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THE AERODYNAMIC CHARACTERISTICS OF A GU25-5(11)8 AEROFOIL FOR LOW REYNOLDS' NUMBERS

by

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Abstract

The paper presents the results of wind tunnel tests of a GU25-5(11)8 aerofoil section over the Reynolds number range, 50,000 to 610,000. For the particular test conditions, the aerofoil exhibits severe degradation of performance below Re = 300,000; a phenomenon which is known to be quite general. This particular aerofoil section has been used for the canards of microlights where low Reynolds numbers are not uncommon.

1. **Introduction**

The performance of any aerofoil is inextricably linked to the state of its boundary layer. If it is separated or detached from the surface, the aerodynamic characteristics are degraded in relation to the degree of separation. The sensitivity of a boundary layer to separate is, amongst other factors, dependent on whether it is of a laminar or turbulent nature. The turbulent layer is far less prone to separation than its laminar counterpart but it does require a sufficiently high Reynolds number for its existence. It is no accident, therefore, that for low Reynolds number flows, in which turbulent flow cannot be maintained, the early separation severely limits the operational range of the aerofoil.

This phenomenon which has been well known for some time (see, for example Karsilschikov & Volkov (1938)) is now the subject of renewed interest and serious research as a consequence of its relevance to contemporary aerofoil applications. These include, inboard sections of helicopter rotors, microlight canards and tail surfaces, lifting surfaces for unmanned vehicles, high aspect ratio sail planes, man-powered craft and associated propellors and jet engine fan blades. Recently careful and rewarding detailed studies of aerofoils at low Reynolds numbers have been performed by, for example, Burns (1981), Mueller & Batill (1982), Mueller et al (1983).

All of these experiments clearly show that the aerofoil performance is not only a function of Reynolds number but within a limited range is also susceptible to aerofoil shape, including roughness, freestream turbulence and background noise levels. In retrospect, this is hardly surprising, for all the effects mentioned tend to encourage transition from laminar to turbulent flow within the critical Reynolds number range and hence significantly improve the performance. It is likely, however, that each aerofoil will have unique and distinctive characteristics, as in the case for the higher Reynolds number flows.

A very useful aerofoil that has been employed on almost all canard microlights is the GU25-5(11)8 Fig.(1). This is one of a family of over 1000 sections proposed by Nonweiler (1968) as a high-lift-low drag section. Unfortunately, only the GU25-5(11)8 section was wind tunnel tested (Kelling, 1968). The measured data, obtained from the very accurate model, agreed well with the theoretical results of Nonweiler. Subsequent practical use of the section, however, has suggested that it is susceptible to surface imperfections including rain droplets, although Too (1980) proposed that a dispersal of these droplets by using a mat paint finish eliminated this particular problem.

Although Kelling (1968) only performed detailed measurements down to a Reynolds number of 630,000, he did allude to a performance limit for lower values. The work reported herein investigated this limit by testing the original model over the range 50,000 to 610,000 in which, for the given test conditions, the flow undergoes transition from that of laminar separation with no re-attachment to that of fully attached and turbulent. These two extremes are illustrated in Fig. 2 together with a mixed characteristic in which the flow flips from that of laminar separation to fully attached followed by "conventional" stall.

2. Test set-up.

The model was mounted vertically in a closed return wind tunnel and the 32 tubes from the pressure tappings were connected to two manually operated selector boxes the output from which was fed to a digital micro-manometer. When the tunnel was running at a speed appropriate to the selected Reynolds number, the manometer reading for each of the pressure tubes was sequentially typed into a micro-computer for data analysis and presentation purposes. Values of pressure coefficient were computed in conjunction with the tunnel calibration and thence integrated by the Trapezoidal Rule to yield values of lift and pitching moment coefficient. The measured data relates to the conditions at the mid span of the model and no account was taken of any spanwise variation. Corrections have, however, been applied for lift interference and blockage, together with a yaw in the tunnel flow of 0.6 degrees (Kelling, 1968). The turbulence intensity of the flow was approximately 0.5% but no assessment of noise levels was made and a discussion of this is given in section 4.

3. **Results**

Figure 2 illustrates the two extremes of this aerofoil's performance. The upper curve is for the fully attached case where turbulent flow exists over a substantial portion of the upper surface and is indicative of moderately high Reynolds numbers. In contrast to this, the lower curve applies to the very low Reynolds number condition for which no fully attached flow was obtained. Here the laminar flow separates without subsequent re-attachment and, as such, the foil is effectively stalled. A typical transitional characteristic is also illustrated and it may be seen that, as the angle of attack increases, the flow flips from one state to the other.

