ESWIRP: European Strategic Wind tunnels Improved Research Potential
Program Overview

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SUMMARY

"European Strategic Wind tunnel Improved Research Potential" ESWIRP is a project in the EU 7th Framework program (FP7), which was aiming at improving the performance capabilities of three strategic wind tunnels in Europe, by strengthening the cooperation between these wind tunnels in a new consortium. The research consortium members are ONERA (operating the S1MA as its largest sonic wind tunnel), DNW (operating the LLF as its largest low speed wind tunnel), and ETW (operating its cryogenic wind tunnel). Together these wind tunnels cover a wide range of experimental conditions of relevance to civil aviation and aeronautical research in general.

The project started in October 2009 for a period of 5 years. The European financial contribution was € 7.2 million.

The project consist of two major parts: 1) the improvements to the testing infrastructure; and 2) the provision of wind tunnel access to research groups which do not usually have the means to access such large-scale test facilities. These topics also involved public dissemination and information activities.

Although the tunnels covered in this project are of complementary nature, the infrastructure activities are joined together, by a common representation of, and approach to, the tunnel performance characteristics. To this end, a generic model of a virtual wind tunnel was developed, enabling operators to assess the effect of the control parameters upon the testing conditions. The final aim of all participants was to provide the user community with an improved capacity to test their innovative ideas, and to be able to do this with increased reliability.

Providing access to those major wind tunnels, mainly concerned research groups from European universities, who had been targeted. The approach taken has included maximum transparency of the process, and support of the researchers by the organizations responsible for the tunnels. In addition, when possible, we encouraged research groups to work together, to obtain the full benefit of economies of scale in research projects.

ESWIRP responds to the targeted approach of the Integrating Activities of the FP7 Capacities Work Programme:

*****Networking activities****, essentially focused around 4 topics:*

- *Organization of information campaigns, lectures and workshops to disseminate knowledge between the partners and future users,*
- *Opening of a website for the consultation of wind tunnel standards,*
- *Exchange of personnel between the Consortium partners to foster spreading of good practices and the exchange technical know-how,*
- *Joint development of a reference wind tunnel parameter database.*

** **Trans-national access** and/or testing services: After the call for proposals by the facility providers, groups of researchers had the opportunity to have free wind tunnel services, including technical assistance to support the corresponding scientific research team(s).*

** **Joint research activities**: Through innovative modeling of wind tunnels, it has helped designers to make better decisions, before the implementation of novel hardware. This is the first time that mathematical modeling has created a standard for wind tunnels. The infrastructure improvements targeted the capability to obtain unsteady test data with high accuracy in the ETW, to improve the capability to simulate aircraft behavior in ground effect in the LLF, and to establish a reliable closed-loop Mach number control in the S1MA wind tunnel.*

ESWIRP is European support for strategic wind tunnels, key research infrastructures in the development process of current and future aircraft. This is the first time that European authorities have given such support.

NOMENCLATURE

AVS	*Anti-Vibration System*
CFD	*Computational Fluid Dynamics*
CRM	*Common Research Model*
CS	*Central Clock Generator*
CUs	*Conditioning Units*
DNW-LLF	*Large Low speed Facility*
DNW	*German-Dutch Wind Tunnels*
EAR	*"Entrée d'Air de Régulation" (additional air inlet for Mach regulation)*
ETW	*European Transonic Wind tunnel*
ESWIRP	*European Strategic Wind tunnels Improved Research Potential Program*
FP7	*7th Framework program*
GFN	*Glass-Fiber Network*
MBGP	*Moving Belt Ground Plane*
ONERA	*Office National d'Etudes et de Recherches Aérospatiales*
PIV	*Particle Image Velocimetry*
SRV	*Swirl Recovery Vanes*
TNA	*Trans National Access*
TR-PIV	*Time-Resolved Particle Image Velocimetry*
TSP	*Temperature Sensitive Paint*
UDAS	*Unsteady Data Storage*

1 INTRODUCTION

"European Strategic Wind tunnels Improved Research Potential" ESWIRP is a project in the EU 7th Framework program (FP7), which was aiming at improving the performance capabilities of three strategic wind tunnels in Europe, by strengthening the cooperation between these wind tunnels in a new consortium. The research consortium members are ONERA (operating the S1MA as its largest sonic wind tunnel), DNW (operating the LLF as its largest low speed wind tunnel), and ETW (operating its cryogenic wind tunnel). Together these wind tunnels cover a wide range of experimental conditions of relevance to civil aviation and aeronautical research in general.

2 THREE EUROPEAN STRATEGIC WIND TUNNELS

2.1 ONERA S1MA wind tunnel

The ONERA S1MA wind tunnel facility is a closed circuit atmospheric wind tunnel with a maximum speed near Mach 1, which provides unique capabilities for testing large models at cruising speed and above. The tunnel is located near Modane, France, and was erected after the Second World War. The tunnel has three exchangeable test sections with a diameter of 8m, which can be transformed into five different test section configurations. The benefit of having large models is essential for testing new concepts and having enough room within the models for housing various devices such as boundary layer control devices, remotely actuated mechanisms, drag reduction devices; aircraft control mechanisms both for handling qualities and efficiency improvement, laminar flow concepts, etc.

Civil transport aircraft developed over the last decades have been designed with a consistently increasing maximum cruise speed. The benefits retrieved from experimental work performed at S1MA are essential for future high-speed research. The S1MA represents a strategic facility which must be closely looked at in terms of capabilities to fulfill the increasing complex requirements of its users.

The design of the next generation of aircraft will be strongly influenced by environmental impacts considerations. Future aircraft configurations will have to compromise between fuel consumption reduction, low noise levels (cabin noise and noise nuisances to the surroundings) and performances. The trade-off between various options at high speed will ideally be determined at S1MA, which has already a long-term experience with motorized models, with high-pressure air supply necessary to study engine installation effects. In this respect, the accumulated experience with testing propeller driven aircraft at S1MA, will serve well for testing future rear-mounted open-rotors configurations, for instance.

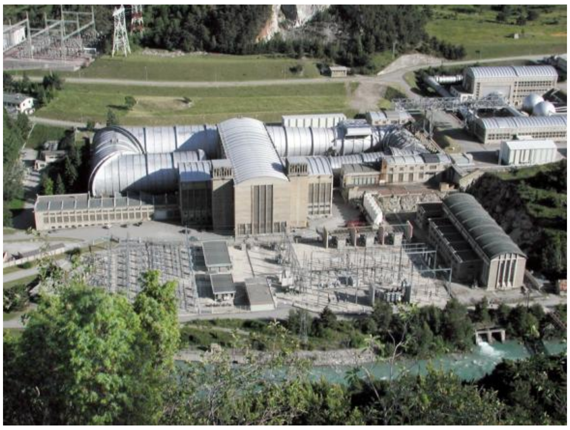
The large facility S1MA is need by aircraft manufacturers worldwide and by a number of researchers, which are taking benefit of its large size, and thus large models where very innovative ideas can be tested.

Amongst the leading criteria to use S1MA are:

- Its access cost,
- Its availability.

The ESWIRP project objectives for S1MA are to save 30 to 35% of the time necessary for an experiment by the way of providing improved quality data with no necessity to repeat data acquisition. This will have a double impact:

- Better quality of the data provided because the aerodynamic parameters will be acquired in perfectly stable conditions,
- Possibility to test more new research ideas for a given budget.



Overview of S1MA wind tunnel

ONERA S1MA test section
Diameter 8 meters
Length 14 meters

2.2 Large Low speed Facility DNW-LLF

The DNW-LLF is a closed circuit low-speed wind tunnel with a maximum speed near Mach 0.4. The tunnel is located near Marknesse in the Netherlands. The tunnel has been in operation since 1980. The LLF has two interchangeable test sections of 9.5m x 9.5m and 6m x 8m (height x width), respectively, with which four test section configurations including one open jet can be realized. The LLF has an internal balance sting system for model support and is further equipped with a Moving Belt Ground Plane (MBGP) with a maximum speed of 40 m/s. The MBGP is provided with a boundary layer removal system that scoops and re-injects the floor boundary layer air into the tunnel. The demand for further improvements in aircraft fuel efficiency as well as for reduction in noise generation around airports makes an upgrade of facility a necessity. Since landing and take-off phases of the aircraft flight are the major factor affecting population, the availability of the best possible experimental simulation capabilities for this phase, where the quality of tunnel, air flow and ground simulation perform an integral part in providing data in the exploration of new possibilities, is essential for progress.

The proposed technical upgrade of the LLF in the framework of ESWIRP foresees major improvements on the existing Moving Belt Ground Plane. Higher relative speeds than achieved today will be obtained. Therefore, the quality of the simulation of the relative motion between an aircraft and the runway will be higher and consequently a considerable increase in data reliability can be reached.

ESWIRP opens the possibility to initiate joint research activities with the Consortium partners to study the impact of the planned upgrade on flow simulation, to prepare the detailed design and to familiarize the aeronautics research community with the improvements in potential obtainable design from improved ground simulation.

