WING DESIGN OF AN OBLIQUE WING COMBAT AIRCRAFT

Dr. R. K. Nangia
Consulting Engineer,
Nangia Aero Research Associates,
Maggs House, Queens Road, BRISTOL, BS8 1QX, UK
Tel: +44 (117)-987 3395 Fax: +44 (117)-987 3395

Dr. D. I. Greenwell
Principal Scientist
Aerodynamics & Hydrodynamics Centre
Defence Evaluation Research Agency,
BEDFORD, MK41 6AE, UK
Tel: +44 (0)123 422 5122 Fax: +44 (0)123 422 5180

SUMMARY

The Oblique Wing (OW) concept is a proposition for meeting rigourous aerodynamic performance goals to Mach about 1.7 over a wide flight envelope up to 40,000 ft. With appropriate wing sweep, high efficiencies can be obtained at low speed. The handling, stability and control issues remain a strong design challenge to ensure adequate stability in pitch, yaw and roll. This has led to a work programme with the objective of assessing the suitability of such concepts for manned and UAV combat aircraft applications.

The military application has a wide operating flight envelope under stealth constraints (30° raked wing-tips). Several types of flows from the planform edges flows interact in different ways as the wing sweep and Mach combinations alter.

After a brief description of flow features, this paper addresses the design case for transonic cruise at low altitudes. This has emphasised control over LE suctions as desired within the neutral point and CG constraints.

We have addressed a major off-design implications e.g. low speed flight with a novel "one-piece" TE that is torsionally flexible. Calculations show that the high-speed supersonic dash will require an amount of "uncambering" with the flexible TE envisaged.

Several avenues for further work have arisen.

1. INTRODUCTION & BACKGROUND

Based on several past studies, the Oblique Wing (OW) concept is a proposition for meeting rigourous aerodynamic performance goals for Mach numbers to about 1.7 over a wide flight envelope up to 40,000 ft (e.g. Refs.1 - 3). With appropriate wing sweep, high efficiencies can be obtained at low speed. The handling, stability and control issues remain a strong design challenge to ensure adequate stability in pitch, yaw and roll. A work programme has been set up with the objective of assessing the suitability of such concepts for manned and UAV combat aircraft applications.

The military application with a wide flight envelope, Fig.2, under stealth constraints implies operation also at "non-optimum" combinations of Mach and sweep angle and in this aspect it is different from the civil types. For example wing-tips can become part of a LE or TE depending on the flight sweep condition.

The stealth requirements lead to a broad definition of 'parallelogram planform' based on 30° raked wing-tips (Fig.1). The aspect ratio varies between 6.0 at 0° to 1.5 at 60° sweep. The thickness of the wing is set by the maximum speed and has been chosen as t/c = 10% normal to the LE. However, in the final configuration, allowance will need to be made for a central "volume" for payload (stores, propulsion & instrumentation).

It is anticipated that TE and Tip Controls will be required to meet the design envelope for trimmed and manoeuvring flight. A novel feature of the military concept is a "one-piece" TE that is torsionally flexible.

In this paper, we look first at flow features. These help to focus on setting the main design problem at transonic speed and addressing the off-design implications at low speeds and high speed supersonic dash.

2. BRIEF DESCRIPTION OF THE FLOW-FIELDS & LOADINGS

Across the flight envelope, several types of flow-fields exist over the different regions of the wing as different combinations of Mach and sweep angle occur (Fig.3). As sweep angle increases there is an increasing tendency for higher LE suctions to appear over the wing LE towards the 'rear' tip. The 'leading' apex remains lightly loaded. The spanwise lift loadings are not naturally elliptic but more biased towards the rear tip.

Tip Flows & Loadings

At low sweeps (<30°), the forward wing-tip behaves as part of TE, whilst the aft wing-tip behaves as part of LE. At 30° sweep condition, both wing-tips behave essentially as side-edges (or 90° sweep). Higher sweeps (e.g. 60°) show that the forward wing-tip becomes part of the LE and the aft-tip becomes part of the TE. Note the vortical flow tendencies as sketched.

For all sweeps except 30°, the wing essentially has zero taper toward both tips implying very high 'local' loadings. The zero taper wings also have difficulty in achieving idealized elliptic loadings near the tips.

At supersonic speeds (sweep near 60°), note the disposition of Mach 1.6 lines. All edges are essentially subsonic. The Mach-lines suggest that there is very little uniform flow as a result of interaction of three conical flows; two from points on the leading wing-tip, and one from the front of the aft-tip as shown.

