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REPORT NO. NADC-81051-60

VALIDATION STUDY OF THE V/STOL
AERODYNAMICS AND STABILITY AND CONTROL MANUAL

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31 MARCH 1981

FINAL REPORT

AIRTASK NO. A03V-320D/001B/0F41-400-000

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

Prepared for
NAVAL AIR SYSTEMS COMMAND
Department of the Navy
Washington, D. C. 20361

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APPROVED BY: J. R. Woods DATE: 5/5/81

J. R. WOODS
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READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NADC-81051-60

2. GOVT ACCESSION NO.: AD-A099 236

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): Validation Study of the V/STOL Aerodynamics and Stability and Control Manual

5. TYPE OF REPORT & PERIOD COVERED: Final Report

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): M. M. Walters

8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Aircraft & Crew Systems Technology Directorate
Naval Air Development Center (Code 60)
Warminster, PA 18974

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
AIRTASK NO. A03V-320D/001B/0F41-400-000

11. CONTROLLING OFFICE NAME AND ADDRESS:
Naval Air Systems Command
Department of the Navy
Washington, DC 20361

12. REPORT DATE: 31 Mar[redacted]81

13. NUMBER OF PAGES:

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):
Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
V/STOL Aerodynamics
Induced Lift
Hover
Transition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):
The mathods contained in the VSTOL Aerodynamics and Stability and Control Manual for the prediction of propulsion induced aerodynamics of V/STOL aircraft in the hover and transition flight regimes were validated against four different V/STOL aircraft configuration. Manual prediction of the induced lift and pitching moment resulted in good correlation with test data for all configurations.

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SUMMARY

The methods contained in the V/STOL Aerodynamics and Stability and Control Manual for the prediction of propulsion induced aerodynamics of V/STOL aircraft in the hover and transition flight regimes were validated against four different V/STOL aircraft configurations. The methods were validated for flight conditions of varying freestream-to-jet velocity ratio, angle of attack, and height above the ground along with configuration variations such as number and location of the jets, wing height, nozzle pressure ratio and lift improvement devices. Manual prediction of the induced lift and total (unpowered plus induced) lift and pitching moment resulted in good correlation with test data for all configurations.

LIST OF SYMBOLS

A - Aspect Ratio

d - Jet exit diameter

d_e - Equivalent diameter

$\overline{D}$ - Mean Planform Diameter

h - Height

h' - Height below which positive lifting pressures due to the fountain are experienced

L - Lift

L_F, L_2, L_3 - Fountain lift

L_s - Suckdown

L_1 - Multiple jet suckdown increment

N - Number of jets and fountains in multiple jet configurations

p - Ambient static pressure

p_n - Jet total pressure

S - Planform area

V_e - Effective velocity, $\frac{V_\infty}{V_j}$

Subscripts

- i - Individual jets
- WA - Thrust weighted average
- ∞ - Conditions at infinity

Mathematical Symbol

- Δ - Incremental quantity

LIST OF FIGURES

LIST OF FIGURES (Continued)

INTRODUCTION

The development of the V/STOL Aerodynamics and Stability and Control Manual at the Naval Air Development Center involves the compilation of semi-empirical methods to predict the propulsion induced aerodynamics of V/STOL aircraft in the hover and transition flight regimes in and out of ground effect. The empirical bases of these methods results in inherent limitations associated with the extent of the test data base and/or use of simple models or model components in the test programs. As a result, verification of the adequacy and limitations of the methods when applied to fully detailed preliminary design configurations is needed as a basis for confidence in the estimated results. The validation effort reported herein was designed to satisfy this need.

Four V/STOL configurations for which sufficient test data existed were used in comparing Manual predictions for both the hover and transition flight regimes. These configurations represent simple and more realistic V/STOL designs of one, two, three, and four-jet arrangements. Manual methods were used to predict the aerodynamics of these configurations for flight conditions of varying freestream to jet-velocity ratio, angle of attack and height above the ground. The induced lift was calculated for all configurations along with the total lift and pitching moment for two configurations for which appropriate data was available.

The capability for predicting the increased lift due to Lift Improvement Devices (LID's) was also exercised for one configuration appropriately outfitted. Additionally, a sensitivity study was conducted for two main parameters in the calculations of hover aerodynamics - the nozzle pressure ratio (NPR) and the planform mean diameter ($\overline{D}$).

Results of the comparisons between test data and Manual predictions are presented indicating the Manual's prediction capability along with recommendations for improvement. Brief descriptions of all models are also included with a summary given of each prediction method used.

APPROACH

The approach taken in planning the validation effort was to exercise the methods presently contained in the Manual which were applicable to hover and transition flight. These methods were applied to as many realistic V/STOL configurations for which sufficient data existed. It was hoped that the selected configurations would be of sufficiently different design as to determine the flexibility of each method in treating geometric variations including wing aspect ratio, planform-to-jet area ratio, number and location of jets, wing height, and use of lift improvement devices. Various flight conditions were also to be used to validate the capability of each method for variations in freestream-to-jet velocity ratio, angle of attack, and height above the ground. Since the methods presently contained in the Manual are restricted to longitudinal aerodynamics, this validation will be similarly limited. Methods for lateral-directional analysis are planned for incorporation in later revisions of the Manual.

The initial step in the validation effort was to calculate the induced lift for each configuration using both of the hover methods and the transition method. The induced lift was calculated for heights above the ground which varied from .75 to 8 jet diameters, but was restricted to zero angle of attack. Of the many data sources available only a few include angle of attack as a test parameter and of those only reference (4) indicates any variation of the induced effects due to angle of attack. As a result, the methods for both hover and transition assume no variation with angle of attack.

Following the calculation of the induced effects, the unpowered aerodynamics were calculated for the two configurations in references (2) and (4) using the methods contained in the first section of the Manual. These calculations were done for various angles of attack based upon the data available for the particular configuration. These lift and pitching moment data were then combined with the induced effects, resulting in the total lift and pitching moment. Comparisons with data were made at each step of the calculations to indicate the Manual capability in predicting each component as well as the total lift and pitching moment.

A sensitivity study was also conducted for the two main parameters in the equations for hover aerodynamics - the planform mean diameter $(\bar{D})$ and the nozzle pressure ratio (NPR). These parameters are the main inputs to the hover equations and most likely sources of error since $\bar{D}$ is calculated graphically and NPR, if not directly given, usually has to be estimated based on inadequate data. A brief description of each of the configurations follows along with a summary of the individual methods used in calculating the hover and transition propulsion induced aerodynamics.

MODEL DESCRIPTIONS

The four configurations used in the validation effort are shown in Figures 1 through 4. The first configuration used, Figure 1, represents a relatively simple design of a supersonic, clipped wing V/STOL aircraft taken from reference (2). This model was used in a test program to determine the effects of various jet numbers, arrangements, and shapes on a wing/body configuration. This model was used in the single- and four-jet arrangement to calculate the height effects on induced lift during hover, and the alpha effects on the total lift and pitching moment in transition flight over an effective velocity ratio, Ve, range of 0.05 to 0.25. This configuration was selected for its relatively simplistic design to be used as the first check of Manual methods.

The second configuration, shown in Figure 2 represents a recent McDonnell Douglas design for a subsonic V/STOL aircraft with swept, tapered wings, reference 3. This configuration was selected because of the three-jet nose-fan arrangement in a realistic V/STOL design and the availability of test data for both fully contoured and flat plate models. Height effects on the induced lift were calculated for this model along with the effects of Lift Improvement Devices.

