

INTAKE AERODYNAMICS INVESTIGATIONS BY CFD AND CONNECTED INLET TESTING

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Abstract

A connected type of aircraft intake test rig has been fabricated and tested. The rig is used as a base for technology programs in the intake aerodynamics field. A combination of CFD (Computational Fluid Dynamics) and testing is used in the program. The purpose with the program is to gain experience in intake aerodynamics and in the future to develop test and CFD methods for intake aerodynamics analysis and problem solving.

Nomenclature

AIP Aerodynamic interface plane (inlet/engine interface)
M2 AIP mean Mach number
D2 AIP diameter
PI Inlet channel total pressure recovery
RMS root mean square

Introduction

A connected inlet test rig has been designed and fabricated. The rig will be used as a base for technology work in the intake aerodynamics field. Both experimental and computational methods will be developed and used to carry out investigations of intake performance related problems and development of analysis and measurement methods for intake distortion. The rig was installed and a first function test was carried out during 1999.

Outline of work

The rig should make it possible to study the complicated intake channel flow, typical for a military fighter engine installation, for basic research work and for problem solving, to a relatively low cost. The investigations are carried out with a combination of computations and experiments. The computations (CFD) are used to identify certain flow patterns and Mach number or pressure profiles in the inlets, which occur at different flight conditions. CFD is also used for design of methods and tools that are to be used for simulation of the flow conditions in the rig. The rig is used for the final measurements including steady state and time varying registration. The steady state data is correlated with the CFD calculations and in certain reference

points the rig test data can be correlated with full model wind tunnel test data.

Test rig

The geometric scale has to be fairly large to be able to do measurements with good precision. In order to provide for extensive measurements with different types of probes and techniques along the intake channel a connected type of rig was chosen instead of ordinary wind tunnel testing. Another advantage with a connected rig is, that it is much cheaper to operate than a large wind tunnel.

A bifurcated, two to one, inlet configuration was chosen. The rig is connected to a compressed air system by two separate feeding lines including venturies for mass flow measurement and control valves for pressure level control. The feeding lines dump the air into two separate feeding chambers. The forward part of the intakes is mounted through the downstream wall of the feeding chambers. The forward part is an assembly of four walls and a flange. The forward outer piece of the upper and lower lips is exchangeable and each sidewall can be replaced.

The single engine interface is connected to an atmospheric outlet. The AIP Mach number (M2) is controlled in discrete steps by a sonic outlet nozzle. The interface diameter (D2) is approximately 0.180 m.

The test envelope that can be fully covered by this type of rig is limited to cases with flight Mach number 0 or close to 0. Since there is no external flow around the intake lips, the intake capture ratio is defined by the feeding line plenum area and the intake cross section area, other parts of the flight envelope has to be simulated by creating relevant flow patterns in the forward part of the inlets.

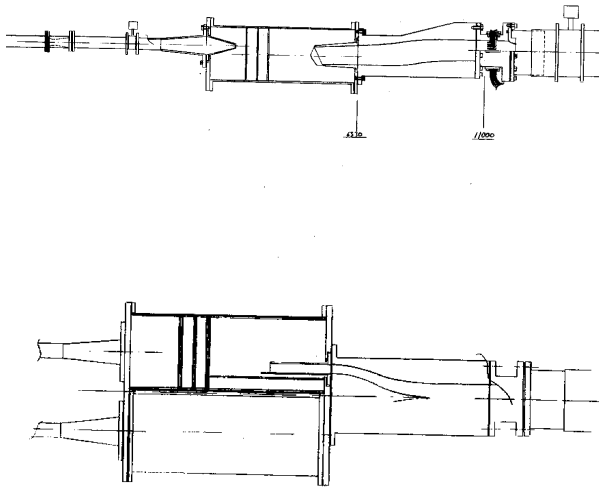


Figure 1. Test rig layout. Upper picture sideview and lower picture top-view.

AIP total pressure recovery.

Figure 2 show a comparison of total pressure recovery data at the engine aerodynamic interface plane from the rig, CFD and wind tunnel tests.

