# MASS FLOW EFFECTS ON THE LOW SPEED CHARACTERISTICS OF AN ADVANCED COMBAT AIRCRAFT.

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## ABSTRACT.

In this paper experimental results obtained on a low speed six components wind tunnel model featuring an internal flow augmentation system are shown to outline how airplane near field distortions induced by air intake operating conditions can modify the aircraft aerodynamics behaviour in term of stability characteristics and foreplane control effectiveness.

## 1. INTRODUCTION.

Aim of the model whose results are herein described is to assess, by using experimental measurements, how the near field changes related to the air intake operating conditions can affect stability and control characteristics of a far-coupled/delta winged canard configuration representative of a modern fighter aircraft.

It is worth to outline how these effects are conceptually different from the so called "mass flow correction" usually applied to wind tunnel data, the last referring to an "internal" momentum variation and accountless of any "external" change in the airplane near field.

Rationale behind the usual approach is that on conventional aircraft configurations seldom a combination of high angle of attack (AoA) and high Mass Flow Ratio (MFR) at the air intake is found.

For example during take off, as a consequence of the low speed and high engine rating involved, MFR is well beyond one but the AoA doesn't exceed 10°-12° at lift off whereas, in normal fligh conditions, maximum incidence can be achieved but MFR is as small as 0.7-0.8 .

On a modern agile combat aircraft this could be not still totally true, conditions of high MFR and high incidence becaming realistic during a close in combat.

Moreover supersonic speed requirements often leads to low aspect ratio / highly swept delta wings featuring, even for intermediate values of the AoA, vortical flows usually organized in fairly well defined structures whose borning, growing and burnsting is ruled above all by the local flow conditions existings where the vortex sheds.

The configuration tested features an air intake located just forward the wing apex and very close to the foreplane (fig. 1) suggesting as realistic that air intake operating conditions, altering the flow characteristics both in terms of local incidence and pressure/velocity gradients, can affect the "external" aerodynamics therefore modifying basic stability and control characteristics.

## 2. EXPERIMENTAL TECHNIQUE AND DATA CORRECTION PROCEDURE.

Suction necessary to obtain model inlet MFR beyond the natural value has been provided by using two ejector units which can be fed with compressed air up to 4.5 absolute atm. thus allowing a model inlet MFR of 2.3 with a tunnel dynamic pressure of 50 $Kg/m^2$; lesser values of the MFR are obtained using combinations of lower feeding pressures and higher wind tunnel dynamic pressures; Reynolds Number ranges between 1. and 1.5 millions.

The inner part of both the ejectors is totally non-metric, thus avoiding any effect related to the momentum variation due to the flow feeding the ejectors and allowing the measurement of additional forces and moments generated by the enhanced internal flow and acting on model ducts by using a special rig (fig. 2).

The effects of this MFR augmentation system can be properly divided in:

- effects on the external aerodynamics, whose determination is the aim of the tests;
- effects on the internal duct that have to be measured in order to allow the determination of the previous ones without spurious contributions.

The additional rig to measure forces and moments generated by the enhanced internal flow consists of two parts:

- the model fuselage (except for the forebody) complete of internal duct and ejector units ;

- an external streamlined non-metric shield in order to avoid any aerodynamic interference on the external fuselage skin thus allowing to measure the net internal contribution.

MFR values are computed by means of static and total pressures measured in a proper duct section according with the following formulae:

$$\frac{p}{p_t} = \left( 1 + \frac{\gamma - 1}{2} \cdot M^2 \right)^{-\frac{\gamma}{(\gamma-1)}}$$

$$MFR = \frac{A_\infty}{A_0} = \frac{M_0}{M_\infty} \cdot \left\{ \frac{1 + \left[\frac{(\gamma-1)}{2}\right] M_0^2}{1 + \left[\frac{(\gamma-1)}{2}\right] M_\infty^2} \right\}^{-\frac{(\gamma+1)}{2(\gamma-1)}}$$

From the working map (fig. 3) of the additional testing rig it is possible to see that the same MFR is given by several coupling of feeding and dynamic pressures. According to the hypothesis that force and moment coefficients are related only to the operating conditions of the duct, that is to say to its MFR, diagrams showing the behaviour of the various coefficients vs. MFR can be obtained (figs. 4 to 9), outlining how small the effects induced by the Mass Flow augmentation system are when compared to the relevant values typical of an aircraft.
The original approach was to test the internal duct installed on the model at conditions of feeding and wind tunnel dynamic pressures suitable to give an appropriate value of MFR according to the working map of fig. 4. In principle, at a given condition of feeding and wind tunnel dynamic pressure, a slight difference in MFR could exists between the intake installed on the auxiliary rig and on the model due to different flow field conditions at the intake itself in the two arrangements.
Experimentally this difference was proven to be very little enabling the use of the data obtained by the auxiliary rig directly to correct the relevant model data.