Reference (3) also contained data for a supersonic V/STOL design which was used in a two- and three-jet configuration as shown in Figure 3. As indicated, a flat plate representation of the design was tested and thus used

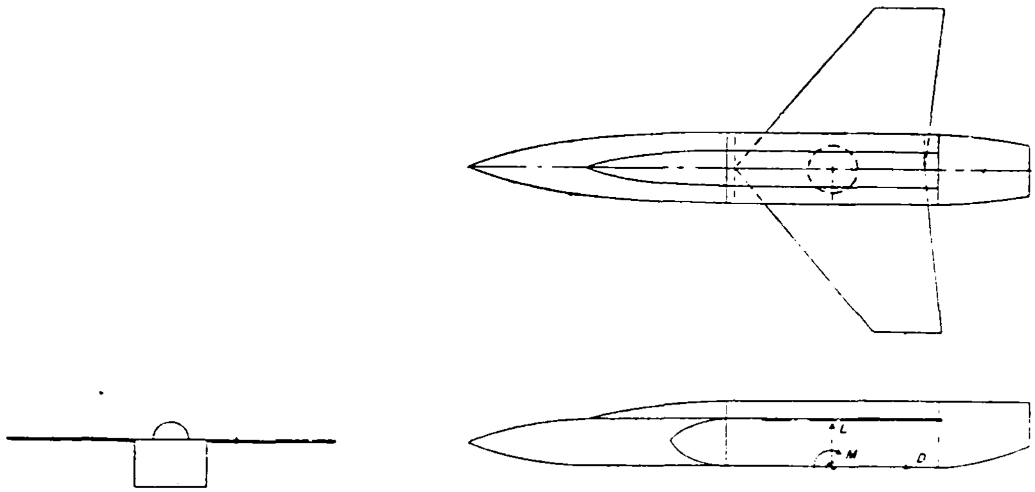


FIGURE 1. Three View of a High Wing Supersonic Wind Tunnel Test V/STOL Model

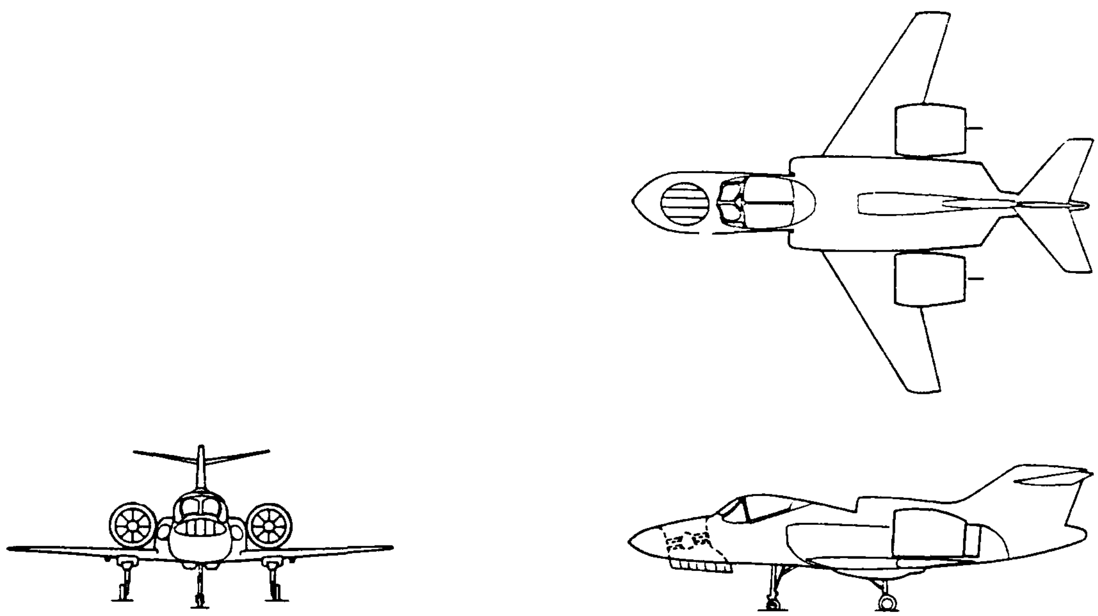
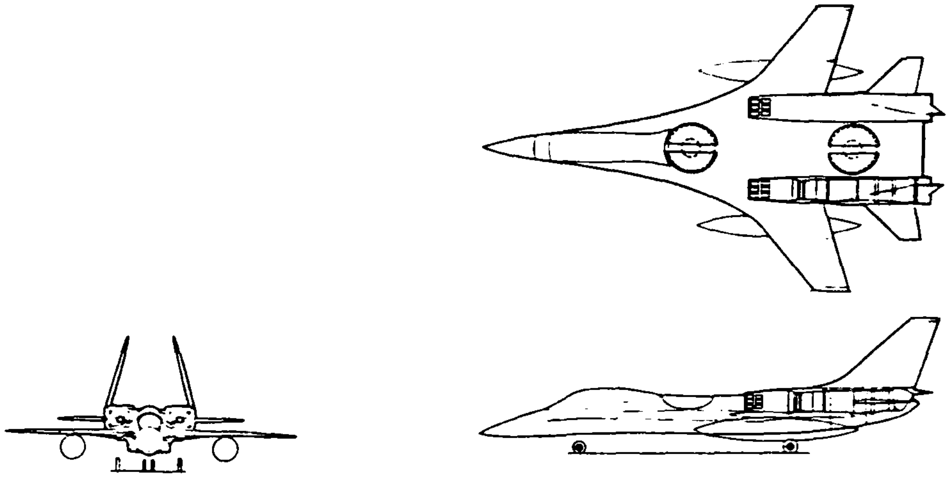
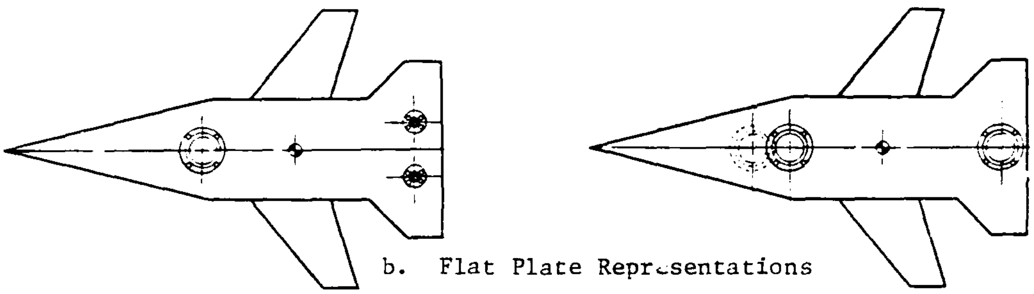


FIGURE 2. Three View of a Low Wing Subsonic V/STOL Configuration



a. Fully Contoured Model



b. Flat Plate Representations

FIGURE 3. Three View of a Low Wing Supersonic V/STOL Configuration

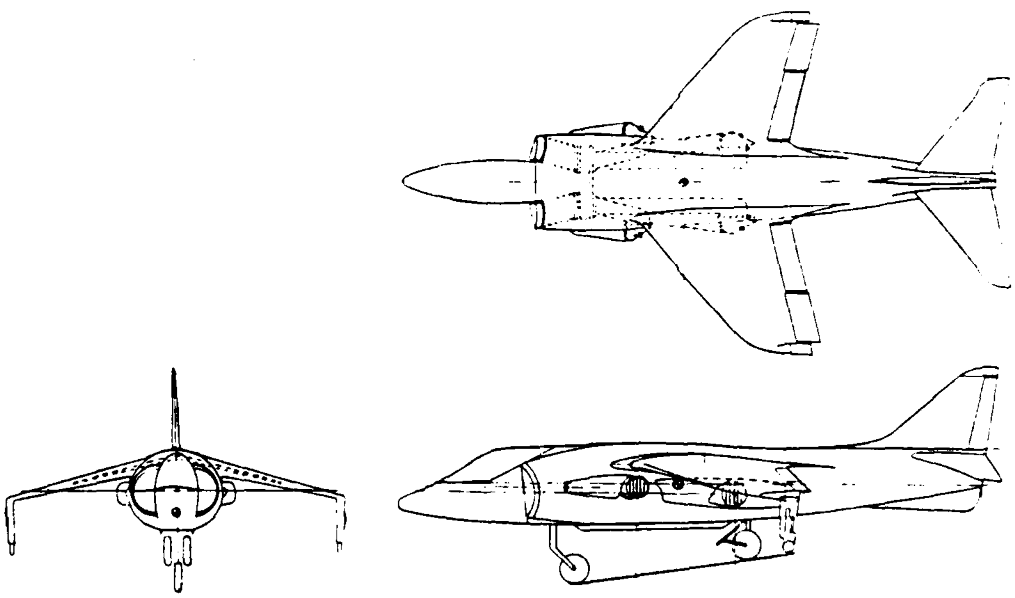


FIGURE 4. Three View of the High Wing Supersonic AV-6A Kestral V/STOL Aircraft

for the validation for both jet arrangements. This model was selected because of the large planform to jet area ratio which results in a highly suckdown oriented design. The height effects on induced lift were calculated for this model for both jet arrangements.