Calculations on a planar wing have shown that for the 60° sweep transonic cruise flight (wing-span 1.0), the neutral point is located at x = 0.788 & y = 0.532 (i.e. more outboard compared with the mid-span geometrical value = 0.5).

Implications of Choosing a Transonic Design Point

Most manouverable combat aircraft need to demonstrate adequate transonic cruise characteristics at low altitudes.

If elliptic loading (or nearly so for minimum lift-induced drag) constraints are applied at the transonic cruise design point (sweep 60°), then this leads to consideration of several design and off-design aspects e.g.

- determination of neutral points throughout the envelope to assist in choosing acceptable CG limits.
- Trimmed flight at low speeds with varying sweep angle. The TE geometry is varied.
- Off-Design Cases such as: (1) Low speed high-lift case at 30° sweep or less, (2) Transonic flight at sweep angles in the range 30° to 60°.
- High speed dash Mach 1.6 at maximum sweep (60°).
- Subsonic and transonic Manoeuvre points with appropriate g-limits.
- Roll, Pitch and Yaw Stability implications, Control laws.

For oblique-wing aircraft, the intuitive feeling is that the main problems are more likely to do with ensuring adequate control rather than drag reduction.

3. METHODS USED

On 'unusual' and asymmetric configurations, the experience suggests that the complexities are too much for an automatic "hands-off" design process to be used with confidence (unique solutions doubted). Therefore we have chosen a process that allows a significant understanding to be gained with reasonable manual control over the design process.

Panel & Euler codes have been utilised that enable assessment of the aerodynamic performance over the Mach number range from low-speed to supersonic.

The camber and twist design, under forces and moments constraints is via a previously validated attained suction design method (Ref.4) using a series of modes and influence functions. The attained suction approach allows development of minimum camber and twist on the wing for given flight conditions: Mach number and Reynolds number. The method needed some adaptation for including asymmetry effects, however.

An inverse design method using 3-D membrane analogy (Ref.5) can be used to "tailor" and "fine-tune" pressure distributions as required. This should be more useful at the later stages in the volume and payload integration studies.

Several utility programmes have been developed to deal with the asymmetric layouts.

Fig.4 shows a typical design chart (x- & y-senses) relating the neutral point location to the centre of pressure (and hence centre of gravity) for a series of different camber design wings. The approach allows an examination of several different assumptions of lift and pitching moment constraints. Note that 'unstable' locations of centre of gravity occur only too 'readily'. For given lift and for neutral longitudinal stability, the CG needs to co-locate with neutral point in x-sense. For achieving near-elliptic spanwise loading, the aim would be to move the CG to mid-span of the wing ($y/b = 0.5$).

The above two requirements can often conflict, suggesting that artificial stability might well be needed for flying such wings.

4. TRANSONIC SPEEDS & DESIGN

Fig.5 shows the pressure distributions on a planar oblique (60°) wing for $\alpha = 0°, 1° \& 2°$, Mach 0.9, obtained with an unstructured Euler method. Note the increasing developing LE suctions as one moves away from the leading apex point. However, closer investigations revealed that LE suctions were not adequately captured with the unstructured Euler method particularly on fairly thin wings unless a very large number of elements were to be used. This put a question mark on its (Euler's) economic use in an attained LE suction design approach. We therefore used a panel method to develop the camber at Mach 0.8 (Fig.6) and CL corresponding to $\alpha = 1.25°$, with requisite constraints. The lift-curve slope predictions from the Panel code were within 5-10% of the Euler results.

On the designed wing, note the presence of increasing negative twist and camber toward the rear tip.

Fig.7 compares the pressure distributions on the planar and designed cambered oblique (60°) wing for $\alpha = 1.25°, 1.5° \& 1.75°$. Note that LE suctions have been appropriately curtailed and 'softened' on the designed wing.

This resulted in slight longitudinal instability which would necessitate an appropriate functioning TE control. Further work is needed with possibly different cambers to see if a stable solution is feasible.

5. LOW SPEED TE CONTROL

At low speeds, the control of the aircraft has been envisaged via a 20% chord, flexible TE control. In the design method, for sake of simplicity and understanding, the modal deflections over the TE were developed by 'blanking' the modes over the rest of the wing. The starting point for the wing was uncambered.

Assuming a 30° sweep flight condition, Fig.8 shows the TE control disposition, with and without an assumption of Cm restraint.

The control dispositions, represent small deflections and can be super-imposed on the transonic designed camber wing.

