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THE LAMINAR WIND TUNNEL OF THE INSTITUTE FOR AERODYNAMICS AND GASDYNAMICS, TECHNISCHE HOCHSCHULE, STUTTGART

By

F. X. Wortmann and D. Althaus
Zeitschrift für Flugwissenschaften, 12, 4, April 1964.
Translated by E. J. MacAdam

Manton Lane,
Bedford.

August, 1964.

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Summary

A medium-sized low-speed wind tunnel with a very low turbulence level has been installed at the Institute for Aerodynamics and Gasdynamics of the Technische Hochschule Stuttgart. The tunnel is built as an open tunnel of the Eiffel design and is virtually made independent of weather conditions by means of wind barriers. The maximum velocity is of 91 m/sec. The rectangular working section with rounded corners measures 0.73 x 2.73m. The instrumentation enables aerofoil section characteristics to be measured over a range of Reynolds numbers from 2.5×10^5 to 6×10^6. The results are processed by transducers and analogue computers and directly presented in form of reduced values on a coordinate plotter. The extremely low turbulence level makes this tunnel ideally suited for investigation of all problems associated with laminar flow and with drag reduction due to laminarisation.

1. Introduction

During the rebuilding of the Institute for Aerodynamics and Gasdynamics of the Technische Hochschule Stuttgart during the years 1958 to 1962, among other things a laminar wind tunnel for low speeds was proposed.

Departing from the usual pattern of this type of equipment, the design of the tunnel was tailored to suit two particular fields of work which appear to us to be also of importance in the future of flight techniques. On the one hand, the tunnel should be suitable for research into high-lift problems, and on the other, help to answer all those questions connected with drag reduction through laminarisation of the boundary layer. While the former largely determined the dimensions of the test section, the latter required an extremely low turbulence level and thus a relatively high cost of construction. The obtainable Reynolds numbers, which in both cases should be as high as possible, could, with a given generator of 180 kW and a building capital of about DM 200,000, only be ensured through a very good tunnel efficiency level. Under present circumstances, the following performance can be obtained: maximum Reynolds number of about 6×10^6 during high-lift tests; maximum speed with an empty tunnel, 91 m/sec; turbulence level $< 2 \times 10^{-4}$ The tunnel lay-out, which is unconventional in many respects, is here briefly described.

2. Design and Construction

A wind tunnel which is to have a low turbulence level requires a high contraction ratio, which in a closed wind tunnel makes a properly designed diffuser necessary. An open tunnel of the Eiffel type is in this respect essentially cheaper, but, however, if one must set it up out of doors, it has the disadvantage that it is greatly dependent on wind and weather. Nevertheless, we decided in favour of this type of tunnel, partly because the tunnel could be situated in a protected spot in the woods, and the annual wind level in Stuttgart is very low, and on the other hand because we hoped, by using a wind guard in front of the tunnel intake, to make it practically independent of the weather.

The dimensions of the tunnel are fixed by those of the test section, whose cross-sectional area of $2m^2$ were based on the assumed generator of 180 kW and the maximum speed of about 90 m/sec required for suction tests. The test section flow power must thus be six or seven times higher than that of the blower. Bearing in mind the need for two-dimensional tests on high-lift devices, a rectangular test section of 2.73 x .73m was chosen.

Figures 1 and 2 show the general arrangement of the tunnel, which can be regarded as having three principal parts: the wind guard; the intake with test section and first diffuser; and finally the fan with the second diffuser. Each group stands on independent foundations and because of the thermal expansion and sound insulation are flexibly connected only.