Overview of DNW-LLF wind tunnel

Test section with a model
8 x 6 meters – shown here a landing (ground effect) test setup

2.3 Cryogenic wind tunnel ETW

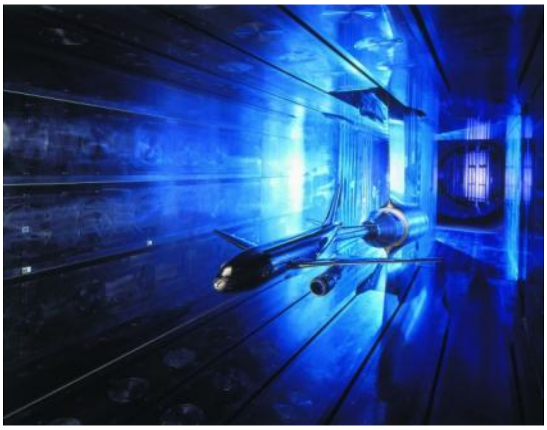
The ETW uniquely achieves real flight Mach and Reynolds numbers for transport aircraft at model scale. This unique capability is gained by cryogenic pressurized operation of the wind tunnel from low speed to a maximum speed of Mach 1.35 at real-flight Reynolds numbers. Using ETW, researchers are able to check scientific concepts for applicability at real-flight conditions effectively and efficiently at low risk. Therefore, ETW contributes to increase aeronautic innovation speed, and enables research to provide breakthrough technologies for ecological and economical optimization of future air transport. The ETW is in operation since 1994. Its test section dimensions are 2.0m x 2.4m (height x width). The test medium nitrogen gas can be pressurized up to 4.5 bar and cooled down to 110K.

Currently ETW has two exchangeable model support modules, so-called model carts for full model support that enable testing at Mach 0.8 up to 50 and 85 million in Reynolds number, matching flight conditions of aircraft as large as the Airbus A340 and A380, respectively. One of the model carts is adapted to allow as well half-model testing. By variation of pressure and temperature flow parameters like Mach number, Reynolds number and dynamic pressure can be varied independently. This enables a distinct separation of compressibility effects, Reynolds number and model deformation effects. Flow separation and its interaction with e.g. the model deformation or shock waves in the flow field in general is highly Reynolds number dependent. Unsteady interaction may occur which then initiates

model vibrations. These physical phenomena often determine the flight envelope boundary of aircraft, and thus its understanding and control is subject to aeronautical research. Compared with CFD and conventional wind tunnels, the ETW wind tunnel circuit itself uniquely facilitates to take into account these phenomena at flight relevant conditions.

The improvements through ESWIRP enable researchers to make better use of these capabilities due to the increased flexibility in tunnel access. The availability of a tool for unsteady force and moment investigations up to real flight conditions additionally opens a new unique area of wind tunnel testing.

Overview of ETW wind tunnel



ETW cryogenic test section
2.4 x 2 meters and 9m length

3 ESWIRP PROJECT - OBJECTIVES AND CONTEXT

The project started in October 2009 for a period of 5 years.

The project consists of two major parts:

1) networking activities between the 3 partners and implement some improvements to the testing infrastructures;

Although the tunnels covered in this project are of complementary nature, the infrastructure activities are joined together, by a common representation of, and approach to, the tunnel performance characteristics. To this end, a generic model of a virtual wind tunnel was developed, enabling operators to assess the effect of the control parameters upon the testing conditions. The final aim of all participants was to provide the user community with an improved capacity to test their innovative ideas, and to be able to do this with increased reliability.

The infrastructure improvements targeted the capability to obtain unsteady test data with high accuracy in the ETW, to improve the capability to simulate aircraft behavior in ground effect in the LLF, and to establish a reliable closed-loop Mach number control in the S1MA wind tunnel.

2) a provision of wind tunnel access to research groups which do not usually have the means to access such large-scale test facilities. These topics also involved public dissemination and information activities.

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ESWIRP responds to the targeted approach of the Integrating Activities of the FP7 Capacities Work Programme.

4 MATHEMATICAL MODELLING

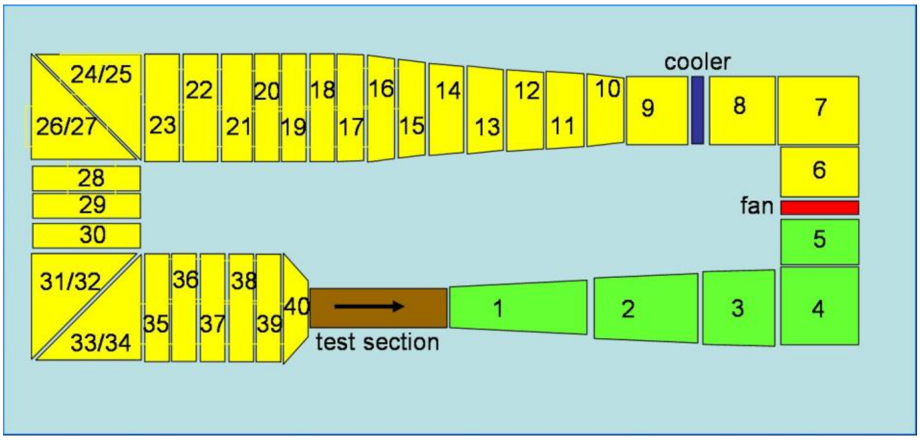
Through innovative modeling of wind tunnels, it has helped designers to make better decisions, before the implementation of novel hardware. This is the first time that mathematical modelling has created a standard for wind tunnels.

The objective behind this approach is that before such far going decisions as to the implementation of novel hardware are being made, the tunnel operator should have a model at his disposal that simulates the interaction between control inputs and physical phenomena in the tunnels and that gives maximum confidence that the new features will work satisfactorily and thus justify the scope of investments. In principle, the proposed model should be universal for all three facilities to demonstrate the complementarities but takes account of the peculiar properties of each. To achieve this it is foreseen that in addition to a generic numerical model three extra modules are required to cope with these diversities.

The mathematical model will consider the existing tunnel geometry, and will aim at a realistic representation of the physical phenomena in the flow. The tunnel will be divided in a number of single volumes defined by an entry station and an exit station (axially). The basic thermodynamic behavior such as: temperature exchanges, pressure loss, mass flow equation (injection or blow-off), will be considered at different stations along the circuit. The main drive of the facility (compressor or fan) will also be simulated, and the tunnel characteristics which are essential to the flow behavior (plenum volume, nozzle, fixed contraction, diffuser, second throat if any, test section, etc.). In the initial phase of the model development, the methodology will be similar for all 3 facilities, although each specific feature shall have to be addressed in a second phase.

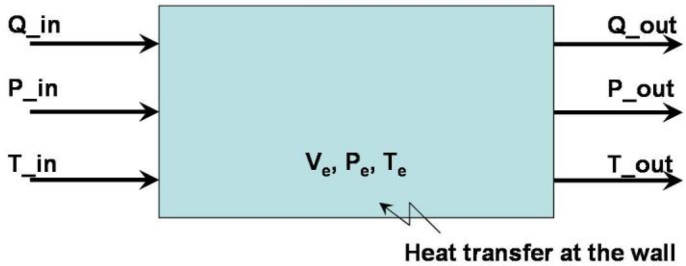
The generic wind tunnel has the same size as ONERA-S1MA, but with some simplifications: the air exchanges with the atmosphere are not simulated and flow temperature is controlled by the mean of an internal heat exchanger.

The circuit is divided into individual volumes in which the time dependent equations are resolved.



"Generic" Wind tunnel circuit diagram

The individual circuit volumes are characterised by their geometry (mean diameter, length and wetted area), their pressure loss coefficient and the thermal exchange coefficient through the walls.



Circuit element module inputs/outputs

The main control parameters of the generic model are the fan rotational speed (RPM) and the water mass flow through the heat exchanger.

Following the generic model, three dedicated models were developed, one per facility (S1MA, LLF and ETW). Each model is based on the generic model but adapted to the specific wind tunnel parameters.

5 INFRASTRUCTURE IMPROVEMENTS OF THE PARTICIPATING FACILITIES

5.1 ONERA S1MA improvement

The proposed upgrade of S1MA within ESWIRP program aims at improving the wind tunnel quality and productivity by implementation of a closed loop Mach number control system. The work has been to determine the best control strategy via a modeling of the flow behavior and then to design and implement a control mechanism.

To reach an acceptable situation the Mach number fluctuation should be limited to +/-0.001, at least up to Mach 0.9, which is an improvement by a factor 5 according to the existing situation. To achieve this goal it has been necessary to design and implement a flow control device at a station to be defined in the wind tunnel circuit.

An air inlet with flaps called EAR inlet ("Entrée d'Air de Régulation" – additional air inlet for Mach regulation) was studied. With this device a small mass flow rate is injected, goes through the fans and goes out by the annular outlet of the wind tunnel located just upstream the convergent.

The purpose of the EAR is to compensate the variation of the pressure losses coming from the model mounting by injecting a small air mass flow rate just upstream the fans of the wind tunnel. The EAR has been then located on the corner #1 of the wind tunnel which is just upstream the fans.

