LOW-SPEED CHARACTERISTICS OF A FIGHTER-TYPE CONFIGURATION AT HIGH ANGLES-OF-ATTACK AND SIDESLIP

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BY

KLAUS HUENECKE, VFW, BREMEN, W.GERMANY

Summary

Force measurements and flow observations were conducted on a fighter-type configuration as an aid to understanding the complex flow phenomena occuring at high angles-of-attack with and without sideslip. The configuration typically was provided with a cranked delta wing of aspect ratio 2.5; leading-edge sweep of 56°; wing-mounted vertical tails; and all moving canard surfaces. The results indicate that certain configurational changes, such as vertical tailplane strakes, are sufficient to eliminate an otherwise unstable roll and yaw behaviour occuring at around 22° angle-of-attack.

1. Introduction

A look at the present day highly maneuverable fighter shows many of them to have wings of relatively low aspect ratio and highly swept leading edges, or wings of less sweep, but combined with a strake (Fig. 1). The most typical wing representing the type of flow common to all of them, is the delta wing, which is also used or planned in combination with canard surfaces.

The characteristic aerodynamic feature of these wings is their ability at maneuvering conditions to generate a stable type of separated flow which has become known as the leading edge vortex. Vortex flow can be found over the entire flight spectrum, from take-off and landing to transonic and even supersonic maneuvering conditions, and is always triggered of if sufficient angle-of-attack is applied (Fig. 2).

Use of the full lift potential of the medium to small aspect ratio wing, however, is generally limited by a gradual or sudden degradation of the lateral/directional characteristics occuring well before maximum lift is reached. For a fighter aircraft, this means imposing a maximum angle-of-attack never to be exceded. It is evident that such a limitation may have serious consequences as to the aircraft's operational effectiveness.

In order to improve the understanding of the flow problems responsible for undesirable behaviour of the aircraft an experimental investigation was conducted, using data from force measurements and flow visualization techniques to analyse the high angle-of-attack phenomena.

2. Model and test techniques

The experiments were carried out at the low-speed wind tunnel facility of the German Aerospace Research Institute at Braunschweig, W.Germany.

The wind tunnel model consisted of

1. a cranked delta wing of aspect ratio 2.49, with a leading edge sweep of 56 deg at the inner portion and 45deg at the outer portion and a taper ratio of 0.15.
2. a movable canard of 8% exposed area
3. wing mounted vertical taiplanes with swept-back and swept-forward leading-edges;
4. a contoured body with faired-over under-fuselage inlets (Fig. 3)

Aerodynamic surfaces of delta profile could be added to the vertical tails (designated vertical tailplane strakes).

The angle-of-attack range for the majority of the tests was from -3 deg to 41 deg, but could be extended up to 70 deg for specially selected configurations.

The angle-of-sideslip range was between -10 deg and + 10 deg.

In addition to force measurements extensive use was made of the oil flow visualization test technique showing flow conditions at the model surface. Information of the spatial flow field was gathered from smoke observations.

3. Results

With the increased performance requirements of modern fighters, the designer is faced with a flowfield of hitherto unknown complexity. Theoretical methods are applicable only to extremely simplified cases, and with limited success. Adding to this is an insufficient understanding of the physical properties of the flowfield itself.

The aim of the present study therefore was twofold:

1. to improve the aerodynamic characteristics of the tested configuration by using add-on devices,
2. to get a deeper insight into the flowfield by referencing force data with oilflow and smoke visualization techniques

3.1 Basic configurations

The basic wing-body combination could be provided with twin vertical tailplanes, the quarter-chord lines of which were swept forward (S 1), unswept (S 2), and swept back (S 3). All tailplanes were of the same volume (Fig. 4).

The lift curves for symmetrical flow conditions are seen to reach a maximum value of C_L = 0.93 at an angle-of-attack of 23°, without any major differences between the 4 configurations discernible (Fig. 5). At post-stall angles-of-attack, however, the swept-forward tailplanes incur larger lift losses than the other tailplanes.