The KESTRAL (AV-6A), reference (4), a clipped delta wing, four-jet V/STOL design shown in Figure 4 was the final configuration used for validation and represents the fore-runner of the only operational V/STOL aircraft against which the Manual could be exercised. Although insufficient data existed for comparison in hovering flight, the total lift and pitching moment in transition flight for various angles of attack were calculated and compared with data. Being the only operational design among the models used, favorable correlation of calculated and test data relative to the other models is highly desirable for developing confidence in the Manual prediction capability.

METHODS SUMMARY

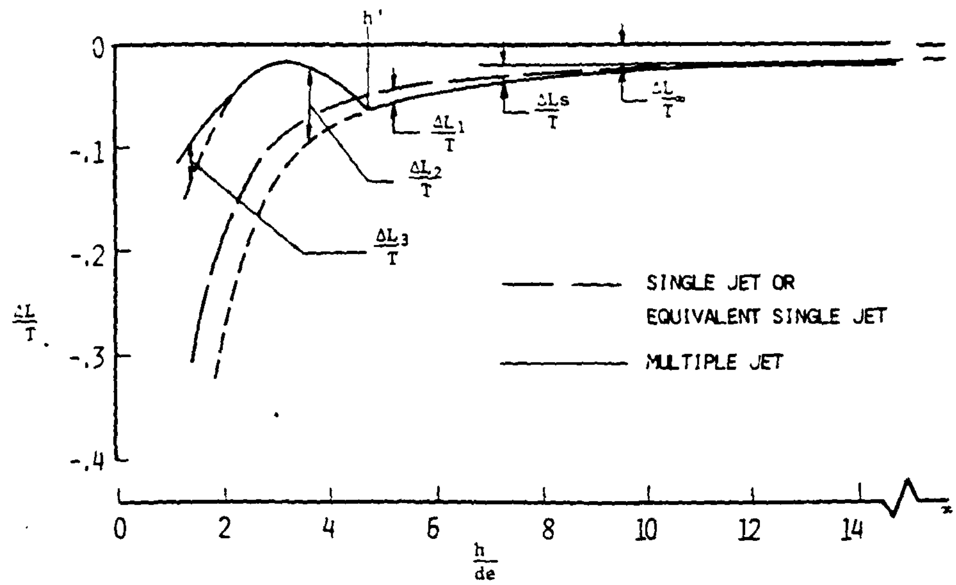
The methods used in the validation effort consist of two independently derived hover methods and one transition method. The two hover methods are similar in their dependance upon $\bar{D}$ and nozzle pressure ratio but differ in their coefficients due to the difference in data bases.

The first hover method, as summarized in Figure 5 and developed in reference (5), consists of separating the suckdown and fountain calculations with a simple summation of the two components to obtain the total induced effect. The suckdown calculations are split into two components - the out of ground effect suckdown, $\frac{\Delta L_\infty}{T}$, and the in ground effect suckdown, $\frac{\Delta L_S}{T}$. For a multiple-jet configuration, an equivalent single-jet is created (equivalent in that the jet exit diameter is the diameter of an area equal to the total jet exit areas in the configuration) with the in and out of ground effect suckdown calculations based on the equivalent jet. A third component, $\frac{\Delta L_1}{T}$ is then added to account for the increased suckdown associated with multiple-jet in ground effect. The fountain effects are accounted for by two terms, $\frac{\Delta L_2}{T}$ and $\frac{\Delta L_3}{T}$, which represent two distinct slopes in a plot of fountain effects data against height above the ground. The remaining equation contained in Figure 5 calculates h', a height below which the positive lifting pressures associated with the fountain are experienced.

The components for the suckdown and fountain and their respective equations form the basis of this method. Additional equations and manipulation of the basic equations are used to determine the effects of LIDs and to account for variations in wing height beyond the wing being coplanar with the fuselage bottom.

Three limitations are inherent with the formulation of this method:

(1) The effects of fuselage roundness are not accounted for, resulting in no differentiation in predictions of configurations with various fuselage contours or between a fully contoured model and its' flat plate representation.



Out of Ground Effect Suckdown

$$\frac{\Delta L_\infty}{T} = -\sqrt{\frac{S}{A}}\ (.016)\left(\frac{P_N}{p}\right)^{-.64}\sqrt{\left(\frac{\partial q/(P_n-p)}{\partial x/de}\right)_{max}\Big/\left(\frac{x}{d_e}\right)_i}$$

or

$$\frac{\Delta L_\infty}{T} = -\sqrt{\frac{S}{A}}\ (.0002528)\left[\left(\frac{P_n}{p}\right)^{-.64} \Sigma_* \ d/d_e\right]^{1.581}$$

In-Ground Effect Suckdown Component

$$\frac{\Delta L_s}{T} = -.015\left[\frac{h/d_e}{\left(\frac{\bar{D}}{d_e}-1\right)}\right]^{-\left[2.2-.24\left(\frac{P_n}{p}-1\right)\right]}$$

$$\frac{\Delta L_1}{T} = .5\,\frac{\Delta L_s}{T}$$

Fountain Component

$$\frac{\Delta L_2}{T} = \left(\frac{h'}{D}-\frac{h}{D}\right).135\ N^2\theta$$

Note: $\frac{\Delta L_2}{T} = 0$ when $h > h'$

also $\frac{\Delta L_2}{T} = 0$ for two jet configurations

$$\frac{h'}{D} = 1.22\,\frac{1}{N}\left(\frac{D'}{d_e}\right)^{.65}$$

$$\frac{\Delta L_3}{T} = 10^{\left(.9-10\frac{h}{D}\right)}$$

FIGURE 5. Schematic and Equations for Calculating Jet-Induced Lift in Hover - Method 1

(2) jet inclination is restricted to 90°
(3) jet exit shape must be circular

The second method applicable to propulsion induced aerodynamics in hover, as summarized in Figure 6, was taken from reference (6). Similar to the first method, the total induced effects are separated into the suckdown and the fountain effects. The suckdown components are dependent upon $\bar{D}$, a non-dimensionalized height, coefficients derived from the data base, and the nozzle pressure ratio through the suckdown extrapolation coefficient, C_{s_1}.

The fountain effects component is a summation of terms based on the number of jets in the configuration. $\frac{\Delta L_F''}{T}$, $\frac{\Delta L_F'''}{T}$, and $\frac{\Delta L_F''''}{T}$ are the basic fountain effects terms resulting from two, three or four jet fountains respectively. These terms are then adjusted by C_{F_3} based on the merging of the jets, such as the four-jet or three-jet arrangement merging to a two-jet arrangement which ultimately merges to a single jet. The resulting fountain effects represent a two-dimensional induced effect which then becomes a three-dimensional effect by adjustment for fuselage contouring through a fountain extropolation coefficient, C_{F_4}. An additional coefficient, C_{F_5}, accounts for LIDs, if applicable.