Main characteristics of the EAR

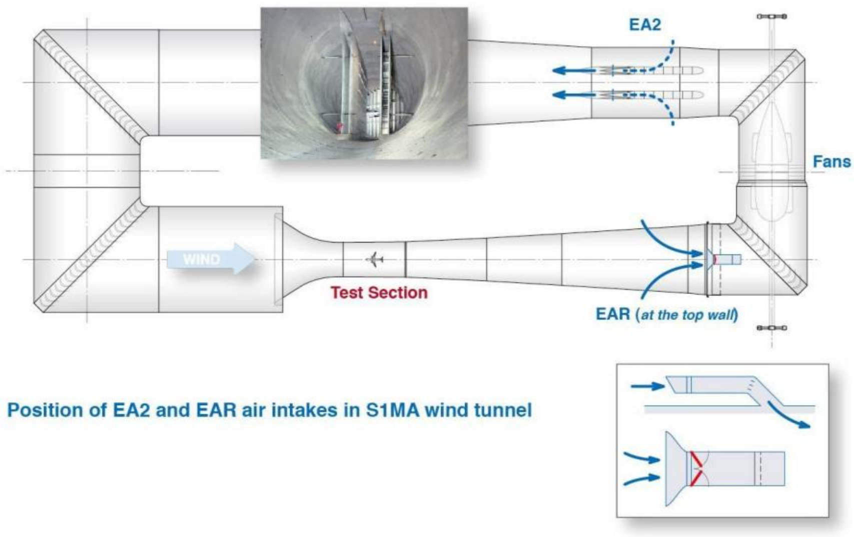
The EAR inlet is running by natural aspiration because the flow pressure inside the wind tunnel circuit in running is always lower than the outside atmospheric pressure. Its location on the corner 1 just upstream the fans is the best favourable one because the internal pressure there is the lowest of the circuit.

The difference of pressure used for the intake is usually included between 2000 and 6000 Pa according to the Mach number and to the pressure losses of the model mounting in the test section. The maximum air rate of the intake is estimated by aerodynamic calculation at 250 kg/s.

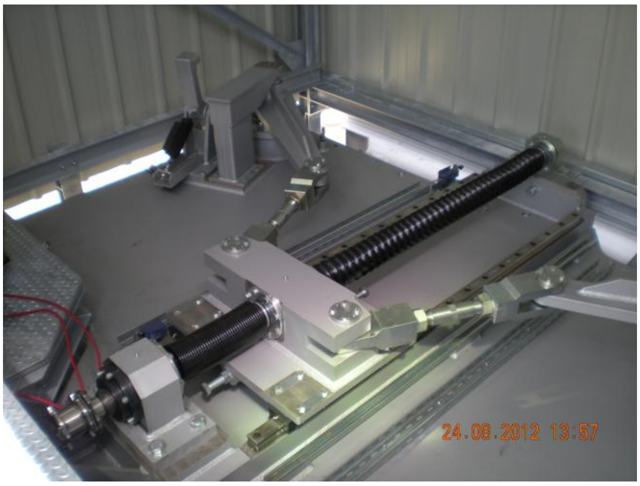
From upstream to downstream the aerodynamic EAR inlet circuit consists of:

- A rectangular convergent with an inlet protection grid of section 4,50 m x 1,60 m which aspirates the air below the existing roof of the so called "air inlet 1" of the S1MA wind tunnel.
- A central caisson of section 2,50 x 1,05 m including two vertical flaps. The aperture angle of the flaps can continuously change between 0° (open position) and 75° (closed position).
- A bend at 45° including 4 blades in order to guide the flow.

The motorization of the flaps is mounted above the central caisson and includes an electric motor with a central screw and two rod-crank mechanisms. The motorization is protected by a shelter which includes also the electric closet. The EAR includes also a footbridge at each side of the circuit for the maintenance.



The mounting of the EAR inlet on the corner 1 of S1MA took place during summer 2012.



EAR inlet circuit mounted without the shelter

Motorization of the flaps

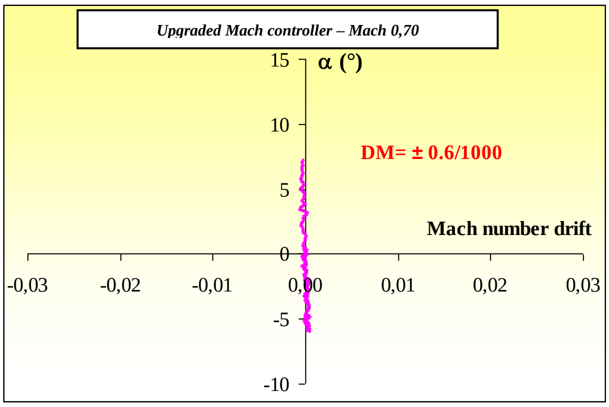
Tests performed to qualify the new Mach number regulation system

Tests were performed in November 2012 using a civil aircraft model at a scale of 1/26 in test section n° 2 – 45 m^2 of the ONERA S1MA wind tunnel in order to qualify the new Mach number regulation obtained with the help of the EAR air inlet.

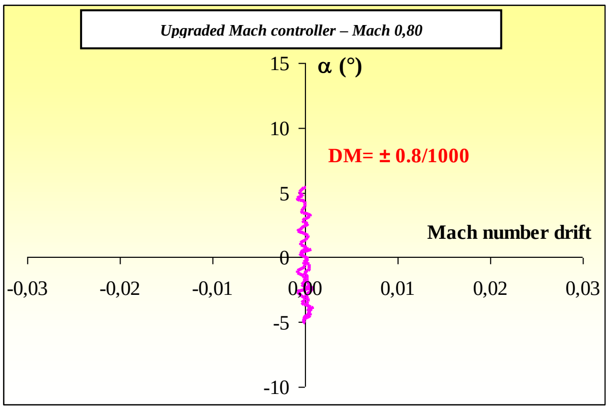
Measurements were performed on one hand with the classical Mach number regulation with the main air inlet and on the other hand with a new regulation, specially developed in accordance with this new additional air inlet (based on the previous developments with large air intake, the idea was to use fan's RPM control to compensate large pressure losses with some time delay in association with a device which can generate limited but fast pressure variations in phase opposition with those of the model during its pitch motion).

The efficiency and the effect on the model of the EAR air inlet were evaluated.

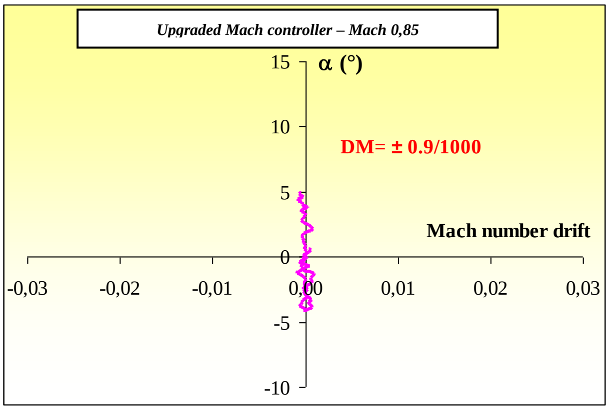
Mach number drifts with the revised controller are presented on figures below:



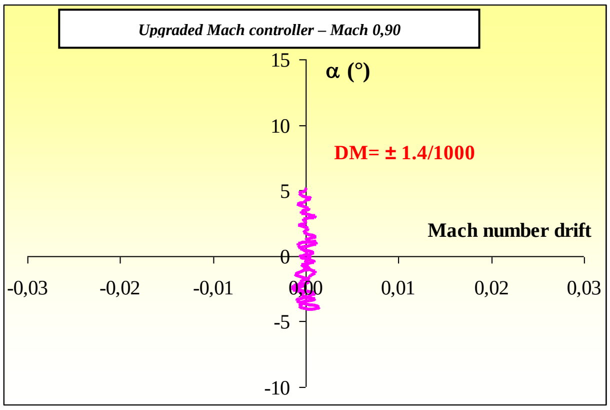
Mach number drift during pitch sweep - Final regulator 2014 – M0=0.7



Mach number drift during pitch sweep - Final regulator 2014 – M0=0.8



Mach number drift during pitch sweep - Final regulator 2014 – M0=0.85



Mach number drift during pitch sweep - Final regulator 2014 – M0=0.90

Plots on figures above illustrate the impressive improvements achieved on S1MA Mach number controller. Indeed, nearly no drifts are observed for all the Mach numbers, even at negative angle of attack.

5.2 DNW- LLF Upgrade

The DNW-LLF wind tunnel has specifically been designed for testing take-off and landing conditions of aircraft. For this purpose, an important simulation technique is the so-called ground simulation. The runway is simulated by a moving belt system with a current maximum belt speed of about 40 m/s. The system furthermore comprises of a boundary layer removal system that scoops and re-injects the floor boundary layer air into the tunnel.

The upgrade of DNW-LLF foresees in a major improvement of the moving belt. The adaptations will enable an improved simulation of the relative motion between a powered aircraft model and the simulated runway.

The required improvements relate to:

- flatness of the belt under expected future heavy upward and downward aerodynamic loads;
- prevention of hot areas on the belt due to friction with the belt bed;
- wear of the belt and therefore a longer lifetime of the belt;
- tracking of the belt under asymmetrical aerodynamic loads.

The realization of these improvements will give a better simulation of the take-off and landing of aircraft, especially for future new engine concepts. The reliability of the system will improve and consequently increase productivity that can be offered to the aeronautic community.

The upgrade concentrates on improvements regarding:

- control concept of the belt,
- belt bed,
- belt suction/blowing system,
- cooling system.

