APPLICATION OF A FULL POTENTIAL METHOD FOR ANALYSIS OF COMPLEX AIRCRAFT GEOMETRIES

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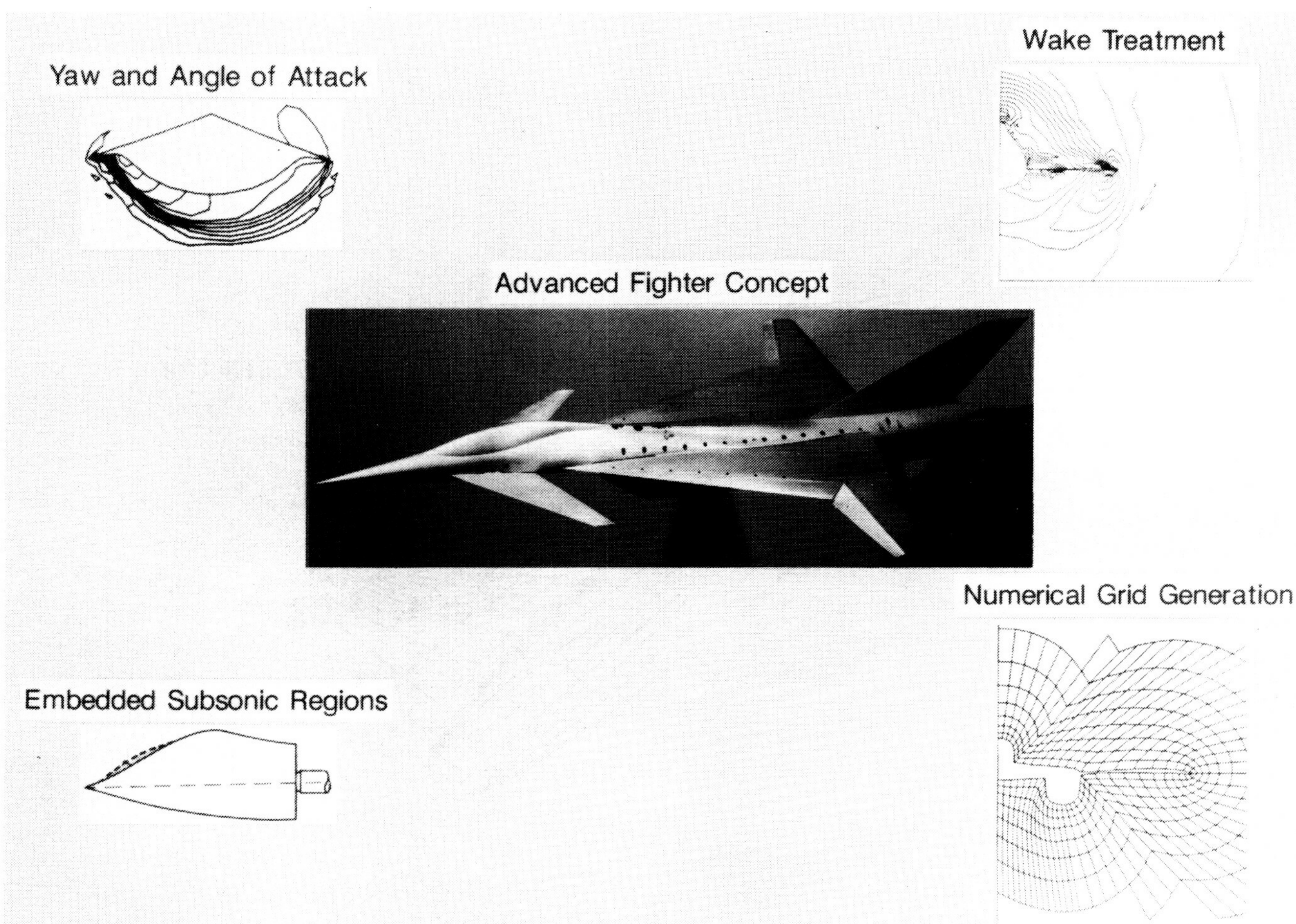
PRESENT ANALYSIS TECHNIQUES

Currently, there are a wide variety of aerodynamic prediction techniques used for the analysis of supersonic flow over aircraft configurations. These methods range from techniques based on supersonic linear theory to nonlinear analysis methods based on the solution of the Euler or Navier-Stokes equations. Linearized methods are commonly used to analyze complex configurations but are frequently unable to provide accurate results in complex flow regions, particularly at high angle of attack and/or high supersonic Mach numbers, due to the restrictions of linearized theory. The more sophisticated Euler and Navier-Stokes solvers can provide accurate results even in complex flow regions but are not yet at a stage where they can be used as practical prediction techniques for complex aircraft designs. The development of efficient full potential solvers now permits accurate nonlinear aerodynamic analysis of supersonic flow over complex aircraft geometries.