At asymmetric flow conditions (β = 10°), a marked kink in the lift curve is observed at C_L = 0.9, α = 20°, the angle for maximum lift being shifted to 35°, with the lift coefficient increasing to around 1.0 (Fig. 6).

The yawing moment curves reveal, however, a serious degradation from an initially stable behaviour, with a change in sign at α = 18°, while maximum lift is reached at considerably higher incidence (Fig. 7).

A change to instability is also observed for the rolling moment, which shows a change in sign twice over the angle-of-attack range (Fig. 8).

A critical angle-of-attack appears to be at about α = 22°, when the rolling and yawing moments are at their maximum adverse values. In order to find an explanation from the fluid dynamics viewpoint, numerous oil flow photographs were made, one of which is shown in Fig. 9.

While the flow on the outer portion of the windward (right) wing shows evidence of complete separation, the flow on the leeward (left) wing maintains an orderly pattern, typical of vortex flow emanating from swept leading edges. Differences as to the extent of the leading edge vortices on both wing halves are caused by different sweep angles associated with asymmetric free stream conditions. Resulting from this is a positive (destabilizing) rolling moment which is revealed in the force data (see Fig. 8). Loss of directional stability is caused by a decreasing vertical tail effectiveness, the vertical tailplanes being not only shadowed by the wing wake, but also through asymmetric loading due to different vortex position and strength on each wing side.

3.2 Configurations with vertical tailplane strakes

As an aid to improving lateral/directional stability some aircraft are equipped with dorsal fins mounted directly ahead of the vertical tailplane. At higher angles-of-sideslip the aerodynamic effect is comparable to a strake.

It was therefore considered, whether or not the diminishing tail effectiveness could be countered by dorsal fins (designated vertical tailplane strakes - v.t. strake)

Subsequently, three different v.t. strakes were investigated, the forward tips of which are located at the wing trailing edge, wing mid chord position, and wing leading edge, respectively (Fig. 10).

The large v.t. strake, extending from the wing leading-edge is seen to yield a remarkable result, in that the wing moment remains positive (stable) over the angle-of-attack range, whereas the shorter strakes do not exhibit a similar characteristic (Fig. 11).

Although strongly non-linear, the rolling moment is also seen to remain stable (Fig.12)

These obvious improvements of the lateral/directional characteristics must be traded against a loss in lift, which is of the order of 20% (Fig. 13). At 20° incidence, however, one third of the engine thrust is acting as lift.

Any angle of sideslip will put the configuration into a non-symmetric flowfield which is the cause of lateral/directional instability. Add-on devices, therefore, should work in such a way as to create as nearly as possible a symmetrical flow condition. This is achieved with the v.t. strakes extending to the leading edge of the wing (Fig. 14). The relatively large size of the strake virtually cuts off the vortex, thus explaining the lift loss which is revealed in the force data (see Fig. 13).

3.3 Flowfield exploration

In the context of small aspect ratio, swept wings now in wide use, we have become familiar with separated flows in general, and vortex flows in particular. A feature of many of those flows in three dimensions is that they are well ordered with a difined stable structure, and that they persist over a greater angle-of-attack range. Designers have increasingly sought to exploit such flows in meeting the maneuvre demands on modern combat aircraft.

However, our understanding of such flows is rather fragmentary and mainly qualitative. Oil flow photographs offer a first indication of the type of flow prevailing, but, by their very nature, whow the effects only at the physical boundary of the configuration tested.

To obtain information regarding the spatial extension of such flows, smoke visualization techniques provide a viable tool. In the course of the present study, extensive use was made of this visualization method, which was combined with the oil flow technique to give a reasonable impression of what the flow looks like.

In contrast to the oil flow technique, which demands full wind tunnel dynamic pressure, investigations with smoke usually have to be performed at low Reynolds number in order to prevent the smoke stream dispersing into the surrounding tunnel flow.

