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A METHOD OF ESTIMATING UPWASH ANGLE AT NOSEBOOM-MOUNTED VANES

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JUNE 1981

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UNITED STATES AIR FORCE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This technical information memorandum documents a theoretically-based method of estimating the upwash angle at noseboom-mounted vanes of an arbitrary aircraft. The method is commonly called the Yaggy-Rogallo technique and has been used successfully for many years at the NASA/Dryden Flight Research Center (NASA/DFRC) and the Air Force Flight Test Center (AFFTC). The technique divides any aircraft into a collection of bodies of revolution

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20. and thin airfoils, makes upwash angle estimates for each component, and combines the individual estimates into a single estimate. Development of the theory for upwash angle estimates of both bodies of revolution and thin airfoils are presented. Recent improvements in solution and use of the Yaggy-Rogallo equations are also presented. Guidelines for using the upwash angle estimates in data reduction and analysis are presented along with comparisons to flight test upwash calibration data showing excellent results. FORTRAN V computer programs were written to simplify and expedite making upwash angle estimates. Listings of the program code, a user's guide, and a programmer's guide are included in the memorandum.

PREFACE

The determination of upwash angle induced by the aircraft at noseboom-mounted angle-of-attack vanes is a problem the flight test community faces on a recurring basis. The Air Force Flight Test Center (AFFTC) and the NASA Dryden Flight Research Center (NASA/DFRC) use variations of an upwash estimation technique developed at NASA/DFRC which is commonly called the Yaggy-Rogallo technique. This technique has been applied successfully to numerous, varied aircraft by both organizations. Confusion on the part of "first-time" users in applying the technique has resulted because there was little formal documentation of the technique and most information was passed by informal contact with previous users. Since no proven computer program existed, numerous procedures to implement the technique were developed. The procedures ranged from hand calculation to use of small programmable calculators to use of desk-top and large mainframe computers. Most of the procedures were insufficiently documented to have any retained value.

Donald R. Bellman of NASA/DFRC was the key individual in development of the Yaggy-Rogallo upwash estimation technique. It was his insight into the work of Yaggy and Rogallo and his expertise in translating their work into an easily used format that led to creation of this technique. He refined the technique and applied it to many projects only one of which is referenced in this memorandum. The technique would have undoubtably been lost due to lack of use had it not been for Edwin J. Saltzman, also of NASA/DFRC. His strong advocacy of the technique and consultation with potential users resulted in its continued use at NASA/DFRC and its introduction to AFFTC. Although no original work by either Bellman or Saltzman was available for use directly in writing this memorandum, the consultation they provided to other users and myself was indispensable to the creation of this document.

The present effort was undertaken to consolidate existing memos, notes, computer programs, and personal knowledge before they were lost. This document is really a collection of work by numerous individuals which was edited and significantly expanded as an expedient method of disseminating information. The list of individuals whose work was incorporated in the text are recognized below. To provide a coherent and understandable document, the author modified and reorganized material, changed notations, and expanded many sections. Errors, inconsistencies, and misunderstandings which were introduced during this process are totally the fault of the author, and in no way reflect on the individuals who contributed to the document. Those who contributed were:

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INTRODUCTION

The accurate determination of angle of attack is a significant problem to much of the flight-test community. Since angle of attack is a primary parameter to performance, stability-and-control, and aerodynamic analyses, angle-of-attack errors affect much flight-test data. The usual approach to minimizing these errors is to obtain indicated angle of attack from the angle-of-attack portion of a noseboom instrumentation unit (NBIU) mounted on a flight-test noseboom. The NBIU normally has a calibration from a wind tunnel which accounts for angle-of-attack errors due to NBIU local flow effects. At subsonic Mach numbers, however, there are errors in indicated angle of attack due to the fuselage and wing upwash which are present even with noseboom-mounted vanes. Angle-of-attack errors caused by the aerodynamic influence of bodies results from two sources; first, effects of local flow about the NBIU such as aerodynamic interference boundary layer effects, and shock interaction and, second, upwash effects of aircraft components such as the fuselage and wing. The NBIU local flow effects can be adequately defined only by wind tunnel testing. The NBIU wind-tunnel calibration curves, however, have an upwash component due to the noseboom used in the tunnel tests which must be adjusted to account for different noseboom configurations. The upwash adjustment for the NBIU noseboom as well as upwash of the wing and fuselage can be estimated using the techniques presented in the memorandum. An in-flight calibration, however, must be performed to establish the angle-of-attack errors and allow empirical adjustment of the upwash estimates.

A good upwash-estimation technique is important both during application of the NBIU wind-tunnel calibration to flight-test data reduction and during analysis of the in-flight upwash calibration. Adjustments to the NBIU calibrations can be adequately predicted by calculation and new curves developed for use in data reduction for removal of NBIU effects prior to any analysis of fuselage and wing upwash. Upwash angle estimates for the fuselage and wing are available well before flight-test results and are, therefore, available for initial prediction. Characteristics of subsequent in-flight calibrations should be consistent with the predicted characteristics. Separation of Mach number and lift effects on upwash angle should be accomplished based on empirical adjustment of the level of initial curves rather than attempts to define characteristics based on the flight test data. It should be emphasized that the empirical adjustment is made only to upwash estimation curves and not to the NBIU wind-tunnel calibration curves.

An upwash estimation technique which has consistently proven to be simply used and give acceptable results is based on work by Paul F. Yaggy and Vernon L. Rogallo and is commonly called the Yaggy-Rogallo technique. The Yaggy-Rogallo technique is based largely on theoretical techniques used by Yaggy and Rogallo in analyzing their experimental investigations with some empirical modification by Yaggy, Rogallo and Donald R. Bellman. The work of Yaggy and Rogallo was refined and simplified by Donald R. Bellman of NASA/Dryden Flight Research Center (NASA/DFRC) for application to flight-test data. Although the technique has been in use for many years at NASA/DFRC and the Air Force Flight Test Center (AFFTC), the theory, procedures, and computer programs were never adequately documented. The equations and solutions developed to implement the technique were often inadequate or had unique characteristics which restricted them from general use. Terminology and notation varied enough to cause considerable confusion in adapting and applying an existing implementation to subsequent aircraft. The procedures for applying the technique varied from hand calculation up through a FORTRAN IV computer program for a large mainframe computer. Documentation for much of the derivation and many of the computer programs was incomplete or nonexistent. The Background section of this memorandum describes the development of the Yaggy-Rogallo technique and reviews applicable, previous work both documented and undocumented.

The Yaggy-Rogallo technique treats any vehicle as a collection of aerodynamic bodies whose upwash may be calculated in one of two ways. Cylinder-like bodies which are basically nonlifting such as nosebooms, fuselages, and stores are treated as bodies of revolution. Primary lift-producing surfaces such as wings, canards, and tails are treated as thin airfoils. A concise method of estimating upwash for each of the two types of bodies has been developed from the work of Yaggy and Rogallo. In the case of both types of bodies, assumptions and refinements were made to simplify application of the equations and expedite making upwash estimates. The upwash for the vehicle is then determined by combining the estimates for the individual parts. The Yaggy-Rogallo Analysis section of this memorandum describes the procedure for dividing a vehicle into components and determining equivalent body shapes. The equations for calculating upwash of the components are described as is the procedure for combining the component upwash estimates into a single estimate for the vehicle. Detailed development of the equations and notation for upwash angle estimates of bodies of revolution and thin airfoils are presented in Appendices A and B respectively. For users who are familiar with the Yaggy-Rogallo technique, a procedural outline is presented in Appendix C for use as a quick reference and checklist in making upwash angle estimates. The equations and procedures were implemented in two FORTRAN V computer programs which are well documented in a user's guide and programmer's guide, Appendices D and E respectively.

Practical application of the current implementation of the Yaggy-Rogallo technique and corresponding computer programs is shown in the Procedural Applications section of this memorandum. Two examples of obtaining upwash angle estimates from Yaggy-Rogallo analysis are presented. The examples show how the aircraft is broken into components and data is obtained for entry into the production software. The card input and printed output are presented to show use of the software and the plotted results are presented to show expected characteristics. The results are applied to actual flight-test data to demonstrate the excellent results which can be expected from use of the Yaggy-Rogallo technique in flight-test data reduction.

BACKGROUND

The present upwash estimation technique evolved through successive refinements by numerous persons and organizations. The original technique was developed by Paul F. Yaggy in Reference 1 and greatly generalized by Vernon L. Rogallo in Reference 2. The technique, which became known as the Yaggy-Rogallo technique, represented any vehicle as a collection of bodies of revolution and thin, lifting surfaces. The basic concepts for calculating upwash angle induced by a body of revolution were developed by Theodor Von Karman in Reference 3. Von Karman obtained good pressure distribution and force coefficient data for airship hulls from potential flow solutions for bodies of revolution with equivalent circular cross sections to the hulls. The same potential flow solution easily yielded estimates of upwash velocity and angle which proved to be usable for a variety of non-lifting bodies. Similarly, John De Young and Charles W. Harper developed a simple method of estimating upwash for arbitrary lifting surfaces in References 4 and 5 (Reference 5 was formerly issued as NACA TN's 1476, 1491, 1772 or References 6, 7, and 8 respectively). Using a modified lifting-line technique they were able to easily estimate upwash with excellent accuracy.

Paul F. Yaggy used Von Karman's work and basic lifting-line theory in a study of upwash angle induced at the propeller planes of multiengine, wing-mounted engines in Reference 1. In order to optimize nacelle angles and reduce propeller stresses, it was required to estimate the upwash angle induced by the wing and nacelle. Yaggy modified Von Karman's development to estimate upwash at an arbitrary point in a plane perpendicular to the longitudinal axis (propeller plane) of nacelles and modified the notation. Yaggy compared his theoretical values to data from a series of nacelle tests from NACA/Ames Aeronautical Laboratory (later NASA/Ames Research Center (NASA/ARC)). Yaggy demonstrated that the theory gave good results for blunt bodies at points very near the front and demonstrated that cooling airflow didn't materially effect results even though the assumptions of potential flow were violated. Yaggy's work was confined to unswept wings and incompressible flow so that basic lifting-line theory gave good results. He did, however, recognize the deficiencies and recommended incorporating John De Young's work if efforts were expanded to swept wings and higher Mach numbers.

Vernon L. Rogallo expanded Yaggy's work to propeller planes of aircraft with swept wings and applied Mach corrections to wing upwash effects. In Reference 2, Rogallo described a means of calculating Mach effects by increasing the effective distance of the wing aft of the propeller plane and increasing the effective wing sweeps. Although Rogallo added Mach effects to the wing component of upwash, he used Yaggy's incompressible solution for nacelles. Rogallo compared his theoretical results with experimental data with good agreement.

The concepts used by Yaggy and Rogallo were expanded to upwash estimation at noseboom-mounted angle-of-attack vanes at NASA/DFRC. Donald R. Bellman and Edwin J. Saltzman modified the technique to account for differences between the propeller and noseboom applications. Reference 9 documents that compressibility corrections were added to the body-of-revolution calculations. The technique for lifting surfaces was also refined to simplify and expedite application with little reduction in accuracy. By certain simplifying assumptions, the independent parameters used were changed to geometric parameters only and the curves were expanded to a range of distances ahead of the wing which would include angle-of-attack vanes. The modified techniques were applied to a noseboom calibration in Reference 10 and to the M2-F1, HL-10, and M2-F2 aircraft in References 11, 12, and 13, respectively, with good comparison with full scale test of the vehicles in NASA/ARC wind tunnels.

LIST OF SYMBOLS AND ABBREVIATIONS

ITEM	DESCRIPTION	USCU[1] UNITS	SI[1] UNITS
	SYMBOLS		
A	body cross-sectional area	in^2	m^2
$a_{\nu n}$	Weissinger influence coefficient for symmetric loading	N-D	N-D
AR	aspect ratio of a lifting surface, $AR=b^2/S$	N-D	N-D
b	span of a lifting surface	ft	m
c	local chord length of a lifting surface	ft	m
$\bar{c}$	mean aerodynamic chord length of a lifting surface	ft	m
C_L	lift coefficient of a lifting surface, $C_L=L/\bar{q}S$	N-D	N-D
C_ℓ	section lift coefficient of a lifting surface, $C_\ell=\ell/\bar{q}S$	N-D	N-D
C_{L_α}	lift-curve slope	/deg	/deg
$\frac{C_\ell c}{C_L \bar{c}}$	span loading coefficient	N-D	N-D
d	longitudinal distance ahead of angle-of-attack vane	in	m
dx	element of the longitudinal axis	in	m
FS	fuselage station	in	m
G_n	dimensionless circulation about the wing at span station n	N-D	N-D
i	incidence angle	deg	deg
K_1	constant, see equation (A32)	in	m

[1] U.S. Customary Units (USCU) and International System of Units (SI) were used interchangeably during analyses in this report. Analyses were based on ratios and non-dimensional parameters as much as possible so that consistency within systems is much more important than the system itself. Conversion factors between systems were obtained from Reference 14 when required.

LIST OF SYMBOLS AND ABBREVIATIONS (CONTINUED)

ITEM	DESCRIPTION	USCU UNITS	SI UNITS
	SYMBOLS		
K_2	constant, see equation (A32)	in	m
K_1'	constant, see equation (A40)	in^2	m^2
K_2'	constant, see equation (A40)	in^2	m^2
k_{av}	average of ratios of actual sectional lift-curve slopes to theoretical values	N-D	N-D
L	lifting surface lift	lbf	n
ℓ	section lift	lbf	n
ℓ	general unit of length (see footnote 3, page 89)	---	---
M	Mach number	N-D	N-D
N	number of points	---	---
P	arbitrary point in flowfield of a body revolution	---	---
$\bar{q}$	dynamic pressure	lb/ft^2	n/m^2
R	equivalent radius of a body, $R = \sqrt{A/\pi}$	in	m
r	perpendicular distance from longitudinal axis to center of pressure of angle-of-attack vane	in	m
S	reference area of a lifting surface	ft^2	m^2
U	longitudinal velocity	ft/sec	m/sec
V	airspeed	ft/sec	m/sec
W	upwash velocity	ft/sec	m/sec
X,Y,Z	general rectangular coordinate system	---	---
α	angle of attack	deg	deg
β	compressibility parameter, $\beta = \sqrt{1-M^2}$	N-D	N-D
Γ	circulation about the wing	ft^2/sec	m^2/sec
ε	upwash angle, $\varepsilon = \sin^{-1}(W/V_T)$	deg	deg

LIST OF SYMBOLS AND ABBREVIATIONS (CONTINUED)

ITEM	DESCRIPTION	USCU UNITS	SI UNITS
	SYMBOLS		
θ	polar coordinate angle, $\theta = \cot^{-1}(d/\lvert r\rvert)$	rad	rad
Λ	sweep angle of a lifting surface	deg	deg
μ	moment per unit length of a doublet element	lbf	n
π	constant, 3.14159	N-D	N-D
τ	dimensionless distance from quarter chord to center of pressure of angle-of-attack vane, $\tau = d/(b/2)$	N-D	N-D
Φ	potential function	N-D	N-D
Ω	angular location of the center of pressure of the angle-of-attack vane	deg	deg
	SUPERSCRIPTS		
$\sim$	value corrected for compressibility	---	---
	SUBSCRIPTS		
0	zero - lift	---	---
C/4	quarter chord	---	---
F	fuselage	---	---
i	the ith point along a body	---	---
LE	leading edge	---	---
LF	local flow	---	---
NB	noseboom	---	---
n	spanwise station influencing upwash at station ν	---	---
r	radial direction	---	---
v	center of pressure of angle-of-attack vane	---	---
ν	spanwise station where upwash estimates can be calculated	---	---
T	true	---	---
TE	trailing edge	---	---

LIST OF SYMBOLS AND ABBREVIATIONS (CONCLUDED)

ITEM	DESCRIPTION	USCU UNITS	SI UNITS
	SUBSCRIPTS		
W	wing	---	---
β	value corrected for compressibility	---	---
Ω	tangential direction	---	---
	ABBREVIATIONS		
AFFTC	Air Force Flight Test Center	---	---
AWACS	Airborne Warning and Control System	---	---
FORTRAN	FORmula TRANslation programming language	---	---
NASA/ARC	NASA/Ames Research Center	---	---
NASA/DFRC	NASA/Dryden Flight Research Center	---	---
NBIU	noseboom instrumentation unit	---	---
Saab	Saab-Scania AB	---	---
SI	International System of Units	---	---
TACT	Transonic Aircraft Technology Program	---	---
USCU	U. S. Customary Units	---	---
WINGLETS	USAF/NASA KC-135/WINGLETS Program	---	---

YAGGY-RAGALLO ANALYSIS

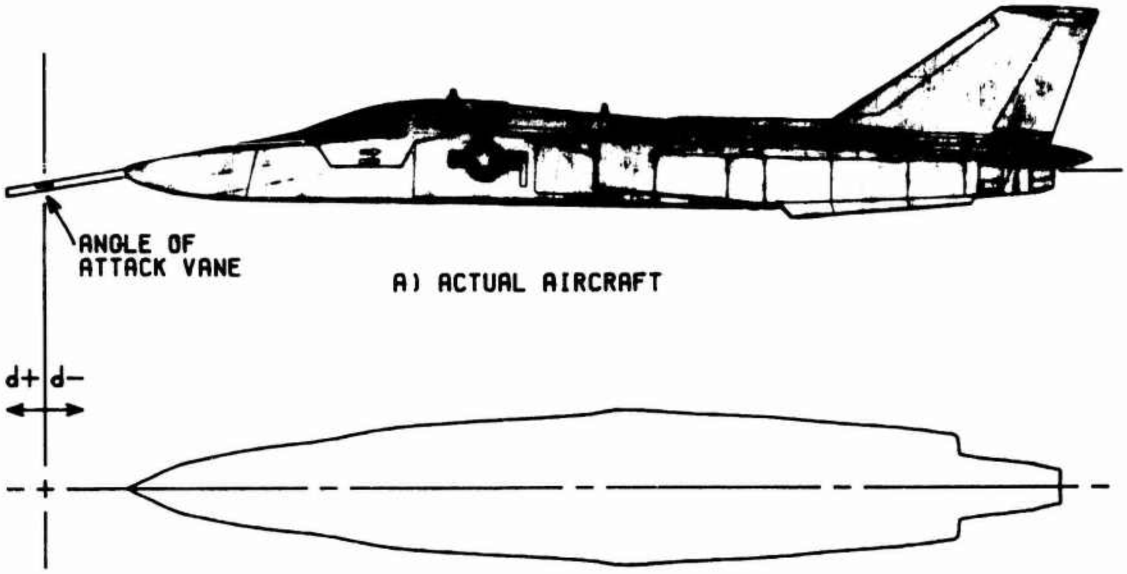
The application of the Yaggy-Rogallo technique to flight test vehicles requires a functional and geometric analysis of the aircraft. The Yaggy-Rogallo technique allows analysis of two functional types of bodies. The actual test aircraft must be represented by a collection of bodies of revolution and thin-airfoil type lifting surfaces. Bodies which are not primarily lifting surfaces such as nosebooms, fuselages, wing-mounted nacelles, and external stores are treated as bodies of revolution. Conventional wings, canards, and horizontal tails (if treated at all) are treated by thin airfoil theory. The analysis of the actual vehicle and division into components is the first and most important step in Yaggy-Rogallo analysis.

Most vehicles are easily analyzed and the definition of the components rather straightforward. There are, however, many new and unique aircraft that are not easily analyzed. Bodies such as the Airborne Warning and Control System (AWACS) fuselage-mounted radome, for instance, are not easily categorized. More common are aircraft such as the F-16 and F-18 which have strakes extending forward along the side of the fuselage. The strakes are not efficient lifters at low angles of attack and have such a low aspect ratio that they are not easily handled by thin-airfoil theory. If the strakes are included in the fuselage analysis, they cause much greater apparent fuselage area than would be obtained from the equivalent-circular-body analysis described in the following sections. The "chine"-type fuselage such as the SR-71 present the same problem to a greater degree. Although no quantitative guidance could be provided, it appears that some combination of increasing the effective diameter of the fuselage and treating them as a very low aspect ratio canard would be appropriate. Another problem arises from wings such as those of the Saab JA37 "Viggen" which have changes in leading edge sweep with spanwise station. Since the theory discussed in later sections assumes a straight quarter-chord line, it is necessary to define an equivalent wing with slightly different geometry and straight quarter-chord. These examples demonstrate the need for a careful analysis of the vehicle and the possibility of the need to change the geometric characteristics to get an equivalent aerodynamic representation.

The upwash of each component obtained from the previous analysis is obtained from an independent analysis of upwash and the results summed. In most cases the results are summed with no regard for interference effects. Where required, there are rather simple means of accounting for first-order interference effects which have been proven with test data. However, for analysis of numerous bodies which are in close proximity and with large interference effects, there is no adequate theory for interference effects. Care should be taken in extending the following analyses to collections of bodies where interference would be a dominate effect.

CYLINDRICAL COMPONENTS

The upwash estimates for non-lifting bodies which the functional and geometric analysis has shown must be treated as bodies of revolution are obtained from equations developed in Appendix A. An equivalent body of revolution, as shown in Figure 1, must be developed for each separate component which must be analyzed. Bodies whose longitudinal axes are not concurrent, such as "drooped" nosebooms, must be analyzed separately since the vane position relative to the axis is different and the bodies have different local angles of attack. Also bodies having different local angle of attack due to induced angle of attack from nearby bodies must be analyzed separately. A coordinate transformation must also be made so that distances are



A) ACTUAL AIRCRAFT

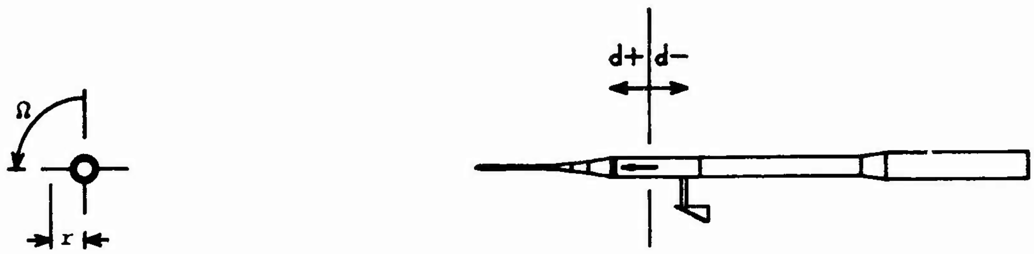
B) EQUIVALENT BODY OF REVOLUTION

FIGURE 1: REPRESENTATION OF NON-LIFTING BODIES

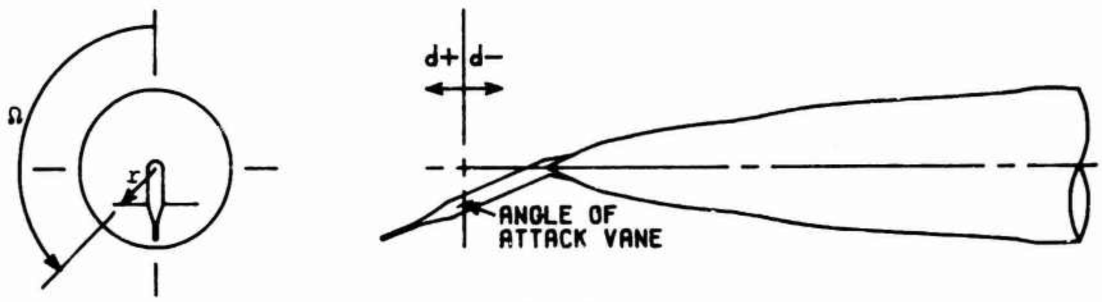
measured forward and aft of the angle-of-attack vane as shown in Figure 2. Once the equivalent geometry has been developed, compressibility effects can be accounted for by further changes to an "effective" geometric configuration. These changes allow upwash estimates to be calculated using equations developed in Appendix A.

Experience has shown that bodies with significantly different cross-sectional shapes can be represented by an equivalent-body-of-revolution analysis with little effect on upwash estimates. The body of revolution is obtained by calculating a radius for a circle with equal area to the actual body. The radius of the equivalent circle, R, is related to the cross sectional area, A, by equation (1). By calculating the equivalent radius at enough sections from plotted or tabulated data the body of revolution can be determined. The centers of the circles lie on the original longitudinal axis and the radii are perpendicular to it. In determining the area of a section, the area attributable to lifting surfaces such as wings or tails is ignored except in unusual cases such as strakes which were discussed previously.

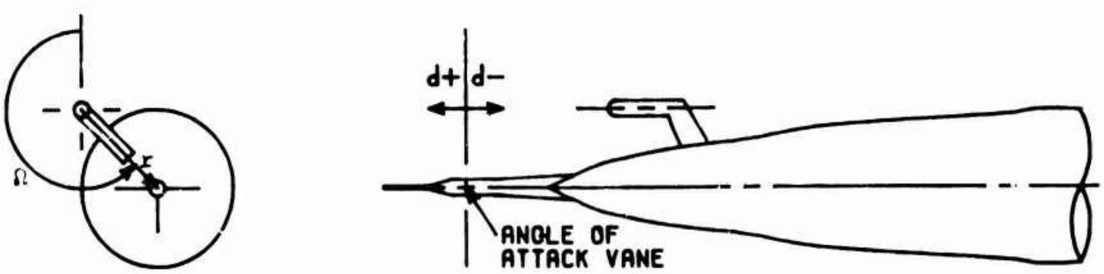
$$R = \sqrt{A/\pi} \qquad (1)$$



A) NOSEBOOM



B) FUSELAGE



C) REFUELING PROBE

FIGURE 2: EXAMPLE VANE LOCATIONS

The location of the center of pressure of the noseboom-mounted vane relative to the centerline of each component must be specified. The radial distance, r, and the angular position, Ω, are specified as shown in Figure 2. It is important in establishing the value of Ω to realize that the technique is extremely sensitive to the value of Ω and that, in many cases, there is significant uncertainty in its value. In most cases, the vertical location of the axis of the equivalent-circular body representing a fuselage is unknown by several inches or more. For the AFFTC standard noseboom instrumentation unit, a ± 7 inch uncertainty could vary the value of Ω from 45° and 135° and vary the upwash estimate from zero to its maximum and back to zero. When there is uncertainty, it is best to make initial estimates with an Ω value of 90° and adjust the value based on an inflight calibration. However, where the body actually is cylindrical and the relative geometry well known such as a probe refueling receptical, the calculated value of Ω should be used. Distances along the longitudinal axis, d, are measured positive forward of a plane perpendicular to the longitudinal axis which contains the center of pressure of the angle of attack vane as shown in Figure 2. To account for compressibility, these actual geometric distances must be adjusted by a compressibility factor, β, defined by equation (2). The effect of compressibility is to create an effective geometry such that sections forward of the vane appear closer to the vane and sections aft of the vane appear farther away. This continues until Mach number, M, of 1.0. Beyond Mach 1.0 the body has practically no effect and upwash is considered to go to zero. For Mach numbers between 0.0 and 1.0 the effective distances are defined by equations (3). The Yaggy-Rogallo equation shown as equation (4) was developed in Appendix A and is used to calculate the upwash angle, ε, per angle of attack, α. The angle $\tilde{\theta}$ is defined by equation (5) as explained in footnote 2 (following page). After substituting this formulation for $\tilde{\theta}$ into equation (4), it can be completely defined and solved.

$$\beta = \sqrt{1-M^2} \tag{2}$$

$$\tilde{d} = d \cdot \beta \qquad d \geq o \text{ (forward)}$$
$$\tilde{d} = d/\beta \qquad d < o \text{ (aft)} \tag{3}$$

$$\frac{\varepsilon}{\alpha} = \frac{\sin^2\Omega - \cos^2\Omega}{2r^2} \int_{\tilde{\theta}_{LE}}^{\tilde{\theta}_{TE}} R^2 \sin\tilde{\theta} \, d\tilde{\theta} \tag{4}$$

$$\tilde{\theta} = \cot^{-1}(\tilde{d}/|r|) \qquad o \leq \tilde{\theta} \leq \pi \tag{5}$$

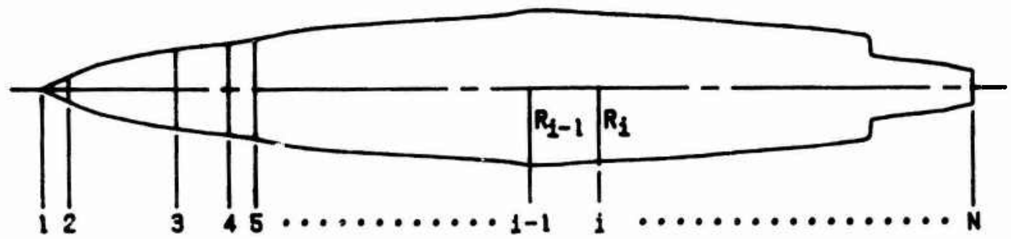


FIGURE 3: SEGMENTATION OF BODIES OF REVOLUTION

Several solutions to equation (4) are discussed in Appendix A and the most practical was determined. The recommended procedure is determination of an upwash estimate through summation of upwash estimates for individual segments of the body when summed from leading to trailing edge. The body is divided into N-1 segments by N points where point 1 is the leading edge and point N is the trailing edge as shown in Figure 3. The length and number of segments should be selected such that the area between points varies linearily, or approximately so, between points. Normally, this is accomplished by selecting points from the fuselage area versus fuselage station plot in such a manner that a straight line between points closely approximates the curve. The fuselage stations must be transformed into distances

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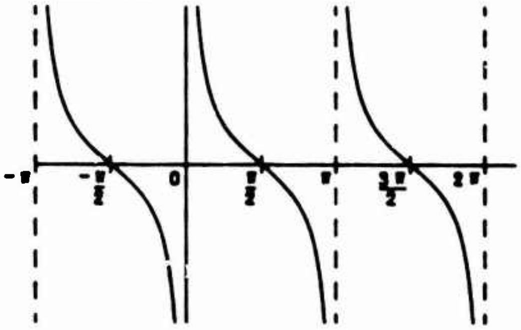
[2]The equation $\theta = \cot^{-1}(d/|r|)$ is the necessary representation of the angle θ. As the value of d moves from far upstream ($d = +\infty$) to far downstream ($d = -\infty$) the angle θ moves from 0 to π as shown in the sketch of the cotangent function. However, most computers do not allow the inverse cotangent function and the inverse tangent function must be used instead. The equation $\theta = \tan^{-1}(|r|/d)$ for $0 \le \theta \le \pi$ is equally valid as the cotangent function. Most computers, however, return inverse tangent values between $-\pi/2$ and $\pi/2$ since this avoids the discontinuity at $\theta = \pi/2$ as shown on the sketch of the tangent function. In this case the equation must be implemented as

$$\theta = \tan^{-1}(|r|/d) \qquad (r/d) \ge 0$$

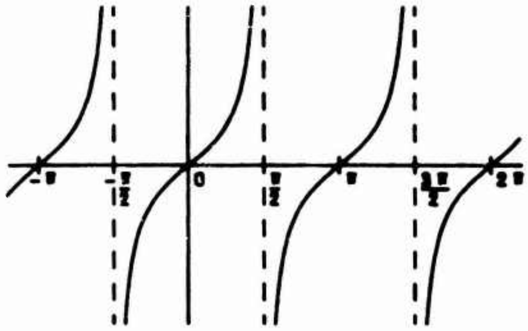
$$\theta = \tan^{-1}(|r|/d) + \pi \qquad (|r|/d) < 0$$

so that θ will move from 0 to π as d moves from $+\infty$ to $-\infty$.