- Linearized Analysis Methods
- Potential Flow Solvers
  - Inviscid
  - Irrotational
  - Isentropic
  - "Weak" Shocks
- Euler/Navier-Stokes Solvers
  - Inviscid/Viscous
  - Rotational
  - Non-Isentropic
  - Rankine-Hugoniot Shock

SUPERSONIC FULL POTENTIAL ANALYSIS METHOD

The underlying philosophy in developing the method strives for ease of implementation while producing useful output for those working on current aerodynamic problems. Steps have been taken throughout the code development process to ensure geometric generality and ease of input necessary to execute the code. This led to the separation of the equation solution procedure and the gridding process. A body-fitted grid system is generated from the geometric definition of the configuration using a numerical grid generation subroutine. To ensure geometric generality, many other features have been incorporated into the code for analysis of complex aircraft shapes. Embedded subsonic regions, which often exist on aircraft at low supersonic Mach numbers, can now be analyzed using a relaxation technique built into the code. Wakes behind lifting surfaces and their effect on downstream lifting surfaces are accounted for in the solution. To assess a vehicle's performance at many flow conditions, the method allows analysis at angles of yaw and/or angle of attack.



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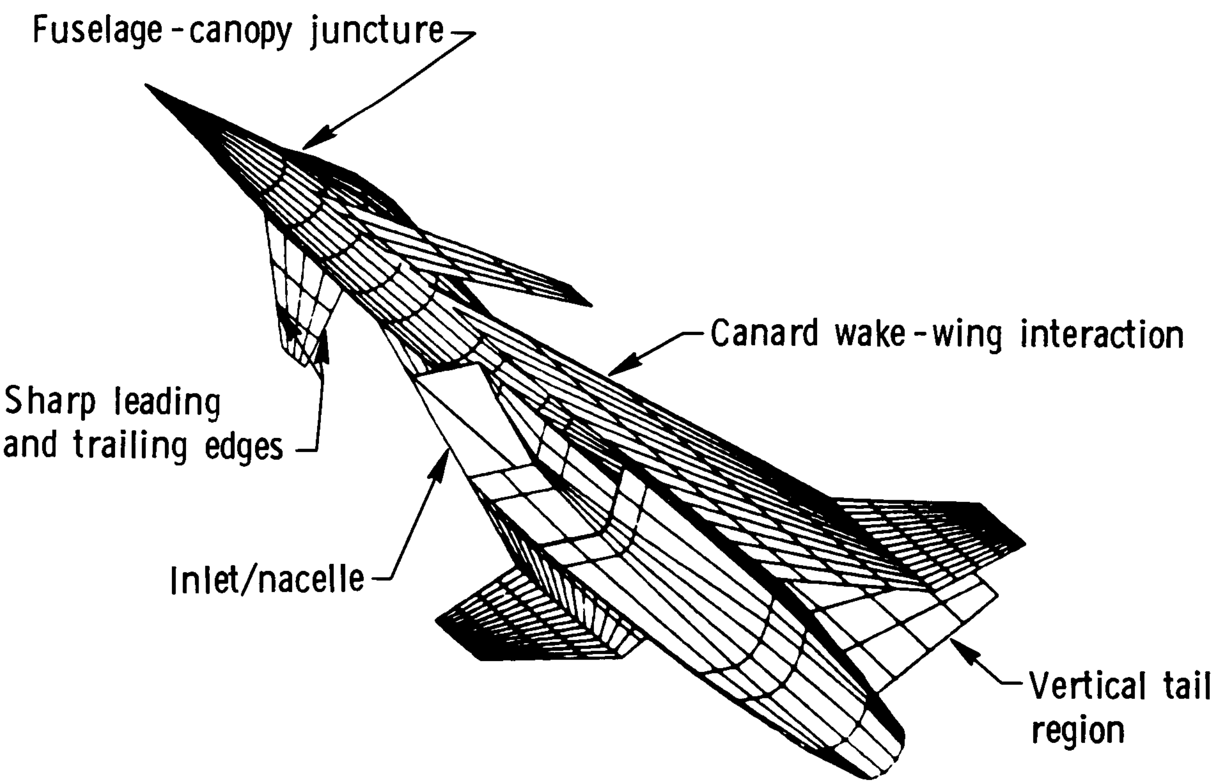
ANALYZING A SUPERSONIC FIGHTER CONFIGURATION

