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The Flow Upstream of Finite Span Spoilers at Supersonic Speeds

by

A. Stanbrook

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The Flow Upstream of Finite Span Spoilers at Supersonic Speeds

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A. Stanbrook

SUMMARY

It is suggested that the flow upstream of swept and unswept spoilers in a supersonic stream may be explained in terms of a vortex type of flow. The presence of this type of flow is shown to be consistent with experimental pressure distributions.

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1 Introduction

In a recent report[1] pressure distributions in the supersonic flow around swept and unswept spoilers have been published. A brief and tentative description of the underlying flow was given. It appears that a more satisfactory explanation of the flow upstream of such spoilers may be developed in terms of the vortex type of flow described in Reference 2. This explanation is developed here starting from the flow around a two dimensional spoiler. The experimental results from Reference 1 are used to illustrate the discussion.

2 Discussion

2.1 Unswept Spoilers

The flow upstream of a two dimensional spoiler (or step) at supersonic speeds has been studied both experimentally[3,4] and theoretically[5]. A general study of supersonic flows involving separation has also been made[6]. As a result the main factors determining the flow are known. The flow characteristics are shown in the sketch in Fig.1. An oblique shock wave occurs upstream of the spoiler causing the boundary layer to separate (at A) and deflecting the flow over the spoiler (B C). The separated boundary layer then forms a free stream surface (A B) dividing the external flow from an eddy flow (A B C) adjacent to the spoiler. The presence of the spoiler assists in stabilising the free stream surface. The mechanism determining the pressure attained upstream of the spoiler involves a balance between the mass flow entrained by mixing at the free stream surface (A B) and the mass flow lost at B due to the pressure drop in the expansion around B. A typical pressure distribution along the surface upstream of the spoiler is illustrated in Fig.2. The suction peak in the pressure distribution immediately upstream of the spoiler is probably due to a small circulatory flow in the eddy region (A B C).

For a spoiler of limited span there is an effect on the pressure distribution upstream of the spoiler due to the additional outlets for the entrained mass flow opened up at the ends of the spoiler. Consequently, there is flow towards the tips beneath the free stream surface and the pressure is reduced. Some pressure measurements obtained by Moeckel[7] show this effect without indicating its spanwise extent because the position of measurement was not specified. The forms of the free stream surface will also be affected by the presence of the tips. A physical model of the flow, based on Reference 2, is suggested in the following paragraphs.

At the tips the free stream surface leaves the spoiler and turns downstream. Once away from the stabilizing influence of the spoiler the free stream surface is distorted under the influence of its own vorticity and a rolled-up vortex sheet develops. This rolling-up begins along the forward face of the spoiler. The probably form of the surface as it rolls up around the tips of the spoiler is sketched in Fig.3. Fig.4 shows the isobar pattern for the flow upstream of an unswept spoiler of finite span in a supersonic stream*. It will be seen that the isobar pattern is almost two-dimensional near the centre of the span but that in the neighbourhood of the tips of the spoiler the local pressures have been reduced. This can be associated with the rolling-up process described above, the partly rolled-up surface inducing higher velocities on the wall beneath it, thereby producing lower static pressures.

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* All isobar patterns and pressure distributions presented were obtained from Reference 1 and refer to configuration 8 of that report (span/height = 12.0 and turbulent boundary layer) at $M = 1.61$ and $R = 0.30 \times 10^6$ (based on spoiler height).

For a spoiler of very limited spanwise extent, as with some air brakes, the free stream surface may not reach the forward face of the spoiler at all but may roll up immediately to form a vortex which turns downstream around the tips.

2.2 Swept Spoilers

The basic description of the flow given above will still apply even when the spoiler has moderate sweep. The flow about a moderately swept spoiler of infinite span is still characterized by the presence of a single oblique shock wave, upstream of the spoiler, and separation of the boundary layer produced by the pressure rise through this shock*. The flow in a section through the shock wave and free stream surface, normal to the spoiler is similar to Fig.1. The flow is deflected in a direction parallel to the wall as well as normal to the wall as in the flow over a moderately swept wedge-sectioned wing with which the separated region may be compared.