This method is more detailed and comprehensive than the previous method. It was developed based on a systematic test program specifically designed to provide a data base for this type of method development. The only limitations of this method are that jet inclination is restricted to 90° and the jet exit shape must be circular.

The method for predicting propulsion induced aerodynamics in transition flight, summarized in Figure 7, was taken from reference (7). This method consists of a basic induced lift term which is then modified by a series of coefficients. The basic lift term represents the induced lift on a 2-D flat plate of aspect ratio equal to one resulting from a normally exhausting, centrally located, circular jet. To convert the 2-D lift to 3-D, coefficients are calculated to adjust for aspect ratio, jet and wing position, nozzle configuration and jet inclination. The pitching moment can then be calculated by multiplying the calculated induced lift on the body or wing by the appropriate arm. This method can also calculate a lift gain which is added to the previous induced lift to account for the jet flap action of jets located near the wing trailing edge. This lift gain is calculated similar to the induced lift with a basic lift term again being adjusted by a series of coefficients to account for jet position, portion of the wing span effected by the jet flap action, and jet deflection.

The limitations of this method, similar to the previous methods, are due to the limited data base upon which the method was formulated. There are three limitations associated with this method:

1. Velocity ratios should be less than 0.3
2. Ground effects are not included limiting analysis to out-of-ground effect operating conditions
3. Most of the available data indicate no effects of angle of attack on the induced aerodynamics, at least in the linear range of the lift curve; since no methods are available to predict induced effects in the stall or post stall region, the method is limited to the unstalled angle of attack range.

Total Induced Lift

$$\frac{\Delta L}{T} = \frac{\Delta L_s}{T} + \frac{\Delta L_F}{T}$$

Suckdown Component

$$\frac{\Delta L_s}{T} = \left(\frac{\Delta L_s - \Delta L_{s\infty}}{T}\right)_{WA} + \left(\frac{\Delta L_{s\infty}}{T}\right)_{WA}$$

$$\frac{\Delta L_s - \Delta L_{s\infty}}{T} = -A\left(\frac{\bar{D}_i}{d_i} + B\right) C_{s_i} \left(\frac{h}{\bar{D}_i - d_i}\right)^{c}$$

$$\frac{\Delta L_{s\infty}}{T} = 0.0667\left(\frac{d_i}{\bar{D}_i} - 0.420\right)$$

Fountain Component

$$\frac{\Delta L_F}{T} = C_{F_2}\left(\frac{\Delta L_F''}{T} \cdot C_{F_3}'' + \frac{\Delta L_F'''}{T} \cdot C_{F_3}'''\right)$$

Coefficients

$C_{s_i} = C_{s_1} \cdot C_{s_2}$

C_{s_1} = 1, reserved for scale effects

C_{s_2} = effect of nozzle pressure ratio

= 1.173 - 0.2495 ln (NPR) $\quad NPR \leq 2.0$
= 1.061 - 0.0889 ln (NPR) $\quad NPR \geq 2.0$

C_{F_1} = 1, reserved for scale effects

C_{F_2} = effect of nozzle pressure ratio

= 0.736 ln (NPR) + 0.481 $\quad NPR \leq 2.0$
= 0.035 ln (NPR) + 0.930 $\quad NPR \geq 2.0$

C_{F_3} = effect of jet merging

C_{F_4} = effect of planform contour

C_{F_5} = effect of lift improvement devices

FIGURE 6. Equations for Calculating Jet-Induced Lift in Hover - Method 2

Transition Induced Lift Loss

$$\left(\frac{\Delta L}{T}\right)_i = \left(\frac{\Delta L}{T}\right)_{i,BASIC} \cdot K_{L,A} \cdot K_{L,X} \cdot K_{L,Z} \cdot K_{L,n} \cdot K_{L,Y} \cdot K_{L,\delta}$$

$\left(\frac{\Delta L}{T}\right)_{i,BASIC}$ - (Basic induced lift component)

Coefficient	Adjusts for
$K_{L,A}$	Aspect ratio
$K_{L,X}$	Jet longitudinal position
$K_{L,Z}$	Jet vertical position
$K_{L,n}$	Jet lateral spacing
$K_{L,Y}$	Nozzle configuration
$K_{L,\delta}$	Jet deflection angle

$$\left(\frac{\Delta L}{T}\right)_{i,TOTAL} = \left(\frac{\Delta L}{T}\right)_{i,BODY} + \left[\left(\frac{\Delta L}{T}\right)_{i,WING} - \left(\frac{\Delta L}{T}\right)_{i,CROSS\ OVER}\right]_{EXPOSED\ WING}$$

FIGURE 7. Equations for Calculating Jet-Induced Lift in Transition

RESULTS

The results of the validation effort are presented in Figure 8 through 16 in the form of plotted comparisons between Manual predictions and test data. There are essentially three groups of comparisons - induced lift in hover which validated the hover methods, Figures 8 through 10; the induced lift in transition which validated the transition method, Figures 11 and 13 (a); and the total (aerodynamic plus induced) lift and pitching moment variation with angle of attack in transition to validate the combining of unpowered and induced aerodynamics, Figures 12 and 13 (b and c).

Figure 8 contains comparisons of induced lift predicted by both hover methods and the test data of reference (2). This suckdown dominated design is predicted very well, with method 2 indicating excellent agreement throughout the entire height range for the single jet configuration and method 1 resulting in similar agreement except at $h/d_e=1$ where the suckdown is over-predicted. However, the results for the four-jet configuration, although reasonable, are not quite as good. Both methods over- and under-predict the data at various heights. Method 1 tends to over-predict the fountain effects compared to the rather small variation due to the fountain as indicated by the data. Method 2 predicts the same muted fountain but at a slightly lower level of suckdown than indicated by the data.

Results of the comparison of induced lift in hover for the two-dimensional low wing supersonic configuration of reference (3) is presented in Figure 9. This configuration, representative of the supersonic V/STOL design in Figure 3, is also a suckdown dominated design because of large planform area surrounding the jets. Method 2 results in an excellent correlation for the two-jet configuration except for the slight under-prediction at $h/d_e=1$. Method 1 tends to slightly under-predict throughout the height range with the exception of $h/d_e=1$ where it reverses and slightly over-predicts the suckdown. Both methods tend to under-predict the suckdown for the three-jet configuration. It should be noted that although a three-jet fountain is created, the suckdown still predominates for this configuration. Although the correlation is not exact, both methods handle this flow situation quite well.

Correlations for the induced lift in hover of the three-jet subsonic V/STOL design of reference (3) is contained in Figure 10. This realistic V/STOL design has a distinct fountain effect as indicated in Figure 3 which was predicted by Method 2 with excellent results. Method 1 accentuates the effect of the fountain at various heights followed by accurate prediction of the suckdown at heights above four jet diameters. Method 2 also accurately predicts the induced lift of the two-dimensional flat plate representation of the same subsonic design as seen in Figure 10. The increased fountain effect realized by the flat undersurface of the model is effectively treated by Method 2. Results are not shown for Method 1 for this configuration because this method cannot differentiate between flat and fully contoured undersurfaces, as explained in the methods summary.

