ICAS-84-2.2.3

EXPERIMENTAL VALIDATION BY FLIGHT MEASUREMENT OF THE PRESSURE DISTRIBUTION COMPUTED ON PILATUS PC-7 WING USING A THREE DIMENSIONAL AERODYNAMIC PANEL PROGRAM

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Abstract

Wind tunnel tests add a considerable amount to the development cost of an aircraft. It is then advisable, particularly for small companies not equipped with their own facilities, to replace, as far as possible, experiments with numerical calculations. This leads to time and money saving especially during those phases of the design requiring lengthy optimization precesses. To do so, the three dimensional aerodynamic panel method of Hunt and Semple has been introduced at PILATUS.

The code validation has been conducted first using the available literature presenting pressure distributions (generally from wind tunnel experiments) and lift and drag data on several combinations of wings and bodies.

Subsequently it has been decided to undertake a flight test campaign to obtain reference data for a further checking of the numerical code. The test resulted in pressure measurements at two span stations on the wing of the company PC-7 demonstrator. Pressure was measured and recorded in flight using a PCM (Pulse Code Modulation) data acquisition system. Chordwise pressure distributions have then been obtained for different flight speeds. The numerical results have been computed approximating PILATUS PC-7 wing with a model using 7 spanwise strips of 30 panels each. The pressure computed at the same spanwise location as used in flight measurements, has been corrected with a three dimensional boundary layer code to account for viscous effects.

An important feature of the numerical code, namely the possibility of evaluating off-body flow field, has been exploited to account for the upwash angle affecting the reading of the angle of attack vane.

Once this correction was done comparisons have been made at the same incidence for the numerical model and the wing in flight. The agreement achieved is good for the several angles of attack considered.

Therefore the test campaign has proven that three dimensional panel codes are able to provide - within the limits of their validity - results which are affordable for a small aircraft company and which can be confidently used during an aircraft development phase.

Introduction

At the beginning of the development phase of its latest project, the PC-9, the Engineering Office of PILATUS Aircraft decided to acquire a numerical code which could enable the group to conduct, in a quick and reliable manner, a whole series of computational activities. This would have reduced, on one side, the necessity for long and expensive wind tunnel tests and, on the other, would have provided all the different development offices with the required aerodynamic data.

Among all computer programs available on the market, it was decided to select the Hunt & Semple panel program developed by British Aerospace in Warton, for its high flexibility of use and the well proven numerical approach

Although the code has been succesfully used in BAe for some years, PILATUS decided to conduct its own validation campaign, mainly to "trim" the method with the kind of configurations and the range of applications typical of PILATUS products, and slightly different from those considered up to then by BAe. The program was in the meantime converted from its original IBM code to the VAX code and this further activity led to the requirement for a final check.

Since the possibility existed to conduct a series of flight tests on the company testbed aircraft (a PC-7 with two instrumented wing sections: see Figure 1), it was thought that a comparison between pressure distributions obtained in flight and those computed by the program on the aircraft wing, would have given a good base for the validation of both the method and the model adopted to represent the aircraft.

Such a comparison was intended to prove the ability of the code to reproduce local flow details (agreement between measured and computed pressure distributions) and confirm its capability of accurately predicting the global loads acting on the aircraft major components. Thus enabling the aerodynamic group to confidently use the program as an optimization tool during the development phase of a project and as a reliable source for the computation of the aerodynamic loads required throughout the whole detailed stressing of the aircraft.

1. The computer model and the numerical results

The Hunt & Semple MkIA panel program is a first order three dimensional panel program; it can treat any given combination of lifting and non lifting three dimensional bodies and it incorporates a boundary layer routine to evaluate viscous effects on lifting surfaces.

The program requires a subdivision of the body under consideration into a set of planar panels which approximate as much as possible to the original shape (see Figure 2). In the present test campaign only the wing of the aircraft has been represented (see Figure 3), since the presence of the fuselage does not affect the pressure distribution in that part of the wing where the instrumented sections are located.