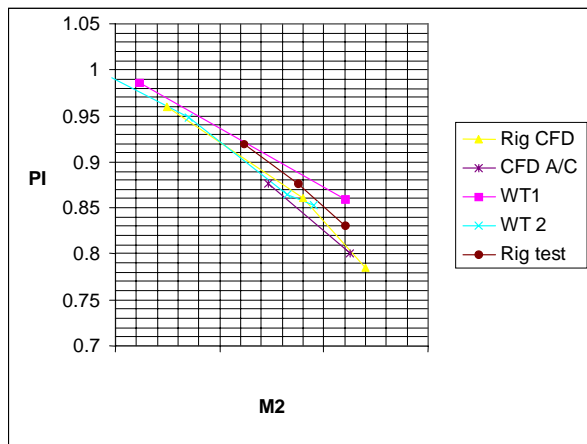


Figure 2: Total pressure recovery at AIP.

Total pressure recovery versus Mach number at the engine/inlet interface station is presented. "WT1" and "WT2" are different sets of wind tunnel test data, "CFD A/C" are calculations with the schematic aircraft model. "Rig CFD" is calculations with the test rig geometry. The measured total pressure recovery data show good correlation with the CFD and wind tunnel test data. The two sets of wind tunnel data are from tests with some difference in the min section area and the min section area is not the same as in the rig test so they are not directly comparable. However the size of the rig intake min-section

area is in between the size of the two wind tunnel models and that is what the pressure loss also indicates.

CFD

A schematic aircraft model, including wings, body and intakes down to the engine inlet is used as reference geometry. By simulating different flight-conditions with this model, desired inlet conditions for the rig can be obtained. The CFD simulation was performed with the commercial CFD code Fluent using the compressible, coupled solver, a realizable k-epsilon model and non-equilibrium wall-functions. An example simulation can be seen in figure 3, which shows the aircraft geometry and computed reversed streamlines from the engine inlet out through the intakes and over the aircraft fore-body. This example is a low-speed flight-condition with 20 degrees yaw-angle. A number of flight cases in the low speed range has been investigated and evaluated concerning flow patterns and pressure profiles. 3-dimensional Navier-Stokes calculations were also used in the design of the rig geometry. In the future, CFD data from the aircraft model will be used as a base in the design of experiments that shall simulate certain flight conditions. CFD on the rig geometry is used to design methods and tools to simulate the flow pattern corresponding to the different flight cases.

CFD results – full scale aircraft

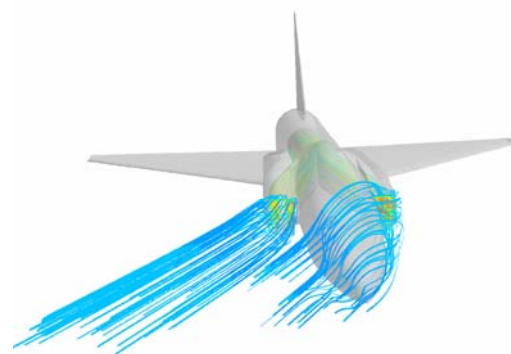


Figure 3, Aircraft CFD simulation

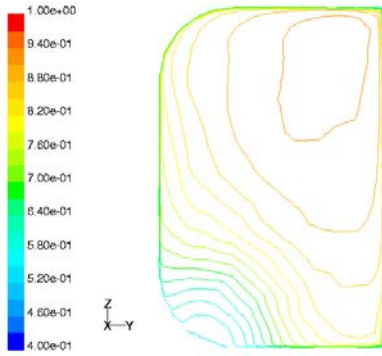


Figure 4. Intake channel min-section total pressure distribution. High flow rate.

