REMFI

Rear-Fuselage and Empennage Flow Investigation

Final Publishable Activity Report

Contract AST3-CT-2004-502895

REMFI
Rear-Fuselage and Empennage Flow Investigation

Dr. A. Abbas[1], J. Dias[2], J. Cabello[3]
[1, 2,3]Airbus España, Av. John Lennon s/n, 28096 Getafe (Madrid) Spain
e-mail: [1] adel.abbas@airbus.com; [2] joao.dias@airbus.com; [3] jose.cabello@airbus.com

Summary

It is known that business needs are placing an ever-increasing demand on the aeronautics industry to develop and manufacture aircraft at lower costs, with improved flight capabilities and a reduced impact on the environment. Hence, a primary objective for the aerospace industry is to offer products that not only meet the operating criteria but also significantly reduce the direct operating costs. Furthermore, research effort with respect to an improved understanding of the flow physics around fuselage / tail combinations remains limited. A successful design approach towards the development of modern transport aircraft has to include the empennage as well. This has to be seen in the light of the fact that performance guarantees for future aircraft have to be granted earlier and with higher accuracy as compared to former developments.

Project Overview

REMFI is an EC 6th Framework Programme (Specific Targeted Research Project - STREP) that started in March 2004 and will last for 36 Months. This project is coordinated by Airbus España and the consortium is composed of 16 partners from 5 different European countries. The consortium gives a good cross-section of the current European research panorama, being composed of 5 industrial partners (Airbus España, Airbus France, Airbus Deutschland, Dassault and ETW), 6 research institutes (ARA, DLR, FOI, INTA, ONERA and CIMNE) and 5 academic institutions (UPM, KTH, TUB, TUBS and RWTH).

Project Approach & Main Objectives

The primary objective of the REMFI project is to provide the European Aerospace Industry with a mechanism to exploit substantial advances made on the research side in the area of design, modelling / simulating tails aerodynamic. The complete and accurate investigation of (at industrial level) new and highly optimised empennage designs has a direct future impact on aircraft design aiming at less fuel consumption due to reduced weight, improved flight trajectories and positive impact on environmental issues. Moreover, it will enable the European aircraft industry to keep a leading role in international competition.

In order to cope with the current aeronautics industrial an integrative approach is proposed. This can be achieved by pushing the state-of-the art tail designs to its utmost level of performance. REMFI will thus focus on three main aspects, (1) the better understanding of the tail flow physics, (2) improved computational prediction capability for fuselage/tail configurations, and (3) analysis and improved experimental techniques for tail flow investigations.

This aims at providing means to: Increase the empennage aerodynamic efficiency and reduce loads; Improve empennage performance and weight for optimised gaps effects, including Re number effects; Investigate sting mounting arrangement effects on empennage wind tunnel measurements; Enhance the current scaling methodologies to free-flight conditions; Reduce fuel burn; Novel design concepts for integrated fuselage / empennage designs; Shorten the design cycle; Reduce the cost of the aerodynamic design of tail and fuselage and reduce the maintenance costs The different activities will be based on the following two-folded approaches:

APPROACH 1

By means of a precise numerical simulation for tail flow phenomena. Besides experiments, which are often the backbone for numerical investigations and in many cases serve for validating codes and models, CFD itself is now a mature instrument in design which means it is becoming a tool in early design stages. At the upstream edge, CFD is also used for complex geometries and flow situations both supporting experiments and providing absolute answers on flow behaviour, including absolute figures for, say, force coefficients. This change in paradigm, when compared to the need in the past "only" to predict the "correct" delta-value in two consecutive solutions, is putting high demands on CFD. The different numerical simulation activities of REMFI include the investigation of the rear-end flow phenomena to improve the understanding of flow physics of tails and enabling for more efficient empennage designs. Especially important is the precise simulation of: Wing downwash; Empennage control surfaces gaps at tunnel and flight conditions; Thick boundary layer at the rear-end; Elevator / rudder efficiency and hinge moments and True flight conditions and Twin sting interference.