1.1 The original wing and its model

The wing is based on two different profiles (NACA 64 series) of 15 per cent thickness at the root and 12 per cent at the tip. These profiles have been modified by PILATUS to reduce the pitching moment coefficient.

The wing is characterized by a 7 degree dihedral and a 2 degree twist; wing taper ratio is 0.56 and aspect ratio is 6.5.

To model the surface 7 spanwise sections have been used. These sections were located along the span according to a cosine law to give a better representation of the lift distribution towards the wing tip. On each section the profile was approximated by 30 panels, whose edges were fixed along the chord by using again a cosine distribution, to accurately represent the profile shape in the leading edge and trailing edge regions.

The location of the spanwise strips was chosen so that two of the control sections were in exactly the same position as the two instrumented sections available on the test-bed wing, corresponding to rib 14 and rib 17 of the wing structure.

No detailed modeling of the wing tip regions was performed as only symmetrical flight conditions at low angles of attack would have been considered in the test phase. In this situation the calculated flowfields are insensitive to the modelization used for the wingtips (closed wingtips or open wingtips).

1.2 The Numerical Results

During the numerical evaluation phase, two sets of computations have been performed. In the first set a preliminary "trimming" of the configuration was done by comparing measured and computed pressure distributions at the same integrated lift coefficient.

This suggested the existence of a discrepancy between the angle of attack of the aircraft, as read by a wing mounted incidence boom, and the nominal freestream value used in the calculations of the wing flowfield.

A row of external off-body points was then added in the numerical model at the boom location to work out an angle of attack correction. The same configuration was then recomputed at the corrected values of the angle of attack. This improved the quality of the results by giving the possibility to compare pressure distributions at the same incidences.

In this second part of the computational phase many cases were run including viscous effects (boundary layer iteration) to investigate the influence of the Reynolds number in this sort of computation.

Special care was taken in defining the combination of Mach number and Reynolds number to be used in the numerical analysis. Each single measurement corresponds to a well defined combination of angle of attack, Mach number and Reynolds number. In order to save computational time it was decided to evaluate the pressure distribution over the whole range of angles of attack obtained in flight, only for two combinations of Mach and Reynolds numbers.

The complete numerical evaluation over the full range of data points (combinations of incidences, Mach numbers and Reynolds numbers) took something like 15 hrs of computational time on a VAX 11-750 computer.

2. The flight test setup (PILATUS Data Acquisition System)

The data acquisition system (DAQUS) used by PILATUS is based on the Pulse Code Modulation (PCM) principle and is illustrated in fig 4. The PILATUS system, that is to say the encoder, decoder and all the peripheral devices, can be broken down into the "Data storage unit" and the "Data processing unit".

2.1 Data Storage Unit

SENSORS - For this test the main sensors were pressure transducers, used in conjunction with a scannivalve, and a potentiometer.

SIGNAL CONDITIONING - This unit converts the transducer output signal to the required ± 5 V input signal specified for the Encoding unit.

ENCODING UNIT - This is the true core of the PCM system. It accepts all outputs from the signal conditioning unit in parallel, and the results output to a single data bus and stored on one track of a tape recorder.

TAPE RECORDER - The PCM system allows for the use of a conventional stereo tape recorder. As only one track is used for data recording the other is available for simultaneous voice recording.

2.2 Data Processing Unit

TAPE RECORDER - An identical tape recorder as described above is used for data replay.

DECODER - The decoder identifies the digital information from the tape and sorts it into its respective channel identification and signal size. The output mode was selected for an analog trace.

OUTPUT DEVICE - The output device used was a U-V paper trace recorder, which allows the output channel to be plotted against time in an quasi-analog form.

3. Comparison between theoretical and experimental results

As a first step in the validation campaign, separate comparisons have been performed between computed and measured pressure distributions relative to the two instrumented sections on the aircraft wing.