Y=COT(X)



Y=TAN(X)



forward or aft of the center of pressure of the vane using equation (6). The corresponding fuselage area must be transformed to the radius of the equivalent circle using equation (7). The distances must be converted to effective distances for each Mach number where upwash estimates are desired using β calculated using equation (2). The effective distances and corresponding effective angles are defined in equations (8) and (9) respectively. Upwash estimates in terms of ε/α can then be calculated using equation (10). The calculations in equations (8), (9), and (10) must be repeated for each Mach number, thus β value, where upwash estimates are desired. This process is demonstrated fully in the Procedural Applications section of this memorandum.

$$d_i = FS_v - FS_i \tag{6}$$

$$R_i = \sqrt{A_i/\pi} \tag{7}$$

$$\begin{aligned} \tilde{d}_i &= d_i \cdot \beta & \quad d \geq o \text{ (forward)} \\ \tilde{d}_i &= d_i/\beta & \quad d < o \text{ (aft)} \end{aligned} \tag{8}$$

$$\tilde{\theta}_i = \cot^{-1}(\tilde{d}_i/|r|) \tag{9}$$

$$\frac{\varepsilon}{\alpha} = \frac{\sin^2\Omega - \cos^2\Omega}{2r^2} \sum_{i=2}^{N} [K_1'(\sin\tilde{\theta}_i - \sin\tilde{\theta}_{i-i}) + K_2'(\cos\tilde{\theta}_{i-1} - \cos\tilde{\theta}_i)] \tag{10}$$

where $K_1' = (R_{i-1}^2 - R_i^2) \,/\, (\cot\tilde{\theta}_{i-1} - \cot\tilde{\theta}_i)$

$K_2' = -K_1' \cot\tilde{\theta}_i + R_i^2$

The summation procedure is very repetitive and becomes tedious when many upwash estimates at several Mach numbers must be made. A FORTRAN V computer program has been written which implements this procedure. It is described fully and in detail in Appendix D.

LIFTING SURFACE COMPONENTS

The upwash estimates for components to be treated as thin-airfoils, as shown by functional and geometric analysis, are obtained from equations developed in Appendix B. The lifting surfaces must be analyzed and, if necessary, equivalent planforms must be developed and equivalent geometric characteristics such as area, quarter-chord sweep, aspect ratio, and span be determined. From these geometric values the upwash estimates for the lifting surfaces can be determined.

Experience has shown that unless the planform of the lifting surface differs significantly from usual configurations, the upwash can be determined from curves or the equation developed in Appendix B. The development assumes that all lifting surfaces be in the horizontal plane of the angle-of-attack vanes and that the vanes are located midspan of the lifting surface. Thus, the location of the vanes relative to the lifting surface are specified by the nondimensional distance, τ, defined by equation (11). The effective wing sweep, Λ_β, can be calculated by using equation (12). These values can be used in equation (13) or the curve in Figure 4 to obtain the upwash parameter $\epsilon AR/C_L$. The upwash parameter for lifting surfaces ϵ/C_L can then be determined by dividing $\epsilon AR/C_L$ by aspect ratio. It is highly recommended that the estimates be implemented in terms of ϵ/C_L for data reduction and analysis. When this is not possible, it may be necessary to accept increased uncertainty and modify the form of the correction as described in the Combination of Component Estimates section.

$$\tau = (FS_v - FS_{c/4}) / (b/2) \tag{11}$$

$$\Lambda_\beta = \tan^{-1}(\tan\Lambda_{c/4}/\beta) \tag{12}$$

$$\epsilon AR/C_L = 10^{[A\log(\tau/\beta) + B\Lambda_\beta + C]} \qquad (\tau/\beta) > 0.4 \tag{13}$$

where $A = -1.488973010$
$B = -0.008447868$
$C = -1.099368684$

COMBINATION OF COMPONENT ESTIMATES

The upwash estimates from various components must be combined during data reduction and analysis to give a total estimate of the upwash angle. The combination of upwash estimates should normally be a straightforward process of combining the estimates for the non-lifting surfaces, combining the estimates for lifting surfaces, and adding the results. The

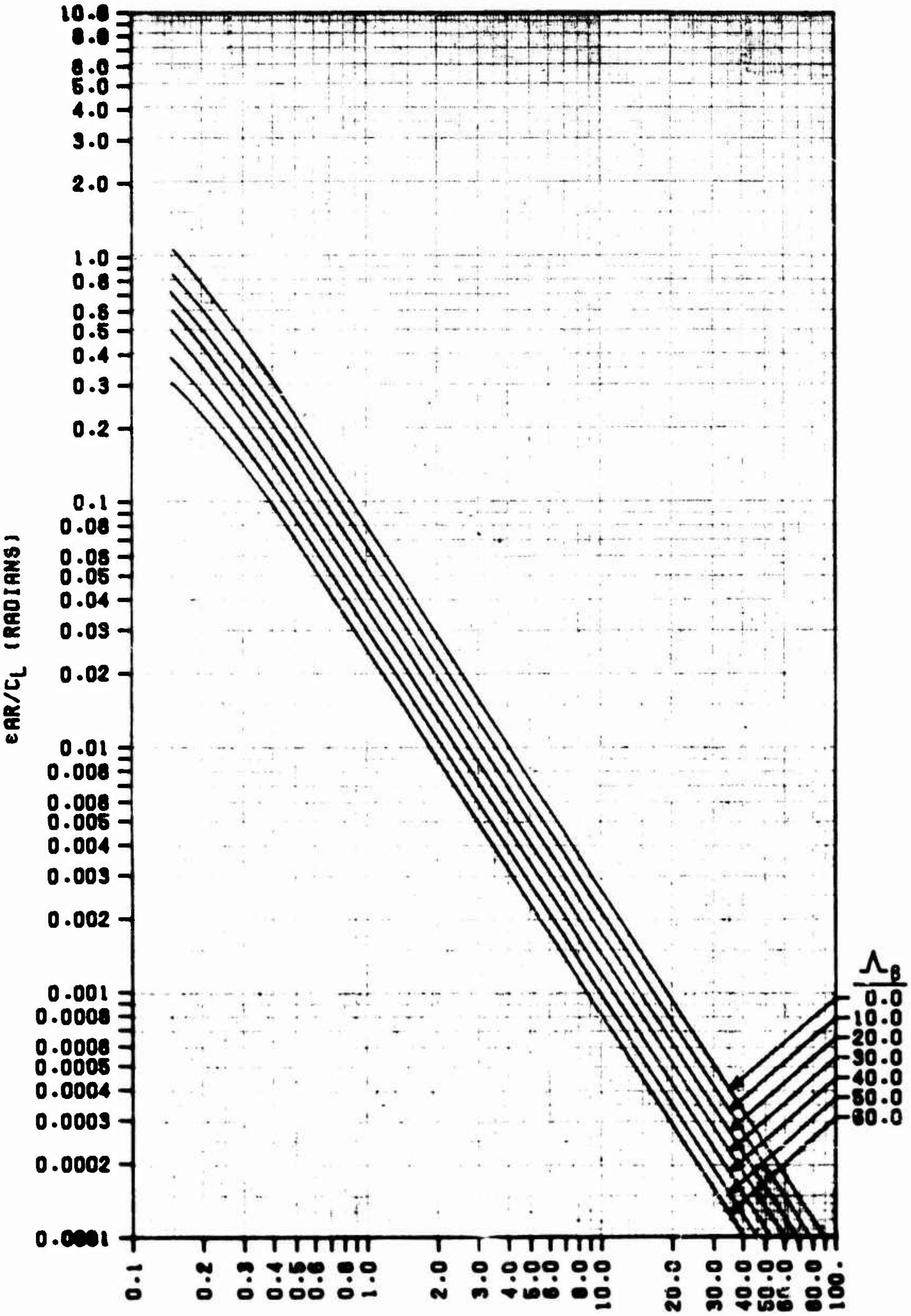


FIGURE 4: UPWASH ESTIMATION CURVES FOR LIFTING SURFACES

process can become more complicated if it is determined to be necessary to include the first order effects due to interference. The process becomes still more complicated and significantly less accurate if the user chooses to modify the form of the lifting surface estimates from values of ε/C_L to values of ε/α. The values of lift-curve slope and zero-lift angle of attack vary greatly across the lift coefficient range and may introduce large errors when used during the modification. Care should be taken during the combining process to insure the best, practical result is obtained.

COMBINATION OF NON-LIFTING COMPONENT ESTIMATES:

The combination of estimates for non-lifting bodies which are treated as bodies of revolution can normally be combined without correction for interference effects. Estimates for a noseboom (NB) and fuselage (F), for instance, can be combined using equation (14). The wing angle of attack, α, must be corrected for the wing and noseboom incidence angles, i_W and i_{NB}, respectively. This is the recommended procedure for most applications.

$$\varepsilon = (\varepsilon/\alpha)_{NB}(\alpha-i_{NB}) + (\varepsilon/\alpha)_F(\alpha-i_W) \tag{14}$$

The 1st order effects of interference can be accounted for by a simple correction discussed in Reference 1. The angle of attack of the various components can be adjusted for upwash of components downstream of the body of interest. The angle of attack of the noseboom, for instance, could be increased by the induced angle of the wing and fuselage at the noseboom. Although the correction is rather simple, it becomes complicated to implement if there are several bodies and adds little to the accuracy of the method since first order interference effects are second or third order effects on upwash angle estimates. Although the method has proven acceptable for a few bodies, the correction may be inadequate for large interference effects of multiple bodies such as stores and external tanks.

COMBINATION OF LIFTING SURFACE ESTIMATES:

The combination of estimates for lifting surfaces is far more difficult than for non-lifting bodies. If only the wing is involved, the entire aircraft lift can be attributed to the wing and the upwash is simply determined from equation (15). If two lifting surfaces are involved such as a wing (w) and canard (c), the equation would be equation (16). Normally it is difficult to accurately divide the lift between the wing and canard. If it is possible, it should be remembered that the lift coefficients are based on the area and dynamic pressure at the surface.

$$\varepsilon = (\varepsilon/C_L)_W \cdot C_L \tag{15}$$

$$\varepsilon = (\varepsilon/C_L)_W \cdot C_{L_W} + (\varepsilon/C_L)_C \cdot C_{L_C} \tag{16}$$

A simpler, but significantly less accurate, method is to convert the lifting surfaces estimates to an ε/α format. The values of lift-curve slope and zero-lift angle of attack vary greatly across the lift coefficient range and may introduce large errors in upwash angle estimates. This is especially true at high angles of attack where upwash angles are large and the lift-curve slope is significantly different than an average value for moderate lift coefficients. The upwash estimate in terms of ε/α can, however, be determined from ε/C_L and the lift curve slope, C_{L_α}, at the appropriate Mach number. If the angle of attack at zero lift is α_0, the upwash angle is given by equation (17). This method is not recommended and should be avoided if possible.

$$\varepsilon = (\varepsilon/C_L)\cdot C_{L_\alpha}(\alpha-\alpha_0) = ((\varepsilon/C_L)\cdot C_{L_\alpha}\alpha) - ((\varepsilon/C_L)\cdot C_{L_\alpha}\alpha_0) \qquad (17)$$

PROCEDURAL APPLICATIONS

The Yaggy-Rogallo technique was used to make upwash estimates for two common flight-test applications. The applications were presented primarily to demonstrate the procedures to be followed in developing upwash estimates and applying them to flight-test data reduction. The results, however, also demonstrated the excellent quality of the upwash estimates and the versatility of the Yaggy-Rogallo technique. The first application discussed is development of total upwash estimates for use in reduction of data from the F-111A/TACT aircraft. Development of the F-111A/TACT upwash estimates was a complete demonstration of the Yaggy-Rogallo technique and showed the excellent absolute level of curves obtained using the technique. The second application discussed is development of corrections to upwash estimates to account for changing noseboom configuration. This application demonstrated the quality of relative values between upwash estimates for two configurations and showed the versatility of the technique. Both applications are documented in the following subsections.

F-111A/TACT UPWASH ESTIMATES

The Yaggy-Rogallo technique was applied to the supercritical wing configuration of the F-111A/TACT aircraft to completely demonstrate a typical application of the technique. This aircraft was selected because the variable wing sweep and large Mach number range of the aircraft allowed maximum demonstration and verification of the technique. Also, a large quantity of high quality, angle-of-attack-calibration data was available for comparison. Upwash estimates were developed for three wing sweeps and for the Mach range from 0.0 to 1.0. The development followed procedures recommended in the Yaggy-Rogallo Analysis section of this memorandum entirely as well as using some alternative procedures necessary to convert the wing upwash estimates from ε/C_L to ε/α format.

The process of making comprehensive upwash estimates began with a preliminary analysis of the test aircraft. As discussed in the Yaggy-Rogallo Analysis section of this report, it was necessary to separate the test aircraft into a collection of bodies to be represented either as bodies of revolution or thin-airfoil lifting surfaces. Analysis of the F-111A/TACT aircraft revealed that only one body of revolution and three lifting surfaces were necessary to represent the aircraft adequately for making upwash estimates. This was due in part to choosing an aircraft equipped with the AFFTC standard noseboom instrumentation unit (NBIU). The NBIU has unique angle-of-attack corrections dominated by local flow effects which can't possibly be estimated using the Yaggy-Rogallo technique; the wind tunnel calibration of the NBIU must be used to correct for local flow effects. The wind tunnel calibration, however, also contains correction for

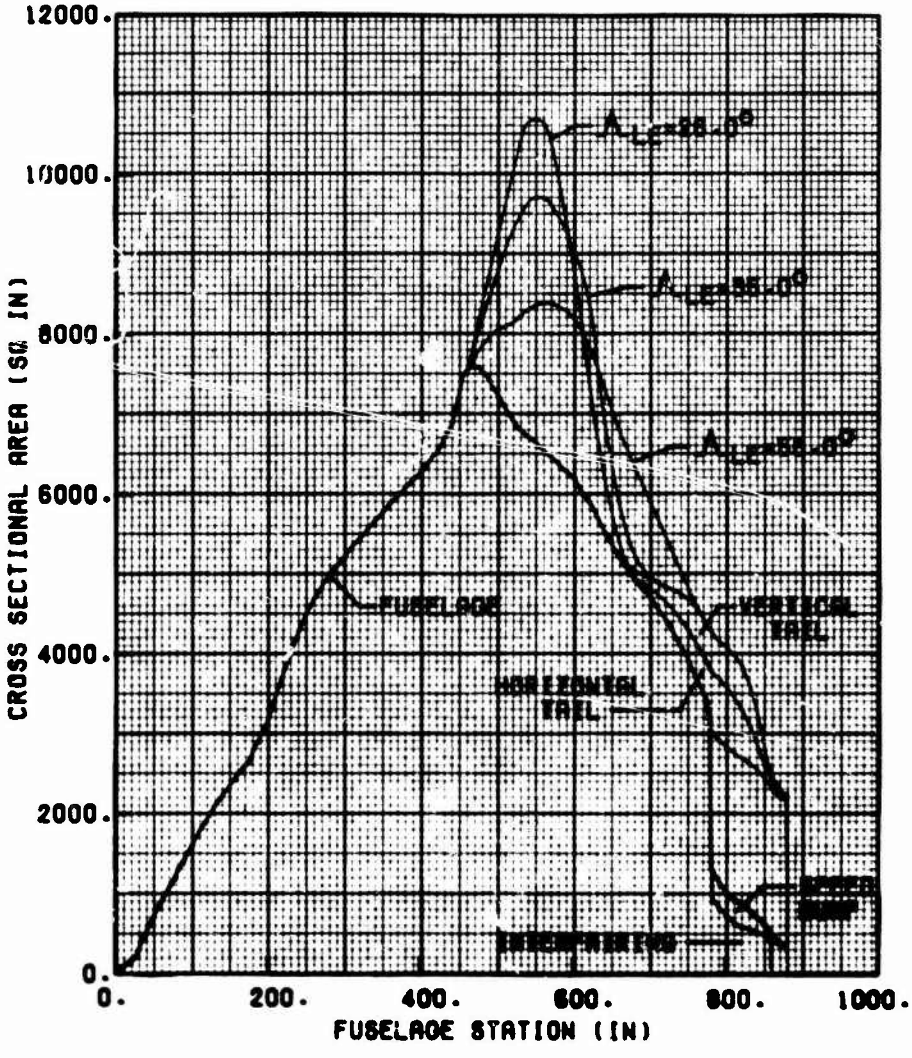


FIGURE 5: F-111A/TACT CROSS SECTIONAL AREA DISTRIBUTION

the upwash of the noseboom used in the wind tunnel tests which normally must be corrected as demonstrated in the following subsection entitled Noseboom Correction Estimates. The F-111A/TACT aircraft was equipped with a noseboom which exactly matched the wind tunnel configuration so that analysis of the noseboom was unnecessary. As with most conventional tails, the upwash of the tail was insignificant and could be ignored. Representing the aircraft was thus reduced to representing the fuselage by an equivalent body of revolution and each of the three wingsweeps by a thin airfoil. Upwash estimates were prepared for the body and each airfoil using procedures recommended in the Yaggy-Rogallo Analysis section of this memorandum. The upwash estimates were prepared using the production software described in Appendix D and are presented as production-software output although the same results could have been obtained by hand calculation if desired. The resulting upwash estimates were compared with flight test angle-of-attack calibrations.

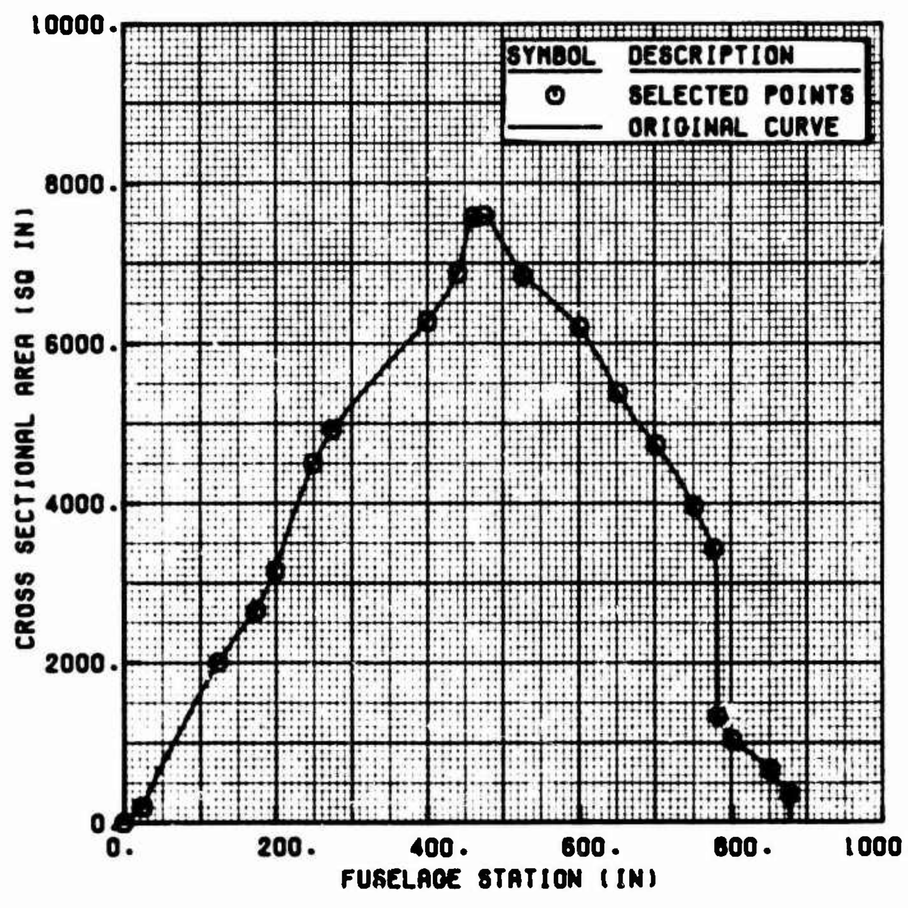


FIGURE 6: F-111A/TACT FUSELAGE CROSS SECTIONAL AREA POINT SELECTION

FUSELAGE UPWASH ESTIMATES:

Upwash estimates for the F-111A/TACT fuselage were obtained by an equivalent-body-of-revolution analysis and the Yaggy-Rogallo production software. In order to define the equivalent body of revolution, a graph of fuselage area versus fuselage station was obtained from the physical description data contained in reference 17. The graph which is shown in Figure 5 had curves for total cross sectional area as well as fuselage alone. All curves except for the fuselage alone were ignored, and that curve was estimated by a series of points chosen along the curve such that straight lines connecting the points accurately represented the curve. In this case twenty-one points were adequate to accurately define the curve as shown in Figure 6. The location of the center of pressure of the angle-of-attack vane was located at fuselage station of -68.45 inches. As previously discussed, the radial distance and angular location were not easily determined. The radial distance was set to the lateral location of 7.875 inches and the angular location was set to 90.0 degrees with the intent of adjusting the level of the upwash estimation curves based on flight test data. The data were entered on punched cards using the User's Guide for the Yaggy-Rogallo Production Software as a reference to obtain the deck shown in Figure 7. The input data deck was processed through program BODY to obtain upwash estimates.

```
HEAD1                              F-111A/TACT AIRCRAFT
HEAD2FUSELAGE                                                          21 POINTS
VANES   IN     -68.45       7.875       90.00
MACHV   11  0.0         0.1         0.2         0.3         0.4         0.5         0.6
MACHV       0.7         0.8         0.9         0.99
AREAV     000.0      0000.0
AREAV     025.0      0200.0
AREAV     125.0      2000.0
AREAV     175.0      2650.0
AREAV     200.0      3150.0
AREAV     250.0      4500.0
AREAV     275.0      4925.0
AREAV     400.0      6275.0
AREAV     440.0      6875.0
AREAV     460.0      7575.0
AREAV     475.0      7600.0
AREAV     525.0      6850.0
AREAV     600.0      6200.0
AREAV     650.0      5375.0
AREAV     700.0      4725.0
AREAV     750.0      3950.0
AREAV     775.0      3425.0
AREAV     781.0      1325.0
AREAV     800.0      1025.0
AREAV     850.0      0650.0
AREAV     875.0      0350.0
END
```

FIGURE 7: "BODY" INPUT DATA FOR F-111A/TACT FUSELAGE

The output of program BODY consisted of two types of lineprinter listings describing the actual geometric data, the effective geometric data, and the upwash estimates. The first page of output shown in Figure 8 printed the input and calculated actual geometric data. The output is described in detail in Appendix C. The remaining output from the input data cards in Figure 7 were pages of the second type of output. One page was printed for each Mach number where an upwash estimate was requested. Figure 9 gives an example of a single page for a Mach number value of 0.8. The effective geometry and incremental upwash estimates are described in detail in Appendix C but the important value is the total upwash estimate in terms of epsilon/alpha which is printed at the bottom of the page. These estimates were plotted versus Mach number as shown in Figure 10 to give a concise upwash estimate for the fuselage.

```
                    YAGGY-ROGALLO UPWASH CALCULATION                  PAGE
                GEOMETRIC DATA FOR CYLINDRICAL COMPONENTS             1/ 1
--------------------------------------------------------------------------
                         F-111A/TACT AIRCRAFT
FUSELAGE                                                         21 POINTS
--------------------------------------------------------------------------
ANGLE-OF-ATTACK VANE LOCATION:
      RADIAL DISTANCE FROM BODY CENTERLINE .............     7.8750 IN
      ANGULAR LOCATION .................................    90.0000 DEG
      LONGITUDINAL STATION OF VANES ....................   -68.4500 IN
COMPONENT AREA DISTRIBUTION:
```

PT NO	LONGITUDINAL STATION (IN)	CROSS SECTIONAL AREA OF BODY AT STATION (SQ IN)	LONGITUDINAL DISTANCE FROM VANE TO STATION (IN)	EQUIVALENT RADIUS AT STATION (IN)
1	0.0000	0.0000	-68.4500	0.0000
2	25.0000	200.0000	-93.4500	7.9788
3	125.0000	2000.0000	-193.4500	25.2313
4	175.0000	2650.0000	-243.4500	29.0434
5	200.0000	3150.0000	-268.4500	31.6651
6	250.0000	4500.0000	-318.4500	37.8470
7	275.0000	4925.0000	-343.4500	39.5939
8	400.0000	6275.0000	-468.4500	44.6922
9	440.0000	6875.0000	-508.4500	46.7801
10	460.0000	7575.0000	-528.4500	49.1039
11	475.0000	7600.0000	-543.4500	49.1849
12	525.0000	6850.0000	-593.4500	46.6950
13	600.0000	6200.0000	-668.4500	44.4243
14	650.0000	5375.0000	-718.4500	41.3632
15	700.0000	4725.0000	-768.4500	38.7816
16	750.0000	3950.0000	-818.4500	35.4588
17	775.0000	3425.0000	-843.4500	33.0183
18	781.0000	1325.0000	-849.4500	20.5368
19	800.0000	1025.0000	-868.4500	18.0629
20	850.0000	650.0000	-918.4500	14.3841
21	875.0000	350.0000	-943.4500	10.5550

FIGURE 8: "BODY" GEOMETRIC DATA OUTPUT FOR F-111A/TACT FUSELAGE

YAGGY-ROGALLO UPWASH CALCULATION
UPWASH ESTIMATE FOR CYLINDRICAL COMPONENTS
MACH NUMBER = .8000

F-111A/TACT AIRCRAFT

FUSELAGE — 21 POINTS

PT NO	LONGITUDINAL DISTANCE FROM VANE TO STATION (IN)	EFFECTIVE DISTANCE FROM VANE TO STATION (IN)	THETA (RAD)	EQUIVALENT RADIUS AT STATION (IN)	INCREMENT IN EPSILON OVER ALPHA
1	-68.4500	-114.0833	3.0727	0.0000	0.
2	-93.4500	-155.7500	3.0911	7.9788	.2385E-03
3	-193.4500	-322.4167	3.1172	25.2313	.1974E-02
4	-243.4500	-405.7500	3.1222	29.0434	.6451E-03
5	-268.4500	-447.4167	3.1240	31.6651	.2478E-03
6	-318.4500	-530.7500	3.1268	37.8470	.4332E-03
7	-343.4500	-572.4167	3.1278	39.5939	.1864E-03
8	-468.4500	-780.7500	3.1315	44.6922	.6172E-03
9	-508.4500	-847.4167	3.1323	46.7801	.1295E-03
10	-528.4500	-880.7500	3.1327	49.1039	.5939E-04
11	-543.4500	-905.7500	3.1329	49.1849	.4237E-04
12	-593.4500	-989.0833	3.1336	46.6950	.1134E-03
13	-668.4500	-1114.0833	3.1345	44.4243	.1127E-03
14	-718.4500	-1197.4167	3.1350	41.3632	.4998E-04
15	-768.4500	-1280.7500	3.1354	38.7816	.3536E-04
16	-818.4500	-1364.0833	3.1358	35.4588	.2499E-04
17	-843.4500	-1405.7500	3.1360	33.0183	.9220E-05
18	-849.4500	-1415.7500	3.1360	20.5368	.1348E-05
19	-868.4500	-1447.4167	3.1362	18.0629	.2022E-05
20	-918.4500	-1530.7500	3.1364	14.3841	.3390E-05
21	-943.4500	-1572.4167	3.1366	10.5550	.8915E-06

TOTAL UPWASH ESTIMATE (EPSILON/ALPHA) = .4926E-02

FIGURE 9: "BODY" UPWASH ESTIMATE OUTPUT FOR F-111A/TACT FUSELAGE

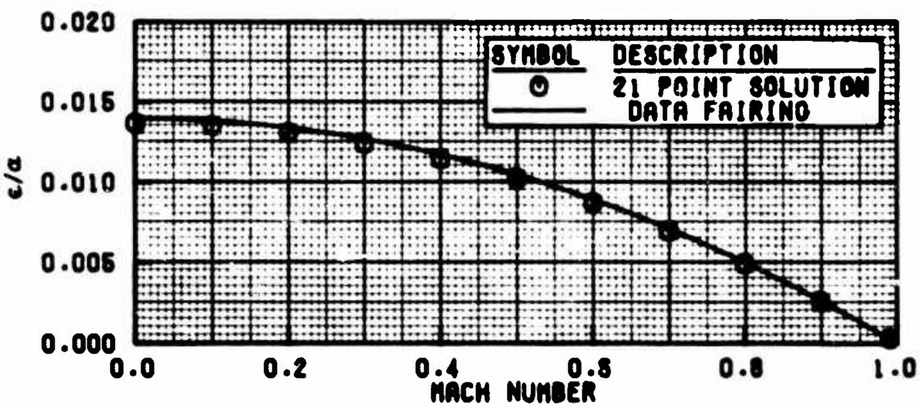


FIGURE 10: F-111A/TACT FUSELAGE UPWASH ESTIMATE

WING UPWASH ESTIMATES:

Upwash estimates for the F-111A/TACT supercritical wing were obtained at three wing sweep angles using a thin-airfoil analysis and the Yaggy-Rogallo production software. Leading edge sweep angles of 26°, 35°, and 58° were selected because they gave a wide range of wing sweep angles and because the best flight test data were available. The geometry of the wing was obtained from physical description data contained in reference 17. The data were for a "theoretical trapezoidal" wing so that it was not necessary to develop an equivalent geometry. The physical data used in the analysis are presented in Table 1. These data were entered on punched cards using the User's Guide for the Yaggy-Rogallo Production Software as a reference to obtain the input data deck, shown in Figure 11 for 26° wing sweep, and two other decks not shown. The input data decks were processed through program WING to obtain upwash estimates for the three wing sweep angles.

TABLE 1: F-111A/TACT WING DATA

Λ_{LE}	WING SPAN	ASPECT RATIO	$\Lambda_{C/4}$	$FS_{C/4}$
26.0	664.02	5.07	23.34	457.28
35.0	617.34	4.39	32.42	442.96
58.0	471.54	2.56	55.70	384.55

The output of program WING consisted of a single page of lineprinter listing for each wing sweep angle. The output for the 26° wing sweep as shown in Figure 12 corresponds to the input data deck in Figure 11. The output which is described fully in Appendix C were obtained for the three wing sweep angles and plotted as shown in Figure 13. This is the recommended form for using the data in data reduction and analysis and normally the data should be left in this form. It is not, however, compatible with many existing data reduction procedures so efforts were made to change the form of the data and combine the data with the fuselage estimates to obtain a single upwash estimate.

```
HEAD1                              F-111A/TACT AIRCRAFT
HEAD2TRAPEZOIDAL WING                                                      26 WING SWEEP
WINGS    IN     -68.45      457.28     664.02        5.07       23.34
MACHV    11  0.0         0.1         0.2         0.3         0.4         0.5         0.6
MACHV        0.7         0.8         0.9         0.99
END
```

FIGURE 11: "WING" INPUT DATA FOR F-111A/TACT 26° WING SWEEP CONFIGURATION

COMBINATION OF COMPONENT ESTIMATES:

Combination of upwash estimates for the F-111A/TACT aircraft was easily accomplished using the procedures recommended in the Yaggy-Rogallo Analysis section of this memorandum. However, the ε/C_L format was incompatible with the programs and data base which were used to compare Yaggy-Rogallo results with flight test data. The estimates were, therefore, converted to an ε/α format using the lift-curve slopes contained in reference 18 and presented in Figure 14 and zero-lift angles of attack (not presented). The results were satisfactory for an angle-of-attack calibration comparison and are discussed in the following subsection. At the lower lift coefficients (0.1 to 0.2), however, a 50% difference in estimated upwash angle was noted between using the average lift curve slope obtained at moderate lift coefficients (near 0.465) and the correct one. Although changing from ε/C_L to ε/α yielded acceptable results for this study, it is not recommended for normal use.