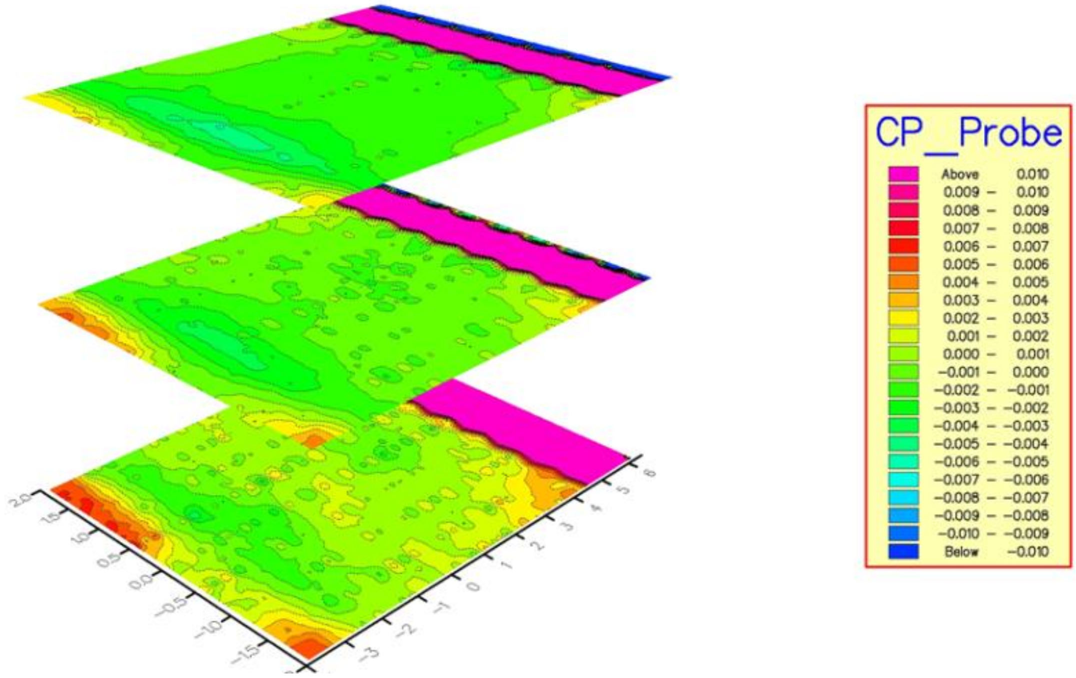
For each item a feasibility study was performed detailing potential benefits and making cost trade-offs. They indicated that the required ground simulation improvements cannot be realised with the existing system (multi-layered fabric belt). The potential benefits can only be realised by implementing a metal belt system.

The metal belt system

The new belt specifications are:

- Belt size 7.92 m x 6 m
- Maximum belt speed Mach 0.25 (80 m/s)
- Longer life-time
- The belt remains flat under the influence of aerodynamic forces introduced by models above the belt
- The flatness of the belt can be measured to enable an automated reaction by the air suction/pressure system
- Boundary layer removal by existing ground-plane (200 mm scoop)

The system corresponding to the above requirements was manufactured by an external company and installed in the beginning of 2013. After a site-acceptance test a dedicated test in the DNW-LLF was performed to optimize the belt settings. They were optimized to obtain a homogeneous pressure distribution above the new moving belt. After optimization a static pressure coefficient $|Cp| < 0.003$ above belt exists up to the nose.



Static pressure distributions of 10 m x 4 m size at 500 mm above the belt for three different velocities: V = 40, 60 and 70 m/s.

The new DNW-LLF belt system is operational for customers since March 2013. The new belt system is a superior ground simulation technique, which meets all DNW requirements. The first industrial test has already been performed in April 2013.

5.3 ETW Upgrade

The design and development of modern high quality transport aircrafts implies the needs of operating closer to the physical flight boundaries. As the flow fields in these regions are characterised by complex 3-dimensional and unsteady behavior the industry is expecting from the wind tunnel performers also accurate and reliable test data from such areas. Those requirements can only be satisfied by providing sophisticated modern instrumentation, ideally non-intrusive one, validated for the cryogenic pressurised operating range of ETW, which is representing the prerequisite for simulations at flight conditions.

The ETW improvements was focused on the provision and verification of appropriate tools and techniques with respect to improve / enhance the test capabilities of ETW and, therefore, extending the portfolio for their customers.

In the frame of the present project 12 individual topics have been identified to be considered for implementation or upgrade which can globally be structured in two main categories, namely the "Enhancement of unsteady/aeroelastic Test Capability & operational Productivity" and the "Development and conceptual Proof of an RC-Slot System".

Enhancement of unsteady/aeroelastic Test Capability & operational Productivity

EXTENSION OF OPERATING RANGE WITH RESPECT TO THE MAXIMUM EIGENFREQUENCY (E-RANGE)

Using a half model for aeroelastic testing is typically striving for an assessment of the unsteady behaviour of aerodynamic forces and moments, pressures and the corresponding model shape. While the base frequency is mostly below 100 Hz first and second harmonics, often stronger amplified, appear at frequencies of a few hundred Hertz. Hence, allowing for a proper analysis and assessment

of aeroelastic characteristics the Eigenfrequency of the model/balance support system should be acceptably higher.

While determining this status, the half model balance was also meshed and subsequently Eigenfrequencies were calculated using a finite element (FEM) code. Meanwhile the mechanical structure itself has been equipped with a series of accelerometers for in situ measurements during testing.

The calculated Eigenfrequency (230Hz) is lower than the measured one of 300Hz. In the follow–on considerations no feasible solution for a reinforcement of the frame structure could be worked out. The modification of the structure of the complete model cart was not been considered as an acceptable improvement in the frame of this project.

INCREASE SPEED OF DYNAMIC MODEL DEFORMATION SYSTEM UP TO 1 kHz

(D-SPT)

With respect to a tracking of the unsteady deformations of wings or high#lift model components the recording capacity of the existing SPT systems was completely inadequate. Hence, a new system based on more modern cameras with increased frame rates but acceptable resolution had to be found and combined with according optical components like objectives, cables, connectors, light sources etc. Following the procurement and software adaptations provided by the supplier basic system trials have been performed in the lab.

This tested system revealed a reliable operation with a frame rate up to 386 Hz providing full resolution and viewing field. It has been installed and operated in the TNA entry for monitoring the behaviour of the HTP of the CRM full model.

TRANSITION DETECTION BY CONDITIONAL SAMPLING (CS-TSP)

The boundary layer transition detection by Temperature Sensitive Paint (TSP) has been successfully developed in cooperation with DLR more than a decade ago and permanently enhanced and automated for cryogenic operation so, that it may be considered as a mature technique. Regarding unsteady measurements the implementation of a phase sampling capability was looking essential and feasible. Unfortunately, all TSP hardware including the paint, the processing and post-processing software as well as the operational knowledge was owned by DLR, hence, their special team had to be recruited each time when an application in ETW was required. This situation in the present period of increasing demands on laminar flow investigation at near flight Reynolds numbers is causing an inacceptable reduction in operational flexibility due to the naturally limited availability of the DLR team.

Consequently, the sub-project CS-TSP aimed at upgrading the conditional sampling as mentioned above, as well as for transfering of hardware, knowledge and software to ETW, including staff training, thus giving a high level of independence to ETW. Hardware has been procured including cameras, objectives, heated boxes and PCs for image control and data processing.

Nowadays, the system can be operated by ETW staff leaving the provision of paint by purchase order to DLR.

UPGRADE FROM STANDARD CRYO#PIV TO TIME RESOLVED CRYO#PIV (TR-PIV)

The general application of the Particle Image Velocimetry (PIV) for non-intrusive flow field measurements in wind tunnels is considered mature for operations at and near environmental test conditions. Also with respect to the approved TNA-entry in the wind tunnel the developed and operated system had to be upgraded for allowing unsteady PIV measurements of wake flows at cryogenic pressurised conditions at low and high Mach numbers. Applying the technique to the according full model revealed the need for a) the design and manufacturing of a new smaller temperature controlled housing for the optical module to be placed below the test section floor, b) the design and manufacturing of a similar large box for the only suitable high speed camera and c) the implementation of a complex new light path for the laser beam. All those challenging tasks have successfully been achieved on time for serving the TNA-entry in ETW, hence, fulfilling the mandatory prerequisite for the relevant project objective.

INCREASE OF THE CAPACITY OF THE UNSTEADY DATA ACQUISITION SYSTEM (UDAS)

The formerly existing unsteady data acquisition system limited the number of input channels to 64.

Based on experiences gathered in recent test campaigns this low number is not adequate for fulfilling client's needs on signals to be acquired in a typical aeroelastic test. Further on, the capacities on electronic filtering units was insufficient too as well as the complete lack of an individual excitation capability for each channel. Comprehensive discussions with the provider of the old system revealed the general possibility of extending the number of input channels but without being able to upgrade the existing hardware to the required standard. Hence, a new 128 channel system has been designed according to ETW's specification, tested for acceptance and finally integrated into the measurement pool.

NEW HALF-MODEL BALANCE FOR REDUNDANCY AND FAST EXCHANGE (NEW HMB)

The existing ETW balance for half model testing has been procured in the last century. Installed in the ceiling of a model cart it can only be accessed after having removed the test section ceiling.