A typical photograph shows the streamlines under the influence of the leading edge vortex (Fig. 15). A complete representation of the flowfield could be constructed from a number of these photographs. At 15° angle-of-attack, and no sideslip, the picture thus generated is one of an orderly developed vortex flow (Fig. 16).

If an angle-of-sideslip is applied, the leading-edge vortex flow developing on the windward (right) wing is seen to interfere intensely with the right vertical tailplane, but still the structure of the vortex flow remains intact (Fig.17)

At 22° angle-of-attack and symmetrical freestream conditions the picture has changed drastically (Fig. 18). Vortex flow is confined to the inner portion of the wing, as is also revealed by the oil flow pattern, but streamlines on the outer portion of the wing are almost free from any significant vortex influence.

Under asymmetric flow conditions, the flowfield development is even more complex (Fig. 19). Whereas the leeside (left) wing, due to greater sweep, shows a well established vortex flow, the windward wing vortex is even more suppressed, leaving no chance for the oncoming flow to develop a lift carrying capability. The resulting flow on the outer portion of the right wing is showing evidence of complete and uncontrolled separation.

Stable vortex flow does not persist over too great an angle-of-attack. At $\alpha = 30°$ there is not much evidence of a leading-edge vortex (Fig. 20). The flow pattern gradually approaches that of a wake behind a flat plate perpendicular to the free stream, leaving little room for the designer to create a flying machine controllable with aerodynamic surfaces alone, unless radically new approaches are made.

