element, and to consider the joint work of the hot cover and cold stringer, or hot panel and cold belt spar of a wing. In the case of use of the material with

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On inspection systems for repairs of composite structures in aircrafts

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Keywords: *vision system,cleaning, repair, composites, documentation, CFRP*

Abstract

In repairs of fiber reinforced products, contaminants like oil or dust and the position and fiber orientation of the plies used, are crucial for success. On-site quality control is usually performed manually and documentation consists of signed procedures. One reason for this manual approach has been the difficulty to apply reliable portable procedures and technology for automatic inspection of both the pre-preg tapes and weaves used to build a carbon fiber reinforced product and of the material to be repaired. Since these materials are black, and/or glossy, display poor contrast and have low form-stability; commercially available inspection systems that can be used during repairs have been scarce. Also strict standards and regulations within the aerospace industry inhibit the introduction of new technologies in the manufacturing chain. In order to reduce the connection between operator/technician skill and resulting quality automated inspection systems can be introduced.

Vision technology based systems are commonly used in many industrial sectors for quality inspection. One well established field of use is found in the electronic industry when verifying the position of electronic components on circuit boards. Another is the automotive industry, for example, in adaptive weld seam tracking.

New and interesting systems for contaminant inspection of fiber reinforced materials are also surfacing, which can be used in repairs to check cleanliness and ensure bondability.

The paper looks at these different technologies, and relates them to the challenges posed by inspection and documentation during repair of aircrafts structures. Thus this paper is a "state of the art" survey of potential vision and contaminant inspection technologies applicable for manufacturing and repair of fiber reinforced products. Technical challenges that must be addressed by a quality assurance system used for repairs are also described.

Abstract for CEAS 2013

Next Generation Radio Occultation Instrument for Weather Forecasting and Climate Research

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Radio occultation (RO) measurements take advantage of the precise navigation satellite signals to profile temperature, pressure and water vapour in the atmosphere with high precision and resolution. The technique was developed in the late nineties and has in a short time advanced to one of the major contributors to weather prediction accuracy. The importance of the measurement is anticipated to increase even further when more instruments are deployed in space. Global coverage, all weather and all day capabilities, 1400 profiles per day and instrument (using Galileo and GPS), vertical coverage from the surface up to 50 km and self-calibration which is inherent in the method are other features that make the method attractive. RO is further very suitable for climate observations and is considered to be the only method that today, within a decade, can detect the global temperature change. The ionosphere electron content, often referred to as space weather, can also be measured which is of great value to e.g. radio communications, power grid disturbances and satellite interference and protection etc.

GRAS (GNSS Receiver for Atmospheric Sounding) is an RO instrument developed by RUAG Space that was first launched on the MetOp-A satellite in 2006. MetOp-A is a polar orbiting weather satellite, the first in a suite of three operated by the European meteorological satellite organisation EUMETSAT. The B satellite was launched in October last year, and the two GRAS instruments on MetOp are today the most important sources of RO measurements. GRAS has from the beginning been a great success, with a performance surpassing other RO instruments.

The new signals gradually becoming available from the satellite navigation systems Galileo, GPS, GLONASS, and Compass will allow for a very high number of daily atmospheric profiles to be measured. The next generation RO instrument which is currently under development will take advantage of these signals to improve measurement performance even beyond the present GRAS instrument. The new signals allow for dual-frequency tracking without anti-spoofing losses. Further, experience from MetOp-GRAS shows that the onboard Doppler and range models are sufficiently accurate to allow for model based signal retrieval in the lower part of the atmosphere. This will enhance the measurement coverage further by providing denser sampling and improves coverage at low altitudes where severe atmospheric conditions can cause strong atmospheric multipath and interference.

A simulation environment has been developed, which includes a wide range of realistic and challenging atmospheric conditions representing the full span of the conditions present on earth. The simulation environment includes atmospheric signal propagation capable of handling severe multipath conditions, GNSS signal modulation, models of the instrument hardware and software, as well as a model of the ground based measurement retrieval process. This environment allows for detailed design and optimisation of on-board instrument algorithms including measurement acquisition and tracking. Further it enables predictions of instrument performance at all altitudes, under the full span of atmospheric conditions as well as for both setting and rising occultations.

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Use of Next Generation Complex COTS in Avionics Requires Extensive Multi-Disciplinary Skills

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Keywords: *COTS, Complexity, multi-disciplinary, skills*

Abstract

The use of commercial-off-the-shelf (COTS) components in avionics increases every year. COTS components are accepted practice throughout the avionics industry, mainly because of a significant number of key components are only available as COTS. Other key drivers are cost, time schedule and keeping pace with emerging technologies.

Keeping pace with innovations has been manageable for the avionics industry up till today despite several discussions of using COTS in safety-critical applications. The author believes this has been possible since the components have not yet required extensive multi-disciplinary skills, and that the industry together with the certification authorities have been able to track the changes.

In late years, however, the innovation pace has increased such that new issues that can affect safety and airworthiness are becoming more and more evident. The certification authorities are aware of this, and have recently released COTS guidance for digital COTS ICs and COTS microcontrollers [1]. (Guidance for COTS graphical processors was already recognized in 2007 [2].) They have also shown interest in COTS through several research projects, e.g. [3-5].

To illustrate the speed with the embedded COTS electronics market is changing, one can count the number of cores in multicore processors. For instance, mobile phones have gone from one core in 2010 to eight cores in 2013 (Samsung's Exynos 5 Octa core CPU [6]), and multicores more suitable for the avionics market are now reaching 12 physical (24 virtual) cores (Freescale's high-performance QorIQ communications processors [7]).

This presentation shows recent trends and innovations within COTS and some industry guidance to cope with these innovations. It also discusses the certification authorities' public COTS guidance briefly. Finally, it shows why the use of next generation complex COTS in avionics requires multi-disciplinary skills far beyond what was required previously. Examples of roles (skills) to be required are:

- Certification specialist – to understand certification requirements, to set up COTS processes, to classify COTS components, and to track all related COTS industry standards.
- Hardware process assurance engineer – to keep track of the required activities to be performed.
- Hardware engineers skilled in high-level COTS architectural solutions – to be able to derate beyond the manufacturer's recommendations, to understand advanced power-aware architectures, to understand complex IO controllers' dependencies etc.
- Hardware engineers skilled in extracting requirements from component metadata, understanding

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Magnetometer Calibration Method for Small Calibration Dataset

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Keywords: *calibration, tri-axial, magnetometer, online*

Abstract

This work presents an estimation method for hard iron calibration settings of a magnetometer where only a reduced dataset is available.

Most 3 axis magnetometer calibration methods require a full rotation about the 3 axis, covering the main directions in the space. These rotations cannot be done in many applications, i.e. when the magnetometer is mounted on a heavy UAV. The main advantage of this method compared with other calibration methods in the literature is the approximation of the offset with measurements only in a few directions of the space.

The method is tested using real data from a magnetometer in the laboratory. The preliminary results show a good performance of this method under the cited conditions.

1 Magnetic interactions

Magnetic field sensors are typically included in solutions for attitude determination. More intense in UAV's systems where weight and size of every single piece is a critical issue.

These sensors are very useful in contribution with accelerometers and gyroscopes for attitude determination of the system and posterior control. On the other hand, due to weakness in earth magnetic field module, it is easily distorted and prone to errors. Main errors observed in a magnetic field sensor are defined as either soft iron effects or hard iron errors [1].

Soft iron effects are generated by an external magnetic field interacting with ferromagnetic materials in the vicinity of the sensor. On the other hand, hard iron errors are resulting effects from permanent magnets associated to the vehicle or environment structure.

Both errors are modeled within the following equation:

$$h_r = Ch_i + b \qquad (1)$$

Where hr denotes magnetic field corrected reading, C is a transformation model accounting for non-orthogonality and soft-iron errors, and b is the hard iron term (offset errors).

2 Magnetometer calibration

Defining both parameters (described in previous section) allows calibration methods to perform a good reading of incoming data from magnetic sensors. However under many circumstances calibration methods requires a

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Miniaturized Foliage Penetration Radar: Technology, Testing and New Developments

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Keywords: *CARABAS, foliage penetration, VHF, UHF, IED, MTI*

Abstract

The work reported here is a continuation of the development accounted for in Flygteknik 2010. Since then the conjectural miniaturized airborne radar system described, has been built and tested with good results. The system – named CARABAS III in continuation of the earlier FOI radars – is now being further improved to handle ground penetration and also detection of humans under forest cover.

The presentation will account for the testing of the system and its outcome. It will also describe the parallel work of enhancing the system.

The system operates at two frequency bands, viz. at low VHF and at high VHF going to low UHF. The lower band is for detection of concealed stationary targets, and the higher for the new applications.

For the new applications careful theoretical modeling has been performed so that the system configuration is optimized with respect to these and to establish the sensitivity requirements.

The important classes of buried targets are mines and IEDs. In modeling and testing at the low frequencies considered, these can be equaled to metallic spheres of equal or smaller sixe than the targets, depending on whether the targets are metallic or non-metallic. It turns out that the radar echoes from buried targets are very weak, which however can be handled by radar imaging at sufficiently short range. CARABAS III has thus been designed to operate at ranges down to 100 m, from a helicopter at 30 m altitude. Another concern is the ground surface clutter competing with the subsurface target. A method of canceling this is by polarimetry, using the association between vertically and horizontally polarized rough surface clutter. This option is included in CARABAS III.

Also for humans under forest cover clutter removal is a necessity. The method of achieving this, is by an enhanced form of MTI-radar, allowing for very sharp filtering between objects moving at walking pace and the stationary ground. This type of radar requires antennas with displaced phase centers. This option has been realized in CARABAS III.

Up to now, testing has mainly covered stationary surface targets but testing of the more advanced applications will commence during the spring and some results from these trials would be available for the conference.

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AIRTRACER – an airborne SIGINT solution

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Keywords: *SIGINT, electronic intelligence, communications intelligence, intelligence cycle, AIRTRACER*

Abstract

Airborne Signals Intelligence (SIGINT) is - as part of Intelligence, Surveillance and Reconnaissance (ISR) - one element used to fulfill the increasing demands for information needed to make political decisions and perform military planning and operations.

Airborne SIGINT – and SIGINT in general - can be of a strategic, operative and tactical nature. The main goal of strategic signals intelligence is to provide preparation time for top level military and political leadership. Communication- and radar signals are usually collected and analyzed regularly over a long period of time. Operative signals intelligence supports the planning and actions of operative organizations by providing intelligence on a time scale in the order of days. Tactical intelligence is performed in real- or semi real-time where a situation has already developed and it is needed to support own assets.

AIRTRACER is an airborne turn-key solution from Saab including aircraft, mission system equipment, infrastructure, training and in-service support. It is well suited for the tactical and the operative and strategic roles and supports all aspects of the intelligence cycle. (Request, planning, collection, analysis, reporting)

The AIRTRACER SIGINT system comprises a communications intelligence (COMINT) capability and an electronic intelligence (ELINT) capability with results that are consolidated on a common view. For both COMINT and ELINT the operating altitude of the aircraft provides long intercept ranges, thus also useful for tactical intelligence gathering at long stand-off distances.

The operating altitude also exposes both the COMINT and ELINT sensors to numerous signals of different kinds which places high demands on technology for receivers and processing. The technology needed by SIGINT today benefits from the speedy development of technologies uses in commercial applications and can be seen to benefit further from this.

The training of SIGINT mission operators is of high importance, both for new operators but also for preparing skilled operators in handling complex operational situations which might occur rarely. AIRTRACER includes an advanced ground-based training simulator which enables the operators to train skills in different scenarios using life like signals.

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Design of A Small Air Data and MEMS INS/GPS Integrated Navigation System for Wing-in-ground Effect Vehicles

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Keywords: *wing-in-ground effect, Air data system, MEMS, INS/GPS navigation*

Abstract

Wing-in-ground (WIG) effect (or surface effect) vehicle is a kind of crafts that have been designed specifically to utilize the benefits of the ground effect and that fly near to the ground which may refer to land, water, ice, snow, sand, and so on. Although it has been released almost one century that the ground effect phenomenon which means an increase of the Lift to Drag ratio because the wing compress air against the surface when the wing of a craft flies in close proximity of the ground. The technology of WIG vehicles is not mature enough so that WIG craft can't make big commercial success. However, it is widely believed that the potential exists for the WIG craft to have practical transport applications over water for its more efficiency than the aircrafts and more rapid than ships.

For the greater safety and efficiency of a WIG effect vehicle, it is extremely important to measure the flight air data and to determine navigation parameter that includes air speed, baro height, attitude, ground velocity and position. All that parameters can be provided by an air data system and the navigation system which is one of the most important avionics electronic systems.

The motivation of this paper is the design, implementation and performance test of a small and low cost air data and MEMS INS/GPS integrated navigation system for a wing-in-ground effect vehicle. The air data and MEMS INS/GPS integrated navigation system provide air data and navigation parameters to the cockpit display with a large LCD screen by which aircrew manage the WIG effect vehicle.

The configuration of the air data and MEMS INS/GPS integrated navigation system includes a pitot probe, two Honeywell precision pressure sensors, a small u-Blox GPS receiver, a self-designed MEMS IMU and an embedded air data and navigation processor PCB based on an ARM chip. The system hardware architecture is illustrated as Fig 1 and the layout of the sensors and PCB is shown in fig 2.

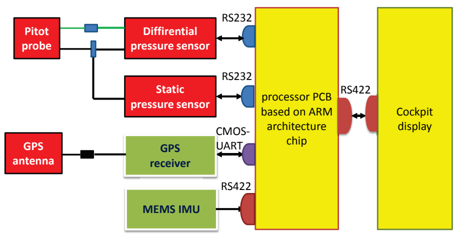

Fig.1 system hardware architecture

Modeling and Numerical Simulation of an Open-Loop Miniature Capacitive Accelerometer for Inertial Navigation Applications

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Keywords: *MEMS, accelerometer, capacitive sensing, modeling, simulation. inertial navigation*

Abstract

The paper deals with an analogue capacitive micro-accelerometer both from the point of view of mathematical modeling and through the achievement of certain numerical simulations which must confirm the mathematical models and in the same time help to establish the optimal architecture of the system. The capacitive transducer is one of differential type, with two fixed plates and one moving, which play the role of proof mass.

1 Introduction

New technology tendencies in systems miniaturization led to the development of an important segment among modern applications - Micro-Electro-Mechanical Systems (MEMS) technology. A short definition of the MEMS is that they are small devices that can integrate both mechanical and electrical components on the same substrate. The process through which they are provided lies in laborious techniques, difficult to implement called generally micro-fabrication. One of the major advantages of such devices is that they sense, control and actuate on micro scale. The MEMS future is the integration and development of a higher complexity and a larger number of such devices as parts of certain equipment as complex and precise as possible [1]-[4].

The interdisciplinary nature of the MEMS is reflected in their widespread use in various fields, such as mobile phone, automotive, medical, aircraft, etc. [5].

One of the most important MEMS sensors, representing the basis of the INS (Inertial Navigation Systems) is the accelerometer. It is an instrument that senses external accelerations and converts them into electrical signals. The physical principle underlying the accelerometer consists in the measurement of the displacement of a proof mass elastic attached on a fixed substrate. The detection of this displacement can be performed in different ways, but one of the most common is the capacitive one. The architecture of the detection circuit can be conceived with a simple structure or a differential structure [6]-[8].

This paper deals with such a detection method, with differential structure, and is related to a research project that wishes the development of *High-precision micro and nano smart sensors for space inertial navigation applications*, project financed by *Romanian Space Agency (ROSA)* at *Department of Electric, Energetic and Aerospace Engineering, Faculty of Electrical Engineering, University of Craiova, Romania.*

Here presented work exposes an analogue capacitive micro-accelerometer both from the

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Hybrid Rockets as a Green Replacement of Solid Rocket Boosters

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Keywords: *hybrid rocket green propellant*

Abstract

Conventional solid rockets exhausts present hazard to the environment. On the opposite several hybrid rockets propellant combinations are environmental friendly and thus represent ideal candidates as a GREEN replacement of current technology particularly when safety and costs are more important than system volume.
This paper describes the research and development activities undertaken at University of Padua, in the design development and testing of a Hybrid Rocket system to substitute solid rocket boosters.
Solid rocket booster are currently used of several system in the defense and aeronautic market. The solid double-base propellant management requires well known safety procedure on order to diminish the intrinsic level of danger. All activities concerning their handling shall respect the same rigid and demanding procedures as the ones, which concern explosive hardware or materials, which finally determine very high management costs. The hybrid rocket technology has been selected as a candidate to substitute the solid rocket booster. As a benchmark case solid rocket boosters able to provide 50 kNs of total impulse, in 3.5 s. In respect to the solid rockets booster technology the hybrid technology provides an intrinsically increased safety level during handling, transportation, storage and installation procedures: this applies in land and especially in naval operation, where stocks of explosive materials are highly avoided.
CISAS development resulted in a flight worth prototype based on N2O/Paraffin, providing 50 kNs total impulse, 20kN peak thrust and 3.5 seconds burn time.
The system was developed through a well-integrated numerical and experimental approach.
Specific numerical models have been developed to design the entire rocket system, from the oxidizer tank to the nozzle. A wide experimental campaign has been conducted on sub-scale models to verify oxidizer behavior and combustion issues. CFD analyses have been performed to analyze the fluid flow within the combustion chamber. About twenty tests on the full scale model have been performed to increase performances till the final target of 93% combustion efficiency.
The results of this research program showed that a hybrid-based system can successfully substitute solid rockets drastically reducing risks and related costs together with environmental pollution.
This paper describes the all design and development phase.

Dispersion and chemical composition of SRM rocket plumes: Model simulations versus in-situ aircraft measurements

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During launches, rockets release large amounts of gases and particles into the atmosphere. For Solid-fueled Rocket Motor (SRM), launches often result into the release of chemically active radicals (chlorine radicals, nitrogen oxides,…), and alumina particles into the stratosphere. In-situ aircraft measurements within SRM plume wakes have shown that, as a result, ozone is largely destroyed within plumes because concentrations of ozone-destroying chlorine radical concentrations can be several orders of magnitude higher in the plume than in the undisturbed atmosphere [Ross et al., 1997]. This transient effect lasts for several hours or as long the exhaust plume is not completely mixed with the ambient air.

We present here numerical simulations of the evolution of SRM plumes and of their chemical compositions in the stratosphere. The focus is on the short-term effect on ozone. The evolution can be divided into two phases: near field phase (jet emerging from the nozzle exit) and far field phase. These two phases are characterised by different driving physical (rocket fluid dynamics versus atmospheric dynamics) and chemical (high temperature versus low temperature chemistry) processes. The temporal and spatial scales are also very different. The spatial scale of interest for the near field plume is of the order of a meter whereas the scales in the far field plume range from several meters to tens of kilometers typically. Exhausts spend about a second in the near-field plume whereas the far-field plume lasts several hours typically. No models are able to treat simultaneously, on one hand, very high temperature chemistry (including afterburning) and jet dynamics and, on the other hand, low temperature (ambient temperature) chemistry and relevant atmospheric dynamical processes. Therefore, we use two specific plume chemistry models for each phase with the results of the near-field plume model being used as inputs for the far-field plume model.

The near-field plume simulations are compared to previous model calculations and the model-calculated chemical evolution of the far-field plume is evaluated against in-situ aircraft measurements carried out in Athena rocket plumes during the ACCESS (Atmospheric Chemistry of Combustion Emissions Near the Tropopause) campaigns [Popp et al., 2002]. The model-calculated dispersion rate of the far-field plume is also evaluated against plume diffusion rates derived from videos, photos, lidar measurements, as compiled by Smith et al. review [1999]. We finely analyse the fate of reactive chlorine and nitrogen in the plume and the possible role of heterogeneous chemistry on alumina particles.

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LCA for Environmental Impact Assessment of Space Systems Eco-design of Space Missions

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Keywords: *LCA, Eco-design, Sustainability, Space Missions*

Abstract

The European Space Agency (ESA) as a public sector intergovernmental organisation, wishes to put the environmental concern as a priority in all its activities as expressed in its Framework Policy on Sustainable Development. The first step in this direction is a deeper analysis and understanding of the environmental impacts of space programmes, to provide ESA with the necessary know-how to take a pro-active role regarding legislation on this topic and to drive technical and scientific innovation in the European space industry. Life Cycle Assessment (LCA) is a powerful method, standardized at international level by ISO, to evaluate the potential environmental impacts of products and services in a comprehensive and objective manner and from a multi-criteria life cycle perspective. ESA has successfully applied LCA to assess the environmental impacts of the European launcher family over their whole life cycle. As a next step in the deployment of life cycle thinking for space applications, ESA is expanding the use of LCA to the entire life cycle of space missions and establishing a common framework for eco-design that can also be used by other European space organisations when performing spacecraft design. This framework shall include methodological and software tools as well as a database dedicated to space activities. To this end, ESA has initiated pilot LCA studies on a representative selection of space missions, including scientific, earth observation, meteorological and telecommunication missions. In addition to the identification of the environmental hotspots of space missions, pilot LCAs will also provide inputs for the development of the dedicated tool and database. This eco-design tool will be used at ESA's Concurrent Design Facility (CDF) and will allow designers to include environmental performance in technology trade-offs in early design phases. The eco-design tool and database will be connected to CDF's design framework, i.e. the Open Concurrent Design Tool (OCDT).

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Clean Space session

Non-Toxic Propellants for Space Propulsion

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Keywords: *Clean Space, Non-Toxic Propulsion*

Abstract

The need for non-toxic propellants is increasing not only due to the fact that classical, hydrazine based propulsion systems are facing legislative regulations but also because non-toxic alternatives could offer significant economic benefits.

Astrium Space Transportation as the main European supplier for launcher and orbital propulsion systems has a vital interest to play an active role in the development and industrialization of components and propulsion systems using non-toxic propellants.

This paper gives an overview over requirements, potential technologies and working areas where Astrium Space Transportation is involved. It discusses state-of-the-art propulsion technologies currently used for different missions and potential replacement options with non-toxic propellants.

In a first step the replacement of Hydrazine as a monopropellant is regarded keeping in mind that there is also a need for an alternative to the even higher toxic MMH used on bipropellant systems.

1 Introduction

Hydrazine based propulsion systems are state-of-the-art for various applications ranging from launchers to small satellites. They have a long heritage and a great variety of space qualified, off-the-shelf available components.

Hydrazine as a monopropellant and MMH (monomethyhydrazine) as a bipropellant are toxic, carcinogenic and mutagenic. Therefore special precautions have to be taken during all operational phases where Hydrazine is being used.

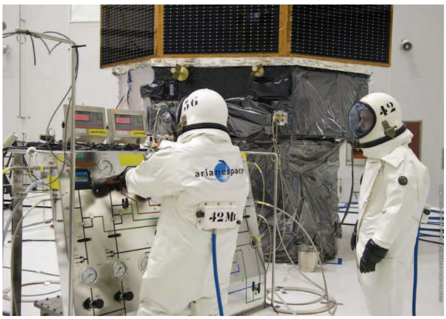

Fig. 1 Conventional Fueling with SCAPE Suit

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Modelling and Simulation of Veson: a Family of Small Sounding Rockets

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Keywords: *rocket engines; ethanol; simulations.*

Abstract. *Aiming to contribute significantly to the formation of space engineers, this work proposes a family of experimental sounding vehicles, Veson (of the Portuguese "Veículo Experimental de Sondagem"), whose finality is to demonstrate the basis of functioning of liquid propellant rocket engines and still to work like a platform of measures and experiences. The first objective of this project is to build a complete simulation, in the sense of containing all the usual components of this type of design. The behavior of the vehicle will be compared with the theory and with similar engines, giving the students an understanding of the processes and methods and also to a critical evaluation of the technologies chosen in different cases. We also considered propellants details as well as environmental aspects. The pair ethanol / hydrogen peroxide (green propellants) has a higher density than most of the propellants, requires a smaller volume reservoir, decreasing the intrinsic weight of the vehicle. Moreover, hydrogen peroxide and ethanol have lower toxicity than other conventional propellants, still presenting good reason fuel/oxidant. The mixture is storable for long periods of time without the need for cryogenic; being compatible with low-cost construction materials such as aluminum and stainless steel. The low cost is an advantage, since Brazil produces large amounts of ethanol. A catalytic combustion chamber coupled to an expansion nozzle with Rao profile can produce enough gas expansion to assure the necessary thrust for a small-medium rocket. We present the simulations for a number of variations of the catalytic rocket engine and its performance in flights. The detailed CFD calculations are used to calibrate the simplified model for the system simulation.*

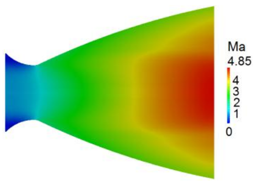

Figure 1. Mach number inside the nozzle.

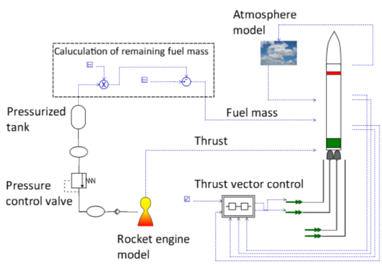

Figure 2. System simulation model built in Hopsan.

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Risk Assessment and Analysis of Disposal and Re-entry of Space Debris

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Abstract

At this very moment there are hundreds and thousands of "dead satellites" orbiting the Earth. Along with them, varying size of space debris are also lingering around the Earth. A recent study has found data indicating that the risk of debris colliding with healthy satellites is significant even if we stop future launches. Most of the Dead Satellites deviate from their Original path of motion due to mis functioning and pose a big threat in space. In the coming years any new launch can result into cascading collisions with exponential increase in space debris. In an effort to pervert such buildup of collisions, this paper suggests methods to remove nonfunctional satellites from orbits by two major methods. In both the methods we will be sending a satellite which will help achieve the operation. The first method focuses on utilising the working parts of the satellite which can be accomplished by using a Radioisotope thermoelectric generator powered satellite having a mechanical arm which will tether with the Nonfunctional Satellite and store it in PICA or AVCOT made compartment. The compartment will shield the satellite during reentry. The second method focuses on getting rid of the satellite by either launching it into deep space or by destroying it during reentry. This is achieved either by gravitational catapulting or by manual catapulting. Apart from suggesting methods we had also analysed the risks of orbital collision and analyse the operational hazard faced by satellites.

1 Introduction

As of 2009, NASA estimated that there are about 19,000 particles that are bigger than 10 cm and approximately about 10 million objects that are smaller than 1 cm. Debris is classified into two categories, large debris (of size greater than 10 cm) and Small debris (of size less than 1 cm). Objects that lie between 1 cm and 10 cm are also considered as large object but we cannot track these objects. So they are ignored. Fig. 1 shows an representation of the current scenario in space.

Whenever a satellite, space mission or a manned mission is launched, they tend to leave behind debris of varying sizes in various orbits. Collision between any two objects can be disastrous and can produce shrapnel from the impact. Each piece of shrapnel has the potential to collide with other objects and can cause further damage. Thus causing a cascade of collisions. When this happens, it can render a whole orbit unusable.

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Multidisciplinary approach for assessing the atmospheric impact of launchers

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Keywords: *rocket exhaust plume, European launchers, atmosphere, CFD, diffusion model*

Abstract

Exhausts from rockets influence the atmospheric chemistry and the atmospheric radiative transfer. Assessing these effects requires a multidisciplinary approach. It ranges from combustion calculations in the rocket engines to plume simulations on different scales. The plume is first analysed with computational fluid dynamic models and engineering methods. Then a diffusion model is applied and lastly a chemical transport model is used for simulations on a global scale. This approach is currently being implemented in the Atmospheric Impact of Launchers project, which is funded by ESA as part of its CleanSpace Initiative. Therefore, the focus of this study lies on rockets launching from Kourou, which are Ariane 5, Vega and Soyuz.

1 Introduction

During ascent a launcher flies through all layers of the atmosphere. Throughout its flight, the rocket's propulsion systems emit chemical products, which can influence the atmospheric chemistry. In addition, the particles coming from the solid rocket motors can affect the atmospheric radiative transfer processes. Especially the potential impact on stratospheric ozone is important. Research in this field serves as a basis for ecologically sensitive design of launch vehicles. This research falls into three main categories: measurement campaigns, computer simulations, and laboratory experiments.

Early studies on the atmospheric impact of launchers were conducted by NASA as part of the Space Shuttle program. Recently, Stevens et al. [21] observed the Space Shuttle's water vapour plume during the Shuttle's last flight.

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Deorbiting of spacecraft at the end of life with electrodynamic tethers stabilized by passive oscillation dampers

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Keywords: *Electrodynamic tethers, satellites deorbiting, passive damping*

Abstract

Since the beginning of human space era the number of debris orbiting the Earth produced accidentally or intentionally by artificial satellites has been continuously growing. Nevertheless, only in the last years the alarming growth of space debris induced many space agencies all over the world to adopt debris mitigation strategies. Present guidelines indicate the need to deorbit new satellites launched into low Earth orbit (LEO) within 25 years from their end of life. Our task, which is part of an international EU-funded project, is to develop a new technology suitable to deorbit a satellite at the end of life with as small an impact as possible on the mass budget of the mission. In fact, a deorbit maneuver with chemical rockets can strongly affect the satellite propulsion budget, thus limiting the operational life of the satellite. An alternative to the traditional chemical rockets consists in using an electrodynamic tether that, through its interaction with the Earth ionosphere and magnetic field, can take advantage of Lorentz forces for deorbiting purposes. This is a particularly promising technique because it is passive, light and effective. However, Lorentz forces produce a low and yet continuous injection of energy into the system that, in the long run, can bring the tether to instability. This paper addresses this issue through the analysis of the benefits provided by a viscous damping device installed at the attachment point of the tether to the spacecraft. The analysis carried out by means of linearization of dynamics equations and numerical simulations show that a well-tuned damper can efficiently absorb the kinetic energy from the tether thus greatly increasing the system stability.

1 Introduction

Due to recent guidelines on the deorbiting of LEO satellites at their end of life provided by the Inter-Agency Space Debris Coordination Committee (IADC) [1] the attention of governments, space agencies and researchers on this issue has grown worldwide in the last years [2]-[5]. Several concepts are under study to provide new alternatives to carry out deorbiting maneuvers in a low-cost, safe and reliable way (Ref. [6] provides a good overview for microsatellites). One of these options involves the use of an electrodynamic tether to produce a Lorentz drag that can rather quickly deorbit small and large satellites [7]. The present work is part of a EU-funded research framework [8] whose aim is to develop the technology of electrodynamic tethers suitable for deorbiting satellites from generic Earth orbits (LEO). One

The ESA Clean Space Materials, Processes and EEE Components Roadmaps

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With the Clean Space initiative, ESA will join forces with the European industry and the national space Agencies in an effort to significantly lower the environmental impact of the space missions. This environmental outlook, will not only assess the impact of European space activities (on earth and in space) but will also comply with current legislation while preparing for future evolution, placing the European industry at a competitive advantage. Environmental regulations in Europe have serious implications for space programme, the most immediate being the possible disruption of qualified materials, processes as well as large design changes in the electronics manufacturing. Through the Clean Space initiative, ways will be defined of meeting the requirements of current and potential future legislations, while minimising supply chain disruptions through active risk mitigation (i. e. development of alternatives).

New material/coating concepts in combination with advanced green or "greener" manufacturing processes and innovative design principles are already available in the industrial portfolio and could be rapidly implemented in selected Satellites, Launchers and Ground Systems applications leading to significant reduction of the environmental impact. In the present European industrial landscape promising and emerging alternatives with Mid to High Technology Readiness Levels (TRL's) offer the strategic opportunity to enable significant weight reduction as a mean to reduce CO_2 emissions, allowing important decrease of energy consumptions during manufacturing while reducing the production steps and leading to a drastic cut of health hazardous chemicals.