The construction of the wind guard is basically of one row of steel girders which carry the roof. Behind an outer baffle of aluminium netting there is a very thick air filter screen, which is practically impenetrable by gusts and turbulence. This consists of a fine-fibred nylon felt and is fixed in place by a rigid grid of high-grade steel wire 2mm in diameter. The resistance coefficient of this screen falls at maximum speed to a value of about 100. Since the screen area is almost 90 times that of the test section cross-sectional area, so the loss of flow remains very small with $100 \times (1/90)^2 = 1.24\%$ of the test section energy. At lower speeds the drag of the screen increases considerably because of the laminar flow around the fine fibres. Because of the very low power requirement this is not important, on the contrary, the increased protective efficiency (of the screen) is highly desirable.

The outer filter screen, which keeps out dust and insects, is followed inside the wind guard by a second filter screen and, in the tunnel intake, by four further screens. These screens, which are all made of artificial fibres, have the object of smoothing out the remaining non-uniformities in flow which are caused by imperfections and boundaries in the screens. On these grounds the resistance values of the screens are graduated in the series 100, 10, 4, 2, 1.5, 0.7. The total power loss of this section reaches about 2.6% of the test section energy at maximum speeds.

The second section, which comprises the intake, the test section with the surrounding pressure chamber, is made of sheet-steel throughout.* In the slightly conical settling chamber of the intake, any fine turbulence produced by the last screen is smoothed out. To avoid any convective secondary flows produced by the heat of the sun, the outer walls are plated with aluminium sheet.

The nozzle directs flow through the test section, which is 3.15m long, 0.73m high and 2.73m broad. It is made of steel girders and 10mm thick steel plates, screwed together. Other non-uniformities were eliminated after the assembly of the complete tunnel, by laying smooth glass plates on optically controlled height marks and filling the space between them with epoxy resin.

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* The construction of the second and third sections as well as the fan was in the hands of Messrs. Dingler, Zweibrücken.

Floor and roof are quite parallel, the side walls diverging slightly, to compensate somewhat for the influence of the wall boundary layer on the pressure distribution. The distribution of static pressure along the test section axis is shown in Figure 3. The pressure drop in the region of the model suspension is very slight and remains under about 0.2% per meter.

In the floor and roof of the test section, two partly transparent rotating plates of 1.2m diameter are set in flush. The electrical drive of the synchronously rotating plates simultaneously controls a pneumatic sealing of the annular clearance between the wall and the plate. Aerofoil section models are normally fitted flush between the two rotating plates. To alleviate the disturbing influence of the wall boundary layer, the rotating plates are partly made of porous sheet, which are connected to the bleed fan.

The whole test section is surrounded by an accessible sub-pressure chamber, in which the pressure is generally brought below the pressure in the test section by means of a fan installed below ground, so that observation windows and such non-uniformities disturb the flow mechanism as little as possible.

The first diffuser, flanged to the whole test section, is made from welded steel tube, The inner surfaces, which produce the transition from the rectangle to the fan ring, are made from smooth and wave-free chipboard. The range of the cross-sectional areas corresponds to a 6^{o} circular cone. Figure 4 shows an internal view of this diffuser.

The third consists of the axial fan with the motor installation and the second diffuser. The eight-bladed fan with a diameter of 2.7m reaches a maximum circumferential speed of 86.5m/sec, so that the disturbance due to noise remains low. The blades at rest are all fully adjustable. The drive installation with a 180 kW polyphase induction motor, a hydraulic coupling and a two-stage transmission, are mounted alongside the tunnel on a common and adjustable foundation. A flat-belt drive connects the fan and the drive installation. The speed is adjusted with the aid of the hydraulic coupling. The drive and the blade settings enlarge the useable range, so that atmospheric pressures of 25 to 500mm water pressure could be reached with good time constancy. At the fan is connected a second diffuser, where the discharge loss is decreased to about 1.2% of the test section energy. The drive installation is controlled from a console in the sub-pressure chamber.

3. Performance and efficiency

The speed of the empty wind tunnel reaches 91m/sec at 10% overload. When very low drag models are installed, for example, laminar aerofoil sections or boundary layer bleed models, this hardly decreases, so that for a reference length of 1m, a Reynolds number of 6.6×10^{6} can be attained. For this reason, the useable model length, where only low incidence ranges are concerned, can at present amount to about 1.8m for wing models. For greater incidence ranges up to about $\pm 20^{o}$, the model length must be limited to about 1m, if the measured lift values are to remain reliable.