Problem Areas

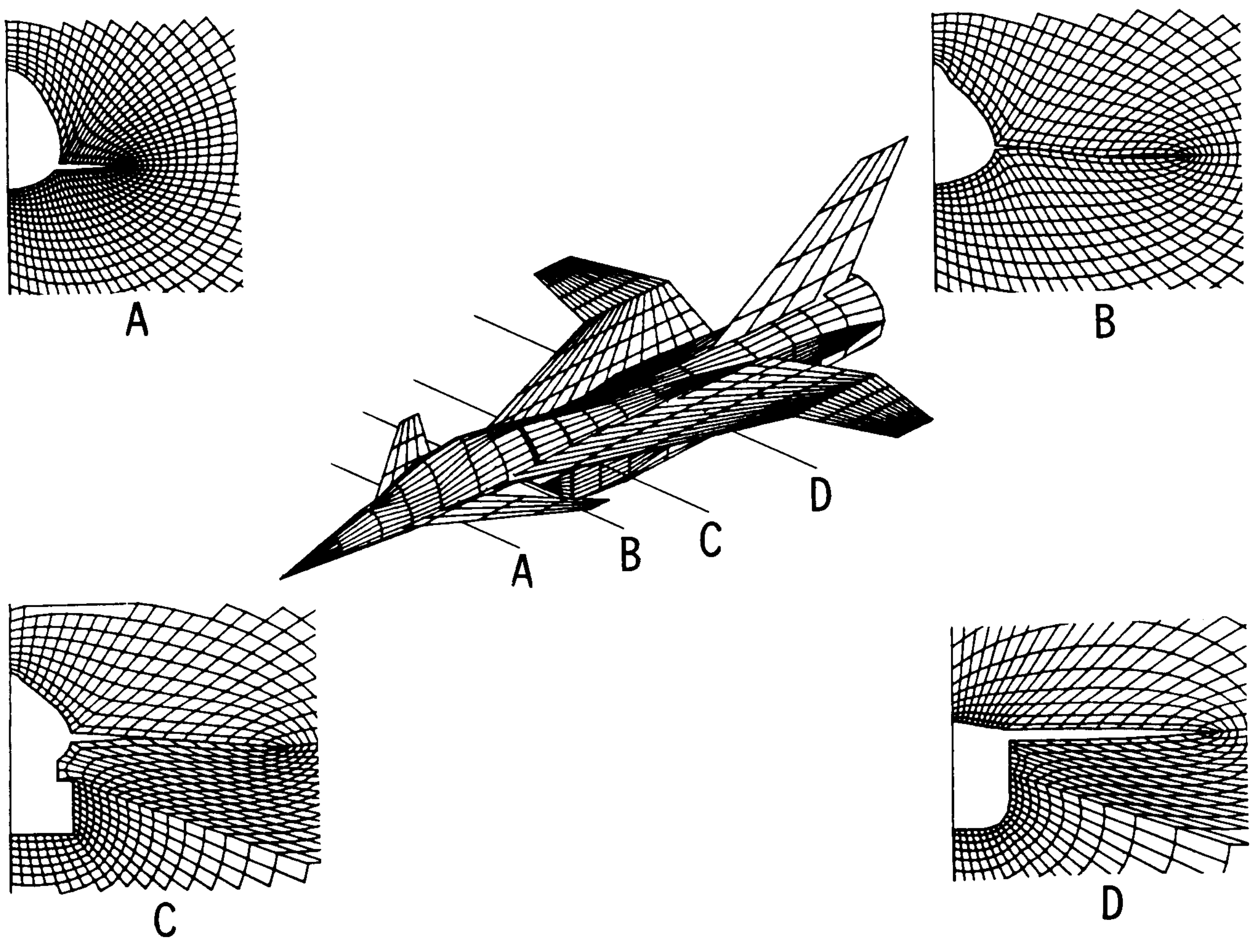
Many aircraft concepts are often difficult to analyze due to the geometric complexity of the configuration. Shown is a wire frame model of a Langley-developed fighter concept that has been analyzed with the full potential code. Before this configuration was analyzed, certain problem areas were identified and prompted the development of many of the enhancements discussed in the previous figure. At low supersonic Mach numbers the fuselage-canopy juncture region is an area where a subsonic pocket of flow may occur. Without the embedded subsonic flow option, a subsonic region of flow would terminate the solution process. Another area that must be addressed is configurations with multiple lifting surfaces and trailing wakes that influence downstream aircraft components. A recent modification enables the researcher to analyze configurations with wing-mounted and centerline-mounted nacelles.