Figure 11 contains the results of validating the transition method for induced lift of the high-wing supersonic configuration of reference (2). Excellent agreement was obtained for both the single- and four-jet arrangement

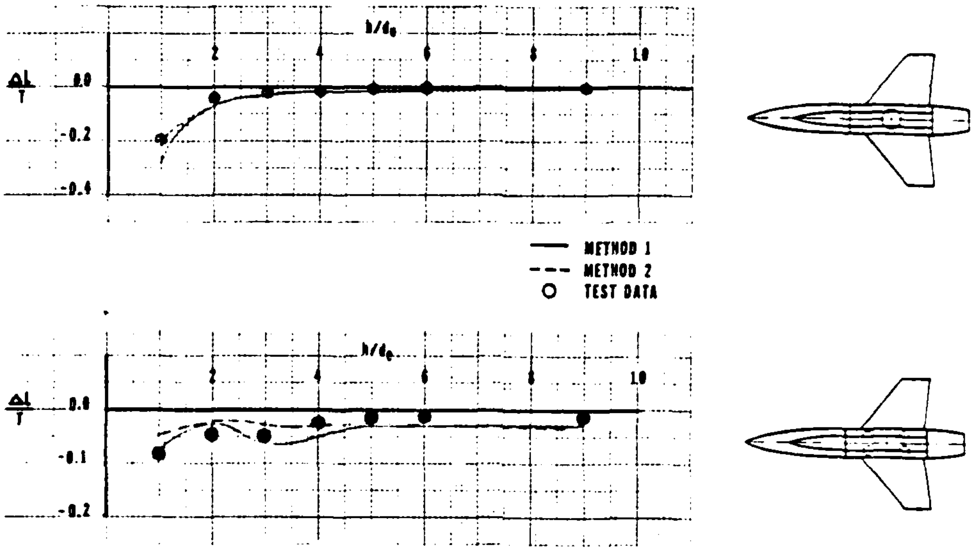


FIGURE 8. Comparison of Prediction and Test Data for Induced Lift of a Single- and Four-Jet High Wing Supersonic Configuration in Hover (reference (2))

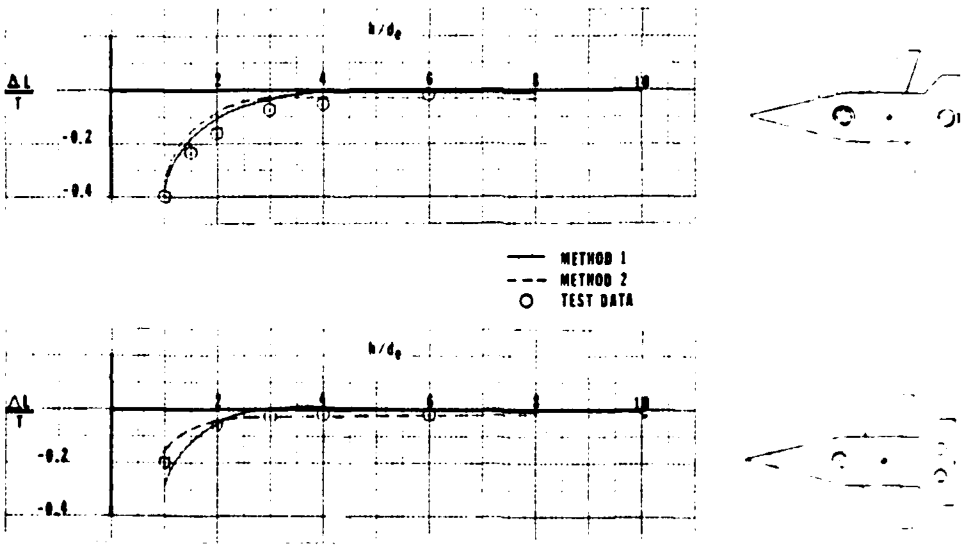


FIGURE 9. Comparison of Prediction and Test Data for Induced Lift of a Two- and Three-Jet Low Wing 2-D Supersonic Configuration in Hover (reference (3))

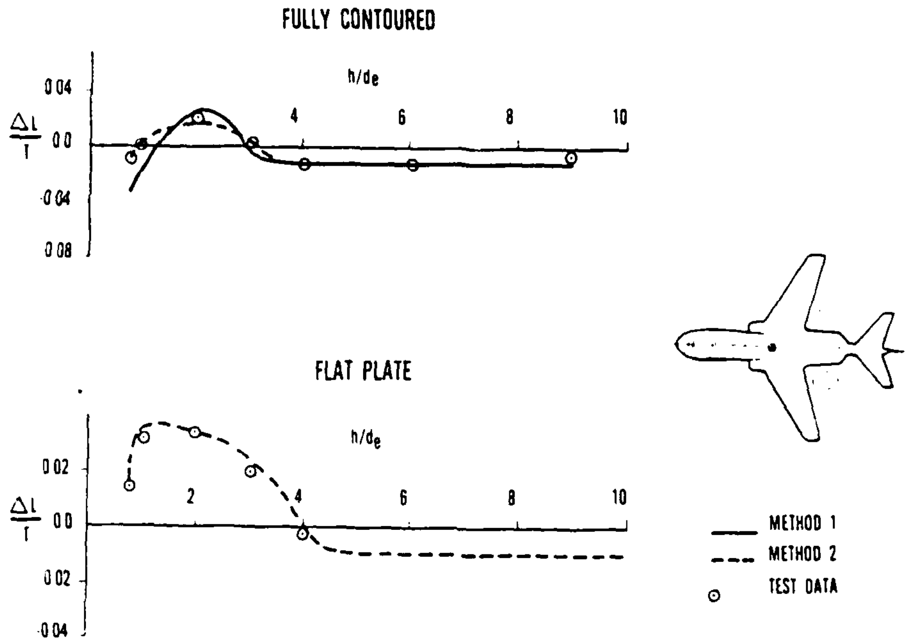


FIGURE 10. Comparison of Prediction and Test Data for Induced Lift of a Three-Jet Low Wing Subsonic Configuration in Hover (reference (3))

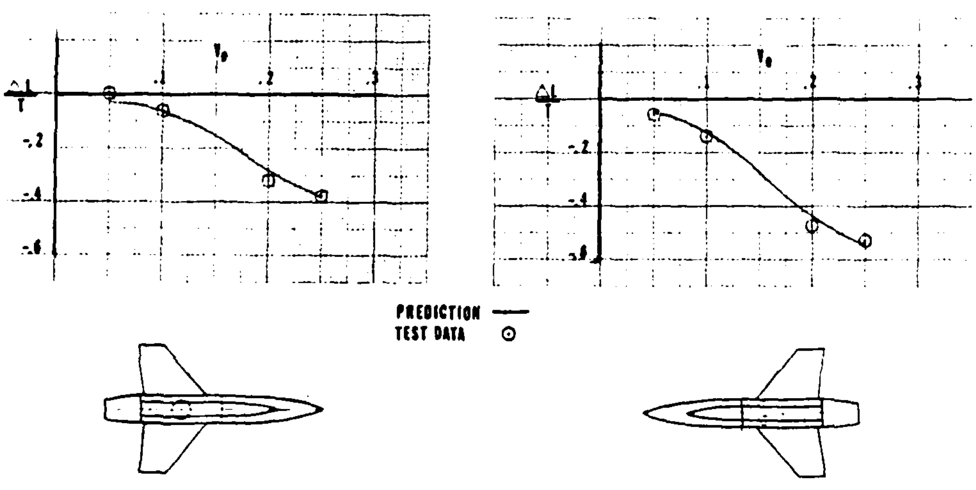


FIGURE 11. Comparison of Prediction and Test Data for Induced Lift of a Single- and Four-Jet High Wing Supersonic Configuration in Transition (reference (2))