When the span is finite the free stream surface again turns downstream at the tips and begins to roll up. The main difference from the unswept case is that conditions at the two tips differ somewhat and that there is probably a stronger spanwise flow beneath the free stream surface which may affect its stability and, thereby, the rolling-up process. Figure 5 shows the isobars for a spoiler swept 15°. It will be seen that the pressures are again reduced locally by the presence of the rolled-up portions of the free stream surface. The region of reduced pressures associated with the upstream tip is more extensive than that associated with the downstream tip. This suggests that the free stream surface rolls up more readily near the upstream tip.

As the sweep of the spoiler is increased to 30° a marked change in the flow occurs. Figure 6 shows the isobars for this case. The shock wave is no longer approximately parallel to the spoiler but is now curved and oblique to it (the isobar for $C_p = 0.2$ may be taken as indicating the approximate position of the shock wave). It will also be seen that the high suction region extends the whole span of the spoiler and that the local reductions in pressure are much larger than before. It is suggested that with increase in sweepback the rolling-up effect spreads in from the tips until a stage is reached where the free stream surface rolls up almost immediately after separating from the wall at the shock wave, without ever reaching the spoiler, and remains on the upstream side of the spoiler as shown in the sketch in Figure 6. This has occurred between 15° and 30° sweep.

The relative strengths of the suction peaks for various angles of sweep may be seen in Figure 7 in which is shown the pressure distribution along a line normal to the spoiler as the sweep is progressively increased. It would appear from this figure that the same type of flow occurs at 30°, 45° and 60° sweep, i.e. the free stream surface rolls up almost immediately after separation without ever reaching the spoiler. At 75° sweep the suction peak in the pressure distribution is almost negligible. The flow about the spoiler at this sweep angle is equivalent (apart from wall boundary layer interference effects) to the flow about a low aspect ratio rectangular wing at an angle of incidence of 15°. It is probable that the shock wave (which is attached to the upstream tip of the spoiler) is not strong enough to cause separation, in which case no vortex would be formed.

3 Conclusions

The following explanation of the flow upstream of swept and unswept spoilers in a supersonic stream is suggested. At small angles of sweep the

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* It is probable that a flow of this type would be difficult to produce experimentally due to end effects at the tunnel walls. As far as is known it has not been attempted.

free stream surface resulting from the separation of the boundary layer at the shock wave rolls up to form vortices near the tips of the spoiler. These vortices trail downstream around the tips of the spoiler. As the angle of sweep is increased the extent of the rolling-up spreads along the span of the spoiler until for sufficiently large sweep the free stream surface rolls up almost immediately after separating from the wall without ever reaching the spoiler.

The presence of these vortices is shown to be consistent with experimental pressure distributions.

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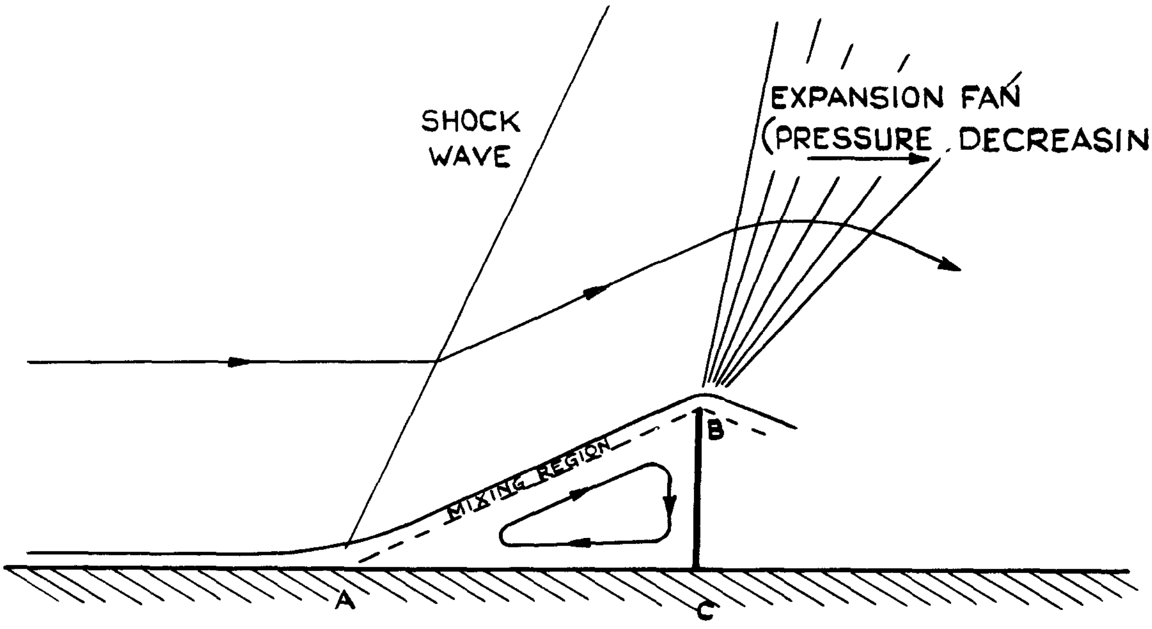