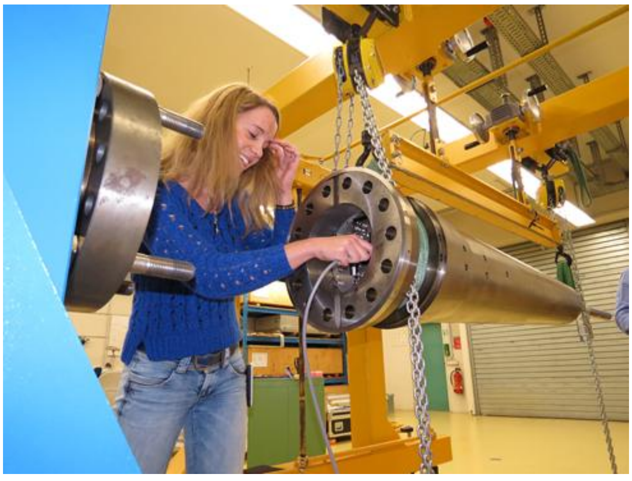
Regarding half model testing no other balance is available for substitution in case of a defect or failure requiring a long period out of service. A critical careful analysis of operations and experiences gathered over more than a decade paved the platform for a new specification containing a set of selected modifications and improvements. In this context the major item has been the provision of a capability to install the new balance without removal of the test section ceiling (a part of a model cart) for time saving reasons. Regarding the load capacities, sensitivities and accuracy no modifications have been made. The raw material for the manufacturing of the frame could be taken from the ETW stock; instrumentation was kept in the responsibility of ETW experienced staff and installed outside the project. These activities are presently still ongoing to be followed by a careful calibration.

THE 2ND ANTI-VIBRATION SYSTEM FOR REDUNDANCY & TIME SAVING (NEW AVS)

For supressing model vibrations due to Eigenfrequencies and, hence, being able testing up to higher angles of attack ETW is operating an in house developed anti-vibration system named ERAS due to the cooperation with an industrial company. While one system is located between the balance and the sting, another system based on linear motors fighting pitch and heave modes is embedded in stub-stings. Unfortunately, a single system is available only but this sensitive piece of equipment has to be removed and installed in different stub-stings depending on the individual test requirements.

To overcome this bottleneck the provision of a 2nd exchangeable system had been considered simultaneously providing a redundancy in case of need for avoiding down times when testing full models.

First considerations did only aim for the provision of a 2nd AVS identical to the existing one but the manufacturer informed that the supplier of the linear motor did not exist anymore. When finally going for an alternative motor this one was not compatible anymore with the existing old drive and control system and had to be replaced and adapted to the new systems. At the end two identical exchangeable AVS no. 2 systems have been ordered and delivered together with the new corresponding control unit.

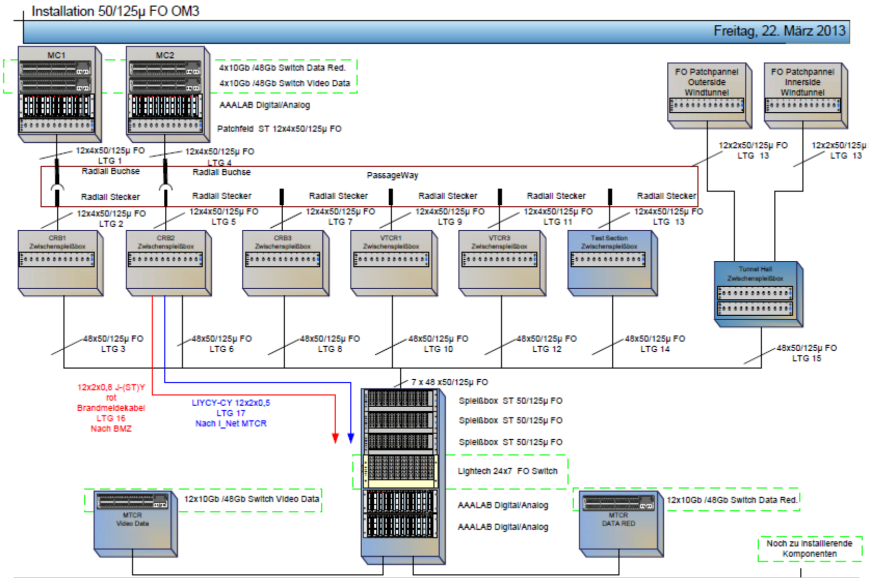


Anti-Vibration System for redundancy & time saving (new AVS)

EXTENSION AND UPGRADE OF THE GLASS-FIBRE NETWORK (GFN)

The high operating costs of cryogenic wind tunnels demand a high level of reliability and quality of data transfer for all systems being activated in a test. This requirement is of major importance in ETW where the tunnel is about 70m away from the main tunnel control-room and series of cables and fibres are running through cryogenic and ambient environment directly to it or to the instrumentation cabin at first and subsequently down to the control units and PCs. Having started tunnel operations in the 90's by using classical copper cables the capabilities of modern measurement and control systems cannot be adequately supported by this type of cable but requiring glass-fibre connections.

The developed and realised concept is based on using 50/125m glass-fibres of the premium quality OM3. Regarding the hardware components, it is at first compiled of 2 pairs of analogue/digital converters, each located in the instrumentation cabin on top of the model cart and in the main control room.



GLASS-FIBRE NETWORK architecture

UPGRADE OF THE CONDITIONING UNITS (ECUS)

Since the early 90's, ETW is operating about 160 conditioning units (CUs) developed by the Dutch research organisation NLR mainly used for the digitisation of analogue signals. Nowadays, their capabilities are not appropriate anymore and some specific features are simply missed. Contacting the original provider and discussing present needs it turned out that no complete replacement of the devices is required rather than individual upgrades by exchanging the main circuit boards to be newly developed. Following the distribution of an RFP the finally settled modification went for a replacement of all these boards for enhancing the capabilities, focussing on a replacement of the data bus by a modern Ethernet bus, the integration of a "True RMS" function and adding a certain number of DAS Hubs for connecting unmodified DAS-bus data acquisition equipment.

In a first step the NLR developed a new circuit board in cooperation with ETW for comprehensive validation testing of the prototype by ETW experts. Following its acceptance all new boards have been provided and installed in the existing units.

TIME SYNCHRONISATION FOR MULTIPLE MEASUREMENT SYSTEMS USING A CENTRAL CLOCK GENERATOR (CS)

Along the performance of unsteady measurements using individual systems no synchronisation of signals is applied as sketched in the upper part of any reliable analysis and a deeper understanding of the flow field behaviour. Moreover, the individual measurement system may be subject of time-wise drifts.

It was concluded that for a clock synchronisation system high precision is required on one side but accessibility and individual adaptivity is to be provided on the other hand with respect to the wide

range of applications specified by ETW and, consequently, a relevant system could only be developed in house.

For the technical approach a suitable clock generator was considered sufficient being able for generating pulses between 0.01 Hz and 10MHz, hence, covering the data acquisition needs and allowing the simulation of an oscillator.

Beside the capability of synchronising input signals in time the system will also allow generating precise signals and time-stamps by itself for triggering external devices.

ENHANCEMENT OF UNSTEADY DATA STORAGE CAPACITY (UDAS)

Initiating activities for improving the capabilities for investigations of unsteady effects is typically attended by the needs for an enhanced data storage capacity. In the present case the acquisition of e.g. dynamic model deformation data and time#/phase resolved TSP and PIV data are pushing for the availability of modular data acquisition and analysis systems for gathering and storing significant amounts of data. Hence, appropriate data storage is the key to provide reliable and rapid "turnaround", i.e. quick saving and access of data for allowing ad hoc detection of testing errors, discrepancies, failures or loss of data. Further on, the operated system has to ensure reliability by automatic health monitoring combined with the capability of being configured for supporting a wide range of individual test setups with different modular measuring techniques and their according components.

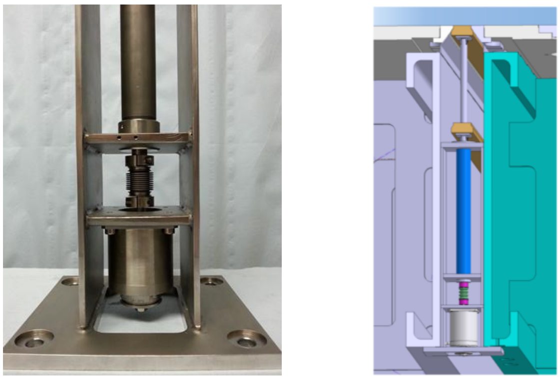
Having performed a thorough evaluation of offered systems with respect to the above equirements a specific unified scalable Gigabit-connected Network Attached Storage (NAS) solution has been selected. This high performance system is using a special operating system providing quick data-read and –write access, inherent redundancy for high access availability and application aware backup/recovery/cloning. Its particular strength is an intelligent use of caching to decouple storage performance from the underlying physical disk-array layout. It uses Non-Volatile Random-Access Memory (NVRAM) as a journal of incoming write requests allowing the system to commit write requests to non-volatile memory responding to writing hosts without delay. Beside other unique features the data acquisition may continue writing a stream of data while preliminary data analysis starts checking consistency and quality of the acquired data. Intelligent continuously running cloning/backup algorithms will significantly reduce the risk of losing valuable test data.