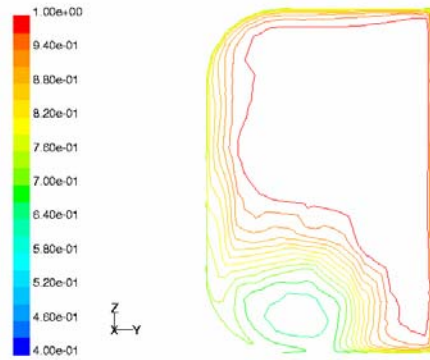


Figure 7. Min section total pressure distribution, high flow rate, 20° yaw angle at 0.2 flight Mach. Lee side

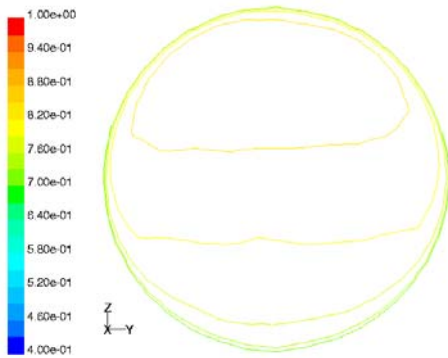


Figure 5. AIP total pressure distribution, high flow rate.

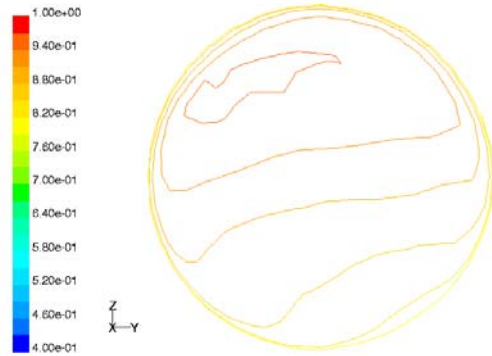


Figure 8. AIP total pressure distribution, high flow rate, 20° yaw angle at 0.2 flight Mach no.

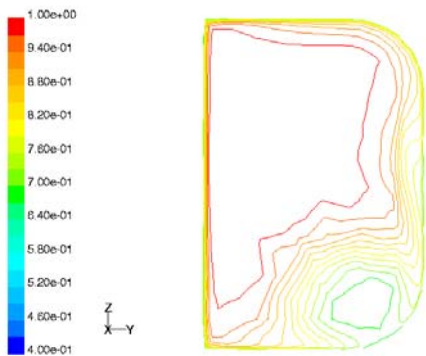


Figure 6. Min-section total pressure distribution, high flow rate, 20° yaw angle at 0.2 flight Mach. Wind side

Figures 6 through 8 show results from a case with yaw angle, at a very low flight Mach no. A yaw angle effect on the total-pressure in the throat, is that the low-pressure area in the lower part of the intake, is right in the corner on the wind side and in the center on the leeward side. At the AIP a characteristic turning of the total pressure peak, to the wind side is recognised.

Test

Tests with simulated flight conditions are performed. Both steady state and time dependent pressures are registered. Conditions corresponding to 0 flight Mach no and a low flight Mach no 0.2, with yaw angle are tested.

Measurements

The inlet mass flow is measured separately for the two inlets. The total pressure is measured upstream of the inlets and by a 40-probe rake at the engine interface station. The rake includes flow angle probes for swirl detection. Static wall-pressures are measured along the intake channel top and bottom walls from the lips down to engine interface. Traversable total pressure probes will be used in at least two stations between the inlets and the bifurcation, in order to follow the flow pattern as it develops along the flow path.

Steady state results

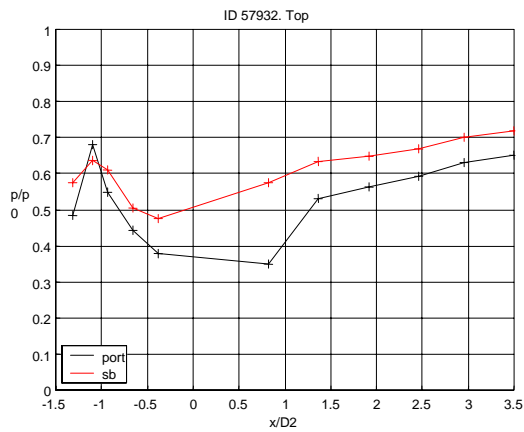


Figure 9. Test rig set for yaw angle simulation. Wall pressures along upper surface centre line in both channels.