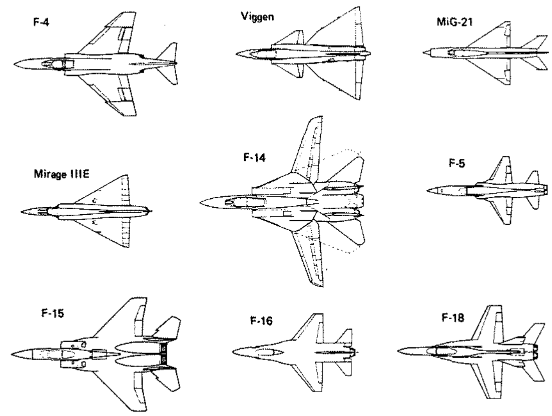

FIG. 1 : LOW ASPECT RATIO WINGS

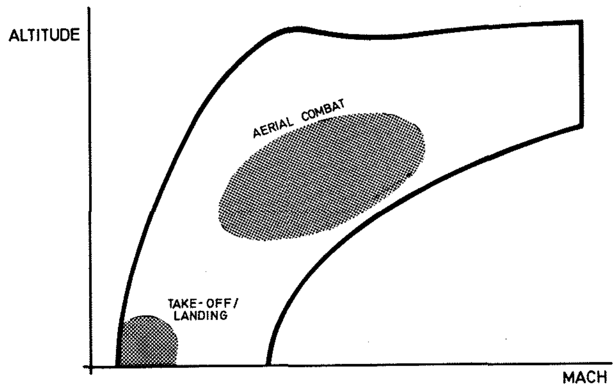

FIG. 2: FLIGHT SPECTRUM

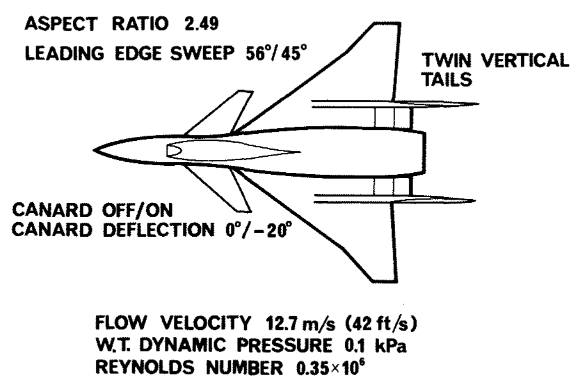

FIG. 3: THE CONFIGURATION TESTED

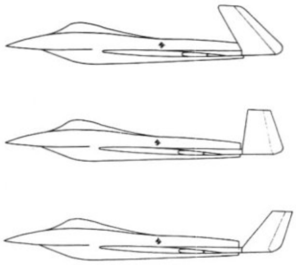

FIG.4: TAILPLANE CONFIGURATIONS

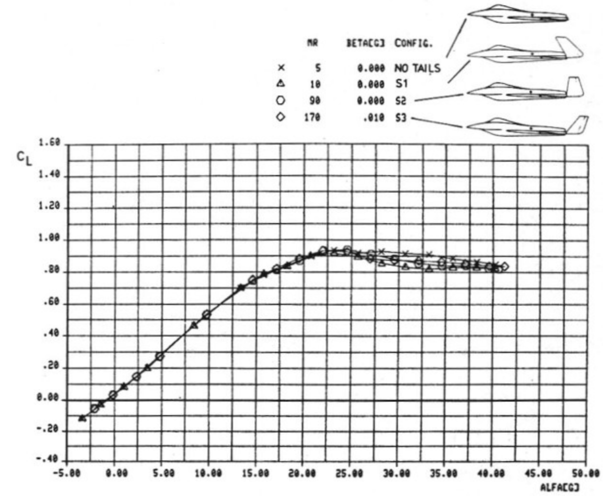