The present paper gives a detailed overview of the European Space Agency Clean Space roadmaps in the field of materials, manufacturing processes and EEE (Electronic, Electrical and Electromechanical) components.

Increased Propellant Throughput for 1N Green Rocket Engine

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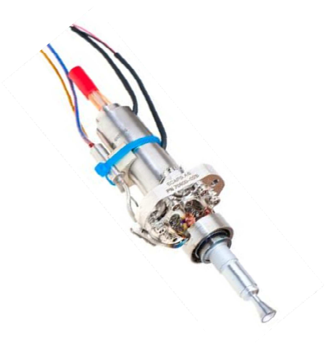
The HPGP propulsion technology includes storable monopropellant blends based on Ammonium DiNitramide (ADN) and thrusters with a high temperature resistant thrust chamber and catalyst. After more than 2 years in space on the PRISMA mission, all planned firings with the High Performance Green Propulsion (HPGP) system using 1 N HPGP thrusters and the storable liquid monopropellant LMP-103S, have successfully been completed and all test objectives have been met.

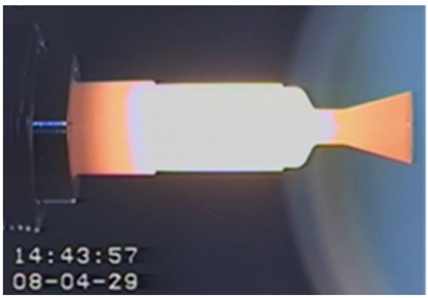
The thruster 1N HPGP thruster for use with the high performance green propellant LMP-103S has been developed for a total maximum propellant throughput of 24 kg (qualification level). This would be sufficient for a portion of the spacecrafts using 1N thrusters. However, since REACH's (Registration, Evaluation, Authorisation and Restriction of Chemical substances within the European Community) inclusion of hydrazine on its list of materials of high concern and the risk of REACH hydrazine restriction, there is greater need to focus on green propellant replacement of hydrazine for all spacecraft. In particular, for the 1N HPGP thruster a significantly greater throughput is required to meet the needs of the majority of spacecraft using this class of thruster.

Based on previous analysis and testing of the thruster, it is expected that the 1N HPGP thruster can handle an increased throughput with the existing configuration. This aspect has to be investigated before proceeding to the qualification phase.

The present paper covers the hot-firing test campaign performed in order to investigate if the maximum throughput can be increased above 50 kg.



ECAPS 1N HPGP Thruster



Hot-firing of a 1N HPGP Thruster

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Life Cycle Assessment – Solid Rocket Motor Case CEAS 2013

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Keywords: *Life Cycle Assessment, Clean Space, Ariane 6, Solid Rocket Motor Case*

Abstract

Environmental impacts, including global warming, are now a major political and economic issue.

Life Cycle Assessment (LCA) is a driver for decision making which allows quantifying products' environmental impact from raw materials phase until end of life.
This methodology is based on the analysis of every aspect and phase of a product or program through its overall life cycle, from design or acquisition to disposal or recycling.

LCA is a structured and standardized method and management tool through ISO 14040 & ISO 14044.

Efficient resources and technologies contribute also to reduce costs by decreasing material inputs, energy consumption and waste.
This approach meets two of the major objectives of all futures Space Programme: costs control and environmental impacts.
Solid Rocket Motor Case study was made through an internationally recognised tool named SimaPro.

Results enable to specify the significant impacts and life cycle phases with a major contribution on the environment.
For the Ariane 6 Solid Rocket Motor Case, raw materials seem to have the biggest impact on abiotic depletion and global warming potential while production phase shows significant impact on aquatic and terrestrial eco-toxicity.

Furthermore the results interpretation allows carrying out improvement on materials and processes with proposal of sustainable solutions.

The oral presentation would depict the methodology implemented within Astrium-ST for the environmental impact assessment and the Ariane 6 Solid Rocket Motor Case study.

1 General Introduction

The application of Eco-Design can benefit business, users and society at the same time because it meets the common interest of obtaining more efficient products in an economic as well as an environmental dimension.

There is a consensus that the most suitable approach to evaluate environmental impact of products and services is the Life Cycle Thinking (LCT) and the Life Cycle Assessment (LCA).

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Environmental impact assessment of space sector: LCA results and applied methodology

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Rainer Zah[3], Simon Gmuender[3], Andreas Ciroth[4]

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[3]EMPA, Switzerland, [4]GreenDelta TC, Germany

Keywords: *Life Cycle Assessment, Space Mission, European Space Agency, Carbon footprint.*

Abstract

In the framework of the Clean Space Initiative, promoted by ESA for increasing attention to the environmental impacts of its space activities, the "LCA4Space project" (ESA Contract No. 4000105605/12/F/MOS) aimed at evaluating, through the LCA methodology, the environmental performances of two space missions (Astra 1N and MetOp-A) together with the elaboration of sector specific methodological LCA guidelines.

The LCA methodology is a holistic approach to estimate the environmental impact of a product or service throughout its life cycle (cradle-to-grave approach). LCA has been widely, and successfully applied to several industrial sectors in order to understand environmental trade-offs, optimize processes, support policy making and as an eco-design tool.

Within this framework, the main objective of the study is to support ESA towards the acquisition of the necessary methodological background and a more comprehensive understanding of a space mission's life-cycle impacts.

A cradle to grave approach was applied to the two missions selected by ESA and a common methodology for European space sector was elaborated. All spacecraft phases from Concept and Design to manufacturing up to End-of-Life, through launch and use, were evaluated.

This analysis has been conducted following ISO standards, ILCD Handbook, prepared by The Directorate General–Joint Research Centre (DG-JRC) of the European Commission (EC) - Institute for Environment and Sustainability (IES), with the support of a software for LCA modelling, openLCA. More than 60 new datasets (import/export to Ecospold), specifically dedicated to space sectors, were created.

Through its relevant outcomes, the project contributed to overcome some barriers that have so far limited the use of the LCA in space sector:

- *Specificity of space projects;*
- *Heavy difficulties in input data collection, due to system complexity and confidentiality problems;*
- *Use of non-standard materials and industrial processes;*
- *Difficulties in qualifying new environmental friendly materials and processes.*

Acknowledgment: *The Authors wish to thank Ms. Luisa Innocenti, Mr. Thiago Soares and Mr. Jakob Huesing (ESA – Clean Space Initiative) for their support along the project.*

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Space Debris Removal from LEO – Controlled Re-Entry using an OTV / Space-Tug vs. De-Orbit Packs

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Keywords: *debris, active removal, de-orbit*

Abstract

Space-debris around Earth is becoming a more and more significant threat to the proper functioning of our satellites in orbit. To cope with this increasing problem, different strategies to enhance mission protection are being established by a European consortium composed in a multi-disciplinary manner, involving research organizations and academia on the one side and industrial companies and SME on the other. The work is being performed within the EC's 7th Framework Programme as a collaborative project in the activity "Strengthening of space foundations" called P2ROTECT (Prediction, Protection & Reduction of Orbital Exposure Collision Threats).

As for debris with certain characteristics like size, mass or the presence of poisonous or hazardous materials an uncontrolled re-entry into Earth's atmosphere is not acceptable, the controlled re-entry by active de-orbiting means is mandatory at least for objects in the LEO.

Within the proposed paper and presentation, based on the current understanding of methods to remove debris actively from space, the current work will be presented in the following fields:

- *Active de-orbiting of one or more objects by an Orbit-Transfer-Vehicle (OTV) / Space-Tug*
- *Active de-orbiting of multiple objects by De-Orbit Packs*
- *Mission design for both concepts*
- *Comparison of total mass and mission cost for both concepts*

The active de-orbiting of debris from LEO will be feasible in an acceptable cost frame only if multiple objects can be removed per mission. The Orbit-Transfer-Vehicle (OTV) approaches and connects to the individual debris, starts together with it the de-orbit maneuver and detaches before re-entry to rise its orbit back to the next debris object to be approached. One main draw-back of this concept is the huge amount of propellant to be carried during the first maneuvers for the following maneuvers. Thus, as an alternative to this solution the utilization of De-Orbit Packs was studied as well.

The De-Orbit Packs to be attached to different debris objects have to provide many of the capabilities of an autonomous spacecraft like propulsion, AOCS, power, thermal control and communications subsystems. Therefore the cost increases due to the fact that multiple complex

ESA Investigation of Additive Manufacturing for Propulsion -

Abstract for Presentation in Clean Space Sessions

Matthew Smith
European Space Agency – ESTEC, Netherlands

Design of space propulsion hardware presents significant challenges: complex geometries, high dynamic loads, high pressures, mass constraints, leak tightness, temperature extremes, and compatibility with caustic and volatile propellants. These lead to high costs and long lead times. Further, designs and performance are constrained by limitations of the traditional manufacturing approaches.

Additive manufacturing offers an alternate approach to conventional manufacturing techniques. It builds element by element or layer by layer to achieve near-net geometries, typically in a single process. The European Space Agency has investigated the potential benefits and challenges of additive manufacturing for space propulsion applications. Clearly positive results have been achieved. Reduced material waste and shorter manufacturing times are evident; but also, designs not possible with conventional processes are becoming feasible. Of course, obstacles remain, but ESA is continuing to investigate and facilitate development of the technology.

This presentation provides an overview of the ESA Propulsion additive manufacturing activities. It describes the findings and identifies future targets.

ESA Green Propulsion Activity - Abstract for Presentation in Clean Space Sessions

Matthew Smith
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Classical propellants (hydrazine, MMH, UDMH, NTO, MON) have had widespread use in spacecraft and launcher chemical propulsion systems over the past 5 decades. These propellants offer reasonable performance; further, processes for their development and use are established. However, these propellants have high toxicity levels that demand special measures to reduce associated health risks. These measures lead to higher costs, extended schedules and still do not fully alleviate safety concerns.

Since 2002, green propulsion has been part of European technology harmonisation planning activity. In coordination with European space industry and national delegates, ESA has established roadmaps and implemented development activities.

In 2011, hydrazine was added to Europe's REACH candidate list of substances of very high concern. This REACH action has contributed to an increased focus on green propulsion development in Europe, as reflected in a recent update of the roadmap.

This presentation addresses green propulsion needs, priorities and issues. It provides an overview of European development activities that have been implemented and those that are targeted near term. It also includes an outlook for the longer term.

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LCA for Environmental Impact Assessment of Space Systems ESA's assessment of European Launchers

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Keywords: *LCA, Eco-design, Sustainability, Launchers*

Abstract

The European Space Agency (ESA) as a public sector intergovernmental organisation, wishes to put the environmental concern as a priority in all its activities as expressed in its Framework Policy on Sustainable Development. The first step in this direction is a deeper analysis and understanding of the environmental impacts of space programmes, to provide ESA with the necessary know-how to be more active in facing legislation on this topic and to drive technical and scientific innovation in the European space industry. Among all European space related activities, a particular attention needs to be paid on the environmental impacts of launchers since launch vehicles' production and operation are core activities of the European space industry. Life Cycle Assessment (LCA) is a powerful method, standardized at international level by ISO, to evaluate the potential environmental impacts of products and services in a comprehensive and objective manner and from a multi-criteria life cycle perspective. Firstly, all incoming and outgoing flows (material and energy flows, both extracted from the environment and released into it) are inventoried for each life-cycle step: LCA is a multi-step approach. Secondly, these flows are aggregated to quantify several environmental indicators (or criteria) covering all environmental issues of the system: LCA is a multi-criteria approach. The idea behind the multi-step and multi-criteria aspects of LCA is to avoid pollution transfers from one life-cycle step to another or from one type of environmental impact (e.g. carbon footprint) to another (e.g. toxicity). The results' interpretation allows to identify the major environmental issues related to the system and which materials, processes, steps of the life cycle, contribute, and to what extent, to the overall environmental impacts of the system. ESA, in a pro-active initiative, has commissioned a consortium led by Bio Intelligence Service to carry out the LCA of the European family of launchers (Ariane 5 ECA, Ariane 5 ES, Vega and Soyuz ST). Given that this study was the first comprehensive LCA of space launchers, and given the complexity of the systems under consideration, the study first aimed to assess the applicability of this methodology to launcher systems and then to apply it to evaluate the environmental impacts of European space launchers. This LCA allowed for a better understanding of the environmental impacts of launchers and the sources of these impacts. This is used to identify where mitigation actions are most effective and to identify the required methodological adaptations in order to set recommendations for further analysis.

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Criteria for the Selection of Targets for Active Debris Removal

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Keywords: *active debris removal (ADR), risk on orbit, ranking of objects, mitigation guidelines*

Abstract

There is consensus that the future evolution of the space debris environment in the LEO (Low Earth Orbit) regime is not stable and that active debris removal (ADR) needs to be considered to control the growth rate. First ADR mission designs are being intensively discussed and significant effort is put into the identification of suitable removal candidate objects.

In this paper we analyze the effect of ADR on the long term evolution of the space debris environment in LEO in different scenarios using the European Space Agency's (ESA) Debris Environment Long Term Analysis (DELTA) model (with variations on the implementation of the mitigation measures, on the traffic models and evolution, on the removal selection criteria and on the solar flux). For each of the scenarios we derive a list of candidates based on the objects involved in catastrophic collisions. A combined list is then created with the objects which appear repeatedly in the different scenarios. Finally, this list is used as input for ADR simulations and the effectiveness of the removal is evaluated in terms of number of objects reduced and number of collisions avoided, as well as the risk reduction for other missions in orbit, after 50 years, 100 years and 200 years.

1 Introduction

The number of human made objects in space has undergone a steady increase since the beginning of spaceflight. The concern that the future environment growth might be dominated by collisions, rather than by launches and explosions, was expressed already decades ago. In response to this, the IADC (Inter-Agency Space Debris Coordination Committee) formulated a set of mitigation requirements that were issued in 2002 [1]. These requirements aimed at a limitation of the growth rate rather than at a reduction of the object population below the current numbers. These IADC guidelines recommend the spacecraft to perform collision avoidance maneuvers while operational, and to be passivated and perform a re-orbit or de-orbit maneuver in order to be outside from the LEO protected regions in less than 25 years at the end of their operational life.

As shown in recent studies undertaken with different environment prediction tools from various agencies [2, 3, 4, 11], the current environment will continue to grow, even in the case of no further mission deployments (i.e. a "no further release scenario"), as can be seen in Fig. 1.

Abstract for CEAS

Linköping, September 2013

Title: Astrium perspective on space debris mitigation & remediation

Authors: P. Voigt, D. Alary, C. Cougnet, M. Oswald, J. Utzmann (Astrium GmbH)

Abstract

The density of space debris has been increasing for decades, with the rising number of satellites, rocket bodies and mission-related debris, and with the fragmentation events. The situation is critical especially in LEO. The destruction of one object yields an additional set of debris, and hence a significant increase of the collision probability for many other objects finally resulting in a chain reaction. Experts predict one large collision every 5 years in 2050 and an acceleration of the chain reaction. This would have a severe impact to the LEO domain as useful regime for satellite operations. Already today space debris is a serious problem which is visible through the regular avoidance maneuvers of the ISS, the threat for sun-synchronous orbits due to the potential destruction of de-functional large Earth observation satellites but also the risk on the safety of ground population due to uncontrolled re-entries (Rosat).

Astrium is aware of this problem and proposes a four-pillar debris mitigation approach. There is a long-term experience in all these four pillars of mitigation as well as on system and architecture level.

First pillar: **Prevention**. Further debris generation shall be prevented by Post Mission Disposals (PMD) of satellites and launchers to reduce the maximum lifetime in operational orbits to 25 years after the end of operations, by transferring them into graveyard orbits according to the IADC guidelines or by re-entering into the earth atmosphere. The PMD can be ensured by on-board capabilities. This has an impact on the system itself. It may also be provided by a special de-orbit kit attached into the satellite by an external removal service. In all the cases the cost of the solutions is a strong driver. So it has to be required by regulation and license issues.

Second pillar: **Avoidance**. Currently LEO-objects larger than ca. 10 cm are tracked by the US SSN so that avoidance maneuvers can be carried out by operational satellites. Also national means (German TIRA or French GRAVES) exist for Surveillance and Tracking, however additional sensors are needed with improved capabilities in order to tackle the debris problem. In the future, debris location could be known better through a European Space Situation Awareness system. Astrium has been and is involved in several ESA system studies in this regard, e.g. the current "CO-II SSA Architectural Design" and the "Assessment Study for Space Based Space Surveillance Demonstration Mission".

Third pillar: **Survivability**. The vulnerability of satellites for untracked debris between 1 mm and 10 cm can be reduced to survive an impact. Different solutions are considered to reduce the vulnerability of satellites in LEO, both at system and satellite architecture levels. In particular, new concepts of shielding are proposed to protect critical equipment against particles of up to 4 mm size. Indeed, it appears that the particles of 2 to 4 mm size are the

De-orbit motor for nanosatellites based on solid propulsion

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Keywords: *Space debris mitigation, de-orbit motor, solid propulsion*

Abstract

Analyses performed by ESA and NASA indicate that the only means of sustaining the orbital environment at a safe level for space operations will be by carrying out both active debris removal and end-of-life de-orbiting or re-orbiting of future space assets.

Existing and expected debris mitigation regulations require LEO spacecraft to de-orbit within 25 years. Given typical spacecraft ballistic coefficients, this places an upper limit of perigee of around 600 km altitude for nanosatellites such as CubeSats. Also with operational nanosatellite constellations being deployed in the coming years there is an increased need to remove small spacecraft from LEO much faster to ensure that defunct satellites can be replaced within the constellation with new satellites.

Practical deployable drag systems being developed as products can lower the ballistic coefficient sufficiently to allow perigee up to 800 km altitude, however this still rules out many launches above that altitude for CubeSats and MicroSats that ride as secondary payloads. There is also the problem that a drag system does not reduce the total intersected time-area product, thus debris impact probability is not reduced even if the lifetime requirement is met.

This paper provides an overview of a recently developed de-orbit system using a CubeSat sized solid rocket motor, that was successfully demonstrated in February 2013 by test firings at ambient and -40 °C.

The system has sufficient propulsive capability to lower the perigee of a 3U CubeSat from a 1000 km altitude circular orbit to an elliptical orbit that complies with the 25 year maximum orbit lifetime. Test results are presented for the de-orbit system, generating around 180 N thrust and 600 Ns total impulse at atmospheric pressure. Furthermore the challenges and solutions of implementing such a system inside a nanosatellite mission (both technical, programmatic and legal) will be addressed.

All thrusters have an off-axis thrust component that causes the spacecraft attitude to be unstable when thrust is applied. Analysis will be

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High Performance Green Propellants

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Keywords: *green propellant, ADN, dinitramide, hydrazine, performance, REACH*

Abstract

The interest in green propellants has emerged during the last decades. To stay competitive on a global market, green propellants need to have equal or higher performance compared to current toxic propellants. Possible green high performance mono, bi, hybrid and solid propellants have been identified and some future key development activities are presented.

1 Introduction

Current propellants, such as hydrazine and its derivatives, nitrogen tetroxide and ammonium perchlorate are associated with health and environmental concerns. This is due to their toxic, volatile, carcinogenic or other harmful properties. In response to this the interest for less toxic or "green" propellants has emerged during the last decades. The last years this has further been emphasized by the REACH regulation which might result in the banning of hydrazine in Europe. If so, other hazardous propellants might be next to follow. It is thus of importance for the European space propulsion community to be proactive and prepare for what might come.

The European space propulsion industries compete on a global market and must be competitive to not lose market shares to countries with more reluctant chemical health regulations. It is thus important not to introduce harsher demands on the propulsion industry than on the chemical industry in general and to not use green propellants with inferior performance. However, high performance green propellants enable increased competitiveness due to easier handling, lower life cycle cost and higher specific impulse.

This paper presents different green propellant alternatives with higher performance than current storable propellants.

2 Liquid monopropellants

A number of different less toxic propellant options have been considered to replace monopropellant hydrazine. They who have received most attention the last years are;

- Hydrogen peroxide
- Nitrous oxide fuel blends
- Ionic liquids

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Ad hoc Collaborative Design with Focus on Iterative Multidisciplinary Process Chain Development applied to Thermal Management of Spacecraft

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Keywords: Collaborative Design, Integration Framework, MDAO, RCE

Abstract

In multidisciplinary design optimization, different experts from different disciplines located often at different sites solve a problem in common. Efficient and effective collaboration is essential. This paper describes an approach how software technologies enable ad hoc collaboration during the development of process chains used in multidisciplinary design optimization. The German Aerospace Center develops a framework that supports this kind of ad hoc collaboration. It is used for optimizing the thermal management of spacecraft. As a result, the development phase of the process chain gets more efficient, because the technical effort of collaboration is reduced.

1 Introduction

The design study of complex objects such as aircraft or spacecraft often involves many different disciplines. The involved experts work in different organisations, which are often spread across multiple sites. Collaborative work requires lots of communication via e-mail or phone and data and tools have to be shared and exchanged. Multidisciplinary collaboration can be cumbersome due to the communication overhead.

In the initial design phase, the tools of the different disciplines are developed and an automated design process chain to couple them is set up. Tools include simulation codes, analysis applications, or optimization algorithms. At this stage, the tools are still evolving and subject to frequent changes because of bug fixes and new features. Keeping the tools of all disciplines at all sites always up to date is a challenge. The conventional approach in multidisciplinary design is collecting all required tools and running them on one dedicated compute machine. This approach can be a limitation due to

- Software licensing issues, as research tools are often based on commercial software for numerical computation and simulation, whose licenses are too expensive for an additional installation on the compute machine.
- Platform specific tools, which require specific operating systems or "exotic" hardware platforms such as compute clusters, graphic cards, accelerators etc.
- Impractical centralized installation of frequent software updates.

This paper describes an approach to support collaboration in initial design phases within distributed environments, where tools can remain at each developer's machine. The approach ensures that every involved discipline can always

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Collaborative understanding of disciplinary correlations using a low-fidelity physics based aerospace toolkit

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Keywords: *Collaborative Design, Multidisciplinary Design and Analysis, Knowledge Management, CPACS, RCE*

Abstract for conference programme

Covering all relevant physical effects and mutual influences during aircraft preliminary design at a sufficient level of fidelity necessitates simultaneous consideration of a large number of disciplines. This requires an approach in which teams of engineers apply their analysis tools and knowledge to collaboratively approach design challenges.

In the current work, recent technical advancements of the German Aerospace Centre (DLR) in data and workflow management are utilized for establishing a toolbox containing elementary disciplinary analysis modules. This toolbox is focussed on providing fast overall aircraft design capabilities. The incorporated empirical and physics based tools of low fidelity level can be used for setting up modular design workflows, tailored for the design cases under consideration. This allows the involved engineers to identify initial design trends at a low computational effort. Furthermore, areas of common physical affinity are identified, serving as a basis for communication and for incorporating tools of higher fidelity in later phases of the design process. Clear visualisation methods aid in efficiently translating knowledge between the involved engineers within the identified areas of common affinity.

A system-of-systems approach is established by applying the elementary aircraft design toolbox for the establishment of requirement catalogues for engine preliminary design. The engine designers at their turn deliver initial performance correlations for application in the aircraft design toolbox. In this way, a clear synergy is established between the design of both the airframe and power plant. Using this approach, engineers of different technical backgrounds share their knowledge in a collaborative design approach.

The use case guiding the present work involves a conventional short to medium range aircraft sent at half the design range. The wing area and aspect ratio are varied to investigate the influence on the engine requirements catalogue for this particular mission.

Abstract: FAS4Europe, what happened then?

In 2010 the European Defence Agency (EDA) commissioned a study into the military aviation sector of Europe's defence industrial base. The task was, with a 2035 perspective, to identify the required key industrial capabilities and propose a roadmap and implementation plan to enable continued access to cost effective European sovereign military systems.

The study, which was undertaken by an industrial consortium that consisted of 29 companies and organisations from 10 European Member States, delivered its report at the beginning of 2012. This concluded that although Europe's military aviation industry was currently in a strong position, that strength was based on past investment and that underinvestment and the lack of new military development programmes put important industrial capabilities, including the key capabilities needed to design and develop new military air systems, at risk. In the meantime military aviation market was becoming more competitive with a number of nations outside Europe are heavily investing to sustain and develop their current military capabilities or seeking to build-up world class industrial capabilities from a lower level.

The report proposed a roadmap in three phases to sustain and develop the industrial capabilities:
- Phase 1: Keeping options open
- Phase 2: Preparing for the future
- Phase 3: Establishing a competitive EDTIB

It also recommended that EDA Member States establish an Aeronautics Working Group (ASG) to plan, coordinate and steer the future activities and to monitor the industrial capabilities at risk.

The ASG was established during 2012 and has commenced consideration of the roadmap proposals. This consideration is on-going against the backdrop of an extremely constrained financial climate which has significantly constrained Member States flexibility.

EDA has in parallel sought to promote the case for Europe's defence aviation industry as a key European asset linked both to future freedom of action and wider industrial excellence. This includes developing a common understanding of the economic benefit – in terms of jobs, exports and technological advance - of investing in Europe's defence industry as opposed to procuring from abroad.

Given the significant investment involved the future of the industry depends critically on political buy-in. .

Military demonstrator projects at GKN Aerospace

Karin Johansson, Patrik Johansson, Melker Härefors
GKN Aerospace Engine Systems

In technology development it is of great important to validate and mature technologies via suitable demonstrations. It is through demonstrators that the industry can realize a position for future engine development in international collaborations.

Demonstrators for new product technologies could be realized using an existing platform. Examples of this are demonstrators that have been performed and are planned using the RM12 Engine platform. For demonstrators at lower technology readiness level (TRL), component test rigs are also an option.

This presentation will highlight some major achievements at GKN Aerospace Systems in this area and present different demonstrations and technology validations on different TRL level, such as:

- Low pressure compressor technology (LPC), e.g. subscale demonstrations within different National and EU-projects as well as full scale demonstration planned for 2014. The LPC technology is dual use and can be applicable both for military fans as well as for commercial LPC.
- New advanced instrumentation technology, e.g. demonstration within NFFP project Wisejet (Wireless Sensors for Jet Engines) together with ÅAC Microtec and Uppsala University.
- Low observable technology demonstrations to reduce Radar Cross Section Signature (RCS) as well as Infrared Signature (IRS). The Low observable technology has been demonstrated in component test rigs as well as on RM12 engine and the technology is applicable on other platforms as well.
- New engine controls demonstration within ETAP, a military European research program. During 2012 a controls technology demonstration was performed on RM12 including multivariable controls technology, fan pressure ratio control, thrust control and control of fan variable guide vanes by electric actuator.
- A sensor for detection of particles (volcanic ash) was demonstrated within NFFP. The sensor based on QCM technology from G&M Norden was tested in wind tunnel at GKN at flight tested using SK60 by Saab.

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Clean Sky Technology Evaluator

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Keywords: *Technology evaluation, Clean Sky program*

Abstract

The Clean Sky program is made up of 6 Integrated Technology Demonstrators (ITD) and the Technology Evaluator (TE). The ITDs are:

- *Smart Fixed Wing Aircraft (SFWA) addressing large aircraft technologies*
- *Green Regional Aircraft (GRA) addressing regional aircraft technologies*
- *Green Rotorcraft (GRC) addressing rotorcraft technologies*
- *Sustainable And Green Engines (SAGE) addressing engine technologies*
- *Systems for Green Operations (SGO) addressing aircraft systems*
- *Eco-Design (ED) addressing aircraft life cycle assessment*

The Technology Evaluator is a simulation network that assesses the performance of the technologies developed in the ITDs.

From the beginning it was recognized that successfully monitoring progress towards the ACARE goals would require a crosscutting evaluation platform in the Clean Sky Program. The TE was born from this need, and its composition reflects the need to pool know-how and simulation/modeling capability that exists among industry, the research establishments and academia.

The approach in the TE is to 'insert' Clean Sky conceptual aircraft into a number of evaluation scenarios. In essence: the technologies developed, matured and demonstrated in the Clean Sky ITDs are 'clustered' in coherent and mutually compatible solution-sets that define a potential future aircraft. These conceptual aircraft are 'flown' (i.e. simulation scenarios are run) and the Clean Sky configurations are compared to the most relevant benchmarks: most importantly the state-of-the-art of aircraft of similar size and role in the year 2000 (ACARE's baseline year). The comparisons are performed at a single flight, or 'mission'; at the level of illustrative airports; and finally across the global air transport system. So the TE approach aims to demonstrate the impact in the overall aviation system of Clean Sky's (research and technology) output by illuminating the 'pathway' from technologies to aircraft and transport system performance.

GKN Aerospace in the Clean Sky demonstrator programme

Robert Lundberg, Anders Sjunnesson, GKN Aerospace Engine Systems
Adrian Bates, GKN Aerospace

Clean Sky is the largest EU-funded demonstrator project in the aerospace sector. In Clean Sky, full scale demonstrators are developed, manufactured and tested. The project consists of a number of integrated technology demonstrators (ITD):

- Smart fixed wing aircraft (SFWA)
- Green regional aircraft
- Sustainable and green Engines (SAGE)
- Green Rotorcraft
- Eco-design

The progress towards the ACARE goals within Clean Sky is continuously monitored by a so called Technology Evaluator activity.

GKN Aerospace Engine Systems (Sweden) is an Associate Partner in Sustainable and Green Engines (SAGE). In this ITD six full scale demonstrator engines are developed and ground tested. GKN is a partner in four of those.
In SAGE 1 the geared Open Rotor demonstrator led by Rolls-Royce, GKN is responsible for the design and development of the intermediate case as well as the rotating frame.
In SAGE 2, the Open Rotor demonstrator led by Snecma, GKN is responsible for the design and development of the rotating structures. These complex structures transfer the torque from the engine to the Open Rotor propellers.
In SAGE 3, the advanced 3-shaft engine demonstrator, led by Rolls-Royce, GKN has developed and tested an innovative intermediate compressor case that was recently tested in a mechanical test rig.
In SAGE 4, the geared turbofan engine demonstrator, led by MTU, GKN is responsible for the turbine structure. A new design, with separated functionality, capable of withstanding significantly higher temperatures is developed.

GKN Aerospace (UK) is a partner in the Smart fixed wing aircraft. GKN is developing co-cured composite parts for the Natural Laminar Flow wing concept. GKN Aerospace also develops integrated ice protection systems for SFWA.

In this presentation we will highlight some major achievements by GKN in Clean Sky, and explain how our effort in this important demonstrator project is supported by national programmes, both in Sweden and in the UK.

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Challenges in national and international R&T collaboration projects.

Saab Aeronautics has a long tradition of research in the aerospace field. The research is divided in different Technology Readiness Levels, TRL1-6 and is financed through internal investments, national and international investors like VINNOVA, FMV and the EC. The TRL1-3, basic technology research and research to prove feasibility, are often done in collaboration with Universities and Research Institutes. To get the technology ready for insertion into products and production it takes proof of concepts and demonstrations in relevant environment. The industry talks about the “Valley of death” which drives the need of demonstrator projects that includes production technology development to keep the production and assembly of aircrafts in Europe.

Saab currently has a prominent role in the Clean Sky project, the role of IMG4 group in European Aerospace together with a fruitful communication with VINNOVA forms the basis and the need for the 2 demonstrator projects LOCOMACHS (FP7 EC) and GF Demo "Next generation composite structures for civil aircraft" (VINNOVA).

The continued use of composite materials in the aerospace industry has been addressed in several past research projects which have focused on new design solutions and composite manufacturing processes. However an area which has been given much less attention up until now is how to achieve a time and cost effective lean assembly production system.
The LOCOMACHS project will focus on significantly reducing or totally eliminating the most time-consuming and hence expensive non-added value operations, e.g. temporary assembly to check gaps, shimming, dismantling and tool handling. The project will improve the design conditions which today strongly dictate the way part manufacture and assembly is performed. Important step changes will be made by dramatically improving the use of tolerance and geometrical variation management.
To support the industrialization of future assembly production lines, key innovations such as intelligent drilling, high speed non-contact hole inspection, compact automation and active flexible tooling will be demonstrated. The design and assembly process improvements and breakthrough technologies will be validated on two physical partial wing box demonstrators, a virtual fuselage section demonstrator and additionally a virtual demonstrator showing a complete wing structure in the context of the next generation lean production flow. This Level 2 project is in the 5th Call FP7-AAT-2012-RTD-1and led by Saab AB .