A more comprehensive picture of this transitional phenomenon is presented in Fig. 3. Here contours of lift and pitching moment are given for Reynolds number and angle of attack. It may be seen from Fig. 3a that for moderate angles of attack (less than 6°) the phenomenon is predominately Reynolds number dependent in that the contours at transition are nearly parallel to the angle of attack axis at a Reynolds number of 300,000. Above $\alpha = 6°$ and for a Reynolds numbers range $70{,}000 \leq Re \leq 300{,}000$ the transition is both angle of attack and Reynolds number dependent.

The Reynolds number quoted here is, of course, based on the freestream velocity and aerofoil chord whilst that of importance to the laminar-turbulent transition is the local boundary layer value which inevitably increases with increasing angle of attack. Thus, whilst the transition depicted in Fig. 3 may be dependent on both angle of attack and Reynolds number, and is a suitable guide to this aerofoil's performance, it is simply that both these factors increase the value of the local boundary layer Reynolds number.

Similar observations may be obtained from the pitching moment contours which well illustrate the conventional stall limit and the relatively constant values for Reynolds numbers above the transition.

To illustrate the above, selected surface pressure distributions are given in Fig. 4. Figure 4a shows the pressure variation for a Reynolds number of 70,000 over an angle of attack range $0 \leq \alpha \leq 17°$ and it may be seen that it is at all times stalled. Even at the high angles of attack where there is the semblance of the normal suction peak, the profile has the characteristic of large trailing edge separation. As may be expected, these data correspond to the lower curve on Fig. 2.

In contrast to these low Reynolds number pressure distributions, Fig. 4b, which corresponds to Re = 610,000, clearly shows the characteristic shape of the designed distribution as predicted by Nonweiler. It may also be observed that the stall, when it occurs, is that of progressive trailing edge separation. For a fixed angle of attack of 6° with increasing Reynolds number, the variation of upper surface pressure as given in Fig. 4c. Here the transition from the stalled case to the design profile is most clear to see.

4. Discussion

It is evident from the foregoing that the GU25-5(11)8 section is no exception to performance degradation at low Reynolds numbers. This particular foil was designed for high lift and low drag on a par with the NACA 6 series. One of its main features is the sustained laminar flow over a susbstantial portion of the aerofoil. In order to maintain attached flow in adverse pressure gradient of the trailing edge region, transition to turbulent flow, by whatever mechanism, is desirable. For the present aerofoil, flow visualisation at Re = 700,000, in conjunction with the detailed pressure distribution, indicated that this was achieved by a classical separation bubble, [Kelling (1968), Lunde (1980)] which was highly two-dimensional. Thus, if the laminar free shear layer does not transit to a turbulent nature and thence re-attach, the aerofoil will stall.

As is well known, transition is highly complex and most sensitive to external perturbations. Indeed, it can only be initiated, in an analytic sense, by such disturbances. The lower the Reynolds number, however, the more difficult transititon becomes to the extent that small disturbances are absorbed by viscous damping. Consider now the present test configuration. The laboratory and tunnel were noisy but levels were unknown, the freestream turbulence level was approximatley 0.5% but the scale and frequency content were unknown and, finally, model vibration during the tests was not considered. All these factors will influence the transition (Mueller & Batill (1982)) and so too will the model set up.

The model was mounted vertically in a 3 ft x 3 ft working section and, at Re = 610,000, the observed oil flow pattern at the wall/aerofoil junction was as sketched in Fig. 5. It may be seen that, as expected, the corner boundary layer separates before the main aerofoil separation bubble, at which the corner flow is enhanced and results in a strong standing vortex, as indicated. It is not unreasonable to speculate that such a pattern may vary depending on the particular set-up. For example, end gaps or using an open jet return tunnel.

All the above influence the Reynolds number at which the aerofoil properties dramatically change. Therefore, the critical region of Re ≈ 300,000 can only be considered to be appropriate for the given conditions and not generally applicable. In still and quiet air an aircraft may experience performance degradation at slightly higher Reynolds number. In constrast to this it is unlikely that any reasonable performance can be expected below Re ≈ 50,000.

5. Conclusions

From the tests performed and the data presented, it may be concluded that, like other aerofoils, the GU25-5(11)8 exhibits performance degradation in the region of Re ≈ 300,000.