## 3. MASS FLOW RATIO EFFECT ON STABILITY AND CONTROL CHARACTERISTICS.

When looking at the corrected data a shift in CL linear branch (figs. 10-11) is present, increasing with MFR, this effects becaming more evident beyond 30°.
About pitching moment (figs. 12-13) a similar shift towards negative values has to be outlined together with a sharp change in the slope $C_{m\alpha}$ beyond $\alpha = 25°$.
The reasons for both the shifts appear to be a coupled effect of a changed local incidence at the foreplane and an enhanced flow over the inner part of the flaperon due to the nozzle stream as it seems to be accounted for when looking at the foreplane-off configuration where the shift in $C_m$, still negative, is smaller (fig. 14) confirming the existence of a downloading of the foreplane for high MFR's ; anyway, in order to define the order of magnitude of the pitch shift it could be defined as equivalent to a flaperon deflection lesser than 2°.
At higher incidecence ( $\alpha > 25°$) a different behaviour can be noticed, low MFR curves being very similar whereas a sharp change occurs for MFR > 1.3 as a consequence of a retarded foreplane stall.
As far as laterals are concerned (figs. 15-18), increasing the mass flow gives a progressive reduction of the unstable $C_{l\beta}$ peak (fig. 16) reaching a fully stable behaviour at the higher values of MFR without any influence by the relevant change in Reynolds Number (fig. 15).
About $C_{n\beta}$ (fig. 17), its trend is similar with a significative reduction of the unstable peak, it is worth to outline that , in the incidence range up $\alpha = 25°$ the reduction in directional stability, when related to the relevant increment in side force (fig. 18), states that the additional side force is located at the intake station.

## 4. FOREPLANE EFFECTIVENESS.

Three different foreplane deflections have been tested both for natural mass flow ( 0.7) and 2.0 in order to assess the effect of intake operating conditions on foreplane effectiveness. The relevant results are shown in fig. 19 in terms of $C_m$ with respect to the foreplane zero deflection.
As it's possible to see from the variation in pitching moment the foreplane effectiveness is pratically unaffected for $\alpha$ lesser than 25° for the whole set of deflections tested; upon this value the trend is different when going from $\delta_{foreplane}$ +10 to -20°, the foreplane effectiveness increment with MFR growing along with negative deflections confirming as the MFR acts substantially reducing the local incidence with a consequent foreplane stall delay.

## 5. CONCLUSIONS.

The effects of air intake operating conditions on external aerodynamics have been assessed as significative at high incidence.

For $\alpha < 25°$ nothing but a slight shift in $C_L$ and $C_m$ has to be pointed out, the variations in $C_{L\alpha}$ and $C_{m\alpha}$ being practically neglegible; otherwise for $\alpha > 25°$ strong depedence of lift, pitching moment, $C_{n\beta}$ and , above all, $C_{l\beta}$ is shown together with an increase of foreplane effectiveness, especially for negative deflections.

Future investigations will assess how these phenomena can modify flaperon effectiveness at high AoA.