This work has opened several avenues for more detailed work e.g. improving modal representation of the TE control and using the designed camber as the basic starting point.

6. SUPERSONIC SPEEDS

Fig.9 shows a first attempt at calculating the Cp and ΔCp distributions at Mach 1.6, $\alpha = 1.0$ for the 60° sweep condition. An unstructured grid Euler method was used. Although, there were some Cp and surface interpolation difficulties near the edges of the planform, nevertheless, the main character of the Cp variations is easily discerned. The Mach-lines of Fig.3 help in broad interpretation of the various zones. Note the loss in lift (ΔCp) behind the Mach-line emanating from aft point on the leading tip.

Further work e.g. on the supersonic behaviour of the transonic wing design needs to be done. This should highlight the TE flap disposition necessary ('uncambering' sense). This will indicate the yaw control required e.g. by tip deflection.

7. INFERENCES, POSSIBLE BENEFITS, FUTURE

The Oblique Wing (OW) concept remains a proposition for meeting rigourous aerodynamic performance goals for Mach numbers to about 1.7 over a wide flight envelope up to 40,000 ft. With appropriate wing sweep, high efficiencies can be obtained at low speed. The handling, stability and control issues remain a strong design challenge to ensure adequate stability in pitch, yaw and roll. This has led to a work programme with the objective of assessing the suitability of such concepts for manned and UAV combat aircraft applications.

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After a brief description of flow features, this paper has focussed on the design case for transonic cruise at low altitudes. This has emphasised control over LE suctions as desired within the neutral point and CG location constraints.

We have addressed a major off-design implications e.g. low speed flight with "one-piece" TE that is torsionally flexible.

Calculations show that the high-speed supersonic dash will require an amount of "uncambering" with the flexible TE envisaged.

Typical results presented demonstrate the flexibility and potential of the techniques used. Although we have shown encouraging capability in the aspects considered, much more can be envisaged. We need to work with the control law designers in order to ascertain the extent of linearisation possible. This should help in setting some bounds on the configurational work needed.

Thoughts need to be given to yaw control using tips.

The approach will provide the data for detail design of wind tunnel models and possibly a flight demonstrator. An understanding of control laws will also arise. As well as assessment of the potential of the aircraft in meeting a given design envelope, the limitations of the design will also be appreciated.

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REFERENCES

[1] 1. KUCHEMANN, D. "The Aerodynamic Design of Aircraft", Pergamon.

[2] 2. JONES, R.T., "Wing Theory", Princeton.

[3] 3. SOBIECZKY, H. et al, "Manual Aerodynamic Optimisation of Oblique Flying Wing", ICAS-98-1.1.3.

[4] 4. NANGIA, R.K., "The Design of "Manoeuvrable" Wings using Panel Methods, Attained Thrust & Euler Codes", ICAS-92.

[5] 5. NANGIA, R.K., "Development of an Inverse Design Technique using 3-D Membrane Analogy", Paper to be published.

LIST OF SYMBOLS

A	Aspect Ratio
b	= 2 s, Wing span
c	Local Wing Chord
c_{av}	= c, Average Wing Chord (varies as wing sweep changes)
C_D	= D /(q S), Drag Coefficient
CG	Centre of Gravity
C_l	= l/(q S b), Rolling moment
C_L	= L/(q S), Lift Coefficient
C_m	= m/(q S c), Pitching Moment (Body Axis)
C_p	Coefficient of Pressure
CP	Centre of Pressure
ΔC_p	Difference in C_p between upper and lower surfaces
D	Drag force
l	Rolling Moment
L	Lift Force
LE	Leading Edge
m	Pitching moment (Body Axis)
M	Mach Number
q	= 0.5 ρ V^2, Dynamic Pressure
R	Reynolds Number, based on c_{av}
s	Wing semi-span
S	Wing Area
t	Aerofoil thickness
TE	Trailing Edge
TEF	Trailing Edge Flap
V	Velocity
x,y,z	Orthogonal Wing Co-ordinates, x along body-axis
α	Angle of Attack
Λ	LE Sweep Angle
η	= y/s, Non-dimensional spanwise Distance
ρ	Air Density

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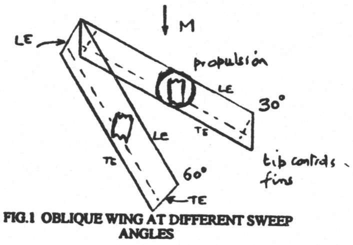


