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ENGINE INTEGRATION ON FUTURE TRANSPORT AIRCRAFT - THE EUROPEAN RESEARCH PROGRAMS DUPRIN/ENIFAIR -

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Abstract

The current development of engines with Very- resp. Ultra-High Bypass-Ratios (VHBR/UHBR) offers the opportunity to reduce fuel consumption, emissions and noise. The increasing diameter of these engines however requires a closer coupling with the wing. On this background the CEC-funded program DUPRIN I was started in 1990, followed by phase 2 and the current program ENIFAIR in order to investigate the effects on overall aerodynamic performance.

For engine simulation in the wind tunnel turbine powered simulators (TPS) were used, representing different types of engines like turbofan, UHBR and the recently developed VHBR. Low-speed tests on a twin-engine transport aircraft model with turbofan resp. UHBR simulators were done in DNW, VHBR-investigations are under preparation. New types of thrust reversers are under development for the VHBR engine, covering hybrid door cascade and hollow door concepts. High speed tests in ONERA S1 are under preparation. Here the model will be splitted into a half model. The numerical work is currently concentrating on application and validation of different Navier-Stokes codes.

The paper describes the main contents of the programs and the results, currently available.

1. Introduction

Since the introduction of the first turbofan engines there was a steady trend to improve the overall quality of this product, including elements like reliability, maintainability, noise, purchase costs, power, emissions and fuel consumption. Especially the latter 3 aspects were responsible for an increase in bypass-ratio, reaching values of 5 to 6 for current turbofans. After a phase of maturing the current situation clearly shows a trend to Very- resp. Ultra-High Bypass ratio engines (VHBR/UHBR), because they offer further reductions in specific fuel consumption (SFC) of 5 to 15 % for the VHBR and 10 to 15 % for the UHBR-category, combined with reduced emissions and noise, the latter especially in the low-speed regime. Since these potential improvements influence the direct operating costs (DOC), the aircraft manufacturer is forced to investigate the consequences for his product, especially in a world of increasing competition between less and less aircraft producers.

A further advantage of VHBR/UHBR engines is, beyond lower SFC, the excessive thrust in the low-speed flight regime, which can be used either for

- reduction in airport noise and pollution, if acceleration and climb rate are set as for a conventional turbofan, or
- reduction in take-off field length and increased climb rate, leading in turn to a reduced noise-pattern in the surrounding area of an airport.

Combined with these chances however, there is a risk, that the increasing diameter of VHBR/UHBR engines can lead to unacceptable engine installation effects, since they will require a closer coupling with the wing, if increasing landing gear heights and corresponding weight increase shall be avoided.

On this background, the international co-operative research program DUPRIN (Ducted Propfan Investigations) was started in 1990 within the BRITE/EURAM aeronautics framework, getting funding from the CEC[1]. After its successful completion, the follow-up phase DUPRIN II started in 1994[2] and since April 1996 the 3 year-program ENIFAIR (Engine Integration on Future Transport Aircraft) is under way.

Since the know how concerning the installation phenomena of VHBR/UHBR engines was quite limited in Europe, the main industrial objectives of the DUPRIN/ ENIFAIR activities are

- to provide the participants from engine- and airframe-industry with a common high-quality know how basis concerning the aerodynamic phenomena for VHBR/UHBR engines in selected positions under the wing and

- to develop, test and validate the experimental and numerical tools, necessary for application in a later product development.

2. Main contents of DUPRIN/ENIFAIR

The general structure of the DUPRIN I/II and ENIFAIR programs consisted resp. consists of the 3 main elements

- design/manufacture of model hardware
- performance/analysis of wind tunnel tests
- application/validation of different CFD methods.

Based on an existing wind tunnel model of a twin-engine transport aircraft, the DLR-ALVAST model, DUPRIN I covered the design and manufacture of each one additional engine simulator for a turbofan and a UHBR engine (one of each was already existing).

With this set of hardware low-speed investigations were made in the German Netherlands Wind Tunnel DNW [3,4]. In parallel, the design for a VHBR simulator was completed. The CFD work in DUPRIN I and II was concentrating on application and comparison of different panel and Euler codes [5-7].

As a logical consequence of DUPRIN the follow-up program ENIFAIR covers the elements, shown in FIG.1. For the completion of model hardware, two VHBR simulators were manufactured. The wind tunnel investigations cover the high-speed tests in ONERA-S1, using 3 different engine types plus, for completion, a low-speed test in DNW with the VHBR engine type together with some general investigations on new types of thrust reversers. The CFD work finally is now concentrating on calculations with different Navier Stokes codes.

Under the coordination of Daimler-Benz Aerospace Airbus, Bremen (DA), ENIFAIR was started in April 1996 with participation of 18 European partners from 7 countries (FIG. 2).

3. Engine Simulators

Since the investigation of engine installation effects is the main purpose of DUPRIN/ ENIFAIR, it is necessary to simulate in the wind tunnel not only the effects due to the existence of different nacelle bodies but also due to the jet flowfield of the engines. This was realized here by using so called turbine-powered simulators (TPS). A TPS for a turbofan engine consists of a fan which is connected to a turbine, driven by pressurized air, coming form outside the model and passing fuselage, wing and pylon. The TPS-body is covered with fan and core cowlings, representing the shape of the corresponding engine. To measure the thrust during the wind tunnel test, a set of pressure and temperature rakes is installed behind fan and turbine and inside the drive air pipe.

3.1 Turbofan engine The TPS used has a fan diameter of 6.4" representing a turbofan with a bypass ratio of about 5. One simulator had been designed and manufactured by DA already ahead of DUPRIN, while a second unit was produced inside the program, also by DA.

3.2 UHBR engine For the simulation of one ultra high bypass-ratio engine a new type of simulator named CRUF (Counter Rotating Ultra-high Bypass Fan) had been developed in cooperation of DLR [8] and the US-company Dynamic Engineering Inc. (DEI). One unit had been manufactured by DEI prior to the begin of DUPRIN, while within the program a second simulator was designed and built by the french company TECHNOFAN, using identical specifications.