Figure 6 shows the first of these comparisons at rib 14 (the inboard one) at an angle of attack of 6.1 degrees. Figure 7 shows a comparison at rib 20 (the outboard one) for an angle of attack of 5.6 degrees.

As it can be seen a satisfactory agreement is obtained in both cases. In figure 8 the discrepancy at the trailing edge region between the calculated pressure (continuous line) and measured pressure (symbols) could be due to the presence of the split flap on the last 20 per cent of the chord, modifying the profile shape. The pressure peak near the leading edge is slightly overestimated by the program.

Again a fairly good agreement is obtained on rib 20, despite some irregularities introduced on the wing shape by the presence of the aileron hinge and gap.

As mentioned before, the greatest difficulty encountered during this preliminary test phase was obtaining a good agreement with flight test data when calculations were performed at the same angle of attack as measured by the flight test boom. The good accuracy of figures 9 and 10 is achieved by showing the comparison at the same integrated lift coefficient. In both calculations no boundary layer effects have been accounted for.

It was then decided before proceding in the validation campaign, to obtain a correction which could relate the angle of attack measured by the boom with the free stream value. The correction proved that at the boom location (approximately one wing chord in front of the leading edge and at 95% of the wing span) a significant upwash from the wing was present. The calibration of the probe shows that the boom always read an angle of attack greater than the value at infinity by a quantity increasing with the wing lift.

Calculations were repeated at the corrected angle of attack corresponding to the free stream value. Viscous effects were also taken into account.

Calulations have been performed only for two combinations of Mach and Reynolds numbers corresponding to the extremes of their ranges as experienced in flight.

Table 1 summarizes the results for the first combination: Re = 7.14×10^6 and M = 0.306. It shows the freestream angle of attack (α_{FS}), the calculated and the measured angles at the boom location (α_{BL}, α_{BM} respectively), the Lift Coefficient (C_L) calculated with and without viscous correction ($C_{L_{INV}}$, $C_{L_{VIS}}$ respectively) and experimental value of C_L ($C_{L_{TEST}}$).

Figures 8 to 11 show the corresponding comparison between numerical and experimental results.

The pressure distribution agreement is acceptable over the whole range of incidences. The shape irregularity of the measured distribution for the lowest angle of attack, derived from atmospheric turbulence, is always present during many of the test flights.

The crossing of the computed pressure distribution at the trailing edge is due to the particular formulation of the Kutta condition adopted to enhance the lift losses due to viscous effects.

As a comparison, figure 12 shows the same pressure distribution as figure 11 without viscous correction. By accounting for boundary layer effects there was a better representation of the leading edge suction peak.

Table 2 summarizes the results for the second Re and M combination (Re = 3.318 x 10^6 M = 0.142), figure 13 presenting the corresponding pressure distributions. The graphs show that there is not a dramatic difference when compared with the previous set of results, from which it is possible to conclude that M and Re did not play an important effect on pressure distributions over the range considered.

Conclusions

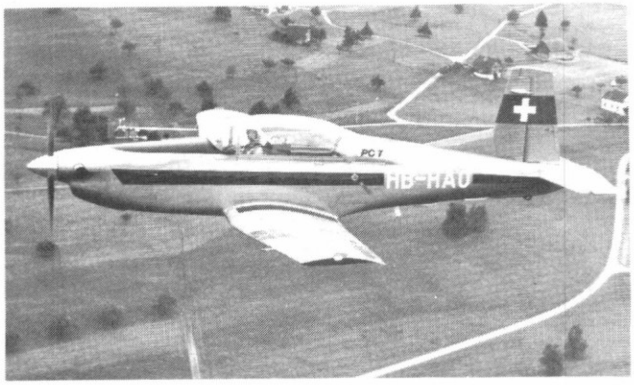
During the described test campaign, it has been possible to acquire a wide experience in the use and interpretation of the Hunt and Semple program, and a confidence in its capabilities.