FIG. 5: BASIC CONFIGURATIONS, β = 0°

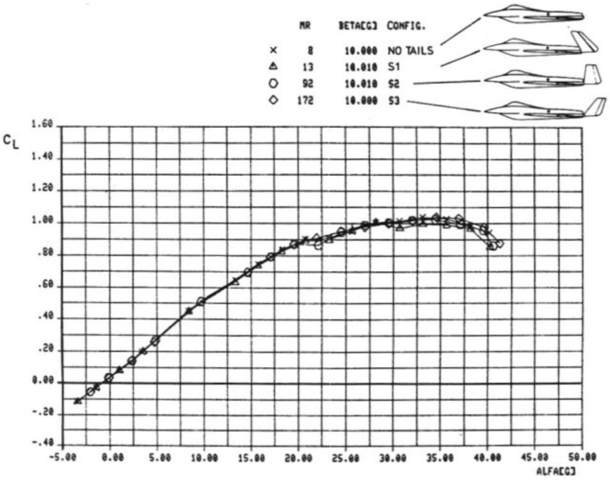

FIG.6: BASIC CONFIGURATIONS, β = 10°

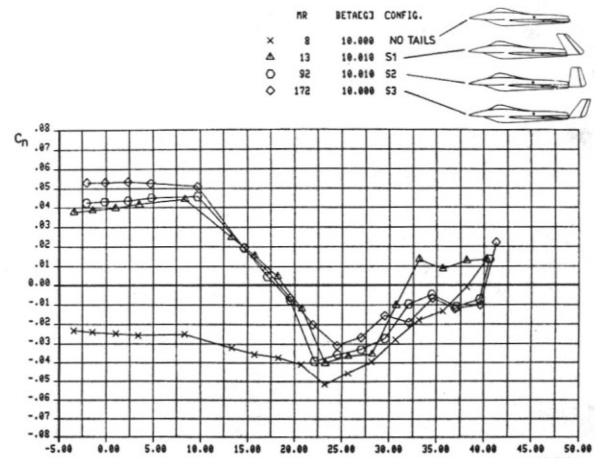

FIG.7 BASIC CONFIGURATIONS, YAWING MOMENT, β = 10°

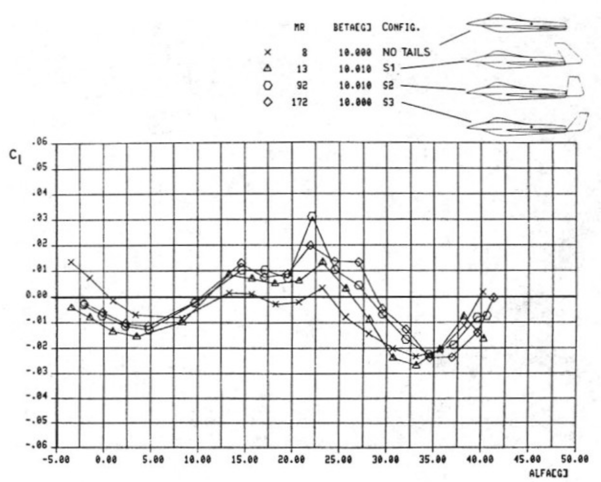

FIG.8: BASIC CONFIGURATIONS, ROLLING MOMENT, β=10°