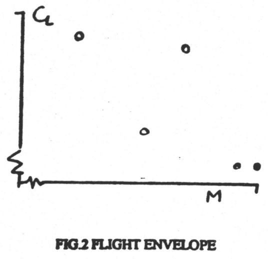
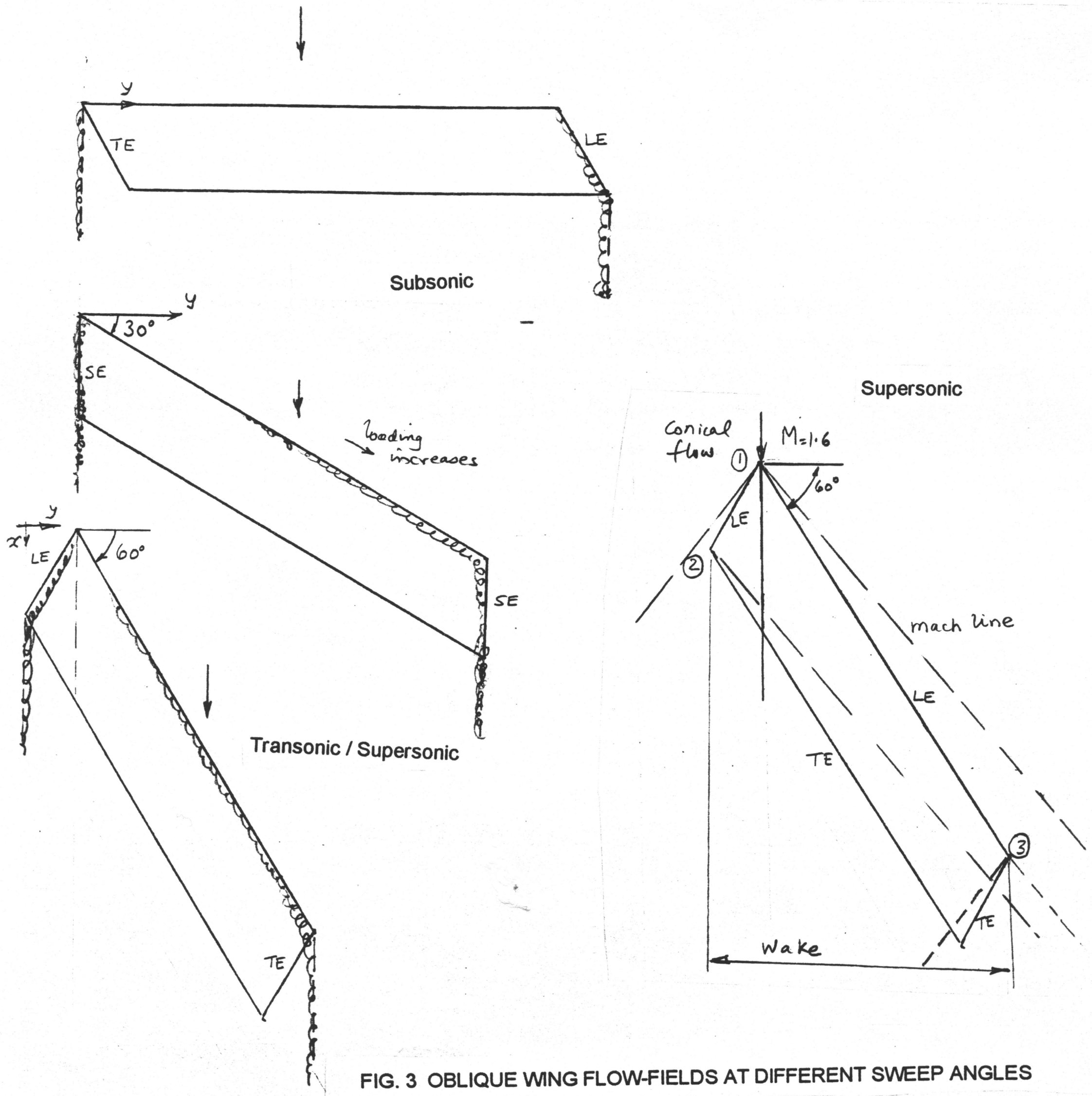