FIG. 1. SUPERSONIC FLOW AROUND A TWO DIMENSIONAL SPOILER.

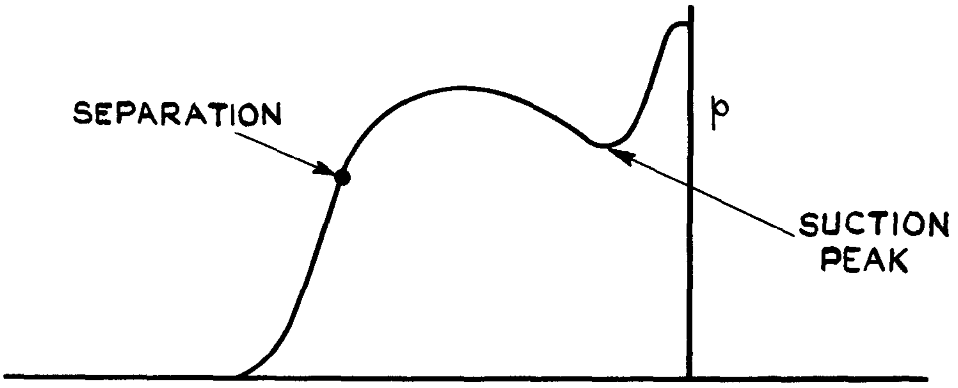


FIG. 2. PRESSURE DISTRIBUTION UPSTREAM OF THE SPOILER IN FIG. 1.