APPROACH 2

By means of detailed experimental study. Wind tunnel tests will contribute to the build-up of physical understanding of the different tail flow phenomena. The testing envelope will cover several conditions for Mach number, Reynolds number, tail settings, elevator and rudder settings variations as well as empennage measurements close to true flight Reynolds numbers.

Two test facilities will be used for conducting the necessary tunnel measurements, the ARA tunnel and the now operational European Transonic Wind tunnel (ETW). This facility offers the capability to obtain aerodynamic data at true flight conditions, where the flow is able to withstand more severe pressure gradients. The exploitation of this capability is crucial for the qualification of the CFD methods to predict these flows and to better understand the Reynolds number effects on tail performance. The data will be obtained at representative flight Reynolds numbers. They will also be used to improve common methods for performance extrapolation from conventional wind tunnel sub-scale to full-scale flight conditions.

A significant potential to improve the accuracy of rear-end measurements is largely seen in the "live-rear-end" technique. However, the live-rear-end technique, although most attractive, still needs to be improved for yielding highest accuracy. The application of the live-rear-end technique requires the employment of a twin-sting model support instead of the commonly used single-sting arrangement. Especially important, for the objectives of REMFI, is to simulate experimentally and precisely: Elevator / rudder gaps effects on empennage performance (efficiency and hinge moments); Twin sting interference; Split fuselage gap size influence on empennage performances; Transition effects on control surface efficiency and hinge moments and Reynolds number effects

The following major achievements are expected: Fully optimised empennage design with highly efficient control surfaces with respect to Elevator / rudder fuselage gaps effects on efficiency and hinge moment and Transition effects on empennage performance, including efficiency and hinge moment; Improved live-rear-end measuring technique including comprehensive understanding of Split gap effects on the empennage measurement accuracy and Twin-sting mounting arrangement effects on empennage measurements accuracy; Comprehensive set of tail-specific data from a real aircraft type configuration containing detailed flow field information up to full-scale Reynolds numbers; Advanced CFD tools for industrial application with specific guidelines for empennage flow simulation; Improved knowledge of scale effects up to true flight Reynolds numbers and New and innovative designs for integrated fuselage and empennage including belly fairing

With the completion of REMFI the improved knowledge and problem adapted design tools will enable the REMFI community to design efficient tail-planes for future European transport aircraft giving rise to: Reduction of development cost and time to market; Reduction of development risk of costly modifications; Improvement of tail-plane commonality on derivatives; Decrease of operating cost by improved flight performance; Improvement of environmental friendliness and Improvement of evaluation quality of novel and unconventional design solutions

Work Package Description & Objectives

The work breakdown structure of the project is divided into five work packages. Work Package 1 is dedicated to the management of the project. A description of the four other work packages and its objectives is given below.

Work Package 2: Empennage Improved Control Surfaces Efficiency

Empennage control surfaces design, such as elevator and rudder, have been mainly based on handbook methods followed by wind tunnel test verification later on in the design process. In the same spirit, control surfaces efficiencies and hinge moment are estimated in the early stages of the design, employing empirical methods. These un-optimised values are crucial for the initial sizing of the actuators and consequently the final empennage weight.