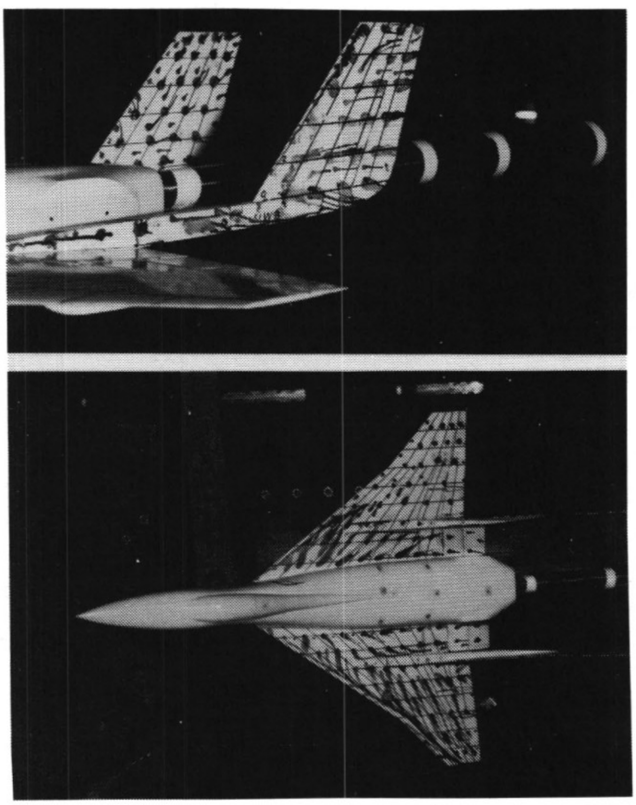

FIG.9: OIL FLOW PHOTOGRAPH, α = 22°, β = 10°

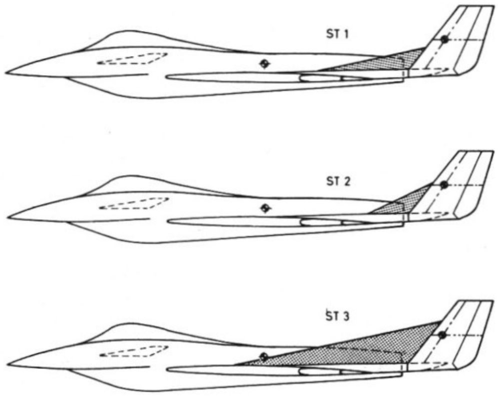

FIG. 10: VERTICAL TAILPLANE STRAKES

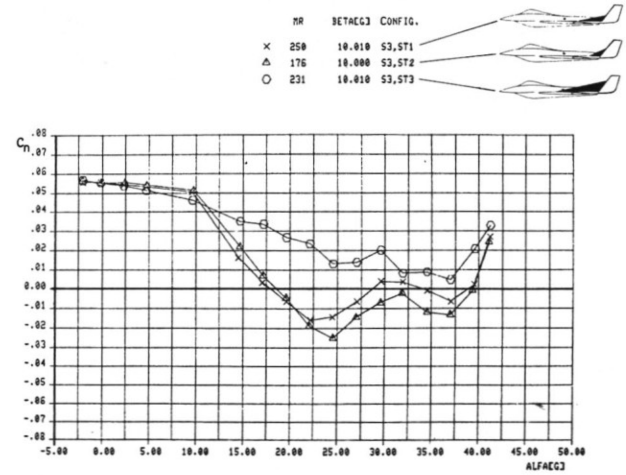

FIG. 11: VERTICAL TAILPLANE STRAKES, YAWING MOMENT

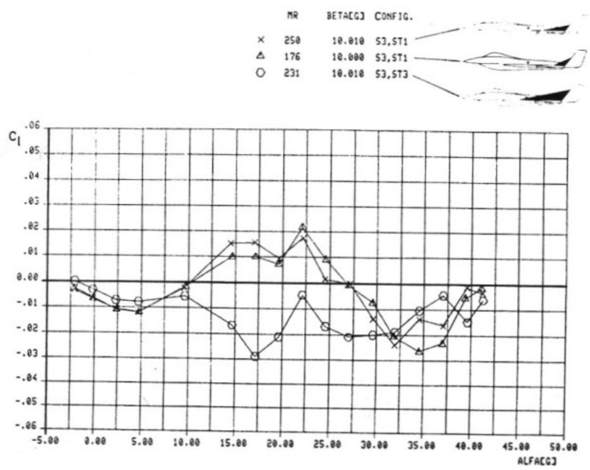

FIG. 12: VERTICAL TAILPLANE STRAKES, ROLLING MOMENT