6. Acknowledgements

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7. References

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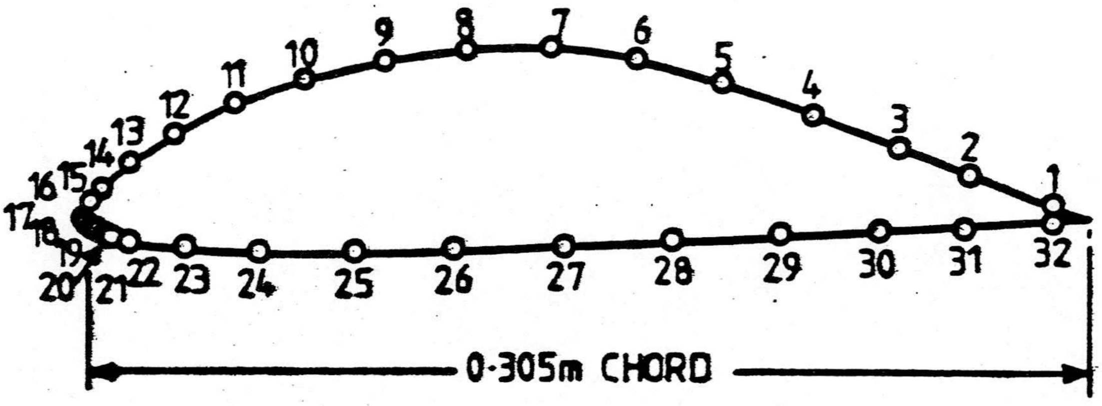


Fig. 1. THE GU25-5(11)8 AEROFOIL AND PRESSURE MEASUREMENT LOCATIONS.