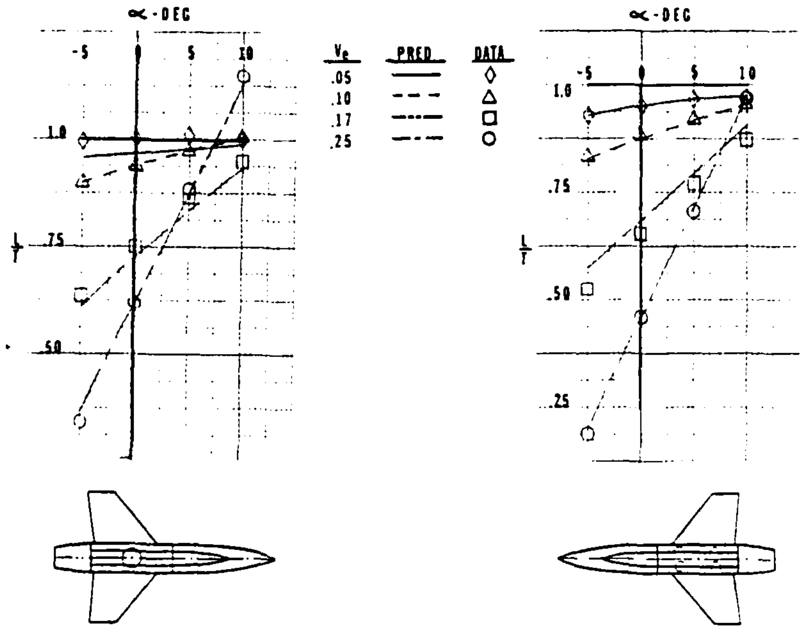
throughout the velocity ratio range. The unpowered lift was then calculated for an angle of attack range of -5° to 10° and combined with the induced effects resulting in the comparisons shown in Figure 12(a) with the subsequent pitching moment calculations compared in Figure 12(b). Excellent agreement was again obtained for all velocity ratios at each angle of attack with the exception of the small difference shown for single jet lift at Ve = 0.05.

The induced lift and total lift and pitching moment associated with the AV-6A Kestral of reference (4) was similarly calculated and compared with test data, the results of which are shown in Figure 13. For this configuration, the total lift and pitching moment were calculated for angles of attack of zero and nine degrees only to coincide with the available data. Good agreement is indicated throughout the figure except for lift at Ve = .25 and α = 9°. As stated previously, reference (4) is the only data source which contains alpha effects in the induced lift. These effects, which cannot be accounted for in the present transition method, cause the discrepency shown in Figure 13(b), and subsequently in Figure 13(c).

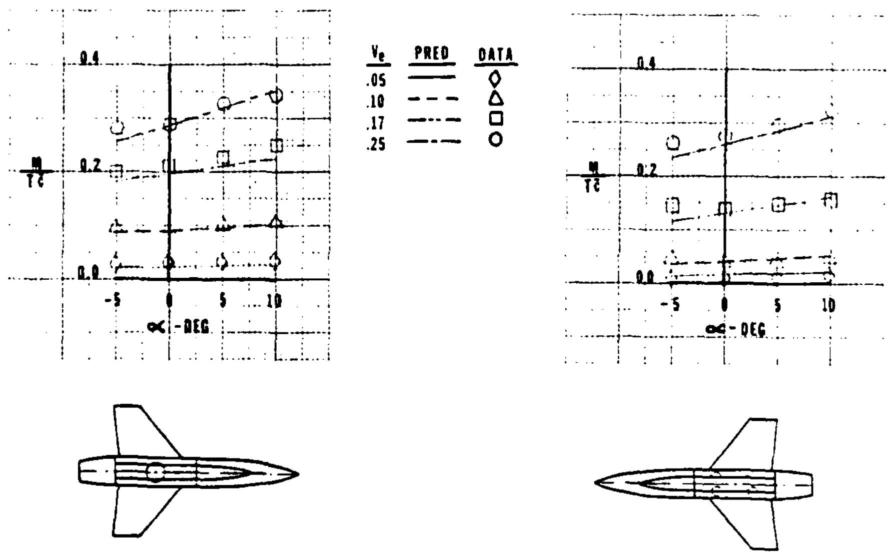
The prediction of induced lift resulting from the inclusion of a LID on the three-jet subsonic configuration of reference (3) is compared with test data for both hover methods in Figure 14. Method 2 alternates between slightly over- and under-estimating the data but, overall, correlates quite well. Method 1 also correlates quite well but seems to be diverging at the lowest height. Kuhn in reference (5) acknowledges shortcomings in predicting the effects of LID's and is presently attempting to incorporate improvements.

The results of the sensitivity study are presented in Figure 15 for $\bar{D}$ and Figure 16 for the NPR. The sensitivity of the induced lift was determined for a $\bar{D}$ variation of ± 10% of the baseline or original $\bar{D}$ used in the calculations for the previous comparisons. This $\bar{D}$ variation was thought to represent the outer limits of the error inherent in the graphical calculation procedure with normal care expected to result in variations of ± 5%. Both hover methods were exercised to determine their sensitivity for the two configurations of references (2) and (3). The results indicate a relative insensitivity of both methods for both configurations beyond an aircraft height of four diameters. However, below this height the sensitivity significantly increases with decreasing height until the spread of the induced lift exceeds 50% of the baseline at $h/d_e=1$. Accordingly, care should be taken in the calculation of $\bar{D}$ to ensure the full potential of the methods capabilities are achieved.

Similar results were obtained for the induced lift sensitivity to nozzle pressure ratio, NPR, as indicated in Figure 16. Instead of using fixed percentages to determine the NPR perturbation, values representative of the outer limits of ratios typical of the configuration/nozzle combination were used to bracket the baseline ratio. The relative insensitive nature of the induced lift beyond heights of four diameters is again contrasted with increasing sensitivity as heights approach one jet diameter. This indicates the need for a reasonable estimate of NPR to ensure the proper ground effects are obtained.

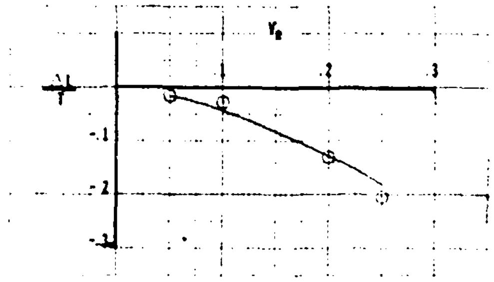


a. Lift

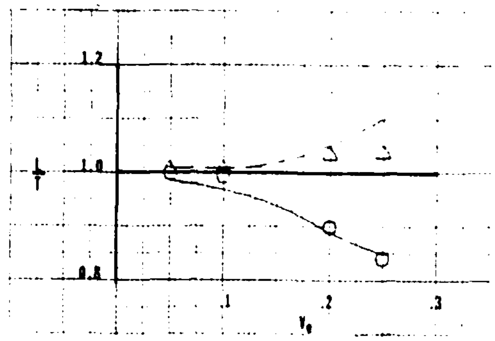


b. Pitching Moment

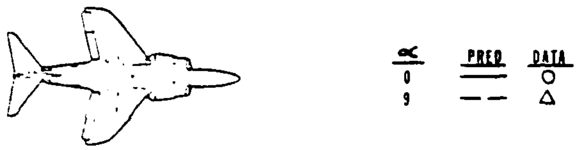
FIGURE 12. Comparison of Prediction and Test Data for the Alpha Effects on Total Lift and Pitching Moment of a Single- and Four-Jet High Wing Supersonic Configuration in Transition (reference (2))

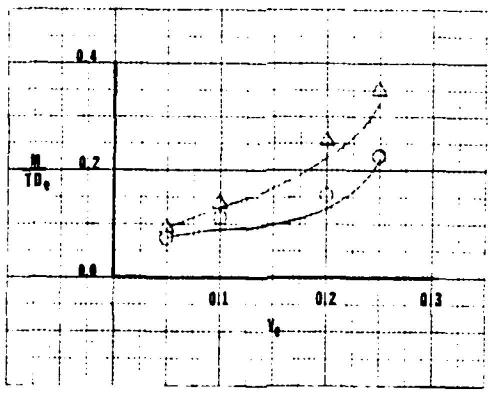


a. Induced Lift



b. Alpha Effects on Total Lift





c. Alpha Effects on Total Pitching Moment

FIGURE 13. Comparison of Prediction and Test Data for the Four-Jet High Wing Supersonic AV-6A Kestral in Transition (reference (4))