FIG. 1 OBLIQUE WING AT DIFFERENT SWEEP ANGLES

FIG. 2 POSSIBLE FLIGHT ENVELOPE

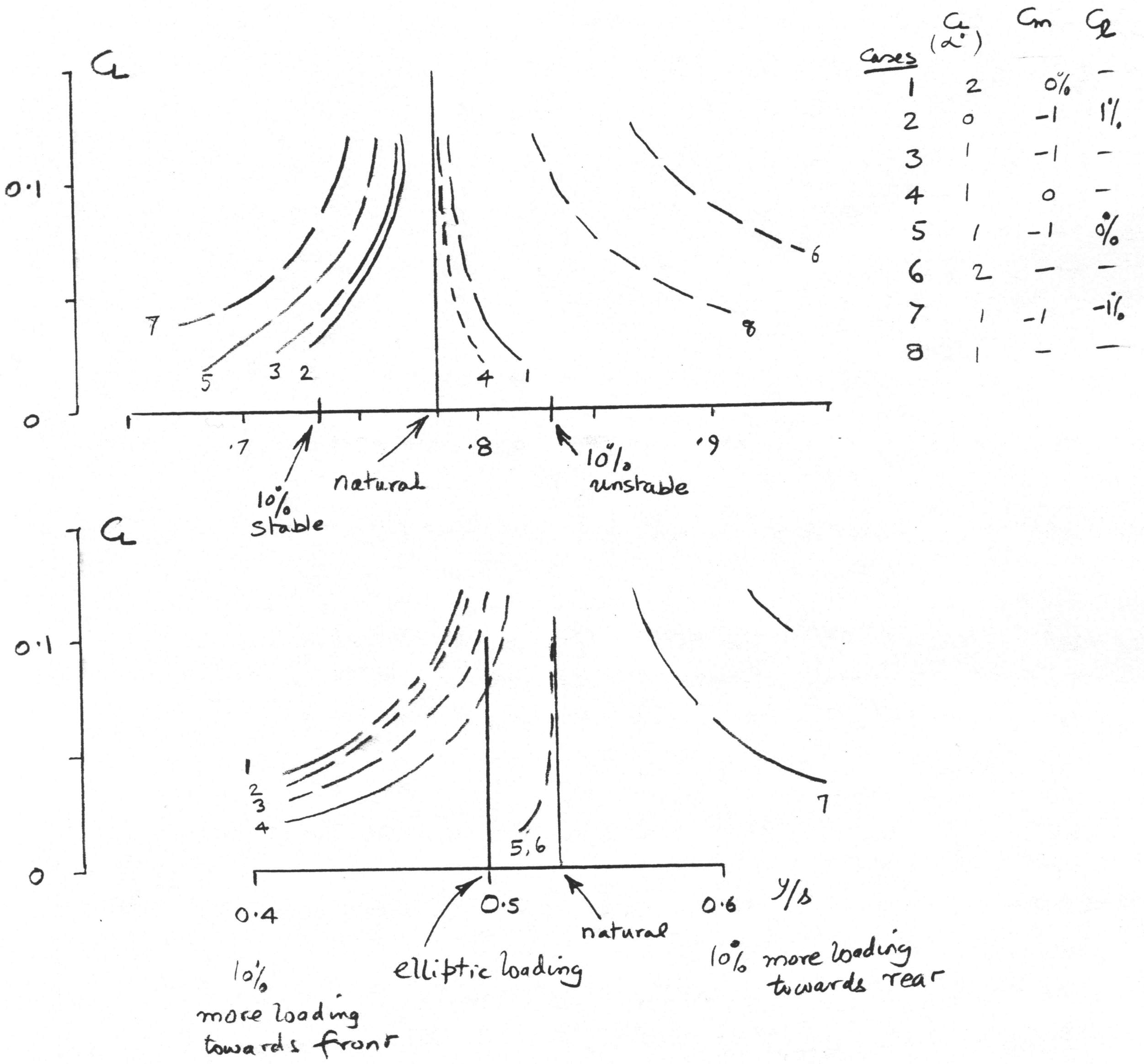


Subsonic

Transonic / Supersonic

Supersonic

FIG. 3 OBLIQUE WING FLOW-FIELDS AT DIFFERENT SWEEP ANGLES



Cases	C_L (α°)	C_m	C_l
1	2	0%	–
2	0	–1	1%
3	1	–1	–
4	1	0	–
5	1	–1	0%
6	2	–	–
7	1	–1	–1%
8	1	–	–