SUPERSONIC FIGHTER CONFIGURATION

Computational Grids

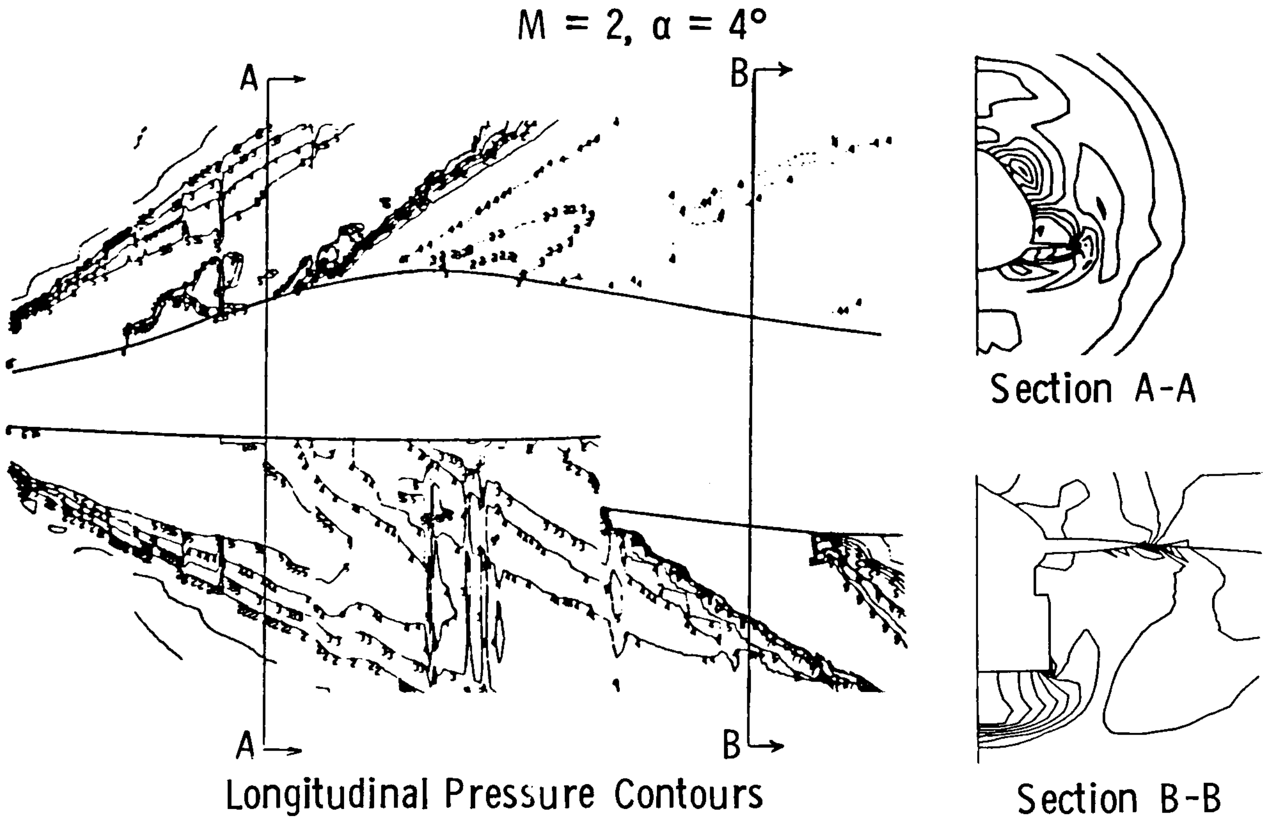
The separation of the gridding and the flow field analysis portion of the code allows verification of the grid system before proceeding with the solution. This has proven invaluable in detecting and correcting possible grid problems or errors in the geometric definition of the model. This figure shows four computational grids used in the analysis of the Langley fighter concept. They also illustrate the geometric complexity that can be accommodated with this code.



SUPERSONIC FIGHTER CONCEPT

Flow Field Solution

Results on the Langley supersonic fighter configuration at M = 2, $\alpha = 4^{o}$ are shown on this figure. These results are in the form of pressure contours in the flow field. Longitudinal pressure contours are plotted on the plane of symmetry. The major characteristics of the flow are evident in this view. Two cross-sectional pressure contour plots are shown on the right of the figure. Section A-A is at a forward location which includes the canard, and the canard shock off the sharp leading-edge is evident in the contour plot. The shock off the nacelle is evident in the contour plot at Section B-B, which is just downstream of the inlet face.