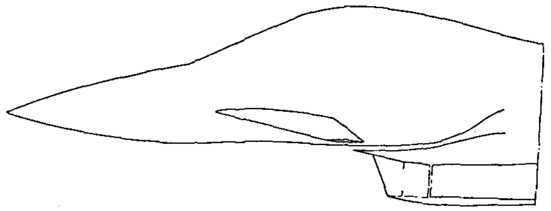


Fig. 1 FOREBODY CONFIGURATION

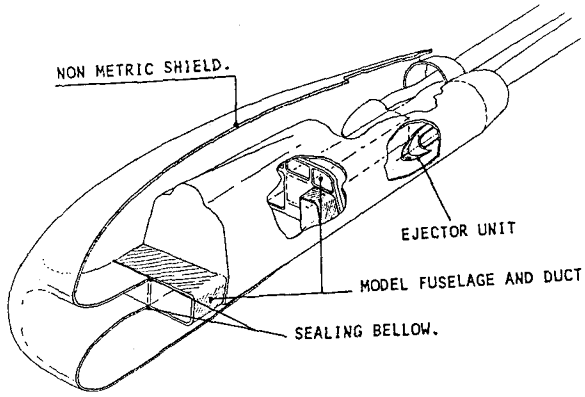
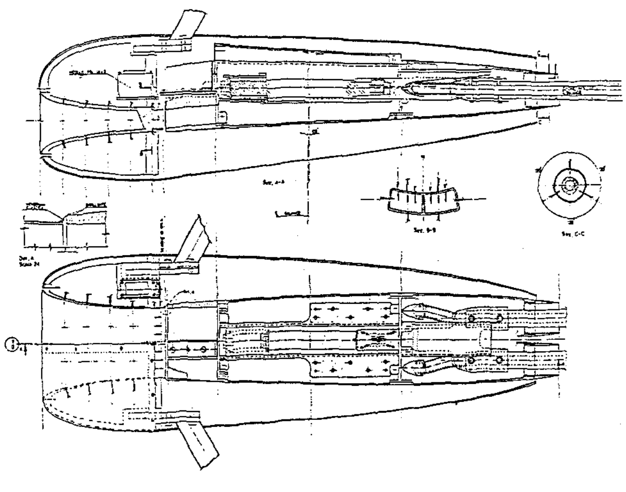


Fig. 2 AUXILIARY RIG.



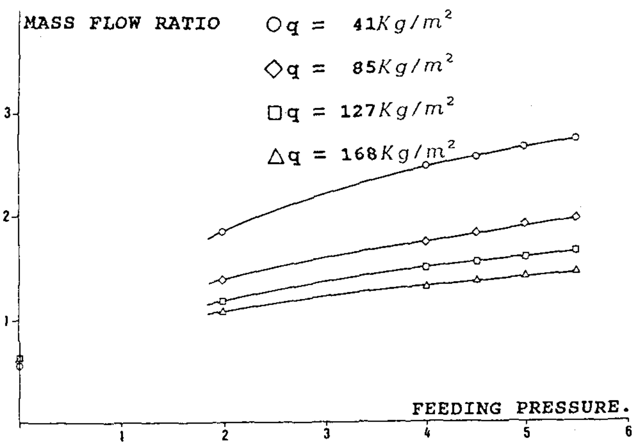


Fig. 3 MASS FLOW AUGMENTATION SISTEM WORKING MAP.

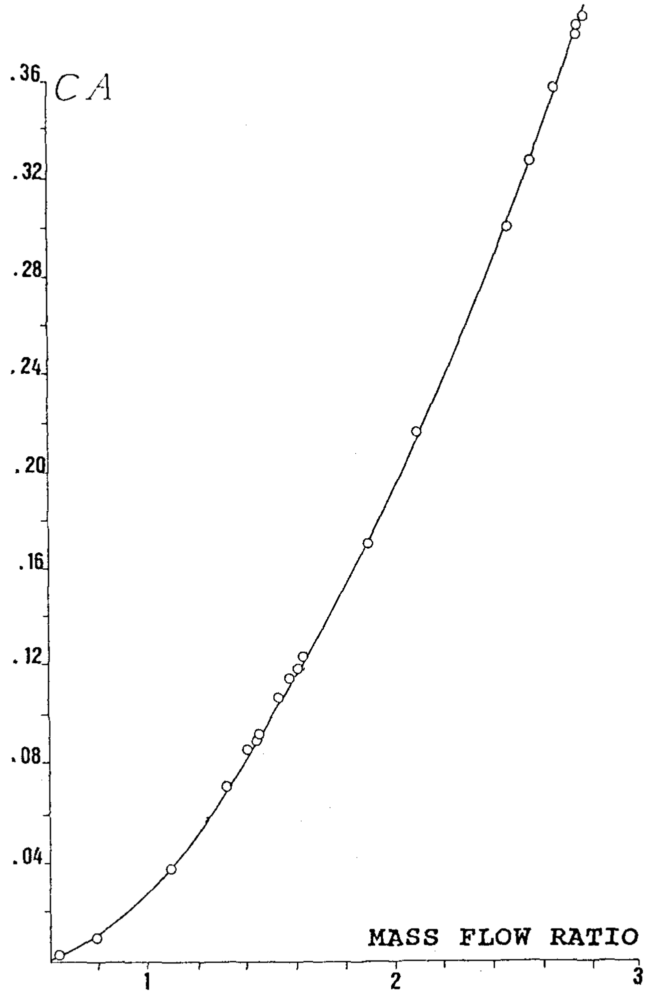


Fig. 4 MASS FLOW AUGMENTATION SISTEM EFFECT ON AXIAL FORCE.