This type of simulator is based on the MTU-CRISP concept of a counter-rotating 2-stage Ducted Propfan. For this purpose, a reverse gear had to be installed between the turbine and one stage of the fan. The fan diameter is 10" and simulates an engine with a bypass-ratio of about 15.7.

3.3 VHBR engine In order to get a complete set of test results, also the category of very high-bypass ratio engines has to be investigated. Since this type of simulator was not existing, a corresponding design was made by DA and DLR during DUPRIN II, followed by the manufacturing of 2 units by the french company Airtechnologies within the current program ENIFAIR. The TPS has a fan diameter of 7.8" and simulates an engine with a bypass ratio of about 9, see FIG. 3. The results of the acceptance tests showed, that the fan performance is matching very well with the calculated results (FIG. 4).

4. Low-speed investigations

4.1 The Wind Tunnel All low-speed tests were resp. will be done in the German Netherlands

Wind Tunnel DNW. This atmospheric tunnel has interchangeable tests sections, from which the 8 x 6 m closed version was used, allowing tests up to a maximum speed of 116 m/s. For tests with complete models an internal balance plus TPS air line system and a sting support system is existing, operating under computer control and allowing tests in the range of incidence between -15° and +45° while the sideslip can range from -30° to +30°.

The drive air for the engine simulators is provided by a compressor station and led via two pipes and low-reaction air line bridges to computer controlled valves and critical venturi nozzles into the model.

4.2 Test setup For all investigations the DLR-ALVAST model was used [9]. This complete model has a span of about 3.4 m and represents an A 320 type of twin-engine transport aircraft in a scale of 1 : 10 (FIG. 5). For the low-speed tests the wing of the carbon fibre model was equipped with slats and flaps, representing take-off and landing configurations. Static pressure ports were installed on fuselage (1 section), wing (9 sections) and nacelle (2 sections). For the tests performed during DUPRIN I/II either turbofan or ducted propfan engines were installed on the model. In case of turbofan simulation the 6.4" TPS-unit were equipped with cowlings, representing a short duct engine of the CFM56 type (FIG. 6), while for the ducted propfan tests the 10" TPS-units were provided with the DLR-CRUF cowlings, corresponding with the MTU-CRISP-type engine (FIG. 7). During ENIFAIR, investigations are planned with the 7.8"-TPS, covering a typical VHBR engine cowling, designed by Rolls Royce (FIG. 8). All 3 engine categories are mounted in a representative position relative to the wing. In order to limit the number of variables, the pylon shape was kept constant concerning thickness, the ending of the upper side at the wing stagnation point, the ending of the rear upper side at the wing trailing edge and the angles of rear- and lower-side.

Since the engines are directly mounted to the model, the actual thrust has to be subtracted from the balance reading in order to get the pure aerodynamic forces and moments. For this thrust accounting the TPS is equipped with measuring rakes behind fan and turbine, while the drive air mass flow is measured by the critical venturi nozzles in the drive air pipe. To get the overall efficiency and the fan mass flow, a pre-test in a so-called calibration tank is necessary prior to the wind tunnel test. For the DNW-tests this calibration work was done in the NLR facility.

4.3 Test results The results of the static pressure ports on wing, fuselage and nacelle are important for an understanding of the engine-installation flow-phenomena as well as for validation of CFD calculations. As a typical example, FIG. 9 and 10 show the pressure distribution on slat and wing on a section inboard of the pylon for the wing without engine and with turbofan resp. UHBR at two different power settings. Incidence was 12° and M = 0.22. Power setting MTO stands for Maximum Take-Off, while TFN is representing a through-flow nacelle with nozzle exit velocity equal to tunnel speed. On slat and wing upper surface the engine installation leads to a loss in lift, being slightly greater in case of the UHBR and independent of the power-setting. On the lower surface of the slat the installation- and power-effects are small or negligible. On the lower surface of the wing the installation of a turbofan (TFN) leads to a small deceleration in the forward part of the wing and small favorable power effects. In the contrary, the UHBR-installation produces a lift loss on the wing lower surface and additional losses occur with increasing engine power. This is due to the fact that the jet flowfield of the UHBR is closer to the wing than in case of the turbofan.

The overall increments in lift, measured by the balance inside the model are summarized in FIG. 11 for an incidence of 10°. While the lift increment due to the installation is of similar order for both engine types, the positive power effects are greater in case of the UHBR due to the positive contribution of the nacelle, which over-compensates the losses on the wing.

The installation- and power-effects on drag are shown in FIG. 12, again for 10° incidence. The installation of a UHBR engine leads to a drag increase of about 68 counts, while in case of a turbofan the value is only 40 counts. This can be explained by the differences in nacelle and pylon surface, i.e. due a difference in scrubbing drag. The increase in drag due to the jet effect for the UHBR is about twice as high as for the turbofan. Main reason for this is the fact, that the jet of the UHBR is closer to the wing, leading to a higher value of induced drag.

The combination of favorable effects in lift and negative increments in drag leads to the lift versus drag results, shown in FIG. 13. The results are for M = 0.22, the wing in take-off configuration and the engines running at MTO-power. Due to compensations of positive and negative increments the total drag at constant lift is nearly the same for both engine types in the main part of the diagram, while in the region of maximum lift the UHBR produces lower drag than the turbofan.

4.4 Thrust Reverser Development Due to the closer coupling between a VHBR-engine and the wing also the efficiency of a thrust reverser will be affected. Furtheron, the reversed flow can influence the aerodynamic loads on the wing in an unfavorable manner. Hispano-Suiza and Hurel Dubois together with SNECMA, CASA and AS work together on design and test of new concepts, reversing the fan flow of the ¾ duct of the VHBR engine. Following some initial studies, 3 concepts were retained, covering

- hollow door
- cascade door hybrid and
- double panel.

After CFD calculations for these concepts were performed, it was decided to use for further experimental investigations the cascade door hybrid concept as baseline (FIG. 14) with the hollow door as a parametric variation of the first type (FIG. 15).