The code has in fact been proven capable of predicting, within an acceptable approximation, the flow behaviour on the PILATUS testbed wing. Therefore the designer has the possibility to use the code to investigate the effects of design changes on the flowfield around the aircraft or to evaluate configurations during the development phase, in a quick and reliable manner.

The accuracy in the prediction of local loads (pressure coefficients) is in fairly acceptable limits, and confirms that the program can be confidently used as a means of evaluating aerodynamic loads on structural components, with the result of bringing to an unique source the determination of the aerodynamic loads for the structural sizing or checking phases.

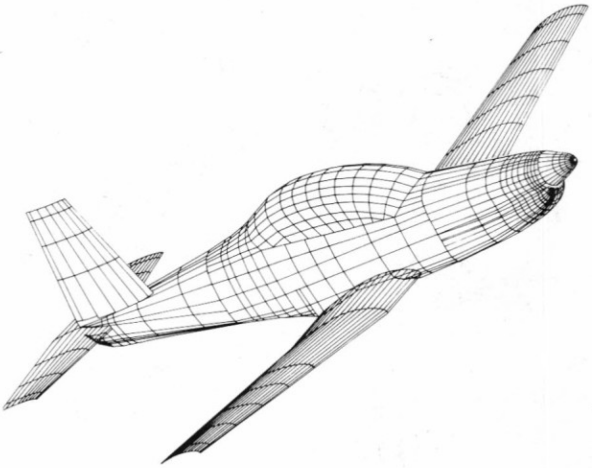
The boundary layer simulation improved the flowfield prediction only at relatively high angles of attack, thus allowing (for low angle of attack) the use of the code to simulate potential flow with a considerable saving in computational time.

Finally, it has been found that the accuracy inherent to this kind of computer code (three dimensional panel programs) is adequate for their application as optimization tools during the development phase of a new project.