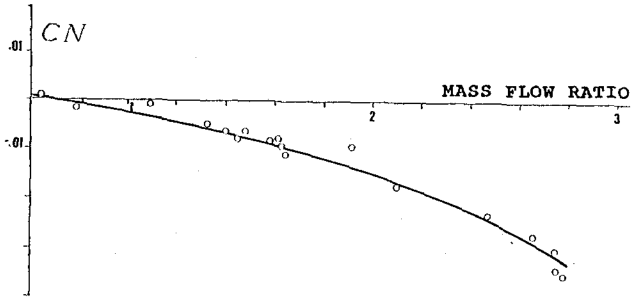


Fig. 5 MASS FLOW AUGMENTATION SISTEM EFFECT ON NORMAL FORCE.

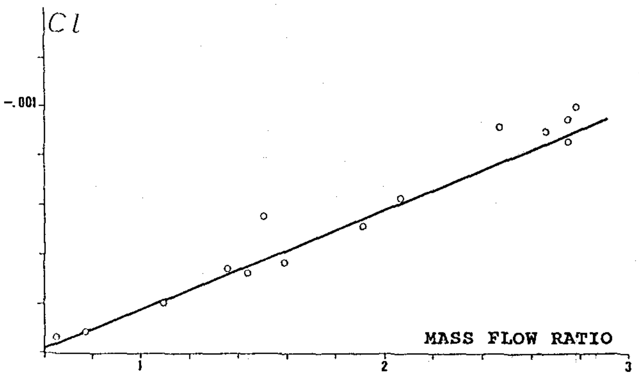


Fig. 7 MASS FLOW AUGMENTATION SISTEM EFFECT ON ROLLING MOMENT.

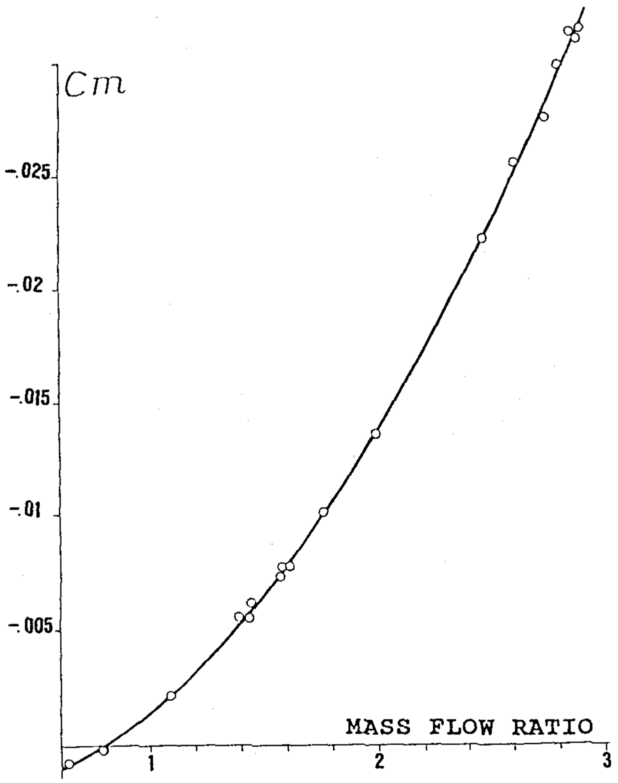


Fig. 6 MASS FLOW AUGMENTATION SISTEM EFFECT ON PITCHING MOMENT.