FIG. 4 TYPICAL NEUTRAL POINT & CG LOCATION RELATIONSHIPS

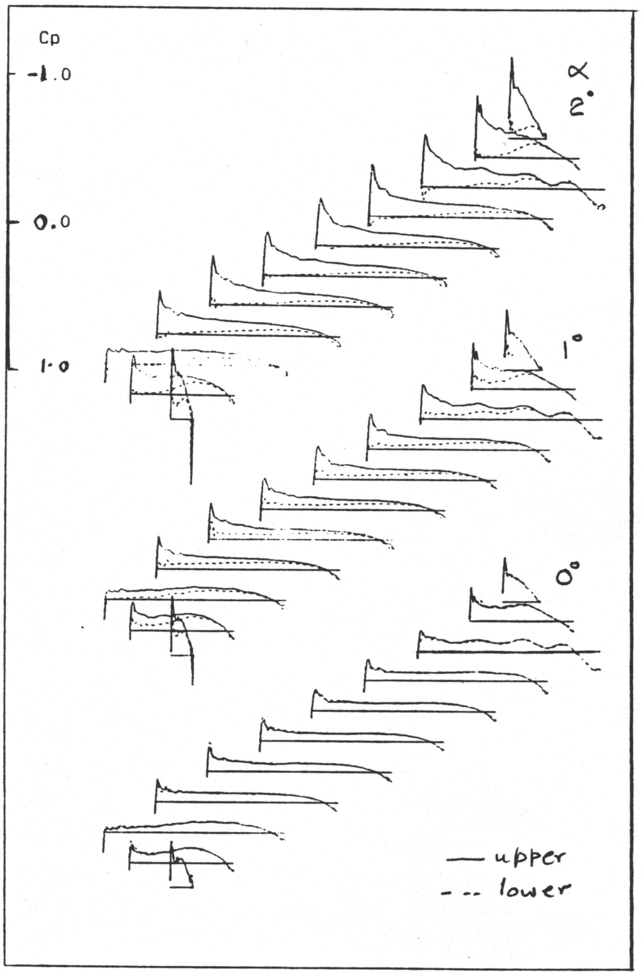


FIG. 5 PRESSURES ON 60° OBLIQUE WING, Mach 0.9, $\alpha = 0°, 1° \& 2°$, EULER

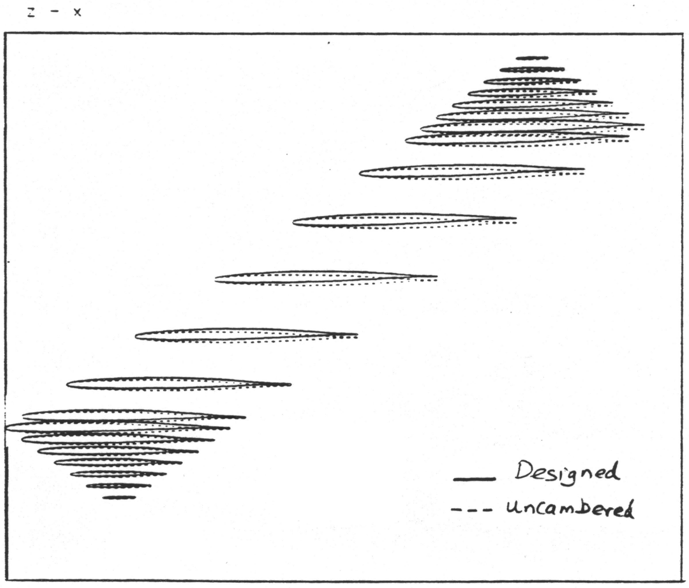