COMPARISON WITH FLIGHT TEST DATA:

The upwash angle estimates generated for the F-111A/TACT aircraft were compared with the actual flight test data obtained during the angle-of-attack calibration. The indicated angle-of-attack values were obtained from the AFFTC NBIU on the aircraft and the true angle of attack values were obtained from the inertial navigation and pitot-static systems. The data were obtained

YAGGY-ROGALLO UPWASH CALCULATION — PAGE 1/ 1

UPWASH ESTIMATE FOR LIFTING SURFACE COMPONENTS

F-111A/TACT AIRCRAFT

TRAPEZOIDAL WING — 26 WING SWEEP

LIFTING SURFACE GEOMETRIC DETAIL:

LONGITUDINAL STATION OF VANES	-68.4500 IN
LONGITUDINAL STATION OF APEX OF QUARTER-CHORD LINE	457.2800 IN
DISTANCE FROM APEX OF QUARTER-CHORD TO VANES (XV).	525.7300 IN
SPAN (B)	664.0200 IN
TAU (XV/(B/2))	1.5835 B/2
ASPECT RATIO	5.0700
SWEEP OF QUARTER-CHORD LINE	23.3400 DEG

LIFTING SURFACE UPWASH ESTIMATES:

MACH	BETA	TAU/BETA	EFFECTIVE WING SWEEP (DEG)	EPSILON AR /CL (RAD)	EPSILON/CL (RAD)	EPSILON/CL (DEG)
0.0000	1.0000	1.5835	23.3400	.025482	.005026	.287976
.1000	.9950	1.5915	23.4449	.025241	.004978	.285247
.2000	.9798	1.6161	23.7684	.024515	.004835	.277038
.3000	.9539	1.6599	24.3387	.023298	.004595	.263285
.4000	.9165	1.7277	25.2111	.021581	.004257	.243880
.5000	.8660	1.8284	26.4847	.019349	.003816	.218663
.6000	.8000	1.9793	28.3411	.016584	.003271	.187418
.7000	.7141	2.2173	31.1410	.013263	.002616	.149880
.8000	.6000	2.6391	35.7222	.009361	.001846	.105786
.9000	.4359	3.6327	44.7098	.004884	.000963	.055191
.9900	.1411	11.2250	71.8961	.000536	.000106	.006063

FIGURE 12: "WING" OUTPUT FOR F-111A/TACT 26° WING SWEEP CONFIGURATION

from numerous constant-altitude accelerations and decelerations accomplished throughout the flight tests. The indicated values were corrected to remove local flow effects determined from a wind tunnel test documented in Reference 19. The curve of local flow errors presented in Figure 15 was used to change the indicated angle-of-attack values to "corrected angle of attack" values. The upwash angle estimates presented in Figures 10 and 13 were then used to obtain "calculated angle of attack" from the corrected values. The data are presented for 26, 35, and 58 degree wing sweeps in Figures 16(a), 16(b), and 16(c), respectively.

The plots of true angle of attack versus indicated angle of attack show errors in indicated angle of attack which are normally attributed totally to upwash. However, when the NBIU calibration was applied to obtain the corrected angles of attack, about half of the error was removed. The upwash angle estimates obtained from the Yaggy-Rogallo technique were applied directly without any modification to obtain the calculated angle of attack values. As can be noted from Figure 16, these estimates were excellent in predicting the upwash angles. Close examination indicates that the Yaggy-Rogallo technique slightly under-estimated upwash angle for the 26 degree wing sweep and slightly over-estimated upwash angle for the 58 degree wing sweep upwash, but the errors could be easily removed by only a small change in level of the upwash estimation curves based on this data. On the 58 degree wing sweep plot, several points which lay outside the data grouping were removed during analysis. The points were not random scatter but were caused by the inability to accurately calculate rate of climb (thus flight path angle) from the pitot static system as the aircraft accelerated or decelerated through a Mach number of 1.0. These points were actually the result of inability to accurately calculate true angle of attack and were not related to the NBIU or the Yaggy-Rogallo technique.

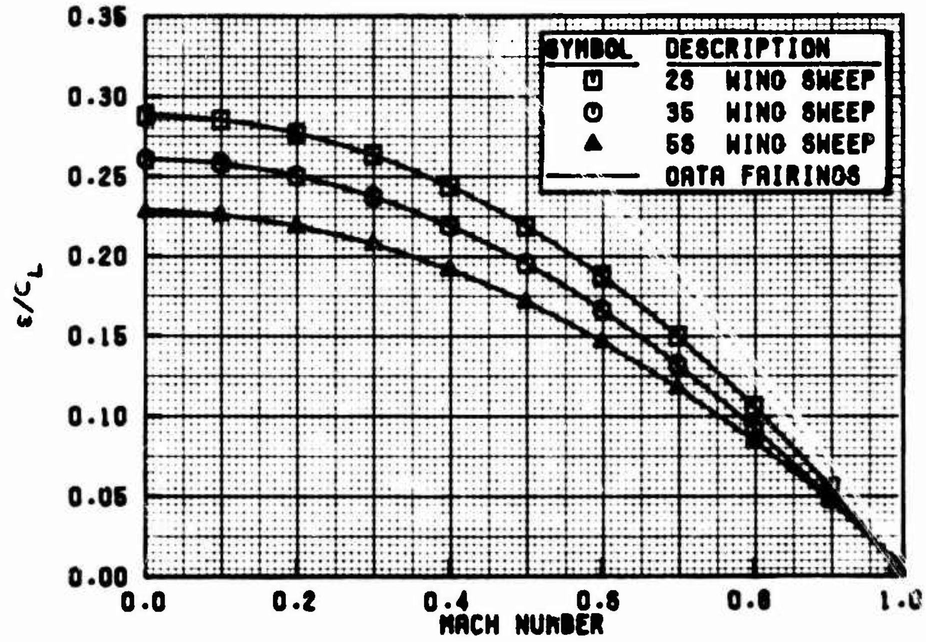
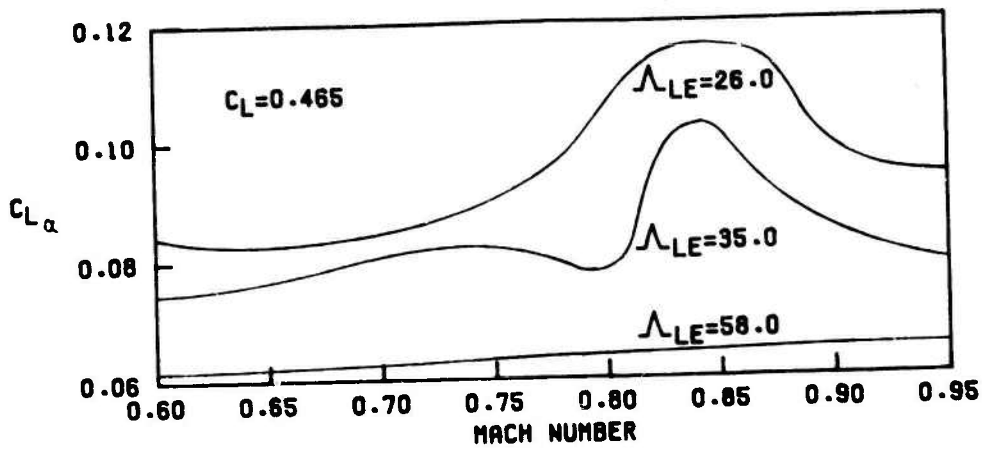
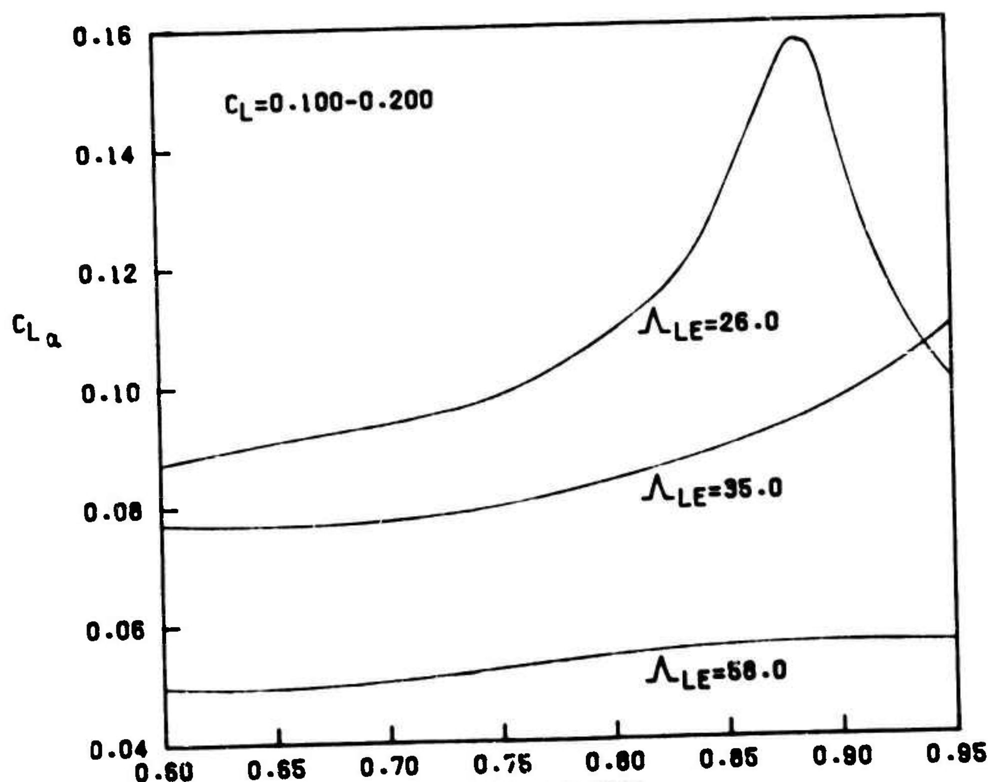


FIGURE 13: F-111A/TACT LIFTING SURFACE UPWASH ESTIMATES



B) DESIGN LIFT COEFFICIENT



A) LOW LIFT COEFFICIENTS

FIGURE 14: F-111A/TACT LIFT CURVE SLOPE

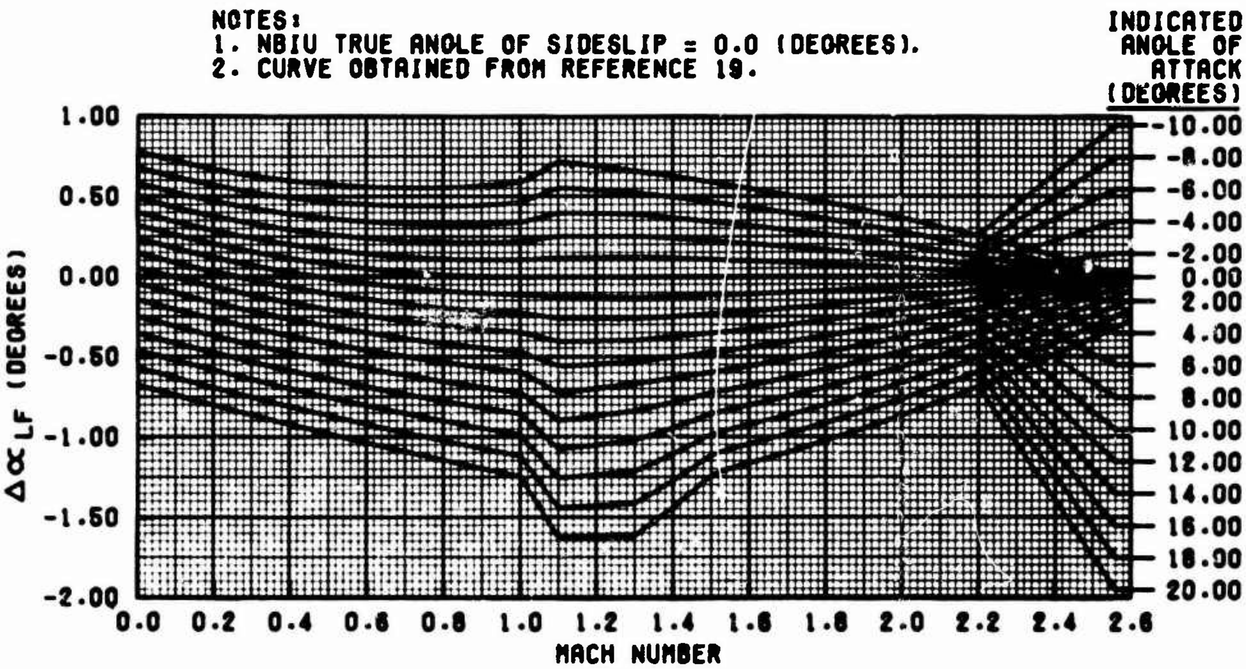
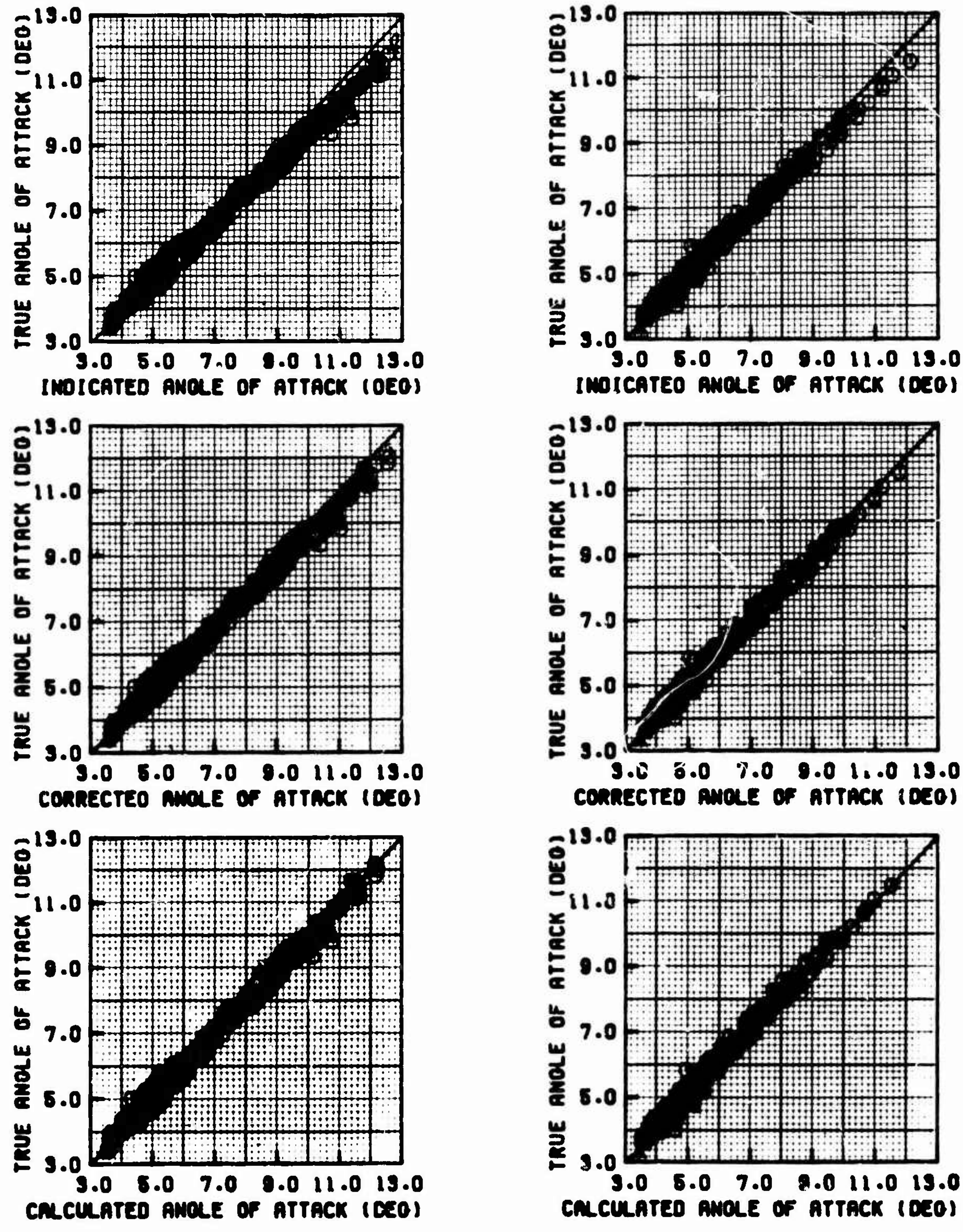


FIGURE 15: AFFTC NBIU LOCAL FLOW CORRECTION



A) 26 DEGREE WING SWEEP

B) 35 DEGREE WING SWEEP

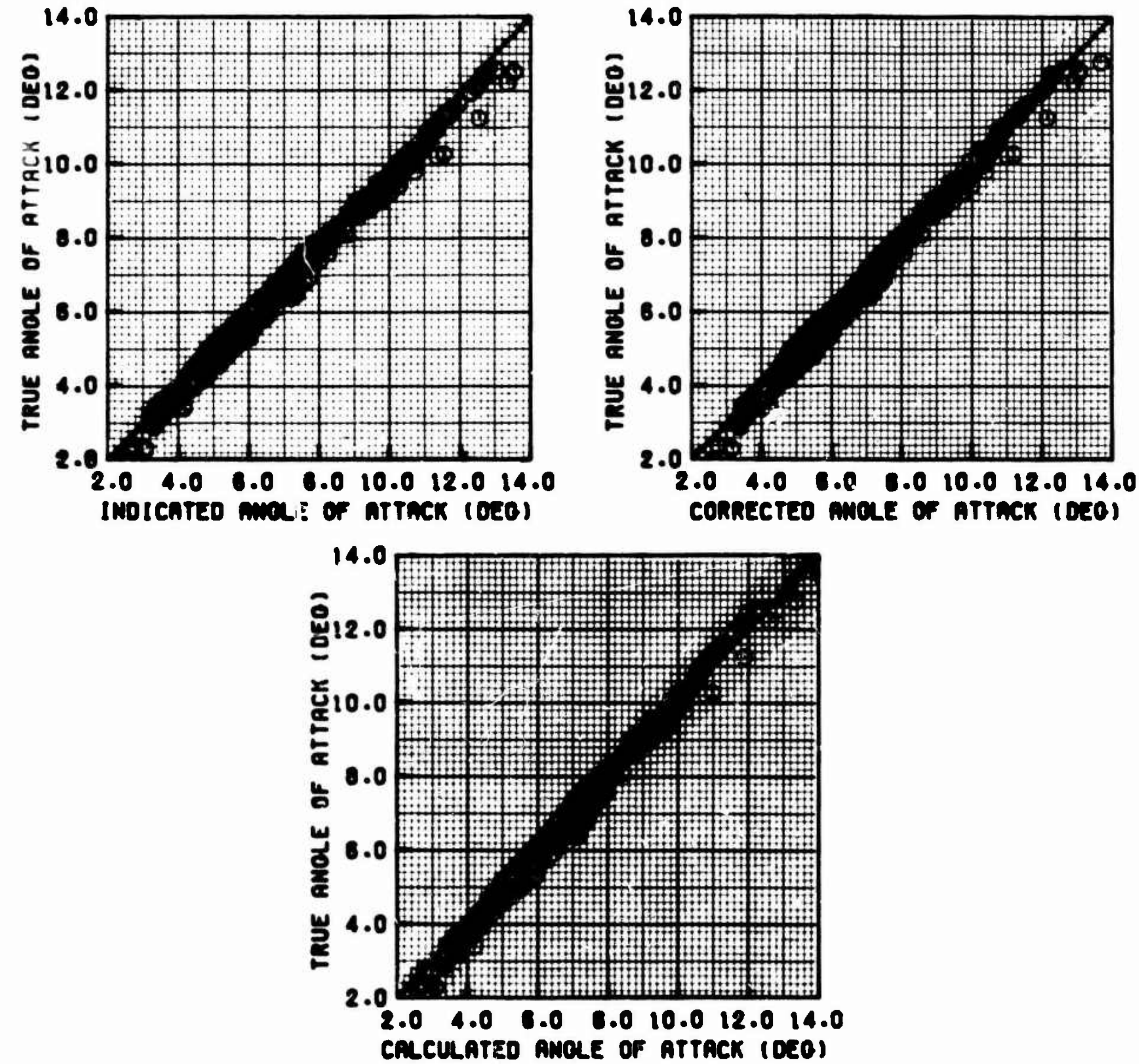
FIGURE 16: F-111A/TACT ANGLE OF ATTACK CALIBRATION

NOTES:

1. $\alpha_{CORRECTED} = \alpha_{INDICATED} + \Delta\alpha_{LF}$

2. $\alpha_{CALCULATED} = \alpha_{CORRECTED} + \epsilon_{YAGGY-ROGALLO}$

3. DATA OBTAINED FROM LEVEL ACCELERATIONS AND DECELERATIONS.



C) 58 DEGREE WING SWEEP

FIGURE 16: F-111A/TACT ANGLE OF ATTACK CALIBRATION (CONCLUDED)

NOSEBOOM CORRECTION ESTIMATES

The correction of the NBIU calibration for changes in noseboom upwash is another important application for Yaggy-Rogallo technique. The NBIU calibration contains an error in angle of attack due to upwash of the wind tunnel noseboom which changes when a different noseboom is used. Rather than subtract the whole upwash estimate predicted by Yaggy-Rogallo from the NBIU calibration data, the difference in upwash estimates between the wind tunnel boom configuration and the test boom configuration is added. This is consistent with the AFFTC philosophy of making only incremental corrections to test data and doesn't tie the user to the Yaggy-Rogallo technique if a new and better technique is developed.

The wind tunnel noseboom configuration shown in Figure 17 was processed through the Yaggy-Rogallo production software as was the KC-135/WINGLETS noseboom configuration shown in Figure 18. The results of both runs are displayed in Figure 19. The difference curve was entered as a correction to the KC-135/WINGLETS upwash estimate and combined with estimates for other components.

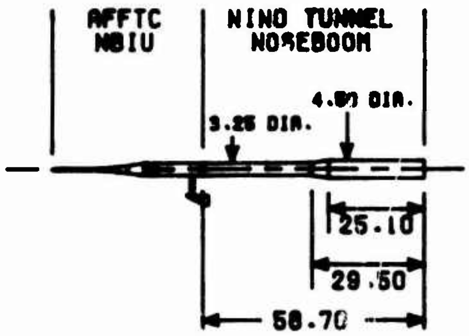


FIGURE 17: WIND TUNNEL NOSEBOOM CONFIGURATION

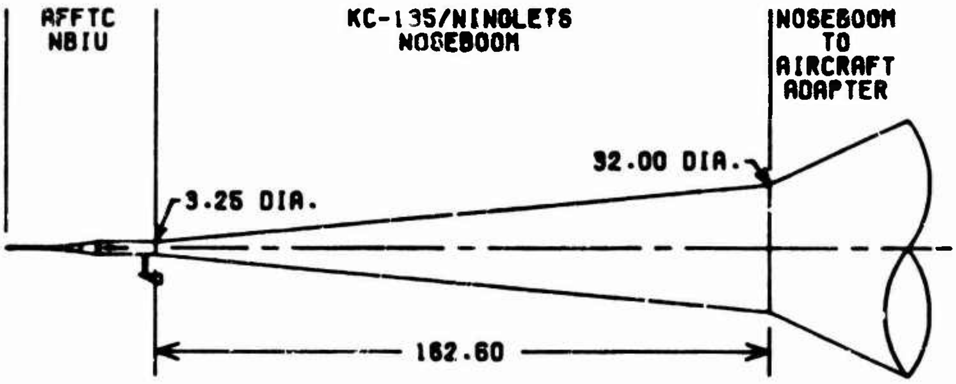


FIGURE 18: KC-135/WINGLETS NOSEBOOM CONFIGURATION

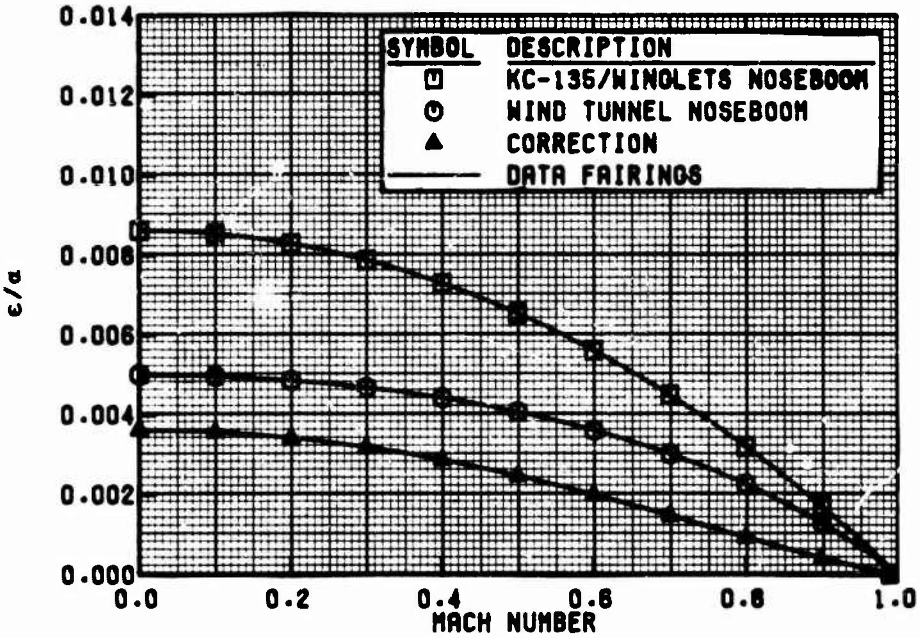


FIGURE 19: KC-135/WINGLETS CORRECTION FOR NOSEBOOM CONFIGURATION

SUMMARY

The Yaggy-Rogallo technique for estimating upwash angles at noseboom-mounted vanes has been documented in this memorandum. The origin of the technique has been investigated and referenced to establish confidence in the technique. The limitations and assumptions have been discussed and recommendations on use of the technique have been made. The source of all curves and equations have been shown and an audit trail of all data has been established. From these investigations, standard software and procedures have been developed and documented for future use.

The use of the Yaggy-Rogallo technique in data reduction and analysis significantly increases the accuracy of angle-of-attack data and reduces the work in analyzing upwash calibration data. By predicting characteristics and, in most cases, the level of curves, the technique allows development of data reduction curves with minimum effort. The newly developed production software produces preliminary curves based on aircraft geometry alone. When used in conjunction with an NBIU wind-tunnel calibration to remove local-flow effects and an upwash calibration to adjust level of the upwash estimation curves, the technique offers a uniform, yet flexible, method of obtaining accurate angle-of-attack data.

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APPENDIX A
DERIVATION OF THE EQUATION FOR UPWASH ANGLE INDUCED BY A BODY OF REVOLUTION

INTRODUCTION

The basic concepts for calculating the upwash angle induced by a body of revolution were developed by Theodor Von Karman in Reference 3. Although the goal of the memorandum was calculation of pressure distribution around airship hulls, part of the solution involved calculation of a potential function for flow around the body of revolution and hence velocity distribution. Paul F. Yaggy applied this theory to determination of upwash angle induced by nacelles on the flow at the propeller plane in Reference 1. In his development Yaggy narrowed the development to determination of induced angle only and validated the technique by comparison with test data on several nacelle configurations.

Yaggy's technique was later applied to nacelles on swept wing aircraft by Vernon L. Rogallo in Reference 2. Although Rogallo corrected other parts of his analysis for compressibility effects, he applied Yaggy's nacelle equations without correction even at high subsonic Mach numbers. Violation of potential flow assumptions at the higher Mach numbers lowered confidence in the calculation. Donald R. Bellman developed a compressibility correction to the Yaggy equation which was used in Reference 9. The correction, which was based on determining an "effective" geometry which varied with Mach number, allowed acceptable estimation of upwash at all Mach numbers. Development of the Yaggy equation and the subsequent compressibility correction are outlined in the following sections.

YAGGY EQUATION DEVELOPMENT

The derivation for upwash induced by a nacelle presented in Reference 1 is suitable for general application except for its restriction to the horizontal meridian plane. The following derivation of the Yaggy equation closely follows Yaggy's original work except for minor terminology and sign changes necessary to make it compatible with currently accepted aircraft coordinate systems. The derivation was also expanded to allow varying radial position around the body.