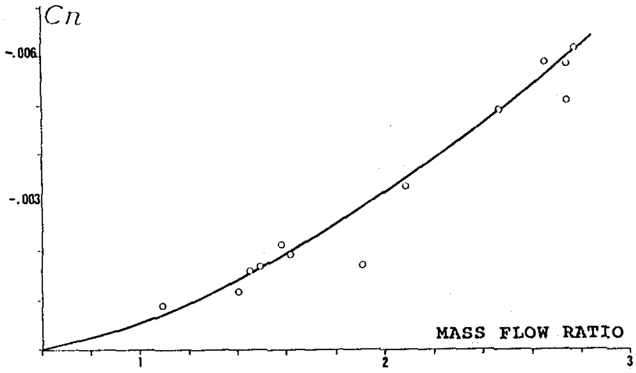


Fig. 8 MASS FLOW AUGMENTATION SISTEM EFFECT ON YAWING MOMENT.

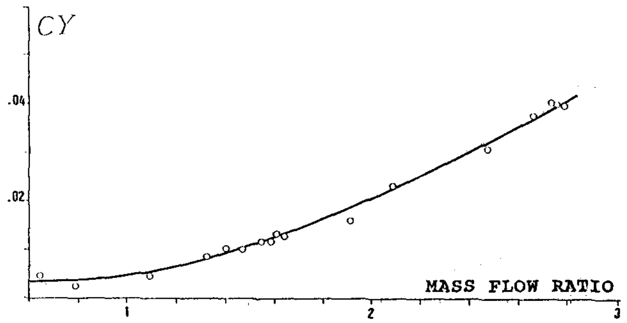


Fig. 9 MASS FLOW AUGMENTATION SISTEM EFFECT ON SIDE FORCE.

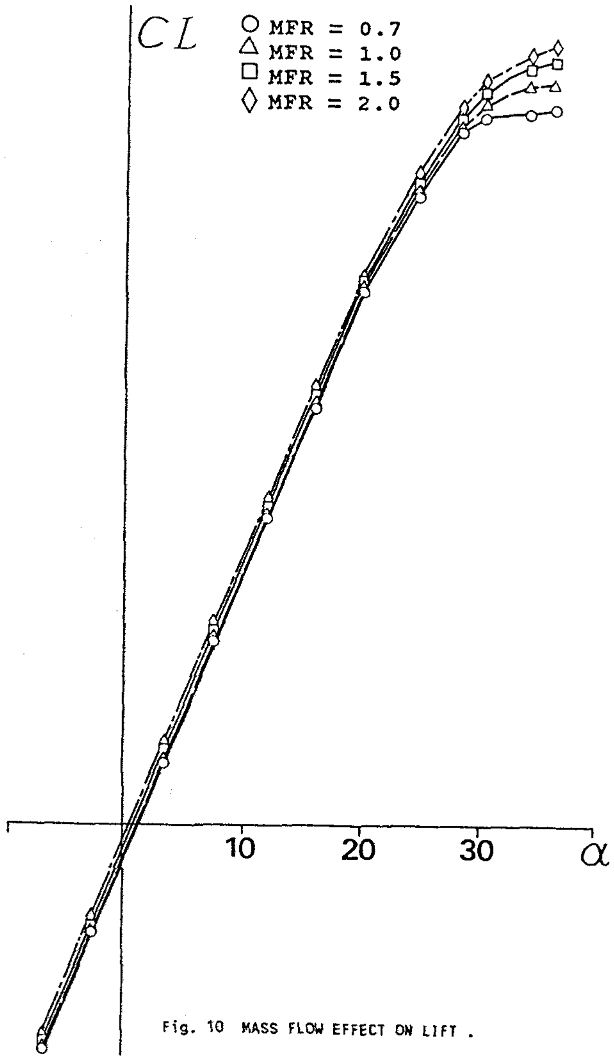


Fig. 10 MASS FLOW EFFECT ON LIFT .

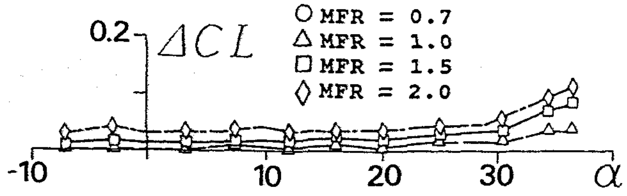


Fig. 11 MASS FLOW EFFECT ON LIFT W.R.T NATURAL MFR.