Based on this concept selection a 360° thrust reverser model will be manufactured for isolated blown tests on the large Scale Thrust Measuring Rig of ARA, Bedford.

Main objective will be to assess the engine discharge compatibility plus isolated effectiveness and to obtain preliminary efflux control visualization in order to study the flow field interactions. Thrust reverser static pressure data will be provided to support installed model analysis. Additionally, the experimental results will be used to validate the CFD calculations.

5. High-speed investigations

5.1 The wind tunnel Following the intense low-speed investigations in DUPRIN I/II the high-speed tests are a major part of the current ENIFAIR program. These tests will allow to achieve a complete set of test results for a transport aircraft model fitted with a turbofan engine as reference plus the two new concepts of VHBR and UHBR-engines. The tests will be performed in the large high-speed tunnel S1 of ONERA-Modane.

5.2 Test setup From the beginning, the DLR-ALVAST model was designed in a manner, which allows to use it either as a complete or half model. Since in the high-speed regime unsymmetrical power settings and sideslip effects are not important, the tests in S1 will be done on the half model configuration (FIG. 16). Overall forces and moments will be measured via an external underfloor balance.

In order to minimize the interaction of the wind tunnel boundary layer with the fuselage flow field, a so called „peniche" will be mounted on the non-metric part between fuselage and wind tunnel floor. The wing in cruise configuration will be equipped with the 3 engine types, described above. Static pressure ports are installed on fuselage, wing and nacelle, as for the complete model. The TPS drive-air pipe is equipped with a low-reaction air-line bridge in order to minimize the residual loads.

Since also here, as in case of the low-speed tests, the engines are mounted to the model, the thrust has to be subtracted from the balance loads to get the required aerodynamic results. For this purpose the same TPS-instrumentation is used together with the corresponding flow meter as in the ONERA drive air pipe.

5.3 Simulator Calibrations To get the missing information concerning overall engine efficiency and fan mass flow, calibrations were done for all 3 engine simulators in the ONERA S4B calibration bench (FIG. 17). For each simulator size (6.4", 7.8", 10"-TPS) a specific inlet (bellmouth) was designed and manufactured. Then, each powered nacelle was installed on the S4B plenum chamber as shown on FIG. 18.

Prior to the calibration program, as well as in the wind tunnel, specific cubic nozzles for each engine type are tested in order to validate the calibration bench and the balance thrust measurements (high level of accuracy and good repeatability are necessary).

The goal of the calibration is to determine, in static conditions, the powered nacelle characteristics: they are obtained mainly by measuring the fan and turbine mass flow, the internal nozzle pressure and temperature and the simulator overall thrust under a range of TPS rotating speeds and simulated Mach numbers of the wind tunnel tests. From these measurements, the calibrations are computed. In this way, a correlation between the different engine running parameters and its thrust is established, giving the possibility to determine the engine thrust during the wind tunnel tests.

5.4 Wind Tunnel Tests Prior to the main program two specific controls are necessary:

- a pressurized air supply and balance check using a dedicated cubic nozzle mounted on the model,
- a transition check, with the clean wing configuration, at 0.75 Mach number which is corresponding to the 'aircraft' design Mach number value.

The main objective of these high speed wind tunnel tests is to determine each engine type installation drag level. Thus, the clean wing configuration will be tested prior to the powered ones.

The wind tunnel test program is defined for a Mach number range from 0.34 up to 0.78 in order to have the knowledge of the compressibility effect and each polar will be obtained from 0.3 to 0.6 lift range. For the powered configurations five TPS rotating speed values will be run at each Mach number.

6. Theoretical investigations

Due to the physical complexity of propulsion airframe integration, besides experimental investigations numerical methods have to be employed to provide as much information as possible. Already in the previous programs DUPRIN I + II, numerical methods for the solution of the Euler equations were used to compute inviscid flow. In ENIFAIR, also methods for the solution of the Navier-Stokes equations shall be employed to provide information about viscous effects. Since the solution of the Navier-Stokes equations for complex configurations is still a challenge, cases of varying complexity will be analyzed. The numerical work has been broken down in 4 specific tasks, which will be outlined below.

6.1 Variation of engine position The objective of this task is to explore the capabilities and limits for choosing the position of different engine types, namely the Turbofan, the VHBR, and the UHBR engine. For flow analysis, the solution of the Euler equations as already used in DUPRIN I + II was chosen, since it allows routine computations for complex geometries at moderate costs. As basic positions, the engine locations as realized in the wind tunnel experiments were chosen. For the Turbofan and UHBR engines, two additional positions were selected, and for the VHBR engine, three further positions were chosen. Up to now, an evaluation of results was made by examining the pressure distributions in wing-sections closely inboard and outboard of the pylon. FIG. 19 shows the pressure distribution computed by BMW Rolls-Royce for the configuration with UHBR engine closely inboard of the pylon. It can be seen that the largest effect is produced by moving the engine downstream, whereas a closer vertical upward movement shows a comparably small effect. In general, the computations for all engines indicate that perhaps there is a greater potential for close coupling of engines than expected.

6.2 Assessment of isolated nacelles In experimental investigations, Turbine Powered Simulators are used to model the engine flow. Due to the physical principles used for these simulations, the correct bypass ratio and the hot core flow can not be simulated in the experiment. Therefore, a comparison of the flow fields of an engine at real conditions and at TPS conditions seems worthwhile to assess the possible error made in windtunnel tests. To perform such a comparison is one of the objectives of this task. The comparison will be made for the three engine concepts for take-off and cruise conditions. The other objective is to check the performance of the turbulence models currently in use for modeling jet flows. The calculation of the jet behaviour is a challenging task for numerical methods and therefore the evaluation of the deficiencies of todays turbulence models is included in ENIFAIR.

For the three engine types investigated within ENIFAIR, Navier-Stokes computations will be performed. Mesh generation performed by CIRA for the configurations is completed and first computations have started. In order to validate turbulence modeling, a further computational test case was included. SNECMA provided experimental data for the jet velocities of a Turbofan engine with an ambient flow of 80m/s. FIG. 20 shows first results of a comparison by SNECMA for experimental and computational data for the axial flow velocity at about 2.5 diameters behind the nozzle exit. The overall agreement is satisfactory.