Within the national GF Demo project, "Next generation composite structures for civil aircraft", two demonstrators will be developed, a wing box and a door unit. Through collaboration with a selection of Swedish SMEer, universities, colleges and institutes, the project will develop the next generation of highly integrated composite structures for reduced weight and fuel consumption. A prerequisite to future business is to be able to demonstrate unique skills in some key areas. A number of such key areas form the framework for this application: aerodynamic and mechanical design of the demonstrators, more integrated structure and systems for aircraft, electromechanical actuators, lightweight design, nano-reinforced composites and competitive development and manufacturing. The project will reinforce Saab and its partners' ability to participate in upcoming demonstrator projects such as Clean Sky 2.

Challenges and Lessons Learned from forming the consortiums and the start–up phases will be presented along with the results up to now.

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Collaborative multi-partner modelling & simulation processes to improve aeronautical product design

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Keywords: *secure cross-organisational collaborative engineering, collaborative modelling and simulation, surrogate modelling, Behavioural Digital Aircraft, Crescendo*

Abstract

Designing a modern aircraft, including all its systems and components, is a tremendous collaborative engineering activity involving teams of engineers from various disciplines working concurrently across organisational and geographical boundaries. To achieve the challenging objectives of contemporary and future aeronautics, and to maintain global industrial leadership, a high level of integrated system design of the aircraft is needed. This requires a higher level of collaborative engineering through modelling and simulation along the supply chain to improve cost and time efficiency.

To achieve a step change in the way multi-disciplinary teams working collaboratively in an extended enterprise carry out modelling and simulation processes, the 'Behavioural Digital Aircraft' (BDA) concept has been developed. We present this concept and the emerging needs for innovative collaboration technologies as well as advanced modelling and simulation technologies. We next discuss the security constraints that teams of collaborating engineers face in practice and that may hamper multi-partner collaborative engineering efforts, and introduces a practical interoperability solution to deal with the security constraints. We finally describe the application of surrogate modelling as an effective method to enable collaborative modelling and simulation activities in the extended enterprise, while allowing partners to protect their intellectual properties. The effectiveness of the surrogate modelling and the interoperability solution are demonstrated in a realistic design case following the BDA concept.

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A Case Study in Aeronautical Engineering Education

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Keywords: *education; pedagogical methodology; aeronautical engineering; aerodynamics; aircraft design.*

Abstract

The great interest of students in aeronautics gives singular characteristics on teaching-learning process that involves this subject. The pedagogical creation is well-suited for this environment. This work presents and analyses the pedagogical implementation of case study in the aerodynamic design course of mechanical engineering from University of São Paulo. A case study was structured in order to develop all concepts of aerodynamics and aerodynamic design as well as the practical issues that involve the aeronautical engineering environment. It was carried out a case study for aerodynamic design development of the aircrafts Douglas DC-9 and Boeing 737 embryonic mark of commercial aviation. The case study involved students in the real design environment. The discussions concerned historical facts, aerodynamic concepts, requirements, design philosophy and technology development. All of them enriched the educational environment and contributed definitely to education in aeronautical engineering.

1 Introduction

The great interest of engineering students in aeronautics, particularly in aerodynamics, gives singular characteristics on teaching-learning process that involves this subject (figure 1). Understand how flying machines fly is an initial motivation for engineering students. The childhood desire can be a potential to learn on present. In the sense, the engineering professor must know this potential and makes it in learning tool. Teaching of aerodynamics is a great pedagogical opportunity to awaken the reminiscent knowledge that is on natural curiosity of people.

Fig 1. More than a century of interesting in aeronautical since 14-bis until Airbus A380

Investigation of multi-fidelity and variable-fidelity optimization approaches for collaborative aircraft design

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Keywords: *Multidisciplinary design optimization, collaborative aircraft design, multi-fidelity, variable-fidelity optimization*

Introduction

During the last decades the demands on safety and environmental performance of aircraft have steadily increased. In the near future, these challenging levels of performance will have to be reached by further improving the current aircraft configurations, whilst, on a longer term, novel configurations will need to be developed. To be able to make these improvements, different conceptual design methods and tools will be required, which are more flexible to support collaborative design, less dependent on statistics and able to exploit in a more efficient manner physics-based analysis tools and optimization approaches

In this paper a conceptual aircraft design workflow developed at the TU Delft, in collaboration with the German Aerospace Center DLR, is presented. A number of design and analysis modules, both off the shelf and in house developed, have been integrated by means of an open-source workflow integration environment. The data exchange is based on the central data model CPACS (Common Parametric Aircraft Configuration Schema) proposed by DLR. The outcome is a flexible design workflow, which enables the use and the interchange of tools that are developed and managed by different experts. The workflow consists of two levels of fidelity, one incorporating empirical and statistical models for initial aircraft sizing and one relying on more physics-based models for higher-fidelity analysis. The adopted multi-fidelity architecture allows the implementation of an efficient variable-fidelity MDO approach, where surrogate models generated using the low fidelity part of the workflow are corrected using a lower amount of more computationally expensive results from the higher-fidelity toolset. This approach is demonstrated for the redesign of single-aisle passenger aircraft wing and it is then compared to a standard MDO approach, based on the generation of a single set of surrogate models, and to a direct simulation-based approach with no use of any surrogate modeling. The results of this study indicate that the variable-fidelity approach converges faster to the same optimum as the single fidelity surrogate modeling approach and its efficiency grows with the number of design variables.

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Cost optimization with focus on reliability and system safety

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Keywords: *system safety, reliability, Markov Analysis, optimization, early design phase,*

Abstract

When developing a safety critical system, there are many aspects that need to be balanced against each other in order to reach an optimal design such as safety requirements, reliability goal, performance specifications and budget constraints. In an early design stage, it is vital to be able to screen the design space for a set of promising design alternatives for further studies. This paper proposes an approach capable of investigating the trade-offs described above, combining the techniques for system safety and reliability analysis with optimization methods. This method has three steps: model building for cost and system reliability and safety, validation and verification of the models and optimization. Markov analysis is employed for modeling the system safety and reliability characteristics and a Genetic Algorithm is used for optimization. The proposed method is applied to the design of an electric supply system for an aircraft, involving selection of components from different suppliers. First a model is built for each objective, i.e. cost, safety, and reliability. Given the usually known failure information and architecture of the system, the states of the system such as full functionality, degraded or partially lost, loss of redundancy or total loss of the system are usually known already in the concept phase. Some of the states are considered system safety states and have certain quantitative requirements, while others may relate to reliability with associated reliability goals. Therefore, the suggested method when modeling both system reliability and safety is Markov analysis. The cost of system development can vary depending on the application and a generic model is therefore used in this paper. The models are validated and optimization is performed. The optimization problem considered is multi-objective by nature with objectives such as system cost (f_1), system reliability (f_2) and system safety (or the probability of unwanted events) (f_3). The mathematical nature of the different objectives differs, the cost objective is deterministic and linear, while both the system safety and the reliability objectives are stochastic and non-linear. Due to the nature of the optimization problem, the optimization technique used is based on a Genetic Algorithm (GA). The obtained result is the selection of suppliers for each component in the system in order to achieve a balance between system safety, reliability, and other design objectives.

Personal Jet
A student project

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Keywords: *Student project, demonstrator, aircraft design*

Abstract

The presented work considers designing, building and flight test of a demonstrator of a personal jet aircraft realized as a student project. The goal is to allow student to participate in an aircraft project from design to flight test in order to acquire aircraft design knowledge from theoretical and practical means. A first theoretical part consists of creating a sizing program for studying different concepts. Then the gathered knowledge will result in the realization of a flying demonstrator. This was realized during a student project over a 5 month period..

1 Background

Since the development of the BD5J, a kit plan, no personal jet has been available to the market. The possibilities for developing a new personal jet is studied, in order to reach a broader market an investigation on certifications regulation is performed. The project aim is to design a single seat sport jet aircraft based on a TJ100A turbine engine. To prove the design a radio controlled sub scale demonstrator will be built and flown, powered by a Funsonic FS70 jet engine.

2 Educational Challenge

Over the years there has been a dramatic reduction in ongoing aircraft projects. Today's aircraft design engineers are lucky if they will be involved in one or two complete projects during their entire careers. This is in sharp contrast to the "golden age", when an engineer was likely to be part of several projects during his career, see Table 1.

This situation creates an issue regarding the education of aircraft design engineers. When they start their professional life they will be assigned to an ongoing project and they may be involved in that for a long time before starting on a new project. The teaching approach as proposed by Linköping University is to allow future aircraft engineers to participate in a complete aircraft design project, from requirements to flight testing, as a preparation for their very first steps into industry.

The other major challenge in aerospace education is changing demands from the industry regarding the type of knowledge the yet to be engineers should be educated for. Most of university aerospace educations are focused on

Feasibility study of a nuclear powered blended wing body aircraft for the Cruiser/Feeder concept

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Keywords: *Cruiser/Feeder, blended wing body, nuclear propulsion, in-flight passenger exchange*

Abstract

This paper describes the conceptual study of a nuclear powered blended wing body aircraft for the cruiser/feeder concept. According to this radically new aviation paradigm, large transport aircraft (cruisers) carry passengers over long distances, while remaining airborne for very long periods. Smaller aircraft (feeders) take off from local airports, intercept the cruiser, dock and enable in-flight exchange of passengers and supplies. Preliminary studies indicated that cruiser concepts based on engines burning kerosene would be too heavy and feeders would need to operate also as tankers. Propelling the cruiser with a nuclear power source would yield very high efficiency parameters, even if the weight of the system would result higher due to the required reactor shielding. The blended wing body configuration was selected both for its potential advantages in terms of aerodynamic and structural efficiency, as well as for the use flexibility of its internal volume, necessary to integrate power plants and shielding, accommodate 1000 passengers and host the loading/unloading station for in-flight payload exchange. The daring nature of the proposed solution is compatible to the foreseen entry into service date, which is set for the last part of this century. The peculiar nature of the aircraft under consideration has required a somehow different conceptual design approach, than generally used for conventional passenger transport aircraft. Apart from the inherent complexity related to the design of such a novel and integrated configuration as a blended wing body, the typical design approach based on the use of simple performance equations and statistics to achieve a first estimation of the main weight contributors was of little use in this case. From one side, the fuel mass used to perform the mission is just negligible; from the other, a method was necessary to account for the weight of the radiation shielding, which is a significant contribution to the overall aircraft weight. Rather than in the numerical results of the sizing process, the value of the design work described in this paper should be found in the very design approach and the preliminary ideas for integrating the passenger docking system and the nuclear power plant.

1 Cruiser/feeder Operations and Cruiser Top Level Requirements

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Virtual Aircraft Multidisciplinary Analysis and Design Processes – Lessons Learned from the Collaborative Design Project VAMP

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Keywords: *Collaborative Design, Multidisciplinary Design, Analysis and Optimization, Knowledge Management, Overall Aircraft Design, Integration*

Abstract

The assessment of unconventional aircraft configurations and novel technologies at high levels of confidence requires integrating all analysis tools of appropriate high levels of fidelity. With this ambition, a design system has been developed and implemented at DLR permitting to combine tools of elevated fidelity in an overall aircraft design (OAD) process with significantly reduced effort. This paper gives an introduction into the distributed design system with its data-centric coupling approach. The application to the optimization of short range aircraft within the DLR project VAMP (Virtual Aircraft Multidisciplinary Analysis and Design Processes) is discussed. A main outcome of the project are the lessons learned which refer to the numeric optimization process as well as to the collaboration process within the team of heterogeneous specialists coming from 11 departments spread over Germany.

1 Introduction

Reliability is key requirement if aircraft design studies aim at the assessment of technologies as basis for strategic forward planning. However, achieving quantified, high levels of confidence is very difficult in OAD: Due to the high number of disciplines involved, only fast tool can be used going in line with strongly simplifying models. While redesigns of conventional aircraft can be calculated satisfactorily making use of empirical correlations, novel technologies and unconventional configurations cannot reach high levels of confidence using conventional OAD methods.

The integration of novel technologies can be realized following two approaches. One alternative is developing novel fast tools which are appropriate for conventional OAD processes and represent the novel technologies in a simplified way. Since by nature there is no reliable experience available, the development and validation of simplifying models can cause excessive effort while still resulting in simplifying models. The other alternative is building an OAD system based higher fidelity models which resolve novel technologies directly. Like this, the effort for the implementation of the novel technologies into the disciplinary analysis models is minimized and accurately modeled physics permit highly reliable results. Interdisciplinary interactions which initially might have not been expected can potentially be observed in the analysis while simplified models would only resolve expected couplings. However, significant effort for computing and the integration of the high number of analysis tools poses a serious challenge.

The German Aerospace Center has launched the project TIVA (Technology

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Application of CAD/CAM/CAE Systems to the Process of Aircraft Structures Analysis by Means of Reverse Engineering Methods

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Keywords: *reverse engineering, identification of the aircraft structure.*

Abstract

The paper deals with application of the reverse engineering approach to the research studies on thin-walled structures. Attention is paid to the methodology dedicated to reverse the design process of aircraft structures and to enable studies intended to evaluate design and strength properties of aircrafts, both newly designed and being in service. The reversing methodology outlined by the authors was used to reproduce bodies and internal structures of selected aircrafts already operated by Polish Air Forces and those that shall be introduced in nearest future. The study reveals a universal algorithm suitable for identification of external loads and aircraft properties related to their static stability as well as for needs of numerical analysis defining dynamic deterioration of structures.

1 Introduction

Strength assessment of aircrafts that have been in service for long years still remains a sophisticated problem since no information is available both on the manufacturer's assumptions with regard to design and calculated lifetime as well as historical information of load spectra the equipment was exposed to in the past. In such a case reasonable decisions related to operation lifetime of aircrafts can be taken only after preliminary investigation of all factors that may affect durability of the structure. Since the operation lifetime depends on many factors and contribution of each factor can be expressed in appropriate figures and calculations, each decision related to the operation history of the equipment should be preceded by a thorough strength analysis. Nowadays, stress distribution within the investigated structures are determined by computations with use of the Finite Element Method, whilst modeling of the associated phenomena for analysis of the structure behaviour must be carried out on the basis of adequate computation models. At present the computation models for assessment of condition demonstrated by thin-walled structures are developed with use of reverse engineering methods.

1.1 Purposes of the study

The analysis of service regimes how aircrafts are operated by Polish Air Forces as well as similar issues to be resolved worldwide involved the need to carry out the following:

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Conceptual Aircraft Design including Hybrid Laminar Flow Control

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Keywords: Hybrid Laminar Flow Control (HLFC), Conceptual Aircraft Design, MICADO

Abstract

Facing the ambitious goals to reduce fuel consumption and ecological impact of commercial aircraft, drag reduction through laminar flow is one of the most promising technologies. Next to natural laminar flow (NLF), hybrid laminar flow control (HLFC) is the best proven concept. The reduction of friction drag, which amounts about half of total aircraft drag, is achieved by an extension of laminar flow area over the surfaces by delaying flow transition.
The net benefit on aircraft level due to the achieved drag reduction is lowered by an additional mass and the suction power requirements from the integrated HLFC system. Another impact can be an additional wing mass, e.g. due to thinner HLFC airfoils. It is thus the main task on conceptual and preliminary design level to find a well-balanced overall design of an HLFC aircraft with optimum key performance characteristics, e.g. minimum block fuel on a selected study mission. This requires an integrated overall aircraft design methodology that incorporates methods for HLFC wing aerodynamics and system component sizing for the specified requirements and design conditions. The main difficulty herein lies in a reliable assessment of aerodynamic characteristics including transition behaviour for a given aircraft configuration and flight condition. Further, a sound HLFC system component sizing has to account for wing pressure distribution and suction velocity requirements. In this paper a methodology for conceptual design and optimization of aircraft with HLFC systems integrated into wing and empennage is described. The conceptual aircraft design platform MICADO is enhanced by the necessary methods for sizing of HLFC system architecture as well as prediction of aerodynamic characteristics, including transition location. The integrated sizing methodology allows to assess the net benefit of HLFC system integration on overall aircraft level and to minimize aircraft fuel consumption by variation of aircraft design parameters, cruise conditions and HLFC system parameters. The applicability of the developed methodology in conceptual aircraft design is demonstrated for a conventional long range passenger aircraft. Exemplary, Fig. 1 shows the resized wing planform of the an optimized HLFC aircraft design with the predicted extend of laminar flow area and the spanwise positions of the compressors determined by the HLFC systems program.

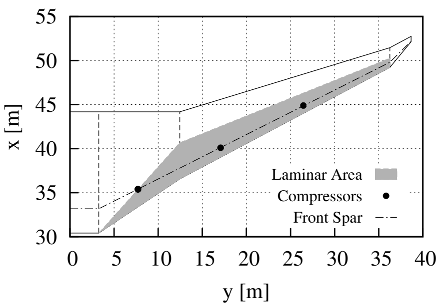

Figure 1: Optimized HLFC aircraft wing planform with laminar area and compressor positions.

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Collaborative Aircraft Design using AAA and CEASIOM linked by CPACS Namespace

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key words: *Aircraft design, geometry representation, CPACS, AAA, CEASIOM*

Abstract

This paper represents a collaborative work between the preliminary design tool AAA and conceptual design tool CEASIOM linked by CPACS. Higher-fidelity analysis can be carried out by CEASIOM with inputs from AAA. The philosophy of the design loop is spelled out in this paper, with a test case Avanti P-180 for higher-fidelity CFD solutions and the pitch control analysis.

1 Introduction & Overview

Figure 1 spells out the details in the early steps of aircraft design for the definition of the configuration. It illustrates two design *loops* in the conceptual design phase that follow the first-guess sizing (usually done by a spread-sheet) to obtain the initial layout of the configuration. The first one, the pre-design loop, is aimed at establishing a very quick (time-scale can be from one to a few weeks) yet technically consistent sized configuration with a predicted performance. The second one, the concept-design loop, is a protracted and labour intensive effort involving more advanced first-order trade studies to produce a refinement in defining the minimum goals of a candidate project. At the end of the conceptual design phase all the design layouts will have been analyzed, and the "best" one, or possibly two, designs will be down-selected to the preliminary design phase. During the preliminary definition, project design is still undergoing a somewhat fluid process and indeed warrants some element of generalist-type thinking, but the minimum goals of the project have already been established during the conceptual definition phase and the aim is to meet these targets using methods with higher order than those used during the conceptual definition phase. Furthermore, the participants in this working group are mostly genuine specialists in each respective discipline. Figure 1 indicates the way in which data, or information, is passed between specialist groups during the design process. The specialist groups must consider the level of advanced technology to be adopted together with all of the other active constraints on the design. The data flow lines indicate how the technology areas influence the aircraft configuration though its performance. The specialist departments/offices provide the input data to the project designers who then coordinate a systematic search to find

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Open Access Publishing in Aerospace – Opportunities and Pitfalls

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Keywords: *aerospace, paper, journal, publisher, open access*

Abstract

The first Open Access (OA) peer reviewed online journals in aerospace were all established after 2007. Still today more and more OA aerospace journals get started. Many publishers are located in less developed countries. The benefits of OA publishing are undisputed in the academic community, but there is disagreement if the new publishers can work to required standards. The current situation is evaluated based on an Internet review. OA journals in aerospace are listed with their major characteristics. Well know OA publishers charge high publication fees, whereas less known OA publishers tend to charge relatively low fees. All publishers need to be carefully checked for their level of rigor in peer review and their offered service in the scholarly publication process. Authors should evaluate OA journals and publishers against provided lists of criteria before submitting their work.

1 Introduction

1.1 Objective

Intension is to explain the background and to systematically present possibilities for researchers in aerospace to have their work published on the Internet so that it can be read without access fees by anybody. Such Open Access (OA) publishing is growing at fast pace. Many models of OA exist and will be presented and discussed to enable subsequent application to OA publishing in aerospace.

Fig 1: Open Access Logos [2], [14]

1.2 Definition of Basic Terms

This contribution is about publishing an academic paper in contrast to publishing an academic books or a thesis. Several terms are defined in this context.

Open Access (OA) means "to provide the public with unrestricted, free access to scholarly research – much of which is publicly funded. Making the research publicly available to everyone – free of charge and without most copyright and licensing restrictions". [1] The Budapest Open Access Initiative [1] recommends establishing the "goal of achieving Open Access

Knowledge-Based MDO for next generation design systems

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Keywords: *MDO, KBE, parametric modeling, Process Integration and Design Optimization*

Abstract

Key to the success of Multi-disciplinary Design Optimization (MDO) are parametric modeling techniques on product side and Process Integration and Design Optimization (PIDO) techniques on simulation process and optimization side. Traditional CAD systems are able to expose product parameters and the external manipulation thereof through their Application Programming Interface (API). However, parameterization is usually limited to a single product topology space, making topology changes hard to perform during MDO studies. Moreover, parameterization is limited to the geometrical aspects. Today's complex engineering designs, however, require the automated analysis of multiple configurations (leading to discrete variables) and multiple disciplines (not only geometry). Knowledge-Based Engineering (KBE) systems overcome the CAD system limitation by capturing relevant product knowledge that "teaches" the system how to automatically generate multiple product topologies and variants from high-level parameter inputs. Moreover, KBE allows for the expression of multi-disciplinary aspects such as cost, structures and aerodynamics, and is therefore not at all limited to the geometry domain. Next to KBE, Simulation Workflow Management (SWFM) software is a key ingredient to MDO. SWFM software implements the PIDO approach through automation of the simulation process and the availability of optimization algorithms. KBE and SWFM are important technology enablers of MDO. But although proven on individual level, an integrated environment that exploits the synergy in combing both, currently doesn't exist. This research has prototyped a first integrated MDO software platform based on the coupling of a KBE platform (namely GenDL) and a Simulation Workflow management system (namely Noesis Optimus). The difference between the proposed approach and all the aforementioned design system configurations is summarized in Fig.1. The combination of these two systems offers to the design engineer two key advantages: 1) the capability of quickly expressing the design problems at hand in a high-level, object-oriented manner while still allowing for full access to the functionality of the underlying KBE platform and 2) a high degree of design automation by delegating to a complete simulation workflow framework the routine design job normally needed to find optimal design solutions or to perform virtual

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UAV Joined-Wing Test Bed

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Keywords: *joined-wing, UAV, design, test bed, studies*

Abstract

The present aviation requirements demand more ecological and "greener" aircraft. The future green aircraft will meet demanding weight reduction, energy and aerodynamics efficiency, a high level of operative performance, in order to be compliant regards to pollutant emissions and noise generation levels. The joined-wing concept is considered as a trade-off variant for green design. This is because of its lower cruise drag and lower structural weight. On the other hand the requirements for low pollution and noise could be met using all-electric aircraft. Designing and producing full-scale joined-wing aircraft is a complicated task partly because of lack of detailed theoretical and experimental studies of joined-wing aerodynamics, structure and performance. Hence the aim of the present study is to design and produce joined-wing unmanned aircraft – test bed or flight laboratory. The basic design incorporates tip-joined front and rear wings with wing-tip vertical joints. The front and rear wing root chords are structurally connected using a keel-like element which starts with the fuselage trough propulsion mounting and ends at the vertical stabilizer. The role of the keel is to increase the strength and the stiffness of the wing. The airframe is mainly of carbon and glass-fiber composite materials. The power plant consist of electrical ducted fan, speed controller and Li-Po batteries. The aircraft integrates Piccolo II Flight Management System which offers a state-of-the-art navigation and flight data acquisition. Prior to production and flight testing of the prototype, aircraft aerodynamics and flight dynamics are being analyzed. Potential models of low-speed aerodynamics and vortex-lattice method have been used to determine aircraft aerodynamics. Also wind tunnel experiments are involved for joined-wing aerodynamics and ducted fan performance. A MATLAB Simulink model is designed in the Aerospace Blockset environment for flight simulations to be performed and flight dynamics to be analyzed. In addition Piccolo II autopilot has its own simulation environment that offers HiL (hardware-in-the-loop) and SiL (software-in-the-loop) simulations. One of the major problems found during simulation is the Dutch roll effect. This is thoroughly discussed in the paper. Finally a joined-wing UAV test bed is produced and flown both in manual and autopilot mode. Some problems that concern autopilot tuning are also described. The joined-wing test bed is planned to be used for real-time flight data acquisition and to solve tasks related to autonomous control and navigation.

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Battery Pack Modeling Methods for Universally-Electric Aircraft

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Keywords: *battery pack model, discharge analysis, universally-electric aircraft, aircraft conceptual design*

Short Abstract

Stimulated by ambitious emission reduction goals like FlightPath 2050 established for the aviation sector, radical technologies and revolutionary design approaches are required for future transport aircraft to fulfill those targets. One approach could be performed with the totally electrification of an aircraft. As one future promising technology advanced battery systems have been identified as potential energy and power suppliers for those concepts. The objective of this paper is to give a deeper insight in battery modeling within a universally-electric aircraft and the integration of such a model in the aircraft sizing process. Furthermore, one approach is described how the required battery capacity for a certain mission can be determined. As baseline for the investigations the Bauhaus Luftfahrt Ce-Liner was used, which is equipped with a universally-electric systems architecture supplied by advanced Lithium-Ion batteries and powering advanced High Temperature Superconducting motors. Assuming the same discharge characteristic of the advanced batteries like for today's Lithium-Ion batteries, different developments of battery parameters like voltage, discharge current or efficiency are discussed for different flight phases of a 900nm mission with a maximum power demand of about 36MW. For example during take-off phase the battery system delivers the highest output voltage during the mission caused by the high state of charge of the battery cells. In fact this is advantageous for the discharge characteristic of the batteries, because the highest power demand occurs during this flight phase and reduces therefore the discharge current. The discharge current in turn has a direct impact on the battery efficiency. Furthermore, based on the results of this paper a simplified approach for battery capacity estimation is proposed for a standard mission profile making an error less than 2% compared to the exact model. The proposed methodology can serve as baseline for future research topics like sizing of thermal management systems or flight profile optimizations.

Comparison of traditionally calculated stability characteristics with flight test data of PW-6U sailplane

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For many years the only method available for dynamic stability analysis lead through aerodynamic derivatives calculations to the analysis of equations of motion. Aerodynamic derivatives were calculated with application of data contained in reports databases like ESDU[1]. Unfortunately data available there have several important limitations like narrow range of aspect ratios or constraint choice of aerodynamic configurations. Recent development of numerical methods allows calculating aerodynamic derivatives for any configuration and any combination of geometrical parameters. However, each numerical method provides only approximate solution due to the assumptions and simplifications incorporated in it. Moreover, traditional method of equations of motion analysis assumed minor disturbances and small range of angles of attack. Both of these assumptions are questionable. Therefore an effort was undertaken under SIMSAC program [2] to develop better software intended for dynamic stability analysis. Results provided by this software [3,4] have to be validated with application of flight test data. Some of this data were already available to software authors; others however had to be collected. This paper presents an example of experiment undertaken to collect such data. Results obtained in the course of this experiment are compared with data calculated with application of traditional methods to observe the differences between them.

An object of the experiment

PW-6U [5] sailplane prototype was used to conduct this experiment as it was easily available for authors of this paper. Not only the ship itself was available but also complete documentation, including inertial data and previous flight tests results were available since PW-6 was developed by WUT a few years ago. The PW-6U is a glass-epoxy two-seater glider with a mid-set wing and a conventional tail. It was designed for beginner instruction, and training of young pilots including cross-country flights and basic aerobatics.

Manoeuvres and test procedures

The following flight modes were tested: phugoid oscillations, short period oscillations, spiral and Dutch roll and rolling. Sailplane reaction to the rolling input was also explored. Finally several points of velocity polar were measured to check the level of performances degradation mentioned above. The last measurement could have appeared critical for comparison of theoretical and flight test results of phugoid oscillations. Flight test programme was developed according to [6].

Simplified stability analysis

Eigenvalues of each flight mode of PW-6U sailplane, resulting from approximate analytical formulae, were calculated with application of dimensional and nondimensional aerodynamic derivatives computed before [7-11]. The task was performed twice. For the first time it was done before flight test campaign, to estimate periods of oscillations for each flight mode. It was necessary to excite oscillations properly, but results were perceived as inaccurate since some data (like airspeed) were assumed, not measured. Then, after flight test campaign, eigenvalues were calculated again, with application of weather and flight parameters experienced during flight test campaign. Moreover, flight testing was conducted for sailplane weights 513kg and 540kg, therefore all eigenvalues were calculated for these two configurations. The second set of eigenvalues was compared with flight test results [12].

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Route Optimization for Commercial Formation Flight Using PSO & GA

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Keywords: *Formation Flight, Particle Swarm Optimization Algorithm, Genetic Algorithm, Path Optimization, Catch-up Point*

Abstract

This paper focuses on the first step of flying in a formation which is forming a group. There are several ways to form the group and fly in a formation. One of these ways is the scheduled take off from a single runway which in all launched aircraft after reaching the cruise altitude must meet one another at certain coordinates to create a formation. In this article, the optimum flight trajectories of aircraft which take off from a runway and want to participate in a formation flight is designed by using Particle Swarm Optimization (PSO) algorithm and the best points for aircraft rendezvous in cruise flight is determined. For ensuring about reliability of resulting trajectories, Genetic Algorithm is implemented beside the PSO. Cases involving a formation consisting of three commercial jets show that a total fuel efficiency of 10% is quite achievable.

Using Monte Carlo Simulation as Support for Decision Making while Negotiating a PBL Contract: A Case Study of the Saab 105 aircraft fleet

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Abstract: In connection with performance-based logistics (PBL) contracts for aircraft fleets it is very important to carefully analyse both operations and maintenance before and during the contract negotiation phase. Monte Carlo Simulation is a valuable methodology in this context since it allows delimiting and exploration of a complex parameter space in a transparent and relatively easily visualized manner. With timely analyses it is possible to identify both technical and economic risks and minimize the possible consequences, a process that benefits both parties in the negotiation process. This paper describes this process in connection with the negotiation of a PBL contract for the Swedish Air Force SAAB 105 (SK 60) trainer fleet between Saab AB and the Swedish Defence Materiel Administration. The information used in the simulations was largely empirical data derived from previous operations of the aircraft system. The main factors that were simulated were Operational requirements, Fleet size, Spares inventories, Maintenance resources and influence of extraneous factors (e. g. weather). The simulations resulted in considerable savings due to reduction of the active fleet size, and increased reclamation of surplus spares and units from retired aircraft. ***Keywords:*** *Performance-Based Logistics, Aviation, Maintenance, Aircraft, Phase-out, Monte Carlo Simulation.*

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SESAR and Military Aircraft: Human Machine Interface definition for 4D Trajectory Management and ASAS Spacing functionalities

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Keywords: *SESAR, Military Aircraft, Human Machine Interface, Initial 4D, ASPA*

Abstract

Single European Sky ATM Research (SESAR) is an ambitious research program funded by European Community and Eurocontrol whose aim is to renovate the European ATM (Air Traffic Management) system toward a Single European Sky (SES). SES will involve not only civil/commercial air traffic but also military air traffic. The integration of military aircraft into a collaborative ATM environment leads to the necessity to solve the problem of making the military aircraft systems interoperable with the Air Traffic Management framework. SESAR procedures identified for a minimum interoperability level are Initial 4D (I4D) and ASAS SPAcing Sequencing and Merging (ASPA S&M) where ASAS stands for Airborne Separation Assistance System. The aim of the paper is to study the accommodation of selected SESAR functionalities (i.e. I4D and ASPA S&M) in the military cockpit configuration of Transport-type and Fighter-type. Typical military cockpit configurations have been analyzed in order to identify cockpit item which could accommodate requirements of SESAR functionalities. By analyzing military cockpit items as well as requirements of Initial 4D and ASPA S&M, a design solution has been identified in concurrence with industry military pilots.