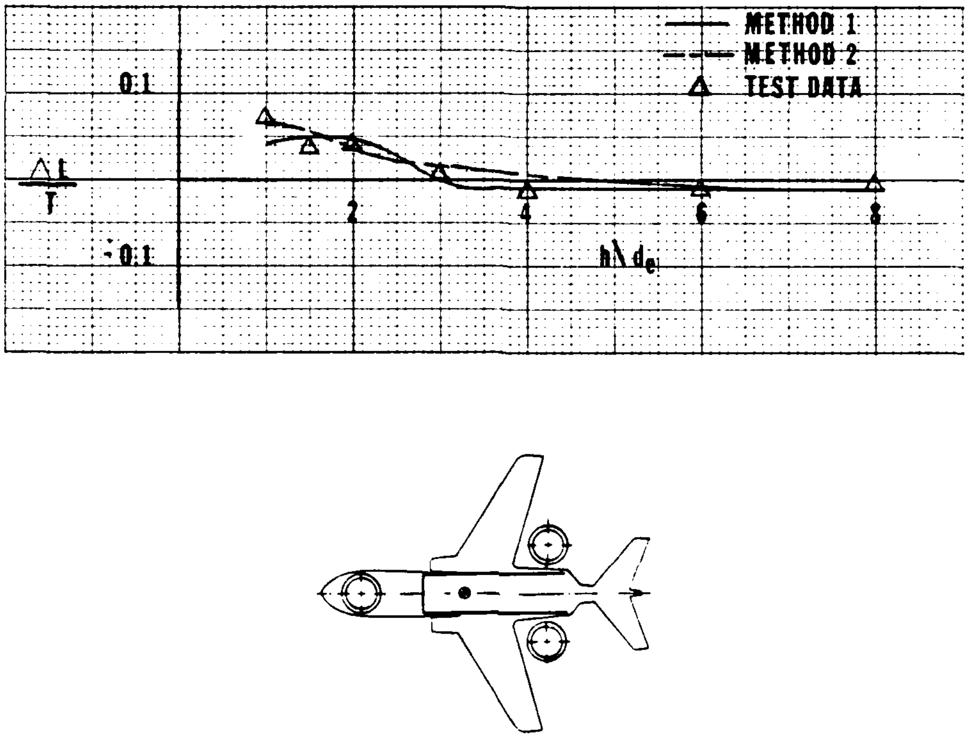
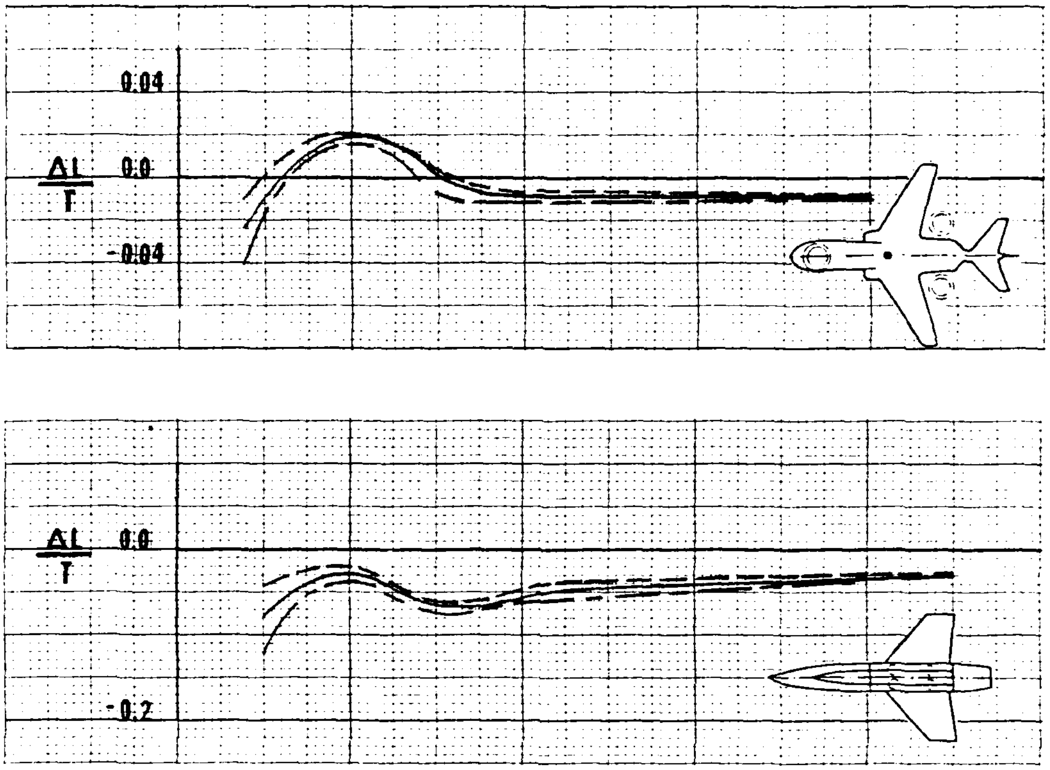
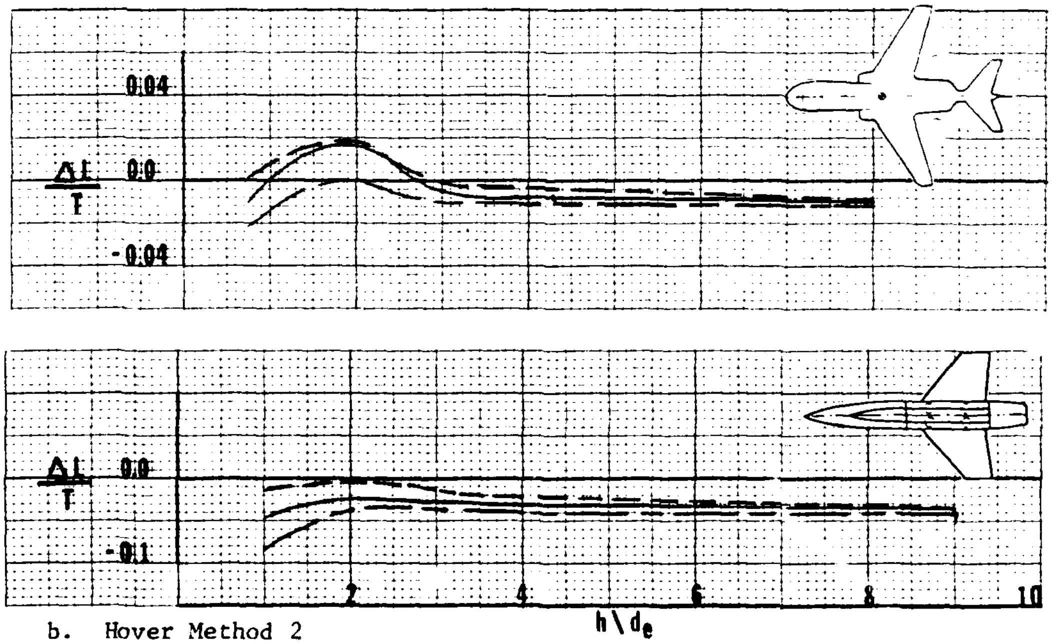


FIGURE 14. Comparison of Prediction and Test Data for the Induced Lift of a Three-Jet Subsonic Configuration with LID's