6.3 Navier-Stokes calculations for cruise configuration The mechanisms playing a role in propulsion airframe integration are very complex, and the solution of the inviscid flow field is insufficient for the analysis of the drag behaviour. Computational methods for solving the Navier-Stokes equations reached a degree of maturity that it was decided to use them in ENIFAIR to support the experimental investigations. The objective of this task is to assess the capability of state-of-the-art computational methods to predict the interference effects for aircraft in cruise configuration.

For the start of the computations, it was decided to first concentrate on the wing/body configuration. With this configuration, problem areas should be identified to finally lead to an improvement of the very complex grids of the installed configurations. Mesh generation was performed by NLR, and CIRA, DLR, NLR, and ONERA performed computations on the wing/body mesh. After the first computations, the block topology was improved to remove singularities. Grid tuning in various regions was conducted to obtain and to improve convergence of the full Navier-Stokes flow solution.

FIG. 21 shows a comparison of pressure distributions computed by CIRA, DLR, NLR and ONERA at a wing section at 33% span. The computational data are quite coherent and agree well with experimental data available for this case. Based on the experiences gained from the studies with the wing/body configuration, NLR completed the mesh generation for the installed configurations with Turbofan and UHBR engine. Computations on these meshes are now underway.

6.4 Navier-Stokes computations for high-lift configuration The performance of the high-lift system is evolving as one of the deciding factors in the design of future aircraft. Therefore, it is of utmost importance that this issue is treated in the framework of propulsion airframe integration. The computation of the viscous flow around high-lift configurations is very challenging, however for future developments it is necessary to explore the capabilities of nowadays numerical methods for such cases. Therefore, it was decided to include a high-lift configuration in the theoretical investigations of ENIFAIR. In order to limit the amount of work, the investigations were concentrated on the ALVAST wing/body configuration with deployed high-lift system, but without installed engines.

Mesh generation for this configuration was performed by DLR. As a first step, a mesh suited for the solution of the Euler equations was generated, however the block topology was defined such that for viscous computations only the first spacings to the wall need to be adjusted. A preliminary computation of the inviscid flow field showed already a qualitatively good agreement with experimental data (FIG. 22). The mesh was then regenerated to adapt the wall spacings for viscous flows. The computations for the solution of the Navier-Stokes equations are in progress.

7. Conclusions

The intentions of the programs DUPRIN I/II and ENIFAIR, described above, was resp. is to provide the partners with a common, high-quality know-how basis concerning the general installation effects of modern VHBR/UHBR engines. Furtheron, the necessary tools for future work, covering model hardware as well as validated CFD codes will be developed.

Within the successfully completed programs DUPRIN I/II, low-speed experiments showed remarkable differences in installation effects between turbofan and UHBR engines, which were in good agreements with CFD calculations, based on panel methods and Euler codes.

The success and splendid cooperation in the team lead to the current program ENIFAIR with the intention to complete the know-how basis by doing high-speed tests will all engine-types, low-speed VHBR-tests, developing new thrust reversers and applying and validating Navier-Stokes codes for cruise- and high-lift configurations.

The progress made so far is promising and there are no doubts, that the program will successfully completed. The results and know-how will form a sound basis for deeper investigations as well as the application in future project work.

8. Acknowledgment

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Dr. R. Dunker and Dr. D. Knörzer of the Directorate General of Science, Research and Development were resp. are the Project Monitors. Their advice and guidance were/are well appreciated.

The dedication and willingness of all participants to the programs contributed in large to the overall success. The authors acknowledge the helpful support of the partners to the paper, presented here.

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9. References

[1] Burgsmüller, W.; Hoheisel, H.; Kooi, J.W.: Results of Engine/Airframe Interference Investigations on Transport Aircraft with Ducted Propfans versus Turbofan Engines. Conference Proceedings, CEC, Aerodays, Naples (04/05 Oct. 1993)

[2] Burgsmüller, W.; Hoheisel, H.; Kooi, J.W.: Engine/Airframe Interference on Transport Aircraft with Ducted Propfans/The European Research Program DUPRIN ICAS-Paper no. 94-6.2.1 (1994)

[3] Burgsmüller, W.; Hoheisel, H.; De La Puerta, B.: European Research Cooperation on Jet Engine Airframe Integration In: Proceedings of the DLR Workshop, Aspects of Engine-Airframe Integration for Transport Aircraft, DLR-Mitteilung 96-01 (1996)

[4] Kooi, J.W.; Kiock, R.; Slauerhoff, J.: Tools for the Experimental Study of the Integration of Ultra-High Bypass Engines on Transport Aircraft AIAA 94-2562 (1994)

[5] Rossow, C.-C.; Hoheisel, H.: Numerical Study of Interference Effects of Wing Mounted Advanced Engine Concepts ICAS-Paper 94-6.4.1 (1994)

[6] Pflug, M.; Haberland, Ch.: On Numerical Jet Flow Simulation of Current and Future High-Bypass Engines. In: Proceedings of the DLR Workshop, Aspects of Engine-Airframe Integration for Transport Aircraft, DLR-Mitteilung 96-01 (1996)

[7] Rossow, C.-C.; Godard, J.L.; Hoheisel, H.; Schmitt, V.: Investigations of Propulsion Integration Interference Effects on a Transport Aircraft Configuration AIAA 92-3097 (1992)

[8] Hoheisel, H.: The Design of a Counter-Rotating High-Bypass Fan Simulator for Windtunnel Investigations DLR-FB 93-20 (1993)

[9] Kiock, R.: The ALVAST Model: Engine Simulation on a Transport Aircraft Model Proceedings of the Conference „Wind Tunnels and Wind Tunnel Test Techniques" 14.-16. April 1997, Cambridge, U.K.