GEOMETRIC/COORDINATE SPECIFICATION:

The geometry of an arbitrary body of revolution as specified in rectangular coordinates is shown in Figure A1. The longitudinal body axis, X axis, is the axis of revolution (axis of symmetry) and is positive forward. The lateral body axis, Y axis, and vertical body axis, Z axis, are positive as shown. The body is at angle of attack, α, such that a transverse flow in the direction of the -Z axis of velocity W is induced. The angle of attack, transverse velocity, and uniform freestream velocity, V_T, are related by equation (A1). The longitudinal velocity component, U, is defined by $U = V_T \cos(\alpha)$. The lateral velocity component is considered identically zero for all cases so that angles of sideslip other than zero are never considered.

$$\alpha = \sin^{-1}(W/V_T) \tag{A1}$$

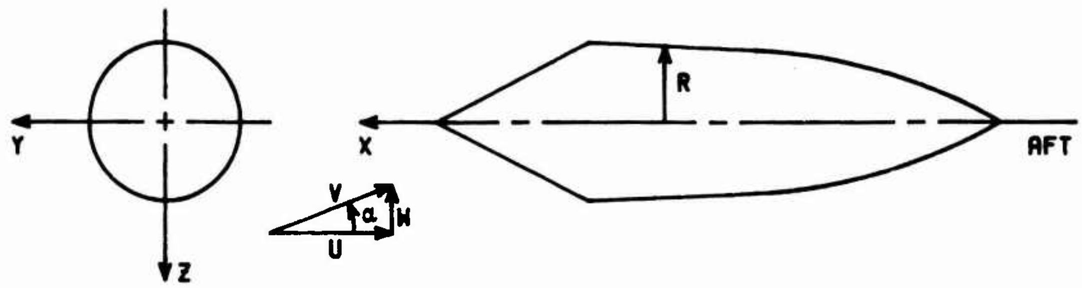


FIGURE A1: BODY OF REVOLUTION IN RECTANGULAR COORDINATES

The potential function for doublet flow is more simply developed in polar coordinates so a coordinate transformation was performed. The angular position around the longitudinal axis, Ω, and the radial distance from the longitudinal axis, r, of an arbitrary point, P, are defined and related to the rectangular coordinate system in Figure A2. Distances along the longitudinal axis are defined by a new variable, d, such that d = 0 where the perpendicular plane containing point P intersects the longitudinal axis. The sign of distances are determined to be positive when the point P is downstream of a doublet element located on an element, dx, of the longitudinal axis. Thus, distances forward of d = 0 are positive and distances aft of d = 0 are negative. The definition of adjusted longitudinal distances and of the remaining angular coordinate, θ, of the polar coordinate system are shown in Figure A3. The angle θ as defined in equation (A2) goes from θ = 0 an infinite distance upstream (forward) to θ = π an infinite distance downstream (aft).

$$\theta = \cot^{-1}(d/|r|) \qquad 0 \le \theta \le \pi \qquad \text{(A2)}$$

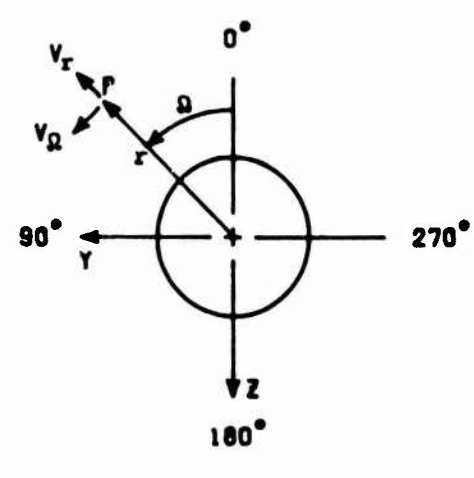


FIGURE A2: DEFINITION OF Ω AND r

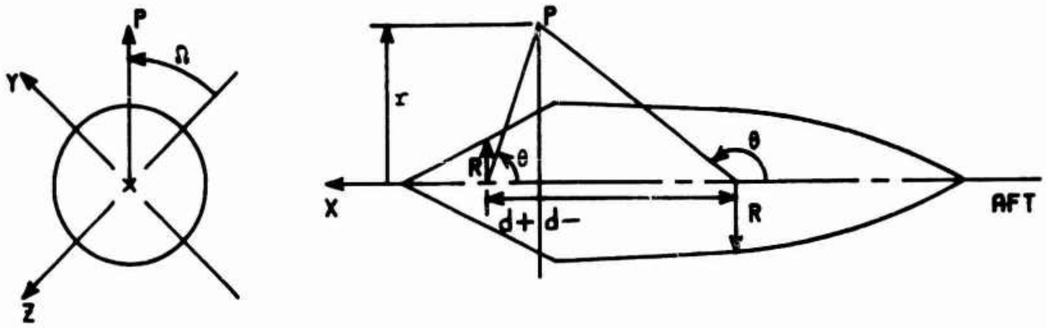


FIGURE A3: DEFINITION OF d AND θ

POTENTIAL FUNCTION DEVELOPMENT:

An infinitely long cylinder of constant radius in a transverse flow may be represented by covering the longitudinal axis with doublets of moment per unit length, μ. If the transverse flow is along the -Z axis and the doublets are oriented with their axes along the Z axis, the potential function of a doublet element of strength μdx in polar coordinates is defined in equation (A3). The potential function for the infinite cylinder can then be obtained by integrating equation (A3) from infinitely upstream where $\theta = 0$ to infinitely downstream where $\theta = \pi$. The potential function is then defined by equation (A4). The potential function for a body of finite length may be obtained by integrating from θ at the leading edge, θ_{LE}, to θ at the trailing edge, θ_{TE}, of the body as in equation (A5).

$$d\Phi = \frac{-\mu}{4\pi r} \cos\Omega \sin\theta \, d\theta \tag{A3}$$

$$\Phi = \frac{-\cos\Omega}{4\pi r} \int_0^{\pi} \mu \sin\theta \, d\theta \tag{A4}$$

$$\Phi = \frac{-\cos\Omega}{4\pi r} \int_{\theta_{LE}}^{\theta_{TE}} \mu \sin\theta \, d\theta \tag{A5}$$

Potential functions for bodies of varying radius, R, can be developed in a similar manner by varying the strength of the doublet elements along the longitudinal axis. The strength of the elements must be related to the radius of the body and the transverse velocity by equation (A6). Substituting equation (A6) into equation (A5) yields the potential function for a finite body of varying radius shown in equation (A7).

$$\mu = 2\pi R^2 W \tag{A6}$$

$$\Phi = \frac{-W \cos\Omega}{2r} \int_{\theta_{LE}}^{\theta_{TE}} R^2 \sin\theta \, d\theta \tag{A7}$$

YAGGY EQUATION FORMULATION:

The velocity components V_Ω and V_r as shown in Figure A2 are defined by equations (A8) and (A9) from References 15 and 16. Differentiating equation (A7) and substituting into equations (A8) and (A9) yields equations (A10) and (A11) respectively. The vertical velocity V_Z is then defined by equation (A12).

$$V_r = - \frac{d\Phi}{dr} \tag{A8}$$

$$V_\Omega = - \frac{1}{r} \frac{d\Phi}{d\Omega} \tag{A9}$$

$$V_r = - \frac{W \cos\Omega}{2r^2} \int_{\theta_{LE}}^{\theta_{TE}} R^2 \sin\theta \, d\theta \tag{A10}$$

$$V_\Omega = \frac{W \sin\Omega}{2r^2} \int_{\theta_{LE}}^{\theta_{TE}} R^2 \sin\theta \, d\theta \tag{A11}$$

$$V_Z = V_\Omega \cdot \sin\Omega - V_r \cdot \cos\Omega \tag{A12}$$

Substituting equations (A10) and (A11) into equation (A12) and rearranging yields equation (A13). But $W = V_T \sin \alpha$, or for small angles of attack $W \doteq V_T \alpha$, so that equation (A13) becomes equation (A14). However, since the induced angle is small, $\varepsilon \doteq V_z/V_T$ and equation (A14) becomes (A15).

$$V_Z = W \frac{\sin^2\Omega - \cos^2\Omega}{2r^2} \int_{\theta_{LE}}^{\theta_{TE}} R^2 \sin\theta \, d\theta \tag{A13}$$

$$V_Z = V_T\alpha \frac{\sin^2\Omega - \cos^2\Omega}{2r^2} \int_{\theta_{LE}}^{\theta_{TE}} R^2 \sin\theta \, d\theta \tag{A14}$$

$$\frac{\varepsilon}{\alpha} = \frac{\sin^2\Omega - \cos^2\Omega}{2r^2} \int_{\theta_{LE}}^{\theta_{TE}} R^2 \sin\theta \, d\theta \tag{A15}$$

COMPRESSIBILITY CORRECTION:

Violation of potential flow assumptions used in formulating the Yaggy equation lowered confidence in the results obtained at high subsonic Mach numbers. Donald R. Bellman developed a compressibility correction based on determining an "effective" geometry which varied with Mach number. To account for compressibility, these actual geometric distances must be adjusted by a compressibility factor, β, defined by $\beta = \sqrt{1-M^2}$. The effect of compressibility is to create an effective geometry such that sections forward of the vane appear closer to the vane and sections aft of the vane appear further away. This continues until at Mach number of 1.0 and beyond the body has practically no effect and upwash is considered to go to zero. For Mach numbers between 0.0 and 1.0 the effective distances are defined by equation (A16). The effective angles are similarly redefined in equation (A17). Equation (A15) then is transformed to equation (A18) when corrections for compressibility are included.

$$\begin{aligned} \tilde{d} &= d\cdot\beta & \quad d &\geq 0 \text{ (forward)} \\ \tilde{d} &= d/\beta & \quad d &< 0 \text{ (aft)} \end{aligned} \tag{A16}$$

$$\tilde{\theta} = \cot^{-1}(\tilde{d}/|r|) \qquad 0 \leq \tilde{\theta} \leq \pi \tag{A17}$$

$$\frac{\varepsilon}{\alpha} = \frac{\sin^2\Omega - \cos^2\Omega}{2r^2} \int_{\tilde{\theta}_{LE}}^{\tilde{\theta}_{TE}} R^2 \sin\theta \, d\theta \tag{A18}$$

YAGGY EQUATION SOLUTION

The solution of the Yaggy equation was accomplished by several techniques to determine the best approach for practical application. The radius of the equivalent body of revolution as a function of θ is rarely an analytic function, but is usually a graphical or tabular representation. The variation of the radius is such that assumptions about the relationship of R to θ are valid only for small ranges of θ. Equation (A18), therefore, was converted to a summation equation so that the integration could be accomplished over small segments by assuming a relationship between R and θ. The integral portion of equation (A18) could be changed to a sum of integrals as shown in equation (A19) or more corcisely in equation (A20). Thus, if the body is divided into N-1 segments by N points where point 1 is the leading edge and point N is the trailing edge, equation (A20) can be substituted into equation (A18) to yield equation (A21).

$$\int_{\tilde{\theta}_{LE}}^{\tilde{\theta}_{TE}} R^2 \sin\tilde{\theta}\, d\tilde{\theta} = \int_{\tilde{\theta}_{LE}}^{\tilde{\theta}_2} R^2 \sin\tilde{\theta}\, d\tilde{\theta} + \int_{\tilde{\theta}_2}^{\tilde{\theta}_3} R^2 \sin\tilde{\theta}\, d\tilde{\theta} + \cdots + \int_{\tilde{\theta}_{N-1}}^{\tilde{\theta}_{TE}} R^2 \sin\tilde{\theta}\, d\tilde{\theta} \qquad \text{(A19)}$$

$$\int_{\tilde{\theta}_{LE}}^{\tilde{\theta}_{TE}} R^2 \sin\tilde{\theta}\, d\tilde{\theta} = \sum_{i=2}^{N} \int_{\tilde{\theta}_{i-1}}^{\tilde{\theta}_i} R^2 \sin\tilde{\theta}\, d\tilde{\theta} \qquad \text{(A20)}$$

$$\frac{\varepsilon}{\alpha} = \frac{\sin^2\Omega - \cos^2\Omega}{2r^2} \sum_{i=2}^{N} \int_{\tilde{\theta}_{i-1}}^{\tilde{\theta}_i} R^2 \sin\tilde{\theta}\, d\tilde{\theta} \qquad \text{(A21)}$$

Further simplification of equation (A21) depended on the method chosen to perform the integration. The term $(\sin^2\Omega - \cos^2\Omega)$ is independent of the integration so Ω was assumed to be 90 degrees so that equation (A21) was transformed to equation (A22). Since the dominant method in past implementations had been numerical integration, several numerical algorithms were tried first.

$$\frac{\varepsilon}{\alpha} = \frac{1}{2r^2} \sum_{i=2}^{N} \int_{\tilde{\theta}_{i-1}}^{\tilde{\theta}_i} R^2 \sin\tilde{\theta}\, d\tilde{\theta} \qquad \text{(A22)}$$

NUMERICAL APPROXIMATIONS:

The initial algorithm investigated for solution of equation (A22) was one that had been used extensively in past application of the Yaggy-Rogallo technique. The algorithm is presented in equation (A23) and assumes that the radius of the segment is constant along its length with a value equal to the aft radius of the actual segment. During a sensitivity study which is discussed in the Sensitivity portion of this subsection, the algorithm was found to have a high sensitivity to the number of segments into which the body is divided. Because of the unacceptable sensitivity, three other numerical algorithms were tried.

$$\frac{\varepsilon}{\alpha} = \frac{1}{2r^2} \sum_{i=2}^{N} R_i^2 \sin\tilde{\theta}_i \; (\tilde{\theta}_i - \tilde{\theta}_{i-1}) \qquad \text{(A23)}$$

The three numerical methods which were investigated were slight variations of the same algorithm. In each case the segment lengths were assumed to be short enough that R and θ could be assumed constant along the segment.

Rear Radius. The first numerical method assumed that each segment of the body was a cylinder with constant radius equal to the rear radius of the segment (R_i) and angle equal to the average value for the rear of the segment (θ_i) and the front of the segment θ_{i-1} so that equation (A22) was transformed into equation (A24).

$$\frac{\varepsilon}{\alpha} = \frac{1}{2r^2} \sum_{i=2}^{N} R_i^2 \sin\frac{\tilde{\theta}_i + \tilde{\theta}_{i-1}}{2} \; (\tilde{\theta}_i - \tilde{\theta}_{i-1}) \qquad \text{(A24)}$$

Forward Radius. Similarly, the second numerical method assumed that each segment of the body was a cylinder with constant radius equal to the forward radius of the segment (R_{i-1}). The angle equal to the average value for the segment was again used on this method. Equation (A22) was transformed into equation (A25) using the second parameters.

$$\frac{\varepsilon}{\alpha} = \frac{1}{2r^2} \sum_{i=2}^{N} R_{i-1}^2 \sin\frac{\tilde{\theta}_i + \tilde{\theta}_{i-1}}{2} \; (\tilde{\theta}_i - \tilde{\theta}_{i-1}) \qquad \text{(A25)}$$

Average Radius. The third numerical method assumed that each segment of the body was a cylinder of constant radius equal to the average of the front and rear radii of the segment. Using these parameters, equation (A22) was transformed into equation (A26).

$$\frac{\varepsilon}{\alpha} = \frac{1}{2r^2} \sum_{i=2}^{N} \left[\frac{R_i - R_{i-1}}{2}\right]^2 \sin\frac{\tilde{\theta}_i + \tilde{\theta}_{i-1}}{2} \; (\tilde{\theta}_i - \tilde{\theta}_{i-1}) \qquad \text{(A26)}$$

Equations (A24), (A25), and (A26) were used to evaluate the sensitivity of numerical-integration techniques to the method of estimating radius, to the choice of number of points, and to round-off and recording errors during hand calculation.

Sensitivity. The sensitivity study was conducted on a typical fighter fuselage by picking various numbers of segments, choosing points to define the segments, and calculating upwash estimates using equations (A23), (A24), (A25), and (A26). The numbers of points chosen were 9, 21, 42, and 83 points along an approximately 900 inch fuselage. For the 9 and 21 point tests, the points were selected to best represent the area versus fuselage station plot with straight line segments. The 42 point test essentially defined the curve exactly and the 83 points were selected by linear interpolation between the 42 points. The sensitivity of the primary method used in the past to the number of points selected is shown in Figure A4 and the sensitivity to the number of points and to the method of estimating radius of the three numerical-integration techniques are shown in Figure A5. The number of points significantly affected the accuracy of the upwash estimates as shown by comparison with the optimum solution obtained from exact integration. If either the forward or aft radius of the segment were chosen as in Figure A5, the technique did not converge to the optimum solution with 83 points. If the average radius were chosen as in Figure A5, at least 42 points were needed and 83 points preferred although 83 points was well within past guidelines for selecting the number of points. The sensitivity of the techniques to round-off errors incurred during hand calculation and recording were insignificant.

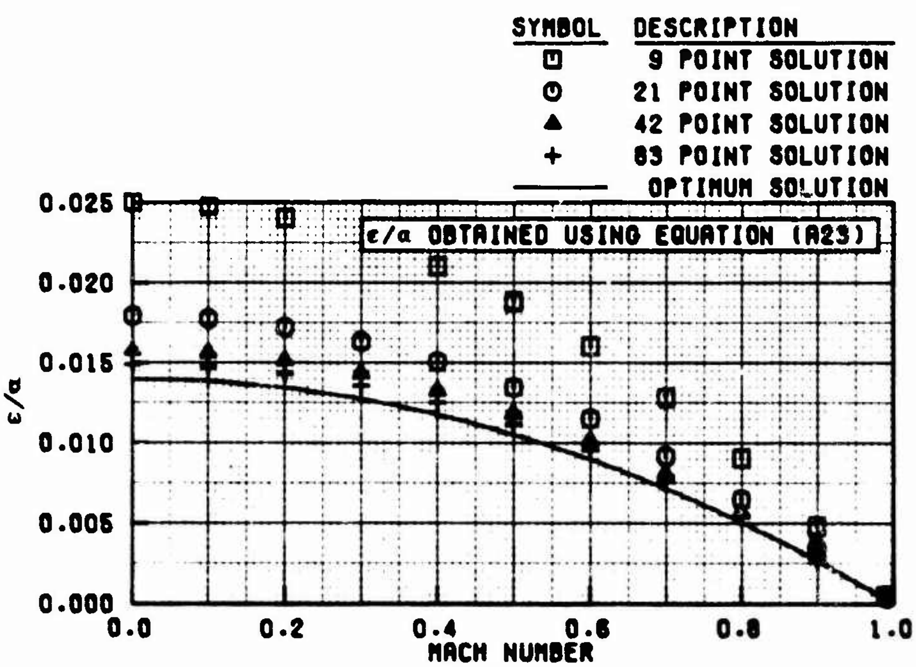


FIGURE A4: SENSITIVITY OF ACCEPTED METHOD

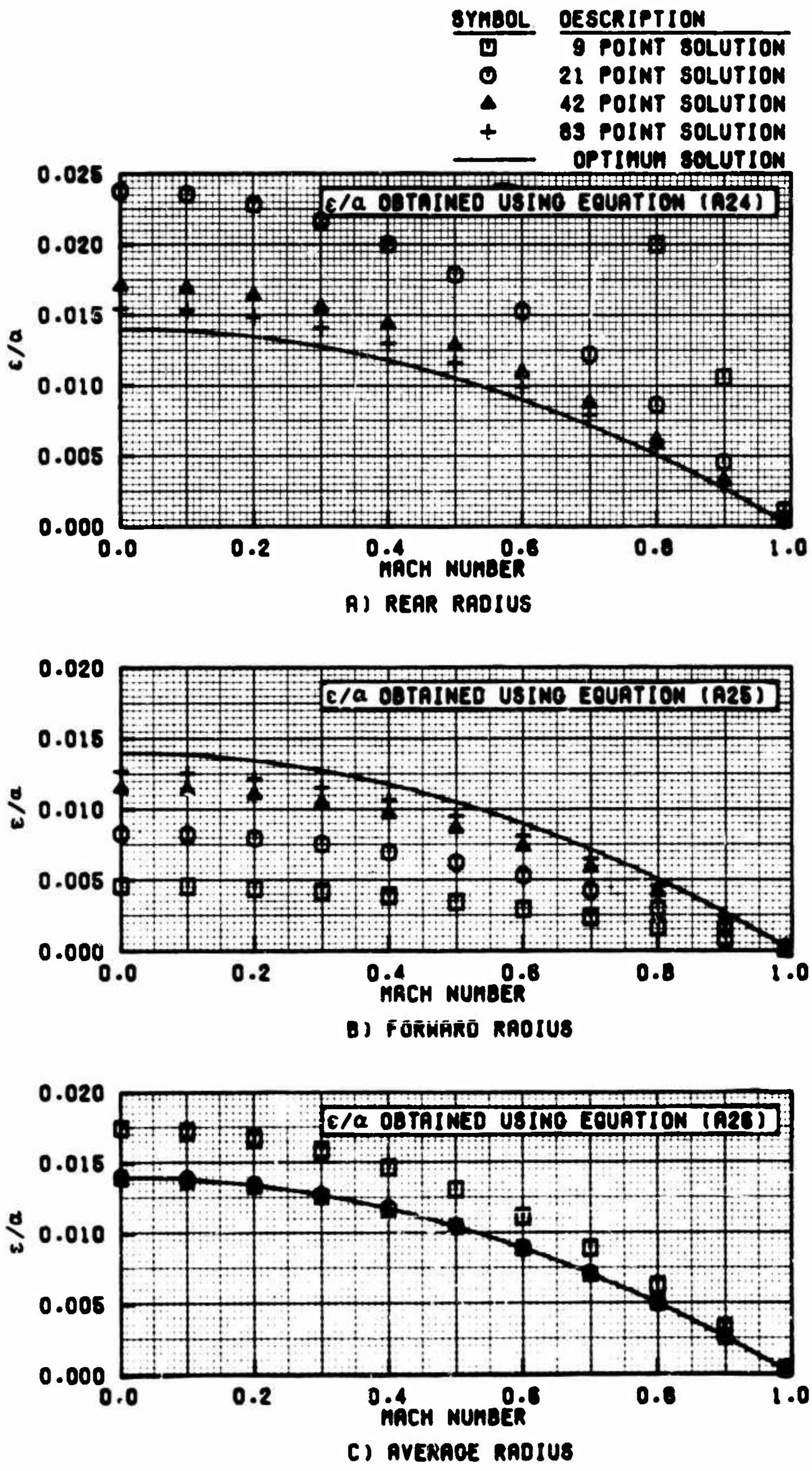


FIGURE A5: COMPARISON OF SENSITIVITY OF THREE NUMERICAL-INTEGRATION METHODS OF UPWASH ESTIMATION FOR A TYPICAL FIGHTER FUSELAGE

The sensitivity study of the numerical techniques indicated deficiencies in the numerical method; the prime one being the extreme sensitivity to the number of points selected. A user could unknowingly select too few points and, coupled with a poor choice of radius, get highly erroneous results. Increasing the number of points and making other assumptions about variations of R with θ could improve the accuracy of the methods to acceptable levels, but make the whole technique ungainly and difficult to implement. Exact integration of the integral portion of equation (A22) proved a better alternative than improved numerical techniques.

EXACT INTEGRATION TECHNIQUES:

Exact integration of the integral portion of equation (A22) is a practical and far more accurate means of solving the equation. As with the numerical methods, assumptions must be made about the variation of R with θ. It is not, however, necessary to assume that the segments approach infinitesimal length and finite-length segments may be used. The length of the segments may be as long as desired if the assumed function of R with θ is valid. Accuracy of the solution is totally dependent on proper selection of the function of radius along the length of the body. Three functions of R with θ were investigated to determine the most practical method for future application.

Finite Cylinder. The finite cylinder was selected as the first estimation of body shape both because of its simplicity and because of its correspondence to the third numerical technique. The radius of the segment was taken as the average of the front and rear radii as shown in equation (A27). Using this relationship which makes R independent of θ, equation (A22) can be transformed to yield equation (A28). The integral can be easily evaluated to yield equation (A29).

$$R = \frac{R_i + R_{i-1}}{2} \tag{A27}$$

$$\frac{\varepsilon}{\alpha} = \frac{1}{2r^2} \sum_{i=2}^{N} \left[\frac{R_i + R_{i-1}}{2}\right]^2 \int_{\tilde{\theta}_{i-1}}^{\tilde{\theta}_i} \sin\tilde{\theta}\, d\tilde{\theta} \tag{A28}$$

$$\frac{\varepsilon}{\alpha} = \frac{1}{2r^2} \sum_{i=2}^{N} \left[\frac{R_i + R_{i-1}}{2}\right]^2 \left[\cos\tilde{\theta}_{i-1} - \cos\tilde{\theta}_i\right] \tag{A29}$$

Finite Cone. The finite cone solution was similarly obtained by assuming that the radius of each segment varies linearly along the segment. The slope of the cone edge is defined by the expression $(R_{i-1} - R_i)/(\tilde{d}_{i-1} - \tilde{d}_i)$ so that the radius is defined by equation (A30). Using the relationship of $\tilde{d}$ to $\tilde{\theta}$ defined in equation (A17), equation (A30) was transformed to equation (A31). Equation (A31) was rearranged to yield equation (A32). Equation (A32) can then be substituted into equation (A22) to yield equation (A33).

$$R = \frac{R_{i-1}-R_i}{\tilde{d}_{i-1}-\tilde{d}_i}(\tilde{d}-\tilde{d}_i) + R_i \tag{A30}$$

$$R = \frac{R_{i-1}-R_i}{\cot\tilde{\theta}_{i-1}-\cot\tilde{\theta}_i}(\cot\tilde{\theta}-\cot\tilde{\theta}_i) + R_i \tag{A31}$$

$$R = K_1\cot\tilde{\theta} + K_2 \tag{A32}$$

where $K_1 = (R_{i-1}-R_i)/(\cot\tilde{\theta}_{i-1}-\cot\tilde{\theta}_i)$

$K_2 = R_i - K_1\cot\tilde{\theta}_i$

$$\frac{\varepsilon}{\alpha} = \frac{1}{2r^2}\sum_{i=2}^{N}\int_{\tilde{\theta}_{i-1}}^{\tilde{\theta}_i}\left[K_1^2\cot^2\tilde{\theta} + 2K_1K_2\cot\tilde{\theta} + K_2^2\right]\sin\tilde{\theta}\,d\tilde{\theta} \tag{A33}$$

$$\frac{\varepsilon}{\alpha} = \frac{1}{2r^2}\sum_{i=2}^{N}\left[(K_1^2-K_2^2)(\cos\tilde{\theta}_i-\cos\tilde{\theta}_{i-1}) + 2K_1K_2(\sin\tilde{\theta}_i-\sin\tilde{\theta}_{i-1}) + K_1^2\ln\left(\frac{\tan(\tilde{\theta}_i/2)}{\tan(\tilde{\theta}_{i-1}/2)}\right)\right] \tag{A34}$$

Linear Area. The third exact integration solution was obtained by assuming that the cross-sectional area of the segments varied linearly along the length of the segment. The area is then defined by the equation (A35). The area, however, is defined by the equation $A = \pi R^2$ and the relationship of $\tilde{d}$ to $\tilde{\theta}$ is defined in equation (A17) so that equation (A35) was transformed into equation (A36). Equation (A36) was then transformed into equation (A37) and substituted into equation (A22) to yield equation (A38). Equation (A38) was integrated to yield equation (A39).

$$A = \frac{A_{i-1}-A_i}{\tilde{d}_{i-1}-\tilde{d}_i}(\tilde{d}-\tilde{d}_i) + A_i \qquad \text{(A35)}$$

$$R^2 = \frac{R_{i-1}^2-R_i^2}{\cot\tilde{\theta}_{i-1}-\cot\tilde{\theta}_i}(\cot\tilde{\theta}-\cot\tilde{\theta}_i) + R_i^2 \qquad \text{(A36)}$$

$$R^2 = K_1'\cot\tilde{\theta} + K_2' \qquad \text{(A37)}$$

where $K_1' = (R_{i-1}^2-R_i^2)/(\cot\tilde{\theta}_{i-1}-\cot\tilde{\theta}_i)$

$K_2' = -K_1'\cot\tilde{\theta}_i + R_i^2$

$$\frac{c}{a} = \frac{1}{2r^2}\sum_{i=2}^{N}\int_{\tilde{\theta}_{i-1}}^{\tilde{\theta}_i}\left[K_1'\cot\tilde{\theta} + K_2'\right]\sin\tilde{\theta}\, d\tilde{\theta} \qquad \text{(A38)}$$

$$\frac{c}{a} = \frac{1}{2r^2}\sum_{i=2}^{N}\left[K_1'(\sin\tilde{\theta}_i-\sin\tilde{\theta}_{i-1}) + K_2'(\cos\tilde{\theta}_{i-1}-\cos\tilde{\theta}_i)\right] \qquad \text{(A39)}$$

Sensitivity. The sensitivity of the exact integration techniques to the method of estimating radius, to the choice of number of points, and to round-off and recording errors was evaluated with the same data points used on the numerical-integration techniques. As expected, all three methods were less sensitive to the number of points selected than the numerical techniques as shown in Figure A6. The finite cone showed some sensitivity, but the finite cylinder and linear area methods were essentially insensitive from 21 through 83 points as shown in Figure A6. Check cases were hand calculated for all three methods and the finite cone proved to be difficult to hand calculate and extremely sensitive to round-off and recording errors. No particular problems were noted with the other methods.

The analysis of both the numerical- and exact-integration techniques indicated that the most practical method of solving the Yaggy equation was the linear-area-variation method. Only on bodies which were actually conical did the finite cone provide better results, and its added complexity and sensitivity were unwarranted. The linear-area-variation method provided the best upwash estimates in practically all cases, was the least sensitive to the number of points selected, and was almost as simple and adaptable to hand calculation as the numerical techniques. Therefore, equation (A21) was solved using the linear-area-variation method to evaluate the integral portion and resulted in equation (A40). The recommended equation for general use and the equation implemented in the production software was equation (A40).

$$\frac{\varepsilon}{\alpha} = \frac{\sin^2\Omega - \cos^2\Omega}{2r^2} \sum_{i=2}^{N} \left[K_1'(\sin\tilde{\theta}_i - \sin\tilde{\theta}_{i-1}) + K_2'(\cos\tilde{\theta}_{i-1} - \cos\tilde{\theta}_i) \right] \tag{A40}$$

where $K_1' = (\tilde{R}_{i-1}^2 - \tilde{R}_i^2)/(\cot\tilde{\theta}_{i-1} - \cot\tilde{\theta}_i)$

$K_2' = -K_1'\cot\tilde{\theta}_i + \tilde{R}_i^2$

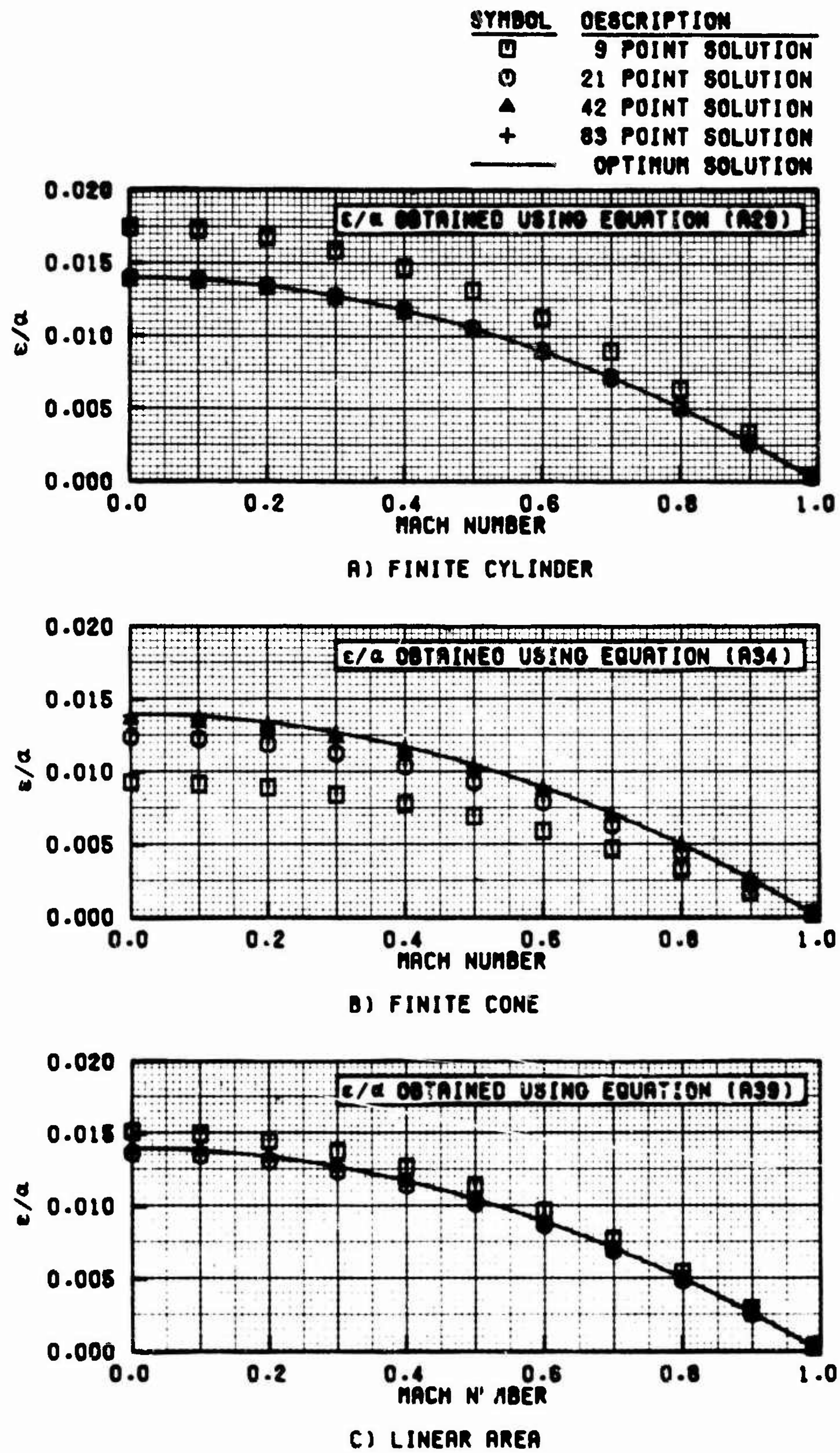


FIGURE A6: COMPARISON OF SENSITIVITY OF THREE EXACT-INTEGRATION METHODS OF UPWASH ESTIMATION FOR A TYPICAL FIGHTER FUSELAGE

APPENDIX B
DERIVATION OF THE EQUATION FOR UPWASH ANGLE INDUCED BY AN ARBITRARY WING

INTRODUCTION

The estimation of induced velocities and angles in the flow field of arbitrary wings is an extensive and complicated subject which received much attention by early theoretical and experimental aerodynamists. The methods and theories developed by early researchers were compared extensively with test results and experimental data. Although individual methods compared more or less favorably with experimental results, general conclusions and trends could be drawn. The most important conclusion was that most aerodynamic characteristics of a vehicle could be obtained accurately by independent treatment of the wing, fuselage, and nacelle components. Except for flow in the immediate vicinity of the junction of bodies, the aerodynamic characteristics could be determined based on geometry of individual components and combined with similar characteristics from the other components with only simple or no interference corrections. Another important conclusion was that the effects due to thickness, twist, camber, and flap deflection could be handled through modification of spanwise loading so that the wing could be assumed to be a "thin airfoil". These conclusions allowed treatment of wing induced velocities and angles independent of other bodies and allowed treatment by a number of powerful theoretical techniques developed for thin airfoils.

Paul F. Yaggy documented in Reference 1 a technique for estimating the upwash angles induced by wings at the propeller planes of aircraft with multiple, wing-mounted engines. Yaggy used basic lifing-line theory to estimate the wing effects for straight wings in incompressible flow. Using a system of horseshoe vortices and equations from H. Glauert in Reference 15, Yaggy estimated the induced angles and confirmed by comparison with experimental data that the technique gave good results. He also confirmed that the span loading of the wing alone could be used in the technique since differences in span loading caused by nacelles had negligible effect on upwash for greatly differing plan forms. The technique worked well for distances greater than 60-percent chord ahead of the leading-edge of the wing and for unswept wings of moderate to high aspect ratio. However, Yaggy recognized deficiencies in the technique and recommended that for swept wings and other configurations, techniques such as those described by John De Young in Reference 5 should be used.