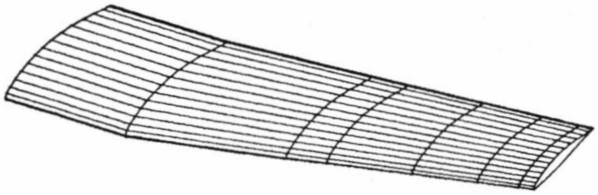
PC-7 Testbed

Figure 1



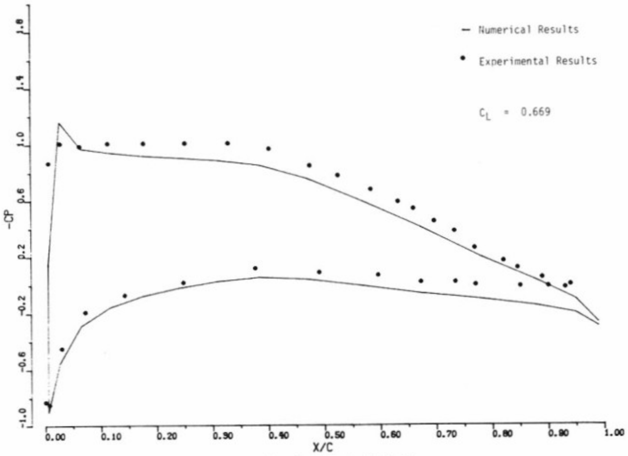
Hunt & Semple Model

Figure 2



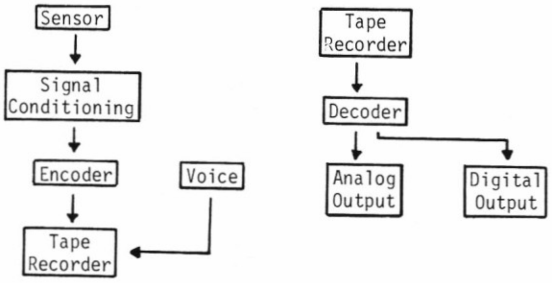
Panelling of PILATUS Test-bed wing

Figure 3



Pressure Distribution at rib N° 14

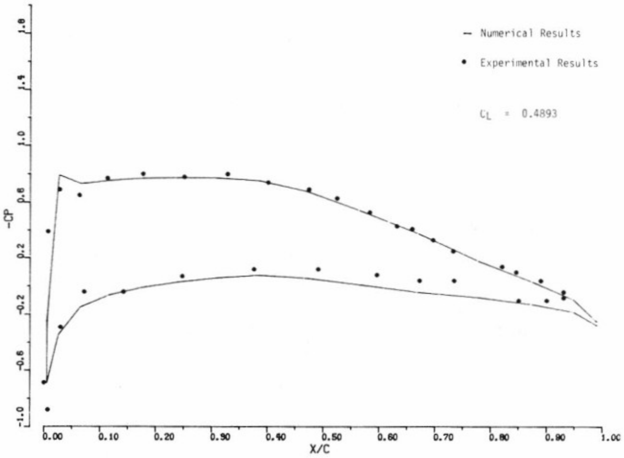
Figure 6



Data storage

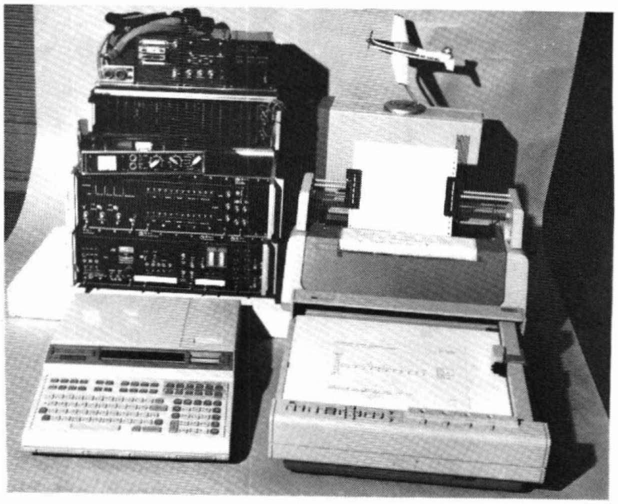
Data Processing

Figure 4



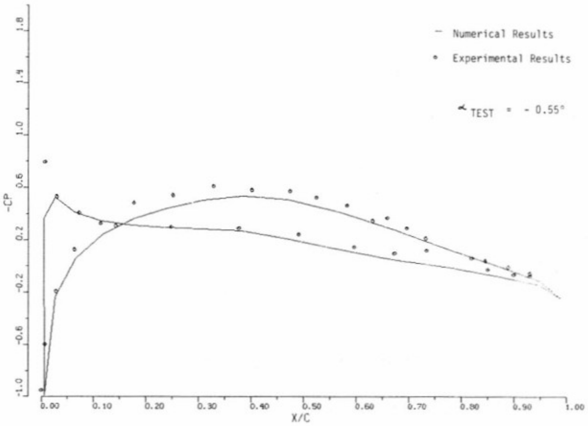