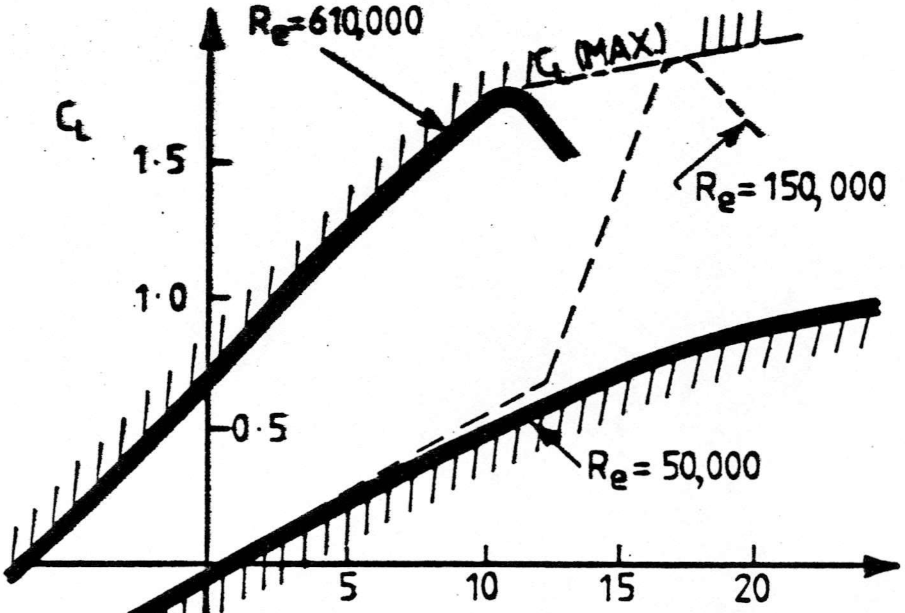
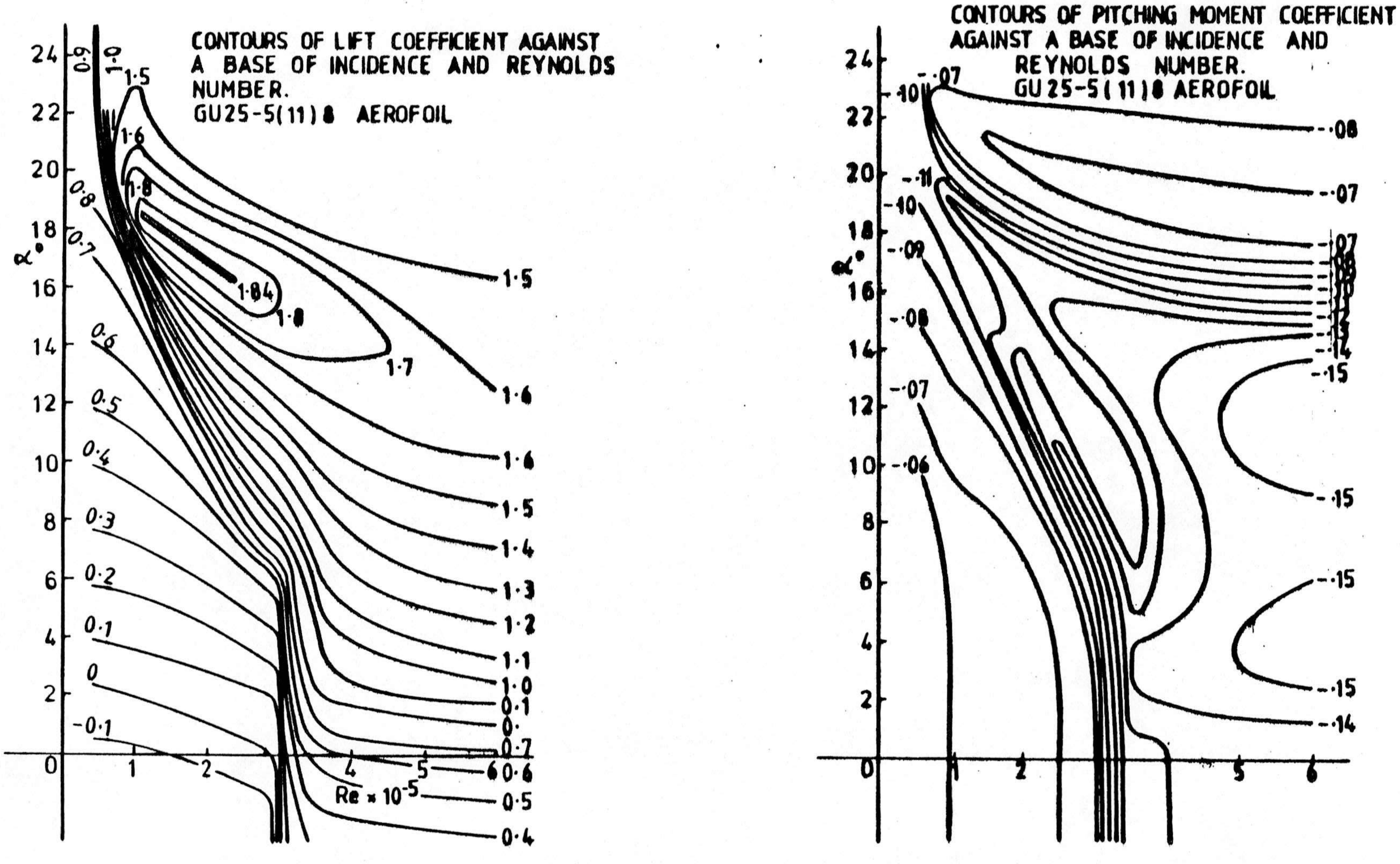


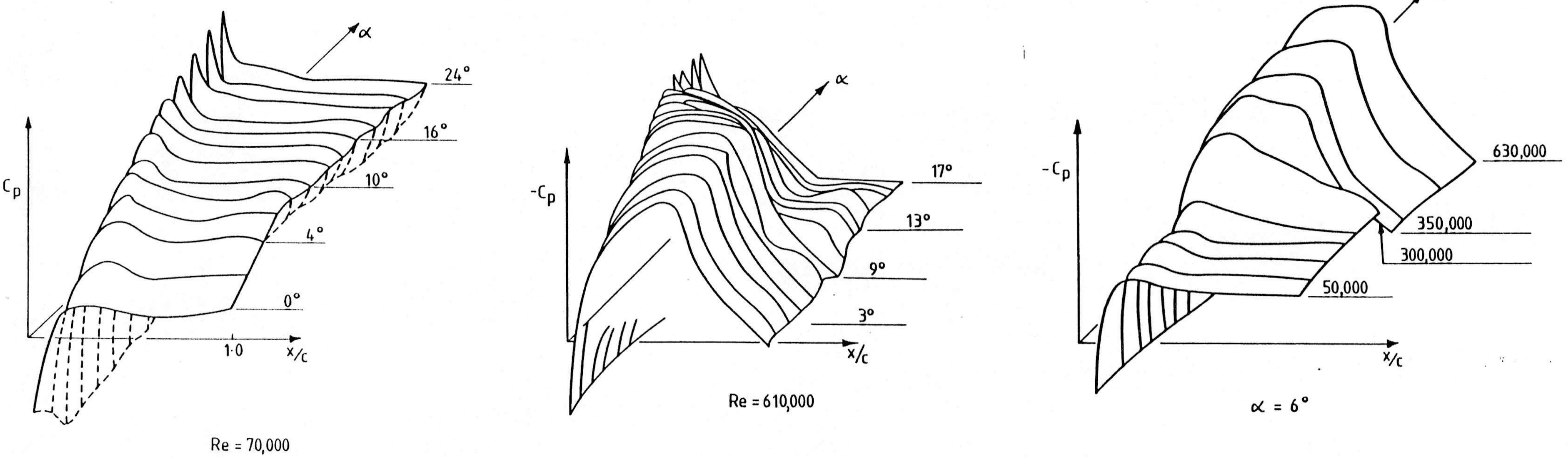
Fig. 2. TYPICAL LIFT CURVES.