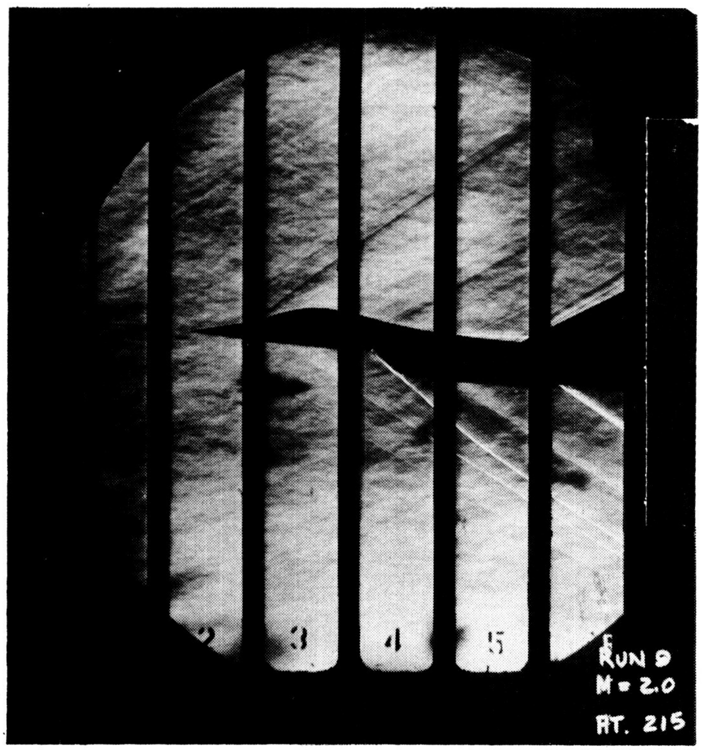


Longitudinal Pressure Contours

SUPERSONIC FIGHTER CONCEPT

Schlieren Photograph $M = 2$, $\alpha = 4^{\circ}$

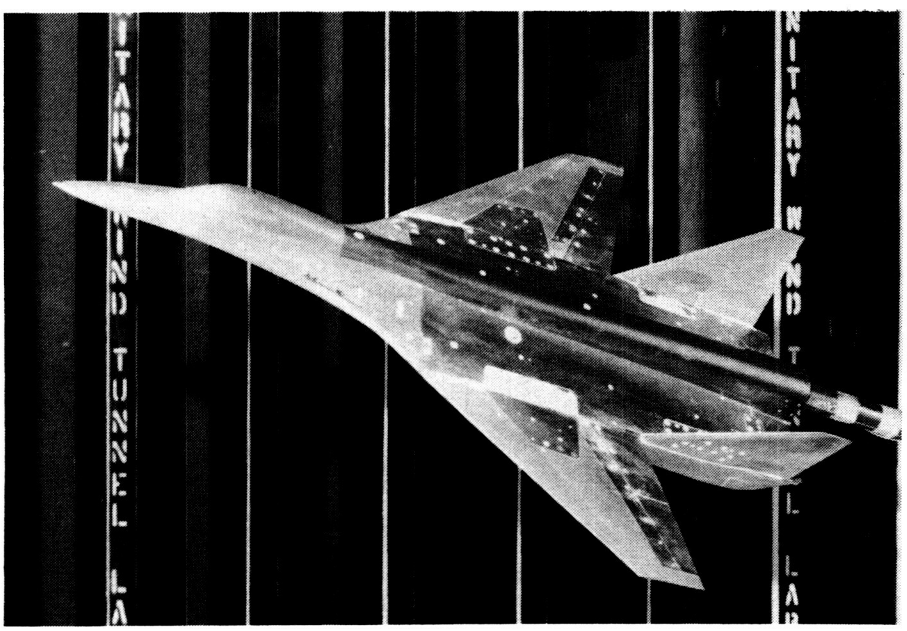
A comparison of the longitudinal pressure contours with a schlieren photograph is helpful in determining the quality of the full potential results. The pressure contours are in good agreement with the flow characteristics seen in the schlieren photograph.



ROCKWELL ADVANCED FIGHTER CONCEPT

The High-Speed Aerodynamics Division at NASA Langley and the Rockwell International Corporation are engaged in a cooperative effort to demonstrate the applicability of new nonlinear analysis/design techniques for advanced supersonic wing design. The effort was aimed at demonstrating the ability of a nonlinear analysis technique based on solution of the supersonic potential flow equations. The cooperative program included both the aerodynamic design and testing of several outboard wing panels for an advanced supersonic fighter concept. The aerodynamic design of the wing panels was a two step process. Standard linearized theory techniques were used to determine a design point(s) twist and camber distribution(s). This was followed by an assessment of the flow quality via the potential flow solver. If necessary the surface contours could be modified in an iterative fashion to prevent flow separation over the wing panels. The purpose of the experimental investigation was to determine the effect on supersonic aerodynamic characteristics of increasing wing sweep and provide a data base for code validation.

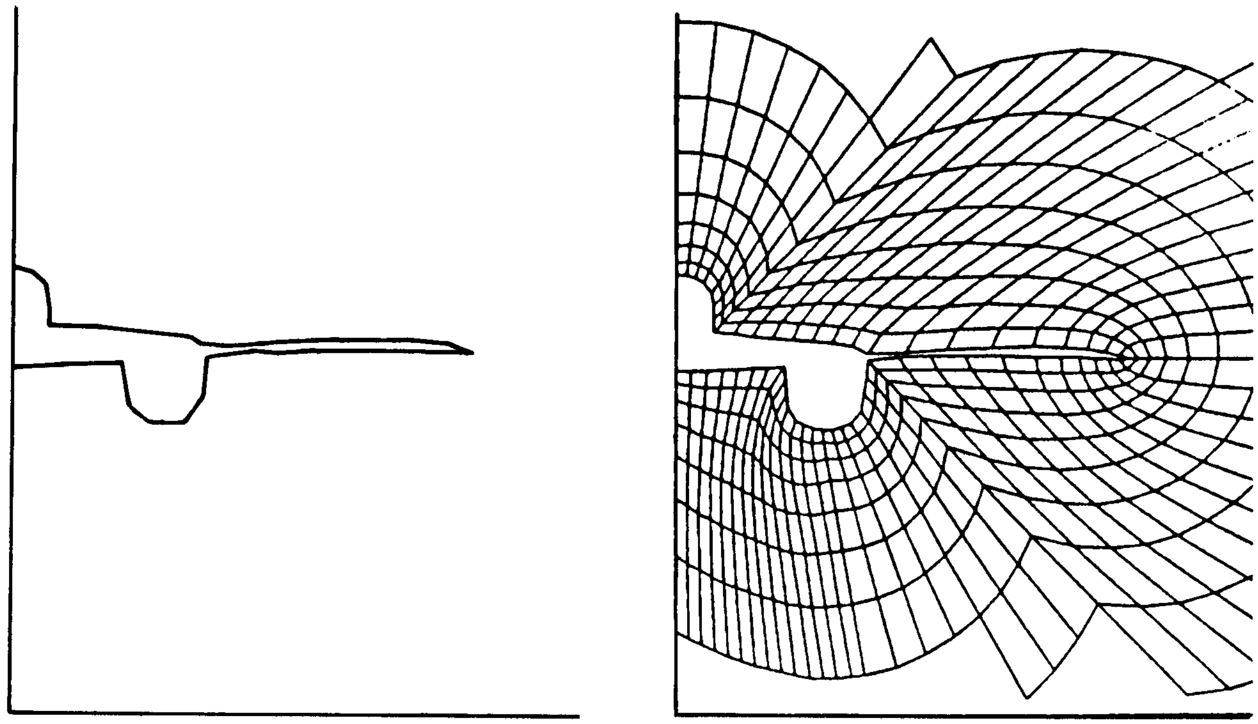
The wind tunnel model is shown installed in the Langley Unitary Plan Wind Tunnel and is a preliminary design version of a Rockwell fighter concept. Five outboard wing panel geometries were tested: a 48° leading-edge sweep baseline; a 55° leading-edge sweep wing with a camber distribution biased toward a maneuver lift coefficient for Mach 1.6; an uncambered 55° reference wing; and two redesigned 48° leading-edge sweep wing panels (multi-operating point wings - subsonic, transonic, supersonic). The redesigned 48° wings represented a low twist cruise wing (M = 1.5) and a high twist maneuver concept (M = 1.6). Testing was performed at Mach numbers of 1.5 to 2.5. Both longitudinal and lateral aerodynamic force characteristics were measured. Surface pressure data were obtained at Mach numbers of 1.5 to 1.8 for the 55° cambered wing and the 48° low and high twist wings.