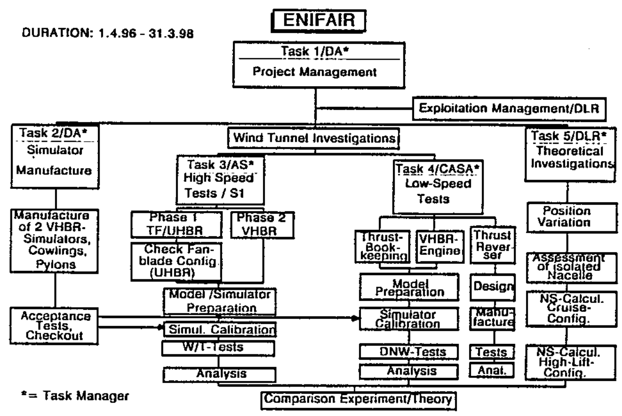

Figure 1: ENIFAIR Program-Structure

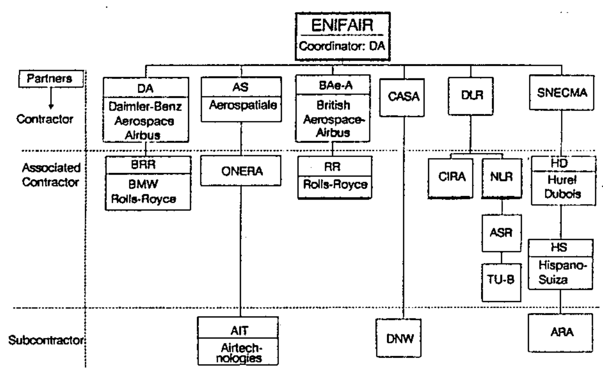

Figure 2: Structure of Participants

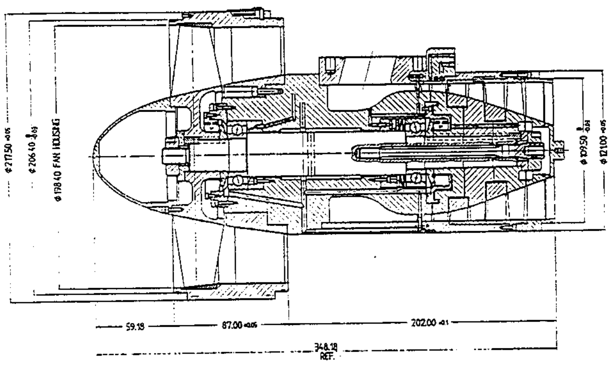

Figure 3: 7.8" VHBR-Simulator

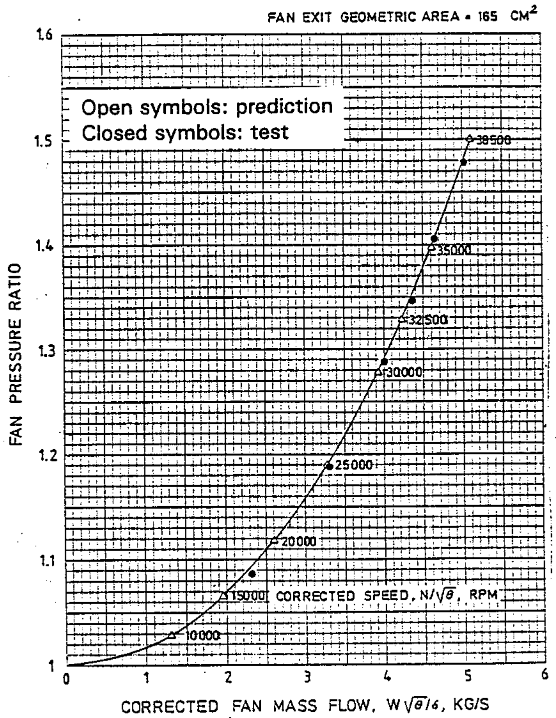

Figure 4: VHBR Fan Performance

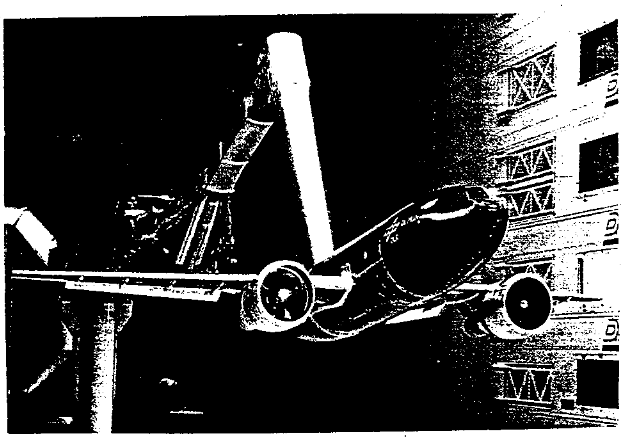

Figure 5: ALVAST Model in DNW

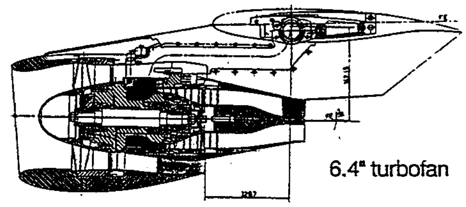

Figure 6: 6.4" TPS with Turbofan Cowlings

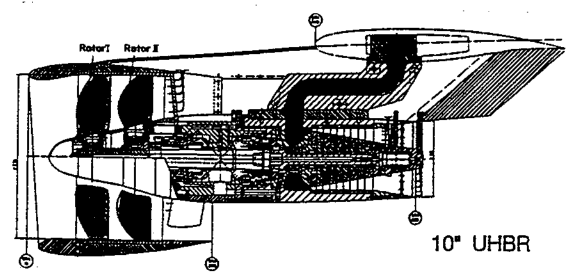

Figure 7: 10" UHBR-TPS with CRUF-Cowlings