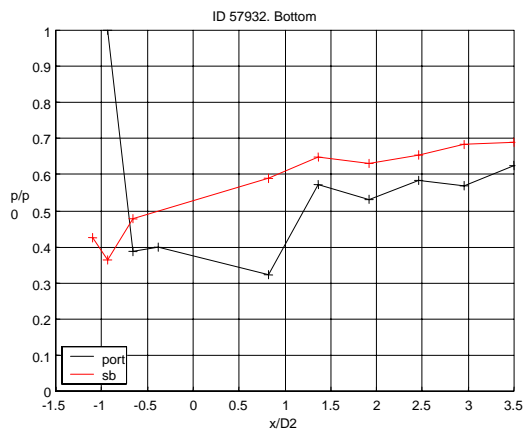


Figure 10. Test rig set for yaw angle simulation. Wall pressures along lower surface centre line in both channels. (First point erroneous for portside intake.)

Figure 9 and 10 show static pressure distribution along the intake channel for a relatively high mass flow setting and with different feeding pressure for the intakes, giving the same effect as a yaw angle in flight.

Intake/engine interface (AIP)

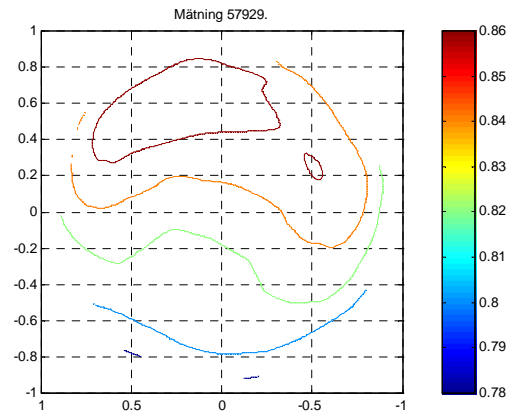


Figure 11. Total pressure map at the engine inlet.

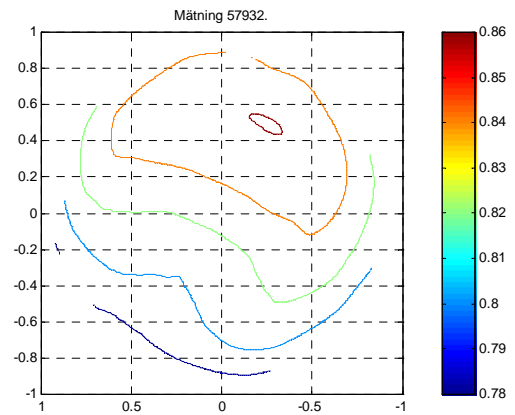


Figure 12. Total pressure map at engine inlet station. Yaw angle simulation.

Figures 11 and 12 show steady state total pressure in the AIP. The two diagrams show the difference in pressure distribution that is caused by a simulated yaw angle. The flow pattern shown in figure 12 corresponds to approximately yaw angle 30 degrees at flight Mach no 0.2.

Intake channel min section

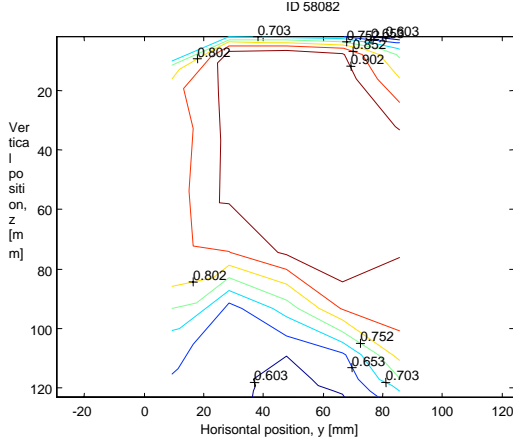


Figure 13. Total pressure map in intake channel, downstream of throat. High flow rate. No yaw angle.