(a)

(b)

Fig.3. CONTOURS of LIFT and PITCHING MOMENT



(a) (b) (c)

Fig. 4. SURFACE PLOTS of PRESSURE COEFFICIENTS

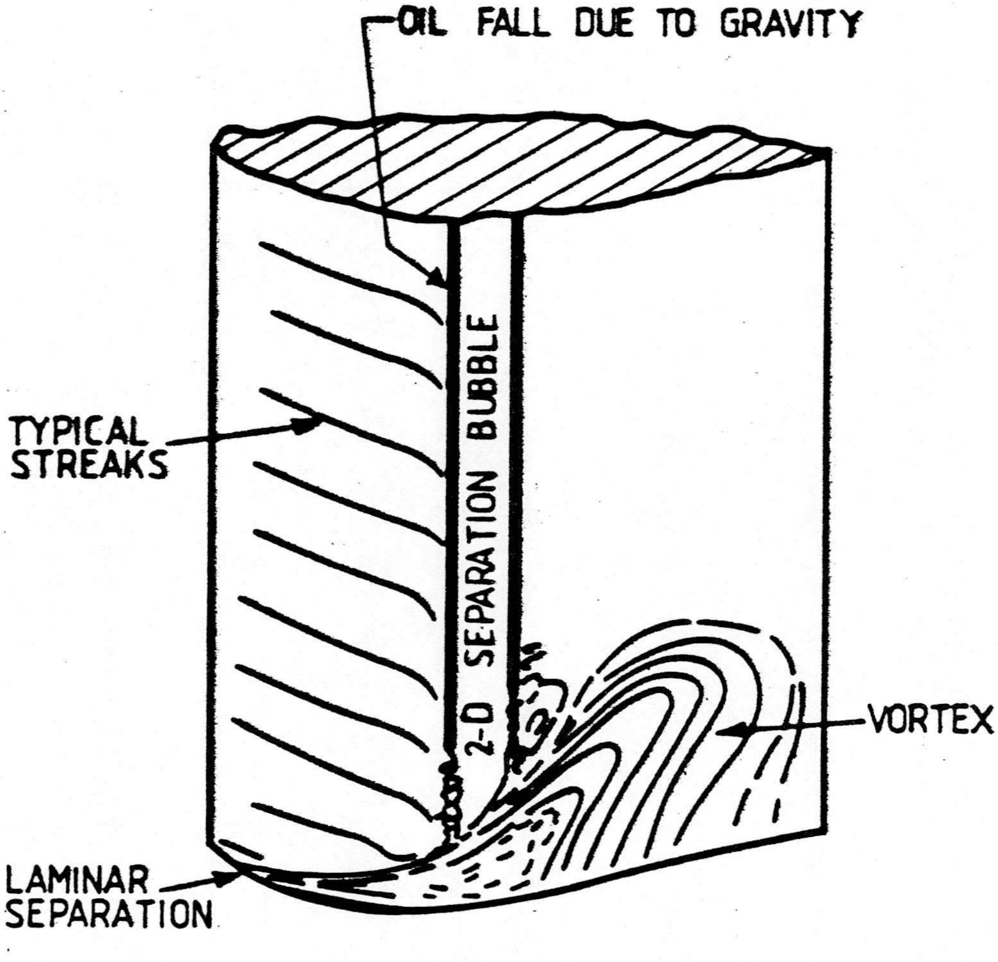


Fig. 5. TYPICAL FLOW PATTERN AT WALL JUNCTION Re = 610,000