1 General Introduction

SESAR (Single European Sky ATM Research) is a research programme co-funded by the SJU (SESAR Joint Undertaking) the European Community and Eurocontrol. The aim of SESAR is to reform ATM (Air Traffic Management) rules and procedures in order to realize the following goals as indicated in the SESAR ATM Master Plan [1]:

- Enable a 3-fold increase in capacity which will also reduce delays, both on the ground and in the air;
- Improve safety performance by a factor of 10;
- Enable a 10% reduction in the effects flights have on the environment and;
- Provide ATM services to the airspace users at a cost of at least 50% less.

The realization of SESAR goals is based on ATM concepts here reported:

- Moving from an airspace to trajectory based operations so that each aircraft

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Enhanced methods for geometric and photometrical alignment when projecting in domes

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Keywords: Flight Simulator Dome, Geometric alignment, Photometric alignment, Camera projector calibration, Automatic calibration

Abstract

When working with flight simulation for the Swedish Armed Forces Sjöland & Thyselius has developed methods to improve quality and decrease time spent when setting up a simulator.

It is very common to use multiple projectors to project the environment image in an aircraft simulator. Any change in the configuration of these simulators amounts to time consuming, often manual, work to adapt and improve the quality of the projections, to give a good simulator experience to the user.

By using different more or less automatic methods to map, calibrate and warp the picture we can reduce this time consuming work and at the same time achieve an improvement of image quality.

Experience from the development work indicates that the methods we have developed at Sjöland & Thyselius show a decrease of manpower needed by about 80% compared to the usual methods, and simultaneously the image quality is noticeably improved.

1 General Introduction

When projecting pictures from multiple projectors and/or onto any surface you will always have several problems with the picture that you want to create. You will get errors in the picture, distortions, unwanted shadows, and other problems. It is a painstaking process to correct these problems, often with very time-consuming hands-on processes.

At Sjöland & Thyselius we have, during our work with flight simulators, discovered several different methods which simplify the work of adjusting pictures and of merging several projected pictures to form a continuous picture on any smooth surface. Several different methods have been developed to solve different problems that you may come up against in such situations, such as correcting colour and mapping coordinates.

2 General description of warping

Warping, or image warping, covers methods for distorting one or several pictures, mainly to correct the image as projected onto a viewing surface. In the case of several pictures, the pictures can also be integrated into one large

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Decision Support for Future Fighter Aircraft

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Abstract

A fighter pilot must be able to react quickly in stressful situations where erroneous decision can have severe consequences, such as mission failure or pilot and aircraft loss. To analyze the situation, the pilot interprets information from sensors that detect and track objects in the surroundings. A decision support system should process this information and aid the pilot to make timely decisions. This paper presents examples of functionalities that can be incorporated in a decision support system in the future.
Keywords: *Decision support, fighter aircraft*

1 Decision Support Functions

A pilot needs to plan where to fly in order to both accomplish the goals of the mission and minimize the exposure to hostile air defense systems. The survivability for a route denotes the probability that the pilot can fly the route unharmed. It depends on the enemies' sensor and weapon capabilities as well as the enemies' intents and opportunities to harm the aircraft [1]. A decision support system (DSS) could estimate the survivability for possible mission routes and suggest the optimal one.

An important part of the pilot's situation awareness is to know the types of the aircraft that are present in the vicinity, for instance to distinguish between enemy fighter and civilian aircraft. Even though different types of aircraft have similar trajectories as long as they fly straight ahead, a fighter aircraft can soon be recognized if it performs dynamic maneuvers. Moreover, an aircraft which has launched a missile usually makes a so-called "gimbal turn", which is a compromise between keeping the opponent within the radar's field-of-view and avoiding the opponent. By automatically analyzing trajectories a DSS can identify aircraft types and give warnings for threatening situations, see e.g., [2, 3].

Air combat between two fighters can be seen as a game where the participants strive for a favorable position relative their opponent and at the same time denying the opponent to do the same. By assuming that the opponent is acting optimally with respect to the combat, it is possible to predict how the opponent will act see e.g., [4]. The DSS can use this information to suggest intelligent actions to be used by the pilot.

Common for the above examples is that the pilot needs to analyze the situation based on information which is noisy or even erroneous due to sensor imperfections or intelligent reports that are outdated. A major challenge is therefore to design a DSS that is able to deal with uncertainties and that the pilot can trust without providing over-confident information.

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Automatic Landing System for Civil Unmanned Aerial System

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Keywords*: Ground Effect, Simulation, Automatic Landing*

In spite of a number of potentially valuable civil UAS applications The International Regulations prohibit UAS from operating in the National Air Space. Maybe the primary reasons are safety concerns. In fact their ability to respond to emergent situations involving the loss of contact between the aircraft and the ground station poses a serious problem. Therefore, to an efficient safe insertion of UAS in the Civil Air Transport System one important element is their ability to perform automatic landing afterwards the failure.

Moreover, the mathematical model of ground effect is usually neither included in the model of the aircraft during takeoff and landing nor in the design requirements of the control system Usually two different mathematical models of the aircraft are used during landing: the first Out the Ground Effect (OGE) and the second In Ground Effect (IGE).

The objective of this paper is to design a longitudinal automatic landing system taking ground effect into account. The designed control system will be tested and implemented on board by using the Preceptor N3 Ultrapup aircraft. In fact, such aircraft is used as technological demonstrator of new control navigation and guidance algorithms in the context of "Research Project of National Interest" (PRIN 2008) by Universities of Bologna, Palermo, Ferrara and the Second University of Naples.

First of all, a general mathematical model of the studied aircraft is built to obtain non – linear analytical equations for aerodynamic coefficients both Out of Ground Effect and In Ground Effect conditions. According to previous researches, aerodynamic characteristics of the aircraft , have been modelled by means of hyperbolic equations in the whole flight envelope. So it is possible to use a single model during the whole landing phase taking into account the actual ground effect.

To overcome the difficulties due to the use of nonlinear models of the aircraft in ground effect for designing the controller, the control system has been designed using the following approach:

- The Landing flight path has been divided into two segments: the descending path for aircraft altitudes $h > b$ (OGE) and the flare for $h <= b$ (IGE);
- The flare manoeuvre starts for $h = b$;
- An acceptable number of linear models has been obtained by means of linearization of the original nonlinear model in various flight conditions;
- A modified gain scheduling approach has been employed for the synthesis of the controller. It is made by six PID and by a supervisor. This one, by using the actual flight altitude, schedules the set of gains to be inserted online, depending on the real flight condition.

Several tests have been carried out by means of simulation, in Matlab Simulink environment. The obtained results show a good accuracy of the control system for trajectory tracking in ground proximity.

Further developments of the present research will be the extension of the designed control system to the take-off phase.

Afterwards the aircraft model will be improved by evaluating both lateral stability derivatives variations In Ground Effect and the bank angle derivatives (ϕ derivatives). The present methodology will be employed to design a Lateral Automatic Landing System.

The obtained results could be used later on, with the purpose to realize a fully autonomous UAS.

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Terminal Route Optimization for Cumulative Noise Exposure

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Keywords: *keywords list (no more than 5)*

Abstract

This paper presents a study on the development of a methodology for the optimization of multi-event aircraft trajectories. The new optimization framework – an extension of the NOISHHH tool originally developed for the environmental optimization of single-event aircraft trajectories – can be employed to synthesize multi-event terminal routes that minimize the community noise impact in near-airport communities due to the aggregated noise exposure of all inbound and outbound traffic over an extended time period. The new framework has been applied to traffic flows on a representative day at a large international airport. The numerical example revealed a significant decrease in the number of people highly annoyed due to aircraft noise in the vicinity of the airport.

1 Introduction

The ever increasing demand for civil aviation traffic has in many countries led to increased awareness with respect to the environmental impact of aviation on near-airport communities, especially with respect to the noise nuisance. At Amsterdam Airport Schiphol (AMS) – the fourth largest airport by traffic movements in Europe – continued public debate has led to a proposition for significant changes in the noise regulations for the neighboring communities. The new regulatory system, which is currently being implemented for a two-year trial period – is expected to accommodate a 15% growth in the number of movements whilst maintaining acceptable noise exposure levels in surrounding communities. The proposed regulatory system is based directly on site-specific, population-based criteria, and aims to limit the number of people being exposed to given aggregated (annual) noise levels. With the new system in place, the opportunity arises to developed new noise abatement terminal routes in an effort to minimize the community noise impact, and hence to still allow the projected growth in the number of movements.

Research aimed at optimizing terminal routes and procedures to minimize the noise exposure has been quite extensive in the last decade. Prats [2] focused on single-event trajectories using optimal control theory, aiming to minimize the noise exposure in a number of highly noise-sensitive areas. Visser and Wijnen [3], Hogenhuis [4], Fernandes de Oliveira [5] and Richter [6] have all considered community noise impact in their optimization studies. In all of these studies, however, only single event aircraft trajectories were considered, whereas the noise regulations around airports are generally expressed in terms of the aggregated noise exposure over a longer time period. With a focus on cumulative noise impact, Braakenburg [7] has shown a significant reduction of noise exposure by applying optimal control theory to arrival ground tracks at a regional airport, taking into consideration the entire yearly fleet mix.

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Innovative Airport and ATM Concept (Operating an Endless Runway)

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Abstract

This paper presents an innovative and radical new concept for future airport operations, consisting of an airport with one circular circumventing runway, called The Endless Runway. This runway is used for take-off and landing in any direction from any point on the circle and offers through this the unique characteristic a sustainable capacity in all wind conditions through the possibility for an aircraft to operate with headwind during the take-off and landing phase. By placing airport facilities inside the circle, the airport will be more compact, runway crossings can be avoided and taxiing aircraft will be able to shorten their global trajectory through optimised arrival and departure routes. The project, the Endless Runway, is partly funded under EC FP7 [1].

1 Introduction

Where SESAR expects a three-fold increase in air traffic for the year 2020, vision statements beyond that date [1][3][4] expect an even further increase to a five-fold increase of aircraft use by 2050, based on the growth of the world population and a progressed mobility. The global fleet of aircraft is expected to grow fivefold from 19,800 in 2011 to a 100,000 aircraft in 2050! As was identified by ACARE, the Advisory Council for Aeronautics Research in Europe, the lack of capacity at airports is a major constraint to growth in air transport today and in the following decades. These numbers demonstrate that without a radical new airport concept providing fast and efficient aircraft handling with capacities beyond state-of-the art, the expected growth in air traffic cannot be realised.

A number of physical constraints on runways and runway operations, such as wake vortex separation minima and cross- and tailwind limits, and of societal and environmental constraints limiting airport and traffic expansion (new runway, night traffic, etc.), make it hard to improve the performance of conventional airport configurations significantly.

Directionality of runways results in a dependency to the wind direction and speed and using the same approach path results in trailing aircraft having to avoid wake vortices from leading aircraft.

This paper presents a fundamentally new and innovative approach to runway operations, where the major motivation of the study is to provide a sustainable airport capacity under all wind conditions whilst maintaining a high level of safety, reducing operating costs, and keeping environmental considerations in mind: *the Endless Runway*. The aim of the project is to investigate, through simulations, the feasibility of the concept.

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Integration Aspects of a Tactile Display in a Fighter Cockpit

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Keywords: *tactile display, flight simulator*

A fighter pilot's task can be time critical and highly demanding on mental workload and/or situation awareness. The visual and aural information channels are already used to their limits in high workload situations. Using another modality like tactile displays could be a solution to decrease workload, reduce reaction time and increase situation awareness.

As part of the FMV supported program "FoT Flygteknik 10-12" a tactile vest was integrated into a simulator to investigate the potentials of tactile display usage and the integration aspects of an aircrew carried tactile display.

Integration aspects include hardware and ergonomic considerations. Aircrew carried equipment in a fighter aircraft need to be safe for ejection both from a mechanical and an electrical point of view. Placements of tactile display elements, tactors, in the aircrew clothing must not interfere with the g-suit and must also be placed so that the tactile signals are sensable.

System integration aspects include considerations of a multimodal design where tactile, audio and visual signals are used together when appropriate and the design of tactile signals to fit together with existing aural and visual signals, in order not to create conflict among the senses.

A number of multimodal signals were designed and demonstrated to fighter pilots in an advanced flight simulator. These signals were of three different categories; attentional, directional and iconical. Typically attention signals aim to reduce pilot response time while directional signals aim at increasing situation awareness and icons aim to get a more complex message across to the pilot. The scenarios used ranged from low level flying in mountain terrain and ground attack against defended targets to peacetime dogfight training.

Positive pilot feedback on the demonstrated tactile/multimodal display led to a further study of the effects and design of directional tactile signals. Various ways, both relative and absolute, of mapping real-world directions to the pilot's body were considered and implemented. For this study a scenario involving evasive actions from an incoming missile was used. The subjective opinions of the pilots indicated that the addition of tactile direction display improved not only situation awareness but also perceived response time and mental workload.

Future research could include more complex scenarios and combinations of techniques for multimodal interaction, for instance the effect of 3D audio in combination with tactile display.

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Early assurance of the Gripen E combat performance by mission simulation

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Keywords: *Mission simulation, Gripen, aircraft development*

Abstract

In the development of the new Gripen E(Echo version) fighter aircraft an early operational evaluation of system design is an essential way of making the right decisions regarding design, functionality and HMI (Human Machine Interface).
Traditionally an operational evaluation of a Gripen version has been done when the aircraft has been about to be delivered to the air force. Because of that some operational remarks were discovered late and could only be adjusted in the next edition release.
In recent years Saab Aeronautics has developed a simulation tool called OpVal (Operational Validation Simulator). This is a facility with eight Gripen cockpit stations collocated and interconnected. It is possible to change the design and functionality in the OpVal cockpit in a short time and compare different concepts to each other.
With this facility it is possible to try out and evaluate new functionality, together with the end-user, in a realistic scenario and therefore send the feed-back direct to the design team before the aircraft is built. For the manufacturer and end user this means gained operational value, reduced development time and reduced cost by making the right design from the beginning.

1 Introduction

Producing fighter systems is a complex and expensive process and has traditionally resulted in a global trend of military aircraft projects that has exceeded time lines and financial limits. Saab Aeronautics has changed the direction of this trend when introducing the Gripen aircraft in the beginning of the 90's.

With the next Gripen project Saab Aeronautics has an ambition to continue in this direction. The key is to identify the system functions and HMI design issues in an early phase of the project and have a close cooperation with the customer to ensure fulfilled operational needs.

Modeling and simulations is an essential way of identifying these issues by investigating the aircraft model in its combat environment.

2 Gripen E

Saab Aeronautics is developing the next generation Gripen fighter aircraft – the "Echo" version for the Swedish Air Force.

Effect on fuel consumption when flying to avoid formation of persistent contrails

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The global warming effect from aviation is not only caused by carbon dioxide (CO_2), but also by the emission of nitrogen oxides (NO_x) and the formation of contrails (Sausen et al., 2005). In order to minimise the climate effect it is therefore important to not only focus on reducing CO_2 emissions, but also reducing other contributors to global warming. This might, for example, be accomplished by developing strategies to avoid flight through ice-supersaturated regions (ISSRs), which would prevent the formation of persistent contrails.

Calculations have been made to show what the annual change in fuel consumption might be for a specific city pair during the cruise phase of a long haul mission over the northern Atlantic Ocean when changing cruise altitude to avoid ISSRs. Actual onboard measurements of relative humidity were collected within the MOZAIC project (Marenco et al., 1998) and are used for this study. A case study was performed based on 92 transatlantic round trip flights operating between Frankfurt and Atlanta during 2008.

The avoidance strategies evaluated are based on a simple contrail avoidance method developed by Mannstein et al. (2005). It is shown that in 50% of the cases it is enough to either ascend or descend by 2000 ft in order to exit an ISSR and avoid the formation of persistent contrails. With a change of 4000 ft the region can be exited in around 80% of the cases. The resulting changes in fuel consumption for the following three avoidance strategies have been evaluated:

- Moderate descent when there is a risk for persistent contrail formation
- Extended descent when there is a risk for persistent contrail formation
- Ascend when there is a risk for persistent contrail formation

Results suggest that only a small penalty in fuel consumption is incurred for a large decrease in contrail formation.

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Integration of ANVIS in the JAS39 fighter aircraft

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Keywords: *JAS39, NVG, ANVIS, NVIS, Flight test*

Abstract

The Swedish air force (SwAF) has since 2009 been able to see in the dark.

This presentation tells the story how the Swedish Defence Materiel Administration (FMV) and Saab Electronic Defence Systems (EDS) in a joint effort studied, developed, integrated, flight tested and fielded a night vision capability for JAS39C/D.

The night vision capability technology used are based on image intensification and commonly known as Aviators Night Vision System (ANVIS).

1 Background

The USAF and RAF have since the early eighties been able to enhance their rotary and fixed wing night operations with the capability of "seeing in the dark". The technology used is image intensification utilizing head mounted Night Vision goggles (NVGs), Night Vision Imaging System (NVIS) adapted and compatible cockpit light sources, displays and transparencies. The complete technology system is often referred to as Aviators Night Vision System (ANVIS).

The Swedish Defence Materiel Administration has since the late eighties conducted technology studies and field trials of Night Vision Systems (NVIS) and NVGs. This has resulted in that the Swedish rotary wing community began to use ANVIS in the nineties. However the fixed wing community still lacked night vision capability.

2 Development of ANVIS for JAS39C/D

The JAS39 Gripen in A and B version lacked the possibility to use ANVIS due to incompatible internal and external lighting, displays etc. However, when JAS39C/D was specified there were requirements for use of ANVIS.

Saab Electronic Defence Systems (EDS) have in later years been engaged in the effort of developing night vision capability for the SwAF fixed wing fighter fleet utilizing NVGs.

The development, integration, flight testing and release to service has been an joint effort by four stake holders, EDS as the display system vendor and ANVIS expertise, Saab Aeronautics as the platform integrator, the Swedish Defence Materiel Administration as the customer and the

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Field service of the Swedish reconnaissance capability in Operation Unified protector

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Keywords: *Field service, JAS39, Operation Unified Protector, Reconnaissance*

Abstract

Operation Unified Protector was an NATO operation enforcing United Nations Security Council resolutions 1970 and 1973 concerning the Libyan civil war. These resolutions imposed sanctions on key members of the Gaddafi government and authorized NATO to implement an arms embargo, a no-fly zone and ***to use all means necessary****, short of foreign occupation, to protect Libyan civilians and civilian populated areas.*

Sweden has a long record of participating in UN sanctioned operations but has not deployed fighter aircrafts since the Congo conflict back in the sixties.

For OUP Sweden deployed JAS39C fighter aircrafts that were supposed to perform defensive counter air (DCA) and tactical reconnaissance (TAR) missions. As the campaign progressed it turned out that the Swedish reconnaissance capability were of very high standard and the mission were concentrated on this task.

The main reconnaissance sensor used by the Swedish air force were the Saab developed SPK39.

This paper tells the story how Saab Electronic Defence Systems (EDS) supported the Swedish reconnaissance capability during the operation

1 Background and history of the SPK39

This section deals with the describing the main sensor used and the development program. It also describes EDS strategy for flight test and field service.

2 Support FL01

Sweden fist deployed a contingent called FL01 that were the air component (Expeditionary Air Wing) of the Nordic Battle group 11 that Sweden was managing.

The FL01 consisted of eight JAS39C fighters, a Lockheed Tp-84T C-130 Hercules configured as aerial tanker. FL01 were based at Sigonella naval air station, Sicily

EDS supported FL01 both on-site and remotely from Sweden.

FL01 performed DCA and TAR missions. The TAR missions were only authorized to report direct threats against the non-flying zone.

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Concept Assessment for Remotely Piloted Commercial Aircraft using Multi-Attribute Nonlinear Utility Theory

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Keywords: *Remotely Piloted Commercial Aircraft, Remotely Piloted Aircraft, Multi-Attribute Non Linear Utility Theory, Stakeholders*

Abstract

This paper outlines the research on Remotely Piloted Commercial Aircraft (RPCA) using multi-attribute nonlinear utility theory, from the perspective of multiple stakeholders in air transportation systems, including airlines, regulating authorities, pilots, and passengers.

In this research, RPCA implies cockpit crew reduction for future commercial passenger aircraft. With ongoing increase in automation, commercial aircraft would be able to fly autonomously without on-board pilots. However, for the backup and safety of the system, pilots would be positioned on the ground for remotely monitoring and controlling the aircraft from a Ground Control Station (GCS). The concept is similar to the currently operated Remotely Piloted Aircraft (RPA).

In order to evaluate the maximum potential of the concept, a long range passenger aircraft is considered as the use case for this study. Major stakeholders and key criteria are identified for this preliminary research. Furthermore, a widely used multi-criteria analysis method: nonlinear utility theory is applied to evaluate a set of scenarios based on number of pilots on-board and on ground.

DORATHEA: AN INNOVATIVE SECURITY RISK ASSESSMENT METHODOLOGY TO ENHANCE SECURITY AWARENESS IN ATM

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The attack of September 11 in 2011 and its subsequent series that targeted the Madrid commuter trains in 2004 and the London public transport system in 2005 foster an increasing concern about the security of critical infrastructures such as airports and ATM in general. Indeed, ATM covers a pivotal role in the supply chain in Europe and is vulnerable to several attacks like terrorism, illegal drug trafficking, human and weapons smuggling. ATM security has been addressed with several guidelines, standards and regulations, among them the ICAO Security Manual for Safeguarding Civil Application, the Single European Sky ATM Research (SESAR) Security Risk Assessment Methodology (SecRAM) and ISO 2700x series. They mainly recommend security measures and activities related to risk assessment in a prescriptive way, offering little help in identifying and prioritising threats according to time and budget constraints.

The increasing complexity of systems that support navigation and surveillance, due to the pervasiveness of emerging technologies and growing number of flights, create the conditions for the rise of unpredicted threats that may potentially turn into dramatic events. This is also driven by the on-going update of legacy systems with new technologies and their connection to innovative systems, which creates a new environment with new threat vectors, for which these systems were not prepared when they were designed.

DORATHEA (Development Of a Risk Assessment meTHodology to Enhance security Awareness in ATM) is a research project co-funded by European Commission Directorate-General Home Affairs, in the frame of the Prevention, Preparedness and Consequence Management of Terrorism and other Security related Risks Programme, with the aim of developing a common methodology for carrying out risk, threat and vulnerability assessments for ATM protection.

DORATHEA aims at increasing the awareness of ATM operators through an innovative security risk assessment methodology for ATM systems, because only a common methodology can provide the necessary basis for a coherent implementation of measures to protect European ATM Critical Infrastructure and clearly define the respective responsibilities of all relevant stakeholders.

The proposed methodology is an extension of ICAO Security Manual and it is based on the strength points of the Safety Assessment Methodology defined by EUROCONTROL.

It comprises three phases. For demonstrative purposes, the methodology is applied to a real case study for the identification of countermeasures in a systematic way, to be adopted as security system requirements at design level.

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Pilots' Performance Optimizing: Dual Approach – Lateral Component of Virtual Flight and Physiological Profiling

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Keywords: *Flight Simulators, Pilot Assessment, Aviation*

Abstract

The main goal of this paper is to provide the latest developments in high level integrating of two different sides of pilots' performances optimizing, focusing on assessment of the contribution of the lateral component of the virtual flight in the optimizing process. In order to achieve this goal, two main sides are considered: first concerning the system able to carry out the task of performances optimizing and second oriented to presenting the results showing the contribution of the lateral component of the virtual flight in optimizing process. An entirely new specially designed intelligent system for high precision assessments of aircraft piloting abilities assisted by a multi-stream data acquisition and processing system for integrating the simulated flight data and the physiological and behavior data will be the basis for all optimizations. As a direct result of the integrated optimization processes implemented for the piloting abilities models, a more solid basis for the decision-making process for setting the pilots' and candidates' hierarchy for admittance to specific flight training programs is provided. The system is intended to work as a complex and parametric set of tools. The engine of the assessment process is a hierarchical set of specific flying stimulus, weighted in the pilot's performances models. The virtual environment hosts all the subjects' flights, where specific visual, sound and tactile information are provided in a cockpit specific form. A library of basic and generic tasks is also developed so that the dynamic complex scenarios can be easily generated, according to the pilots' training level; each flight situation is enriched by considering stimulus hierarchies, one stimulus category at one time (visual, flight, navigation and environment integration). The main tasks are distributed in few sub-systems: the simulation sub-system for the virtual environment management, the flight simulation sub-system and the multi-stream data acquisition sub-system for data integration in simulated flight and for physiological and behavior data management. Separate, a sub-system for processing, structuring and correlative analysis of all the information provides the decision making sub-system with all profiling data. The data acquisition stream rate is variable, but for academic purposes the rate of 2 samples per second proved to be satisfactory. Each of these variables is processed afterwards so that a set of performance data can be synthesized (e.g.: average values, symmetry and form of distributions). All the information operated by the integrated adaptive system is stored in secured relational structured databases: the basic scenario database, the complex scenario database, the subjects' database and the results database.

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Validation of a numerical simulation tool for aircraft formation flight.

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Keywords: *Formation flight, drag reduction, panel methods.*

Abstract

The use of formation flight for increased fuel efficiency has received a lot of attention in the last couple of years.

This paper covers a numerical simulation of a NASA test flight utilizing a formation of two F18A Hornet aircraft. The numerical simulation was made using an adapted version of the vortex lattice method TORNADO, allowing for several aircraft to be simulated in a trimmed condition. The numerical results showed good agreement with the flight test data. Some discrepancies due to the numerical model not covering viscous diffusion was found as expected but not quantified or analyzed.

1 Background

The physical phenomenon behind the drag reduction encountered in formation flight has been understood for a long time, but formation flight has never seriously been employed in civilian airline traffic. On the military side, formation flight has been extensively used for tactical considerations such as navigation or suppressive fire coverage and only exceptionally as a fuel saving measure. The increased fuel efficiency is due to the decrease in induced drag caused by the upwash formed by the vortex system of a lifting wing. The formation flight then becomes a virtual extension of the span of the constituent aircraft thereby increasing the aspect ratio.

Several studies have been performed showing large potential savings in fuel consumption; The NACA study supplying the flight test date used in this paper reported a reduction in fuel consumption of 20% for a fighter type aircraft, the McDonnell Douglas (now Boeing) F/A-18 Hornet. This is a number significantly higher than the potential fuel savings from design changes.

As an example of the systematic benefits of employing formation flight for fleet operations in the north Atlantic, a conservative stance on what the in-operation fuel savings would be to assume a 5% save, based on the NASA results. Just for the trans-Atlantic routes with 385 flights a day, each direction, each burning 50 tons of fuel this would mean that in absolute numbers a flight-in-formation scheme would save 2000 ton of aviation fuel saved, each day.

While Flight tests results are closer to a real situation, they are also prohibitively expensive for mapping out a large array of tests, and some data may be inaccessible for measurement. This paper aims at showing the validity of using a Vortex Lattice Method (VLM) to assess benefits

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Towards Optimized Profile Descents at Malta International Airport through Revised Approach Procedures

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Keywords: *trajectory optimisation, SIDS, STARS, PBN, OPD, RF Turn*

Abstract

Traditionally, an aircraft descends from cruise level towards the aerodrome in a stepped manner as directed by Air Traffic Control to ensure safe separation between aircraft, particularly in the terminal area. A descednt methodology that is now being preferred is that of optimised profile descents (OPD). In OPDs, the aircraft descends from the Top-Of-Descent (TOD) point towards the aerodrome following a smooth, continuous descent profile that is optimal from an operational perspective of choice, until it intersects the glide slope of the Instrument Landing System (ILS). OPDs are advantageous because they consume less fuel and generate fewer emissions than their stepped counterparts.

This paper presents a proposal of new approach procedures for use in the approaches to Malta International Airport (MIA) that will facilitate the introduction of OPDs. With around 28,000 aircraft movements per annum at MIA, this can be achieved by giving Air Traffic Control Officers (ATCOs) a selection of approach procedures on which to direct in-trail aircraft without imposing altitude constraints. The discussion includes a study of current procedures, a statistical analysis of historical radar plots, the presentation of the proposed approaches, and a forecast of the potential gains in terms of fuel burn and emissions expected through fast-time simulation.

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Optimal Spot-out Time – Taxi-out Time Saving and Corresponding Delay

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Keywords: *Taxi-out; Taxiing; Spot-out time control; Uncertainty; Airport operation*

A departure queue management has been proposed to reduce fuel burn and emissions during airport ground operation. The departure aircraft usually blocks off once it is ready for pushback. However, the aircraft has to be queued and might have to wait at the runway because of congestions, as certain minimum separation is required between two take-off aircraft. Queuing and waiting causes additional fuel burn and emission and some of it can be avoided.

On the other hand, in departure queue management concept, the spot-out time of each departure aircraft is shifted later so that the aircraft goes to the runway and take-off smoothly. If the aircraft can wait at the gate with engines off instead of waiting on the taxiway, unnecessary fuel consumption can be reduced. However, assigning block off time to each aircraft is a challenging topic which has been a subject of several researches.

Although the departure queue management has a potential to improve ground operation as explained above, this concept can have negative effects, not yet considered by other researches. One such possible negative effect is take-off delay.

If the spot-out time is controlled to save taxi-out time, the take-off time can be potentially delayed due to various uncertainties. Here, "taxi-out time" is defined as the time between pushback start and take-off, and "delay" is defined as the difference of take-off time between the nominal case and the spot-out time controlled case. Even if a large margin is set to absorb uncertainties, the expected delay will be close to 0, but not definitely 0 as long as the spot-out time is shifted later. According to other researches, the taxiing time is reduced as long as further delay is not caused, but strictly speaking, this cannot happen. Even if delay is caused, it is usually attributed to a "rare unexpected event". However, from airlines' perspective, it is important to know how much take-off delay is caused as well as how much fuel saving is expected. If the take-off time is delayed, the arrival time will also be delayed or more fuel might be consumed for speeding-up to arrive on time. Therefore, the "real" optimal airport operation should be discussed from various perspectives.

This research is unique in terms of considering important factors of various stakeholders, not considering fuel saving only. The purpose of this research, at present, is to provide the relationship between the trade-off factors to stakeholders, and proceed with the discussion about optimal airport operation. In this paper, the relationship between taxi-out time saving and take-off delay at Tokyo International Airport is revealed quantitatively. First, a stochastic simple airport operation model is developed based on the actual data at Tokyo International airport. Next, the assumed ATC operation for departure queue management is explained, and a simple queue management algorithm is proposed. Using the proposed model and algorithm, the expected trade-off relationship between taxi-out time saving and take-off delay is shown.

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Enhancing Situation Awareness with a Large Area Display

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Keywords: *Situation Awareness, Display*

Abstract

The long term vision of presenting the "Big picture" to the pilot as Eugene Adams envisaged in the 80´s is about to become true. Today we have the technical solutions to be able to collect and present the information on one large display in a structured and beneficial way. Saab Aeronautics has studied possibilities for a large area display (LAD) and its potential use in a future manned fighter aircraft context. This paper addresses what could be gained by introducing a large area display and why this is a desirable way forward. A LAD is essential for helping the pilot to achieve an improved Situation Awareness. Collected information from different sensors is fused together and presented in one view. A LAD offers the possibility to have one overview of the situation and one zoomed-in detailed picture at the same time on the same display. The pilot can easily pan the view and select interesting areas to zoom in to. The area on a LAD has the benefit of providing a homogeneous display area. Also, information that is dynamically presented to various places, such as dynamic symbols or cursors etcetera is easier to follow, and has a continuous motion, in the homogeneous display area of a LAD. By arranging information in close proximity in a LAD pair-wise comparisons can be made better than when the perceptual task is divided between displays.