Pressure Distribution at rib N° 20

Figure 7



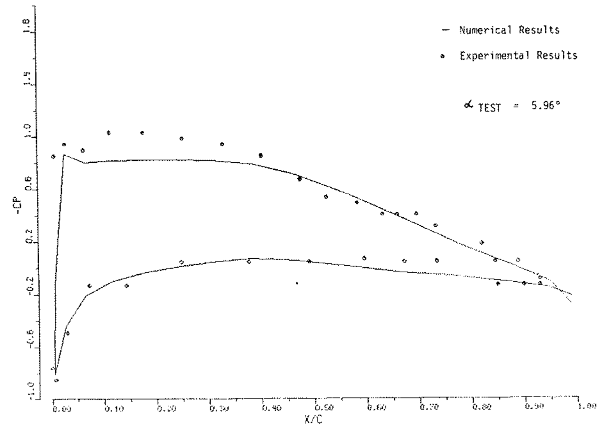
PILATUS DAQUS

Figure 5



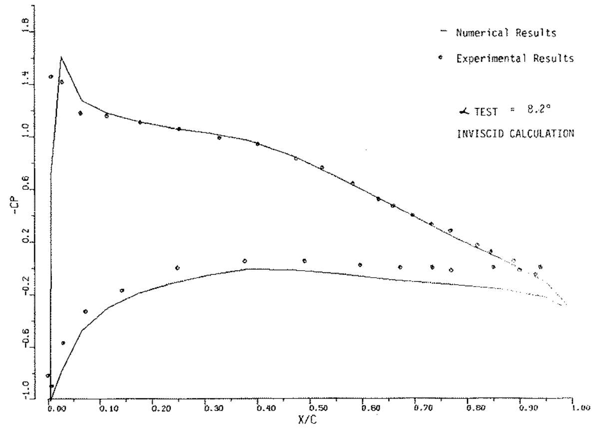
Pressure Distribution at rib N° 20

Figure 8



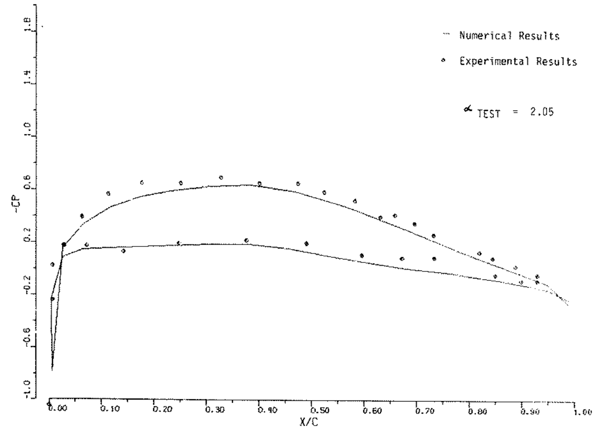
Pressure Distribution at rib N° 20

Figure 9



Pressure Distribution at rib N° 14

Figure 12



Pressure Distribution at rib N° 20

Figure 10

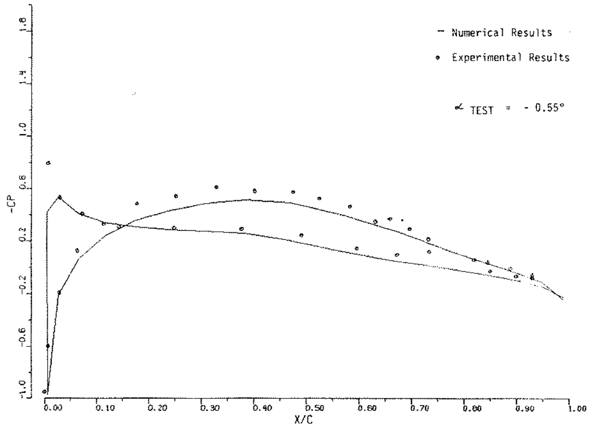
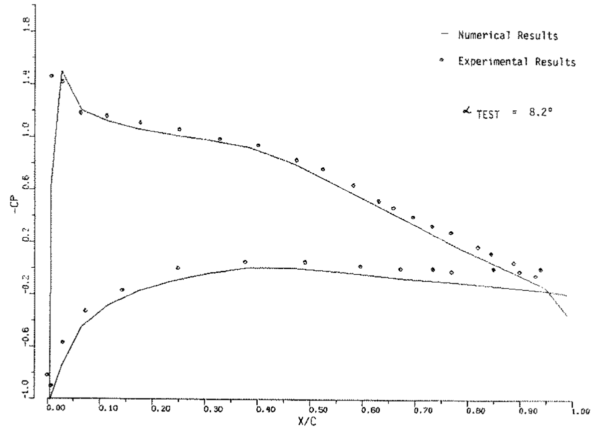