Development and conceptual Proof of a RC-Slot System

Wind tunnel walls may be solid, slotted or perforated. Striving for a transonic wind tunnel with low wall interference the original ETW configuration for testing full models is characterised by longitudinal slots in the floor and ceiling of the test-section. By the end of the last century the capability of testing half-models has been added requiring the attachment of such models to the ceiling for keeping the capability of transporting the model in and out by taking the benefit of the model cart concept. For this type of testing all walls may be closed or, for high speed operation, slotted but then with the top and bottom wall closed. The slot configuration is achieved by using prefabricated inserts being manually bolted to the wall structure. Logically, the relevant work requires access to the tunnel under environmental conditions.

Depending on the individual test scenarios and the tunnel status at the end of a campaign (cold or warm) the nitrogen gas in the tunnel has to be released and the tunnel warmed up and purged before getting access. Additionally to this time consuming and costly procedure the test section will be blocked by the slot exchange team for any parallel work. Several approaches to overcome this bottleneck and saving cost and time have been initiated without finding an efficient and acceptable technical solution. The re-consideration in ESWIRP targeted to investigate new concepts and performing a proof of concept in the cold at the end.

An essential aspect for the design has been the requirement of not affecting in any way the flow around the test object, which would lead to a complete recalibration of the tunnel over the full operating range.



RC-Slot system - Gliding part with drive

In the next step a suitable motor including gear has been validated in operation and output power at cryogenic conditions. The experiments were conducted loading the motor by connecting proper weights for simulating realistic conditions including friction.

Subsequently, a full scale demonstrator of a single slot channel device has been built and tested under ambient and cryogenic conditions in the variable temperature room.

6 TRANS NATIONAL ACCESS (TNA): INFORMATION CAMPAIGN AND CALL FOR PROPOSAL

A series of three workshops have been organized in order to give maximum opportunity to research groups to propose and discuss potential projects with the three ESWIRP consortium members. Invitations for the workshops were sent out to experts at aeronautic university faculties and industry from the European Union and its Associated Members. All of these three ESWIRP workshops took place near one of the participating wind tunnels and lasted for two days.

The ESWIRP website presented all relevant information for the workshops (i.e. topics, deadlines, workshop announcements etc.) including an expert system enabling potential users of the facilities matching their needs with the Consortium's capabilities.

At all workshops both the ESWIRP wind tunnel experts and the independent experts, who later on formed the "ESWIRP review team", were present to advice and support the project teams. Shortly after the accomplishment of each workshop its complete documentation was published on the TNA webpage of the ESWIRP website "www.eswirp.eu". The Consortium has organised 3 workshops with a progressive approach.

First workshop – Cologne – ETW facility – November 2010

- To collect a first panel of ideas, and confront various test objectives

Second workshop – Modane/Bardonecchia – S1MA facility – March 2011

- To consolidate the ideas for the projects for forming potential consortia

Third workshop – Zwolle/Marknesse – LLF facility - October 2011

- To prepare answers to the call for proposal
- To implement consolidation of the interested partners

30 participants including the ESWIRP team attended the first workshop.

During these 3 workshops tours to each of the participating wind tunnel were organised, all participants had the opportunity for discussing measurement techniques and tunnel capabilities with local experts. This clearly contributed to a better understanding.

It was the opportunity for the participants to gather sufficient information to be able to answer the TNA call for proposal. Technical information on wind tunnel capabilities, through technical presentations and visits, were given during these 3 meetings and mail exchanges between the workshops. During the meetings, it was also possible for them to ask the Consortium about administrative rules for this TNA.

During the 3 workshops, the Consortium reached more than 80 persons, coming from 12 countries. After the third Workshop, the Consortium has issued the Call for Test Proposals. Four projects were selected.

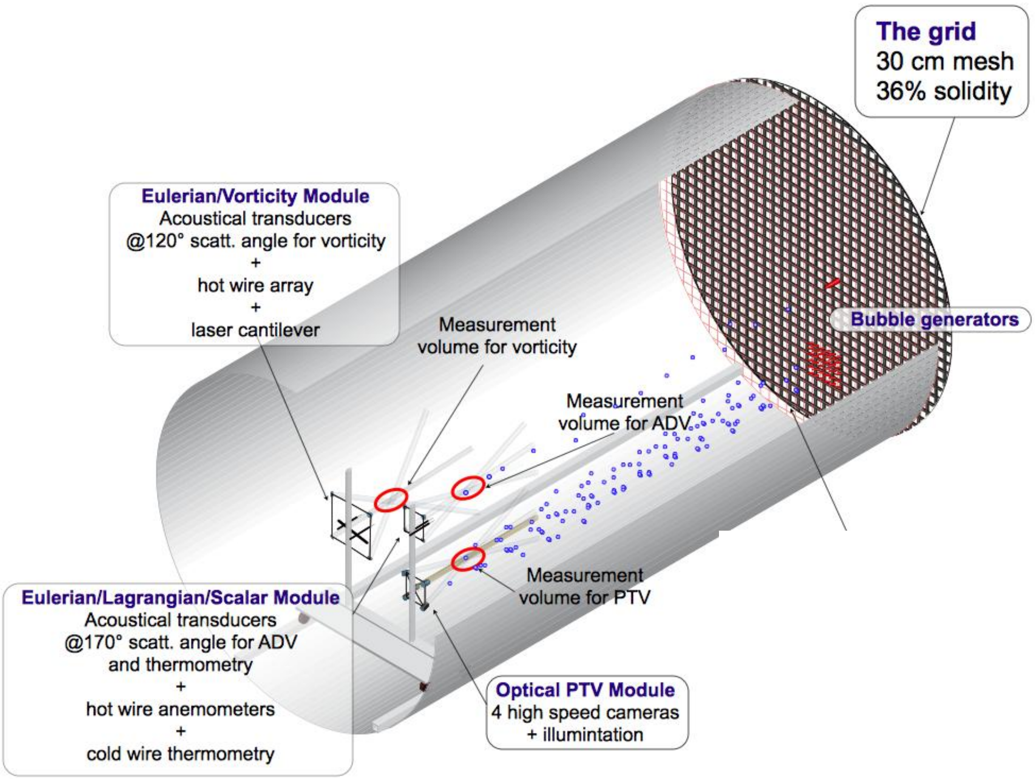
6.1 Project for S1MA wind tunnel

Investigation of the small scale statistics of turbulence in the Modane S1MA wind-tunnel

The proposal aims at a detailed experimental investigation of the statistical properties of turbulent flows at large Reynolds numbers. Though computational fluid dynamics has known impressive progress in the last decades, so have the requirements in terms of modelling accuracy. Effects of turbulence are among the most difficult to simulate and predict and they still require fundamental investigations and experiments to be better understood. As recently discussed during a dedicated session of the French Academy of Science, dedicated to advances in fluid mechanics research, one crucial and well identified challenge concerns the comprehension of energy cascade and dissipative mechanisms of turbulence which have important consequences in practical situations as aerodynamics, combustion, pollutant dispersion, etc.

The primary goal is to take advantage of the unequalled large-scale dimensions of the ONERA S1MA wind tunnel facility in Modane, to make available to the broad scientific community experimental turbulence data with unprecedented resolution (both spatial and temporal) and accuracy (in terms of statistical convergence quality).

The experiment focuses the study on grid generated turbulence. A large scale grid (10m in diameter, with a mesh size of 0.625m) was used as turbulence generator, as it is known to produce canonical homogeneous and isotropic turbulence. This is an academic flow known to produce almost perfectly homogeneous and isotropic turbulence (HIT) which remains a unique playground to investigate fundamental properties of turbulent flows. The characteristics of turbulence were measured downstream by different instruments mounted on a mobile cart in the test section from X ~ 0 to X ~ 15 m. Measurements were performed during some fifteen hours of testing, at six X positions of the mobile cart and for velocities in the test section ranging from 20 m/s to 45 m/s.



Sketch of the planned experiment. The cylinder represent the test section S1MA (8m in diameter and 14m long).

The objective is to produce a database as complete as possible, in terms of characterization of the turbulence, which will help the research community to get a better insight in longstanding mysteries which still limit the capacity to understand and accurately model turbulent flows.

These include, among others, turbulence intermittency, mixing and dispersion properties, and the link between Eulerian and Lagrangian descriptions of turbulence. For this purpose, several measurements have been implemented:

- Hot-wire anemometry
- Laser cantilever anemometry
- Lagrangian particle tracking
- Vortical acoustic scattering
- Micro-pitot tubes

To achieve this ambitious project, a large international consortium of 22 scientists with complementary expertise allowing to span a large spectrum in terms of measurement techniques, high resolution instrumentation and signal processing has been selected.

The laboratories involved are given below:

- Laboratory LEGI - Laboratoire des Ecoulements Géophysiques et Industriels (Grenoble)
- Institut de recherche en sciences et technologies pour l'environnement et l'agriculture - IRSTEA (Rennes)
- Neel Institute(Grenoble)
- LEGI (Grenoble)
- ENS-Lyon
- Laboratory PPRIME (Poitiers)
- Laboratory COmplexe de Recherche Interprofessionnel en Aérothermochimie - CORIA (Rouen)
- Academy of Science of the Czech republic

- University of Oldenburg
- Max Planck Institute (Gottingen)
- Royal Institute of Technology - KTH (Stockholm)

From a scientific point of view, although the acquired data just started to be processed, the ESWIRP TNA team says the campaign has been successful. The first analysis shows indeed that the smallest scales of the flow were well resolved what the main challenge was. The different diagnoses are consistent within each other, with different levels and ranges of noise. The combination of the data recorded with the several instrument should improve the overall quality of the measurements. The coming months will be devoted to a deep quality assessment of the acquired data, in order to quantify precisely the actual resolution of the several performed measurements and to build a complete database, ought to become open to the scientific community within a period 2 years starting from the completion of the database.