The tactical overview is often complex and requires many layers and icons to provide a clear and dynamic visual presentation to the aircrew. A LAD makes it easier to visualize the different zones to fly in and to give a good overview of the whole mission. With a LAD it will also be possible to expand and enlarge pictures and video inputs using a pilot selectable display section. Pictures and video can be displayed in the most optimal format for the situation and managed in a flexible manner. Using new cuing solutions such as touch control and innovative command options will enable the designer to utilize new display feedback capabilities more intuitive to the future user. A LAD will offer flexibility in the layout of display. Display modes can be tailored to the optimal size depending on content and mission phase and not constrained to a limited display area. Also, the use of a LAD opens up for synergies with other display techniques including multi-modal interaction and advanced visual display design. For instance, the use of perspective representations is potentially aided by a large display area. Use of peripheral vision (eg. visual flow) increase drastically with a LAD that can make use of a larger field of view.

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The Russian Federation Airspace Structure Analysis with the Use of ATM Research Simulation Tool

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Keywords: *air traffic control, airspace structure, route network structure, simulation tool*

Abstract

Airspace usage effectiveness assessment research is a significant component of airspace structure design and modernization. This paper is devoted to this type of research in the Russian Federation with the use of a set of research Air Traffic Management (ATM) simulation tools (KIM OrVD). Key features of KIM OrVD program, which provide an opportunity to conduct the complete cycle of simulation, are considered in this paper following the example of modernized airspace usage effectiveness assessment. The methodology (scheme) describing all the stages of the research is presented. Research results show the benefits of Moscow air traffic control center (ACC) route network and airspace structure.

1 Introduction

The measures of the Russian Federation Airspace structure modernization are performed as part of the Federal target program "Modernization of the Russian Federation Unified system of Air Traffic Management (ATM) (2009-2015)". They involve air traffic control centers (ACC) enlargement, airways structure upgrade, new Standard Instrumental Departure (SID)/Standard Terminal Arrival Route (STAR) schemes generation for airports.

The need for measures is based on the following factors. The area of Russian Federation Airspace which is served by the ATM system exceeds 25 million square kilometers, the length of airways is about 800,000 km including about 500,000 km of international airways. The use of the airspace of the Russian Federation constantly increases due to the geographical position of the Russian Federation and the growth of the number of flights in the direction of South-East Asia - Europe, South-East Asia - the United States through the Russian Federation Airspace. Also, the number of international flights to/from the airports of the Russian Federation is growing, and the need in domestic flight operations increases.

The existing Russian Federation Airspace structure does not allow of conflict-free flights within its most overloaded areas. There is a problem of conflicts at intersections of transit flights and arrival/departure flows close to major airports. At low intensity of the traffic such problems are almost invisible, but because of the growth of traffic now there are already problems at the intersection of routes of such flights.

These problems are particularly acute in Moscow's center, through which more than 50% of all transit flights across the Russian Federation Airspace pass. The majority of the traffic flows to the Moscow airports

Geospatial Intelligence for Air Operations

The role of geospatial intelligence in air operations is currently emerging in a larger scale. The tactical loop for air operations requires semi-automated processes to manage information retrieval as well as the increased demand to share data. Large amounts of data derived from imagery, full-motion video and other remotely sensed data merged with information from sources such as statistical databases, geosms, twitter messages and crowdsourced data must be found, sorted, geocoded and interpreted to be used in mission planning stations for analysis, for navigation planning, for tactical management etc. New technology is driven by demands on real time information and possibilities to analyse, merge and share data throughout intelligence analysis and mission preparation, air recce and combat mission support and finally evaluation and mission report. This presentation will present some trends within the area of integrating geospatial intelligence into air operations.

One significant trend is fusion of intelligence derived from several different intelligence disciplines such as images and analysis of geospatial information, from signals such as radio traffic, information from interpersonal contacts, from open source, gathered from analysis of weapons and equipment, or even financial intelligence data from analysis of monetary transactions. When the multisource information is visualized in a map, new patterns can emerge and be interpreted. Experiences from recent conflicts show that missions involve a complexity regarding cooperating aircrafts, homeland defense, groundbased systems as well as civil organizations. In the efforts, information must be shared, often in real-time. The aim to act on the same map has therefore never been more challenging and requires well configured and verified systems.

Techniques need to be improved or developed for automatic data mining and interpretation of the data. Augmented reality is emerging which is overlaying the real world with other relevant information, and may be a technique that can also be of interest for air operation systems. Advanced techniques involve working with semantics and artificial intelligence to improve interpreting solutions. Standards, the development of the web including new techniques for serving data increases the possibilities to distribute and receive information between different data sources via Internet as well as using other communication solutions. Data sharing also means improvement in security solutions must be made to manage requirements on confidentiality in military systems to be able to both protect and share data.

The technology level within the civil and military communities is similar and it is no longer the case that technology is developed for the military community with a possibility of use in the civil sectors. On the contrary, the trend is that the civil demand has evolved and leads to solutions that sometimes exceed military needs. As a consequence, parallel developments for similar demands for both civil and military users is about to become obsolete. The use of technology across the civil/military border is possible without major technical difficulties.

Unmanned collaborating autonomous aircraft

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This paper describes the results of a project that was performed within the framework of the European Technology Acquisition Programme (ETAP), by Saab AB, Cassidian (part of EADS Deutschland GmbH) and Dassault Aviation. In this study a group of five Unmanned Combat Air Vehicles (UCAV) performs a ground attack mission against three targets. By using collaboration and a high level of autonomy the group is able to re-plan and execute the mission despite “opposing” activities and events, e.g. air defense or malfunctions or losses of systems or vehicles. Due to the high level of autonomy and the low level of operator interaction required, only a single or a small number of operators are sufficient to control the whole group of five UCAV.
The study focused on some specific problems or capabilities. For the Flight Management the focus was on the capabilities for

- Rendezvous
- Refueling
- Flight in the target area

For the Mission Management the study focused on the following capabilities.

- Survivability (Long Term and Short Term)
- Prepare for Weapon release
- Manage and update the mission
- Monitor and execute the mission

In case of *stressors*, defined as any event or condition that has a potentially adverse effect on the mission goal, the Mission Plan will be adapted to try to cope with the new situation. The first step is to analyze the *impact* of the stressor, and then to determine a *reaction type*, e.g. re-route, move weapon release point, move task to another platform, etc. The adapted Mission Plan has to fulfill a number of constraints. The survivability functions typically give constraints of *where **not** to be*, (prohibited areas) while weapon functions give constraints of *where to be* (required areas). And such constraints typically overlap. The Mission Plan also has to fulfill the Rules of Engagement defined for the mission. Some of these rules can be handled as lists of allowed weapons, allowed targets, etc, while others require human operator intervention. The necessary involvement of operators is handled by giving each task an *Autonomy Level*, such that task can be either fully automatic, or the operator has a time interval to reject the task, or the operator must accept the task within a time interval. Most typical is that weapon release was defined to require operator acceptance, otherwise the weapon release was not performed.
The execution of the tasks were then dependant on that the Flight Management could control all five platforms to fly their defined trajectories safely, with anti-collision functions, and obey the defined waypoint constraints e.g. at weapon release point.

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Demonstration of Satellites Enabling the Insertion of Remotely Piloted Aircraft Systems in Europe

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Keywords: *Unmanned Aircraft, UAS, RPAS, Remotely Piloted Aircraft System, Simulation, Airspace*

1 Abstract

Unmanned Aircraft Systems (UAS) gain increasing interest and use for civil applications. However, regulation for integration in airspace is not harmonised in Europe. Also flying beyond the line of sight (BLOS) is only possible by use of command & control communication through a reliable relay system. The ESA project DESIRE (Demonstration of Satellites Enabling the Insertion of Remotely Piloted Aircraft Systems in Europe), investigated to fly an UAS as IFR (Instrument Flight Rules) traffic within national borders in controlled, non-segregated airspace by communication link via satellites. A real-time man-in-the-loop simulation environment has been set-up, where real air traffic controllers, a real pilot (for other traffic), and a pilot at an UAS ground control station (GCS) participated to evaluate the concept. Several representative scenarios were evaluated, including emergency situations. Also the additional work load brought to air traffic controllers was investigated using the NASA TLX method.

We have shown that integration of UAS in controlled airspace is a feasible concept. Air traffic controllers indicated that control of the UAS did not differ significantly from control of other, manned aircraft, although at the beginning a slightly increased workload was observed. We have also demonstrated that UAS emergency procedures can be designed equivalent to those of manned aircraft, such that the air traffic controller will understand and is able to predict the behaviour of the UAS in several loss-of-satellite-communication situations.

The simulations paved the way for real flight demonstrations with a Male UAV in non-segregated airspace in 2013.

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Fusion of Information from SAR and Optical Map Images for Aided Navigation

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Keywords: Navigation, SAR, Image Matching

1 Abstract

The goal of this work is to formulate the method for using SAR and optical images or map information, *e.g.* Google Maps, in order to fuse information from these sources and utilise it for absolute navigation. The method can be useful as an alternative to high precision navigation aids, such as Global Navigation Satellite System, of which GPS NavStar is the most famous one, to stabilise inertial based navigation systems which are known to be prone for long term drift. The method has many similarities to the known visual odometry method or a method of aided navigation where optical cameras and maps are used to navigate by matching the camera images and the map. However, the fusion of the SAR and optical map images is not as trivial task as to match optical camera images to the map images, since the SAR images have quite different properties than the optical images. The SAR images show the reflectivity of the scene for radar frequencies instead of visible light frequencies. This implies that completely different information can be contained in the SAR images compared to the optical images, although some of the features in the images are clearly very similar. This makes the fusion of SAR and optical images a promising method for remote sensing applications. As a navigation tool, SAR is not sensitive to occlusions from clouds like optical sensors are, giving a less weather sensitive position sensor. As means for extracting useful information from the images, an edge detector (Canny edge detector) and an image or pattern matching method (Chamfer matching, here modified to resemble least squares formulation) will be used in order to match SAR images to the optical map images. In this way a statistical performance measure, covariance, of the estimates can also be obtained. The obtained results on the real SAR images and very simple optical map images from Google maps, see Fig. 1, show that the performance of the matching method is quite good, with small errors and variance, even with these simple means, see Fig. 2 for an example.

Figure 1: Optical image of the Washington DC.

Figure 2: Example of the matching result with a patch from a SAR image.

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A New Safety Net for Tower Runway Controller: Preliminary Results from SESAR Exercise at Hamburg Airport in Detection of Conflicting ATC Clearances

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Keywords: **ATC Clearances, Runway Controller, Runway Incursions, Hamburg Airport**

Abstract

One of the most serious safety concerns in air traffic control are runway incursions. A runway incursion is defined by International Civil Aviation Organization (ICAO) as "any occurrences at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft" [1]. Traditional Advanced Surface Movement Guidance and Control Systems (A-SMGCS) level 2 safety systems detect runway incursions and potential collisions. The subsequent alerts to controllers often require immediate reaction. A new, additional safety net for tower runway controllers was developed to provide longer reaction times for certain kinds of imminent runway incursions. This new safety net detects if controllers give a clearance to an aircraft or vehicle contradictory to another clearance already given to another mobile. The new safety net, developed in context of SESAR, was tested in a shadow mode validation exercise at the operational environment of Hamburg Airport (Germany). Operational feasibility was tested in order to clarify if operational requirements in terms of usability are fulfilled. At the same time operational improvements regarding safety were studied e.g. if the new safety net detects all defined conflicts.

A data logging was made to measure reaction time of the developed Conflicting Air Traffic Control Clearances System (CATC), in interaction with the electronic flight strips (EFS) system.

1 Introduction

Chicago Midway International Airport, December 1st 2011, runways in use are 31C for take-off and landing and runway 22L for take-off. There are two air traffic controllers, one is handling the regular traffic, a second is plugged in as "ground control 2" monitoring the tower frequency and working a VIP arrival checklist.

The tower runway controllers know that a VIP arrival is planned for later the day, which would effectively shut down the airport. This creates a lot of pressure to get as many departures and arrivals through as possible. For this reason the tower runway controllers decide to open runway 31R as an additional departure runway. Figure 1 shows the runways in use at Chicago Midway Airport.

The Servitisation of the Aerospace Industry and the Affect on its Product Development

Johanna Wallin

The long life cycles and product complexity of aircraft engines imply that every engine is an opportunity to supply a stream of spare parts and maintenance services. And since availability of the engine is increasingly valued, rather than the ownership of it, offers such as TotalCare by Rolls Royce has arisen. In these “power by the hour” offers, the functionality of the engine is sold, but the ownership remains with the OEM (Original Equipment Manufacturer). This business model provides a steadier revenue stream for the OEM during the life cycle of the engine. The safety issue is of large concern in an industry that risks several lives at engine failure. This implies the regular schedule of maintenance and overhaul, which are services of large cost to the engine owner. It has also lead to large investments in monitoring systems to predict the need for services and exchange of spare parts prior to failure (Ward and Graves, 2007). This is further examples of the “servitisation” of the aerospace industry and the increased complex Product-Service Systems (PSS). With this emerges the need for the companies in the industry to build the capability to develop PSS in a systematic way similar to the “traditional” product development. However, a product development that includes the development of services, software and business models demands a higher complexity of team composition, ways of working, processes, methods and tools for an integrated connection between business development, service development, software development and product development. The purpose with this study is to develop and validate process, methods and tools for PSS development in the aerospace industry.

The case company GKN Aerospace Engine Systems (previously known as Volvo Aero) is a developer of commercial aircraft engine components and military aircraft engines. Data has been collected through three years of observations at the case company as well as 35 semi-structured interview sessions with stakeholders of business, product, service and PSS development that are distributed across several functions and hierarchy levels at the company. Workshops have also been held to test creative methods for PSS development teams.

This research has shown how the servitization of the aerospace industry is evident not only for OEM but also for 1st tier suppliers as the case company. As the offers no longer consist of products (hardware) only but also of various value adding services, this changes the view of the value stream within the organization. The value stream of services runs in parallel with the value stream of products.

This research has shown an increased need for collaboration and a larger degree of complexity in the collaborative network as the aerospace industry is servitized. The collaboration involves more stakeholders, which including the customer and user who need to collaborate for a longer period of time, through the whole life cycle of the PSS. To handle the challenges of servitization it is importance to have a larger degree of cross-functionality in the teams compared to product development. Hence, includes product, service and business expertise within the team.

Individuals with double competences or experience from more than one area deserve special attention, because they can play an important role in the communication between different areas of expertise that are new to this collaboration. Further, this research has shown that the teams need to focus more on the time perspective of products and services, discuss the ownership and value creation of products and services through the lifecycle and preferable visualize this for better communication.

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Gripen Core; an aircraft simulator family based on model reuse and customer adaptation

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Keywords: *Aircraft Simulator, Software Product Line, Customization, Configurator.*

Abstract

Aircraft developers are experiencing a growing product complexity, including advanced technologies and more interconnected mechanical, electronic, and software parts. Simulation is increasingly used to understand, develop, and verify aircraft systems, but also as a means in the training of pilots and ground crew.

Different approaches are used to manage the increasing amount of information and knowledge in various stages of the product lifecycle. "Reuse" and "Model Based Development" are two prominent trends to manage complexity and to improve development efficiency [1].

This presentation is focused on the combination of methods and techniques within;

- modeling and simulation-based development, and
- (re)use of simulation models through the product line concept.

With increasing computational performance and efficient techniques for building simulation models, the number of models increase, and their usage ranges from concept evaluation to end-user training. The activities related to model verification & validation contribute to a large part of the overall cost for development and maintenance of models.

The Environmental Control System (ECS) in the Saab Gripen fighter aircraft together with related simulation models is used as an example. It is a complex system that includes both H/W and S/W. ECS provide cooling of the avionics equipment, and also tempering and pressurizing the a/c cabin. An essential task is to provide conditioned air to the On-Board Oxygen Generating System (OBOGS), which provides breathing air to the pilots. The ECS S/W controls and monitors pressure, temperature, and flow levels in various parts of the system [2].

The ECS H/W model is developed in the Modelica language [3] and the S/W is developed in the Simulink tool [4]. A combined simulation model is obtained by using the Hosted Simulation methodology. Both Simulink and Dymola can be used as hosting tools.

The ECS H/W model has several variants, e.g. one simple and one detailed variant. The model layout is hierarchical and the Modelica construction *replaceable* is utilized to obtain the different variants of the model. Additional variant handling is performed by parameter selection in the simulation environment.

All models needed for simulation of an entire aircraft is handled through the *Gripen Core* model storage. The Gripen Core methodology aims to reduce the number of similar models created by different teams during design, testing, and end-user support of aircraft

Enabling Uncertainty Quantification of Large Aircraft System Simulation Models

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Abstract

A common viewpoint in both academia and industry is that that Verification, Validation and Uncertainty Quantification (VV&UQ) of simulation models are vital activities for a successful deployment of model-based system engineering. In the literature, there is no lack of advice regarding methods for VV&UQ. However, for industrial applications available methods for Uncertainty Quantification (UQ) often seem too detailed or tedious to even try. The consequence is that no UQ is performed, resulting in simulation models not being used to their full potential.

In this paper, the effort required for UQ of a detailed aircraft vehicle system model is estimated. A number of methodological steps that aim to achieve a more feasible UQ are proposed. The paper is focused on 1-D dynamic simulation models of physical systems with or without control software, typically described by Ordinary Differential Equations (ODEs) or Differential Algebraic Equations (DAEs). An application example of an aircraft vehicle system model is used for method evaluation.

UQ is commonly seen as a value adding activity that increases the credibility of a simulation model. However, analysis of industrial applicability and estimations of the UQ workload are rare. This work has shown that a comprehensive but not excessive UQ of a large aircraft system simulation model may be very time-consuming. The UQ workload of the ECS model is estimated to be twice the time for the model development, verification, and steady-state validation.

As a comparison, our gut feeling of what a model sponsor may consider affordable in terms of UQ workload is, say, 10% relative to the sum of model development, verification, and steady-state validation. Furthermore, UQ does not have all the answers. Questions such as “How uncertain is UQ?” can always be asked. Will the system design be better and sounder and will we become wiser with much more UQ data? It should not be forgotten that even with poor or unknown accuracy of the simulation results, models are useful for many activities during the development phase.

To find a way forward, simplifications, compromises, and methods to ease the UQ workload have been discussed in this paper. Without adding too much uncertainty to the UQ, a number of simplifications are available. The most significant measures proposed in this paper concerns reducing the number of uncertain parameters, simplifying the characterization of uncertainties, and simplifying the uncertainty propagation. All in all, these simplifications make UQ of large aircraft system simulation models more feasible.

Despite the proposed simplifications, a comprehensive UQ will remain a significant part of the model development budget. However, if the UQ implies that a physical system-level test rig is no longer necessary or can be significantly simplified, a large UQ workload can motivated.

Finally, the NASA Standard for Models and Simulations describes factors that affect the credibility of the results, i.e. how useful they are (NASA 2008). In this case, “Result uncertainty” is only one of eight factors. “M&S management” and “People qualification” may be mentioned as two other factors. In other words, although a UQ is carried out in detail with high quality, it is still a fact that if the simulations that will be a basis for design decisions have been carried out with poor configuration management of the model and its inputs and by inexperienced personnel, the risk of large uncertainties and even errors in simulation results is high. A balance of available funds between the various factors that affect the credibility of the simulation result is desirable.

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PRESAGE: VIRTUAL TESTING PLATFORM APPLICATION TO THRUST REVERSER ACTUATION SYSTEM

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- *Virtual platform & Virtual testing*
- *Electrical actuation system*
- *Modeling and simulation*
- *Mechatronic*
- *Thrust reverser*

Abstract

The purpose of this article is to demonstrate the interest and the need to rely on modeling and simulation of mechatronic systems in case of testing application and to contribute to the "democratization" of the use of models and "virtual testing".

Indeed, the systems are becoming increasingly complex: more dynamic, more optimized. Add for that the development schedules are more and more restricted with reduced budgets. These constraints which are antagonistic tend to emerge a new generation of designing and testing: the "virtual test platform".

We propose industrial methods and appropriate tools to develop this virtual test platform.

It is with this objective that CERTIA (Provider of test benches and studies) and the company AIRCELLE (designer and integrator of nacelles), with significant experience in their respective fields, have developed the platform "PRESAGE" for virtual testing in collaboration with academic partners such as Ecole Centrale de Lille, INSA Toulouse and ESIGELEC Rouen.

1 Introduction and background

It is now established that world of new equipment and systems design and world of tests means technologies both evolve towards more innovation and more specificity to electrical systems.

However, these steps forward associated with more electric systems induce several difficulties such as:

- The increase in complexity of the power system,
- New thermal-mechanical coupling,
- Interaction between electromechanical system and flexible structure.

Integration of On-Board Power Systems Simulation in Conceptual Aircraft Design

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Keywords: *Conceptual aircraft design, system simulation, onboard power systems, knowledge based engineering*

Abstract

This paper describes the methodology of generating aircraft system simulation models out of basic information, available during conceptual design phase and shows an implementation example with help of the freeware simulation software HOPSAN.

Due to the highly matured products in the aviation industry with its finer product enhancements, higher estimation accuracy in the conceptual design process is required. Therewith, aircraft system(s) simulations become more and more common within this phase.

Because of the limited direct concept related data available at this stage, the traditional method of crating physical simulation systems by the bottom up approach with help of (standard) components libraries is not applicable; Instead, the respective systems architecture as well as their composition has to be declarative predefined in a flexible, wide range applicable manner. These system technology driven design declarations -combined with the a project data- results in roughly pre-tuned system simulation models which may help to conduct more detailed investigation of the project such as performance or derated/fault system behavior.

This (system architecture) knowledge based approach is shown on the whole aircraft system level down to the detail implementation of the control surface actuator systems of the primary flight control system

1 Introduction

Performing the transition from prototype based development towards model based product development, computer simulations within different development stages and different approaches become more and more common. Key prerequisite paving the way towards simulation based development is the enormous increase of computer performance, pressing down the costs as well as the expenditure of time for model development, execution and analysis. Within aircraft industry most research and also industrial funds are invested in later design stages like preliminary or detail design, like e.g. the huge European Project "CRESCENO" [1] or e.g. the integration of Dymola in the Dassault CATIA V6 design environment [2].
This paper will focus on the integration of simulation already during conceptual aircraft design and allowing a stepless (data) transition from conceptual design to the more detailed preliminary design phase. This will include both

Boxprop, a forward swept joined-blade propeller

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Abstract

One of the greatest potential advances in aircraft fuel consumption and operating cost within the next 20 years is the introduction of engines with high speed propellers, e.g. open rotor fans.

One drawback with the counter-rotating open rotor is the increased noise it may generate, at least in comparison with a future generation ultra high bypass engine integrated in a conventional noise attenuating nacelle. The open rotor noise is to a great extent caused by the interaction of the wake of the forward propeller with the aft one. Also the weight of the open rotor engine and the reduced fan efficiency caused by exposure to the full flight speed, somewhat counteract the improved propulsive efficiency.

A propeller blade, just as an aircraft wing, generates a tip vortex, which is associated with the blade's induced drag and also contributing to increased noise when interacting with the aft propeller. It is well known that winglets and double wings joined at the tip (box wings) can reduce the tip vortex local strength and also decrease wing induced drag. Further, by analogy to a wing, a forward swept propeller may enjoy a tip flow less compromised by boundary layer effects. For a counter-rotating propeller pair the increased axial separation between the tips of the forward and rear propeller reduces the strength of the forward blade wake where it arrives at the rear blade. However, forward swept, thin bladed propellers are prone to aerodynamic instability and flutter.[1]

To exploit these improvements to propeller aerodynamics a double bladed high speed propeller has been proposed, see figure 1.[2]

The double, tip-joined, blades are stiffer and may allow a forward swept design without flutter. By suitable shaping the blades centrifugal force is carried by tensile stresses, avoiding excessive bending. An initial design study shows that the stacking line therefore must approximate a rotating catenary. To avoid a bending moment in the blade stub shaft, the inner portion of the blade must have rearward sweep smoothly changing to a forward swept outer portion.

For a counter-rotating propeller pair various combinations of forward and rearward sweep, simple and joined-blade propellers are possible.

The properties of a joined-blade propeller are still relatively unknown, and there are both aerodynamic and mechanical issues which need to be understood to assess its development potential.

A proof-of-concept investigation has started to develop a geometric layout algorithm, as well as mechanical and aerodynamic analysis.

[1] Woodward, R, et. al., Takeoff/Approach Noise for a Model Counterrotation Propeller with a Forward-Swept Upstream Rotor, NASA Technical Memorandum 105979,AIAA-93-0596

[2] Avellán R, Lundbladh A., Air Propeller Arrangement and Aircraft, International application published under the patent cooperation treaty, WO2011/081577 A1, 2011.

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Development of a preliminary design method for hybrid propulsion aircraft

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Keywords: *diesel, hybrid propulsion, aircraft sizing, Weight Fractions Method*

Abstract

Standard design procedures are not readily applicable to aircraft that use multiple energy sources; innovative concepts like hybrid propulsion systems require new approaches in weight and performance prediction. Therefore, developing green propulsion concepts for aviation requires changes in standard procedures for the preliminary aircraft design.
In this paper the application of a new methodology to account for the changes in the governing equations when using hybrid propulsion is explored.
The focus is on hybrid propulsion systems based on diesel heavy fuel ICE (Internal Combustion Engine) combined with electric motor in a parallel configuration. This study relies on simple structure and material performance indexes, neglects stability and control analysis, and uses simplified aerodynamic models.

1 Introduction

Aircraft environmental impact has emerged as a key factor in aircraft design. Since air passengers are projected to grow at a rate of 5 percent per year through 2020, aircraft design will require new solutions and concepts to meet environmental requirements: in this context "green design" paradigms should play a key role, in order to describe actions to reduce emissions and noise, defining green aircraft technologies.
In particular, environmental impacts from hydrocarbon fuels have adverse effects both on global warming and local air quality: this is leading to the introduction of cleaner energy sources and systems. Research on unconventional aircraft propulsion systems is now advancing, with the aim to reduce aircraft emissions and noise.
Hydrogen [1], [2], [3] solar energy systems [4], electric systems, fuel cells [5] and power management and distribution are currently the most investigated alternative energy sources for aircraft applications [6].
With the energy crisis still looming, initiatives such as More Electric Engine (MEE) and More Electric Aircraft (MEA) are promoted [6]: in this context hybrid combustion-electric power, helping in reducing fuel usage, is considered because of its potential advantages. Reduced emissions, increased performances (especially at altitude, since air density does not affect electric motor performances), lower operating costs, increased safety due to redundancy, reduced risk of explosion or fire in the event of an accident

Novel Pulse Detonation Engine Concept

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Abstract:

The presentation introduces the ongoing research efforts carried out by the National Research and Development Institute for Gas Turbines COMOTI, in collaboration with the Von Karman Institute of Fluid Dynamics, the Technical University of Lund, and the Academy of Sciences of Moldova, towards developing a new, breakthrough, high speed propulsion technology based on the principle of pulsed detonating combustion.

The central idea of the investigated propulsion technology is the replacement of the gas turbine in a typical aviation engine of today by a simpler and at least as effective system. The advantages of the approach are multiple: a decrease in engine weight, size and cost, as well as an increase of the maximum temperature downstream of the combustor, due to the removal of the turbine blades, allowing for higher engine performances.

The concept uses the conservation of impulse for the combustor exhaust jet released tangentially, to rotate the entire combustor assembly. The combustor assembly contains several can combustors rotating together and connected together through a disk to a central shaft and enclosed in a stationary pressurized shroud. The shaft of the combustor assembly is connected, and provides power, to a compressor upstream of the combustor that provides pressure to the combustor shroud. The remaining energy will be used to power the aircraft. The typical approaches to extract this energy are via a propeller connected, possibly through a gear box, to the main shaft, via a main exhaust nozzle that collects the flow from the combustors re-axialize it, and accelerates it to provide reactive thrust, or via a combination of the two. If the propeller solution is used, like in a turboprop, after the momentum transfer to the rotating combustor assembly, the low kinetic energy, high pressure jet is collected into an exhaust chamber, connected to a nozzle that further extracts the potential energy from the burned gas, providing additional thrust for the aircraft, such that a full expansion of the exhaust gas is achieved. The solution has the disadvantage of requiring the addition of a gearbox, to match the optimal propeller speed and the speed of the compressor and of the rotating combustor disk. If the reactive nozzle solution is preferred, like in a turbojet, the losses incurred through the re-axialization of the flow are higher. To diminish them, the fraction of the energy transferred to the shaft can be controlled through the shape of the rotating combustor nozzles, and the direction of the jet exiting the combustors. Thus, as the jet direction is closer to the axial direction, the tangential impulse transmitted to the central shaft decreases, up to a point where only the energy required to balance the compressor work is converted into rotational speed. The remaining energy, both potential (pressure) and kinetic (velocity) is extracted from the flow by means of the engine exhaust nozzle.

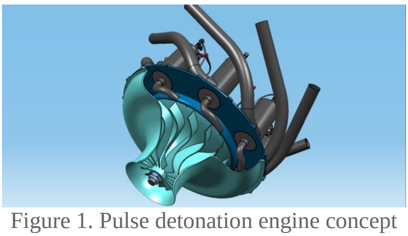

Figure 1. Pulse detonation engine concept

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Numerical Criterion to Optimize the Performance of a Gas Turbine Combustor

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Keywords: *Combustor, Performance Optimization, Emission*

Abstract

This paper considers different performance parameters of a gas turbine combustor simultaneously and introduces a single numerical criterion, with weighing coefficients, to optimize its overall performance. Four main performance parameters have been selected to be included in this criterion to demonstrate the concept. These are combustion efficiency, combustor exit temperature pattern factor, overall pressure loss ratio and emission levels of NO_x. A single can combustor is simulated and ANSYS® is employed to carry out this parametric study.

The criterion is able to identify the ideal optimum design point of gas turbine combustor and to exclude combinations of parameters that result in an unacceptable value for any of the selected performance indices.

1 Introduction

The gas turbine combustor is a complicated system and many factors characterize its performance. Some of these factors include overall pressure loss ratio, combustion efficiency, exit temperature pattern factor and emission levels of NO_x. Other requirements for good performance, such as stable combustion, good re-light capability and a wide range of operating points, may be added to the above set. Also, emission levels of CO, and unburned hydrocarbons may be added to satisfy environmental requirements.

Design and development of combustors today involve extensive use of empirical correlations, component development tests and Computational Fluid Dynamics (CFD). Amongst these, CFD is the least expensive method for performance optimization. Furthermore, it becomes reasonably accurate and reliable, especially with the computational power available today.