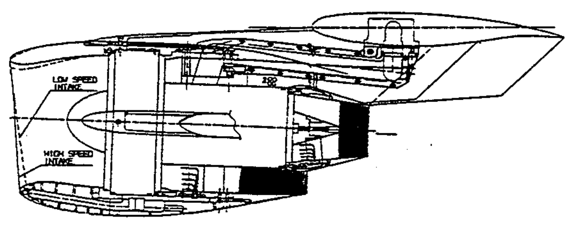

Figure 8: 7.8" TPS with VHBR-Cowlings

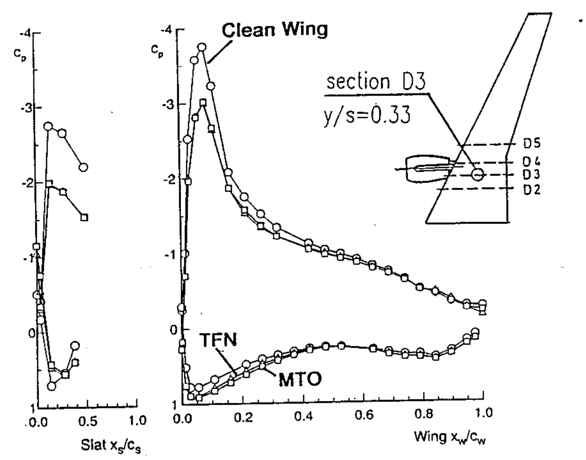

Figure 9: Wing Pressure Distribution I/B of Pylon Take-Off Config., M=0.22, α =12°, Model with Turbofan

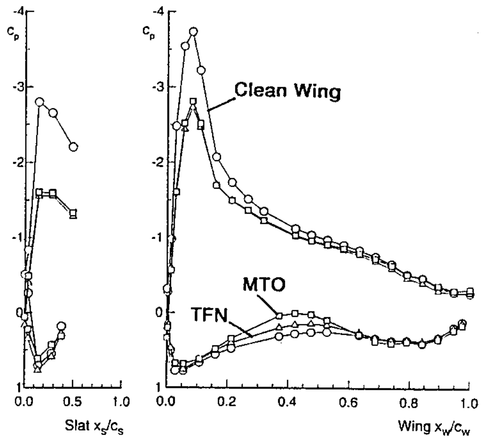

Figure 10: Wing Pressure Distribution I/B of Pylon Take-Off Config., M=0.22, α =12°, Model with UHBR

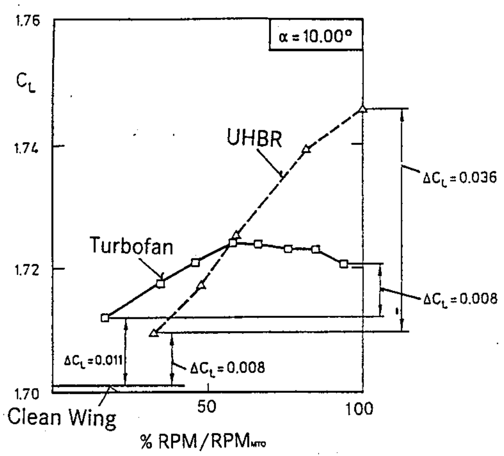

Figure 11: Engine Jet-Effect on Lift, M=0.22, Take-Off Config.

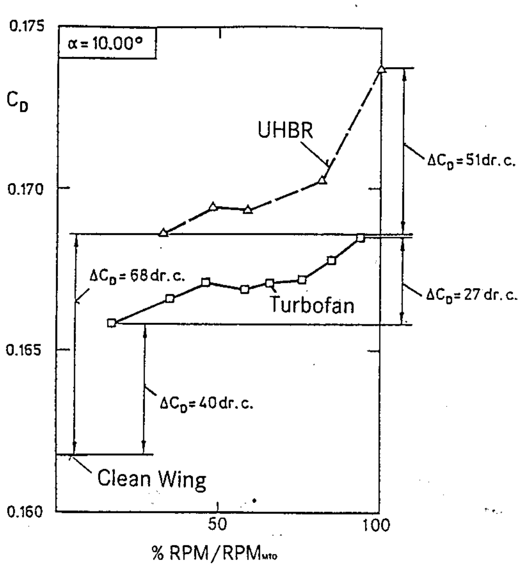

Figure 12: Engine Jet-Effect on Drag, M=0.22, Take-Off Config.