Vernon L. Rogallo expanded Yaggy's work to swept wings and high subsonic Mach numbers in Reference 2. Based on Yaggy's recommendation, Rogallo incorporated De Young's technique for estimating wing-induced upwash angles. In Reference 6 De Young investigated three possible replacements for basic lifting-line theory; two were modified lifting-line techniques and the third a lifting surface technique. As expected, the Falkner lifting surface technique was most accurate but most difficult and time consuming for making estimates of wing-induced upwash angles. Of the two modified lifting-line techniques, the Weissinger technique proved superior to the Mutterperl technique and gave only slightly less accurate results than the lifting surface technique. The Weissinger technique was considerably less time consuming, easier, and proved to be the method best suited to an overall study of effects of geometry and wing loading on wing-induced upwash angle. The comparison of the three methods was done by comparing the three methods with experimental data of aerodynamic center, lift curve slope, and other aerodynamic parameters. Because the techniques did accurately predict other aerodynamic characteristics, equations developed by De Young in Reference 4 for induced downwash were considered adequate. Rogallo adapted the equations to upwash prediction by changing the influence coefficients and applied the equations to prediction of upwash angle at the propeller planes of wing-mounted engines. He compared the results with experimental data at Mach numbers of 0.32 and 0.90 and at wing sweeps of 0.0 degrees and 40.0 degrees with good results.

The equations developed by De Young from Weissinger and reiterated by Rogallo in Reference 2 were not well suited for flight test application. The estimates from these equations were confined to distances close ahead of the wing where propeller planes would normally lie. Also, calculation of upwash from the known influence coefficients required inputting estimates of span loading which often were not readily available. Investigation by Don Bellman of NASA/DFRC led to a presentation of the data in a concise form which was easily used in making upwash estimates for flight test application.

WEISSINGER METHOD

The Weissinger method of prediction of wing-induced upwash is a modified lifting-line theory considered by De Young and Rogallo to be the best technique. The method uses a lifting-line located at the quarter-chord line and continuous sheet of trailing vortices as shown in Figure B1. The strength and variation of the vortex filament is specified by a boundary condition at a finite number of control points along the three-quarter-chord line. Flow perpendicular to the surface of the "thin airfoil" is not allowed at these control points. Weissinger investigated the use of 7, 15, and 31 control points to accurately represent the wing. Although there were small gains in accuracy with the greater number of points, the gains were negligible and seven points were used in all referenced analyses. The spanwise location of the seven points was specified in terms of the dimensionless lateral coordi-

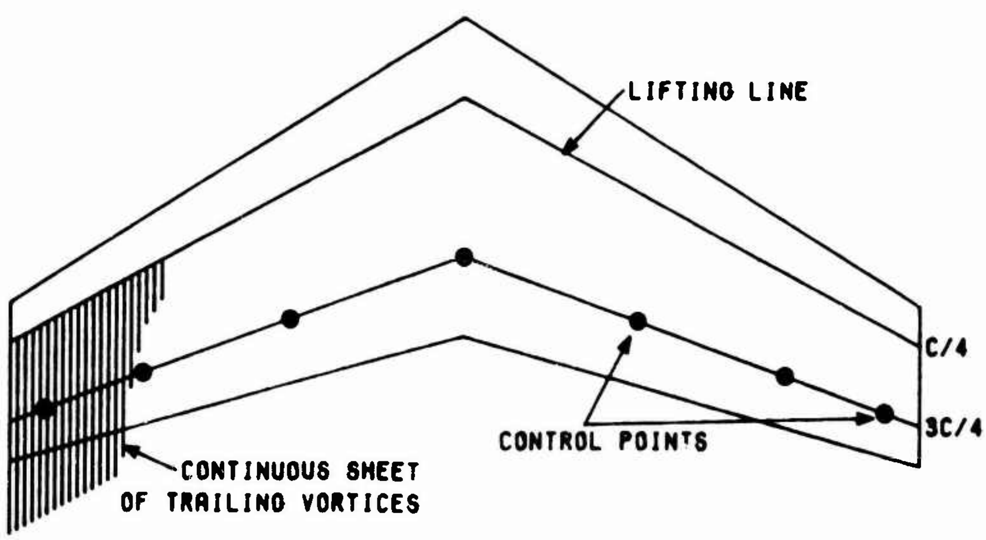


FIGURE B1: WEISSINGER ESTIMATION TECHNIQUE

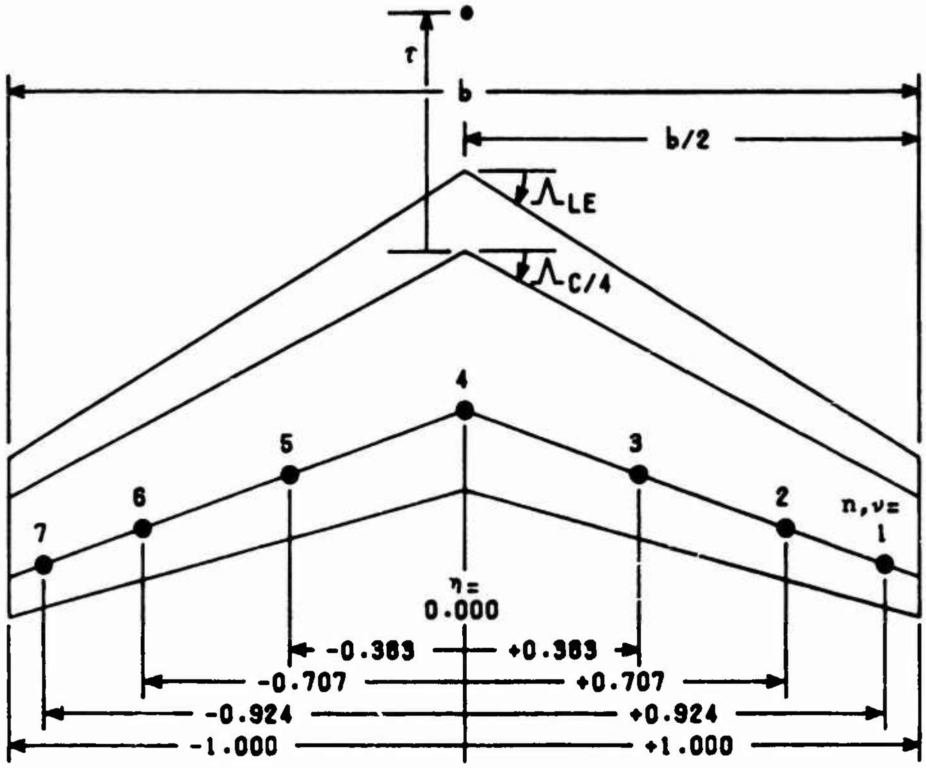


FIGURE B2: 7-POINT WEISSINGER TERMINOLOGY

nate, η, which was defined by equation (B1) where y is the lateral coordinate and b is the wing span. The spanwise location of the nth control point is defined by equation (B2). The location of the seven points is shown in Figure B2.

$$\eta = \frac{y}{(b/2)} \tag{B1}$$

$$\eta_n = \cos\,(n\pi/8) \tag{B2}$$

The equations for calculation of induced upwash which Rogallo adapted from De Young's development in Reference 4 were the result of Weissinger analysis. The upwash can be calculated at points with specific spanwise coordinates, η_ν, corresponding to Weissinger's control points as defined in equation (B2) and ahead of the leading edge of the wing. To simplify the analysis, De Young assumed symmetric loading so that the analysis could be confined to four points (ν = 1, 2, 3, 4) and intermediate results, if necessary, could be determined from interpolation as discussed in Reference 4. The equation for induced velocity, W, over freestream velocity, V_T, is equation (B3).

$$(W/V_T) = \sum_{n=1}^{4} a_{\nu n}G_n \tag{B3}$$

The value of V/V_T is a function of influence coefficients, $a_{\nu n}$, which control the influence that the dimensionless circulation, G_n, at the nth semispan station has on the spanwise station ν where upwash estimates are required. The dimensionless circulation is defined by $G_n = \Gamma_n/bV_T$ where the circulation at spanwise station n, Γ_n, is dependent on Mach number and geometry. Equation (B3) is awkward to work with for quick, easy estimates of upwash. The equation was rearranged and rewritten in Reference 2 to put upwash in terms of unit lift coefficient and other more easily understood terms. Equation (B4) is the rearranged equation.

$$\left[\frac{W/V_T}{\beta C_L/k_{av}}\right] = \frac{1}{2\left[\frac{\beta(b^2/S)}{k_{av}}\right]} \sum_{n=1}^{4} a_{\nu n} \left[\frac{C_\ell c}{C_L \bar{c}}\right]_n \qquad \text{(B4)}$$

where

M = Mach number

β = $\sqrt{1-M^2}$

C_L = total lift coefficient

k_{av} = average of ratio of actual sectional lift-curve slopes to theoretical values

S = total wing area

C_ℓ = section lift coefficient

c = section chord length

$\bar{c}$ = mean aerodynamic chord length

The parameter $[C_\ell c/C_L\bar{c}]$ is the span loading coefficient which is presented in references 6 and 7 for numerous, varied configurations. Results in these references indicate that the span loading coefficient is not a function of Mach number, but is only a function of effective geometry. The influence coefficients are functions of effective wing sweep defined by equation (B5) and dimensionless distance ahead of the quarter-chord line defined by equation (B6). The influence coefficients used throughout this analysis are given in Figure 17, p. 35-46 of Reference 2.

$$\Lambda_\beta = \tan^{-1}\left[\frac{\tan\Lambda_{C/4}}{\beta}\right] \qquad \text{(B5)}$$

$$\tau = \frac{\text{distance ahead of } C/4}{(b/2)} \qquad \text{(B6)}$$

BELLMAN PARAMETERIZATION

Don Bellman of NASA/DFRC simplified application of the Weissinger technique in making upwash estimates for flight test use. Through the use of normalizing parameters, the Weissinger technique was adapted to general flight test application and the range of τ/β values extended to values which would include nosebooms. Initially equation (B4) was simplified and converted to parameters more generally used by flight test personnel. Since the upwash angle, ε, is defined by $\varepsilon = \tan^{-1}(W/V_T) \approx (W/V_T)$ and aspect ratio, AR, is defined by $AR = b^2/s$, equation (B4) was rewritten as equation (B7). The value of ν can be set to 4 by assuming that the noseboom is on the centerline (midspan) of the wing ($\eta = 0$) or close enough that interpolation is unnecessary.

$$\frac{\varepsilon AR}{C_L} = \frac{1}{2}\sum_{n=1}^{4} a_{4n}\left[\frac{C_\ell c}{C_L \bar{c}}\right]_n \qquad (B7)$$

Research in many of the references indicated that span loading coefficients varied very little directly with Mach number but had major variation with Λ_β with minor variations due to taper ratio, λ. Further analysis showed that the minor variations of span loading coefficient due to taper ratio had negligible effect on upwash estimates. Values of influence coefficient are a function only of τ/β and Λ_β as shown in Reference 2. From this functional analysis it was concluded that the parameter $\varepsilon AR/C_L$ could be plotted versus τ/β with lines of Λ_β. Bellman generated a curve which was disseminated to numerous projects and used successfully both at NASA/DFRC and AFFTC. Several curves derived from the original were obtained from different sources. Because the curves from different sources differed slightly in detail and there were questions concerning the range of independent parameters over which the curves were valid, the original curve could not be determined. Since the original analysis was no longer available, independent curves were developed which could be substantiated with data and documented.

DATA ANALYSIS AND FAIRING:

Redevelopment of the Bellman curve was done with theoretical and experimental data from three references and included twenty-two span loadings substantiated by numerous tests and studies. Data with seven geometric wing sweeps were used and in every case possible, the data were used at more than one effective wing sweep to insure that Λ_β was normalizing Mach effects on span loading. Taper ratios from 0.0 to 1.0 were used to validate the assumption that data with all taper ratios could be combined. Aspect ratios from 2.0 to 10.0 were used to insure that $\varepsilon AR/C_L$ normalized aspect ratios effectively. A summary of data included in the analysis is given in Table B1.

Values of $\varepsilon AR/C_L$ were calculated for effective wing sweep values 0.0, 31.0, 45.0, and 60.0 degrees and for τ/β values from 0.15 to 0.70 using equation (B7). The data were plotted and faired as shown in Figure B3. The data appear nonlinear at lower τ/β values, but become linear above τ/β of 0.4 when plotted on a log-log plot. Some minor disagreement between the data and fairings can be seen at τ/β of 0.7 and Λ_β of 45.0 and 60.0. These discrepancies were attributed more to inability to accurately read the influence coefficient curves than to trends in the data. As stated in the note in Figure B3, there is some ordered effect within Λ_β groupings attributable to taper ratio. Generally lower taper ratios are at the top of the grouping and higher values at the bottom of the grouping, but the effects

TABLE B1: SUMMARY OF INCLUDED DATA

POINT NUMBER	Λ_{β}	$\Lambda_{C/4}$	TAPER RATIO	ASPECT RATIO	SPAN LOADING COEFFICIENT REFERENCE AND FIGURE
1	0.0	0.0	0.0	3.0	NACA TN 1491, FIG 10(C)
2	0.0	0.0	---	----	ELLIPTIC LOADING
3	0.0	0.0	0.4	10.0	NACA TN 2795, FIG 7(B)
4	0.0	0.0	0.5	3.0	NACA TN 1491, FIG 10(C)
5	0.0	0.0	1.0	3.0	NACA TN 1491, FIG 10(C)
6	31.0	31.0	0.4	4.7	NACA TN 1476, FIG 2(D)
7	45.0	31.0	0.4	4.7	NACA TN 1476, FIG 2(D)
8	45.0	35.0	0.5	6.0	NACA TN 2795, FIG 3(A)
9	45.0	40.0	0.4	10.0	NACA TN 2795, FIG 7(A)
10	45.0	45.0	0.0	3.0	NACA TN 1491, FIG 10(B)
11	45.0	45.0	0.5	3.0	NACA TN 1491, FIG 10(B)
12	45.0	45.0	1.0	3.0	NACA TN 1491, FIG 10(B)
13	60.0	31.0	0.4	4.7	NACA TN 1476, FIG 2(D)
14	60.0	35.0	0.5	6.0	NACA TN 2795, FIG 3(A)
15	60.0	40.0	0.4	10.0	NACA TN 2795, FIG 7(A)
16	60.0	45.0	0.0	3.0	NACA TN 1491, FIG 10(B)
17	60.0	45.0	0.5	3.0	NACA TN 1491, FIG 10(B)
18	60.0	45.0	1.0	3.0	NACA TN 1491, FIG 10(B)
19	60.0	56.3	0.0	2.0	NACA TN 1491, FIG 7
20	60.0	60.0	0.0	3.0	NACA TN 1491, FIG 10(A)
21	60.0	60.0	0.5	3.0	NACA TN 1491, FIG 10(A)
22	60.0	60.0	1.0	3.0	NACA TN 1491, FIG 10(A)

were not well defined and are insignificant for almost all applications. Although there were perceivable differences between the data fairings in Figure B3 and Bellman curves from other sources, the differences are within limits that could arise from interpretation of the data and were ignored. The new fairings were used in all analyses in this memorandum and in development of the production software presented in Appendices D and E.

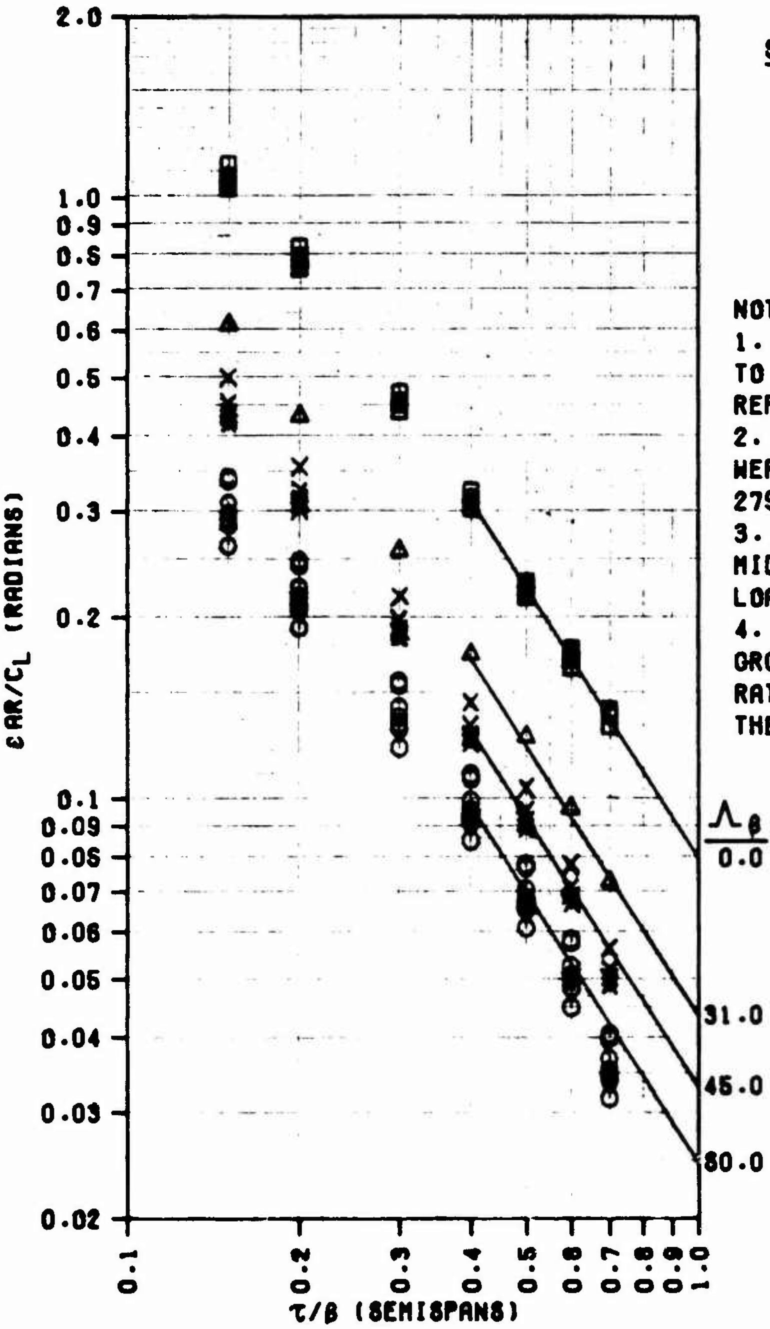
CURVE FIT:

The data fairings in Figure B3 were fitted with an equation to alleviate curve reading in future applications. The equation (B8) is valid for τ/β values above 0.4 and is the recommended procedure to extrapolate to τ/β values higher than 0.7. For τ/β lower than 0.4, the data were faired at the four wing sweeps where data were available and interpolated to obtain values at intermediate wing sweeps. The results are given in Figure B4. The assumptions in the technique deteriorate rapidly as τ/β goes below 0.15 and no confidence is possible in extrapolation below 0.15.

$$\log(\varepsilon AR/C_L) = A\log(\tau/\beta) + B\Lambda_{\beta} + C \qquad \tau/\beta > 0.4 \tag{B8}$$

where

$A = -1.48897301$
$B = -0.008447868$
$C = -1.099368684$



SYMBOL	Λ_β	POINT NUMBERS
⊡	0.0	1-5
▲	31.0	6
×	45.0	7-12
⊙	60.0	13-22

NOTES:

1. POINT NUMBERS CORRESPOND TO SPAN LOADING COEFFICIENTS REFERENCED IN TABLE B1.
2. INFLUENCE COEFFICIENTS WERE OBTAINED FROM NACA TN 2795, FIGURE 17.
3. CURVE WAS DERIVED FOR WING MIDSPAN AND SYMMETRIC SPAN LOADING.
4. SCATTER WITHIN WING SWEEP GROUPINGS VARIES WITH TAPER RATIO GENERALLY WITH 1.0 AT THE BOTTOM TO 0.0 AT THE TOP.

FIGURE B3: FAIRING OF UPWASH ESTIMATION CURVES

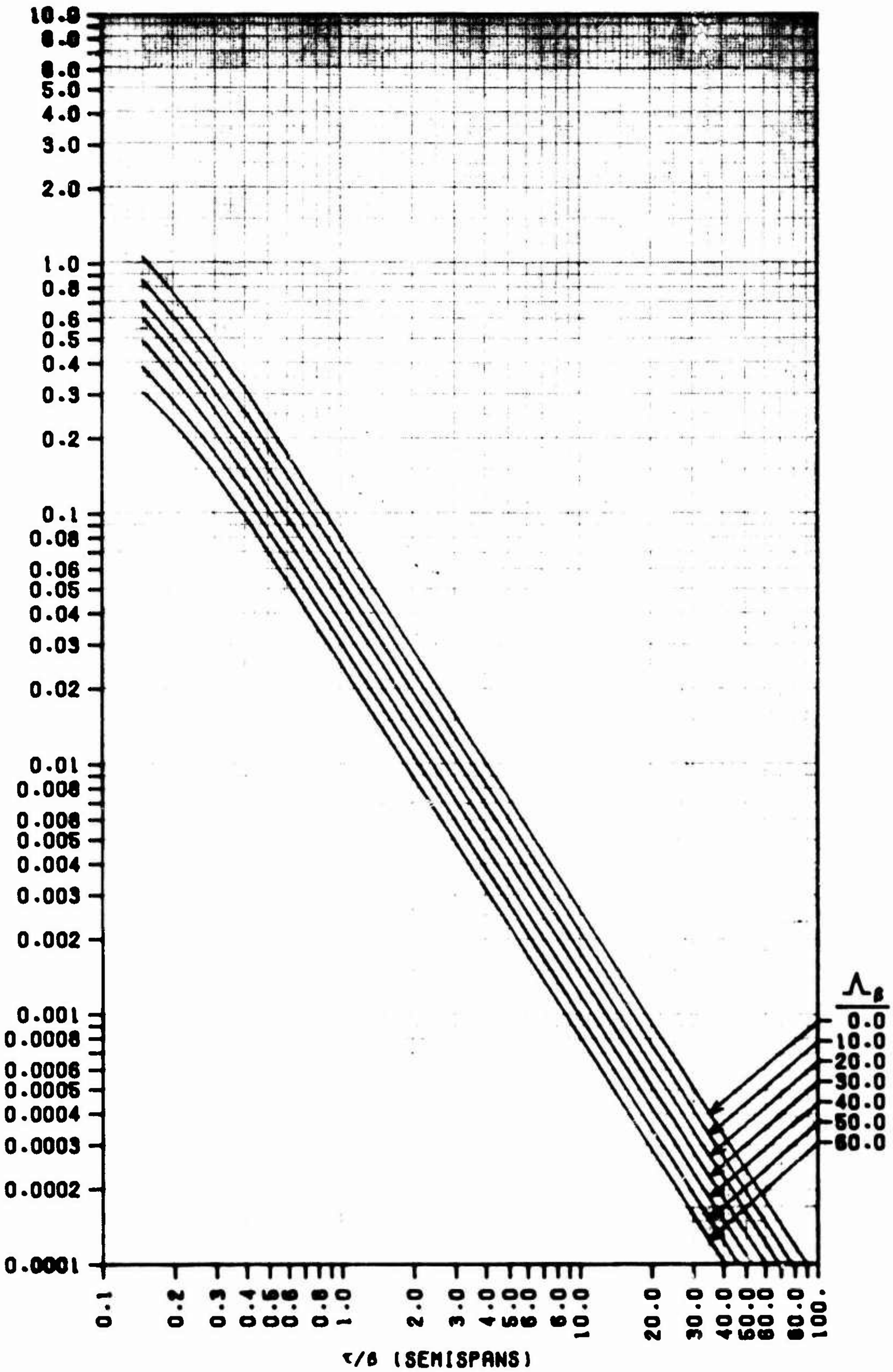


FIGURE B4: EXTRAPOLATION OF UPWASH ESTIMATION CURVES

APPENDIX C
PROCEDURAL OUTLINE FOR THE YAGGY-ROGALLO UPWASH ESTIMATION TECHNIQUE

The outline contained in this appendix is a concise presentation of the procedures necessary to generate upwash angle estimates using the Yaggy-Rogallo technique. It is intended as a quick reference and checklist for users who are familiar with the Yaggy-Rogallo technique and does not replace the detailed discussion elsewhere in the memorandum.

PROCEDURAL OUTLINE FOR THE YAGGY-ROGALLO
UPWASH ESTIMATION TECHNIQUE

I. Perform Yaggy-Rogallo analysis
  A. Define geometric configuration(s) to be analyzed
  B. Divide aircraft into two types of components
    1. Non-lifting bodies
    2. Lifting surfaces
    3. Other (see discussion for classifying components)

II. Define Upwash Estimates for Individual Components

  A. Cylindrical Components
    1. Designate individual components
      a) Each component with non-concurrent centerline
      b) Each component where a separate estimate is desired
    2. Define cross sectional area distribution of each component
      a) Obtain definition of cross sectional area versus fuselage station for aircraft
        i) Plot
        ii) Tabulation
        iii) Scale drawing
      b) Eliminate area due to lifting surfaces such as wings, tails, or canards
      c) Generate final plot of cross sectional area versus fuselage station
    3. Select points from curve and assign numbers
      a) Points selected so that straight line segments connecting them adequately define curve
        i) Each data point consists of two values
          (1) Fuselage station
          (2) Corresponding cross sectional area
        ii) At least two points must be selected (1000 points is maximum number for use of production software)
        iii) Accuracy depends on how well straight-line segments represent curve; not on spacing of points
      b) selected points are numbered from 1 to N
        i) Point "1" is at leading edge of body
        ii) Point "N" is at trailing edge of body
        iii) Points designated at ith point
    4. Define location of angle-of-attack vane
      a) Longitudinal location of angle-of-attack vane
        i) Designated by center of pressure of vane(s)
        ii) Fuselage station must be in same reference system as rest of data
      b) Angular and radial location
        i) Designated by center of pressure of vane(s)
        ii) Known geometry
          r = distance from centerline to center of pressure
          θ = angular location of center of pressure with 0° being vertically above centerline (degrees)
        iii) Unknown geometry
          r = distance from plane of symmetry to center of pressure
          $\theta = 90.0^{\circ}$

5. Select Mach numbers where upwash estimates are desired
   a) Restrictions
      i) Mach numbers must be greater than or equal to 0.0
      ii) Mach numbers must be less than 1.0
   b) Recommended range and spacing
      i) 0.0 to 1.0 in steps of 0.10 is usually acceptable
      ii) 0.0 to 1.0 in steps of 0.025 is more than adequate
      iii) Range and spacing should be adjusted to meet project needs
6. Select "production software" or "hard calculation" approach (Results will be almost identical but "hand calculation" is long, tedious, and time consuming)
   a) "Production software" approach (consult User's Guide for Yaggy-Rogallo Production Software)
      i) Develop HEAD1 card
      ii) Develop HEAD2 card
      iii) Develop VANES card
      iv) Develop MACHV card(s)
      v) Develop AREAV cards
      vi) Run BODY program
      vii) Skip to step II, A, 13. of this outline
   b) Hand calculation approach
      i) Establish a work sheet for actual geometric calculations
      ii) Establish a work sheet for effective geometric calculations and upwash estimates for each Mach number where an upwash estimate is desired
      iii) Calculate compressibility factor, β, for each Mach number and place at top of work sheet

$$\beta = \sqrt{1-M^2}$$

7. Perform coordinate transformation so that distances fore and aft are measured from the center of pressure of the angle of attack vane (distances are positive forward)
      i) Equation uses fuselage stations previously determined

$$d_i = FS_v - FS_i$$

      ii) Record values on actual geometry worksheet

8. Calculate equivalent radius at each selected fuselage station

$$R_i = \sqrt{A_i/\pi} \qquad i = 1,N$$

9. Calculate effective distances corresponding to each geometric distance. Must be repeated for each Mach value and placed in individual worksheets.

$$\partial_i = d_i \cdot \beta \qquad d \geq 0 \text{ (forward)}$$

$$i = 1,\ N$$

$$\partial_i = d_i/\beta \qquad d < 0 \text{ (aft)}$$

10. Calculate effective angles corresponding to each geometric distance. Must be repeated for each Mach value and placed on individual worksheets.

$$\theta_i = \cot^{-1}(\partial_i/|r|) \qquad i = 1,N$$

11. Calculate the contribution of each segment, $\Delta(\varepsilon/\alpha)$, to upwash angle estimates

$$\Delta(\varepsilon/\alpha) = [K_1'(\sin\tilde{\theta}_i - \sin\tilde{\theta}_{i-1}) + K_2'(\cos\tilde{\theta}_{i-1} - \cos\tilde{\theta}_i)]$$

where $K_1' = (R^2_{i-1} - R_i^2) / (\cot\tilde{\theta}_{i-1} - \cot\tilde{\theta}_i)$

$K_2' = -K_1'\cot\tilde{\theta}_i + R_i^2$

12. Sum contributions of all segments to obtain an upwash angle estimate for the body at each Mach number.

$$\frac{\varepsilon}{\alpha} = \frac{\sin^2\Omega - \cos^2\Omega}{2r^2} \sum_{i=2}^{N} \Delta(\varepsilon/\alpha) \qquad \text{(for each Mach)}$$

13. Plot upwash angle estimates as ε/α versus Mach number and check for appropriate characteristics

B. Lifting Surface Components

1. Designate individual components

2. Define an "equivalent planform" for each lifting surface having straight leading and trailing edges and tips parallel to free-stream flow.
   a) Define geometry of lifting surface
      i) Fuselage station of quarter-chord line at midspan, FS_{C4}
      ii) Span of lifting surface, b
      iii) Aspect ratio of lifting surface, AR
      iv) Sweep of the quarter-chord line, Λ_{C4}
   b) Define fuselage station of center of pressure of angle-of-attack vanes, FS_V
3. Select Mach numbers where upwash estimates are desired
   a) Restrictions
      i) Mach numbers must be greater than 0.0
      ii) Mach numbers must be less than 1.0
   b) Recommended range and spacing
      i) 0.0 to 1.0 in steps of 0.10 is usually acceptable
      ii) 0.0 to 1.0 in steps of 0.025 is more than adequate
      iii) Range and spacing should be adjusted to meet project needs
4. Select "production software" or "hand calculation" approach
   a) "Production software" approach (consult User's Guide for Yaggy-rogallo Production Software)
      i) Develop HEAD1 card
      ii) Develop HEAD2 card
      iii) Develop WINGS card
      iv) Develop MACHV card(s)
      v) Run WING program
      vi) Skip to step II, B, 7.
   b) "Hand calculation" approach
      i) Establish a worksheet for each lifting surface to be analyzed

ii) Calculate compressibility factor, β, for each Mach number on place adjacent to the Mach value on worksheet

$$\beta = \sqrt{1-M^2}$$

5. Calculate dimensionless parameters
   a) Calculate dimensionless distance, τ, of the center of pressure ahead of quarter-chord of wing

   $$\tau = (FS_V - FS_{c/4})/(b/2)$$

   b) Calculate effective wing sweep, Λ_β

   $$\Lambda_\beta = \tan^{-1}(\tan\Lambda_{c/4}/\beta)$$

   c) Calculate dimensionless parameter, τ/β

6. Calculate upwash parameter, $\varepsilon AR/C_L$
   a) $\tau/\beta \geq 0.4$

   $$\varepsilon AR/C_L = 10^{[A\log(\tau/\beta) + B\Lambda_\beta + C]}$$

   where A = -1.488973010
   B = -0.008447868
   C = -1.099368684

   b) $0.15 \leq \tau/\beta < 0.4$
   Curve lookup

   c) $\tau/\beta < 0.15$
   Assumptions violated (see text)

7. Calculate ε/C_L

   $$\varepsilon/C_L = (\varepsilon AR/C_L)/AR$$

8. Plot upwash angle estimates as ε/C_L versus Mach number and check for appropriate characteristics

III. Combine upwash estimates from various components
   A. Cylindrical components
      1. Account for incidence angles such as noseboom incidence, i_{NB}, and wing incidence, i_W

      2. Combine upwash angle estimates

      $$\varepsilon = (\varepsilon/\alpha)_{NB}(\alpha - i_{NB}) + (\varepsilon/\alpha)_F(\alpha - i_W)$$

      3. If interference corrections are required, see text.

   B. Lifting-surface components

1. Develop lift coefficient for each component
   i) Divide lift among component
   ii) Develop C_L for each component based on lift of component, area of component, and local dynamic pressure

2. Calculate total upwash estimate

$$\varepsilon = (\varepsilon/C_L)_W \cdot C_{L_W} + (\varepsilon/C_L)_C \cdot C_{L_C}$$

3. If required, change to ε/α format (not recommended)

$$\varepsilon = ((\varepsilon/C_L) \cdot C_{L_\alpha} \alpha) - ((\varepsilon/C_L) \cdot C_{L_\alpha} \alpha_0)$$

   i) ε/C_L is a function of Mach number
   ii) C_{L_α} and α_0 are a function of Mach number and lift coefficient

IV. Apply Results

A. Use for preliminary estimate
B. Adjust level of curve based on flight test data to obtain final curves.

APPENDIX D
USER'S GUIDE FOR THE YAGGY-ROGALLO PRODUCTION SOFTWARE

INTRODUCTION

The equations and procedures developed for application of the Yaggy-Rogallo upwash estimation technique were incorporated in two production computer programs. Equations developed in Appendices A and B were implemented in a manner to insure maximum capability for users with a minimum requirement of time and effort. The language used was American National Standards Institute (ANSI) FORTRAN 77, commonly called FORTRAN Version 5 (or FORTRAN V), as described in Reference 20. This newest version of FORTRAN was used to insure the longest possible useful life for the software but, more importantly, FORTRAN V supposedly has greater commonality among computers than FORTRAN IV. Every effort was made to create software which would move easily between computers. Only a single card, the file declaration or "PROGRAM" card, of each program is non-ANSI. No suggested control-card setups were included in the User's Guide since the programs are very small and easily adapted to numerous application techniques.