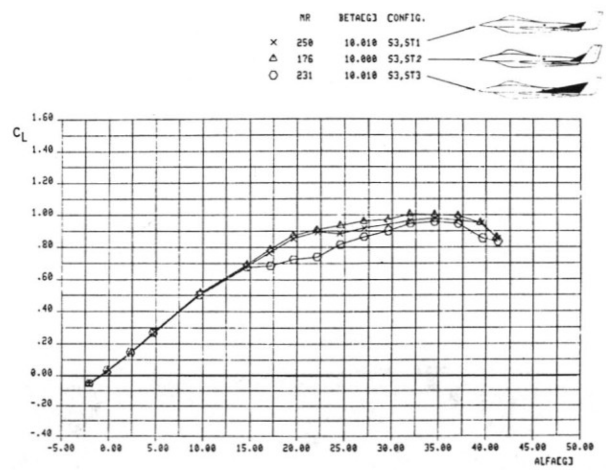

FIG. 13: VERTICAL TAILPLANE STRAKES, LIFT COEFFICIENT

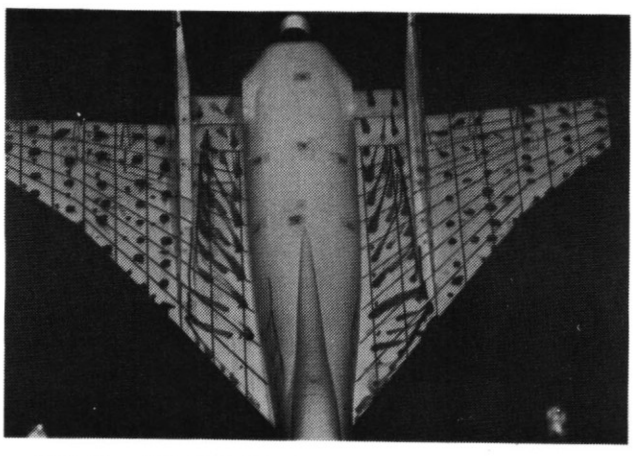

FIG. 14: V. T. STRAKES IN ASYMMETRIC FLOW
$\alpha = 22°$, $\beta = 10°$

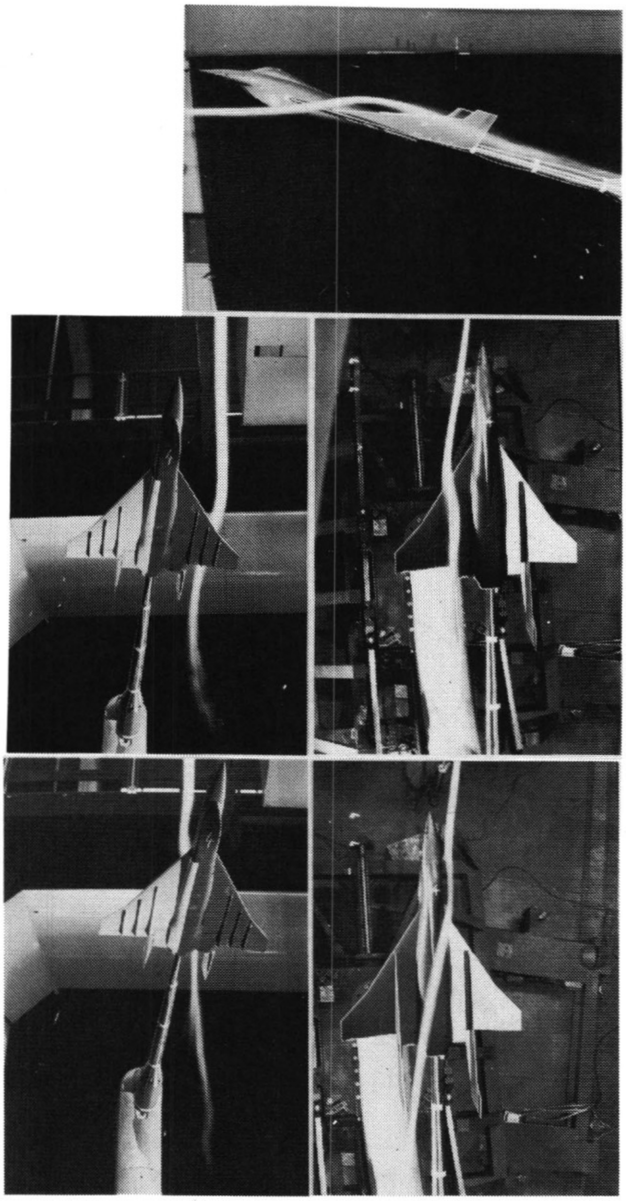

FIG. 15 : STREAMLINE PATTERN $\alpha = 15°, \beta = 10°$