For these reasons, the maximum Reynolds number remains strictly below $Re = 6 \times 10^{6}$, which seems adequate, as for example the high lift behaviour of wing sections generally are only slightly altered for Reynolds numbers above $Re = 6 \times 10^{6}$. (2).

Through the coupling, transmission, flexible belt and fan, about 68% of the engine output is delivered to the air stream. The radiated power in the empty test section is 6.75 times greater than the output given out by the fan.

4. Measuring devices

The lift and drag of a smooth two-dimensional aerofoil section model are ascertained in the usual manner (1, 3) from the pressure distributions on the tunnel wall and in the wake of the model, and in this way the mean value of the pressure distributions can be produced experimentally. However, by means of a pneumatic selector switch, one can relinquish integration and measure single pressures by a multi-tube-manometer. From the ascertained mean values of the pressure differentials in the wake and on the tunnel wall, it is possible, if one wishes to measure the undisturbed atmospheric pressure and the static pressure and maximum total pressure in the wake, to ascertain the reference lift and drag values inclusive of all corrections.

The tedious test and plotting work is greatly reduced by means of a data processing machine. This has five acceleration compensated pressure transducers** at its disposal whose electrical output is processed in three analogue computers** and finally produced on an X - Y co-ordinate plotting table*** as reference lift and drag values. As the wake traverse rake travels also in position and direction in the model wake, it is only essentially an extension of angle of incidence in aerofoil section tests.

A complete aerofoil section polar for one Reynolds number can be produced in about five minutes. To increase the accuracy of measurement, we have raised the linearity of the pressure transducer by a special compensation and in addition have adjusted the transducers to suit the greatly varying pressures. The installation can be calibrated and tested either in separate parts or completely through high-precision calibration transducers, which work through the immersed-jar principle (4). The whole control can be repeated for every polar measurement.

Below this installation, force balances for two- and three-component measurements are available, which work partly with strain gauges, partly with inductive switches. Measuring data are also taken nondimensionally in general in the analogue computers and plotted by the X, Y printer.

5. Standard and Calibration Tests

The dynamic pressure distribution normal to the flow direction over a mean cross-section of the test section is remarkably even. The variations are less than ± 0.025%. The temporary fluctuations of dynamic pressure are very slow and also hardly exceed ± 1% in windy weather.

To test the suitability of the tunnel for aerofoil section measurements, more aerofoil section models of known NACA cross-sections with chords of 0.5 and 1.0m were made and tested. Figures 5, 6 and 7 show a section of these tests and a comparison with the results produced in the well known NACA low low turbulence tunnel (Langley Field)(3).The agreement of the profile-polars is

** CMR-pressure measurement transducer and CMR-Analogue computer by Messrs. Hartmann & Braun, Frankfurt am Main.
*** X and Y Co-ordinate Plotting Table. Bryans Aeroquipment, Ltd.(Format DIN A 3)

unusually good, if one takes into consideration that slight differences in the placing of the cover cause considerable changes in drag. Contrary to the NACA test, the observed differences show no systematic tendency and are no doubt caused by model surface irregularities.

Comparative measurements of the model with 0.5 and 1.0m depths of profile allow one to recognise that the influence of the wall boundary layers on the big models, which have been tested up to the present, still decreases much in extent.

Figure 8 shows the model of a laminar wing. Figure 9 gives an impression of the test-section in which a fuselage model has been set up.

The tunnel has meanwhile been used for several investigations of the possibilities of improving NACA aerofoil sections (5) and the further development of special laminar sections (6, 7, 8). The Deutsche Forschungsgemeinschaft, Bad Godesberg made available the means for building the installation and for instrumentation.