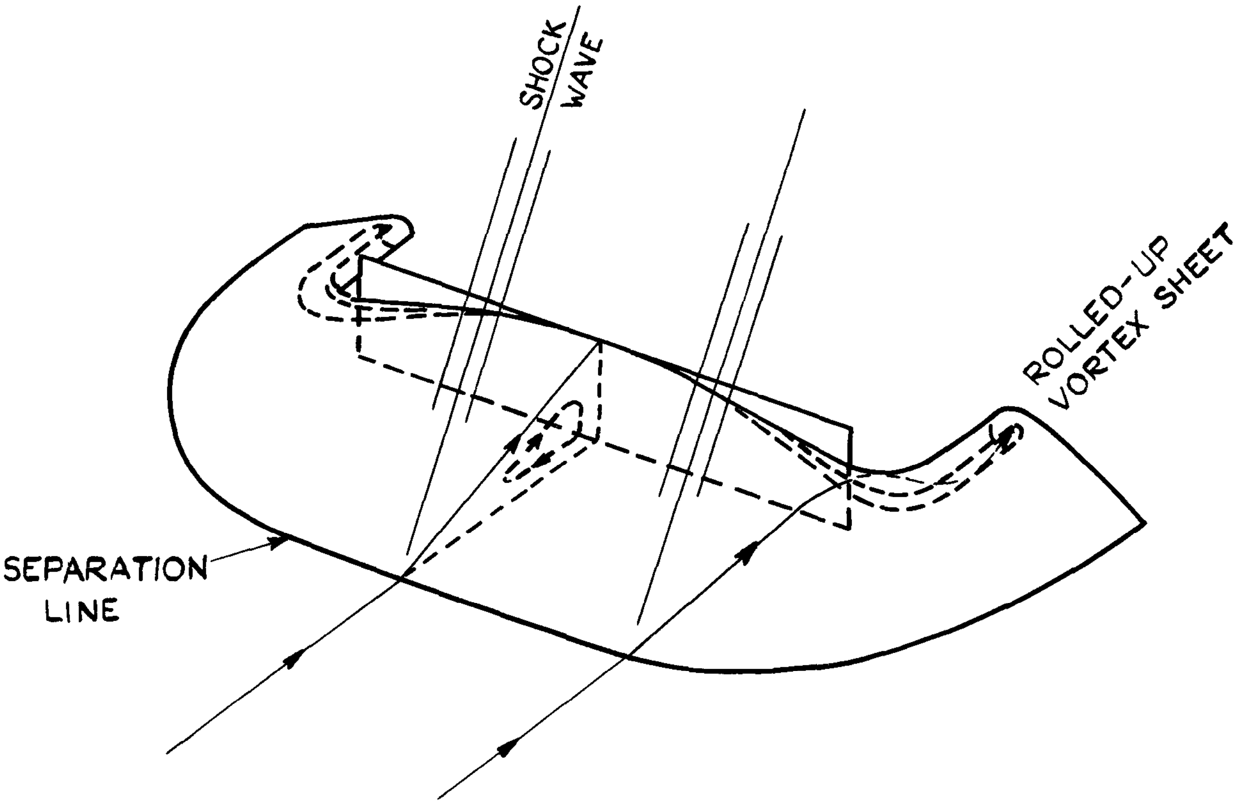


FIG. 3. SUPERSONIC FLOW AROUND AN UNSWEPT SPOILER OF FINITE SPAN.

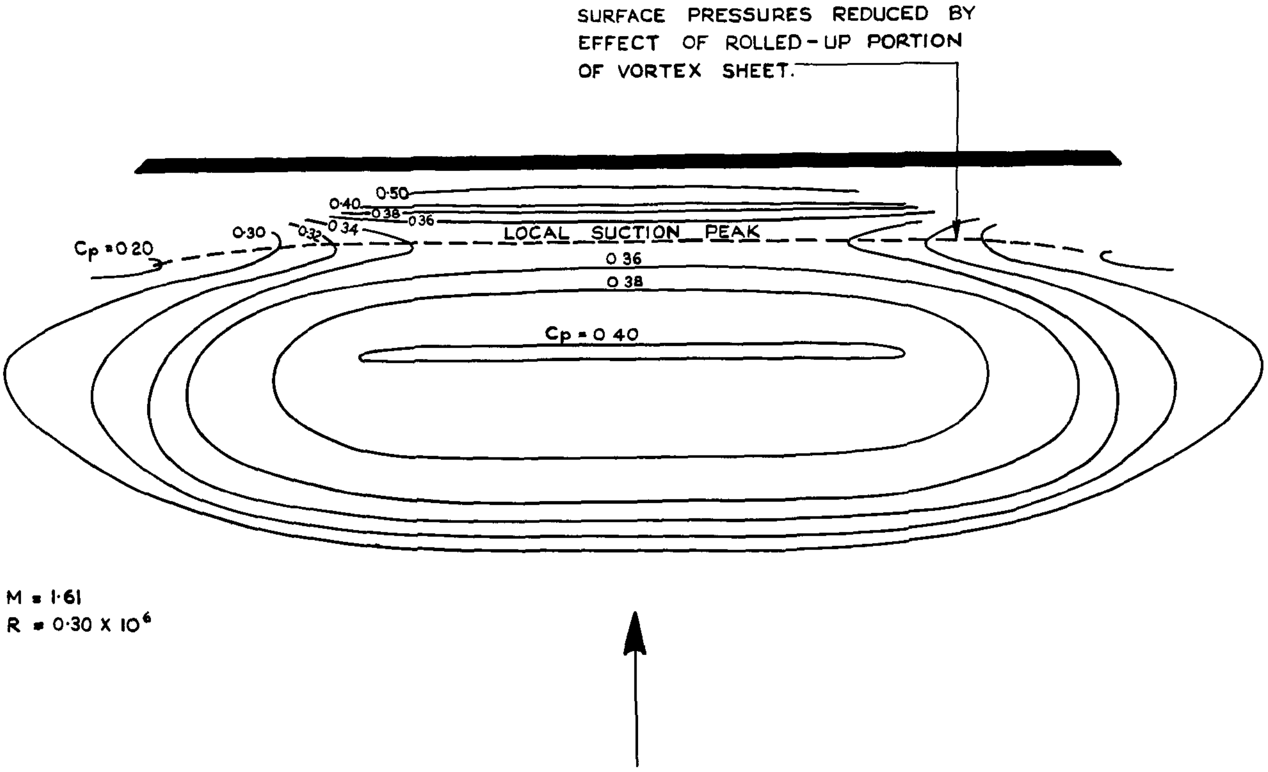

SURFACE PRESSURES REDUCED BY EFFECT OF ROLLED-UP PORTION OF VORTEX SHEET.