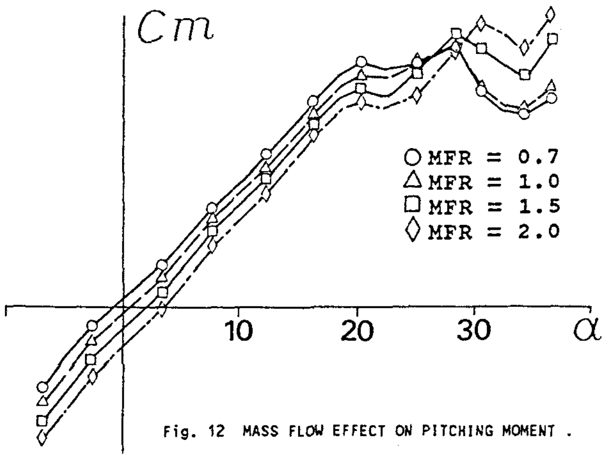


Fig. 12 MASS FLOW EFFECT ON PITCHING MOMENT .

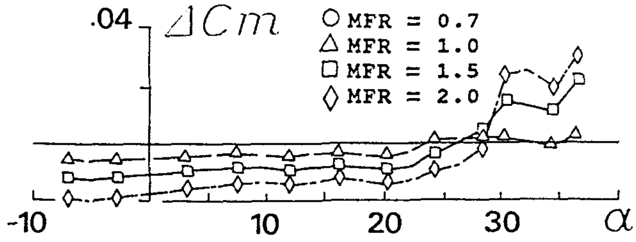


Fig. 13 MASS FLOW EFFECT ON PITCHING MOMENT W.R.T NATURAL MFR.

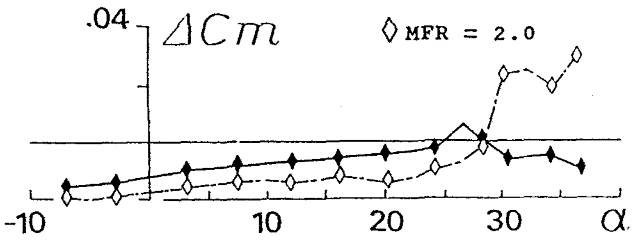


Fig. 14 MASS FLOW EFFECT ON PITCHING MOMENT OF FOREPLANE OFF CONFIGURATION.

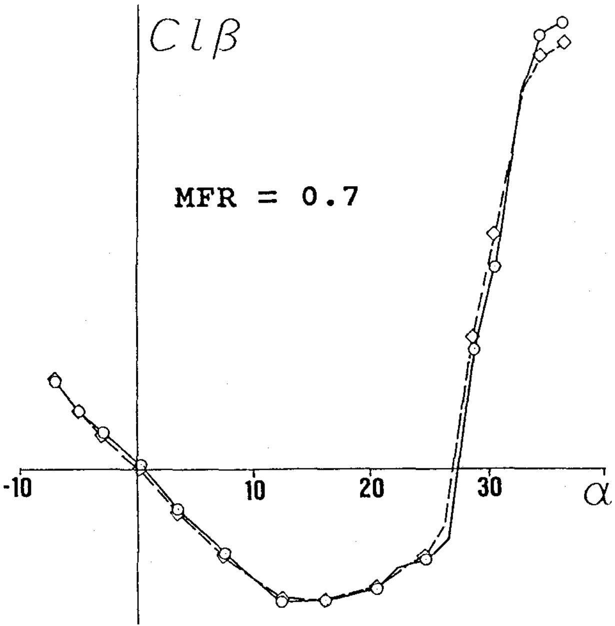


Fig. 15 REYNOLDS EFFECT ON LATERAL STABILITY.