6. References

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Translator's note: I would like to thank the Editor of 'Zeitschrift fur Flugwissenschaften' for his kind permission to translate this article, and Messrs. T. T. E. B. Bateman and A. B. Haines for their assistance in the editing of this translation.

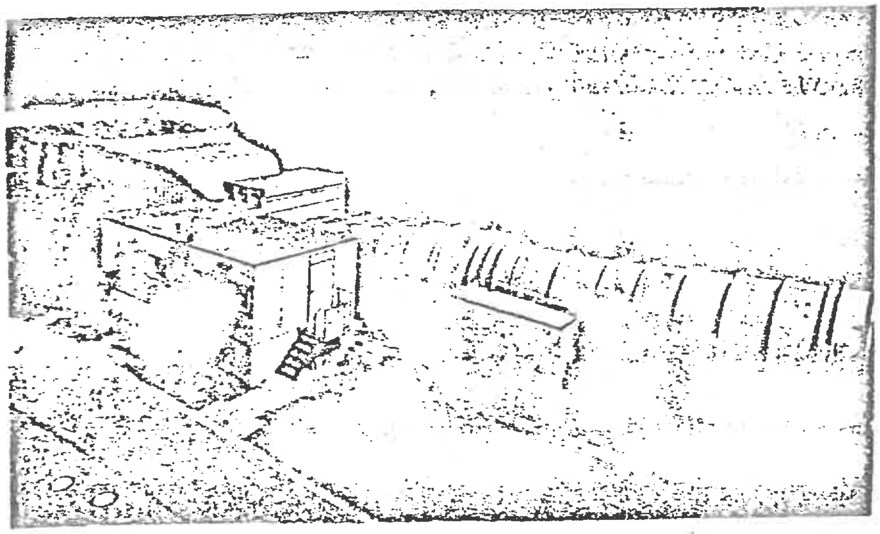


Fig. 1. GENERAL VIEW OF THE LAMINAR WIND TUNNEL.