FIG. 6 DESIGNED CAMBER, Mach 0.8, C_L corresponding to $\alpha = 1.25°$

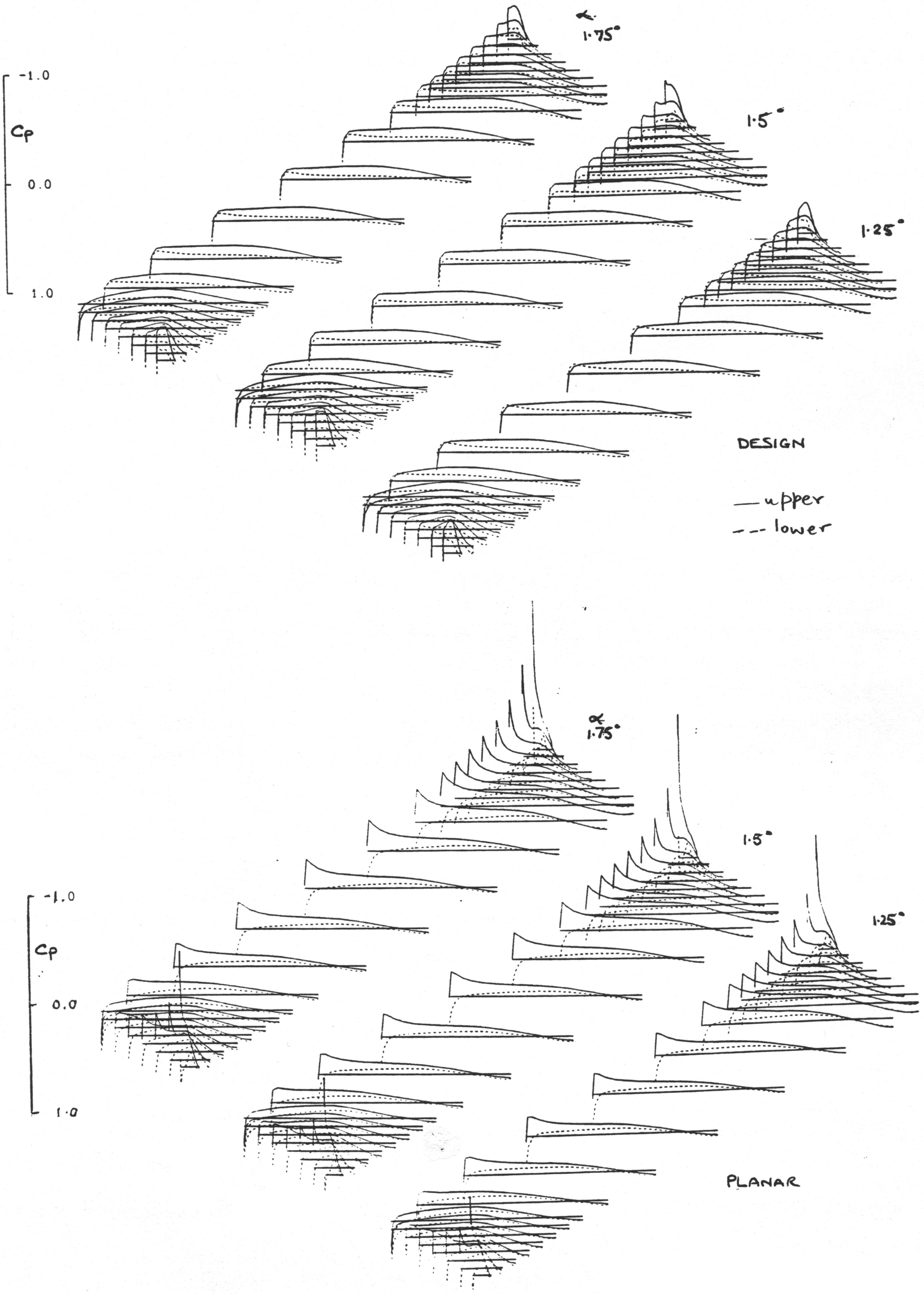


FIG. 7 COMPARISON OF PRESSURES ON 60° OBLIQUE WING, PLANAR & DESIGNED Mach 0.8, α = 1.25°, 1.5° & 1.75°