The two computer programs correspond to the two types of components into which an aircraft would be divided in the preliminary stages of a Yaggy-Rogallo analysis. Program BODY is intended for making upwash estimates for components which are designated as bodies of revolution and program WING is intended for making upwash estimates for components designated as lifting surfaces. Although the two programs are completely independent, there is great similarity in their internal development, input and output, and there is a large degree of commonality in the input data cards which reduces the amount of work to prepare input cards. Both programs extensively check the input data to determine any inputs which would cause abnormal termination of the program, and, to the maximum extent possible, check for errors which would give unreasonable results. Messages are written by both programs to the user if unexpected inputs are encountered to aid in locating the erroneous card(s). The following sections describe the input data, the output, and error checking for both programs in detail. If more detail is needed, the user should consult the Programmer's Guide or program listings in Appendix E.

PROGRAM BODY - BODY-OF-REVOLUTION UPWASH ESTIMATOR

Program BODY makes upwash estimates for bodies of revolution using equations recommended in Appendix A. The program does not require the user to develop the equivalent body-of-revolution, angular relationships, and "effective" geometry required by the final equations, Instead, the input is in more familiar terms such as longitudinal (fuselage) station, longitudinal (fuselage) cross sectional area and Mach number, with the program calculating other needed parameters. The program can calculate upwash estimates for as many bodies as the user desires during a single run. The normal output is a comprehensive, lineprinter listing of the input data, the calculated geometric data, the effective geometric data, and the upwash estimates. Should the user improperly prepare the input data, the output data will be greatly abbreviated and consist of as much information as possible on the location and nature of the error. The error messages are output by error-checking portions of code and depend on the location and type of error. The input, output, and error checking are described more fully below.

BODY INPUT CARDS:

The input cards for program BODY consist of six types of cards which are arranged into data sets as shown in Figure D1. Each card of the input data sets contains one of six card identifiers entered as alphanumeric data in the first five columns of the card. The card identifiers are used as card titles in discussing the cards as well as serving as flags in the error checking process. The remainder of the card contains input data to be used in calculating upwash estimates or labeling output. There are limitations on the number and range of some parameters which must be observed. The content of each type of card and limitations on specific variables will be discussed in detail below, but the critical information is summarized for quick reference in Figure D2.

HEAD1 Card. A single HEAD1 card is the first card of each input data set. The card identifier is the alphanumeric characters "HEAD1" in the first five columns. Columns 6 through 80 contain 75 alphanumeric characters of user-supplied heading. This heading is the first of two lines of heading printed on each page of output to identify and clarify the output.

HEAD2 Card. A single HEAD2 card is the second card of each input data set. The card identifier is the alphanumeric characters "HEAD2" in the first five columns. Columns 6 through 80 contain 75 alphanumeric characters of user-supplied heading comprising the second heading line to be printed on each page.

VANES Card. A single VANES card is the third card of each input data set. The card identifier is the alphanumeric charcters "VANES" in the first five columns. The information on this card specifies the location of the center of pressure of the angle-of-attack vane relative to the centerline of the body of revolution and the longitudinal (fuselage) station reference plane. The first parameter is a two-character abbreviation for the units of length in which other parameters will be input. Two alphanumeric characters such as "IN" for inches or "CM" for centimeters are entered in columns 9 and 10 and stored in variable UNIT. The only use within the program for this variable is as a column heading for all columns having units of length; no units checking or conversion is done. Nothing adverse will happen within the program if the abbreviation doesn't agree with the actual units or even if the field is blank. It is important, however, that all values be entered in consistent units of length. If the vane radial distance is entered in inches, for instance, the longitudinal stations must be in inches and the areas must be in square inches to obtain valid results. Accurate entry of the units abbreviation will act as a reminder of this fact and is highly recommended. The next parameter is the longitudinal station of the center of pressure of the angle-of-attack vane. The parameter is entered in columns 11 through 20 in F10.0 format and stored in variable FSVANE. The next two parameters are the radial distance from the centerline and angular location around the centerline of the center of pressure of the angle-of-attack vane which are stored in variables RVANE and ANVANE respectively. The radial distance is measured from the centerline to the center of pressure; it must be non-zero and should be entered as a positive value in F10.0 format in columns 21 through 30. The angular location of the center of pressure is measured positive clockwise when facing forward and is zero when vertically above the centerline. The value of the angle

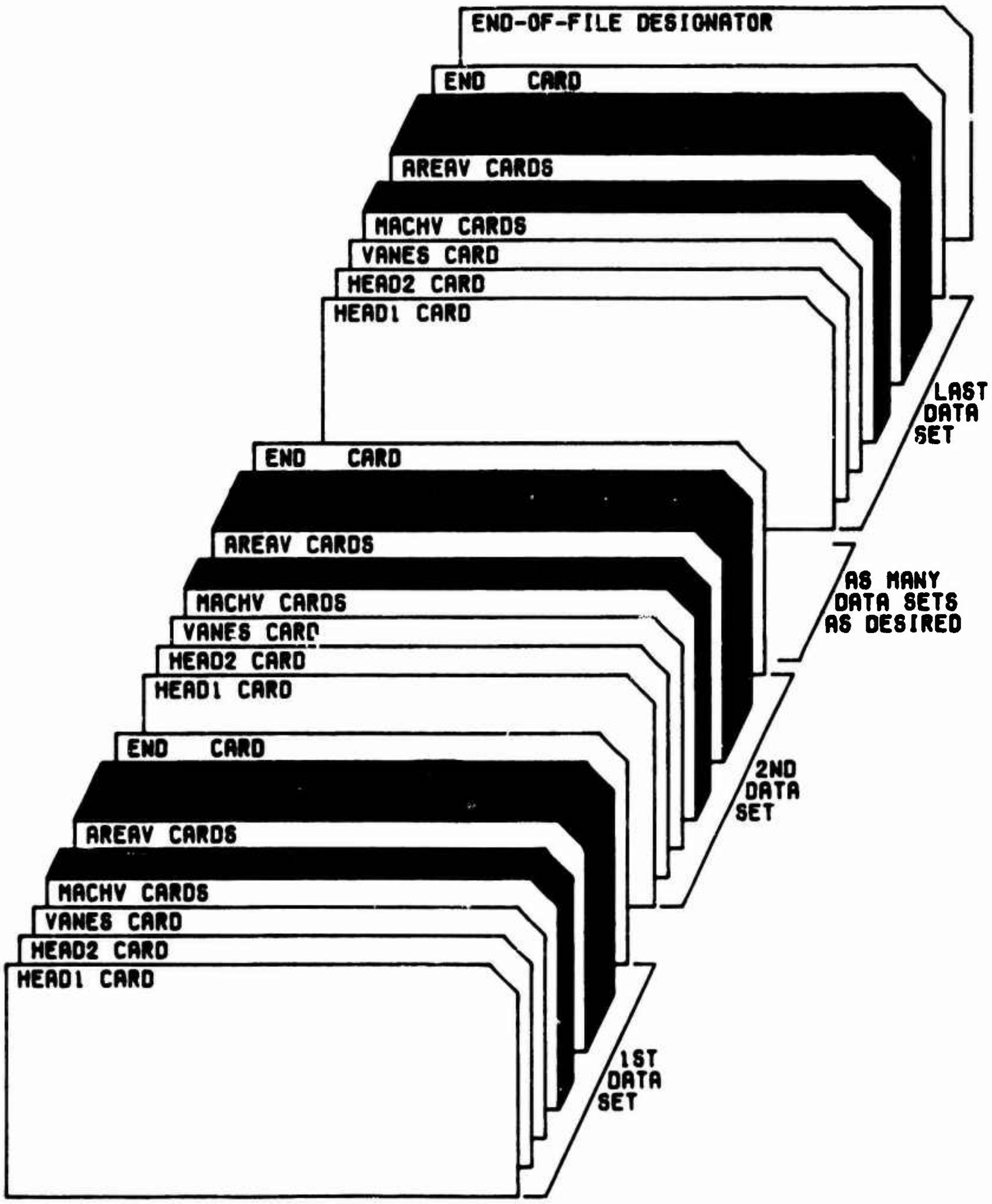


FIGURE D1: CYLINDRICAL COMPONENT DATA CARDS

CARD TYPE	NO OF CARDS	VARIABLE	FORMAT	COLUMNS	DESCRIPTION
HEAD1	1	HEAD	A5	1- 5	Card identifier - Must be "HEAD1"
		HEAD1	A75	6-80	First line of user specified heading
HEAD2	1	HEAD	A5	1- 5	Card identifier - Must be "HEAD2"
		HEAD2	A75	6-80	Second line of user specified heading
VANES	1	HEAD	A5	1- 5	Card identifier - Must be "VANES"
			3X	6- 8	Blank
		UNIT	A2	9-10	Two alphanumeric characters as abbreviations for units of input (eg; IN, CM, FT)
		FSVANE	F10.0	11-20	Longitudinal station of center of pressure of angle-of-attack vane
		RVANE	F10.0	21-30	Radial distance from body centerline to center of pressure of angle-of-attack vane
		ANVANE	F10.0	31-40	Angular location of angle of attack vane - Must be in degrees
			40X	41-80	Blank
MACHV	1 to 14 (as req'd)	HEAD	A5	1- 5	Card identifier - Must be "MACHV" on each card
			3X	6- 8	Blank
		NMACH	I2	9-10	Number of Mach number values to be read from all MACHV cards (Note: This variable is active on first card only)
		XMACH	7F10.0	11-80	Seven Mach number values (Note: Number of MACHV cards must match exactly the number of cards to read in "NMACH" values at 7/card)
AREAV	2 to 1000 as req'd)	HEAD	A5	1- 5	Card identifier - Must be "AREAV" on each card
			5X	6-10	Blank
		FS(I)	F10.0	11-20	A single longitudinal station value
		AREA(I)	F10.0	21-30	A single station area corresponding to the FS value on the same card
			50X	31-80	Blank
END	1	HEAD	A5	1- 5	Card identifier - Must be "END " (Note: This terminates a data set)
			75X	6-80	Blank

FIGURE D2: SUMMARY OF DATA CARDS FOR PROGRAM BODY must be entered in degrees in F10.0 format in columns 31 through 40.

MACHV Cards. One or more MACHV cards follow the VANES card in each input data set. Each MACHV card has the alphanumeric characters "MACHV" in the first five columns as the card identifier. The first MACHV card only has variable NMACH in I2 format in columns 9 and 10. NMACH contains the number of Mach numbers where upwash estimates are desired. The number of Mach numbers is limited to 98 by program dimensions and efforts to enter more values will abnormally terminate the program. Each MACHV card will hold up to seven values of Mach number in 7F10.0 format in columns 11 through 80. Since seven values per field for fourteen cards yields ninety-eight values, the program expects no more than fourteen MACHV cards. The program expects all Mach number values to be entered in the first NMACH fields and only enough cards to contain NMACH fields to be in a data set. Thus, if seventeen Mach number values are to be read in, it would require exactly three MACHV card; the first two would contain full seven fields each and the third would contain three Mach number values in the three left-most fields. All Mach number values must be greater than or equal to 0.0 and less than or equal to 1.0 as assumed in deriving the basic equations.

AREAV Cards. At least two AREAV cards must follow the MACHV card(s) in each input data set. Each AREAV card has the alphanumeric characters "AREAV" in the first five columns as the card identifier. The AREAV cards contain the longitudinal station/body cross sectional area pairs necessary to describe the body. Values are entered with one pair per card to allow easy insert or removal if it is found that more or fewer points are needed to describe the body accurately. The longitudinal station value of a pair is entered in F10.0 format in columns 11 through 20 and stored in the FS variable array. The corresponding body cross sectional area of a pair is stored in F10.0 format in columns 21 through 30 and stored in the same element of the AREA variable array. The arrays are dimensioned to 1000 in the program and exceeding 1000 AREAV cards will cause abnormal termination. The cards must be ordered within the AREAV cards in ascending value of longitudinal station. Two consecutive cards with equal values of longitudinal station are allowed to easily account for sudden increases in fuselage area such as at inlets. In this case a zero value will be assigned to the increment upwash for the segment.

END Card. A single END card must follow the AREAV cards to end reading of AREAV cards and to terminate the input data set. The card identifier is the alphanumeric characters "END " in the first five columns. The rest of the card is blank.

BODY OUTPUT:

The output of program BODY consists of two types of lineprinter listings as shown in Figure D3. The first type of listing shown in Figure D3(a) lists the actual geometric data for the body as input by the user and the calculated geometry for the equivelent-body-of-revolution. The second type output shown in Figure D3(b) lists the effective geometric data and upwash estimates calculated for a specific Mach number. The format of both types of pages were planned such that the actual printing takes only 7.5 inches in width and about 8.5 in length with 40 data points per page and 6 lines per inch. This leaves adequate margins, when trimmed to 8.5 by 11.0, to place the pages in notebooks and reports. Both types of pages are repeated as required to accommodate the number of points up to 1000. Further details of both pages are in-

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FUSELAGE 21 POINTS

ANGLE-OF-ATTACK VANE LOCATION:

RADIAL DISTANCE FROM BODY CENTERLINE .... 7.8750 IN
ANGULAR LOCATION .... 90.0000 DEG
LONGITUDINAL STATION OF VANES .... -68.4500 IN

COMPONENT AREA DISTRIBUTION:

PT NO	LONGITUDINAL STATION (IN)	CROSS SECTIONAL AREA OF BODY AT STATION (SQ IN)	LONGITUDINAL DISTANCE FROM VANE TO STATION (IN)	EQUIVALENT RADIUS AT STATION (IN)
1	0.0000	0.0000	-68.4500	0.0000
2	25.0000	200.0000	-93.4500	7.9788
3	125.0000	2000.0000	-193.4500	25.2313
4	175.0000	2650.0000	-243.4500	29.0434
5	200.0000	3150.0000	-268.4500	31.6651
6	250.0000	4500.0000	-318.4500	37.8470
7	275.0000	4925.0000	-343.4500	39.5939
8	400.0000	6275.0000	-468.4500	44.6922
9	440.0000	6875.0000	-508.4500	46.7801
10	460.0000	7575.0000	-528.4500	49.1039
11	475.0000	7600.0000	-543.4500	49.1849
12	525.0000	6850.0000	-593.4500	46.6950
13	600.0000	6200.0000	-668.4500	44.4243
14	650.0000	5375.0000	-718.4500	41.3632
15	700.0000	4725.0000	-768.4500	38.7816
16	750.0000	3950.0000	-818.4500	35.4588
17	775.0000	3425.0000	-843.4500	33.0183
18	781.0000	1325.0000	-849.4500	20.5368
19	800.0000	1025.0000	-868.4500	18.0629
20	850.0000	650.0000	-918.4500	14.3841
21	875.0000	350.0000	-943.4500	10.5550

A) GEOMETRIC DATA

FIGURE D3: PROGRAM BODY SAMPLE OUTPUT

YAGGY-ROGALLO UPWASH CALCULATION — PAGE 1/ 1

UPWASH ESTIMATE FOR CYLINDRICAL COMPONENTS

MACH NUMBER = .8000

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FUSELAGE — 21 POINTS

PT NO	LONGITUDINAL DISTANCE FROM VANE TO STATION (IN)	EFFECTIVE DISTANCE FROM VANE TO STATION (IN)	THETA (RAD)	EQUIVALENT RADIUS AT STATION (IN)	INCREMENT IN EPSILON OVER ALPHA
1	-68.4500	-114.0833	3.0727	0.0000	0.
2	-93.4500	-155.7500	3.0911	7.9788	.2385E-03
3	-193.4500	-322.4167	3.1172	25.2313	.1974E-02
4	-243.4500	-405.7500	3.1222	29.0434	.6451E-03
5	-268.4500	-447.4167	3.1240	31.6651	.2478E-03
6	-318.4500	-530.7500	3.1268	37.8470	.4332E-03
7	-343.4500	-572.4167	3.1278	39.5939	.1864E-03
8	-468.4500	-780.7500	3.1315	44.6922	.6172E-03
9	-508.4500	-847.4167	3.1323	46.7801	.1295E-03
10	-528.4500	-880.7500	3.1327	49.1039	.5939E-04
11	-543.4500	-905.7500	3.1329	49.1849	.4237E-04
12	-593.4500	-989.0833	3.1336	46.6950	.1134E-03
13	-668.4500	-1114.0833	3.1345	44.4243	.1127E-03
14	-718.4500	-1197.4167	3.1350	41.3632	.4998E-04
15	-768.4500	-1280.7500	3.1354	38.7816	.3536E-04
16	-818.4500	-1364.0833	3.1358	35.4588	.2499E-04
17	-843.4500	-1405.7500	3.1360	33.0183	.9220E-05
18	-849.4500	-1415.7500	3.1360	20.5368	.1348E-05
19	-868.4500	-1447.4167	3.1362	18.0629	.2022E-05
20	-918.4500	-1530.7500	3.1364	14.3841	.3390E-05
21	-943.4500	-1572.4167	3.1366	10.5550	.8915E-06

TOTAL UPWASH ESTIMATE (EPSILON/ALPHA) = .4926E-02

B) EFFECTIVE DATA AND UPWASH ESTIMATES

FIGURE D3: PROGRAM BODY SAMPLE OUTPUT (CONCLUDED)

cluded below.

Geometric Data. The first page(s) output by BODY for each input data set present the geometric data for the case as shown in Figure D3(a). The output is identified by the two lines of user-supplied heading entered on the HEAD1 and HEAD2 cards and printed between the dashed lines directly below the standard headings. The next information is the location of the angle-of-attack vane relative to the centerline of the equivalent-body-of-revolution as read from the VANES card. The radial distance from the body centerline and the longitudinal station of the vanes are printed and labeled with the dimensional abbreviation input in variable UNIT. It is reiterated that no conversions or checks are done to insure consistency of units. The angular location is printed and labeled in its mandatory units of degrees.

The component area distribution is then printed along with preliminary calculations of the dimensions for the equivalent-body-of-revolution. The point numbers are assigned to longitudinal station values used to define the actual geometry of the body in a consecutive manner as the AREAV cards are read. This is the means of identifying the points and segments of the geometric data listing and corresponding points on the effective data listing. The longitudinal stations and corresponding cross sectional area of the body at the station are printed exactly as read from the AREAV cards in the input data set. The longitudinal distance from the vane to the appropriate station is the distance used to determine upwash and is calculated by the algebraic addition of the longitudinal station and the longitudinal station of the angle-of-attack vane. The equivalent radius at the station is calculated as the radius of a circle having an area equal to the cross sectional area of the station. All values on the geometric data page represent purely geometric relationships which do not vary with Mach number. The geometric data are output as one set per input data set.

Effective Geometry and Upwash Estimates. The second type of page(s) output by BODY are the effective geometry and upwash estimates shown in Figure D3(b). These values are Mach number dependent and there is, therefore, one set of pages for each Mach number requested on the MACHV card(s). The appropriate Mach number is printed as part of the standard heading on each page directly above the two lines of user-supplied heading from the HEAD1 and HEAD2 cards. The point numbers on this page directly correspond to those on the geometric data. The longitudinal distance from the angle-of-attack vane to the longitudinal station is reprinted on this page for completeness. The actual longitudinal distances are corrected for compressibility which decreases distances ahead of the vane and lengthens distances aft of the vane to yield effective geometric distances. The angles between the centerline of the body and lines connecting the center of the equivalent circles at each effective station are calculated as THETA and printed in units of radians. The equivalent radius at the station, which is reprinted for completeness, and THETA are the primary inputs to determine the upwash increment for the segment in terms of upwash angle, epsilon, over angle of attack, alpha. The upwash increment for a segment is printed at the longitudinal station for the aft station of the segment. On the last page of listing for each Mach number is printed the sum of upwash estimates for all segments to give a total upwash estimate for the body at the given Mach number in terms of epsilon over alpha.

BODY ERROR CHECKING:

Program BODY performs numerous error checks as data is read and as upwash calculations are made. The main purpose of the error checking is to avoid abnormal termination of the program or to give the user as much information as possible on the location and nature of the error if termination is unavoidable. Several minor-error checks are made which change internal values which are obviously wrong and would cease execution of the program immediately if uncorrected. These changes which were included mainly to protect the user from gross misapplication or keypunch errors are not accompanied by error messages. Since these checks might limit the experienced user, give unexpected results, or cause confusion due to apparent inconsistencies, they are discussed briefly. The main body of the checks are for major errors with input data which do not have easily determined solutions and which must terminate program execution. These major-error checks write error messages to the user prior to termination to identify where and why termination occurred. Both the minor-error and major-error checks are discussed below.

Minor-Error Checking. Errors which appear obvious and usually result from keypunch errors or gross misapplication of the technique were corrected without accompanying output messages. This was done to allow continued execution of the program so that output could be produced to aid error analysis and so that subsequent data sets could be processed. In some cases this results in invalid or unexpected results which should be investigated and fixed; in other cases it simply allows data to be entered in a convenient manner when it would normally terminate program execution.

Mach number values entered on MACHV cards were checked for values less than 0.0 and greater than 1.0. Obviously values less than 0.0 have no meaning and usually result from keypunch errors. Values less than 0.0 were changed to 0.0 internally but printed at their original value to allow them to be found and corrected. Mach number values greater than 1.0 are equally invalid since velocities cannot be induced ahead of a body in supersonic flow. Upwash estimates for Mach numbers greater than 1.0 were set to zero and execution continued.

The longitudinal station values input on AREAV cards to define the body of revolution were checked on input to insure there were no descending data values. This was necessary to insure valid upwash estimates were obtained. Two cards with the same longitudinal station were allowed, however, to conveniently represent step increases in cross sectional area such as at inlets without resort to one station slightly less and one slightly more than the actual station. An incremental upwash of 0.0 was assigned to the "segment" defined by the two equal longitudinal stations.

Major-Error Checking. Checking for major errors which necessitated program termination was accomplished in subroutine RDDATA. Any major error discovered resulted in an error message followed by program termination.

Normal program termination resulted from reading an end-of-file designator while attempting to read a HEAD1 card. Unexpected reading of an end-of-file designator by any other read statement results in the statement

"   " IS IN ERROR - END-OF-FILE ENCOUNTERED where the quotes have the five alphanumeric characters of the card identifier being sought when the end-of-file designator was encountered. The input data set should be reassembled with the proper number and types of cards. A related message results if the input data set is improperly arranged or a card identifier is misspelled. The statement

"   " IS IN ERROR - CARD READS "   "

will be printed if an unexpected card identifier is encountered. The first set of quotes enclose the five alphanumeric characters of the expected identifier while the second set enclose the eighty alphanumeric characters on the card actually read. Deck must be checked for proper order of the input data set.

Other major errors result from improper number or arrangement of the AREAV cards. As the cards are read, the longitudinal station values are checked for ascending order. If a descending value is found, the statement

LONGITUDINAL STATION IS NOT IN ASCENDING ORDER

is written and execution terminated. The AREAV cards must then be manually checked and reordered. If reading of AREAV cards is terminated normally by reading an END card and only one AREAV card has been read, the statement

NUMBER OF LONGITUDINAL STATIONS MUST EXCEED 1

is written. Since two cards are necessary to define a single segment, at least one additional AREAV card must be added to adequately define the body of revolution.

PROGRAM WING - LIFTING SURFACE UPWASH ESTIMATOR

Program WING makes upwash estimates for lifting surfaces using equations developed in Appendix B. The user is required to input the geometry of the lifting surface to be analyzed and the location of the center of pressure of the angle-of-attack vane. In most cases the test aircraft will resemble the Weissinger planform discussed in Appendix B closely enough that geometric data can be obtained directly from the physical description of the aircraft and input into the program. If, however, the test aircraft doesn't match the assumed planform closely enough, the user must enter the geometry of an "equivalent" Weissinger planform as discussed in the Yaggy-Rogallo Analysis section of this report. The program calculates all "effective" geometry to account for compressibility effects and calculates upwash estimates. The program can calculate upwash estimates for as many lifting surfaces as the user desires during a single run. The normal output is a comprehensive, line-printer listing of the input geometric data, the effective geometric data, and the upwash estimates. Should the user improperly prepare the input data, the output will be greatly abbreviated and consist of as much information as possible on the location and nature of the error. The error messages are output by error-checking portions of code and depend on the location and type of error. The input, output, and error checking are described more fully below.

WING INPUT CARDS:

The input cards for program WING consist of five types of cards which are arranged into data sets as shown in Figure D4. Each card of the input data sets contains one of five card identifiers entered as alphanumeric data in the first five columns of the card. The card identifiers are used as card titles in discussing the cards as well as serving as flags in the error checking process. The remainder of the card contains input data to be used in calculating upwash estimates or labeling output. There are limitations on the number and range of some parameters which must be observed. The content of each type of card and limitations on specific variables will be discussed in detail below, but the critical information is summarized for quick reference in Figure D5.

HEAD1 Card. A single HEAD1 card is the first card of each input data set. The card identifier is the alphanumeric characters "HEAD1" in the first five columns. Columns 6 through 80 contain 75 alphanumeric characters of user-supplied heading. This heading is the first of two lines of heading printed on each page of output to identify and clarify the output.

HEAD2 Card. A single HEAD2 card is the second card of each input data set. The card identifier is the alphanumeric characters "HEAD2" in the first five columns. Columns 6 through 80 contain 75 alphanumeric characters of user-supplied heading comprising the second heading line to be printed on each page.

WINGS Card. A single WINGS card is the third card of each input data set. The card identifier is the alphanumeric characters "WINGS" in the first five columns. The information on this card specifies the location of the center of pressure of the angle-of-attack vane relative to the location of the lifting surface and the geometry of the lifting surface. The first parameter is a two-character abbreviation for the units of length in which other parameters will be input. Two alphanumeric characters such as "IN" for inches or "CM" for centimeters are entered in columns 9 and 10 and stored in variable UNIT. The only use within the program for this variable is as a column heading for all columns having units of length; no units checking or conversion is done. Nothing adverse will happen within the program if the abbreviation doesn't agree with the actual units or even if the field is blank. It is important, however, that all values be entered in consistent units of length.
If the longitudinal station of the center of pressure of the angle-of-attack vane is in centimeters, for instance, the longitudinal station of the quarter-chord line at midspan and the span must also be in centimeters to obtain valid results. Accurate entry of the units abbreviation will act as a reminder of this fact and is highly recommended. The next parameter is the longitudinal station of the center of pressure of the angle-of-attack vane. The parameter is entered in columns 11 through 20 in F10.0 format and stored in variable FSVANE. The next parameter is the longitudinal station of the quarter-chord line at midspan and is stored in variable FSQCL. FSQCL is entered in columns 21 through 30 in F10.0 format. The last three parameters which give the planform geometry

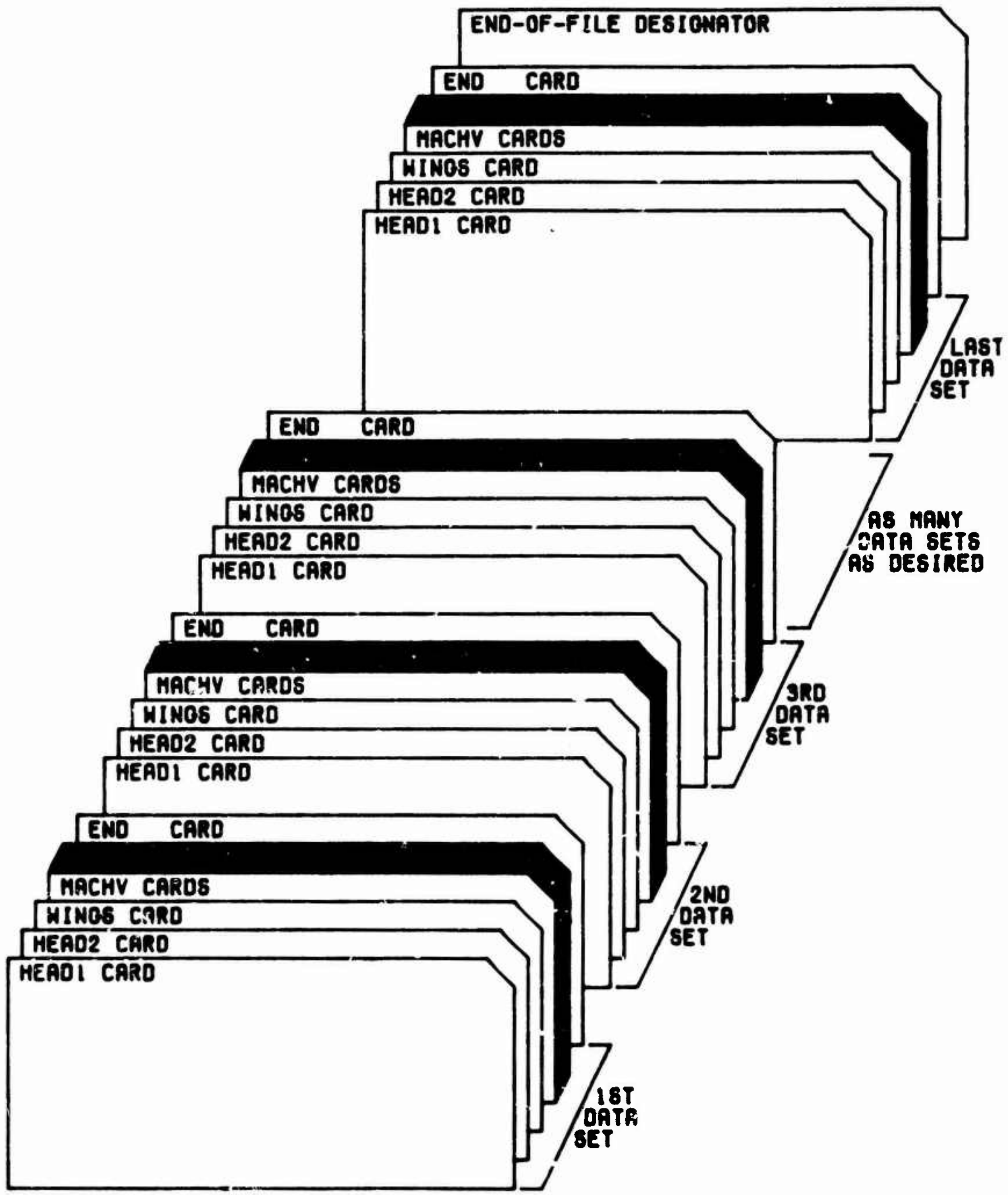

FIGURE D4: LIFTING SURFACE COMPONENT DATA CARDS

CARD TYPE	NO. OF CARDS	VARIABLE	FORMAT	COLUMNS	DESCRIPTION
HEAD1	1	HEAD	A5	1- 5	Card identifier - Must be "HEAD1"
		HEAD1	A75	6-80	First line of user specified heading
HEAD2	1	HEAD	A5	1- 5	Card identifier - Must be "HEAD2"
		HEAD2	A75	6-80	Second line of user specified heading
WINGS	1	HEAD	A5	1- 5	Card identifier - Must be "WINGS"
			3X	6- 8	Blank
		UNIT	A2	9-10	Two alphanumeric characters as abbreviation for units of input (eg; IN, CM, FT)
		FSVANE	F10.0	11-20	Longitudinal station of center of pressure of angle-of-attack vane
		FSQCL	F10.0	21-30	Longitudinal station of quarter-chord line at midspan
		SPAN	F10.0	31-40	Span of lifting surface
		AR	F10.0	41-50	Aspect ratio of lifting surface
		WSQCL	F10.0	51-60	Wing sweep of quarter chord line
			20X	61-80	Blank
MACHV	1 to 14 (as req'd)	HEAD	A5	1- 5	Card identifier - Must be "MACHV" on each card
			3X	6- 8	Blank
		NMACH	I2	9-10	Number of Mach number values to be read from all MACHV cards (Note: This variable is active on first card only)
		XMACH	7F10.0	11-80	Seven Mach number values (Note: Number of MACHV cards must match exactly the number of cards to read in "NMACH" values at 7/card)
END	1	HEAD	A5	1- 5	Card identifier - Must be "END " (Note: This terminates a data set)
			75X	6-80	Blank

FIGURE D5: SUMMARY OF DATA CARDS FOR PROGRAM WING are the span of the lifting surface, aspect ratio of the lifting surface, and sweep of the quarter-chord line. The parameters are stored as variables SPAN, AR, and WSQCL respectively. All three are entered in F10.0 format in columns 31 through 40, 41 through 50, and 51 through 60 respectively. The remainder of the card is blank.