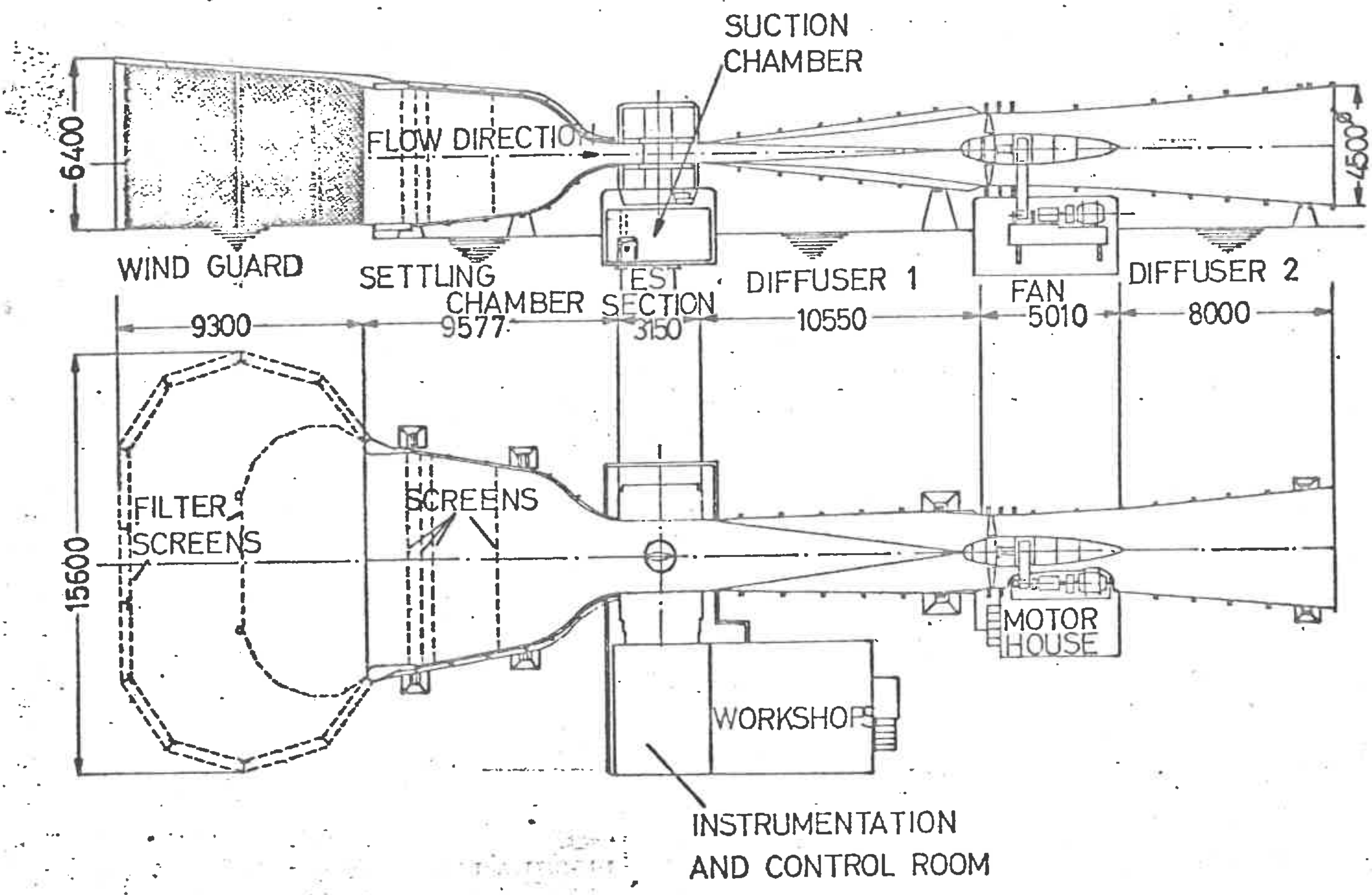


Fig. 2. GENERAL LAYOUT OF THE LAMINAR WIND TUNNEL.
(Dimensions in mm.)