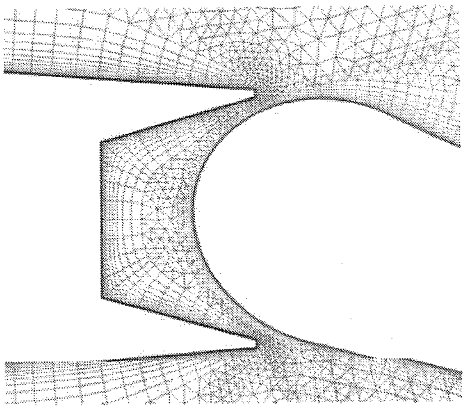

Figure 1 - Rudder shroud gap Unstructured Chimera Mesh example

Wind tunnel tests, performed for empennage design verification and aerodynamic data production are usually carried out under low Reynolds number conditions. Elevator and rudder efficiency and the corresponding hinge moment were found to strongly depend on the transition strip location producing uncertain aerodynamic data, with relatively large error margin. Consequently, this has a large impact on the aerodynamic loads estimation, size and weight of the empennage control surfaces and finally the necessary actuator. On the other hand, gaps between empennage control surfaces (elevator and rudder) and rear fuselage can cause an important loss in the control surfaces efficiency together with an increase in the empennage parasitic drag. Particular attention will be paid to the analysis of tail-specific flow phenomena, especially the separation behaviour on the aft-fuselage and tail surfaces. The qualification of the methods will also comprise the applicability of CFD on simplified geometries to estimate tail plane effectiveness as well as hinge line moments. The validation test data will further be used for the separation of Reynolds number effects to derive extrapolation strategies for the reliable scaling from tunnel to real flight condition.

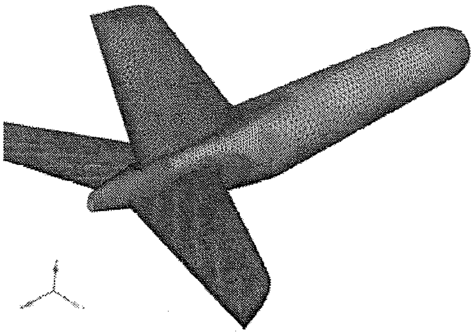

Figure 2 – Tail Stall Investigation: Unstructured Mesh Example

The main objectives of work package 2 would be then to: Understand tail flow physics in order to improve prediction capabilities and accuracy of empennage performance including hinge moments, and transition effects; Develop the ability to correctly simulate gaps effects on empennage performance; Develop the capability of reliable scaling of sub-scale wind tunnel data to full-scale flight conditions and to Understand and improve the capability for the accurate simulation of tail stall mechanism

Work Package 3: Sting Mounting Arrangement Investigation

Despite the fact that efforts are under way to expand industrially applicable methods towards full Reynolds stress modelling or LES and DES simulations (see e.g. 5th framework project FLOMANIA), computational predictions for aerodynamic design are currently relying on mostly linear eddy-viscosity models (EVM) in a Reynolds-

Averaged Navier-Stokes (RANS) framework. This approach, however, has reached a good state of maturity and reliability also in conjunction with more accurate and elaborate modelling practices and can thus be considered as an appropriate tool for the tail flow investigations in REMFI.

The twin-sting measurement technique has been introduced to reach a minimized interference of the model support with the rear end. However, there remains an influence of the support on the fuselage pressure depending on the distance of the twin booms from the model centre line. Other influences include the wing twist due to the rear fuselage pitching moment and the alteration of the wing flow owing to the booms and thus the general flow characteristics. The aim of this task is to clarify the impact of the lateral wing-sting boom spacing on the empennage performance employing the state of the art Navier-Stokes simulations.

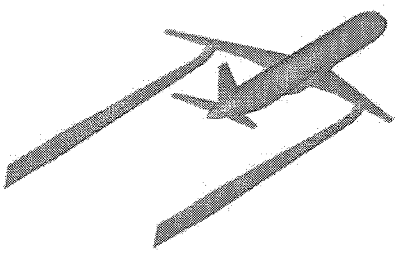

Figure 3 - Twin-Sting CFD Modelisation Example

Additionally, when using twin-sting measurement techniques there may be also a local balance, which obliges to have a gap in the rear fuselage. Up to now this gap has not been sealed to avoid interference with the measurements. Due to pressure differences across this gap there may be a cross flow through the gap, which perturbs the flow and the measurements in the rear end. Some analysis will be performed in order to define a suitable criterion for the selection of the position of this gap. Also a detailed analysis of the flow through the gap will be performed, in order to investigate the origin of the drag measurements perturbations.