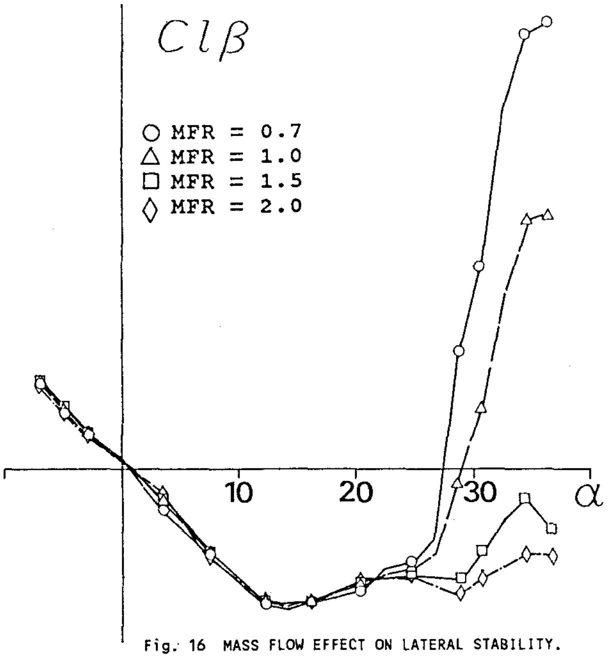


Fig. 16 MASS FLOW EFFECT ON LATERAL STABILITY.

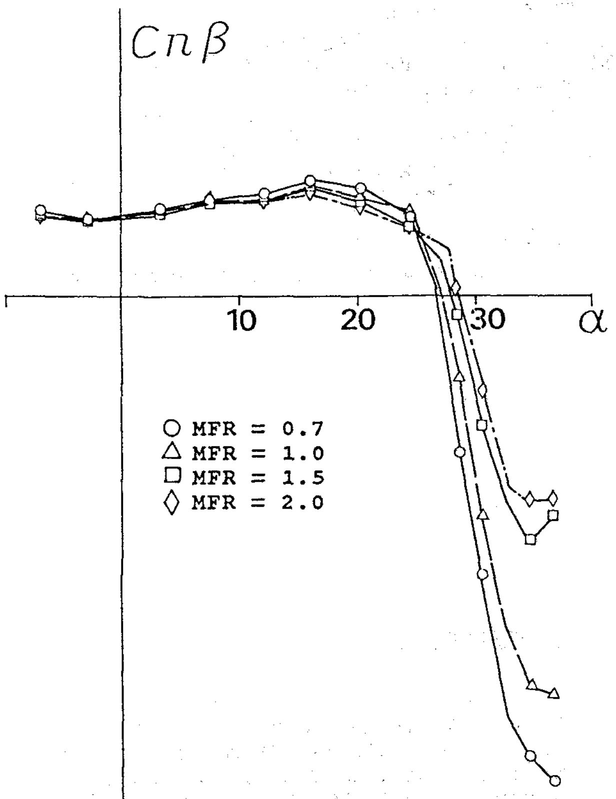


Fig. 17 MASS FLOW EFFECT ON DIRECTIONAL STABILITY.

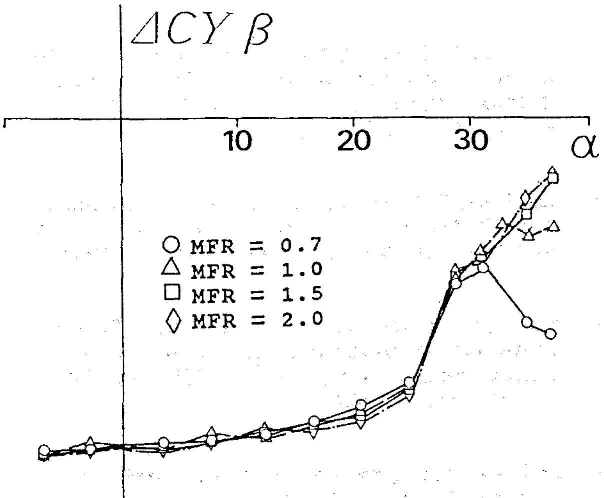


Fig. 18 MASS FLOW EFFECT ON SIDE FORCE.

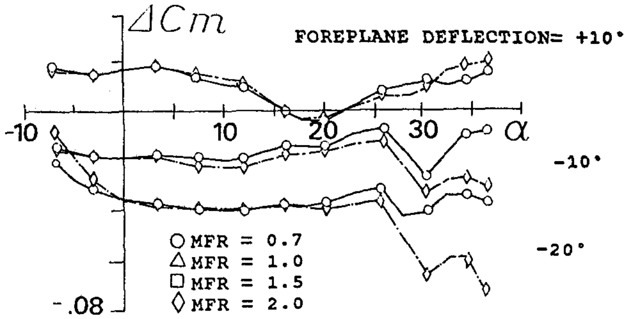


Fig. 19 MASS FLOW EFFECT ON FOREPLANE EFFECTIVENESS.

## 6. REFERENCES.

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