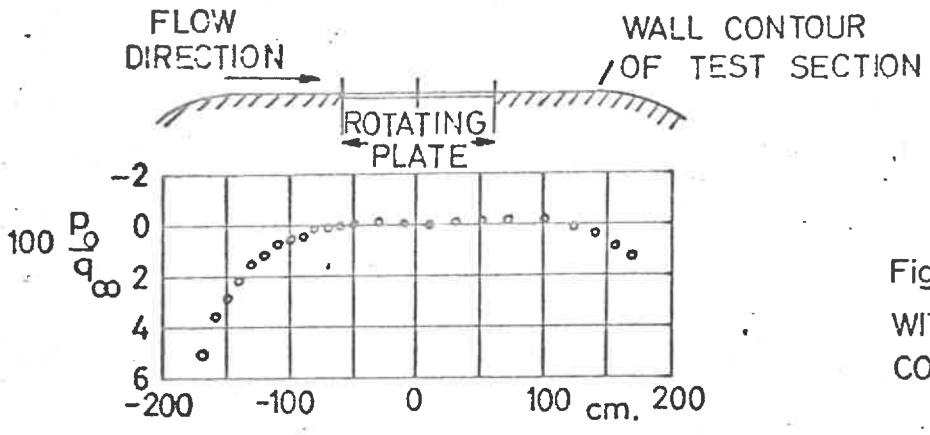
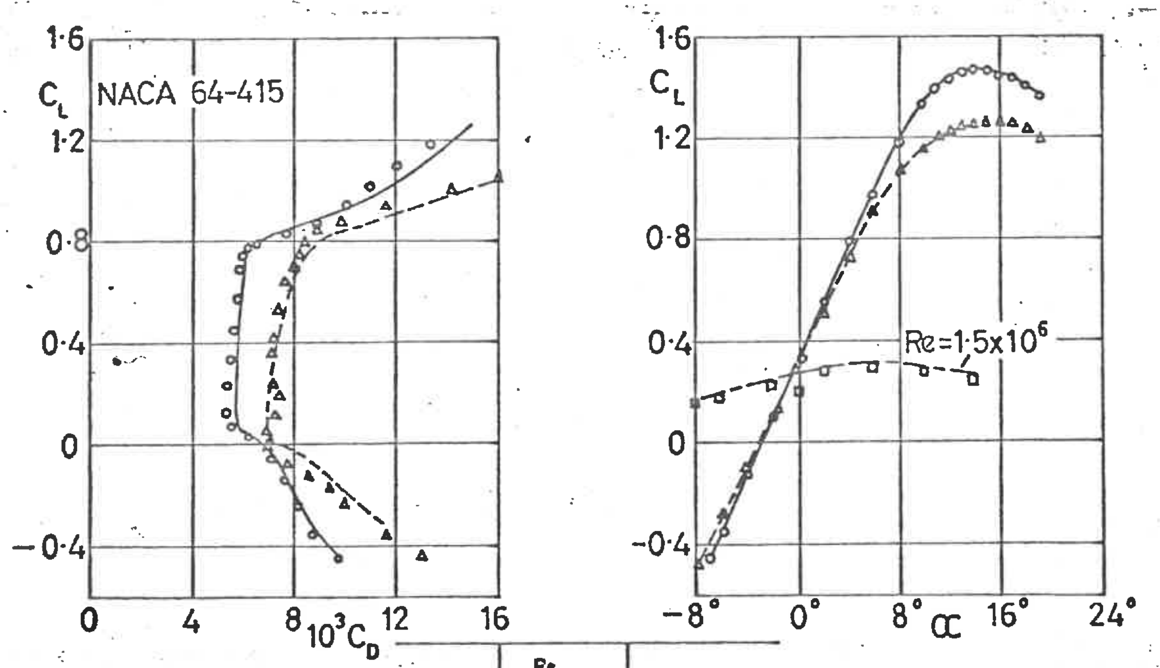


Fig 3.

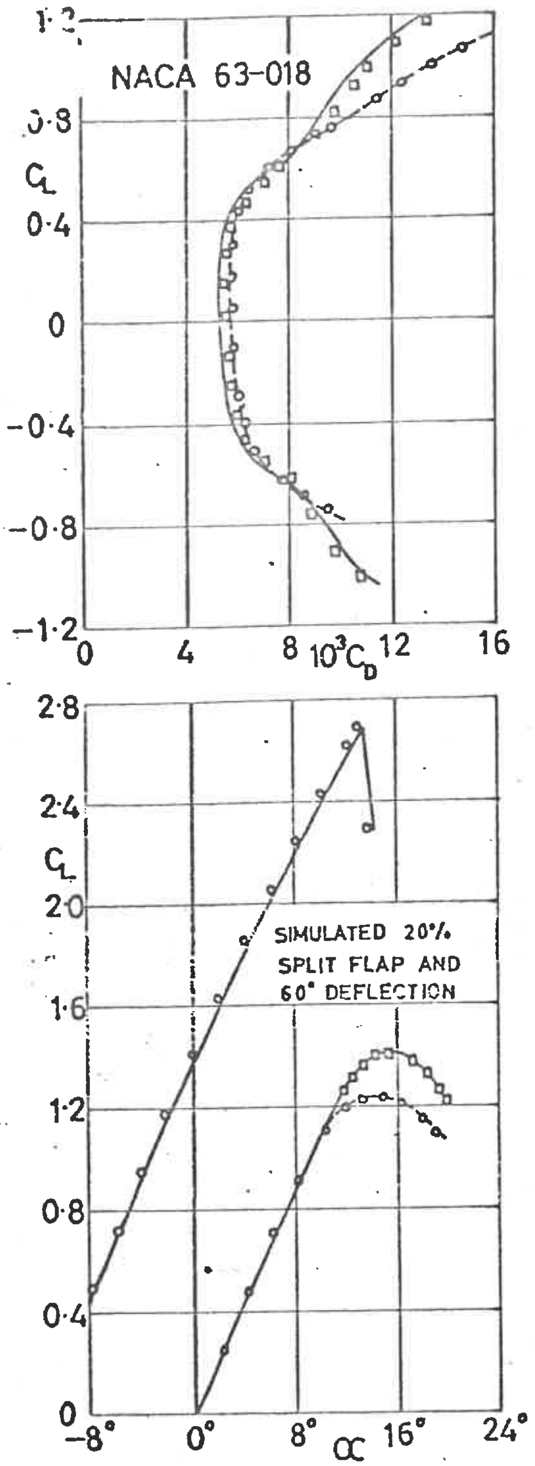
RANGE OF STATIC PRESSURE ALONG THE AXIS OF THE TEST SECTION AT q_∞ = 350 mm. WATER.