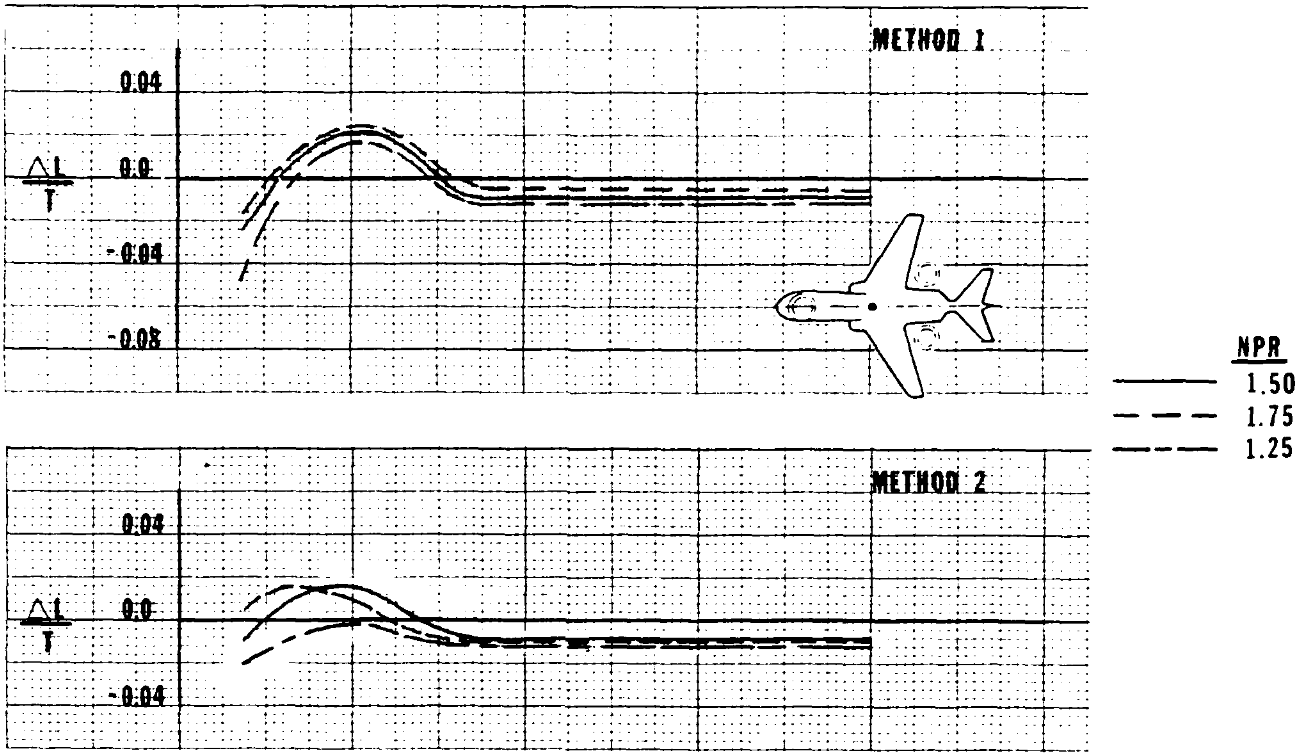


a. Hover Method 1

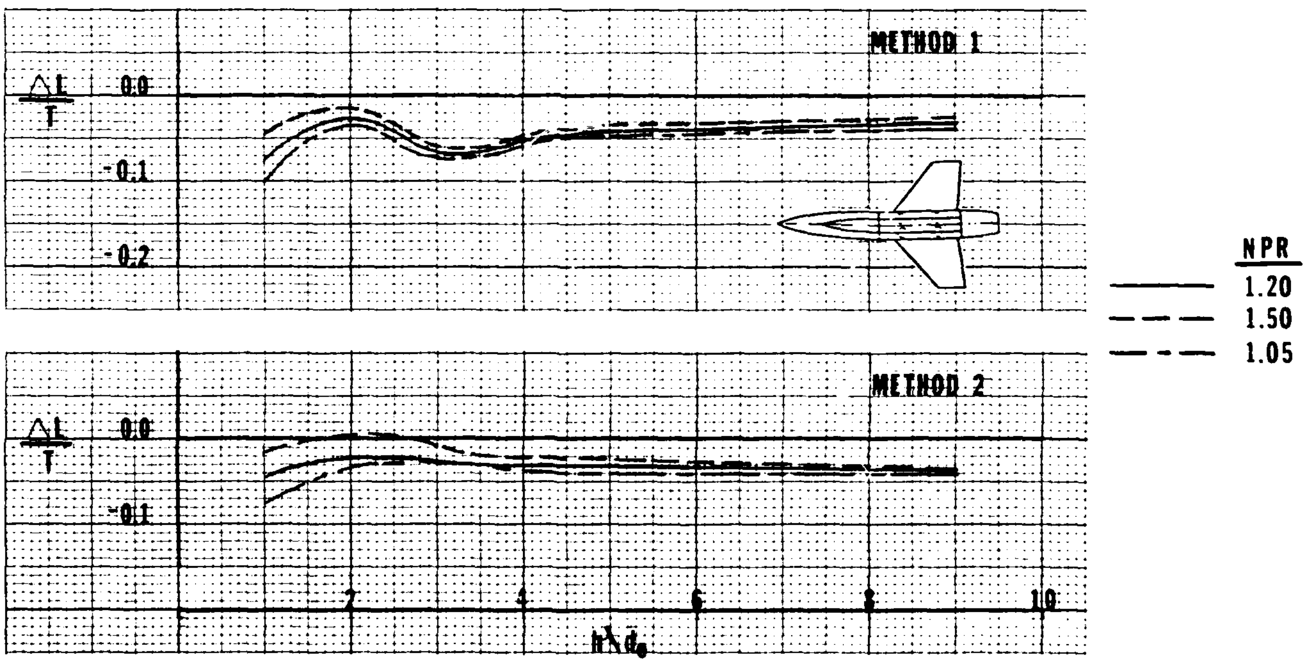


b. Hover Method 2

FIGURE 15. Sensitivity of Induced Lift to Mean Planform Diameter, $\bar{D}$, for a Subsonic and Supersonic Configuration (references (2) and (3))



a. Three-Jet Subsonic Configuration (reference (3))



b. Four-Jet Supersonic Configuration (reference (2))

FIGURE 16. Sensitivity of Induced Lift to Nozzle Pressure Ratio, NPR

CONCLUSIONS

The results of this validation effort indicate the V/STOL Aerodynamics and Stability and Control Manual to be an effective, efficient analysis tool for the prediction of propulsion induced aerodynamics for V/STOL aircraft in hover and transition flight. The variety of configurations used demonstrated the flexibility of the methods contained in the Manual to address not only a variety of planform shapes, but also various numbers of jets, jet arrangements, fuselage contouring and secondary effects such as lift improvement devices. The validation also indicated the effectiveness of the methods for predicting the unpowered aerodynamics and their combination with the induced effects to provide the total lift and pitching moment variation with angle of attack and effective velocity ratio.

The validation effort also enabled an evaluation to be made of the two methods contained in the Manual for the prediction of hover aerodynamics. For the configurations used in this effort, Method 2 provides slightly more accurate predictions than Method 1, but at the expense of proportionately more time required for performing the calculations. The decision as to which method should be used depends upon individual circumstances of accuracy desired and time available. The use of either method, however, results in predictions with an accuracy more than sufficient to satisfy the objective of a preliminary design stage type of analysis.

RECOMMENDATIONS

1. An on-going validation effort should be undertaken to constantly exercise the Manual against new sources of data, and if necessary, to update the methods to account for any discrepancies.

2. Particular attention should be given to validating and improving the fountain prediction of both hover methods. This area is clearly the only significant source of error when reviewing the results of the data comparisons.

3. Additional data sources, when available, should also be reviewed with emphasis on determining the influence of angle of attack.

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