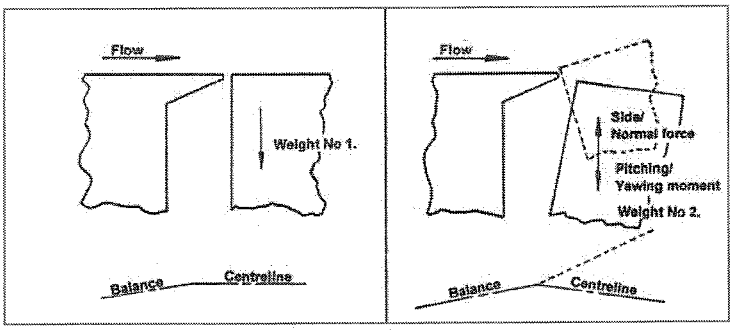

Figure 4 - Split-Fuselage Gap Example

Activities in work package 3 will focus mainly on the following aspects: Accurate simulation of twin sting booms location and shape effects on the empennage performance, efficiency and aerodynamic loads, including Reynolds number effects;

Develop a methodology for the prediction of wing deformation caused by twin sting mounting arrangement and to Define a suitable criterion for the selection of the position of the gap for Live Rear End measurement techniques. Estimate drag causes and interference effects due to cross flow through gap

Work Package 4: Experimental Verification Study

Very early in the preparation of the REMFI project it became clear that thorough wind tunnel tests on the tail plane are mandatory, since even the most powerful state-of-the-art CFD tools are not reliable enough to assess the empennage aerodynamics within the required accuracy.

To date only a limited amount of tail-specific aerodynamic measurement data exists within industry and the research community, and there is virtually no experimental data basis providing sufficient resolution and accuracy essential for the precise understanding of tail aerodynamics and the subsequent validation of respective numerical methods. In order to keep the project cost as low as possible, it has been decided to use as many components and parts as possible from an existing model. AI-D offered to make available, for REMFI's need, an advanced transport aircraft configuration, i.e. geometric information and the model. This model (1:50 scale) is a cryogenic full span model representing the state-of-the-art technology.

Two test facilities have been selected. For the first time comprehensive tail plane measurements will be conducted in the European Transonic Wind tunnel ETW. This facility, established and jointly funded by four European nations, offers the capability to obtain aerodynamic data at true flight conditions, where the flow is able to withstand more severe pressure gradients. The exploitation of this capability is crucial not only to better understand the Reynolds number effects on tail-plane performance but also for the qualification of the CFD methods to predict these flows. The second test campaign will be carried out in the ARA wind tunnel. This facility has been selected since ARA is specially suited for testing in the lower Reynolds number regime, and the same model used in the ETW can be employed with only minor adaptation needed. Due to easy access to the test section (ambient environment) model configuration changes can be performed quickly. The planned test series will therefore focus on those investigations, which require time-consuming model changes (gap effect / transition effect tests). The policy to use one and the same model in both wind tunnels not only avoids a duplication of model costs but also supports a dependable data comparison to assure consistency in the results

All test campaigns will be conducted with a twin-sting support. This type of support allows the precise measurement of forces directly at the rear end of the model. For this purpose the rear fuselage section of the model is mechanically separated from the main body and equipped with a live-rear-end balance. This balance is specially adapted featuring a relatively high stiffness to minimise tail movements without compromising measurement accuracy. The live-rear-end technique still needs to be improved in REMFI for yielding highest accuracy to meet the ambitious objectives.

Some further effort is needed on the twin-sting support to minimise the interference effects between the support booms and the empennage. In REMFI three different boom positions will be tested. The target is to gain knowledge on the (positive) impact of an increased spacing and, moreover, to generate validation data for the CFD tools to predict the sting effects. The model will also receive a rear-end motorisation, i.e. a remotely controlled motorised horizontal tail plane. The motorisation allows quick and easy HTP angle settings. The employment of the remotely controlled HTP will boost productivity rate and thus will give ETW an important competitive advantage. The employment of this technology is therefore critically important for the success of the ambitious test schedule.