FIG. 4. ISOBARS UPSTREAM OF AN UNSWEPT SPOILER IN SUPERSONIC FLOW.

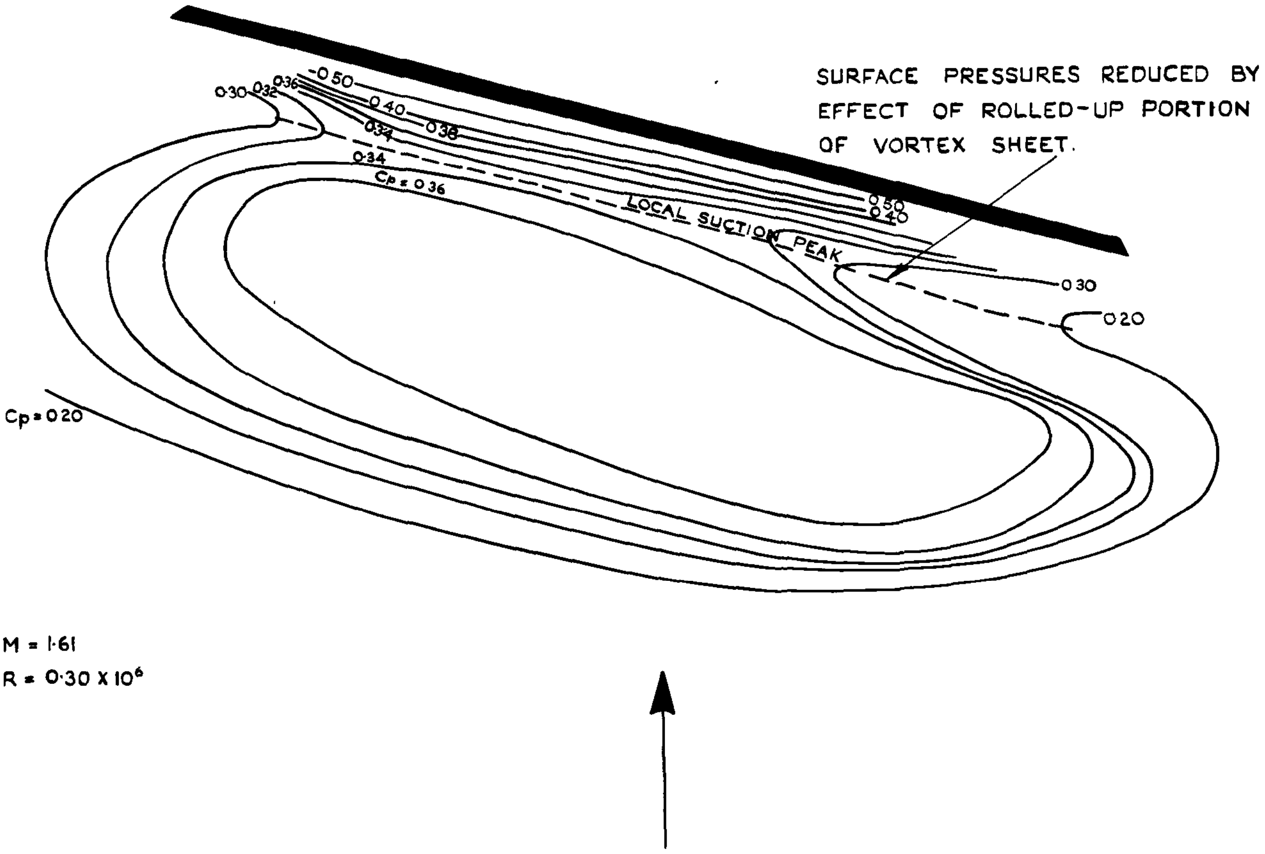

SURFACE PRESSURES REDUCED BY EFFECT OF ROLLED-UP PORTION OF VORTEX SHEET.