Figure 13



Pressure Distribution at rib N° 14

Figure 11

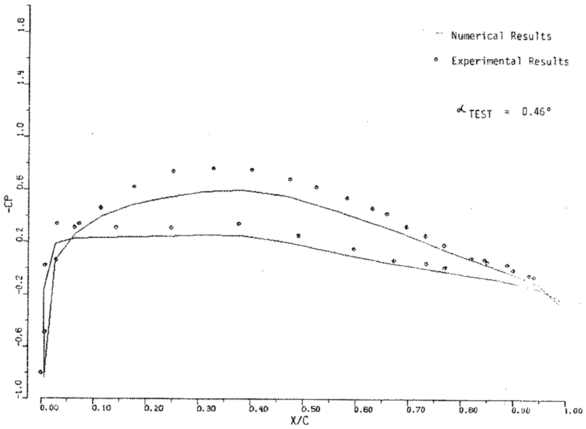


Figure 14

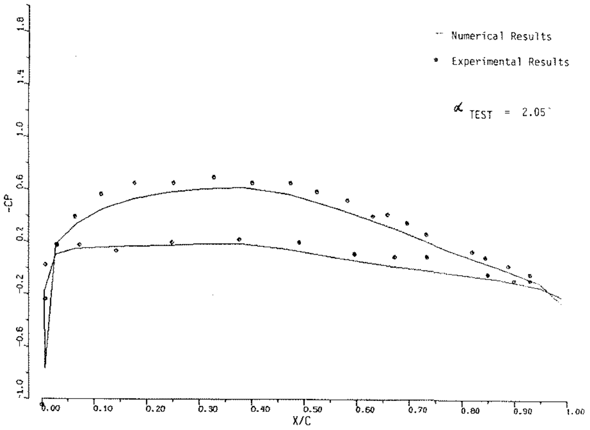


Figure 15

α_{FS} [°]	α_{BC} [°]	α_{BM} [°]	$C_{L\ INV}$	$C_{L\ VIS}$	$C_{L\ TEST}$
- 0.7	- 0.57	- 0.55	0.130	0.118	0.144
0.19	0.46	0.46	0.208	0.192	0.190
1.55	2.08	2.05	0.328	0.300	0.323
4.9	6.00	5.96	0.620	0.573	0.685
6.83	8.20	8.2	0.789	0.711	0.727

Re = 7.14 10^6 /m

M = 0.306

Table 1

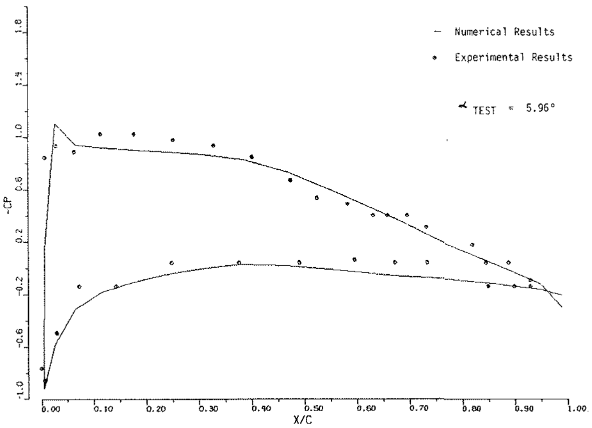


Figure 16

α_{FS} [°]	α_{BC} [°]	α_{BM} [°]	$C_{L\ INV}$	$C_{L\ VIS}$	$C_{L\ TEST}$
- 0.7	- 0.57	- 0.55	0.128	0.111	0.144
0.19	0.46	0.46	0.205	0.181	0.190
1.55	2.08	2.05	0.322	0.287	0.323
4.90	6.00	5.96	0.608	0.553	0.685
6.83	No convergence	8.2	0.777	No convergence	0.727

Re = 3.318 10^6 /m

M = 0.142

Table 2