ROCKWELL ADVANCED FIGHTER CONCEPT

Cross Section and Grid at 65-Percent Body Station

As stated before, it is best to study representative computational grids on the configuration before proceeding with the flow field analysis. This figure is an example of a cross section and computational grid used in the analysis of the Rockwell fighter concept. Notice that the Rockwell fighter concept has a wing-mounted nacelle while the Langley fighter had a centerline-mounted nacelle.

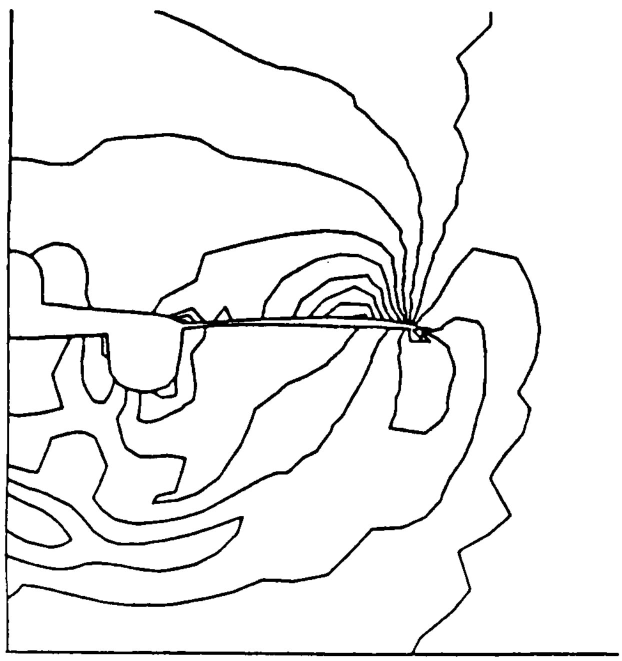


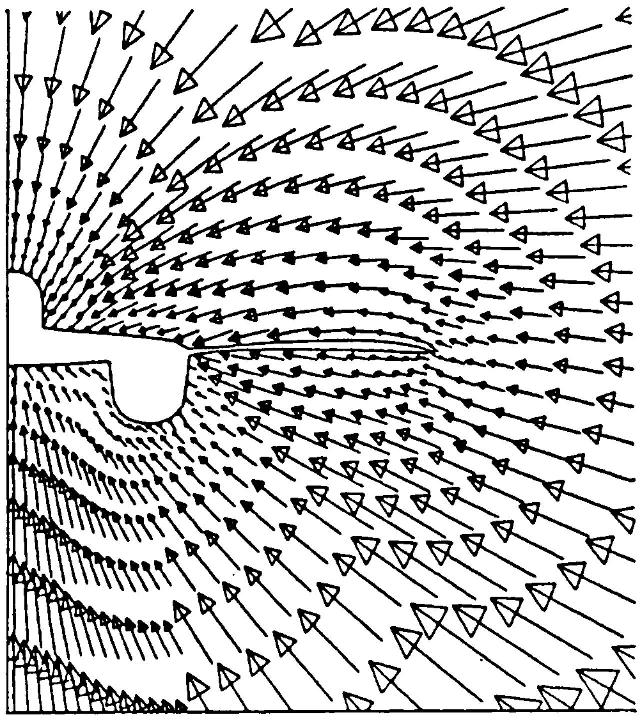
ROCKWELL ADVANCED FIGHTER CONCEPT

Pressure Contours and Crossflow Velocity Vectors

Results from the full potential analysis of a configuration can be presented in many ways. Pressure contours and crossflow velocity vector displays are useful to evaluate the flow structure about the configuration. The pressure contours and crossflow velocity vectors from the analysis of the Rockwell fighter concept at $M_\infty = 1.6$, $\alpha = 4.46°$ are shown here. The circular shock below the wing of the fighter, which is caused by the nacelle, shows up well in the crossflow pressure contour plot.