FIG. 5. ISOBARS UPSTREAM OF A 15° SWEPT SPOILER IN SUPERSONIC FLOW.

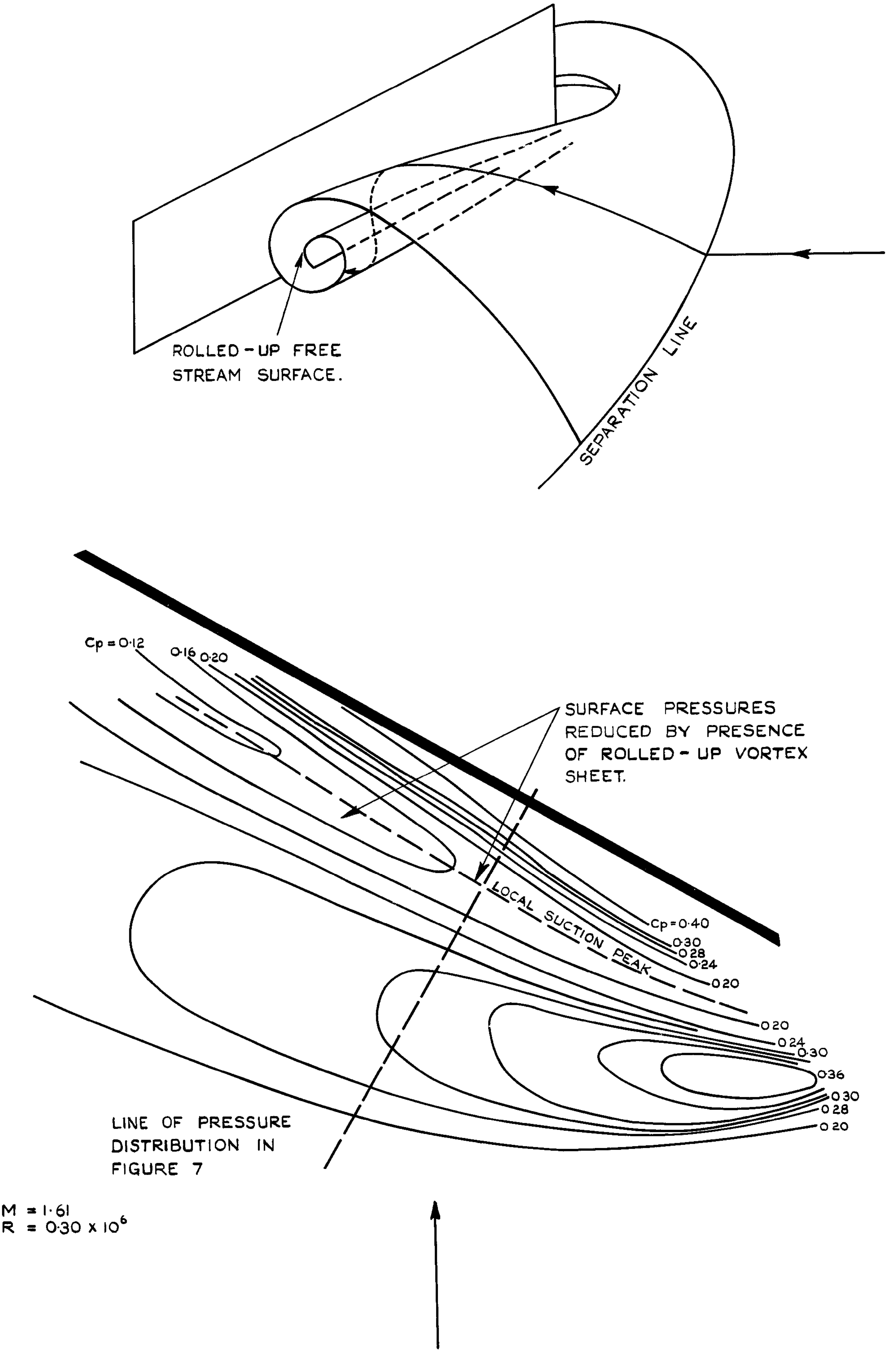
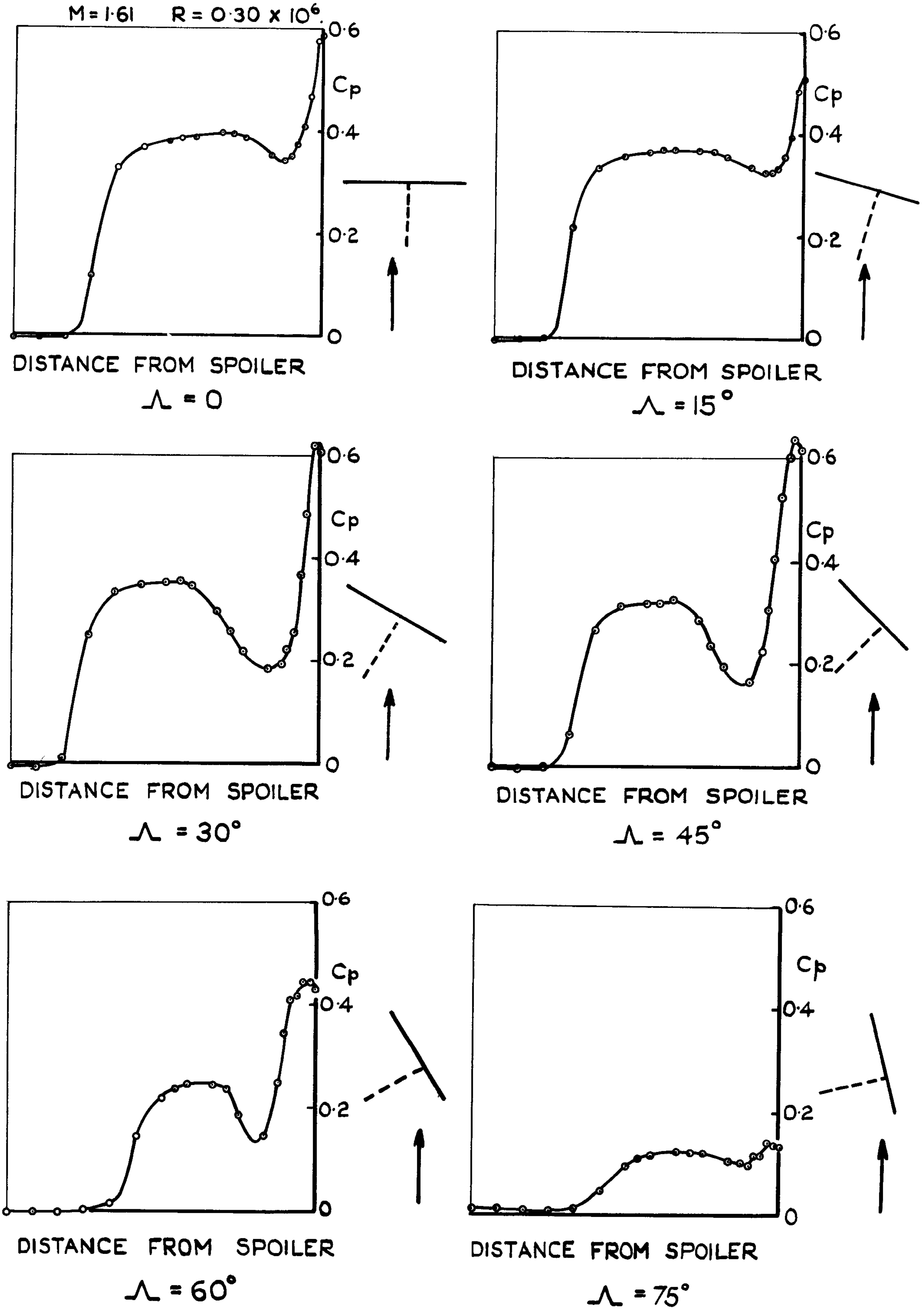


FIG. 6. SKETCH OF FLOW PATTERN AND ISOBARS UPSTREAM OF A 30° SWEPT SPOILER IN SUPERSONIC FLOW.



PRESSURE DISTRIBUTION ALONG BROKEN LINE IN SKETCH IN EACH CASE.

$M = 1{\cdot}61 \quad R = 0{\cdot}30 \times 10^6$.

FIG. 7. PRESSURE DISTRIBUTION ALONG A LINE NORMAL TO SPOILER FOR A RANGE OF SWEEPBACK ANGLES.

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