Fig. 4. IS REPRODUCED TOGETHE WITH FIGS. 8 AND 9 FOR CONVENIENCE IN PRINTING.



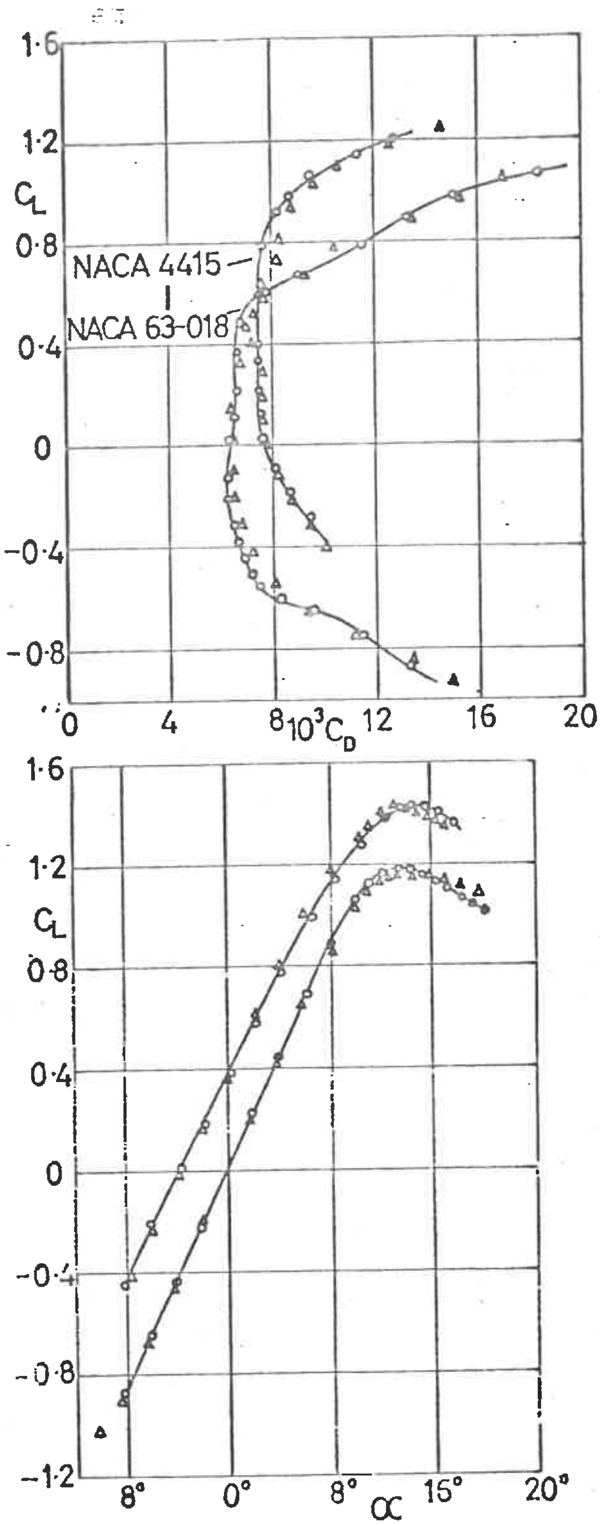
	Re	
——	3·0x10^6	NACA
– – –	1·0x10^6	NACA
o	3·0x10^6	TH STUTTGART
Δ	1·0x10^6	TH STUTTGART