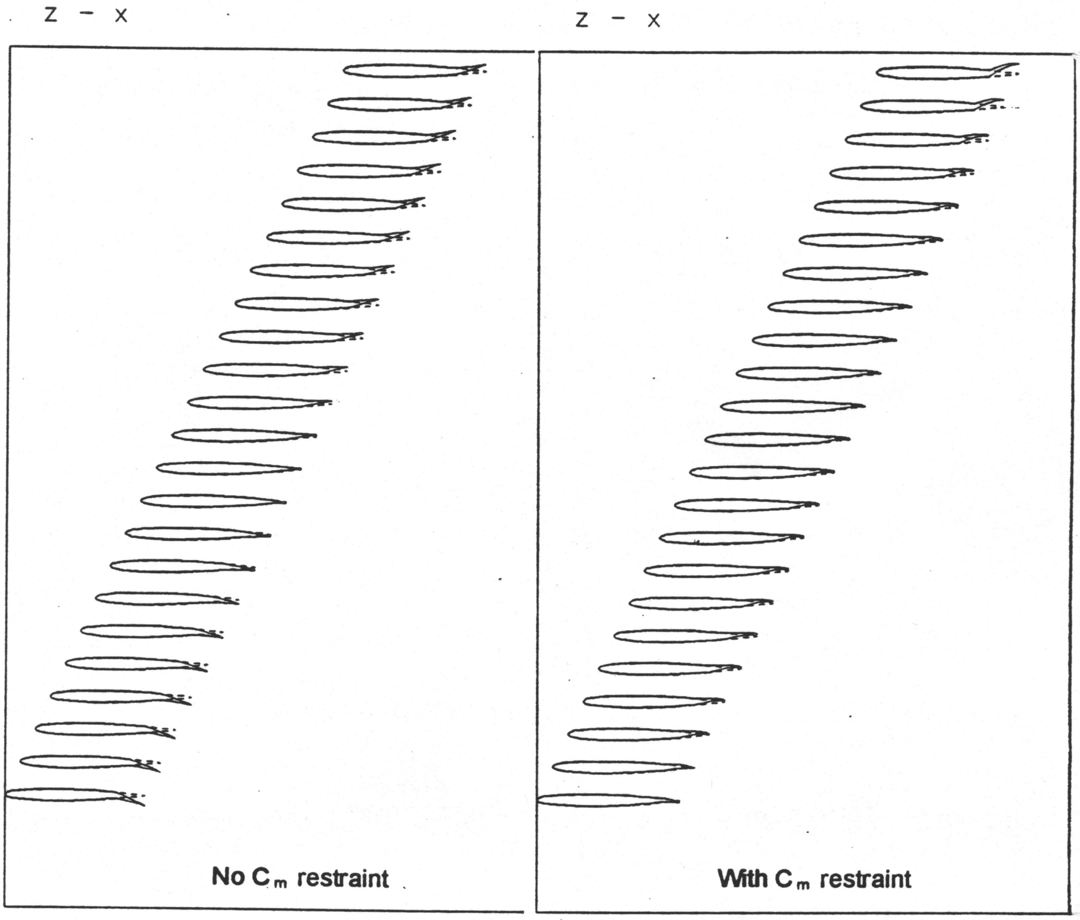


FIG. 8 30° OBLIQUE WING, TE DISPOSITION WITH & WITHOUT A C_m RESTRAINT, LOW SPEEDS

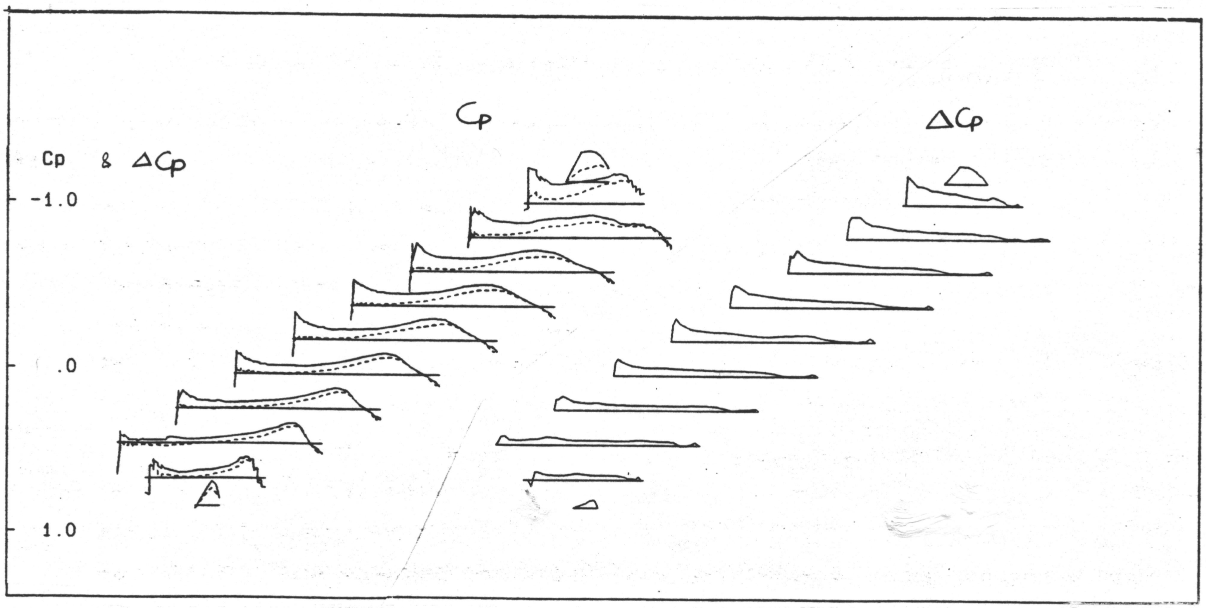


FIG. 9 60° OBLIQUE WING, Cp & ΔCp DISTRIBUTIONS AT MACH 1.6, α = 1°