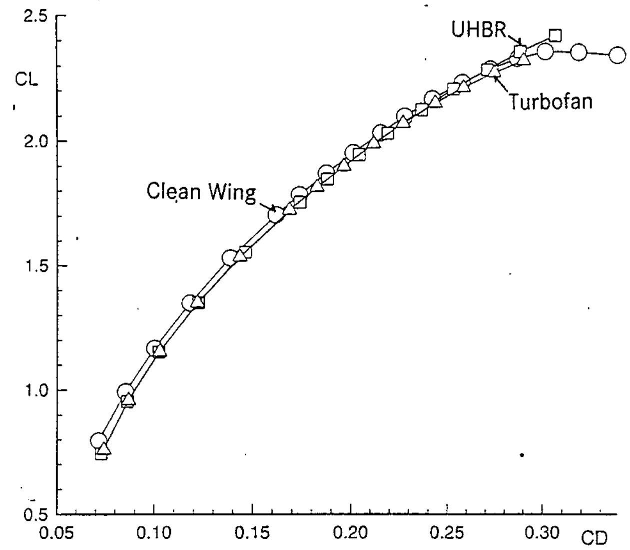

Figure 13: Engine Installation Effects, Take-Off Config., MTO-Power, M=0.22

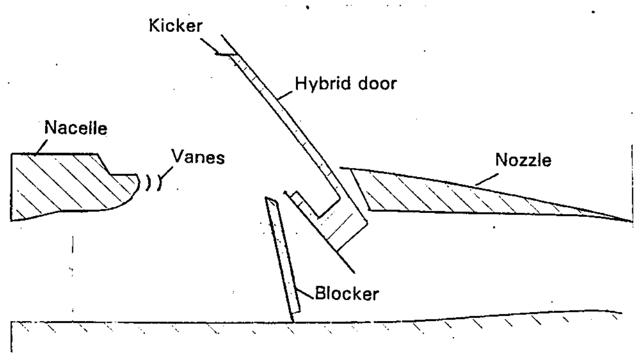

Figure 14: Cascade Door hybrid Thrust Reverser

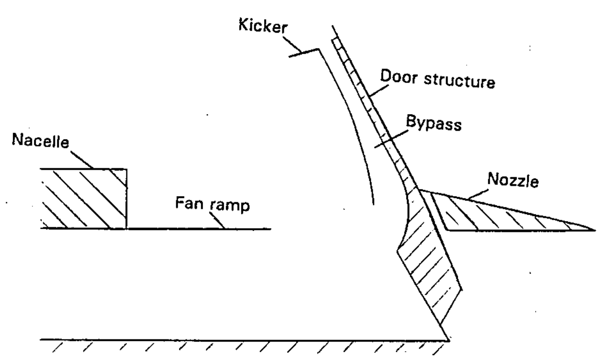

Figure 15: Hollow Door Thrust Reverser

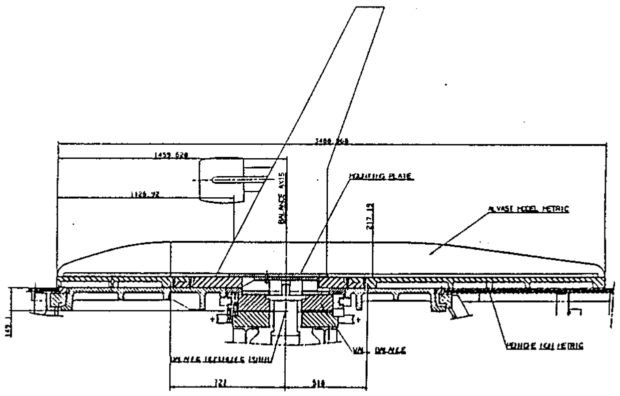

Figure 16: Model Test Setup in ONERA S1 Tunnel

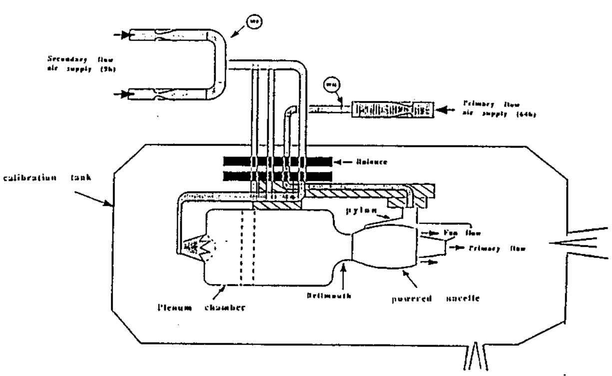

Figure 17: Test Bench for TPS-Calibrations

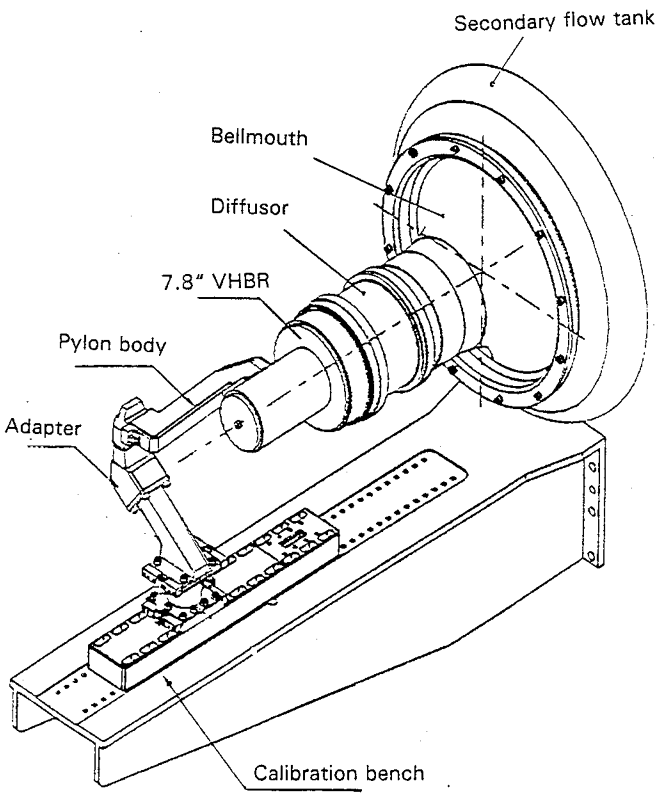

Figure 18: VHBR-TPS with Bellmouth on Calibration Test Bench

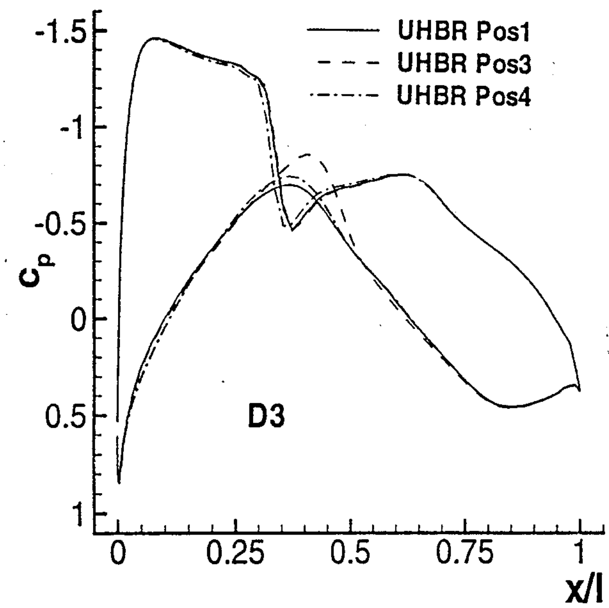

Figure 19: Wing pressure distribution for position variation of UHBR engine (M=0.75, α =1°)