MACHV Cards. One or more MACHV cards follow the VANES card in each input data set. Each MACHV card has the alphanumeric characters "MACHV" in the first five columns as the card identifier. The first MACHV card only has variable NMACH in I2 format in columns 9 and 10. NMACH contains the number of Mach numbers where upwash estimates are desired. The number of Mach numbers is limited to 98 by program dimensions and efforts to enter more values will abnormally terminate the program. Each MACHV card will hold up to seven values of MACH number in 7F10.0 format in columns 11 through 80. Since seven values per field for fourteen cards yields ninety-eight values, the program expects no more than fourteen MACHV cards. The program expects all Mach number values to be entered in the first NMACH fields and only enough cards to contain NMACH fields to be in a data set. Thus, if seventeen Mach number values are to be read in, it would require exactly three MACHV cards; the first two would contain full seven fields each and the third would contain three Mach number values in the three left-most fields. All Mach number values must be greater than or equal to 0.0 and less than or equal to 1.0 as assumed in deriving the basic equations.

END Card. A single END card must follow the MACHV cards to end reading of AREAV cards and to terminate the input data set. The card identifier is the alphanumeric characters "END " in the first five columns. The rest of the card is blank.

WING OUTPUT:

The output of program WING consists of a single page of line-printer listing as shown in Figure D6. The output lists the actual geometric data for the lifting surface as input by the user as well as the calculated and effective geometry at each Mach number requested and upwash estimates for each specific Mach number. The format of the listing was planned such that the actual printing takes only 7.5 inches in width and about 8.5 in length with 40 data points per page and 6 lines per inch. This leaves adequate margins, when trimmed to 8.5 by 11.0, to place the pages in notebooks and reports. The page is repeated as required to accommodate the number of Mach number values requested.

The output is identified by the two lines of user-supplied heading entered on the HEAD1 and HEAD2 cards and printed between the dashed lines directly below the standard headings. The next information is the location of the lifting surface relative to the center of pressure of the angle-of-attack vane and the geometry of the planiform as read from the WINGS card. The distances and dimensions are printed and labeled with the dimensional abbreviation input in variable UNIT. As with program BODY, no conversions or checks are done to insure consistency of units.

YAGGY-RUGALLO UPWASH CALCULATION PAGE
UPWASH ESTIMATE FOR LIFTING SURFACE COMPONENTS 1/ 1

F-111A/TACT AIRCRAFT

TRAPEZOIDAL WING 26 WING SWEEP

LIFTING SURFACE GEOMETRIC DETAIL:

LONGITUDINAL STATION OF VANES	-68.4500 IN
LONGITUDINAL STATION OF APEX OF QUARTER-CHORD LINE	457.2800 IN
DISTANCE FROM APEX OF QUARTER-CHORD TO VANES (XV).	525.7300 IN
SPAN (B)	664.0200 IN
TAU (XV/(B/2))	1.5835 B/2
ASPECT RATIO	5.0700
SWEEP OF QUARTER-CHORD LINE	23.3400 DEG

LIFTING SURFACE UPWASH ESTIMATES:

MACH	BETA	TAU/BETA	EFFECTIVE WING SWEEP (DEG)	EPSILON AR /CL (RAD)	EPSILON/CL (RAD)	EPSILON/CL (DEG)
0.0000	1.0000	1.5835	23.3400	.025482	.005026	.287 76
.1000	.9950	1.5915	23.4449	.025241	.004978	.285247
.2000	.9798	1.6161	23.7684	.024515	.004835	.277038
.3000	.9539	1.6599	24.3387	.023298	.004595	.263285
.4000	.9165	1.7277	25.2111	.021581	.004257	.243880
.5000	.8660	1.8284	26.4847	.019349	.003816	.218663
.6000	.8000	1.9793	28.3411	.016584	.003271	.187418
.7000	.7141	2.2173	31.1410	.013263	.002616	.149880
.8000	.6000	2.6391	35.7222	.009361	.001846	.105786
.9000	.4359	3.6327	44.7098	.004884	.000963	.055191
.9900	.1411	11.2250	71.6761	.000536	.000106	.006063

FIGURE D6: PROGRAM WING SAMPLE OUTPUT

The Mach number data, effective geometry, and upwash estimates are then printed with one line per Mach number value requested. The first and second values are the Mach number and corresponding compressibility factor labeled MACH and BETA respectively. The effective distance of the angle-of-attack vane ahead of the quarter chord line in terms of τ/β and the effective wing sweep for the particular Mach number value are then printed. The upwash parameter $\varepsilon AR/C_L$ calculated for the Mach number value is then printed as EPSILON AR/CL in radians. The upwash angle estimate per unit lift coefficient in radians and then degrees are printed as EPSILON/CL as the last two values.

WING ERROR CHECKING:

Program WING performs numerous error checks as data is read and as upwash calculations are made. The main purpose of the error checking is to avoid abnormal termination of the program or to give the user as much information as possible on the location and nature of the error if termination is unavoidable. Several minor-error checks are made which change internal values which are obviously wrong and would cease execution of the program immediately if uncorrected. These changes which were included mainly to protect the user from gross misapplication or keypunch errors are not accompanied by error messages. Since these checks might limit the experienced user, give unexpected results, or cause confusion due to apparent inconsistencies, they are discussed briefly. The main body of the checks are for major errors with input data which do not have easily determined solutions and which must terminate program execution. These major-error checks write error messages to the user prior to termination to identify where and why termination occurred. Both the minor-error and major-error checks are discussed below.

Minor-Error Checking. Errors which appear obvious and usually result from keypunch errors or gross misapplication of the technique were corrected without accompanying output messages. This was done to allow continued execution of the program so that output could be produced to aid error analysis and so that subsequent data sets could be processed. In some cases this results in invalid or unexpected results which should be investigated and fixed; in other cases it simply allows data to be entered in a convenient manner when it would normally terminate program execution.

Mach number values entered on MACHV cards were checked for values less than 0.0 and greater than 1.0. Obviously values less than 0.0 have no meaning and usually result from keypunch errors. Values less than 0.0 were changed to 0.0 internally but printed at their original value to allow them to be found and corrected. Mach number values greater than 1.0 are equally invalid since velocities cannot be induced ahead of a body in supersonic flow. Upwash estimates for Mach numbers greater than 1.0 were set to zero and execution continued.

Major-Error Checking. Checking for major errors which necessitated program termination was accomplished in subroutine DATARD. Any major error discovered resulted in an error message followed by program termination.

Normal program termination resulted from reading an end-of-file designator while attempting to read a HEAD1 card. Unexpected reading of an end-of-file designator by any other read statement results in the statement

"   " IS IN ERROR - END-OF-FILE ENCOUNTERED

where the quotes have the five alphanumeric characters of the card identifier being sought when the end-of-file designator was encountered. The input data set should be reassembled with the proper number and types of cards. A related message results if the input data set is improperly arranged or a card identifier is misspelled. The statement

"   " IS IN ERROR - CARD READS "   "

will be printed if an unexpected card identifier is encountered. The first set of quotes encloses the five alphanumeric characters of the expected identifier while the second set enclose the eighty alphanumeric characters on the card actually read. Deck must be checked for proper order of the input data set.

Other major errors result from errors in input data values which would abnormally terminate execution. If one or more errors are found, a statement

INPUT DATA ERRORS:

is printed followed by an explanation of the input data errors. The center of pressure of the angle-of-attack vanes must be well ahead of the quarterchord line of the lifting surface. If the distance is found to be zero a message

DISTANCE FROM WING TO VANE MUST BE NON-ZERO

will be printed. If the value for span of the lifting surface is found to be negative or zero, a message

SPAN MUST BE NON-ZERO, POSITIVE VALUE

will be printed. If the value for aspect ratio is found to be negative or zero, a message

ASPECT RATIO MUST BE NON-ZERO, POSITIVE VALUE

will be printed. The wing sweep angle of the quarter-chord line must be greater than zero (aft sweep) because no forward sweep data was analyzed. If the sweep is less than 0.0 a message

SWEEP ANGLES LESS THAN 0.0 ARE INVALID

is written. If the sweep is greater than 90.0 a message

SWEEP ANGLES GREATER THAN 90.0 ARE INVALID

is written. If no Mach number values are specified, the program need not be executed; therefore, if the number of Mach number values specified by variable MACHS is zero a message

NUMBER OF MACH NUMBERS MUST BE GREATER THAN 0

is written.

Another message is written if the center of pressure of the angle-of-attack vanes doesn't lie far enough ahead of the quarter-chord line. The production software uses the equation described in Appendix B to calculate the upwash parameter. As explained in the derivation, the equation is valid only for τ/β values greater than 0.4. Therefore, if τ/β is less than 0.4 a message

TAU/BETA VALUES LESS THAN 0.4 ARE INVALID

is written.

APPENDIX E
PROGRAMMER'S GUIDE AND PROGRAM LISTINGS FOR THE YAGGY-ROGALLO PRODUCTION SOFTWARE

INTRODUCTION

Programmer information and program listings for the two programs developed to implement the Yaggy-Rogallo upwash estimation technique are included in this appendix. Both programs are ANSI-standard FORTRAN V with the exception of a single file-declaration list on the first card of each program. Practically no user or programmer guidance is supplied as comments within the code because of the extreme simplicity of the code and the production nature of the software. A user's guide to input, output, and error checking for both programs is included in Appendix D.

Program BODY is the program which calculates upwash estimates for bodies of revolution using equations developed in Appendix A and program WING is the program which calculates upwash estimates for lifting surfaces using equations developed in Appendix B. The two programs are completely independent, but there is great similiarity in their internal development, input, and output. Information needed to understand the working or limitations of these programs or to modify them is included in the following sections.

PROGRAM BODY:

Purpose. Program BODY implements the Yaggy-Rogallo technique of making upwash angle estimates for bodies of revolution. The body is entered as a series of longitudinal station/cross sectional area pairs which describe the distribution of area along the body length. At each station a radius is calculated which is the radius of a circle having an area equal to the actual area at the station. The upwash angle estimate for a segment between two adjacent stations is calculated by assuming the area of intermediate sections varies linearily as described in Appendix A and implemented in equation (A40).

Conditions of Validity.

(1) The specified location of the center of pressure of the angle-of-attack vane must not lie on the centerline of the equivalent body since this is a singularity in the original equations. Mathematically the radial distance from the centerline of the equivalent body to the center of pressure of the angle-of-attack vane, r (variable RVANE), cannot be equal to zero.

(2) Program dimensions limit the body to 999 segments (1000 longitudinal station/cross sectional area pairs).

(3) Program dimensions limit the number of Mach number values per input data set to 98.

(4) Mach number values requested must be greater than or equal to 0.0 and less than or equal to 1.0 since other values have no meaning in upwash calculations.

Storage Required.

	Octal Words	Decimal Words
PROGRAM	150	104
COMMON	15701	7105
TOTAL	16051	7209

Subprograms Used.

ABS, ATAN, EPOAL, RDDATA, SQRT, WRITE2

COMMOM Inputs. Only the common inputs used by this program are described below.

COMMON/BBB/FSVANE,RVANE,ANVANE,NMACH,XMACH(98),FS(1000),AREA(1000)

	INPUT	DESCRIPTION	UNITS
r	RVANE	Radial distance from the centerline of the equivalent body to the center of pressure of angle-of-attack vane	ℓ [3]
Ω	ANVANE	Angular location of the center of pressure of angle-of-attack vane around the equivalent body centerline with 0 being vertically above the centerline	deg
	NMACH	Number of Mach number values where upwash angle estimates are desired	N-D
	XMACH	Mach number values where upwash angle estimates are desired	N-D

COMMON/CCC/NPTS,NPGS,X(1000),R(1000)

	INPUT	DESCRIPTION	UNITS
	NPTS	Number of points into longitudinal station/longitudal station pairs used to describe the equivalent body (Number of AREAV cards read by RD-DATA)	N-D
x	X	Longitudinal distances from center of pressure of angle-of-attack vane to longitudinal station	ℓ
R	R	Equivalent-circle radii at each longitudinal station	ℓ

COMMOM Outputs. Only the common outputs used by this program are described below.

COMMON/DDD/XE(1000),THETA(1000),DELEOA(1000),SUM

	OUTPUT	DESCRIPTION	UNITS
$\tilde{x}$	XE	Effective longitudinal distances from center of pressure of angle-of-attack vane to longitudinal stations	ℓ
$\tilde{\theta}$	THETA	Angle between body centerline and line connecting vane and center of equivalent circles	rad
$\Delta(\epsilon/\alpha)$	DELEOA	Increment in ϵ/α for a segment of the body	N-D
$\Sigma\Delta(\epsilon/\alpha)$	SUM	The sum of $\Delta(\epsilon/\alpha)$ values to give the ϵ/α for the whole body	N-D

[3]Units specified as units of length, ℓ, are not in any particular units of length but all parameters having units of ℓ must be in the same unit of length, e.g., all in inches or all in centimeters.

<u>Program Description.</u> Program BODY calculates upwash estimates for bodies of revolution. BODY uses subroutine RDDATA to read a single input data set, check the input for errors, and call WRITE1 to print the actual geometric data for the body. The effective body geometry is then calculated from the actual geometry by BODY. Increments in upwash angle due to each segment of the body are calculated using function EPOAL and summed by BODY to obtain an upwash angle estimate for the whole body. WRITE2 is called to print the effective geometry and upwash estimates. RDDATA is then called to read another input data set or terminate execution.

<u>Program Listing.</u>

```
      PROGRAM BODY(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     FILE DECLARATION LIST NON-ANSI
C     -------------------------------------------------------------
C     PROGRAM BODY IS A FORTRAN V PROGRAM FOR MAKING UPWASH ESTIMATES
C     FOR BODIES OF REVOLUTION USING THE YAGGY-ROGALLO TECHNIQUE. THE
C     DERIVATION OF EQUATIONS USED IN THIS PROGRAM AND A USER'S GUIDE
C     ARE CONTAINED IN "A METHOD OF ESTIMATING UPWASH ANGLE AT NOSEBOOM-
C     MOUNTED VANES",AFFTC-TIM-81-1,JUNE 1981.
C     QUESTIONS, COMMENTS, OR REQUESTS FOR THE USER'S GUIDE SHOULD BE
C     DIRECTED TO KEN RAWLINGS, 6520TG/ENDT (STOP 239),AIR FORCE FLIGHT
C     TEST CENTER,EDWARDS AFB,CA 93523 OR TELEPHONE (805) 277-3779.
C     REVISION RECORD:
C     WRITTEN BY        PAT JUENEMANN                    APR 1980
C     REVISED BY        KEN RAWLINGS                     JUN 1981
C     -------------------------------------------------------------
      COMMON/BBB/FSVANE,RVANE,ANVANE,NMACH,XMACH(98),FS(1000),AREA(1000)
      COMMON/CCC/NPTS,NPGS,X(1000),R(1000)
      COMMON/DDD/XE(1000),THETA(1000),DELFDA(1000),SUM
   10 CALL RDDATA
      DO 50 J=1,NMACH
      SUM=0.
      AMACH=XMACH(J)
      IF(AMACH .LT. 0.0) AMACH=0.0
      IF(AMACH .GT. 1.0) AMACH=1.0
      BETA=SQRT(1.0-(AMACH*AMACH))
      DO 30 I=1,NPTS
      IF(X(I)  .LE. 0.0)  GO TO 20
      XE(I)=X(I)*BETA
      THETA(I)=3.1415926/2.0
      IF(XE(I) .NE. 0.0) THETA(I)=ATAN(ABS(RVANE)/XE(I))
      GO TO 30
   20 XE(I)=-999999999.9999
      IF(BETA  .NE. 0.0) XE(I)=X(I)/BETA
      THETA(I)=3.1415926/2.0
      IF(XE(I) .NE. 0.0) THETA(I)=ATAN(ABS(RVANE)/XE(I))+3.1415926
   30 CONTINUE
      DO 40 I = 2,NPTS
      DELFDA(I)=0.0
      IF(RVANE     .EQ.          0.0) GO TO 40
      IF(THETA(I)  .EQ. THETA(I-1)) GO TO 40
      DELFDA(I)=EPOAL(R(I),R(I-1),THETA(I),THETA(I-1),RVANE,ANVANE)
      SUM=SUM+DELFDA(I)
   40 CONTINUE
      CALL WRITE2 (XMACH(J))
   50 CONTINUE
      GO TO 10
      END
```

FUNCTION EPOAL:

Purpose. Function EPOAL calculates the upwash estimate for a single segment of an equivalent body of revolution using the linear-area method recommended in Appendix A and implemented in equation (A40).

Conditions of Validity.

(1) The angle at the leading edge of the segment, θ_{i-1}, and the angle at the trailing edge of the segment, θ_i, cannot be equal.

(2) The radial distance from the body centerline to the center of pressure of the angle-of-attack vane, r, cannot be zero.

Storage Required.

Octal Words	Decimal Words
70	56

Subprograms Used.

COS, SIN, TAN

Calling Statement.

FUNCTION EPOAL (RI,RIM1,THI,THIM1,RVANE,ANVANE)

Calling Argument Inputs.

INPUT		DESCRIPTION	UNITS
R_i	RI	Radius of equivalent circle at trailing edge of segment	ℓ
R_{i-1}	RIM1	Radius of equivalent circle at leading edge of segment	ℓ
θ_i	THI	Angle for trailing edge of segment	rad
θ_{i-1}	THIM1	Angle for leading edge of segment	rad
r	RVANE	Radial distance from equivalent body centerline to center of pressure of angle-of-attack vane	ℓ
ϕ	ANVANE	Radial location of center of pressure of angle-of-attack vane around body centerline	deg

Functional Output.

Output		DESCRIPTION	UNITS
$\Delta(\epsilon/\alpha)$	EPOAL	Upwash increment for a single segment in terms of upwash angle, ϵ, per angle of attack, α	N-D

Program Listing.

```
      FUNCTION EPOAL (RI,RIM1,THI,THIM1,RVANE,ANVANE)
      REAL K1,K2
      K1=((RIM1*RIM1)-(RI*RI))/((1./TAN(THIM1))-(1./TAN(THI)))
      K2=(RI*RI)-(K1/TAN(THI))
      SUMM=(K1*(SIN(THI)-SIN(THIM1)))+(K2*(COS(THIM1)-COS(THI)))
      FACTOR=(((SIN(ANVANE/57.2958))**2)-((COS(ANVANE/57.2958))**2))
     1        /(2.*RVANE*RVANE)
      EPOAL=FACTOR*SUMM
      END
```

SUBROUTINE RDDATA:

Purpose. Subroutine RDDATA reads one input data set per call, checks data for input errors, and passes information out through common.

Conditions of Validity.

(1) Data must be formated in 80-column card images as described in Appendix D, Users Guide for the Yaggy-Rogallo Production Software.

Storage Required.

	Octal Words	Decimal Words
PROGRAM	406	262
COMMON	10030	4120
TOTAL	10436	4382

Subprograms Used.

ABS, SQRT, WRITE1

Calling Statement.

CALL RDDATA

Input File Inputs.

	INPUT	DESCRIPTION	UNITS
	HEAD1	First line of user-supplied heading (75 alphanumeric characters)	N-D
	HEAD2	Second line of user-supplied heading (75 alphanumeric characters)	N-D
	UNIT	Abbreviation for units of length for input values (2 alphanumeric characters)	N-D
FS_V	FSVANE	Longitudial (fuselage) station of center of pressure of angle-of-attack vane	ℓ
r	RVANE	Radial distance from the body centerline to the center of pressure of the angle-of-attack vane	ℓ
Ω	ANVANE	Angular location of the center of pressure of angle-of-attack vane around the body centerline with 0 being vertically above centerline	deg

	NMACH	Number of Mach number values where upwash angle estimates are desired	N-D
	XMACH	Mach number values where upwash angle estimates are desired	N-D
FS	FS	Longitudinal (fuselage) stations used to describe equivalent body	ℓ
	AREA	Longitudinal (fuselage) station cross sectional areas corresponding to stations in array FS	ℓ^2

<u>COMMON Outputs.</u> Only those common values output by this subroutine are discussed below.

COMMON/AAA/HEAD1,HEAD2,UNIT

OUTPUT		DESCRIPTION	UNITS
	HEAD1	First line of user-supplied heading (75 alphanumeric characters)	N-D
	HEAD2	Second line of user-supplied heading (75 alphanumeric characters)	N-D
	UNIT	Abbreviation for units of length for input values (2 alphanumeric characters)	N-D

COMMON/BBB/FSVANE,RVANE,ANVANE,NMACH,XMACH(98),FS(1000),AREA(1000)

OUTPUT		DESCRIPTION	UNITS
FS_V	FSVANE	Longitudinal (fuselage) station of center of pressure of angle-of-attack vane	ℓ
r	RVANE	Radial distance from the body centerline to the center of pressure of the angle-of-attack vane	ℓ
Ω	ANVANE	Angular location of the center of presure of the angle-of-attack vane around the body centerline with 0 being vertically above centerline	deg
	NMACH	Number of Mach number values where upwash angle estimates are desired	N-D
	XMACH	Mach number values where upwash angle estimates are desired	N-D
FS	FS	Longitudinal (fuselage) stations used to describe equivalent body	ℓ
	AREA	Longitudinal (fuselage) station cross sectional area corresponding to stations in array FS	ℓ^2

COMMON/CCC/NPTS,NPGS,X(1000),R(1000)

	OUTPUT	DESCRIPTION	UNITS
	NPTS	Number of points into longitudinal station pairs used to describe the equivalent body (Number of AREAV cards read by RDDATA)	N-D
	NPGS	Number of pages required for NPTS at 40 points per page	N-D
x	X	Longitudinal distances from center of pressure of angle-of-attack vane to longitudinal stations	ℓ
R	R	Equivalent-circle radii at each longitudinal station	ℓ

Messages.

(1) "   " IS IN ERROR - CARD READS "   "

Error message printed when RDDATA encounters an unexpected card identifier. First quotation marks contain card identifier of card expected and second prints 80 alphanumeric characters on card actually read.

(2) LONGITUDINAL STATION IS NOT IN ASCENDING ORDER

Error message printed when the longitudinal station FS(I) on an AREAV card is less than that on the preceding card.

(3) "   " IS IN ERROR - END-OF-FILE ENCOUNTERED

Error message printed when an end-of-file is encountered during reading of any card other than a HEAD1 card. Quotation marks contain card identifier of card expected when end-of-file was encountered.

(4) NUMBER OF LONGITUDINAL STATIONS MUST EXCEED 1

Error message printed when only one AREAV card is read and NPTS equals one.

Program Listing.

```
      SUBROUTINE RDDATA
      COMMON/AAA/HEAD1,HEAD2,UNIT
      COMMON/BBB/FSVANE,RVANE,ANVANE,NMACH,XMACH(98),FS(1000),AREA(1000)
      COMMON/CCC/NPTS,NPGS,X(1000),R(1000)
      CHARACTER HEAD1*75,HEAD2*75,HEAD3*75,HEAD*5,HEADER*5,UNIT*2
C     READ 'HEAD1' CARD ---------------------------------------------------
      HEADER='HEAD1'
      READ(5,100,END=90) HEAD,HEAD1
      IF(HEAD .NE. HEADER) GO TO 50
C     READ 'HEAD2' CARD ---------------------------------------------------
      HEADER='HEAD2'
      READ(5,100,END=80) HEAD,HEAD2
      IF(HEAD .NE. HEADER) GO TO 50
C     READ 'VANES' CARD ---------------------------------------------------
      HEADER='VANES'
      READ(5,110,END=80) HEAD,UNIT,FSVANE,RVANE,ANVANE
      IF(HEAD .NE. HEADER) GO TO 50
C     READ 'MACHV' CARD ---------------------------------------------------
      HEADER='MACHV'
      DO 10 J=1,92,7
      READ(5,120,END=80) HEAD,MACH,(XMACH(I),I=J,(J+6))
      IF(HEAD .NE. HEADER) GO TO 50
      IF(J .EQ. 1) NMACH=MACH
      IF(NMACH .LE. (J+6)) GO TO 20
   10 CONTINUE
C     READ 'AREAV' CARDS --------------------------------------------------
   20 HEADER='AREAV'
      NPTS=0
      DO 30 I=1,1000
      READ(5,130,END=80) HEAD,FS(I),AREA(I)
      IF(HEAD .EQ. 'END  ') GO TO 40
      IF(HEAD .NE. HEADER) GO TO 50
      NPTS=NPTS+1
      X(I) = FSVANE - FS(I)
      R(I) = SQRT(ABS(AREA(I)) / 3.1415926)
      IF(I .EQ. 1) GO TO 30
      IF(FS(I).LT.FS(I-1)) GO TO 60
   30 CONTINUE
   40 NPGS=(NPTS/40)+1
      IF(NPTS .EQ.       1) GO TO 70
      CALL WRITE1
      RETURN
   50 BACKSPACE 5
      READ(5,100) HEAD,HEAD3
      WRITE(6,140) HEADER,HEAD,HEAD3
      STOP
   60 WRITE(6,150)
      STOP
   70 WRITE(6,160)
      STOP
   80 WRITE(6,170) HEADER
   90 STOP
C     FORMAT STATEMENTS ---------------------------------------------------
  100 FORMAT(A5,A75)
  110 FORMAT(A5,3X,A2,3F10.0)
  120 FORMAT(A5,3X,I2,7F10.0)
  130 FORMAT(A5,5X,2F10.0)
  140 FORMAT(1H1,'"',A5,'" IS IN ERROR - CARD READS "',A5,A75,'"')
  150 FORMAT(1H1,'LONGITUDINAL STATION IS NOT IN ASCENDING ORDER')
  160 FORMAT(1H1,'NUMBER OF LONGITUDINAL STATIONS MUST EXCEED  1')
  170 FORMAT(1H1,'"',A5,'" IS IN ERROR - END-OF-FILE ENCOUNTERED')
      END
```

SUBROUTINE WRITE1:

Purpose. Subroutine WRITE1 prints the actual geometric data for the body with 40 points per page and up to 25 pages as required. One set of pages is printed for each input data set of the input file.

Storage Required.

	Octal Words	Decimal Words
PROGRAM	411	265
COMMON	10030	4120
TOTAL	10441	4385

Calling Statement.

CALL WRITE1

COMMOM Inputs. Only the COMMON inputs used by this subroutine are described below.

COMMON/AAA/HEAD1,HEAD2,UNIT

	INPUT	DESCRIPTION	UNITS
	HEAD1	First line of user-supplied heading (75 alphanumeric characters)	N-D
	HEAD2	Second line of user-supplied heading (75 alphanumeric characters)	N-D
	UNIT	Abbreviation for units of length for input values (2 alphanumeric characters)	N-D

COMMON/BBB/FSVANE,RVANE,ANVANE,NMACH,XMACH(98),FS(1000),AREA(1000)

	INPUT	DESCRIPTION	UNITS
FS_v	FSVANE	Longitudinal (fuselage) station of center of pressure of angle-of-attack vane	ℓ
r	RVANE	Radial distance from the body centerline to the center of pressure of the angle-of-attack vane	ℓ
Ω	ANVANE	Angular location of the center of pressure of angle-of-attack vane around the body centerline with 0 being vertically above centerline	deg
	NMACH	Number of Mach number values where upwash angle estimates are desired	N-D

	XMACH	Mach number values where upwash angle estimates are desired	N-D
FS	FS	Longitudinal (fuselage) stations used to describe equivalent body	ℓ
	AREA	Longitudinal (fuselage) station cross sectional areas corresponding to stations in array FS	ℓ^2

COMMON/CCC/NPTS,NPGS,X(1000),R(1000)

	INPUT	DESCRIPTION	UNITS
	NPTS	Number of points into longitudinal station longitudinal station pairs used to describe the equivalent body (Number of AREAV cards read by RDDATA)	N-D
	NPGS	Number of pages required for NPTS at 40 points per page	N-D
x	X	Longitudinal distances from center of pressure of angle-of-attack vane to longitudinal stations	ℓ
R	R	Equivalent-circle radii at each longitudinal station	ℓ

Printer Outputs.