$M_\infty = 1.6$, $\alpha = 4.46°$

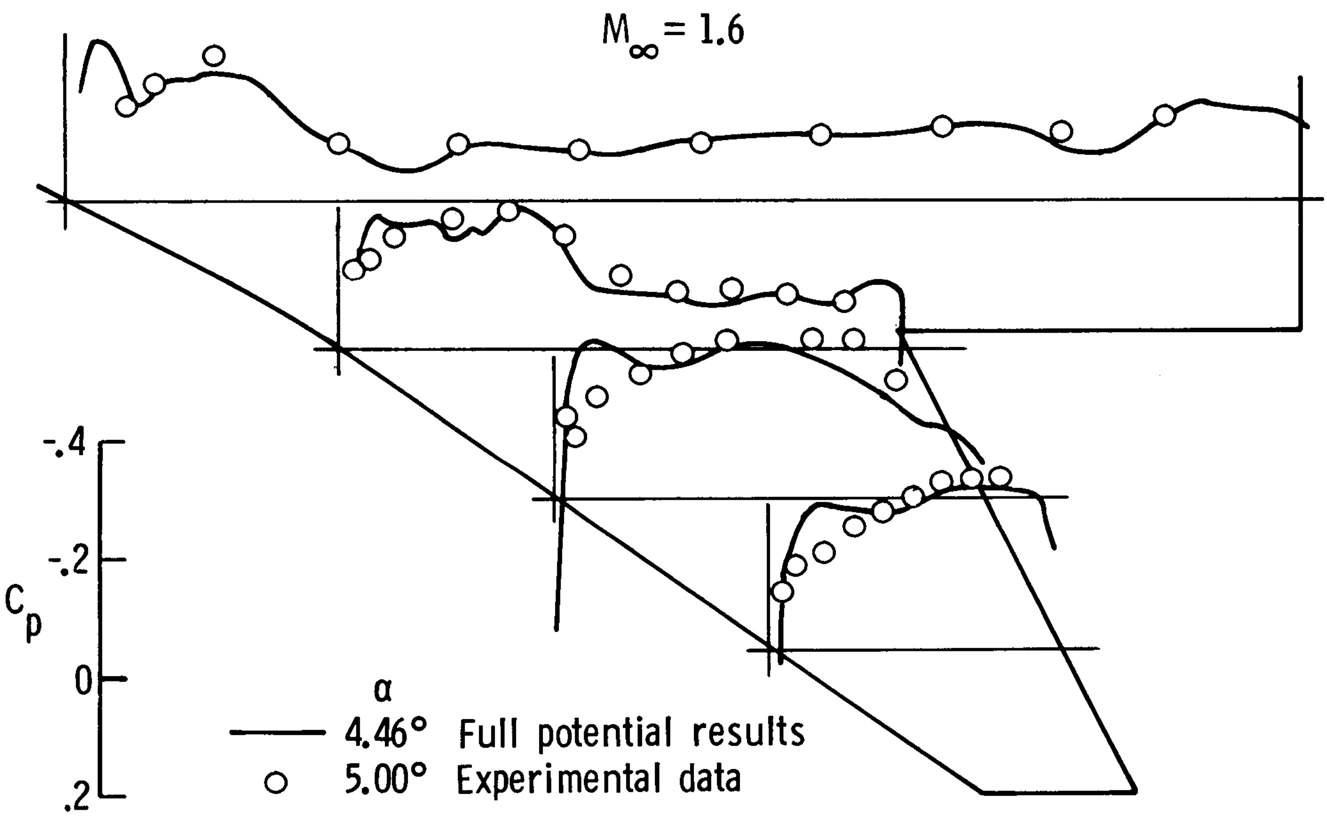




ROCKWELL FIGHTER CONFIGURATION

Upper Surface Pressure Distribution

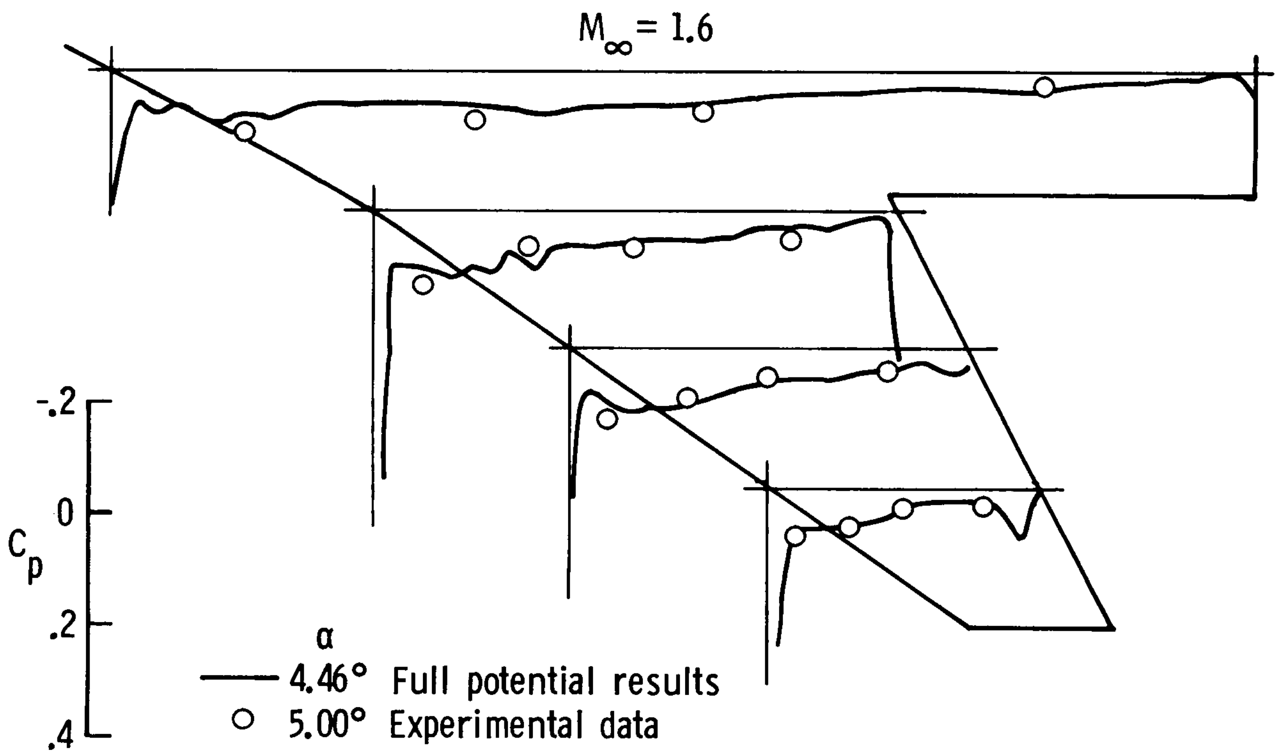
The potential flow predictions and the measured surface pressure data for the twisted and cambered 55° sweep configuration at $M_\infty = 1.6$ (nacelle off) are shown in the figure. Upper surface pressure comparisons are made at four span stations. Again the agreement is quite good even near the leading edge. The comparisons are not quite as good at the leading edge for the two outboard span stations on the upper surface of the wing. This is a result of poor grid resolution near the outboard LE. To improve the results at these stations more grid points must be used near the leading edge as well as employing a smaller marching step size in this region of the calculation.



ROCKWELL FIGHTER CONFIGURATION

Lower Surface Pressure Distribution

The lower surface pressure comparisons for the 55° sweep configuration at $M_\infty = 1.6$ are also shown in the comparison between theory and experiment and are very good. Similar good agreement has been observed for the 48° sweep wing tested earlier in the Rockwell Trisonic facility prior to the UPWT test. Research (Kenneth M. Jones and Barrett L. Shrout, NASA Langley) is in preparation which will include the complete force and pressure data for the five wing panel geometries tested. These data should provide a strong data base for advanced supersonic fighter designs.



ROCKWELL FIGHTER CONFIGURATION

Force Comparisons

Comparisons of the analysis and the experimental force data for the twisted and cambered 55° sweep wing panel are presented in the figure. The agreement between the potential flow analysis and the UPWT data at the design point ($M = 1.6$, $C_L = 0.32$, $\alpha = 4.46^0$) is quite good. To achieve the desired C_L of 0.32 the angle-of-attack must be increased to 5.25° with a corresponding performance penalty (L/D reduction). The 55° twist and camber distribution from the linear design code was not refined via the potential flow code since the flow quality was deemed satisfactory. However, if the performance loss is important, then a refinement of the twist and camber distribution followed by reanalysis with the potential flow code should be investigated to more closely achieve the design goal.