6.2 Project#1 for LLF wind tunnel *- Investigation of the APIAN propeller in non-uniform flow (APIAN-INF) in the DNW-LLF*

Because of their high propulsive efficiency compared to turbofans, propellers are generally considered as an interesting option for the propulsion system of future generations of passenger transport aircraft. The large rotor diameter(s) combined with interior noise constraints have driven possible propeller aircraft lay-outs towards a rear-fuselage mounted pusher propeller configuration. In this setup, the propeller blades operate in the wake of the upstream pylon, leading to non-uniform inflow on the propeller disk, hence unsteady blade loads and associated increased propeller noise emissions. Literature has shown that pylon blowing can mitigate this noise penalty due to the pylon wake interaction by re-filling the pylon wake deficit. The proposal aims at experimental and numerical investigations of the aerodynamic and aero-acoustic response of an isolated propeller in a non-uniform flow field caused by an upstream installed pylon model. For this purpose the existing and well investigated propeller model from the European APIAN project is reused.

The primary goal is to take advantage of the large scale dimensions of the German-Dutch Large Low speed Facility (DNW-LLF) wind tunnel facility in the Netherlands, to make experimental aero-acoustic and aerodynamic data with high quality available to the scientific community. Especially the large open jet test section with the acoustic absorbing treatment on the walls is suitable for acoustic far-field measurement.

The first objective of the experiment focuses the study on aero-acoustic measurements of far-field data with different measurement techniques. For the measurement of unbiased narrow band data a large number of inflow microphones could be traversed over a wide range of 10 m in stream wise direction to the propeller model. With another large set of fixed microphones outside of the flow the directivity of the propeller noise could be measured over a wide directivity range at a distance of up to 20 m from the source. By means of 3 phased microphone arrays the distribution of the noise sources is localized from different observer positions outside of the open jet flow.

Acoustic measurements with the propeller model were performed during some twenty four hours, at several positions upstream and downstream of the propeller model and for a range of velocities between 40 m/s and 70 m/s and a range for the angle of attack between +/-6 deg.

The second objective of the experiment focuses the study on aerodynamic flow around the propeller by means of three components participle image telemetry (PIV) measurements. PIV-measurements were performed during some twenty four hours, at several positions upstream and downstream of the propeller model and for a constant velocity of 60 m/s and a range for the angle of attack between +/-6 deg.

For both the acoustic and aerodynamic measurements three main configurations were investigated:

- Isolated propeller
- Propeller with pylon installed upstream of the propeller with several pylon blowing rates
- Propeller without pylon and installed swirl recovery vanes (SRV)

The third objective of the experiment focuses on the calibration of the inflow and out-of-flow measurement systems by means of two artificial acoustic calibration noise sources.

- Plasma noise source based on spark technology (provided and operated by ONERA)
- Calibration noise source based on loudspeaker technology (provided and operated by Airbus)

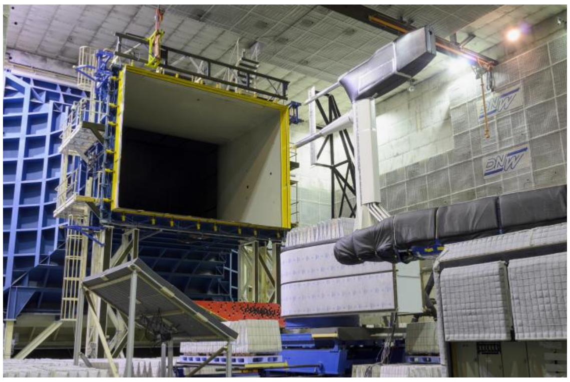
After the removal of the propeller model these sources are placed at the former location of the propeller. Acoustic calibration measurements were performed during some twenty four hours, at several positions of the sources and different signal types. The sources are operated for a range of velocities between 40 m/s and 80 m/s.

For this purpose, several measurements have been implemented:
- Acoustic measurements:
- Inflow far-field microphone technique
- Out-of-flow microphone technique
- Phased microphone array techniques
- Plasma spark calibration noise source (by ONERA)
- Loudspeaker calibration noise source (by Airbus)
- Rotor performance measurements
- Rotating shaft balance (RSB) technique
- Torque meter
- blade pressure sensors (27 Kulites)
- RPM signals
- Flow measurements
- Standard wind tunnel parameter
- Model position
- 3 components particle image velocimetry (PIV) technique

To achieve this project, an international consortium of about 20 scientists with complementary expertise allowing to span a large spectrum in terms of measurement techniques, high resolution instrumentation and signal processing has been selected.

- Technical University of Delft (The Netherlands)
- Research institute INCAS (Romania)
- Research institute TsAGI (Russia)
- University of Cambridge (United Kingdom)
- Technical University of Braunschweig (Germany)
- Research institute DLR Braunschweig (Germany)
- Research institute ONERA (France)
- Airbus industries (France)

APIAN-INF propeller model with installed pylon



Acoustic calibration setup with installed loudspeaker noise source (provided and operated by Airbus).

Although the acquired data could only be online processed and preliminary reviewed, the ESWIRP TNA team says the campaign has been successful. The amount of acquired data is much larger than expected. For a research test the productivity of the PIV and acoustic measurements was surprisingly high and is comparable to an industrial test program. The first analysis of the acoustic data and the PIV data show indeed that the pylon wake interaction noise with the propeller can successfully be reduced by means of controlled pylon blowing. Furthermore, it could be demonstrated that by means of a static rotor installation, like the applied swirl recovery vane system, some characteristics of a counter rotating open rotor (CROR) propeller system could be investigated by a more experimental simplified test setup.

The different acoustic measurement techniques, like the inflow and out-of-flow far-field measurements and the phase microphone array measurements are consistent within each other, with different approaches and observer positions. The combination of the data recorded with the several instrument should improve the overall quality of the measurements. The coming months will be devoted to a deep quality assessment of the acquired data, in order to quantify precisely the actual resolution of the several performed measurements and to build a complete database, ought to become open to the scientific community within a period 2 years starting from the completion of the database.

6.3 Project#2 for LLF wind tunnel *- New Mexico*

The wind energy community is still demanding high-quality data on wind turbines to validate CFD simulations and design codes. This holds true for performance data, flow field information and certification load cases. In 2006 such a data set was gathered during a wind tunnel test campaign at DNW-LLF financed by the EU and designated Mexico. This data-set has been used extensively worldwide and is part of Energy Technology Network (IEA) Wind Task 29 Mexnext (www.mexnext.org). During the last decade the technology involved in wind turbine design and manufacturing has evolved strongly giving rise to a need for more detailed wind turbine data. Amongst others, noise has become an important aspect of wind turbine design. Since it is hard to gather these data on a full-scale rotor in controlled conditions a controlled test environment is needed.

The primary goal is to take advantage of the available of an existing wind turbine model (Mexico) in combination with the large scale dimensions of the German-Dutch Large Low speed Facility (DNW-LLF) wind tunnel facility in the Netherlands, to gather experimental aero-acoustic and aerodynamic data with high-quality and make this test setup available to the scientific community. Especially, the large open jet test section with the acoustic absorbing treatment on the walls is suitable for acoustic far-field measurements. Moreover, the 9.5 x 9.5 open jet with Seifert Flügel offers the possibility to test a large scale wind turbine model in a controlled environment.

The test combined several objectives into one experiment in which several test and measurement techniques were combined. Since, the wind tunnel configuration and set-up for this experiment (9.5 x 9.5 m open jet with Seifert Flügel) is unique and is solely in use for the Mexico wind turbine rotor, special care had to be taken to verify the quality of the wind tunnel flow.

For the various purposes of the test, several measurements techniques have been implemented:

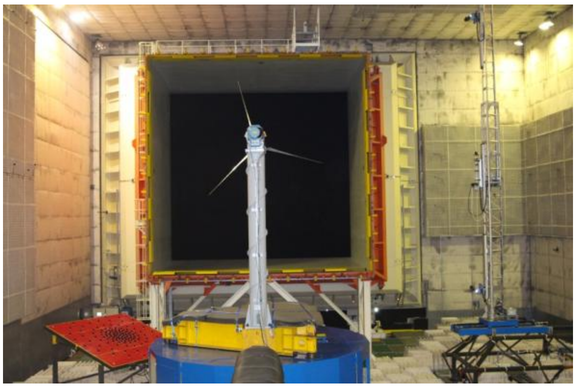
- Flow measurements
- Standard wind tunnel parameters
- Pitot-static tube at wind tunnel centre-line
- Pitot-static tube at PIV-plane
- Model position
- Yaw of attack variations
- 3 components particle image velocimetry (PIV) technique.
- Static pressure at the collector
- Acoustic measurements:
- Out-of-flow microphone technique
- Phased microphone array techniques
- DNW array technique installed upstream of the wind turbine rotor

- Rotor performance measurements
- Wind turbine loads (external balance)
- Torque (power adsorbed by the controller - brake)
- Blade pressure sensors (Kulites)
- RPM signals
- Blade angles
- Blade strain gauges (individual blade loads)

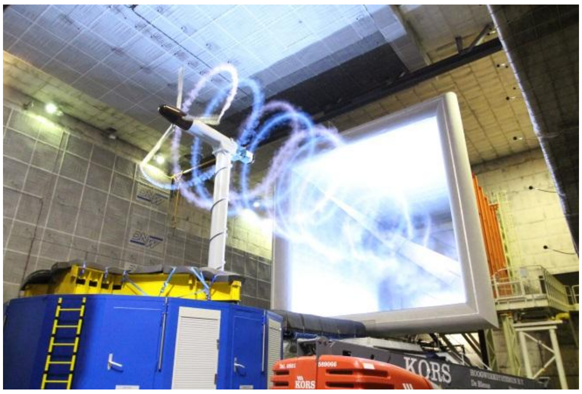
To achieve these measurements an international team was formed.