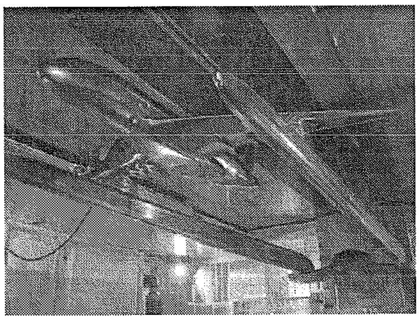

Figure 5 – Twin Sting Support

The main objectives of this work package will be to: Improve the knowledge on Control surface efficiency and hinge moment behaviour; Control surface gap effects; Scale effects on tail flow characteristics up to flight-scale Reynolds numbers and to Establish an experimental tail-specific data base for the assessment/improvement of the prediction tools

Work Package 5: Innovative Fuselage and Empennage Design

This work package will focus mainly on the investigation of innovative novel aerodynamic design solutions, which are not yet realised at current conventional designs but are very promising to enhance the aerodynamic performance of future aircraft. In the past, the aerodynamic design of wing belly fairings has been handled independently from the design of the front/rear-fuselage and empennage parts, because the extension of the belly was limited to the cylindrical part of the fuselage and it was assumed that the interaction with the other parts was negligible.

The main reason for the limitation of the belly to the cylindrical fuselage part was the constraint that the necessity of new belly designs for future A/C versions with stretched fuselage should be avoided due to cost reasons. This forced the belly to be terminated in front of the upswept fuselage rear part and lead to belly designs, which were supposed to be shorter than aerodynamically desirable. In that respect especially the shape of the belly fairing rear part is essential to minimise the drag. An elongation of

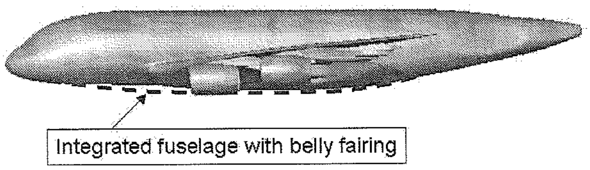

Figure 6 - Integrated belly-fairing example

the belly onto the rear fuselage could result in a better flowfield avoiding flow separation on the rear part and achieving decreased drag. However, for short aircraft the cylindrical part of the fuselage is not long enough for appropriate belly fairing design. Therefore, the belly has to be extended to the rear fuselage and probably also to the front fuselage. Hence interference effects between belly, front/rear fuselage and empennages become more important.

In most of the transport aircraft the rear fuselage tailcone behind the horizontal tailplane (HTP) is used for the installation of the Auxiliary Power Unit (APU) which is needed for the independent hydraulic and electric power supply on ground and as backup system for the power supply in flight. The air intake is often located in the tailcone on the upper or lower side and the exhaust on the base area. To guaranty the restart capability during the flight limited pressure differences between the air intake and exhaust have to be assured. To minimise the installation drag and to assure an appropriate system function the accurate prediction of the large boundary layer at the fuselage tail cone is a prerequisite.

The necessity of an accurate and fast prediction of the effect of different A/C components on drag during the design phase is of significant importance. The progress in drag prediction capabilities over the past two years using unstructured CFD techniques have shown that even if a systematic offset between the absolute experimental and the theoretically derived values exists, small differences due to geometry changes can be computed. Due to the different flow phenomena at the fuselage rear end it has to be investigated whether the effects of dorsals, onglets or other small devices on the flow, especially on the drag, can be predicted accurate enough by means of CFD methods.

The main objectives of this work package are: To evaluate the improvement potential of integrated designs of the front/rear fuselage and belly fairing and identify the impact of these solutions on the empennage design; To improve the evaluation accuracy of the boundary layer characteristics in the very rear part of the fuselage for a more precise prediction of the flow conditions for an improved design of the APU air intake and exhaust and to Assess and improve the capability to predict the effects of small geometry changes on the flow characteristics, especially on drag

Acknowledgements

This project runs under the EC 6th Framework Programme with contract number AST3-CT-2004-502895. The authors would like to thank the entire REMFI consortium.

References

[1] REMFI Consortium, "Rear-Fuselage and Empennage Flow Investigation, Description of Work", 2004