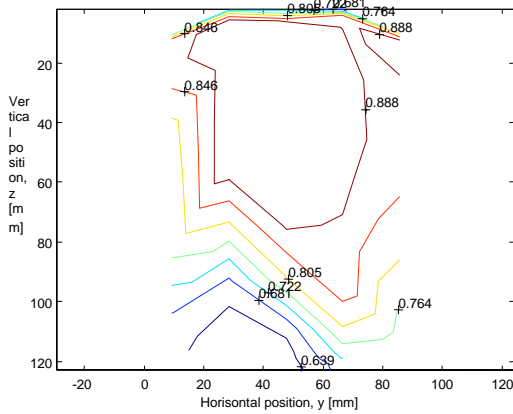


Figure 14. Total pressure map in intake channel, downstream of throat. High mass flow rate. Yaw angle simulation.

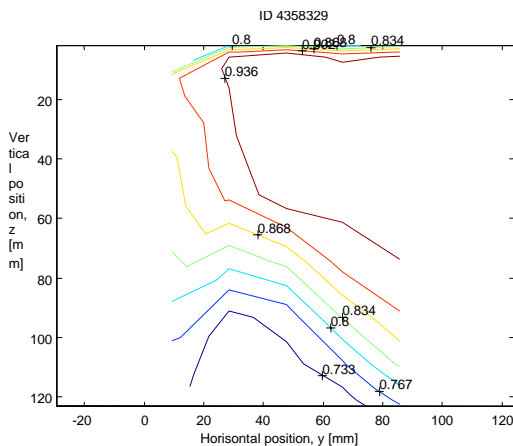


Figure 15. Total pressure map in intake channel, downstream of throat. Low massflow rate. No yaw angle.

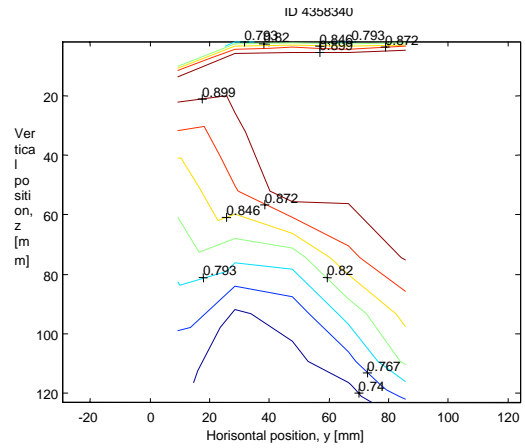


Figure 16. Total pressure map in intake channel, downstream of throat. High mass flow, yaw angle simulation.

Figures 14 through 16 show steady state total pressure maps in a section just down stream of the starbord intake throat, with and without yaw angle simulation, and at two flow rates.

Instationary Measurements

A rake for time varying registration of the intake/engine interface total pressure is available. The rake consist of 40 fast response miniature pressure transducers mounted in 8 rakes forming 5 rings covering equal parts of the cross section area.

Test result instationary measurements.

So far only RMS-values of the time varying pressures have been extracted from the data. The RMS-values are plotted in the same manner as the steady state total pressures. The plots give a picture of in what areas high fluctuations in pressure occur.