- The laboratories and people involved are given below:
- Technical University of Denmark (DTU)
- Energy research Centre of the Netherlands (ECN)
- Technical University of Delft (The Netherlands)
- Technology Institute of Israel (Technion)

The data analysis done until now indicates that the data is of high quality. All priority 1 test conditions have been measured as well as some priority 2 and 3 test conditions. Independent verification of the wind tunnel calibration and wind turbine set-up blockage effect showed good agreement between pressure and PIV data, establishing confidence in the wind tunnel calibration and simulation. Detailed flow fields have been recorded for future validation of CFD codes. Extensive acoustic data has been gathered for validation of design codes. The overall comprehensive data set is made available to the involved parties and will become available to the scientific community within the coming years.



Wind tunnel set-up, from left to right acoustic array, 9.5 x9.5 contraction with Seifert Flügel



Visualisation of the tip vortex by means of smoke

6.4 Project for ETW wind tunnel

The TNA test in the European Transonic Windtunnel ETW performed world-wide unique unsteady measurements of the wake flow field by time-resolved PIV (Particle Image Velocimetry) and unsteady deformation measurements for a cruise aircraft configuration at real-flight Reynolds and Mach numbers. These conditions can be achieved only by the combination of cryogenic temperatures (115K) and a tunnel pressure of approx. 300kPa in ETW. The study is needed to further the understanding of the occurring phenomena and the validation of CFD codes (Computational Fluid Dynamics).

The results of this scientific test are expected to give valuable insights in the development and downstream propagation of wing wake flows as well as the resulting effects on the empennage. These scenarios are of high interest to the international aircraft industry due to the potentially heavy unsteadiness of separated wing flow at the borders of the flight regime that may cause an excitation of the empennage.

The main objectives of this test campaign were as follows:

- Time-resolved PIV investigations of separated wing flow (operated by DLR).
- Wall Interference Investigations.
- Acquisition of validation data for numerical calculations.
- Investigations of unsteady HTP inflow at stall conditions (low and high speed).
- Buffet investigations at limits of flight envelope.
- Acquisition of data to be compared with existing CRM wind tunnel data.

More than 40 international aerodynamic specialists from various European institutions, US NASA, Russian TsAGI and Japanese JAXA met at ETW to attend the experimental test entry of the project "Time-resolved Wake measurement of Separated Wing Flow & Wall Interference Investigations".

Tests were performed with the NASA CRM full model, which was provided by NASA. This model was previously tested in the NASA NTF and AMES 11ft. wind tunnels several times and was also used in the NASA Drag Prediction Workshop. For this model a comprehensive data base is available in the public domain and enables the comparison of the ETW wind tunnel data to both numerical calculations obtained by CFD and other wind tunnel data bases. For the integration of the NASA model, ETW designed and manufactured interface components to enable the mounting of the ETW Balance B004 and the AVS system in the sting line.

One of the main objectives for this test was the visualisation of the vortices behind the wing by means of PIV. Due to the nature of this high speed separated flow, a new time resolved PIV system was implemented in ETW and operated by DLR Göttingen.

Further Measurement Equipment

Among the huge number of measurement techniques applied, the following peculiarities should be pointed out:

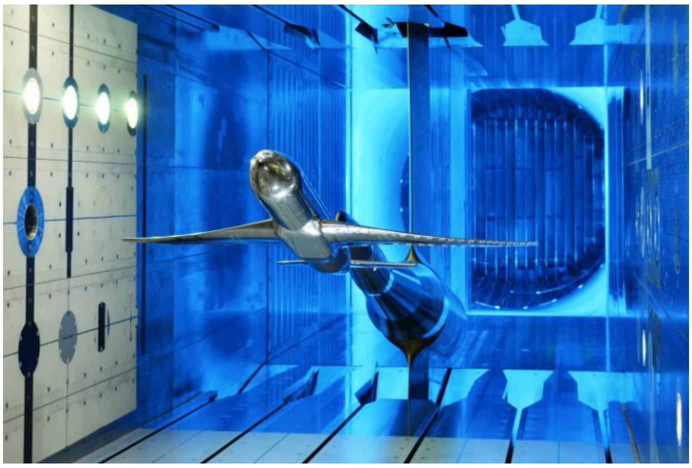
- The model was well equipped with 253 pressure tapings on the wings, which were recorded with five scanners installed in the model nose.
- Markers for the Stereo Pattern Tracking (SPT) System were attached on both the port lower wing and HTP surface. Based on wind-off reference measurements over the entire incidence range of the model, the system can identify the displacement between loaded and unloaded conditions, which then can be finally transformed into wing twist and bending information. For the illumination of the SPT markers LED lights were installed at several positions in the test section.
- The model was mounted on the ETW-B004 six-component strain gauge balance.
- The model support system attached to the MC2 sting boss flange comprised the conical stub sting incorporating the AVS anti-vibration unit. The new bent strut sting component was attached to the ETW stub sting using a flange joint. The NASA Upper Swept Strut sting component was attached to the ETW bent strut using a conical joint with setting screws.
- The model incidence and sideslip were derived from on-board instrumentation combined with the Sector Roll System (SRS) instrumentation. The on-board instrumentation measured the angle between the model reference axis and the horizontal plane irrespective of the model roll, pitch (and yaw) angles.
- The model attitude was measured directly by an on-board inclinometer attached to the inclinometer bracket, which, in turn, was mounted to the balance adapter.
- A three-axis Entran accelerometer, installed within the model inclinometer heated package, was attached to the model adapter in the front fuselage to monitor model dynamics. Two additional accelerometers were installed in the fuselage nose and in the rear fuselage to provide additional information on the model dynamics characteristics.

Tests were performed at Mach numbers in the range of 0.25 to 0.87 and at Reynolds numbers between 2.9 and 30.0 million. The tunnel temperature varied between 300 and 115 K and pressure levels from 111 to 445 kPa were achieved. The TR-PIV measurements were performed by DLR Göttingen at fixed model incidences.

The test results have been made available to the involved scientists and the evaluation and the comparisons between CFD and other experimental results is still going on.

The PIV results achieved both at sub- and transonic stall conditions show turbulent flow structures in the wake of the wing, which provide an insight into turbulent energies and frequency spectra. For the first time PIV measurements have been successfully carried out at such high Mach number (up to 0.85) and Re-numbers (Re up to 30 Million).

The assessment and analysis of the Time-Resolved PIV data was performed by DLR Göttingen. The figure above provides a preliminary result for a Mach number of 0.85, which was presented at the ESWIRP workshop at ETW on 24 & 25 September 2014. The plot provides the instantaneous velocity field for a spanwise position of 56.5 %, a Reynolds number of 30.0 million, a cryogenic temperature of 116 K and a model incidence of 4.5 deg. In addition a second image obtained 500µs later is included to illustrate the changes of the velocity fields. A more comprehensive analysis of the TR-PIV data will be provided by DLR.



The CRM Model in ETW test section during ESWIRP TNA test

7 CONCLUSION

One of the ACARE activities was to identify the strategic research capabilities and infrastructure needed to assure the European leadership in aeronautics. Among the infrastructure, three wind tunnels, the DNW-LLF, the ETW and the ONERA-S1MA were identified as strategic to the future of European aeronautical research and industrial development. With this endorsement from ACARE, further steps toward Europeanization of research access and facility development could be taken.

The operators of the above three facilities formed a consortium to jointly further the capabilities of their experimental research facilities and to provide valuable wind tunnel access to the academic research community. Within the EU-FP7 ESWIRP project (European Strategic Wind tunnels Improved Research Potential), upgrades were performed, combining the support from the European Commission with national funds. Furthermore, successful research groups from a range of European academic institutions were provided with EC-funded access to those renewed capabilities in order to perform large-scale scientific experiments. More than 100 scientists from 17 different nations including Russia, USA and Japan made use of this opportunity. The research ranged from fundamental turbulence studies to the influence of high Reynolds number boundary layers on aircraft performance, through to rotor performance under difficult flight conditions.

Common to all the Trans-National Access academic projects was the possibility to generate high-quality and previously unattainable experimental data for important publishable research. Hence, enabling researchers and graduate students to further the development of their own scientific tools for the good of the aerospace community, and the verification of those tools in the public domain.

8 ACKNOWLEDGMENTS

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