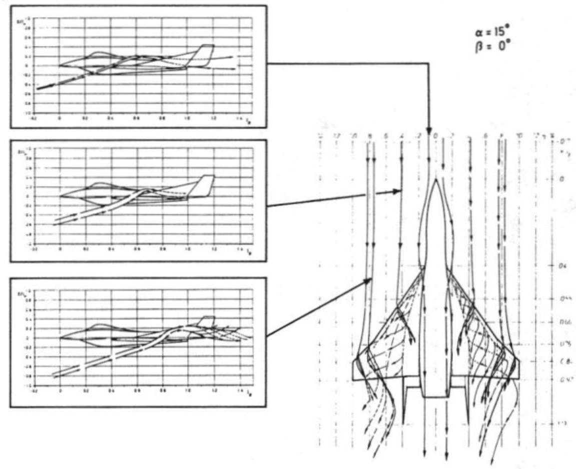

FIG. 16 : FLOW REPRESENTATION

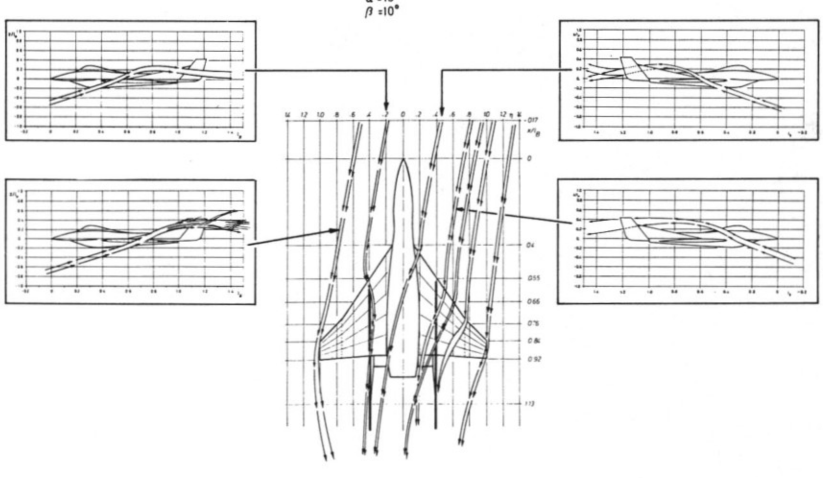

FIG. 17 : FLOW REPRESENTATION

FIG. 18 FLOW REPRESENTATION

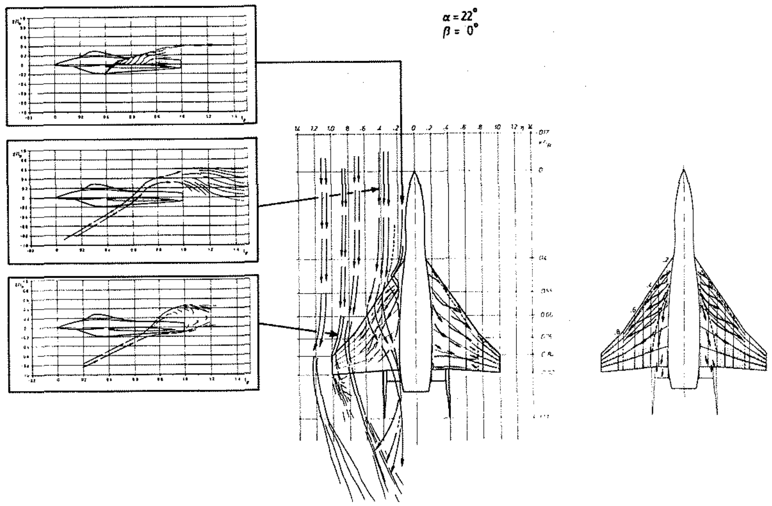

FIG. 19 : FLOW REPRESENTATION

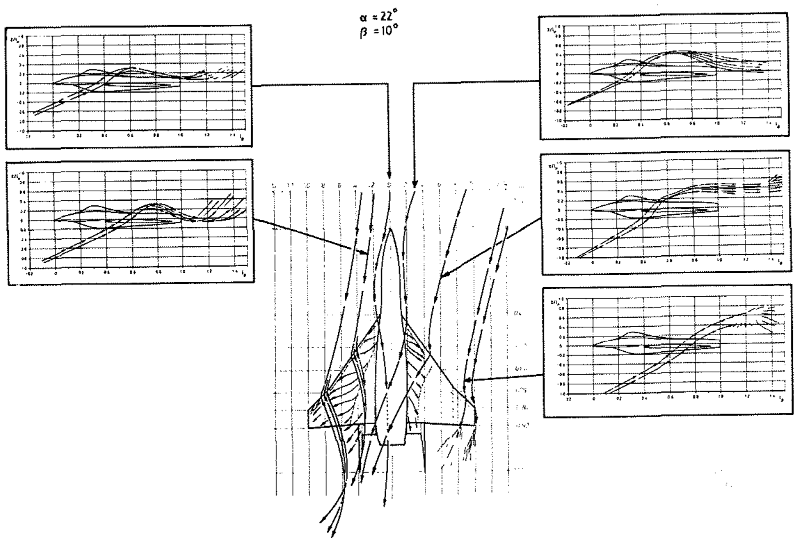

FIG. 20: FLOW REPRESENTATION