A numerical study was conducted to determine the effects of fuel spray characteristics on combustion efficiency and overall temperature distribution factor at the exit of the combustor using the KIVA-3V code [1]. Another numerical study investigated the effects of combustor-diffuser flow interaction on pressure drop, temperature pattern factor, and combustion efficiency [2]. A more recent experimental study assesses the effects of fuel temperature on combustion efficiency, stability, and NO_x and unburned hydrocarbon emissions [3]. All the mentioned studies and similar researches determine trends of performance

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Set-based compressor design method accounting for efficiency and stability

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Keywords: *set-based, design, optimization, compressor, CFD*

Abstract

Ever growing environmental requirements on emissions and perceived noise levels as well as the desire to reduce specific fuel consumption are the major drivers in the development of aircraft engines. The general way of increasing efficiency of turbofan engines is to increase component efficiencies, bypass ratio and overall pressure ratio while keeping the engine weight low. Concerning the low pressure system, the reduction in weight can be realized by decreasing the number of stages in the compressor while keeping the total pressure ratio constant. This leads to an increased aerodynamic load per stage which makes it more difficult to maintain a high efficiency at the aerodynamic design point while keeping a sufficiently high stability margin along the compressor working line. The conventional blade design philosophy has been focused on high efficiency at one design point, however as stability are critical for meeting modern compressor requirements there is a need to extend the blade design process to also account for off design performance such as part speed. As a consequence, more computational resources are required and the total design time may increase. In this work a set-based design method for compressor stages are presented where a balance between stability at part speed and efficiency at design point are sought for rather than purely a compressor with high efficiency. Response surfaces and low complexity modeling are used prior to the 3D optimization in order to accelerate the total design time. The method makes use of a global optimization algorithm where the end result is an optimal set of compressor stages, i.e. a pareto-front, which shows the trade-off between efficiency and stability. Thus, the designer has the freedom of selecting an appropriate balance between the two objectives. Furthermore, if any aerodynamic or geometrical requirement is changed during an ongoing project, the pareto-front and its underlying database can be used to efficiently find a valid alternative design. Examples will be shown where the design method has been used to improve aerodynamic performance of a compressor originally designed by GKN aerospace engine systems. It is also shown that the method is capable of designing stages that is well matched with the flow conditions occurring in the multi-stage environment.

LIF experiments in a turbulent reactive flow using an afterburner

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The paper presented here presents Planar Laser Induced Fluorescence “PLIF” measurements in a premixed methane-air turbulent flame in afterburner system installed on a gas turbine engine. The PLIF measurements are based on capturing the fluorescence of Hydroxyl (OH).

The postcombustion system used here was designed and manufactured at INCDT - COMOTI and was installed behind a Garrett 30-67 gas turbine engine used as a gas generator. The PLIF measurement installation is briefly described in figure 1:

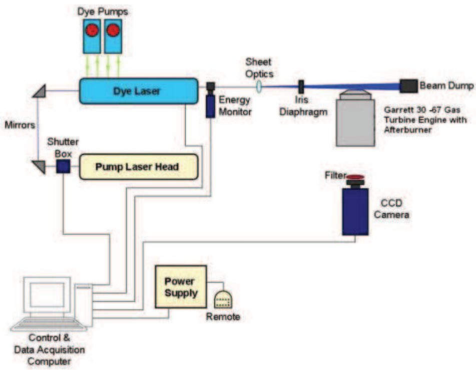

Fig. 1

The PLIF can by briefly explained in a few sentences: the LASER radiation is tuned to specific wavelengths and will excite certain species (molecules), in our case OH, to a higher energy level. Fluorescence occurs when this excited state decays and emits radiation of a longer wavelength than the incident laser radiation. Quenching is negligible and the fluorescence signal is proportional to the OH concentration. The colors of the images captured using the LIF system represent absolute concentrations of OH and not just relative fluorescence intensities.

From the very beginning it should be mentioned that the OH radical is a chemical species that is created and destroyed very quickly in the combustion process. For this reason, its presence can be detected only in flame front, providing a very accurate indication of its position. As shown in Figure 2, the average flame position coincides with recirculation area which is formed downstream of the flame holder. It may be noticed, also, the phenomenon of "turbulent brush". In other words, the average thickness of the flame front is much larger than its instantaneous thickness. This phenomenon arises because of intermittent turbulence, which makes a specific

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C^*-Efficiency Evaluation of Transpiration Cooled Ceramic Combustion Chambers

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Keywords: Ceramic Combustion Chamber, Transpiration Cooling, Characteristic Velocity

Nomenclature

a	Sonic velocity, m/s
A	Cross section area, m^2
c^*	Characteristic velocity, m/s
C_F	Thrust coefficient
d	Diameter, m
F	Thrust force, N
g_0	Gravitational acceleration, m/s^2
I	Specific impulse, m/s
k_T	Transpiration cooling coefficient
l	(Chamber) length, m
l^*	Characteristic chamber length, m
$\dot{m}$	Mass flow, kg/s
p	Pressure, Pa
R	Mass mixture ratio (oxidizer to fuel)
V	Volume, m^3
η	Efficiency
ρ	Density, kg/m^3
τ	Coolant ratio

Subscript

0	Initial, injection
c	Chamber
e	Exit (nozzle)
fu	Fuel
id	Ideal
k	Coolant
ox	Oxidizer
t	Throat (nozzle)
vac	Vacuum

Abstract

Achievable benefits of the transpiration cooled ceramic thrust chamber are the reduction of weight and manufacturing cost, as well as an increased reliability and higher lifetime due to thermal cycle stability. The transpiration cooling principle however reduces the engine performance. In order to evaluate the performance losses a c^*-analysis is performed.

Due to the transpiration cooling the characteristic velocity decreases with increasing coolant ratio. The goal of the chamber development is therefore to minimize the required coolant mass flow.

The paper discusses the test specimen set up for the ceramic thrust chamber tests. Chamber operating parameters are listed. The paper discusses the impact of transpiration cooling on the calculated c^* efficiency. The evaluation is based on test results with the ceramic combustion chamber conducted in four separate test campaigns between 2008 and 2012.

1 Introduction

The transpiration cooling principle, while slightly reducing the specific impulse, highly increases chamber wall lifetime. Furthermore, depending on the ceramic materials used in thrust chamber construction, it is possible to substantially reduce the engines mass and manufacturing cost, compared to that of metallic engines. A small fraction of propellant is routed

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BioJet Fuels & Space Plug-and-Play Avionics - Two Current Projects within the Swedish Defence Materiel Administration, FMV

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FMV

The Swedish Defence Materiel Administration, FMV - first established in 1630 - designs, develops and procures materiel for the Swedish Armed Forces. This presentation covers two current projects run jointly by FMV, the Swedish Defence Research Agency (FOI), US Air Force Research Laboratory (AFRL) and industry – BioJet Fuels for military applications and Space-Plug-and-Play Avionics.

The BioJet Project

FMV has an assignment from the Swedish Government to establish a bilateral collaboration with the USAF/AFRL in a BioJet demonstration program. The program involves testing and demonstration of a third generation bio-based alternative military jet fuel of type Alcohol To Jet (ATJ). FMV plans contracts with Swedish and US aerospace industries and BioJet fuel manufacturers. The final goal is to perform flight demonstrations with a JAS 39E Gripen aircraft with the GE F414 engine.

The Swedish Armed Forces strive to find new solutions for future jet fuels, supporting government goals to protect the environment and secure supplies. Alternative fuels for transportation has been an important topic for several years and the potential for alternative jet fuels for military and commercial aviation has recently grown.

The FMV presentation will give an insight into different types of alternative jet fuels and the technical challenges in the qualification process and the production of alternative fuels.

Space Plug-and-Play Avionics (SPA)

Robust miniaturized electronics and plug-and-play technology are key factors in order to reduce weight and volume and enable rapid development of applications for the aerospace and other systems, such as unmanned aerial vehicles (UAV), unmanned ground vehicles (UGV) etc.

SPA is defined as an interface-driven set of open standards, encompassing hardware, software, and protocols, intended to promote the rapid affordable design and integration of advanced system buses and payloads.

On August 28th 2009, the United States and Sweden signed a bi-lateral project agreement to work on nanosatellites and SPA in the "NAPA"-project (Nanosatellite Plug-and-Play Architectures), in which FMV, FOI and ÅAC Microtec AB represent Sweden.

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Sustainable Alternative Fuels for Aviation: International Emission Targets vs. Corporate Sustainability Aspirations

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Keywords: alternative fuels, sustainability criteria, supply chain management, risk management, corporate responsibility

Abstract

Alternative fuels are seen as a major enabler by the aviation industry to achieve its emission reduction goals in the coming decades. However, vast quantities are needed, potentially leading to significant social and ecological side-effects. This situation is aggravated by the multi-tiered character of most alternative fuel supply chains. Respective fuels are sourced and produced by a multitude of providers in various regions around the globe, affecting a wide range of stakeholders. As such, although the final users are seen responsible for the sustainability of "their" alternative fuels, they can hardly guarantee that no impacts were incurred along the process. Therefore, an active sustainable supply chain management is needed to address the root-causes of inter-organizational sustainability issues. In this context, following an introduction of the role and challenges of biofuel for aviation's emission targets, a structural framework is used to discuss the corporate role in ensuring the sustainability of alternative fuels. Findings imply, that much more intense partnerships along the supply chain from the airlines down to agricultural players are needed, making the aviation industry jointly responsible to help improve structural and individual supplier capabilities for a sustainable alternative fuel production. Taking these developments into account we propose a change towards more industrial vertical integration as this would facilitate the provision of sustainable jet fuel.

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Coupled CFD simulation of gas turbine engine core

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Keywords: *CFD, gas turbine engine core, coupled simulation, operating*

Abstract

The experience in gas turbine engine core's workflows simulation using modern computational fluid dynamics is described in the paper. The capabilities of software for coupled simulation of gas turbine engine core workflows are shown. Advantages and disadvantages of the methods used are pointed out. The results of coupled CFD simulation of simplest gas turbine engine in single software package are given. It is shown that the results of the coupled CFD simulation are in good agreement with the results of calculation using calibrated one-dimensional thermodynamic model.

TRANSONIC COMPRESSOR FLUTTER RESEARCH WITHIN THE FUTURE PROJECT

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ABSTRACT

Flutter in jet engine and gas turbine compressors is one of the major problems facing the blade designer. Methods development is continually delivering improved methods that allow the inclusion of new physics. In particular with new and advanced methods the need grows for experimental validation that is adapted for the method. In the European framework program the FUTURE project is dedicated to flutter, and as part of this one work package addresses the objective of validation on a transonic research compressor. In the present paper an overview of the performed work within the transonic compressor work package is given together with a synthesis of the main results.

The objective of the work is to enhance the physical understanding of engine relevant compressor flutter and to generate experimental data on a rotating 1 ½ stage compressor rig to improve flutter design rules and prediction methods. The aim is to take a significant step forward from towards more realistic experiments. The focus is on flutter with real mode shapes and IGV-rotor and rotor-stator interactions in a rotating environment. In contrast to a common design objective, to design for avoidance of flutter, a rotor blisk was specially designed to allow for a rotor-blade flutter within the operating domain of the compressor. Both a free flutter test campaign as well as a forced response test campaign where defined. Free flutter tests gives a direct determination of the flutter limit as function of operational conditions. The free flutter experiments are complemented by forced response experiments to assess the aero damping characteristics at stable operation using a novel excitation system developed as part of the research work. Aerodynamic damping and the prediction of aerodynamic damping is an important part also of the assessment of the dynamic strain on the blades resulting from excitation. The use of the excitation system allows measurements in a wider range of running conditions, and data at extended operation that may be inaccessible in free flutter regions.

To assess the aerodynamic damping from the measured total damping there is need for a well determined mechanical damping. Hence, a state-of-art method previously developed with the support of European Community in ADTurB II was re-used and adapted to measure mechanical damping of the blisk under rotation. The insight gained from this mechanical characterization is in itself an important and unique result from the project.

The data gained from the two compressor test campaigns in conjunction with the data from the mechanical characterization will provide valuable insight to the parameters controlling flutter in an engine relevant environment and also directly give a measure of the reliability of the flutter prediction methods used in the design of the rotor.

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Efficiency improvement of a multistage compressor by optimization stagger angles of blade rows

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Igor N. Egorov
Sigma Technology, Russian Federation

Keywords*: optimization, CFD, gas turbine engine, compressor, blades*

Abstract

Modern computer technologies now allow to conduct rather complex numerical calculations in a relatively short period of time. Thus, it has become possible to employ optimization methods in the design of various parts of gas turbine engines.

The results of two optimization tasks of seven-stage high pressure compressor are presented in this paper. The goal of the first optimization task was to improve the compressor efficiency at one operating mode (100% rotation frequency) by optimizing the blade stager angles of the guide vanes of the three first stages. As a result of solving this task, the HPC efficiency increase by 0.3% was achieved at required rotation frequency. This result was confirmed by experimental test.

The goal of the second optimization task was to improve the compressor efficiency at two operating modes (80% and 100% rotation frequencies) by optimizing the blade stager angles of all blade rows. As a result of solving this task, the HPC efficiency increase up to 1.2% was achieved at required rotation frequencies.

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Numerical simulations of two-phase turbulent reactive flows

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Keywords: *3D RANS, ANSYS CFX, combustion chamber assembly, Jet-A*

Abstract

In order to develop a new multiple-fuel combustion chamber, a series of numerical simulations has been conducted on an existing combustion chamber, in order to determine the modifications required to allow its proper operation for multiple liquid fuels and fuel mixtures. The combustion chamber used in the simulations comes from a Garrett gas turbine engine, model GTP 30-67. A three-dimensional unsteady RANS numerical integration of the Navier-Stokes equations has been carried out, using an Eddy Dissipation combustion Model (EDM) and the k-ε turbulence model, implemented in a numerical simulation conducted using the commercial software ANSYS CFX. To verify the numerical simulations accuracy, the outlet temperature has been recorded along 600 time-averaged iterations and compared with the designed turbine inlet temperature. Numerical simulations results have a good accuracy in this particular case, so it can be concluded that the used numerical models are valid and appropriate for use to simulate the combustion process under different conditions. Thus the results obtained in these simulations will help adapt the existing combustion chamber to different fuels and fuel mixtures.

1 Introduction

In order to develop a new combustion chamber, a series of numerical simulations have been conducted on an existing combustion chamber, in order to determine the modifications required to allow its proper operation for multiple liquid fuels and fuel mixtures.

The combustion chamber used in the simulations comes from a Garrett gas turbine engine, model GTP 30-67. Garrett GTP 30-67, a shaft power gas turbine engine, is a compact, lightweight, shaft power source which is readily adapted to fit various types of enclosures and installations. The engine provides a mounting pad and drive shaft for installation and drive of an AC generator. The ambient air is compressed by a single stage centrifugal compressor, mixed with fuel in the combustion chamber and the mixture's ignited. The resultant high energy gases drive a radial inward-flow turbine wheel. The rotating shaft power of the turbine wheel drives the compressor impeller and an accessory gear train to provide reduced rpm shaft power. The remaining power is the engine power output. This gas turbine was used mainly to

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Numerical evaluation of combustion chamber performances for an aircraft engine

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Extended abstract

Today's aircraft propulsion systems have been vastly improved in many ways over the years, but they have remained essentially unchanged in terms of their basic design and operation.The thrust of the present aircraft engine is developed by compressing air in the inlet and compressor, mixing the air with fuel, burning the mixture in the combustor and expanding the gas stream through the turbine and nozzle. The expansion of gas through the turbine supplies the power to turn the compressor. The net thrust delivered by the engine is the result of converting internal energy to kinetic energy.

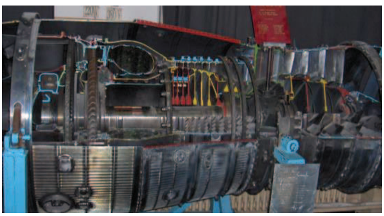

Fig. 1

The main part of a gas turbine engine is the gas generator, whose major components – compressor, combustor and turbine – are common to the turbojet, turbofan, turboprop and turboshaft engines (fig.1).

*The **main focus of this paper** is to find a new configuration of aircraft engine, namely an engine with two main combustion chamber (fig. 2), one on the same position like in classical configuration, between compressor and turbine (combustion chamber no. 1) and other situated after turbine but not with the role of afterburning, (combustion chamber no. 2).*

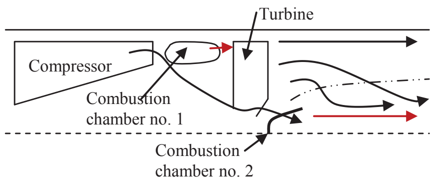

Fig.2

The advantages of this solution are:

- *a higher thermodynamic cycle efficiency and thrust in comparison to traditional constant-pressure combustion gas turbine engines. The most far-reaching applications would be to merge the strengths of current gas turbine in a hybrid propulsion system.*
- *the possibility to increase the pressure ratio of turbine by extracting the flow stream after turbine in the inner nozzle;*

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A unified method of identification and optimization of airfoils for aircrafts, turbine and compressor blades

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Keywords: *airfoils, design optimization, combinatorial-cyclic method, turbine engines.*

Abstract Topics below are rather undesired, but important, outcome not yet completed research on the aircraft airfoils, turbine and compressor blades, parametric design of airfoils, establishing the relationships based on the results of experiments in a wind tunnel, developing databases for determining the relationships between airfoil parameters and lift and drag coefficients. Reliable database created as a result of the research work allows to simulate the wind tunnel. Very early on, however, was necessary to extend the developed specialized software for a new applications, and it meant the need for generalization of software, e.g. for gas turbine engines, propellers, etc. But after some time it turned out, that in order to achieve the required accuracy, the changes are needed in the underlying assumptions, set decades ago. In addition, coordinate measuring machines and systems, and associated software were not always as accurate as expected. Concepts how to solve it and develop software carrying out these tasks are presented in the article. It is like to withdraw from the old path and look for a new path that will lead to the reliable data base. Processes related to air or gas flow should be similarly defined in all the specialized software applications (e.g. aircrafts and turbine engines). Accuracy (10^{-9}mm) achieved in virtual measurements within the integrated system can be used to verify the results of CMM and other measuring systems, provided that an appropriate software has been developed.Over the last two decades, passenger and military aircrafts, became a fully high technology products, and design, engineering, manufacturing of these aircrafts is carried out entirely within integrated CAD/CAM/CAE systems. It should be emphasized that in these systems, all the tasks related to the definition of the geometric shape of the structure are realized by Nurbs geometry concepts. Because this geometry can define all surfaces, and solids that occur in engineering practice, therefore, the software-based identification and optimization of even the most complex shapes have become feasible, at least, by a virtual prototyping approach. There is a meaningful difference, as far as time-consuming factor is concerned, whether an interactive mode is used or program-oriented definition of any engineering problem, described by using a build-in basic system language (e.g. GRIP in Siemens NX system, updated APT, etc.). Such a programming is becoming the necessary qualification for engineers of high technology products, particularly, when the highest quality, optimization, CNC manufacturing, and reverse engineering are of a primary concern.

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The Attitude and Orbit Control System on Solar Orbiter

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Keywords: *Space probe, scientific, Sun, observation, ESA*

Abstract

Solar Orbiter is the first mission in ESA's Cosmic Vision programme to start its implementation phase and is scheduled for launch in 2017. The mission lifetime will be 7 years. Solar Orbiter will study the Sun in detail and its effects on the solar system. The spacecraft will carry a suite of complementary instruments that will measure the particles, fields and waves of the plasma through which it travels, and at the same time make observations of the Sun's surface and outer atmosphere, the photosphere and corona. Figure 1 shows an impression of the spacecraft observing the Sun.

In 2012, OHB Sweden was awarded the contracts for both the Attitude and Orbit Control and Propulsion subsystems on Solar Orbiter.

This presentation provides an overview of the Attitude and Orbit Control System on Solar Orbiter. The development is challenging in many respects.

The Solar Orbiter will go closer to the sun than any other man-made object and will come as close as within 28% of the Earth-Sun distance. During its mission, it will be obstructed by the sun during long periods of time. In addition, the transfer into its operational orbit includes an intricate trajectory with several planned gravity assist fly-by maneuvers of both the Earth and Venus. All these preconditions put very high requirements on advanced safety and autonomy functionality that needs rigorous verification during the development of the AOCS.

The presentation provides an overview of the Solar Orbiter AOCS system including its architecture, functionality, design, development and verification approach and its industrial organisation.

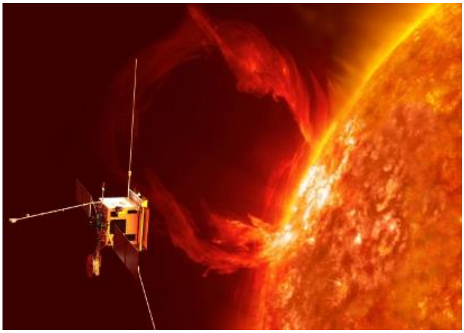

Fig. 1 Artist's impression of Solar Orbiter observing the Sun *(Image: ESA/AOES).*

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The PRISMA Formation Flying Mission

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Keywords: *Formation Flying, Rendezvous, Autonomous, GPS, Vision Based*

Abstract

PRISMA consists of two spacecraft: Mango and Tango. The Mango spacecraft is 3-axis stabilized and has a propulsion system providing full 3D orbit control. Tango is 3-axis stabilized with a solar magnetic control system without orbit control capability. The two spacecraft were launched clamped together into a 700 km SSO and Tango was successfully separated from Mango on August 11, 2010. This marked the start of a one-year mission of nominal experiments within the area of formation flying and rendezvous, followed by an extended mission phase which was completed by February 2013.

PRISMA demonstrates technologies for formation flying and rendezvous. OHB Sweden is the prime contractor for the project which is funded by the Swedish National Space Board with additional support from DLR, CNES, and DTU. The mission includes flight qualification of several sensor and actuator systems and in-flight execution of a range of GNC experiments using this equipment. The spacecraft are equipped with Vision Based, GPS, RF-sensor navigation systems and have three different propulsion systems. Apart from OHB Sweden's GNC experiments, the propulsion manufacturers (ECAPS, NanoSpace) and the participating organizations DLR, CNES, DTU act as experimenters in the mission.

PRISMA has successfully demonstrated all of its primary and secondary goals. This presentation gives an overview of the achievements made with focus on the results obtained within the formation flying experiments under OHB Sweden responsibility. As an example, Figure 1 shows Tango from 6 m distance during one of the experiments. The picture was obtained with the on-board video system.

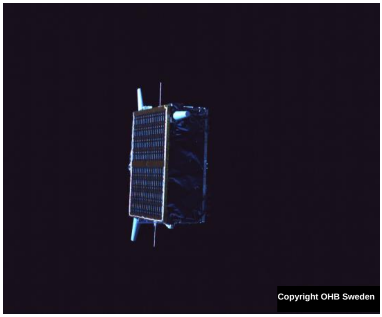

Fig. 1 Tango seen by the DVS on Mango at 6 m.

In April 2013, the Mango spacecraft started a one and a half year long journey towards another target object to demonstrate rendezvous and inspection within the IRIDES experiment (Iterative Reduction of Inspection Distance with Embedded Safety). Tango was shut down permanently and Mango initiated a series of optimized orbit manoeuvres in order to put the spacecraft on a drift towards the new object. The rendezvous is expected in the second half of 2014 and will demonstrate optical relative navigation and the characterization of the rendezvous object and its motion. The rendezvous strategy within IRIDES includes a series of safe drift manoeuvres passing the rendezvous object successively reducing the closest relative distance. The demonstrated technologies for this rendezvous are believed to play an important role in future developments associated with space debris mitigation. The presentation will also provide a brief overview of this experiment.

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Feasibility Study of small Satellite Launcher Vehicle launched from atmospheric Carrier Aircraft

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Keywords: *Space Vehicle, carrier aircraft, air launch*

Abstract

The paper deals with the feasibility study of an air-dropped small satellites launcher vehicle. A conceptual design methodology has been defined and then applied to various case-studies, in order to evaluate the main flight, mission and system performances of the unconventional space vehicle (SV) that may be either launched from a supersonic fighter aircraft or from a subsonic cargo aircraft. The SV concept presented is a fast and affordable solution able to access space from any sites of the world in all weather conditions. It is a missile-like solution able to inject in Low Earth Orbits a small payload (mass lower than 200 kilograms) in a few hours, through a low cost mission. At the beginning, the paper presents a short investigation of traditional European space launch capabilities, highlighting the lack of dedicated transport solutions for Nano and Micro-satellite families and proceeding with the analysis of the state of the art of new concepts of unconventional launch solutions. The paper then describes the conceptual design methodology developed, used to accomplish the feasibility study of the SV. This proposed methodology has been translated into a flexible numerical program in Matlab® language, which allows evaluating the main flight and system performances of the SV, after being dropped from its carrier aircraft. The most promising design alternatives, which may be air-dropped either in subsonic or in supersonic flight regimes, are finally described and shown in the paper. Eventually main conclusions are drawn.

1 Introduction

Generally, the ability to insert a limited payload mass in Low Earth Orbits (LEO) from an air-dropped spacecraft is extremely interesting and stimulating for the aerospace research community, especially for small satellites developers. Space is playing an increasingly important role in the leverage and execution of military, scientific and civil protection missions. For these reasons since the last few years the increasing demand and consolidated capability of accessing space have been generating a high request for affordable, strong, continuous, and flexible space access solutions. The "help from space", in general the need to use space technologies and space systems, is typically required for particular events sometimes defined as hostile environments. In these circumstances the capability of inserting in a very short time a

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Guidance Systems for Sounding Rockets

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Keywords: *Boost Guidance Systems, TVC, Canard, Cold gas.*

Abstract

RUAG Space has a long history of guidance systems for sounding rockets. In total more, than 240 sounding rockets have been guided with a system by RUAG Space AB.

1 S19

S19 Boost Guidance System is a family of guidance systems for sounding rockets. NASA launches typically five to ten sounding rockets every year guided with S19 from White Sands Missile Range in New Mexico, USA. The purpose of using a guidance system is that the impact dispersion can be reduced and the number of launch opportunities are increased since the wind constraints are highly relaxed. The rockets are mainly used for solar, stellar and related deep-space research,

Typically, the S19 is used during the first 18 seconds of the flight or up to an altitude of 5-8 km. The rocket is controlled by measuring the attitude using the onboard gyro. The canards on the S19 module produce the control torques to guide the rocket. The sounding rockets reach altitudes of 200-450 km.

Several versions of the S19 have been used. The original system was analog and was later replaced by digital versions using rate-integrating gyros.

Figure 1: The very first S19 system.

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Time-Triggered Ethernet Communication in Launcher Avionics

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Keywords: *Time-Triggered Ethernet, launcher avionics*

Abstract

Experiences and results from using Time-Triggered Ethernet technology in two studies on launcher avionics are presented. In the first study, a protocol implementation in software was used, with an evaluation system using COTS hardware. In the second study, a Time-Triggered Ethernet IP block was integrated within a system-on-chip in an FPGA.

1 Introduction

Current European launchers Ariane5 and Vega have similar avionics architectures resulting from work performed in the late 1980-ies. The main principle is a flight control system based around a MIL-STD-1553 data bus and an independent telemetry system having local communication links. The operation life time for this avionics architecture will be more than 25 years, from first launch in 1995 with last launch after 2020.

The next generation launcher, Ariane6, is planned to be operational before 2025. For this launcher a new avionics concept with higher performance and lower cost is envisaged. One of the main methods to reach the cost objective is to integrate several functions in the same hardware, for instance by using the same computer and network both for flight control and telemetry. Fig. 1 below shows a possible avionics configuration for a launcher with such a common network.

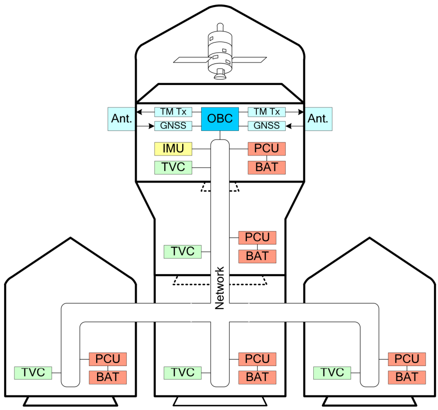

Fig. 1 Tentative launcher avionics configuration

The baseline configuration selected for Ariane6 will be a three-stage vehicle. The lower stage consists of three motors with 135 tonnes of solid propellant. The second stage has one motor, which is identical to the bones in the first stage. The upper stage is based on the Vinci cryogenic engine. Finally there will be a 5.4 m diameter fairing that provides the same volume for satellite payloads as the Ariane5 launcher. Ariane 6 is targeted for a payload capacity of 3 – 6.5 tonnes while Ariane5 can handle payloads of more than 10 tonnes.

The motor control will be electric and thus there will be batteries and power control units in all stages, feeding power to the main thrust vector control units and the rest of the avionics.

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Environmental impact assessment of the PROBA 2 mission

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Keywords: *Life Cycle Assessment, hybrid LCA, Input Output database*

Abstract

A Life Cycle assessment (LCA) of the PROBA 2 satellite mission was performed in order to elaborate a methodological framework and database for ESA space missions and to identify environmental hot spots of the PROBA 2 mission from a life cycle perspective.

The LCA model which we applied for the space mission uses a combination of physical and cost data in a so called hybrid LCA. Physical data were derived from an LCA (process) database, while cost data were used from an Environmentally Extended Input Output (EEIO or IO) database. LCA databases contain products and processes with the related environmental flows, such as emissions and use of energy. The units in an LCA database can be mass (product) or distance (transport). Input-output databases describe the sale and purchase relationships between economic sectors (agriculture, industry, services) within an economy and link them to the environmental flows resulting from these activities. Monetary units such as Euros or dollars are used to express the environmental flow per economic sector.

Modelling the environmental impact of man-hours in high-tech contexts with LCA databases is very time consuming and still might cause an underestimation of their impacts. Therefore, the environmental impact of man-hours is modelled with IO data.

The results of the hybrid LCA show that, when the launch is not taken into account, the environmental impact of the PROBA 2 mission is mostly generated in phase C & D (production, verification and testing). The contribution of phase E1 (launch preparation and commissioning) and B (design) to the total impact of the mission is also significant. The remaining phases, A (design) and E2 (use), have a minor influence on the environmental profile.

For the PROBA 2 mission excluding launch, the impact on climate change is ten times higher for the hybrid LCA than for the process-based LCA. The results are similar for all other impact categories for which all resources and emissions are included in the IO database (radioactive emissions, some toxic emissions, some specific metals and land use data are not included in the US IO database).

This study indicates that using only easily retrievable process-based data may lead to an underestimation of the environmental impact of a space mission.

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SKYLON D1 Performance

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Keywords: *SKYLON, upper stage, mission strategies)*

Abstract

For over 20 years Reaction Engines Ltd. (REL) studied the design of a Single Stage to Orbit (SSTO) reusable launch vehicle with a fixed take-off mass of 275 tonnes – SKYLON C1. The take-off mass was fixed for historical reasons (from the HOTOL programme) and the payload mass was allowed to vary as the project progressed, culminating with the result of a 10.25 tonne payload into a 300 km, low inclination, circular orbit.

Since 2010 REL have been working on their final design – SKYLON D1. The design requirement for this vehicle is very different – a SSTO reusable launch vehicle with a payload of 15 tonnes to the standard LEO orbit - having been derived from REL market analysis between 2005 and 2010. In 2012 REL started work to evaluate this system in the context of a European market, and the interim results of REL analysis are reported showing that payloads into GTO of 6.4 tonnes can be achieved with a fully reusable system and when combined with onboard electric propulsion on station masses of 5.6 tonnes.

1 Introduction

For 30 years engineers in the UK have investigated the design, manufacture and operation of a reusable spaceplane, that would operate from a runway and deliver and retrieve payloads to and from Earth orbit. The premise for this work has been that a Reusable Launch Vehicle (RLV) will always be more cost effective than an expendable launch vehicle in the medium to long term, and that a Single Stage To Orbit (SSTO) RLV will always be more cost effective than a two stage to orbit RLV system providing it has a reasonable payload fraction.

2 Background

Work on the SSTO / RLV concept started in the 1980s with the British Aerospace / Rolls Royce HOTOL project (see Figure 1)[1]. This was a concept for a SSTO spaceplane powered by a combined cycle, pre-cooled, airbreathing rocket engine that transitioned to pure cryogenic rocket propulsion at Mach 5 in order to complete its ascent into orbit. At the time a payload of 7 tonnes into low inclination, Low Earth Orbit (LEO) was targeted, and in order to standardise the design process a Gross Lift Off Mass (GLOM) of 275 tonnes was fixed, and the payload allowed to vary from one design iteration to the next. In the 5 year lifetime of the project the best calculated payload performance of HOTOL was estimated to be about 5.5 tonnes.