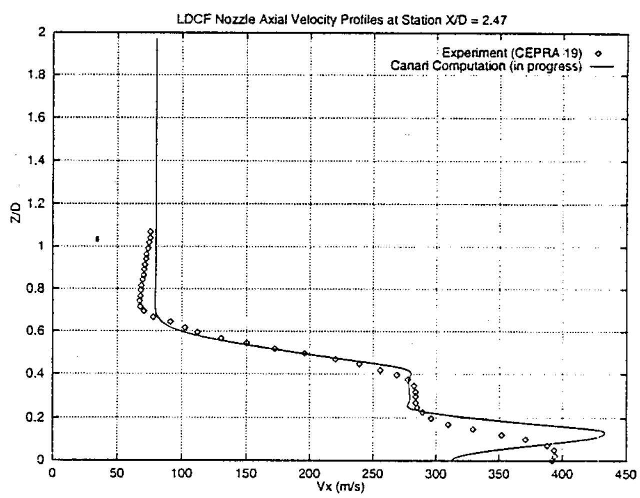

Figure 20: Axial velocity distribution in the jet of long cowl nacelle

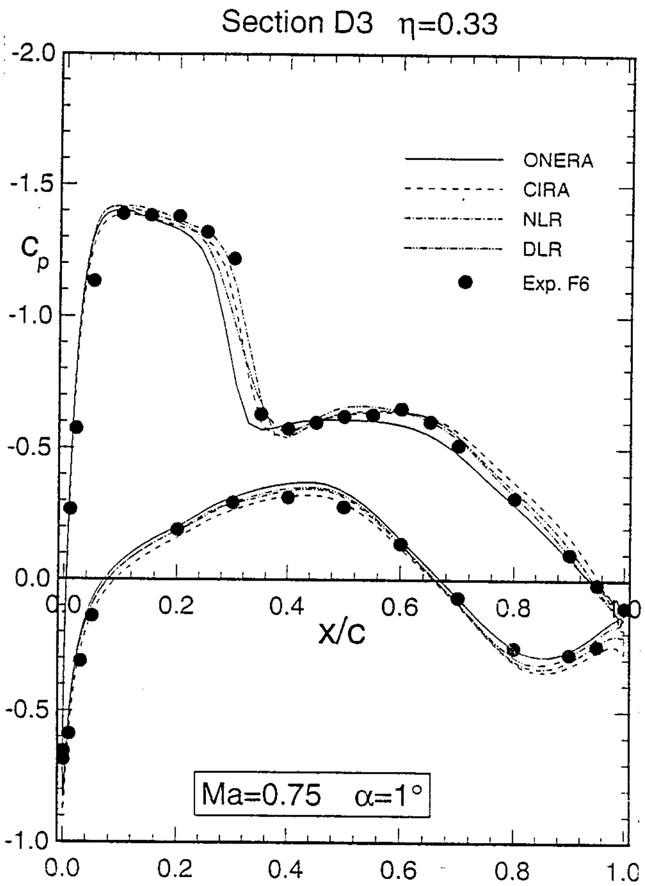

Figure 21: Pressure distributions for ALVAST wing/body configuration

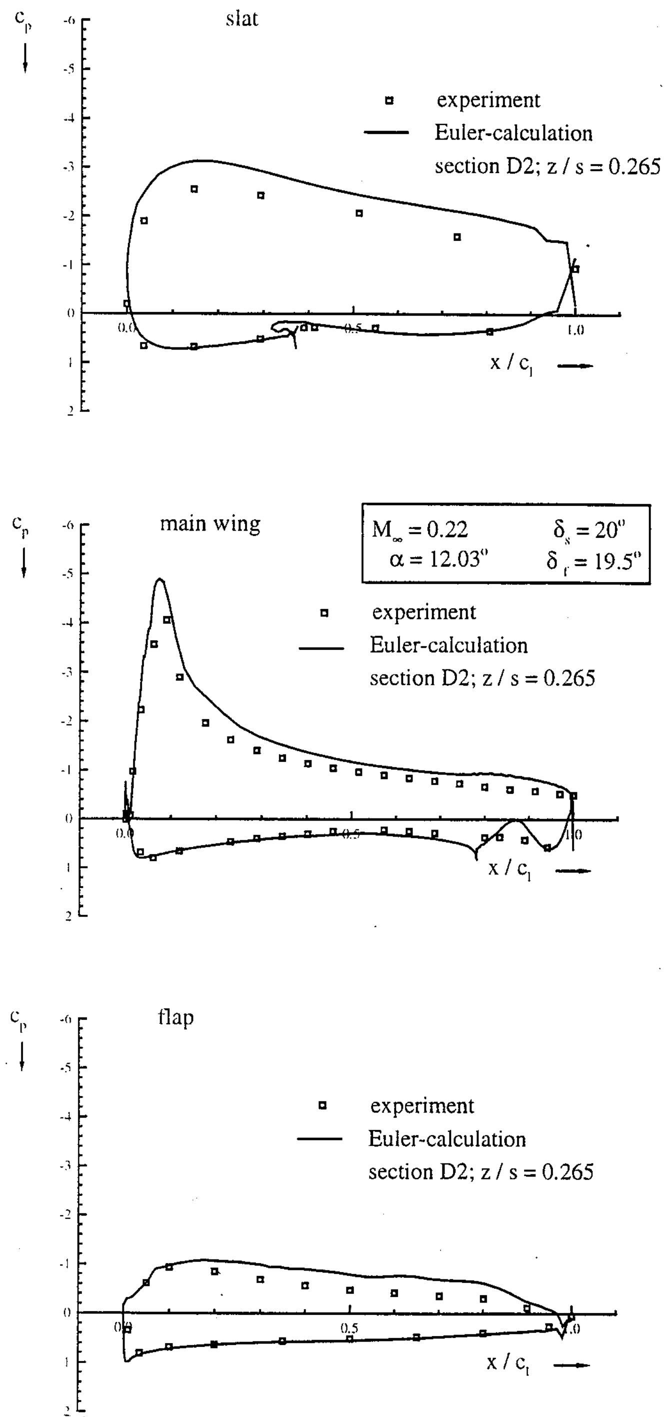

Figure 22: Pressure distribution of ALVAST wing/body high lift configuration