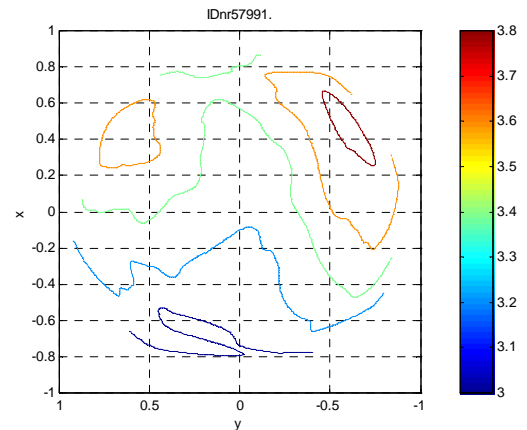


Figure 17. RMS-values of total pressure fluctuations. Low massflow, no yaw angle

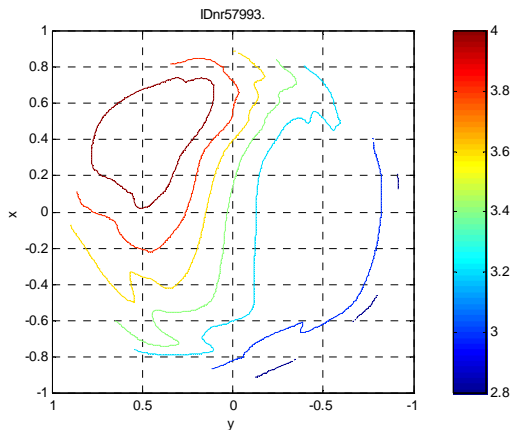


Figure 18. RMS-values of pressure fluctuations. Low massflow rate, yaw simulation.

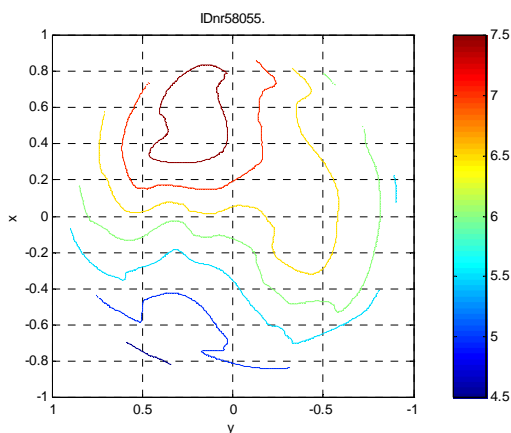


Figure 19. RMS-values of total pressure fluctuations. High mass flow, no yaw angle

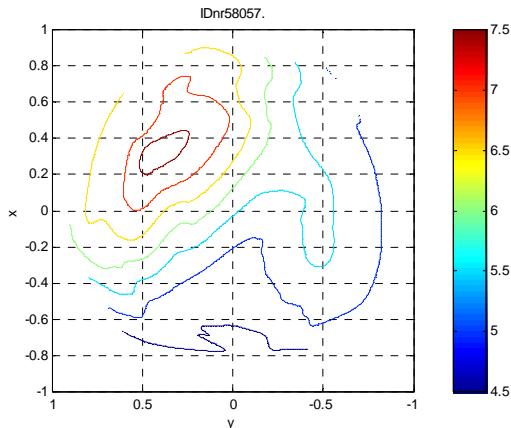


Figure 20. RMS-values of total pressure fluctuations. High mass flow, sideslip simulation

Figures 17 through 20 show RMS-values of the total pressure fluctuations with and without sideslip simulation and at two flow rates. The plots show a similar pattern as the steady state total pressure, which means that the fluctuation amplitude is high where the total pressure level is high and the whole pattern turns over with the high level area to the windward side, when a sideslip angle is applied.

Conclusions

The purpose with this test rig is to increase knowledge of intake flow and develop methods for evaluation and problem solving in the field of intake aerodynamics and engine installation. In times when the development projects are few can a rig like this be a source of inspiration and serve as a base for technology and demonstrator programs. The rig has limitations in possibilities to simulate flight cases, but it has also advantages regarding availability, test cost, and accessibility for measurement equipment.

Steady state data from the intake rig show good correlation with CFD-calculations and wind tunnel test data. It seems possible to correlate the rig tests data with CFD on a full aircraft model but certain rules for this process has to be worked out since the flow pattern or total pressure distribution depends on a number of parameters as flight speed, intake flow speed, and attitude angles.

The instationary measurements look promising but needs more work to show its full potential. Future work will give more detailed information including time varying pressure distortion and AIP flow swirl. The aim is to be able to detect where the different types of distortion is induced and thereby get opportunities to avoid it. Another issue in this technology work is to address intake distortion analyse and evaluation methods and the impact of inlet distortion on engine function and performance.

Acknowledgements

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