Following the termination of the HOTOL project in 1989 a group of engineers, led by Alan Bond (the inventor of the RB545 engine used in HOTOL), formed Reaction Engines Ltd (REL), a company dedicated to act as a repository for the knowledge gained during the HOTOL project, and to improve the design. The new system, designated SKYLON [2 & 3], retained a GLOM of 275 tonnes but now

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ASTRODYNAMICS SYMPOSIUM (C1) Mission
Design, Operations & Optimisation (1) (6)

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FROM SMART-1 to ELECTRA - THE IMPLEMENTATION OF ELECTRIC PROPULSION IN SPACE

Abstract

In September 2003, ESA launched the lunar probe SMART-1 with OHB Sweden (at the time the Space System Division of Swedish Space Cooperation) acting as the prime contractor. Using a single electric thruster providing only 70 mN of thrust, SMART-1 traversed through the radiation belts under the worst solar storm conditions ever recorded to successfully reach the Moon in November 2004.

Five years later, OHB-Sweden developed the first European subsystem using only electric propulsion for station keeping maneuvers once on the geostationary orbit.

Nowadays this double legacy is an important contributor to the implementation of the Electra program, aimed at developing Europe’s first all-EP telecommunication satellite from transfer to end of life. Thanks to the significant propellant mass savings offered by electric propulsion, Electra will be able to host the same payload capability as traditional telecom satellites whilst achieving a much lower launch mass, thus offering an attractive concept to the end user.

The paper will discuss the challenges associated with the implementation of all-electric propulsion on telecom satellites, and explain how the experiences of SMART-1 and other relevant missions have contributed to Electra. The first Electra mission is planned to be launched in the 2017-2018 timeframe.

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Magnetic Satellite Attitude Control: analysis of ASRE design method under perturbations

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Franco Bernelli-Zazzera
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Keywords: magnetic, attitude, control, satellite

Abstract

This paper presents the results of a purely magnetic attitude control system designed for Low Earth Orbit satellites. The satellite control system is designed using a non-linear control technique based on the Approximating Sequence of Riccati Equations (ASRE). In this technique, the non-linear control problem of the optimization of a cost function is turned into an equivalent linear-quadratic and time variant problem introducing an iterative sequence. The behavior of the satellite is discussed under perturbations and model uncertainties. The simulations show a good performance under these conditions.

1 Satellite attitude dynamics and kinematics equations

The satellite attitude dynamics is[1]

$$I\dot{\omega}_I = -\omega_I \wedge I\omega_I + N \tag{1}$$

where ω_I is the angular velocity of the satellite expressed in the Body Coordinate System (pi) with respect to an inertial frame, I is the inertia matrix and N are the external and control torques. The control system is particularized for a nadir pointing aircraft. Therefore, the Local Vertical Local Horizontal (LVLH) reference frame is introduced as reference, because the three axes of this reference system are exactly the target attitude. Then, let A^{pi}_{lvlh} represent the transformation matrix from LVLH to the Principal Inertia (pi) axes frame and ω_{pi} the angular velocity of the spacecraft with respect to the $LVLH$ frame, so that assuming a circular orbit $\omega_I = \omega_{pi} + A^{pi}_{lvlh}\omega_{lvlh}$. Furthermore, as a full magnetic control is designed, ignoring perturbation effects, $N = m \wedge B$, where m is the magnetic moment generated by the magnetorquers and B is the magnetic field of the Earth in the principal inertia frame. Taking all of this in consideration, the dynamics are written as:

$$I\left[\dot{\omega_{pi}} + \left(\omega_{pi} \wedge A^{pi}_{lvlh}\omega_{lvlh}\right)\right] =$$
$$= -\left(\omega_{pi} + A^{pi}_{lvlh}\omega_{lvlh}\right) \wedge I\left(\omega_{pi} + A^{pi}_{lvlh}\omega_{lvlh}\right) +$$
$$+m \wedge B \tag{2}$$

On the other hand, the kinematic equation can be expressed using quaternions as [2]:

$$\begin{bmatrix} \dot{q_1} \\ \dot{q_2} \\ \dot{q_3} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} q_0 & -q_3 & q_2 \\ q_3 & q_0 & -q_1 \\ -q_2 & q_1 & q_0 \end{bmatrix} \cdot \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} \tag{3}$$

where:

$$q_0 = \sqrt{1 - q_1^2 - q_2^2 - q_3^2} \tag{4}$$

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Buckling and Modal Analysis of Rotationally Restrained Orthotropic Plates

Abajo D. and Villarreal E.

Keywords: *Buckling, Orthotropic Lay-Out, Dynamic Load Factor, Rotationally Restrained Plate*

Abstract

The results of this study have been performed at Aernnova Aerospace inside the European project DAEDALOS. The analysis is focused on the static buckling, modal analysis and vibration buckling of orthotropic plates with four-edges simply supported, rotationally restrained and linearly biaxial loaded.

The parametric solution of this problem allows making a more accurate initial sizing of typical aerospace structural components, like stiffened panels, where both static and dynamic buckling loads for composite structures are fundamental for the final design.

The parametrically restrained four edges allows a more suitable solution than known buckling curves of simply supported or clamped metallic plates. The obtained results show an important buckling factor gauge respect the simply supported plates due to rotationally stiffness.

Finally, the dynamic analysis of the problem shows the buckling factor gauge for load frequencies higher than the first natural frequency taking into account the initial plate imperfection.

1 Approximate Analysis

The approximate analysis carried out in this study is based on the general linearly biaxial loaded case shown in Figure 1. This analysis includes a static buckling [section 2.1], modal [section 2.2] and dynamic or vibration buckling analysis [section 2.3]. These analyses are carried out considering composite linear continuum mechanics [section 1.1], variation methods of the system energy [section 1.2] and solving the system of equations assuming shape functions as Ritz-method [section 1.2.2].

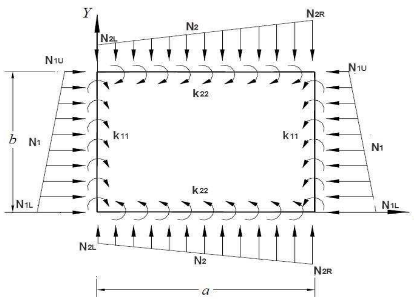

Figure 1: Model of Rotationally Restrained Plate

Modelling of the cyclic behaviour of superalloys

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ABSTRACT

In the aviation industry today there is a trend of increasing operating temperatures in turbine engines. The advantages with higher temperatures in the engines are improved performance and efficiency. During a flight cycle the engine components are exposed to cyclically varying thermal and mechanical loads, which might cause thermo-mechanical fatigue (TMF) of the material. For prediction of the TMF life it is important to have a material model that can cover the temperature range of interest for the analysed component. The material model should also capture the decisive material mechanisms active in the component during the flight. Therefore the constitutive model should be able to mimic phenomena such as cyclic hardening/softening, the Bauschinger effect, ratchetting, shake down, creep and stress relaxation.

The focus of this contribution is to investigate and develop modelling of cyclic plasticity phenomena observed for superalloys in low-cycle fatigue (LCF) experiments at different temperatures. For the modelling of the cyclic phenomena a Chaboche-type of material model, cf. [1], is chosen as a base model. Firstly, the mechanical behaviour of Ni-based superalloy Haynes 282 is studied using LCF experiments for room temperature and 650°C. The material model is calibrated and the robustness and uniqueness of the identified material parameters are ensured by performing sensitivity analyses. The base model is extended to include several kinematic hardening variables and it is studied how this affects its response. Furthermore, the influence of uncertainties in experimental data on identified material parameters, fatigue life predictions and finite element (FE) predictions is investigated.

Additionally, the base model is modified to account for the cyclic softening observed for Haynes 282 at high temperatures. The material model is then calibrated for a range of elevated temperatures (400-730°C) and a temperature dependence is established for the material parameters. The temperature dependence is validated against experiments with good results. An FE example is given to illustrate the consequences when including cyclic softening in the material model. The slow evolution of the cyclic softening requires many loading cycles to develop and therefore a technique for cycle extrapolation, cf. [2], is incorporated in the FE analysis to increase the efficiency of the computations.

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Tensegrity Structures for Aircraft Applications

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Keywords: *Lightweight structures, Tensegrity*

Abstract

By definition, tensegrity structures are a special case of trusses in which there are members designed for specific functions. Some elements can carry only tension loads (cables) and others can carry both tension and compression loads (bars).

This concept of structure is very used in modern art. One of the most known tensegrity artist is Kenneth Snelson, who became famous by the Needle Tower (Fig.1).

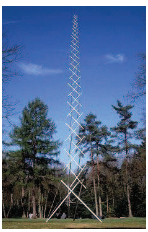

Fig.1 Snelson's Needle Tower.

As the figure shows, tensegrity structures are frequently very beautiful. Other important fact about this kind of structures is that they tend to be lighter in comparison to other kinds of structures.

This comes from the fact that some cables have high tensile strength, much higher than bars. Just as an example, some carbon fiber cables have rupture strength of about 5GPa.

This means that if well designed (so the whole structure is always stable), they can be very effective.

There are others benefits of tensegrity structures. Even for large displacements, they can still withstand with no permanent deformation in its members. Another advantage has to do with its ease of assembly.

One intrinsic characteristic of some tensegrity systems is the possibility of change of shape (morphing). One classic example of a movable tensegrity system is the human body. The

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Development of heat resistant composite structures within collaborative project SHEFAE

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Keywords: *Polymer composites, heat resistance, aero-engine, thermal management*

Abstract

The paper presents an overview of a collaborative R&D project, SHEFAE – "Surface Heat Exchangers For Aero-Engines" alongside with discussion on the efforts at Swerea SICOMP and GKN to support the project through development of a heat resistant Mount Composite Structure (MCS). Different available polymeric composite materials for high temperature applications are reviewed and presented.

1 General Introduction

Six partners (four European and two Japanese) are collaborating in SHEFAE with the objective to develop aero-engine thermal management technologies that enables improved overall structural efficiency and/or cooling for future engines. Surface air oil heat exchangers are integral feature of current advanced turbofan engine designs. As such they are not contributing to the load carrying structure, and occupy surfaces that potentially can be used to limit engine noise. In response to this, SHEFAE is exploring possibilities to develop a load carrying surface cooler integrated to the engine with a light-weight polymeric composite MCS. Figure 1 shows a possible mounting of the structural surface cooler and the MCS.

The MCS component requirements are challenging for polymer composite materials. Maximum interface surface temperatures, thermal expansion, failure modes such as fire and hot air jets and overall manufacturability issues are severe constraints with influence on selection of suitable composite constituents and manufacturing. The paper will present an overview with respect to high temperature composites and their suitability in a MCS.

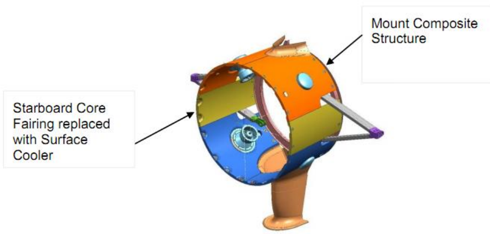

Fig. 1 Possible surface cooler and MCS

Acknowledgement

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Uncertainties in Early Phases of Aerostructure Design

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Keywords: *Geometric Variation, Simulation, Robust Design, Uncertainty Quantification*

Abstract

Every manufactured product is different. This variation can be detrimental to quality and product functionality. In an aerospace context, this variation may even result in serious threats to the safety and reliability of aircraft. However, it is not the variation itself that is harmful, but the effects it has on functionality. This is an important distinction to make.

Reducing sources of variation is often associated with tightening tolerances and increasing cost. Instead, it is preferable to eliminate the effects of this variation by making designs more robust. This idea is at the core of robust design methodology.

The research presented in this paper aims at identifying the role of robust design in general, and geometry assurance in particular, in early phases of aerospace component design. Methods for evaluating the effects of geometric variation on the functionality of aero engine components are put forth. A simulation tool for performing multidisciplinary analyses is developed. By connecting geometry assurance tools with computational fluid dynamics and finite element analysis software, the aerodynamic, thermal, and structural effects of geometric variation can be evaluated. In addition, optimization procedures for surpassing this variation are investigated.

1 General Introduction

In today's aerospace industry, simulation is increasingly being used to reduce cost and time to market. Unlike physical experiments, where conditions cannot be controlled exactly, simulations are inherently deterministic – the same simulation always yields the same output. However, this does not mean that simulations are more accurate than physical experiments. Instead, the validity of a simulation model is measured only on how accurately it reproduces the real-world results. [1]

Deficiencies in simulations can arise from many things. According to Oberkampf, DeLand [2], they can arise come from inadequate physical understanding and mathematical modeling of reality. They can arise from programming error, or the designer's inability to correctly interpret results. The focus of this paper, however, is the inherent deficiency in simulations when it comes to accounting for the geometric variation that stems from an imperfect manufacturing process. In this paper, the effects of geometric variation, and its relation to other sources of uncertainties, will be

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A cost efficient 3D permeability measurement method for composite manufacturing

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Keywords: *transverse permeability measurement, capillary pressure, compressibility*

Abstract

*In order to optimize the process times for composite manufacturing numerical methods have become increasingly important to understand the whole process, such as the liquid composite molding (LTM). Simulations of LTM processes use most often the Darcy equation where permeability (**K**) is an important part. In many cases permeability is dominated by the two main permeability components in the ply planes (K_{xx}, K_{yy}), but when simulating, for example, vacuum injection the third component, the through-thickness of the material stack K_{zz}, is required.*

*Various methods have been proposed to determine the permeability of a material stack. Each method has its difficulties in determining K_{zz}. Nedanov and Adrian have proposed a simple method to determine **K** by point-infusion on top of the material stack. The three components are determined through a mathematic model based on isotropic transformation. Although, determine the three components might be computational taxing.*

We suggest a ratio simplification of this model that approximates the results.

The method assumes that the flow front through the stack has an ellipsoidal shape. That is, the distribution in the x-, y-and z-direction is dependent on the time it takes for the resin to penetrate through the material stack. By using a transparent form, for example a vacuum bag on a glass sheet, the flow front can be observed when the resin has just penetrated through the material stack and measuring the flow front propagation in the x-and y-direction.

An advantage with the ratio-simplified method is that it resembles an actual industrial process for K_{zz} better then a dedicated one dimensional measurement of the permeability through the stack.

The proposed ratio-simplified model has been evaluated with two types of lay-ups, unidirectional and quasi-isotropy, three types of preforming and two types of resin. Comparing the results for K_{xx} and K_{yy} measurements with the ratio-simplified method shows good agreement with dedicated one dimensional measurement of the two components.

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Topology optimization w.r.t. stress and fatigue

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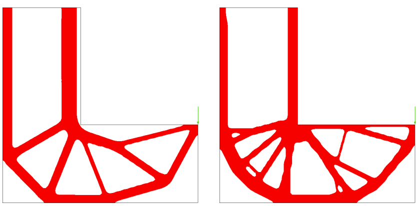
Keywords: Topology optimization, stress constraints, fatigue constraints, computational cost

Abstract

The presentation will concern structural topology optimization (TO) in conceptual design stages and we will show the importance of using constraints which correspond to the actual requirements that the structure will be subjected to in later design stages. Traditionally, TO is used for finding the stiffest structure for a prescribed mass, which generates designs that are far from feasible with respect to e.g. stress and fatigue.

By minimizing the mass of a structure which is subjected to static stress and fatigue life constraints, we obtain designs which appear more like final designs, see Fig. 1a. The structural members are sized with respect to static and fatigue stresses and the designs are also free from large stress concentrations, which is not the case for the traditional formulation, see Fig. 1b.



(a) Stress constrained TO (b) Traditional TO

Figure 1: Designs for an L-shaped beam in 2D

However, the improved conceptual designs are obtained at the cost of a more complicated and expensive optimization problem. For example, the local nature of stresses and fatigue failure requires methods that reduce the number of constraints; applying constraints to stress clusters, where each cluster contains stresses from several points in the structure, was in [1] and [2] proven to be an adequate way of obtaining stress and fatigue constrained designs at a reasonable computational cost.

Compared to manual design and traditional TO, stress and fatigue constraints allow for lighter designs and a faster product development process, as manual iterations between designers and stress engineers are avoided.

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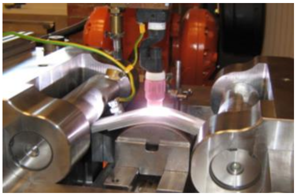
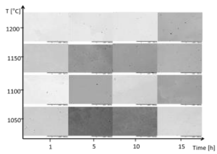
Weldability Limits for Superalloys

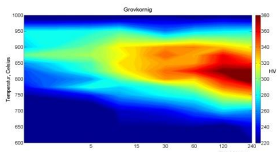
The goal is to find superalloy combinations, welding methods and appropriate heat treatments to increase the potential for GKN´s future in hot gas turbine structures applications. This is done trough comprehensive experimental work combined with deep study of material properties and also evaluation of existing theoretical models that can be of interest for increased understanding of the hot cracking mechanisms.

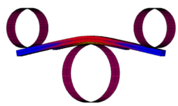
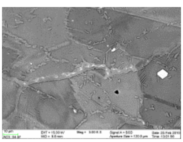
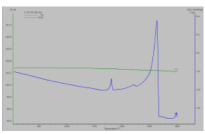
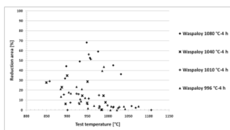
Varestraint Testing - This method can be used in several different ways to trigger hot cracking in the material and can give very representative results compared to welds done on real components in production. The basic idea is that the material is bent during welding which cause deformation and also crack formation in the area were the ductility is low. Depending on the selected material and weld parameters a threshold on the applied strain can be used as criteria for when cracks form even in relatively resistant materials.

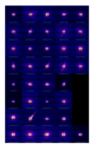




Repair Welding, Heat Treatments, FEM, SEM, DSC, Hot ductility testing, Synchrotron analysis – These are examples of other useful methods in the path of getting closer to the true answer on materials hot cracking sensitivity. Multiple overlapping welds and different heat treatments are necessary for repair work and to obtain required material properties. With FEM analysis the temperature, strain and stresses can be simulated in order to get information about their distribution and also it is one of the keys to be able to predict upcoming cracking problems in the future. On the other hand reliable material data and representative comparisons with real welds are needed. Therefore SEM studies in regions near or in front of a crack can give further information about wanted or unwanted phases and structures. Further DSC can be used to identify when a certain reaction takes place and if it can be related in some degree to crack formation. Also the hot ductility can give answers to what might happen in the two-phase liquid/solid region where the hot cracking is most likely initiating. Even results near the beginning of precipitation can be of importance and then the small particle size on the nm-scale makes cooperation with synchrotron facilities as MAX-lab very useful.







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Detailed modeling of low velocity impact on a hybrid wing box structure

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Abstract

Laminated composites are widely used in aircraft applications due to their low weight properties. They also possess good in-plane strength and stiffness properties. Unfortunately, composite laminates exhibit poor resistance to low velocity impact resulting from runway debris, tool drop etc. The internal damage caused by such impact events significantly reduces the strength of the composite structure.

Damage tolerant approach for composite laminates assumes that impact damages caused by a certain level of impact energy are present in the structure and that they have to be taken into consideration in the aircraft design process.

The impact itself is a dynamic event involving the motion of the impactor, the motion and the deformation of the target, the indentation in the contact zone and the development of irreversible damage in the laminate. The response of the composite structure to the impact is affected by a number of parameters such as: the shape and weight of the impactor and the target, the impact energy, the properties of the composite material, the layup sequence and the boundary conditions. These parameters determine the maximal force in the contact area during the impact and the extent of the damage development in the laminate. The size and the shape of the damage subsequently affect the residual strength of the structure.

A large variety of failure modes can be generated during impact. Experimental evidence show compressive matrix and fiber failure close to the impact area and matrix cracks throughout the thickness of the laminate. These cracks induce delaminations between the layers which then grow driven by interlaminar stresses. Delaminations are often peanut shaped and are oriented in the fiber direction of the lower layer at a given interface. The orientation of matrix cracks varies through the laminate. These cracks are mainly driven by shear tractions on the fracture plane, possibly promoted by normal traction. This indicates that matrix cracks develop under a tri-axial stress state.

The residual strength of a laminate is seriously reduced by the impact event. Subsequent in-plane loading in compression can result in buckling of the delaminated areas, increasing interlaminar stresses and further growth of delaminations.

Based on the above, several useful conclusions for modeling work can be formulated:

Variable Fidelity Loads Process in a Multidisciplinary Aircraft Design Environment

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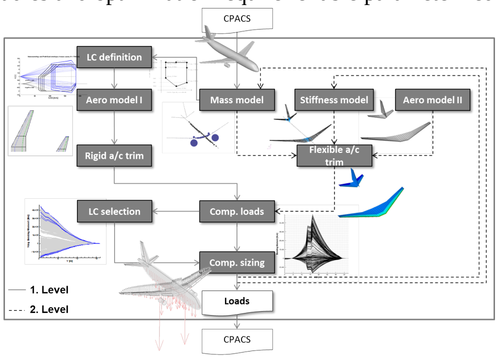
Introduction

One of the current main efforts in the development of more efficient aircraft is the integration of different disciplines in collaborative design activities. To increase the fidelity of aircraft preliminary design, the use of physics-based methods is of great importance. In this context, aircraft loads and aeroelasticity play a critical role, determining reliable and not too conservative loads as early as possible in the design. The capability of handling several load cases with different mass configurations and flight points is essential to correctly describe the expected loads on the aircraft. Design tasks such as trade studies and optimization require reliable parameterized processes and models.

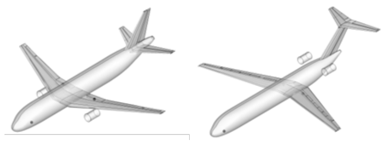


In the presented paper, a fully automated process for the estimation of aircraft flight loads in a multidisciplinary design framework being developed at the DLR is described. Design space „zoom" functionalities are provided through the combination of simplified methods capable of handling thousands of load cases in a few seconds and more advanced methods including aeroelastic models and structural optimization.

Loads Process: Two-Level Approach

A two-level fidelity approach is used for the loads analysis. The first level consists of a rigid aircraft analysis for the first design loads, stiffness and mass estimations. The second level involves an FEM based method for aero-structural coupled analysis. Both levels are integrated in the same tool and can be chosen according to the design task. The developed loads process includes: model generation, load case definition and selection, aircraft trim, component loads calculation as well as stiffness and mass estimation.

Application



Application studies of two different aircraft configurations with similar operational requirements are presented. These include a conventional short to mid-range 150 passenger aircraft and a laminar flow forward swept alternative. The loads of the different fidelity approaches are compared as well as the influence of the aircraft configuration.

One configuration is conventional with an aft swept wing, conventional tail and engines mounted under the wing. The second concept is primarily designed to reduce fuel consumption. Besides others, this should be achieved by an aerodynamic design of the wing geometry in order to preserve laminar flow condition. This is achieved by a laminar flow wing design with optimized airfoils, forward sweep and rear mounted engines, for a clean wing configuration. Horizontal and vertical tailplanes are arranged in a T-tail format.

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High temperature hold time fatigue crack growth behaviour of Inconel 718

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Keywords: *nickel-base superalloys, fatigue crack propagation, Inconel 718, hold times, grain boundary embrittlement*

Abstract

Inconel 718 is a frequently used material for gas turbine applications at temperatures up to 650°C. The main load cycle for such components is typically defined by the start-up and shut-down of the engine. It generally includes hold times at high temperatures, which have been found to have a potential for greatly increasing the fatigue crack growth rate with respect to the number of load cycles. However, these effects may be totally or partly cancelled by other load features, such as overloads or blocks of continuous cyclic loading and the actual crack propagation rate will therefore depend on the totality of features encompassed by the load cycle. It has previously been shown that the increased crack growth rate found in hold time experiments can be associated with a damage evolution, where the latter is not only responsible for the rapid intergranular crack propagation during the actual hold times, but also for the increased crack growth during the load reversals. Since this damage evolution, as well as the resulting crack propagation behaviour, is affected by other load events, it becomes important to understand the interaction between hold times at high temperature and other load events, such as cyclic loadings and overloads, in order to be able to model the behaviour during real load cycles.

Here, an overview of recent research at Linköping University will be presented, where the main focus has been placed on hold time fatigue crack growth at 550°C, which is a common temperature for gas turbine discs. For understanding the damage evolution which occurs during hold times, simplified load cycle types, representing the start-up-continuous run-and shut down of a gas turbine, were considered. By mechanical testing, results regarding the fatigue crack propagation behaviour, as well as the evolution of the damaged zone in front of the crack tip, were established. From this, a model has been set up which is capable of describing the observed crack propagation behaviour.

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Topology design of a metallic load introduction bracket manufactured by ALM

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ABSTRACT

The usage of numerical optimization within the development process for aircraft structures enables the engineer to reduce cost and weight for new airplanes. Next to the evolution of optimization methods also manufacturing approaches are enhanced, like e.g. the ALM (Additive Layer Manufacturing) process.

So far results of topology optimization for metallic structures are used to derive design ideas which were transferred manually into a manufacturable design. Therefore SoA manufacturing processes like milling or casting are considered.

The application of the ALM process enables the engineer to transfer topology optimization results near-net-shape to the ALM manufacturing. Therefore defined manufacturing driven design constraints need to be considered during the optimization process to minimize the post-treatment effort.

Key aspect of the presentation is to show the development process and lessons learnt for a topology optimized metallic load introduction bracket manufactured by ALM. This investigation was made in cooperation with EOS (leading manufacturer of laser sinter equipment) and Altair (topology optimization software).

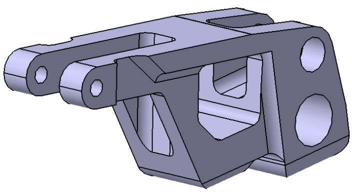

Figure: Milled load introduction bracket

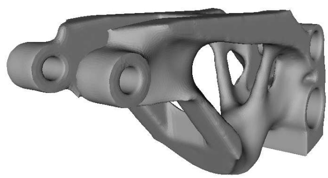

Figure: ALM load introduction bracket

Keywords:
- Topology optimization
- Additive layered manufacturing
- Aerospace

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Studies on manufacturing-related management accounting

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Keywords: *operations management, performance measurement, decision making.*

Abstract

The purpose of this paper is to provide perspectives on some aspects concerning the relationship between manufacturing operations management and management accounting. This will increase the knowledge and understanding of how management accounting information supports manufacturing decision making.

Findings from four studies designed to investigate the informational relationship between management accounting and operations management in companies is reported. Results show that there are many factors to consider when choosing and designing an appropriate management accounting system. Contextual factors include market, manufacturing strategy, technology, and organization.

This paper contributes with some explanatory aspects on the practical problem and investigates some potential ways forward concerning manufacturing-related management accounting.

1 Introduction

In companies with complex products and complex production systems it is hard to see economic consequences of activities made in production. In order to create a financially successful company there is a need to understand the economic consequences of decisions and actions in production. Consequently, there is a need for good transparency between the production and accounting/finance functions. The purpose of this paper is to provide perspectives on some aspects concerning the relationship between production and management accounting. This study is concerned with the informational relationships between management accounting and operations management of manufacturing firms, particularly advanced manufacturing technology companies.

In 1987, Johnson and Kaplan wrote that more or less all the management accounting practices used at that time had stopped their development in 1925. The manufacturing environment as well as the competitive environment has changed since then and much research shows that the traditional way of managing the operations is not suitable in this new environment [1-5]. Different management accounting systems seem to be needed for different types of manufacturing systems. For a management accounting system to be utilized to its full potential to support the manufacturing decision making it needs to be used in the right context for which it has been developed. Figure 1 on next page shows an illustration where information to support decision making flows between production/manufacturing functions and accounting/finance departments through the management accounting system. This paper focuses on the bold arrows between the management accounting system and the production.

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Direct-hit development of manufacturing processes: Thermo-mechanical forming of Titanium aero engine structures

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Abstract

In order to increase the competitiveness of the Swedish aerospace industry, alternative manufacturing processes for static load carrying aero engine structures are desired. Presently, these components mainly consist of large-scaled single castings. To increase the in-house level of processing, the Swedish aero engine industry focus on fabricated alternatives by introducing new manufacturing processes and create relations with adjacent sub-suppliers. The concept of fabrication involves forgings, sheet metals and small ingots assembled by welding. The possibility to reduce weight, i.e. fuel consumption and product cost also exists.

In the aerospace industry extremely high demands on safety and reliability exists which requires precise knowledge regarding the influence on the material and its properties through the whole fabrication chain. The advanced Finite Element (FE) technology makes precise analyses possible assuming that proper material descriptions are used. Analyses of sheet metal forming provides with information of formability, thinning, springback, resultant mechanical properties and residual stress state which are important input to analyses of subsequent welding and heat treatments. One challenge in producing complete structures based on fabrication is related to the accuracy in numerical predictions of shape deviation using FE-analyses, in order to effectively compensate forming tools for springback and accumulated shape distortions.

By fundamental research on and development of thermo-mechanical processes for hot sheet metal forming of titanium, this project shall result in that a few SME can further develop their processes for product and process development. The project gather competence from the Swedish aero engine industry GKN Aerospace, acknowledged R&D within forming processes, FE-modelling and SME with experience of forming. The aims of the project are:

Development of methodologies for thermo-mechanical material characterisation of Ti-6Al-4V and FE-models for hot sheet metal forming. Suggestion of forming procedures suitable for production of titanium components in which resultant geometry and properties are secured.

Activities where Swedish SME takes necessary development steps, in order to produce desired titanium sheet metal parts and develop into new sub-suppliers for the Aero engine industry.

This presentation summarise results obtained in present and previous research and development projects regarding short lead time design, compensation and manufacturing of deep drawing tools of titanium and super alloys. The research funding by VINNOVA - NFFP 4 and 5 for SME, BFS and GKN Aerospace Sweden are gratefully acknowledged.

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A400M Aeroelastics and Dynamic Tests

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[1] *Structural Dynamics and Aeroelasticity Domain*

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Keywords: *Dynamic Loads, Aeroelasticity, Structural Dynamics, Flight Test, Ground Vibration Test.*

Abstract

Between December 2009, with the Airbus A400M First Flight, and the recent delivery of the first A400M to the French Air Force in August 2013, a fruitful flight test campaign has involved four prototypes and the first series aircraft.

This paper is devoted to present the A400M ground and flight tests used in the aeroelastics and dynamic loads models validation. Dynamic loads are among the A400M sizing critical load cases. For this reason the dynamic loads model validation is a critical issue in the certification path.

The first ground test that will be presented is the complete aircraft (A/C) Ground Vibration Test (GVT) that will be briefly described, to continue with Finite Element (FE) model updating to match test results. Next test will focus on Landing Gear (LG): the Drop Test, used to validate the isolated LG model and to demonstrate the LG target characteristics.

Taxi tests were performed in August 2010 at Francazal runway near Toulouse. The runway was equipped with an artificial (1-cos)-20-meters obstacle to validate the taxi loads model. A set of taxi runs with different speeds, with and without braking and/or reverse were performed. Flight test results will be compared with numerical simulations and the model update process will be described.

During all the flight test campaign, every severe landing was registered and analyzed. Several "hard landings" with sink speeds close to 12 ft/s will be compared with the numerical simulations. The LG and A/C coupling for dynamic loads calculation validation by using the controlled flight test firm landings will be shown.

The aeroelastic model for gust calculations has been validated using the same Flight Vibration Test (FVT) used for flutter envelope expansion. The FVT will be briefly described and the aircraft response to control surface sweeps and pulses compared with the numerical simulations.

The wake vortex model for wake encounter loads has been the last aeroelastic model to be validated, following a dedicated flight test campaign involving two A400M prototypes and a jet airliner.

In all cases, the paper will briefly describe the modelling techniques, the pre-test numerical simulations and the post-test updates when needed.