Fig. 5 COMPARISON OF RESULTS WITH NACA TESTS [1] ON NACA 64-415 AEROFOILS SECTION AT REYNOLDS NUMBER $Re = 1{\cdot}0 \times 10^6$ TO $1{\cdot}5 \times 10^6$ AND $Re = 3{\cdot}0 \times 10^6$



	Re	
——	6·10⁶	NACA
– – –	3·10⁶	NACA
□	6·10⁶	TH STUTTGART
○	3·10⁶	TH STUTTGART

Fig. 6. COMPARATIVE RESULTS AS IN FIG. 5 ON NACA 63-018 AEROFOIL, SECTION PARTLY WITH A 60° DEFLECTED SPLIT FLAP CHORD t=1·0m.



	t (m)
—○—	1·0
△	0·5

Fig. 7. RESULTS ON 2 NACA AEROFOIL SECTIONS WITH CHORDS t=0·5m AND t=1·0m AT EQUAL REYNOLDS NUMBER. $Re = 2{\cdot}0 \times 10^6$

Fig. 4. VIEW OF THE FIRST DIFFUSER, LOOKING TOWARDS THE STATIONARY FAN.
THE WOOL TUFTS SHOW THE PATTERN OF FLOW.

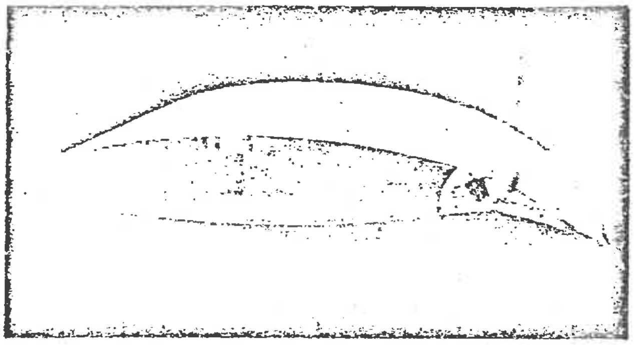


Fig. 8. WIND TUNNEL MODEL OF FX 62-K-153 AEROFOIL SECTION, THICKNESS 0·7m.
SEE REF. 8.

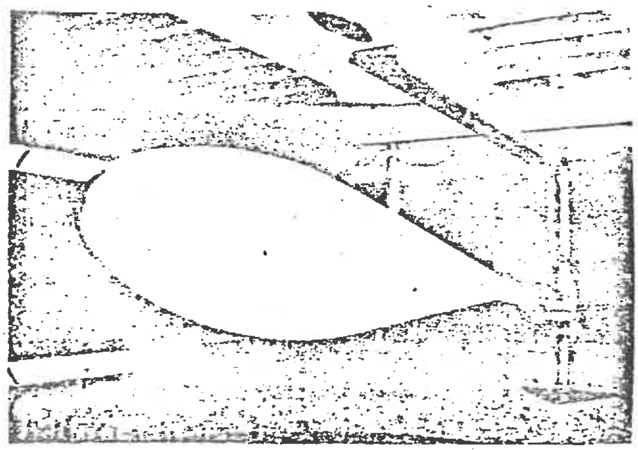


Fig. 9. A 1·5m. LONG FUSELAGE MODEL INSIDE THE TEST SECTION.