M = 1.6, Nacelle Off

	Linear Analysis	Full Potential Analysis	UPWT Data	UPWT Data
α	4.46	4.46	4.46	5.25
C_L	0.32	0.292	0.283	0.32
C_D	0.0438	0.0402	0.0398	0.045
C_M	-0.061	-0.0565	-0.0530	
L/D	7.31	7.26	7.11	7.0

CONCLUDING REMARKS

A supersonic potential flow solver has been developed to analyze the flow over complex realistic aircraft geometries. Enhancements to the method have been made to accommodate regions of subsonic flow, the effect of trailing wakes on other aircraft components (wing, body, tail, etc), and the modeling/gridding of complete configurations. Validation of the method has been demonstrated by comparisons with experimental aerodynamic force and surface pressure measurements. The predicted results are in very good agreement with the experimental data. The bibliography contains additional information on the use of the potential flow code to predict the aerodynamics of high-speed wing/body configurations, waverider concepts, TAV, and the Space Shuttle orbiter package.

Further work is planned to investigate the quality of the flow field results obtained with the potential code. This capability is important in assessing inlet and control surface placement. Additional analysis of supersonic aircraft concepts is planned to complete the validation of the method and the gridding package. A vectorized version of the code is under development.

Future code development will be in the area of a supersonic Euler solver which is compatible with the geometry and gridding package employed in the present technique. The Euler solver will overcome the isentropic restrictions of the potential method and hopefully retain the ability to treat complex aircraft geometries.

- A Supersonic Full Potential Method Has Been Applied To The Analysis Of Realistic Aircraft Configurations
  - Good Agreement With Experimental Data
    - Surface Pressure Distributions
    - Aerodynamic Force Estimates
- Additional Validation Of Method
  - Investigate Quality Of Results In The Flow Field
  - Analyze Additional Complex Geometry Configurations
  - Vectorize Code
- Future Work
  - Investigate Supersonic Euler Solver

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