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Strength of non-crimp fabric composites under multiaxial loads – modelling and testing

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Keywords: *Composite materials, Elastic properties, Multiaxial loads, Non-crimp fabrics, Strength*

Abstract

Polymer composites reinforced with carbon fibre non-crimp fabrics allow cheaper and faster manufacture of low weight components for aircraft, but current material models are unreliable. The Swedish NFFP project ReFACT aims to develop more reliable models for design of such materials under mixed in-plane and/or out-of-plane loads.

1 Introduction

Polymer composites reinforced by carbon fibres offer superior strength and stiffness per unit weight and are therefore increasingly used in aircraft. Impregnation of textile fibre preforms allow more complex geometries and significant savings in production time and cost in comparison to conventional unidirectional pre-impregnated fibre composites. Non-crimp fabrics (NCF) offer less reductions in strength and stiffness than conventional woven preforms, due to a much smaller waviness of the fibres. The project ReFACT considers NCF composites under mixed in-plane and out-of-plane loading.

2 Materials and experiments

An HTS/RTM6 carbon fibre/epoxy NCF system has been tested under mixed in-plane shear, tension and compression. Tests have also been done under uniaxial out-of-plane shear, tension and compression. Demonstrators are to be tested under mixed triaxial stresses. Finally, pure resin and fibre bundles impregnated with resin were tested to provide data for modelling.

3 Modelling

An engineering model has been developed to predict elastic properties and strength of NCF plies under uniaxial in-plane or out-of-plane loading. A 3D FE model for a representative volume element has been developed for accurate predictions and for combinations of plies under more complex load cases. The models are based on basic test data for pure resin and fibre bundles impregnated by resin.

4 Conclusion

Model predictions have so far been in good agreement with experiments, and will be further validated by the demonstrator tests. The models will allow more reliable design of NCF composites with arbitrary layup and architecture of the fibre preform.

The relationship between alloying elements and properties for titanium alloys Ti-6Al-4V and Ti-6Al-2Sn-4Zr-2Mo

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Future engines are required to meet ever increasing efficiency, environmental and economical requirements. This results in increased pressure ratios and therefore higher temperatures. The increased pressure leads to higher temperatures, which makes it necessary to replace titanium alloys with Ni-based superalloys in the front end of the engine. Unfortunately this results in increased engine weight leading to increased fuel consumption. Today GKN Aerospace Engine Systems (GAES) uses Ti-6Al-4V alloy (Ti-64) at low to intermediate temperatures and Ti-6Al-2Sn-4Zr-2Mo alloy (Ti-6242) for compressor structures working at temperatures up to 450°C. However, GAES believes that there is a possibility to increase the maximum working temperature of Ti-6242 even more by increased understanding of the relationship between the mechanical properties such as creep, physical phenomena such as oxidation mechanism (alpha case) at the high temperature regimen, and the specific criteria used for structural design. Therefore, at GAES the main focus of research work on titanium alloys is to develop increased understanding of how different elements (O, N, B, Si) affect the properties of the alloys Ti-64 and Ti-6242. This will enable GAES to offer lightweight structural design in titanium for future high efficiency jet engines. Some of the main findings of this research work will be presented here.

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A Combined Numerical and Statistical Approach to Crack Propagation Modeling and Prediction of Crack Propagation Rates

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Keywords: *Fatigue crack propagation, Crack closure*

Abstract

In order for the engineer to correctly predict the operational life of a component it is important to understand the physical background to fatigue, i.e. the growth of fatigue cracks. In the industry, the dominating models used for crack propagation analyses are based on either a pure curve fit procedure or models that intend to capture the physical phenomenon related to the crack growth. The present study attempts to make more accurate life predictions of aircraft engine components by employing a more physical approach to crack propagation modeling. In particular, the paper deals with the derivation of five parameters in the NASGRO® equation for crack growth. Four of these parameters were derived by curve fitting to experimental data and one parameter, the crack closure, was derived by means of finite element analysis. This differs from the empirical method, currently in industrial use, determining life where all five parameters are obtained from curve fitting. Both methods were evaluated and compared to experimental data for cast Inconel 718 using statistical tools. The crack closure, here assumed to be induced by plasticity, was determined by numerical simulations of fatigue crack growth of a semi-circular surface crack in a 3D domain. The objective was to obtain an unequivocal value of Newman's plane stress/strain constraint factor, α, which is directly related to the closure level. In this study experimental data of cast Inconel 718 test specimens at different temperatures, and for three R-ratios, was utilized. The numerical analysis used a kinematic multi-linear hardening constitutive model and crack propagation was modeled by releasing all nodes at the crack front after unloading in a one-node-per-one-cycle debonding scheme. Different values of the plane stress/strain constraint factor were found for each of the three R-ratios, i.e. an unequivocal value was not obtained and instead an average was used. The predicted lives were calculated by use of the established parameters in the NASGRO® equation and were compared to the actual lives observed in the experimental testing. The proposed method gave similar results as to the empirical pure curve fit method, although the models credibility is increased due to the better understanding of the crack closure phenomenon. Hence, the model can be expanded for different geometries with different crack closure levels resulting in more accurate life predictions. Consequently, the study provides a basis for further improvements of the crack propagation modeling.

1 Notations

The notations used in the paper are listed and explained in Table 1 below.

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Swedish and European research collaboration in simulation supported POD

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Keywords: *Nondestructive evaluation, Simulation, Eddy current, Probability of detection (POD), EU collaboration project*

Abstract

This paper summarizes the main contributions from GKN Aerospace Engine Systems (GKN) and Chalmers University of Technology within the European collaboration project PICASSO. PICASSO is a recently finished research project within the 7th European framework programme. The paper starts with a description of the overall objectives of the project and describes the Swedish collaboration. We will then go through the main results, conclusions and finally discuss the continuation of GKN and Chalmers research within the 6th Swedish National Aeronautical Research Programme.

The goal of this project was to build a new and novel concept of simulation supported probability of detection (POD) curves. The POD methodology is used for quantitative non-destructive testing (NDT) process capability assessments within aerospace. The POD result is usually obtained by extensive experimental work often associated with significant costs and long lead times. The experimental campaign is usually technically difficult and often not feasible to realize in the desired way. The estimation of a POD curve is based on statistical treatment of inspection data and a confidence level is conventionally used in order to have a conservative estimate, see Fig 1. The objectives of PICASSO were:

- to have more accurate and reliable POD curves,
- to overcome the cost and lead time issues of the experimental work needed for POD assessment, by using NDT simulation,
- to increase the knowledge and understanding of NDT capability.

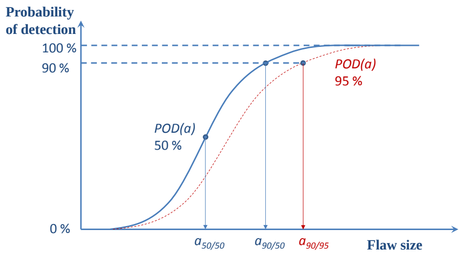

Fig. 1 POD curve with 95 % lower confidence limit.

The technology developments of the project were tested and evaluated against a set of validation cases proposed by the engine manufacturers. The results showed that mathematical modelling can give fast and accurate POD estimations. The model can give quantitative results and understanding of the procedure capability but requires good knowledge of the NDT process.

To summarize it is concluded that mathematical modelling is a key for increased reliability of future NDT processes within aerospace. The tools of modelling are giving the possibilities not only to improve NDT systems but also to optimize them in order to meet increasing demands on component operation and safety.

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Calibration and validation of material models for containment simulation and design

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Abstract

Many parts of a modern civil aero engine have a requirement on containment capability. That means that the structures surrounding the rotating parts of the engine have to prevent penetration in case of a blade off scenario in order for the surrounding fuselage to escape damage.

Traditional analysis methods are often of empirical nature and are valid only for a limited design space. The methods are also proprietary to the OEM's and expensive to make further refinements to. Therefore a physics based approach using FEA is preferable in order to minimize the need of empirical data. A modern method for numerical calculations should be firmly based on material characterisation through repeatable experiments and must be able to simulate and analyse the containment potential of a structure in detail.

Impacts of blade fragments on the containment structure occur at both high speeds and high temperatures meaning that the material models in numerical simulations need to be based on and validated by experiments performed under similar conditions. In order to accurately model the material of interest, nickel alloy 718, under these conditions a test method based on tensile loading of straight specimens in a VHS high velocity machine from Instron has been developed. The method covers strain rates up to $1000s^{-1}$ and in order to take thermal effects into consideration the Instron machine was equipped with an induction heater enabling test temperatures of 650°C.

Results from the tensile tests were used to find parameters for material models, able to capture the behaviour of the material over a wide range of temperatures and strain rates. The material models Johnson-Cook and Zerilli-Armstrong both take strain rate hardening and thermal softening into account when calculating the plastic strain, and parameters for both these models were evaluated.

In order to validate the parameters in the material model an experiment was designed. The experiment was based on a reverse impact methodology using an instrumented slender rod as a target. A disc of the sheet material is shot at the target using an air gun and the force history from the impact is recorded. The experiment is designed to be easily simulated aiming at comparing the force histories in order to validate the material models.

The designed impact experiment was also used to validate simulations regarding impact velocity necessary to produce a "just cracked" state in the impacting disc. These simulations are based on a damage evolution model for the material.

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Efficient production of aircraft engine components using an innovative scheduling procedure

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Keywords: *production scheduling, optimization, job shop, mixed integer linear programming*

Abstract

The multitask cell at GKN Aerospace Engine System's site in Trollhättan, Sweden, is a flexible job shop containing ten resources aimed at being flexible with regard to product mix and processing types. The products currently processed in the multitask cell are mainly combustor structures for aero engines. Significant for the aero engine industry is its high quality requirements. Therefore, expensive processing machines of high quality are needed in order to be able to meet these requirements. Due to small product volumes, often many different processing operations are carried out in each machine. In the multitask cell, each operation is allowed to be processed in a subset of the five main multipurpose machines. The problem of scheduling the processing of the parts, continuously arriving at the cell, gives rise to a complex combinatorial scheduling problem. The goal of this scheduling is to facilitate a higher utilization of the cell while minimizing the total tardiness and the cell throughput time.

We show how optimal, or near-optimal, schedules for the processing of parts in the multitask cell can be found by the use of an iterative procedure using a time-indexed mathematical optimization model. Since the main disadvantage of a time-indexed formulation is that the numbers of variables and constraints grow with the number of time steps, an iterative procedure has been developed in which the time-indexed model is solved for smaller and smaller time steps, i.e., with an increasing accuracy. The solution from the previous iteration is used as a starting solution and its makespan, i.e., the largest job completion time, is used to determine the next time horizon in order to keep the total number of time steps needed as small as possible in the next iteration.

Apart from the inclusion of the scheduling of maintenance activities and the limited availability of fixtures, we also demonstrate the possibility to deal with time windows with no personnel present in the workshop. Such time windows are present in the multitask cell, for example, every night between midnight and 6 a.m. and only unmanned processing is then allowed. The consideration of unmanned night shifts enables the scheduling of jobs with a significant amount of unmanned processing just before the beginning of the night shift, in order to meet the scheduling goals of high utilization and low tardiness and throughput times.

We compare the schedules for the coming shift for a set of real data instances collected in the multitask cell with the schedules constructed from the first in first out (FIFO) priority dispatching rule and a built-in scheduling method from the multitask cell control system based on a critical ratio (CR) dispatching rule. We also show that our procedure is able to find optimal, or near-optimal, schedules for the coming shift within a reasonably small amount of computing time.

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Anisogrid technology made available for the west – a cooperation between RUAG, KTH and CRISM

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Keywords: *Anisogrid, Adapter, NRFP, KTH, RUAG*

Abstract

This paper describes how Russian anisogrid technology and design philosophy has been made available for western space applications through cooperation within the NRFP (Nationellt Rymdtekniskt Forskningsprogram) between RUAG Space AB, The Royal Institute of Technology (KTH) and Central Research Institute of Special Machinery (CRISM) .

1 Introduction

1.1 History

Lattice structures (or truss structures) have been frequently used through history. Larger structures like bridges, cranes and towers are very visible examples. Older race cars (with tube chassis) and aircrafts are medium sized but more invisible examples.

These structures are built up from rigidly connected ribs to globally form load carrying structures.

The most common topology used for such lattice structures is a triangle pattern like the classical isogrid pattern. There are however other topologies in use as well. Examples are orthogrid and anglegrid which together with isogrid structures were used in early projects (see fig. 1). In Russia a designer named Vladimir Shukhov used other topologies like the anisogrid (Anisotropic grid), which will be the focus of this paper.

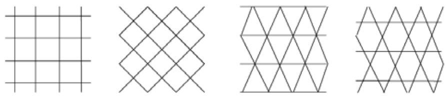

Fig. 1 From left to right: Orthogrid, Anglegrid, Isogrid and Anisogrid

The first hyperboloid lattice structure was a 25 m high tower built by Shukhov for the 1896 All-Russian Industrial and Handcraft Exhibition [1]. The same Shukhov later (1920 - 1922) built the 160 m high radio tower in Moscow (named the Shukhov Tower). This tower was originally projected to be 350 m high but due to the lack of material it came out smaller [2].

The Shukhov tower has a topology which combines strength and lightness. Compared to the 350 m high Eifel tower, the projected 350 m high Shukhov tower would use three times less material!

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Robust Design and DFM-methods for jet engine components

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Keywords: *Robust design and manufacturing, Design For Manufacturing, Producibility*

Abstract

One of the most important goals when designing jet engines is to reduce weight and at the same time maintain or improve the performance. To accomplish this, different concepts for materials and physical configurations are under investigation and development today. For some components, typically structural components, one approach is to use fabrication instead of large forgings and castings. Using a fabrication process, in which smaller parts are assembled and joined together, has a high complexity as the need for different manufacturing processes will increase as well as the complexity of other production related activities.

Producibility is a collective term for capabilities and restraints that determine to what extent the product can be produced in a robust and efficient way in serial production. The purpose of this research project is to define a framework for the prerequisites and the building blocks required for a methodology to reach high robustness and manufacturability.

The approach for a methodology reported here is built from three parts:

The first part is a framework for how to structure and integrate manufacturing targets and requirements in the product development process. The targets are directed to how well the product can be produced in serial production, measured in terms of quality, time and cost.

The second part is a study of the geometrical robustness in the fixturing and joining process. The project has used methods and tools for robust design developed for the automotive industry and evaluated how the methodology can be used on jet engine components. An important conclusion is that it is very important to analyze the robustness of the locating scheme. Great improvements can be made when using optimization to define the locating scheme.

The third part is about methods for how to make an analysis or assessment to compare different concepts and design solutions. Traditional methods for Design For Manufacturing evaluate one manufacturing process at a time. We have found that, comparing the alternative fabricated product designs, is rather complex as they are designed from a combination of several different parts and materials integrated into one component. This will result in an analysis of many different combinations of manufacturing methods and inspection techniques which makes the evaluation very comprehensive and requires a good knowledge base.

This work is funded by VINNOVA (Swedish agency for innovation systems) and the NFFP5 program. The support is gratefully acknowledged.

System for lifetime assessment of laser welded titanium components based on automated defect detection

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Increasing fuel costs and environmental requirements in the air transport industry drives the development of lighter constructions, reducing security margins in contrast to more strict regulations and higher safety requirements from society. These aspects have focused the development of non-destructive testing (NDT) technologies to detect possible initialisation of in-service defects at an early stage already in the manufacturing process. Also new manufacturing concept requires more sophisticated methods of inspection (NDE) that besides being tailored for a high degree of automation also increases the information exchange with the whole production process.

Laser welding of thin titanium components, a critical component of many jet-engines, has demonstrated a tendency of generating pores in clusters with a prescribed orientation. These pores, also known as chain porosities, are often of harmless sizes (50-100 micrometer) as individuals. Though the cluster as such, depending on the distances and orientations in between the pores, may have an impact on the structural integrity. Usually conventional radiography is applied which provides a two dimensional projection of the three dimensional information and the estimated distance between the pores, if even detected, becomes very conservative by nature. Recently developed digital x-ray technology has shown to provide high enough resolution to detect individual pores of the size specified above. The digital radiographic technique also enables inspection procedures with more than one projection and can thus provide information of depth and position of the pores within the projected volume (tomosynthesis).

The project that is presented here is a collaboration project between Chalmers and GKN, and is performed within the Swedish National Aeronautical Research Program (NFFP). The project includes the development of a mathematical model of the radiographic NDE system that is intended to be used in production. This model has then been used in the development of algorithms that based on radiographic information retrieves pores, their individual position in the component and their dimensions. The model is then also used in the specification of used radiographic procedure when it comes to number of projections and quality criteria of each projection. Since these synthetic radiographs also has been used for creating training sets in the development of a filter chain, a model of x-ray related noise, quantum noise, has been included in the model.

This presentation describes the development of a methodology that aims to incorporate non-destructive evaluation with, in this case, structural integrity and thereby providing more accurate lifetime assessment for jet-engine components. The project is an example of a new emerging research area, Integrity and quality assessment by NDE (IqNDE) that intends to change the dimension of the output from a nondestructive system. When the output no longer is limited to be information of the defects but instead gives information in qualitatively terms, e.g. fracture toughness, fatigue strength, strength or ductility, it will increase the economic value of the inspections.

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Fatigue Crack Propagation with Peridynamics: a sensitivity study of Paris law parameters

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Keywords: *computational mechanics, non-local methods, peridynamics, crack propagation*

Abstract

Structural failure is a phenomenon that has to be anticipated and possibly avoided by designers and engineers. The modeling of damage propagation phenomena is usually a difficult task because it is necessary to have the capability of describing generation and growth of material discontinuities. Recently a general and powerful method based on the peridynamic non-local theory has been introduced. This approach is more general in the sense that the crack is free to appear in every part of the structure, following only physical and geometrical constraints. In this paper a high cycles fatigue model has been introduced using the peridynamic approach. Correlations between the peridynamics fatigue model parameters and the classical Paris law parameters will be presented.

1 General Introduction

For structural components it would be of the highest importance to be able to describe the damage process in order to evaluate their life expectancy for a safe use and to define a proper repairing and maintenance program. The numerical approaches used in structural mechanics face always the problem of dealing with discontinuities since the underlying theory, continuum mechanics, is based on a differential approach and the derivatives involved in the formulation are not defined across discontinuities. In the past such a limitation was not perceived as strong because the first manifestation of a crack was often chosen as failure condition. Furthermore in advanced engineering fields, such as aeronautics and aerospace, cracks were closely monitored on the field with very limited attempts to simulate their evolution.

In the last thirty years a few approaches have been proposed to deal with discontinuities in structural materials: interface elements and Cohesive Zone Models (CZM) [1] can only be applied if the path of the discontinuity is known a priori and it is limited by the element discretisation; the extended finite element method (XFEM) [2] is more recent and, although overcoming some of the CZM drawbacks, requires ad-hoc strategies for the definition of the node sets for enrichment and the evaluation of the enrichment functions and it is not easily applicable to 3D cases. Similar approaches are presented as an ad hoc modifications of techniques originally based on a differential formulation of continuum mechanics.

Recently a powerful method based on the peridynamic theory [3] has been introduced in which internal forces are expressed through

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Advantages of an Integrated Simulation Environment

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Keywords: Simulation, MDAO, Integration, CPACS, RCE

Abstract

Numerical simulation software in the field of aircraft design can be classified as first, second or third generation Multi-Disciplinary Analysis and Optimatzion (MDAO) system. The most challenging task nowadays is to create a third generation MDAO because there are no good-practice rules how to create a useful software system. The prerequisite for a success-story of such a software is a successful consideration of the dependency of simulation scenario (workflow), simulation models and the simulation data. Some good-practice rules for developing a third generation MDAO can be extracted from monolithic first generation systems regarding this dependency. The still under development software *RCE for CPACS* is a system for applied numerical aviation pre-design simulations and a technology carrier for evolving a third generation MDAO.

1 Conclusion

Current third generation MDAO systems do not consider the relationship between the simulation workflow, its underlying simulation models and the data processed in the simulation. There are several drawbacks this situation brings into effect. Some effects are related to the quality trustness of the simulation outcome while others affect the control concept of the simulation. If the relationship between these aspects can be considered in a simulation environment many quality-decreasing aspects can be reduced. In addition to the three simulation aspects "workflow", "models" and "data" a fourth aspect "supporting software libraries" is introduced. Our answer to the question how a third generation MDAO system should be designed is to consider the relationships and peculiarities of the workflow system, the simulation models and the data format in every part of the whole simulation environment.

The German Aerospace Center (DLR) developed a third generation MDAO system with consideration of the relationship of all four simulation aspects. It is based on the CPACS data format which holds process and product information, a concept for integrating CPACS into simulation models and a concept to combine CPACS and simulation models into a simulation workflow system called "RCE for CPACS". This solution is a collaborative work of most aeronautic institutes of DLR. The key roles maintain within the Institute for Aerodynamics and Flow Technology, Institute of Air Transportation Systems and Simulation and Software Technology. DLR pursues the objective to evolve this solution to a standard simulation environment for us and all our partners in research and industry. It is still under development and will enhance in the future with ideas from inside DLR and from the growing open source community. Collaboration with partners and integration of their solutions into our software is part of our interests.

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The effect of Engine Dimensions on Supersonic Aircraft Performance

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Keywords: *aircraft design, supersonic, propulsion*

Abstract

In aircraft design a critical part of the design is the engine selection. This is typically making a selection from exiting engines. Looking at a next generation future fighters, however, where the time of deployment may be 20-30 years in the future this is not a valid approach as there will be an evolution in the engine designs. E.g. a new European fighter aircraft will most likely be a collaborative project also involving the development of an engine for that aircraft. In this study conceptual engine-airframe co-design is demonstrated, using models of comparable fidelity for both the engine design and the aircraft design. This co-design leads to a deeper understanding of the tradeoffs from both sides, and means that also more radical designs and innovations can be evaluated in a fair way.

The most important characteristics of an engine are the thrust, the specific fuel consumption, the dimensions and the weight. One parameter of critical importance is the engine diameter. This will have a great influence on trust and fuel consumption. At the same time the engine diameter influence the maximum cross section area of the aircraft; this in turns has a strong influence on the wetted area and on the wave drag in supersonic flight.

As a baseline for this study the GE F100 is used. The aircraft under study is a representation of the F-16, since a lott of data are available in the open literature.

Cost Efficient Advanced Leading Edge Structure

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Stefan Nyström Saab AB

The COALESCE2 project was a collaboration study of new technology and design integration applied to aircraft fixed leading edge structure. The project was funded by the European Commission within the 7th Framework Programme and was ended in October 2012

The overall objective was to develop new integrated technology and design concepts for fixed leading edge structure to achieve greater than 30% reduction in recurring manufacturing and assembly cost compared to today's highly fabricated structure.

The COALESCE project explored material and processing technology options for both metallic and composite structural solutions that resulted in preferred concepts that best met the critical structural requirements which were defined in the beginning of the project. A key requirement was the cost and simplicity of manufacture; however structural performance, in service maintenance, systems access and environmental impact requirements were also features in the concept and technology selection process.

The concept development studies were not limited to the standard configuration of the leading edge structure seen on the majority of commercial aircraft today but was extended to explore the structural design space and design possibilities when using less conventional leading edge control mechanisms. In order to show that the down selected design and technology solutions were cost efficient and met fundamental structural requirements, manufacturing and assembly process simulations were produced and bird strike simulations were carried out.

The project was subdivided into five operational work packages with definition of requirements in WP1, technology development in WP2, concept design and development in WP3&4 and conclusions in WP5.

Technologies investigated in WP2 include manufacturing processes like Laser Beam Welding, Friction Stir Welding and Additive Layer Manufacturing. Furthermore development of different automated manufacturing methods like Automated Fibre Placement (AFP) combined with Hot Drape Forming (HDF) and robotic pick and placement. New material concepts like Scalmalloy®, Shape Memory Alloy Hybrid Composites (SMAHC) and thermoplastic CFRP have been investigated and demonstrated in different structural details such as leading edge skins and ribs, access panels and slat fairing.

Technologies from WP2 were partly used for development of innovative low cost design concepts for a typical leading edge slat configuration (WP3) and for a Krueger Flap type design (WP4). The area for the design was restricted to two parts, inner and outer, of the wing leading edge. The design concepts as well as the technology parts in WP2 were then evaluated with reference to assessment criteria taking into account cost, weight, part count, compatibility with high-rate production, ease of repair/replacement, damage resistance, general design requirements (e.g. EMH, temperature capability, erosion resistance etc) and environmental impact (during manufacture and end-of-life disposal).

MIDCAS: The European Detect & Avoid project

MIDCAS (Mid-air Collision Avoidance System) is the European Detect & Avoid (D&A) project gathering most European groups active on the topic with the purpose to identify and agree adequate technology, contribute to standardization and demonstrate a D&A system for RPAS able to fulfil the expected requirements for Traffic Avoidance and Collision Avoidance in non-segregated airspace. The intention is to demonstrate by actually flying a RPAS equipped with a demonstrator D&A system in non-segregated airspace at the end of the project, where the process of approval for such a flight will be one of the contributions to the standardization work.

The project is conducted in close cooperation with European regulatory bodies to provide the technical background for them to establish D&A standards, hence standards and solutions need to progress in parallel. The project uses an incremental design approach and has an interactive dialogue with major stakeholders to inform about the progress of the work and ensure stakeholder feedback which is key to the iterative approach, in close connection with the works of standardization groups like EUROCAE WG73.

Performing the development and standardization for future D&A technology in parallel is considered a key contribution for integration of manned and unmanned aviation flying routinely in non-segregated airspace.

The project logic is to a large extent based on the development of a safety case which in turn will be supported by simulations. Data from performed demonstrations and flight tests, with both manned aircraft and RPAS, will be used to correlate the simulations for confidence.

Target Level of Safety (TLS) is defined as the acceptable risk for collisions with other aircraft. This top event is broken down to all different contributors to a collision and results in safety requirements for the D&A system. The system engineering process has identified the need of three major functions in the D&A system; Situation Awareness, Traffic Avoidance and Collision Avoidance to assist the RPA pilot in fulfilling his responsibilities.

Situation Awareness provides the RPA pilot with necessary information to understand and interact with the D&A system and to communicate with ATC. The Traffic Avoidance function is needed to handle the responsibility of the RPA pilot to maintain separation to other airspace users in some airspace classes. The Collision Avoidance function is the last instance maneuvering to avoid an imminent midair collision when all other safety nets have failed.

The design work has completed the first two iterative design steps. Increment 2 has recently been evaluated in simulations and increment 3 design is now being finalized. Simulation evaluation includes different types of simulations incl Desktop simulations, Monte Carlo simulations and ATC simulations.

Desktop simulations are used to evaluate performances of the D&A design whereas Monte Carlo simulations generate statistical results from a large number of scenarios as input to evaluating overall safety levels achieved by the D&A system.

ATC simulations are used to evaluate the D&A system in an operational environment with air traffic controllers, airline pilots and RPA pilots to see that overall behaviour of the RPAS equipped with a D&A system is acceptable from the operational point of view.

Simulation evaluation will be followed by flight testing to evaluate the D&A design in real flight using first a manned test aircraft to get real environment feedback and in a second step to evaluate the system on a RPAS. Results from both simulations and flight tests are used to update and mature the design in the next iterative design step.

Presentation

Around the World with a Solar Powered Aircraft

Abstract:

The presentation will cover the design, development, and flight test of the Solarimpulse HB-SIA aircraft. The Solarimpulse program was initiated by Bertrand Piccard and Andre Borschberg in Switzerland in 2003.

It is the one and only manned solar powered aircraft which has demonstrated a more than 24 hour flight with more energy on board at the end than at the beginning. It is a true “all electric” aircraft.

An overview about the transcontinental mission flight in 2012 from Switzerland to Marokko and in 2013 across the United Sates will be provided as well.

Finally an outlook on the status of the development of the record aircraft HB-SIB, which is to start the flight around the world in 2015, will be given.

H.Ross
Member of the Solarimpulse Core Team

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Finite Element Model Correlations and Response Predictions of Spacecraft Structure

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Keywords: *Finite Element Model, Structural Dynamics, Model Correlation, Frequency Response, Base Force Assurance Criterion.*

1 Abstract

Finite Element Models (FEMs) are widely used to predict the behaviour of a complex structure such as a spacecraft before its realization. The capability of the model to accurately predict the performance of the actual system is vital for the successful completion of the mission and hence it is assessed by comparing the analytical results with the experimental data. Modal Assurance Criterion (MAC) and Normalised Cross Orthogonality (NCO) check are the most commonly employed methods in the space industry for the validation of FEMs. In order to match the degrees of freedom of analytical and experimental models, a test-analysis model is used in the NCO.

In this study, Monte Carlo simulations were used to determine the robustness of a System Equivalent Reduction Expansion Process (SEREP) based test-analysis model when experimental and analytical modes of different spacecraft contain various levels of inaccuracy. It has been observed that, the probability to clear the NCO check is determined mainly by the number of modes used in the SEREP reduction.

The effectiveness of MAC and NCO criteria on the response prediction of spacecraft models under the base excitation is also carried out. It is observed that neither MAC nor NCO is suitable to predict the forced response characteristics such as the peak acceleration response. Then, a criterion termed as Base Force Assurance Criterion (BFAC) is defined using the experimentally determined dynamic force at the base and the finite element predicted force in a similar way as MAC was defined. In this study, the results obtained from the real FEM of the spacecraft were taken as the experimental results and those obtained from intentionally erroneous FEMs were considered as the analytical results. The method is applied to assess the performance of different spacecraft models under base excitation and observed that BFAC can correlate the acceleration error in a better way than MAC or NCO.

2 Introduction

The modal assurance criterion [1] and normalised cross orthogonality [2] check are the accepted criteria in the space industry to assess the accuracy of the finite element model of the spacecraft [3, 4]. An accurate FEM is required as these FEMs are used in the coupled load analysis of the spacecraft and the launch

Application of the Mixed H2/H$_{oo}$ Method to Design the Microsatellite Attitude Control System

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Keywords: *microsatellite, robust control, uncertainty model*

Abstract

Due to the space missions' limited budget, small satellite cluster or constellation would be an economical choice. From risk-sharing viewpoint, a number of smaller satellites have a significant reliability advantage over a bigger one. By and large, artificial satellites are subject to two kinds of uncertainty: structure uncertainty that represent some satellite parameter variation and the unstructured uncertainty, which represent some kind of the satellite model error. On the other hand, the Satellite Attitude Control (SAC) design becomes more vulnerable to uncertainty disturbances like model error and moment-of-inertia variation as the satellite has great decrease in size and weight. This is the case for a microsatellite with mass less than 100kg where the ACS performance and robustness becomes very sensitive to both kinds of uncertainties. Therefore, the design of the SAC has to deal with the drawback between controller performance and robustness. The purpose of this work is to model a microsatellite and to perform a mixed Control via LMI optimization.

1 Introduction

Microsatellites play important role in space missions, such as position location, Earth observation, atmospheric data collection, space science and communication. Some spacecraft used to observation need high-accuracy performance on pointing requirement, so it's necessary to apply a three-axis attitude control, leading a multivariable control system [1]. In the face of disturbance and uncertainty, it's necessary to design a robust control for analysis and synthesis of attitude control system. Examples of satellite robust control system design using multi-objective and nonlinear approaches can be found in [2] and [3], respectively. Low orbit spacecraft are under a more strong influence of gravity gradient torque, aerodynamic torque and magnetic torque. Some equipment on the microsatellite like cameras, telescopes and solar array can move causing change on moment of inertia. Microsatellites with mass less than 100kg are more sensitive to moment of inertia variation and disturbances like external torques. In this work will be use a kind of robust control called mixed control. This combination was introduced by Bernstein and Haddad [4], the idea is to minimize a norm of a transfer