	INPUT	DESCRIPTION	UNITS
	NPGS	Number of pages required for NPTS at 40 points per page	N-D
	HEAD1	First line of user-supplied heading (75 alphanumeric characters)	N-D
	HEAD2	Second line of user-supplied heading (75 alphanumeric characters)	N-D
	UNIT	Abbreviation for units of length for input values (2 alphanumeric characters)	N-D
r	RVANE	Radial distance from the body centerline to the center of pressure of the angle-of-attack vane	ℓ
Ω	ANVANE	Angular location of the center of pressure of angle-of-attack vane around the body centerline with 0 being vertically above centerline	deg

FS_v	FSVANE	Longitudinal (fuselage) station of center of pressure of angle-of-attack vane	ℓ
FS	FS	Longitudinal (fuselage) stations used to describe equivalent body	ℓ
	AREA	Longitudinal (fuselage) station cross sectional areas correrponding to station in array FS	ℓ^2
x	X	Longitudinal distances from center of pressure of angle-of-attack vane to longitudinal stations	ℓ
R	R	Equivalent-circle radii at each longitudinal station	ℓ

Program Listing.

```
      SUBROUTINE WRITE1
      COMMON/AAA/HEAD1,HEAD2,UNIT
      COMMON/BBB/FSVANE,RVANE,ANVANE,NMACH,XMACH(98),FS(1000),AREA(1000)
      COMMON/CCC/NPTS,NPGS,X(1000),R(1000)
      DIMENSION LINE6(2),LINE7(2),LINE8(2)
      CHARACTER HEAD1*75,HEAD2*75,UNIT*2,TITLE1*32,TITLE2*41
      CHARACTER LINE1*30,LINE2*50,LINE3*50,LINE4*50,LINE5*28,LINE6*34
      CHARACTER LINE7*34,LINE8*34,LINE9*52,DASH4*4,DASH13*13,DASH15*15
      DATA TITLE1/'YAGGY-ROGALLO UPWASH CALCULATION'/
      DATA TITLE2/'GEOMETRIC DATA FOR CYLINDRICAL COMPONENTS'/
      DATA DASH4,DASH13,DASH15/'----','-------------','---------------'/
      DATA LINE1/'ANGLE-OF-ATTACK VANE LOCATION:'/
      DATA LINE2/'RADIAL DISTANCE FROM BODY CENTERLINE ..............'/
      DATA LINE3/'ANGULAR LOCATION ..................................'/
      DATA LINE4/'LONGITUDINAL STATION OF VANES .....................'/
      DATA LINE5/'COMPONENT AREA DISTRIBUTION:'/
      DATA LINE6/'                    CROSS SECTIONA',
     1           'L  LONGITUDINAL     EQUIVALENT   '/
      DATA LINE7/'PT    LONGITUDINAL  AREA OF BODY ',
     1           '    DISTANCE FROM   RADIUS AT    '/
      DATA LINE8/'NO     STATION      AT STATION   ',
     1           '    VANE TO STATION STATION      '/
      DATA LINE9/'(  )            (SQ  )         (  )          (  )'/
C     PRINT GEOMETRIC DATA FOR CYLINDERICAL COMPONENTS ----------------
      LPT=0
      DO 20 I=1,25
C     PRINT PAGE HEADINGS FOR GEOMETRIC DATA ---------------------------
      WRITE(6,100) TITLE1
      WRITE(6,110) TITLE2,I,NPGS
      WRITE(6,120) DASH15,DASH15,DASH15,DASH15,DASH15
      WRITE(6,130) HEAD1
      WRITE(6,130) HEAD2
      WRITE(6,120) DASH15,DASH15,DASH15,DASH15,DASH15
      WRITE(6,140) LINE1
      WRITE(6,150) LINE2,RVANE,UNIT
      WRITE(6,160) LINE3,ANVANE
      WRITE(6,150) LINE4,FSVANE,UNIT
      WRITE(6,170) LINE5
      WRITE(6,180) LINE6
      WRITE(6,180) LINE7
      WRITE(6,180) LINE8
      WRITE(6,190) LINE9
      WRITE(6,200) UNIT,UNIT,UNIT,UNIT
      WRITE(6,210) DASH4,DASH13,DASH15,DASH15,DASH13
C     PRINT ONE PAGE OF GEOMETRIC DATA ---------------------------------
      DO 10 J=1,40
      LPT=LPT+1
      IF(LPT .GT .NPTS) RETURN
      WRITE(6,220) LPT,FS(LPT),AREA(LPT),X(LPT),R(LPT)
   10 CONTINUE
   20 CONTINUE
      RETURN
C     FORMAT STATEMENTS ------------------------------------------------
  100 FORMAT(1H1,T24,A32,T73,'PAGE')
  110 FORMAT(1H ,T19,A41,T72,I2,'/',I2)
  120 FORMAT(1H ,5A15)
  130 FORMAT(1H ,A75)
  140 FORMAT(1H ,A30)
  150 FORMAT(1H ,T10,A50,3X,F10.4,1X,A2)
  160 FORMAT(1H ,T10,A50,3X,F10.4,1X,'DEG')
  170 FORMAT(1H ,A28)
  180 FORMAT(1H ,T10,A34,A34)
  190 FORMAT(1H ,T19,A52)
  200 FORMAT(1H+,T20,A2,16X,A2,13X,A2,13X,A2)
  210 FORMAT(1H ,T09,A4,2X,A13,2X,A15,2X,A15,2X,A13)
  220 FORMAT(1H ,7X,I4,2X,F13.4,2X,F15.4,2X,F15.4,2X,F13.4)
      END
```

SUBROUTINE WRITE2:

Purpose. Subroutine WRITE2 prints the effective geometric data for the body with 40 points per page and up to 25 pages as required. One set of pages is printed for each Mach number where upwash estimates are requested.

Storage Required.

	Octal Words	Decimal Words
PROGRAM	347	231
COMMON	11633	5019
TOTAL	12202	5250

Calling Statement.

```
CALL WRITE2(AMCT)
```

COMMON Inputs. Only the COMMON inputs used by this subbroutine are described below.

COMMON/AAA/HEAD1,HEAD2,UNIT

	INPUT	DESCRIPTION	UNITS
	HEAD1	First line of user-supplied heading (75 alpha-numeric characters)	N-D
	HEAD2	Second line of user-supplied heading (75 alpha-numeric characters	N-D
	UNIT	Abbreviation for units of length for input values (2 alphanumeric characters)	N-D

COMMON/CCC/NPTS,NPGS,X(1000),R(1000)

	INPUT	DESCRIPTION	UNITS
	NPTS	Number of longitudinal station longitudinal cross sectional area pairs used to descirbe the equivalent body (number of AREAV cards read by RDDATA)	N-D
	NPGS	Number of pages required for NPTS at 40 points per page	N-D
x	X	Longitudinal distances from center of pressure of angle-of-attack vane to longitudinal stations	ℓ

COMMON/DDD/XE(1000),THETA(1000),DELEOA(1000),SUM

OUTPUT		DESCRIPTION	UNITS
$\tilde{x}$	XE	Effective longitudinal distances from center of pressure of angle-of-attack vane to longitudinal stations	ℓ
$\tilde{\theta}$	THETA	Angle between body centerline and line connecting vane and center of equivalent-circle	rad
$\Delta(\varepsilon/\alpha)$	DELEOA	Increment in ε/α for a segment of the body	N-D
$\sum\Delta(\varepsilon/\alpha)$	SUM	The sum of $\Delta(\varepsilon/\alpha)$ values to give the ε/α for the whole body	N-D

Program Listing.

```
      SUBROUTINE WRITE2(AMCT)
      COMMON/AAA/HEAD1,HEAD2,UNIT
      COMMON/CCC/NPTS,NPGS,X(1000),R(1000)
      COMMON/DDD/XE(1000),THETA(1000),DELEDA(1000),SUM
      DIMENSION LINE1(2),LINE2(2),LINE3(2),LINE4(2)
      CHARACTER TITLE1*32,TITLE2*42,HEAD1*75,HEAD2*75,UNIT*2
      CHARACTER LINE1*35,LINE2*35,LINE3*35,LINE4*35
      CHARACTER DASH4*4,DASH6*6,DASH10*10,DASH15*15
      DATA TITLE1/'YAGGY-ROGALLO UPWASH CALCULATION'/
      DATA TITLE2/'UPWASH ESTIMATE FOR CYLINDRICAL COMPONENTS'/
      DATA DASH4,DASH6,DASH10/'----','------','----------'/
      DATA DASH15/'---------------'/
      DATA LINE1/'       LONGITUDINAL      EFFECTIVE     ',
     1           '          EQUIVALENT   INCREMENT   '/
      DATA LINE2/'PT    DISTANCE FROM    DISTANCE FROM',
     1           '          RADIUS AT    IN EPSILON  '/
      DATA LINE3/'NO    VANE TO STATION  VANE TO STATI',
     1           'ON   THETA    STATION      OVER ALPHA '/
      DATA LINE4/'                ( )              ( )    ',
     1           '      (RAD)      ( )              '/
C     PRINT UPWASH ESTIMATES FOR CYLINDERICAL COMPONENTS ---------------
      LPT=0
      DO 20 I=1,25
C     PRINT PAGE HEADINGS FOR UPWASH ESTIMATES --------------------------
      WRITE(6,100) TITLE1
      WRITE(6,110) TITLE2,I,NPGS
      WRITE(6,120) AMCT
      WRITE(6,130) DASH15,DASH15,DASH15,DASH15,DASH15
      WRITE(6,140) HEAD1
      WRITE(6,140) HEAD2
      WRITE(6,130) DASH15,DASH15,DASH15,DASH15,DASH15
      WRITE(6,150) LINE1
      WRITE(6,150) LINE2
      WRITE(6,150) LINE3
      WRITE(6,150) LINE4
      WRITE(6,160) UNIT,UNIT,UNIT
      WRITE(6,170) DASH4,DASH15,DASH15,DASH6,DASH10,DASH10
C     PRINT ONE PAGE OF UPWASH ESTIMATES ---------------------------------
      DO 10 J=1,42
      LPT=LPT+1
      IF(LPT .GT. NPTS) GO TO 30
      WRITE(6,180) LPT,X(LPT),XE(LPT),THETA(LPT),R(LPT),DELEDA(LPT)
   10 CONTINUE
   20 CONTINUE
   30 WRITE(6,190) DASH10
      WRITE(6,200) SUM
      RETURN
C     FORMAT STATEMENTS -------------------------------------------------
  100 FORMAT(1H1,T24,A32,T73,'PAGE')
  110 FORMAT(1H ,T19,A42,T72,I2,' /',I2)
  120 FORMAT(1H ,T30,'MACH NUMBER = ',F6.4)
  130 FORMAT(1H ,5A15)
  140 FORMAT(1H ,A75)
  150 FORMAT(1H ,T8,A35,A35)
  160 FORMAT(1H+,T20,A2,15X,A2,20X,A2)
  170 FORMAT(1H ,T7,A4,2X,A15,2X,A15,2X,A6,2X,A10,2X,A10)
  180 FORMAT(1H ,T7,I4,2X,F15.4,2X,F15.4,2X,F6.4,2X,F10.4,2X,F10.4)
  190 FORMAT(1H ,T67,A10)
  200 FORMAT(1H ,T27,'TOTAL UPWASH ESTIMATE (EPSILON/ALPHA) = ',F10.4)
      END
```

PROGRAM WING

PROGRAM WING:

Purpose. Program WING implements the Yaggy-Rogallo technique of making upwash angle estimates for lifting surfaces. The lifting surface is estimated by a thin airfoil with trapezoidal planform as described in Appendix B and the upwash angle is calculated using equation (B8).

Condition of Validity.

(1) The lateral location of the angle-of-attack vane must be very near the midspan of the lifting surface.

(2) The longitudinal location of the angle-of-attack vane must be ahead of the quarter-chord line of the lifting surface. Mathematical calculations require only that the value be non-zero to continue program execution but the basic assumptions of the equations require the effective distance to be at least 0.4 of the span of the lifting surface.

(3) The specified span and aspect ratio of the lifting surface must be a non-zero, positive values.

(4) The specified quarter-chord sweep angle must be greater than or equal 0.0 and less than or equal 90.0.

(5) Program dimensions limit the number of Mach number values per input data set to 98.

(6) Mach number values requested must be greater than or equal to 0.0 and less than or equal to 1.0 since other values have no meaning in upwash calculations.

Storage Required.

	Octal Words	Decimal Words
PROGRAM	140	96
COMMON	1266	694
TOTAL	1426	790

Subprograms Used.

ALOG10, ATAN, DATARD, SQRT, TAN, WRITE3

COMMON Inputs. Only the COMMON inputs used by this program are described below.

COMMON/EEE/FSVANE,FSQCL,XV,SPAN,TAU,AR,WSQCL,NMACH,XMACH(98)

INPUT		DESCRIPTION	UNITS
FS_v	FSVANE	Longitudinal (fuselage) station of center of pressure of angle-of-attack vane	ℓ
$FS_{c/4}$	FSQCL	Longitudinal (fuselage) station of quarter-chord line at midspan	ℓ
X_v	XV	Longitudinal distance from midspan of quarter-chord line to longitudinal station of center of pressure of angle-of-attack vane $X_v = FS_{c/4}-FS_v$	ℓ
b	SPAN	Span of the lifting surface	ℓ
τ	TAU	Dimensionless distance from quarter chord to center of pressure of angle-of-attack vane	N-D
AR	AR	Aspect ratio of the lifting surface, $AR = b^2/S$	N-D
$\Lambda_{c/4}$	WSQCL	Sweep of the quarter-chord line of the lifting surface	deg
	NMACH	Number of Mach number values where upwash angle estimates are desired	N-D
	XMACH	Mach number values where upwash angle estimates are desired	N-D

COMMON/FFF/BETA(98),TOB(98),WSB(98),EARCL(98),ECLR(98),ECLD(98)

β	BETA	Compressibility parameter, $\beta = \sqrt{1-M^2}$	N-D
τ/β	TOB	Distance ahead of quarter-chord line corrected for compressibility	N-D
Λ_β	WSB	Sweep of quarter-chord corrected for compressibility $\tan \Lambda_\beta = \tan \Lambda_{c/4}/\beta$	deg
$\epsilon AR/C_L$	EARCL	Lifting surface upwash parameter	N-D
ϵ/C_L	ECLR	Upwash angle per unit lift coefficient in radians	rad
ϵ/C_L	ECLD	Upwash angle per unit lift coefficient in degrees	deg

Program Description. Program WING calculates upwash estimates for lifting surfaces. WING uses subroutine DATARD to read a single input data set and check the input for errors. It then calculates upwash estimates for all Mach numbers requested and calls WRITE3 to print the effective geometry and upwash estimates. DATARD is then called to read another input data set or terminate execution.

Program Listing.

```
      PROGRAM WING(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     FILE DECLARATION LIST NON-ANSI
C     ------------------------------------------------------------------
C     PROGRAM WING IS A FORTRAN V PROGRAM FOR MAKING UPWASH ESTIMATES
C     FOR LIFTING SURFACES USING THE YAGGY-ROGALLO TECHNIQUE. THE
C     DERIVATION OF EQUATIONS USED IN THIS PROGRAM AND A USER'S GUIDE
C     ARE CONTAINED IN "A METHOD OF ESTIMATING UPWASH ANGLE AT NOSEBOOM-
C     MOUNTED VANES",AFFTC-TIM-81-1,JUNE 1981.
C     QUESTIONS, COMMENTS, OR REQUESTS FOR THE USER'S GUIDE SHOULD BE
C     DIRECTED TO KEN RAWLINGS, 6520TG/ENDT (STOP 239),AIR FORCE FLIGHT
C     TEST CENTER,EDWARDS AFB,CA 93523 OR TELEPHONE (805) 277-3779.
C     REVISION RECORD:
C     WRITTEN BY        KEN RAWLINGS                      JUN 1981
C     ------------------------------------------------------------------
      COMMON/EEE/ESVANE,FSOCL,XV,SPAN,TAU,AR,WSOCL,NMACH,XMACH(98)
      COMMON/FFF/BETA(98),TOB(98),WSB(98),FARCL(98),FCLR(98),FCLD(98)
      DATA A,B,C/-1.42897301,-0.008447868,-1.0993686847
   10 CALL DATARD
      IF(NMACH     .EQ.    0) GO TO 10
      TAU=XV/(SPAN/2.)
      IERROR=0
      DO 50 I=1,NMACH
      IF(XMACH(I) .GE. 0.0) GO TO 20
      BETA(I) =1.0
      GO TO 40
   20 IF(XMACH(I) .LT. 1.0) GO TO 30
      BETA(I) =0.0
      TOB(I)   =99999.9999
      WSB(I)   =90.0
      FARCL(I)=0.0
      FCLR(I) =0.0
      FCLD(I) =0.0
      GO TO 50
   30 BETA(I)=SQRT(1.-(XMACH(I)*XMACH(I)))
   40 TOB(I)=TAU/BETA(I)
      IF(TOB(I)     .LT. 0.4) IERROR=1
      WSB(I)=(ATAN(TAN(WSOCL/57.2958)/BETA(I)))*57.2958
      FARCL(I)=10.0**((A*ALOG10(TOB(I)))+(B*WSB(I))+C)
      FCLR(I)=FARCL(I)/AR
      FCLD(I)=FCLR(I)*57.2958
   50 CONTINUE
      CALL WRITE4
      IF(IERROR .EQ. 1) WRITE(6,100)
      GO TO 10
  100 FORMAT(1H0,'TAU/BETA VALUES LESS THAN 0.4 ARE INVALID')
      END
```

SUBROUTINE DATARD:

Purpose. Subroutine DATARD reads one input data set per call, checks data for input errors, and passes information out through common.

Conditions of Validity.

(1) Data must be formated in 80-column card images as described in Appendix C, User's Guide for the Yaggy-Rogallo Production Software.

Storage Required.

	Octal Words	Decimal Words
PROGRAM	450	296
COMMON	172	122
TOTAL	642	418

Subprograms Used.

ABS, WRITE3

Calling Statement.

CALL DATARD

Input File Inputs.

INPUT		DESCRIPTION	UNITS
	HEAD1	First line of user-supplied heading (75 alphanumeric characters)	N-D
	HEAD2	Second line of user-supplied heading (75 alphanumeric characters)	N-D
	UNIT	Abbreviation for units of length for input values (2 alphanumeric characters)	N-D
FS_V	FSVANE	Longitudinal (fuselage) station of center of pressure of angle-of-attack vane	ℓ
$FS_{c/4}$	FSQCL	Longitudinal (fuselage) station of quarter-chord line at midspan	ℓ
	SPAN	Span of the lifting surface	ℓ
AR	AR	Aspect ratio of the lifting surface, $AR = b^2/S$	N-D
$\Lambda_{c/4}$	WSQCL	Sweep of the quarter-chord line of the lifting surface	deg

	NMACH	Number of Mach number values where upwash angle estimates are desired	N-D
	XMACH	Mach number values where upwash angle estimates are desired	N-D

COMMON Outputs. Only those common values output by this subroutine are discussed below.

COMMON/AAA/HEAD1,HEAD2,UNIT

	OUTPUT	DESCRIPTION	UNITS
	HEAD1	First line of user-supplied heading (75 alphanumeric characters)	N-D
	HEAD2	Second line of user-supplied heading (75 alphanumeric characters)	N-D
	UNIT	Abbreviation for units of length for input values (2 alpanumeric characters)	N-D

COMMON/EEE/FSVANE,FSQCL,XV,SPAN,TAU,AR,WSQCL,NMACH,XMACH(98)

	OUTPUT	DESCRIPTION	UNITS
FS_v	FSVANE	Longitudinal (fuselage) station of center of pressure of angle-of-attack vane	ℓ
$FS_{c/4}$	FSQCL	Longitudinal (fuselage) station of quarter-chord line at midspan	ℓ
X_v	XV	Longitudinal distance from midspan of quarter-chord line to longitudinal station of center of pressure of angle-of-attack vane, $X_v = FS_{c/4} - FS_v$	ℓ
b	SPAN	Span of lifting surface	ℓ
τ	TAU	Dimensionless distance from quarter chord to center of pressure of angle-of-attack vane	N-D
AR	AR	Aspect ratio of the lifting surface, $AR = b^2/S$	N-D
$\Lambda_{c/4}$	WSQCL	Sweep of the quarter-chord line of the lifting surface	deg
	NMACH	Number of Mach number values where upwash angle estimates are desired	N-D
	XMACH	Mach number values where upwash angle estimates are desired	N-D

Messages.

(1) "   " IS IN ERRROR - CARD READS "   "

Error message printed when DATARD encounters an unexpected card identifier. First quotation marks contain card identifier of card expected and second prints 80 alphanumeric characters on card actually read.

(2) "   " IS IN ERROR - END-OF-FILE ENCOUNTERED

Error message printed when an end-of-file is encountered during reading of any card other than a HEAD1 card. Quotation marks contain card identifier of card expected when end-of-file was encountered.

(3) INPUT DATA ERROR:

Error message printed when an error is encountered in the input data. It will be followed by one or more of the following messages:

(a) DISTANCE FROM WING TO VANE MUST BE NON-ZERO

Error message printed when the fuselage station of the center of pressure of the angle-of-attack vane (FSVANE) exactly equals the fuselage station of quarter-chord line at midspan (FSQCL).

(b) SPAN MUST BE NON-ZERO, POSITIVE VALUE

Error message printed when the span of the lifting surface (SPAN) is zero or negative.

(c) ASPECT RATIO MUST BE NON-ZERO, POSITIVE VALUE

Error message printed when the aspect ratio of the lifting surface (AR) is zero or negative.

(d) SWEEP ANGLES LESS THAN 0.0 ARE INVALID

Error message printed when the sweep of the quarter-chord line of the lifting surface (WSQCL) is less than 0.0.

(e) SWEEP ANGLES GREATER THAN 90.0 ARE INVALID

Error message printed when the sweep of the quarter-chord line of the lifting surface (WSQCL) is greater than 90.0.

(f) NUMBER OF MACH NUMBERS MUST BE GREATER THAN 0

Error message printed when the number of Mach number values where upwash angle estimates are desired (NMACH) is equal to 0.

Program Listing.

```
      SUBROUTINE DATARD
      COMMON/AAA/HEAD1,HEAD2,UNIT
      COMMON/FFF/FSVANE,FSOCL,XV,SPAN,TAU,AR,WSOCL,NMACH,XMACH(98)
      CHARACTER HEAD1*75,HEAD2*75,HEAD3*75,HEAD*5,HEADER*5,UNIT*2
      CHARACTER ERR1*45,ERR2*45,ERR3*45,ERR4*45,ERR5*45,ERR6*45
      DATA ERR1/'DISTANCE FROM WING TO VANE MUST BE NON-ZERO  '/
      DATA ERR2/'SPAN MUST BE NON-ZERO,POSITIVE VALUE         '/
      DATA ERR3/'ASPECT RATIO MUST BE NON-ZERO,POSITIVE VALUE '/
      DATA ERR4/'SWEEP ANLGES LESS THAN 0.0 ARE INVALID       '/
      DATA ERR5/'SWEEP ANLGES GREATER THAN 90.0 ARE INVALID   '/
      DATA ERR6/'NUMBER OF MACH NUMBERS MUST BE GREATER THAN 0'/
C     READ 'HEAD1' CARD ------------------------------------------------
      HEADER='HEAD1'
      READ(5,100,END=50) HEAD,HEAD1
      IF(HEAD .NE. HEADER) GO TO 30
C     READ 'HEAD2' CARD ------------------------------------------------
      HEADER='HEAD2'
      READ(5,100,END=40) HEAD,HEAD2
      IF(HEAD .NE. HEADER) GO TO 30
C     READ 'WINGS' CARD ------------------------------------------------
      HEADER='WINGS'
      READ(5,110,END=40) HEAD,UNIT,FSVANE,FSOCL,SPAN,AR,WSOCL
      IF(HEAD .NE. HEADER) GO TO 30
C     READ 'MACHV' CARDS -----------------------------------------------
      HEADER='MACHV'
      DO 10 J=1,92,7
      READ(5,120,END=40) HEAD,MACHS,(XMACH(I),I=J,(J+6))
      IF(HEAD .NE. HEADER) GO TO 30
      IF(J .EQ. 1) NMACH=MACHS
      IF(NMACH .LE. (J+6)) GO TO 20
   10 CONTINUE
C     READ 'END  ' CARD ------------------------------------------------
   20 HEADER='END  '
      READ(5,100,END=40) HEAD
      IF(HEAD .NE. HEADER) GO TO 30
      XV=ABS(FSOCL-FSVANE)
      IF(NMACH .EQ.    0) GO TO 60
      IF(XV    .EQ.  0.0) GO TO 70
      IF(SPAN  .LE.  0.0) GO TO 70
      IF(AR    .LE.  0.0) GO TO 70
      IF(WSOCL .LT.  0.0) GO TO 70
      IF(WSOCL .GT. 90.0) GO TO 70
      RETURN
   30 BACKSPACE 5
      READ(5,100) HEAD,HEAD3
      WRITE(6,130)HEADER,HEAD,HEAD3
      STOP
   40 WRITE(6,140) HEADER
   50 STOP
   60 MACHS=0
   70 NMACH=0
      CALL WRITER
      WRITE(6,150)
      IF(XV    .EQ.  0.0) WRITE(6,160) ERR1
      IF(SPAN  .LE.  0.0) WRITE(6,160) ERR2
      IF(AR    .LE.  0.0) WRITE(6,160) ERR3
      IF(WSOCL .LT.  0.0) WRITE(6,160) ERR4
      IF(WSOCL .GT. 90.0) WRITE(6,160) ERR5
      IF(MACHS .EQ.    0) WRITE(6,160) ERR6
      RETURN
C     FORMAT STATEMENTS ------------------------------------------------
  100 FORMAT(A5,A75)
  110 FORMAT(A5,3X,A2,5F10.0)
  120 FORMAT(A5,3X,I2,7F10.0)
  130 FORMAT(1H1,'"',A5,'" IS IN ERROR - CARD READS "',A5,A75,'"')
  140 FORMAT(1H1,'"',A5,'" IS IN ERROR - END-OF-FILE ENCOUNTERED')
  150 FORMAT(1H ,'INPUT DATA ERRORS:')
  160 FORMAT(1H ,T10,A45)
      END
```

SUBROUTINE WRITE3:

Purpose. Subroutine WRITE3 prints the actual geometric data, effective geometric data, and upwash-angle estimates with 40 points per page and up to 3 pages as required. One set of pages is printed for each input data set of the input file.

Storage Required.

	Octal Words	Decimal Words
PROGRAM	472	314
COMMON	1306	710
TOTAL	2000	1024

Calling Statement.

```
CALL WRITE3
```

COMMOM Inputs. Only the COMMON inputs used by this subroutine are described below.

COMMON/AAA/HEAD1,HEAD2,UNIT

INPUT	DESCRIPTION	UNITS
HEAD1	First line of user-supplied heading (75 alpha-numeric characters)	N-D
HEAD2	Second line of user-supplied heading (75 alpha-numeric characters)	N-D
UNIT	Abbreviation for units of length for input values (2 alphanumeric characters)	N-D

COMMON/EEE/FSVANE,FSQCL,XV,SPAN,TAU,AR,WSQCL,NMACH,XMACH(98)

INPUT		DESCRIPTION	UNITS
FS_v	FSVANE	Longitudinal (fuselage) station of center of pressure of angle-of-attack vane	ℓ
$FS_{c/4}$	FSQCL	Longitudinal (fuselage)station of quarter-chord line at midspan	ℓ
X_v	XV	Longitudinal distance from midspan of quarter-chord line to longitudinal station of center of pressure of angle-of-attack vane, $X_v = FS_{c/4}-FS_v$	ℓ
b	SPAN	Span of lifting surface	ℓ
τ	TAU	Dimensionless distance from quarter chord to center of pressure of angle-of-attack vane	N-D

AR	AR	Aspect ratio of the lifting surface, $AR = b^2/S$	N-D
$\Lambda_{c/4}$	WSQCL	Sweep of the quarter-chord line of the lifting surface	deg
	NMACH	Number of Mach number values where upwash angle estimates are desired	N-D
	XMACH	Mach number values where upwash angle estimates are desired	N-D

COMMON/FFF/BETA(98),TOB(98),WSB(98),EARCL(98),ECLR(98),ECLD(98)

β	BETA	Compressibility parameter, $\beta = \sqrt{1-M^2}$	N-D
τ/β	TOB	Distance ahead of quarter-chord line corrected for compressibility	N-D
Λ_β	WSB	Sweep of quarter-chord corrected for compressibility, $\tan \Lambda_\beta = \tan \Lambda_{c/4}/\beta$	deg
$\varepsilon AR/C_L$	EARCL	Lifting surface upwash parameter	N-D
ε/C_L	ECLR	Upwash angle per unit lift coefficient in radians	rad
ε/C_L	ECLD	Upwash angle per unit lift coefficient in degrees	deg

Printer Outputs.

OUTPUT		DESCRIPTION	UNITS
	HEAD1	First line of user-supplied heading (75 alphanumeric characters)	N-D
	HEAD2	Second line of user-supplied heading (75 alphanumeric characters)	N-D
	UNIT	Abbreviation for units of length for input values (2 alphanumeric characters)	N-D
FS_V	FSVANE	Longitudinal (fuselage) station of center of pressure of angle-of-attack vane	ℓ
$FS_{c/4}$	FSQCL	Longitudinal (fuselage) station of quarter-chord line at midspan	ℓ
X_V	XV	Longitudinal distance from midspan of quarter-chord line to longitudinal station of center of pressure of angle-of-attack vane, $X_V = FS_{c/4} - FS_V$	ℓ
b	SPAN	Span of lifting surface	ℓ
τ	TAU	Dimensionless distance from quarter chord to center of pressure of angle-of-attack vane	N-D

AR	AR	Aspect ratio of the lifting surface, $AR = b^2/S$	N-D
$\Lambda_{c/4}$	WSQCL	Sweep of the quarter-chord line of the lifting surface	deg
	NMACH	Number of Mach number values where upwash angle estimates are desired	N-D
	XMACH	Mach number values where upwash angle estimates are desired	N-D
β	BETA	Compressibility Parameter, $\beta = \sqrt{1-M^2}$	N-D
τ/β	TOB	Distance ahead of quarter-chord line corrected for compressibility	N-D
Λ_β	WSB	Sweep of quarter-chord corrected for compressibility, $\tan \Lambda_\beta = \tan \Lambda_{c/4}/\beta$	deg
$\varepsilon AR/C_L$	EARCL	Lifting surface upwash parameter	N-D
ε/C_L	ECLR	Upwash angle per unit lift coefficient in radians	rad
ε/C_L	ECLD	Upwash angle per unit lift coefficient in degrees	deg

Program Listing.

```
      SUBROUTINE WRITE3
      COMMON/AAA/HEAD1,HEAD2,UNIT
      COMMON/FFF/FSVANE,FSQCL,XV,SPAN,TAU,AR,WSQCL,NMACH,XMACH(98)
      COMMON/FFF/BETA(98),TOB(98),WSB(98),EARCL(98),FCLR(98),FCLD(98)
      DIMENSION LINE10(2),LINE11(2)
      CHARACTER HEAD1*75,HEAD2*75,UNIT*2,TITLE1*32,TITLE2*46
      CHARACTER LINE1*33,LINE2*50,LINE3*50,LINE4*50,LINE5*50,LINE6*50
      CHARACTER LINE7*50,LINE8*50,LINE9*33,LINE10*37,LINE11*37,LINE12*41
      CHARACTER DASH6*6,DASH10*10,DASH15*15
      DATA TITLE1/'YAGGY-ROGALLO UPWASH CALCULATION'/
      DATA TITLE2/'UPWASH ESTIMATE FOR LIFTING SURFACE COMPONENTS'/
      DATA DASH6,DASH10,DASH15/'------','----------','---------------'/
      DATA LINE1/'LIFTING SURFACE GEOMETRIC DETAIL:'/
      DATA LINE2/'LONGITUDINAL STATION OF VANES .....................'/
      DATA LINE3/'LONGITUDINAL STATION OF APEX OF QUARTER-CHORD LINE'/
      DATA LINE4/'DISTANCE FROM APEX OF QUARTER-CHORD TO VANES (XV).'/
      DATA LINE5/'SPAN (B) ..........................................'/
      DATA LINE6/'TAU (XV/(B/2)) ....................................'/
      DATA LINE7/'ASPECT RATIO ......................................'/
      DATA LINE8/'SWEEP OF QUARTER-CHORD LINE .......................'/
      DATA LINE9/'LIFTING SURFACE UPWASH ESTIMATES:'/
      DATA LINE10/'                                EFFECTIVE',
     1            '   EPSILON AR                  '/
      DATA LINE11/'MACH     BETA      TAU/BETA     WING SWEE',
     1            'P   /CL          EPSILON/CL  EPSILON/CL'/
      DATA LINE12/'(DEG)           (RAD)         (RAD)       (DEG)'/
C     PRINT GEOMETRIC DATA FOR CYLINDERICAL COMPONENTS ----------------
      NPGS=(NMACH/40)+1
      LPT=0
      DO 20 I=1,3
C     PRINT PAGE HEADINGS FOR GEOMETRIC DATA -------------------------
      WRITE(6,100) TITLE1
      WRITE(6,110) TITLE2,I,NPGS
      WRITE(6,120) DASH15,DASH15,DASH15,DASH15,DASH15
      WRITE(6,130) HEAD1
      WRITE(6,130) HEAD2
      WRITE(6,120) DASH15,DASH15,DASH15,DASH15,DASH15
      WRITE(6,140) LINE1
      WRITE(6,150) LINE2,FSVANE,UNIT
      WRITE(6,150) LINE3,FSQCL,UNIT
      WRITE(6,150) LINE4,XV,UNIT
      WRITE(6,150) LINE5,SPAN,UNIT
      WRITE(6,160) LINE6,TAU
      WRITE(6,170) LINE7,AR
      WRITE(6,180) LINE8,WSQCL
      IF(NMACH .EQ. 0) RETURN
      WRITE(6,140) LINE9
      WRITE(6,190) LINE10
      WRITE(6,190) LINE11
      WRITE(6,200) LINE12
      WRITE(6,210) DASH6,DASH6,DASH10,DASH10,DASH10,DASH10,DASH10
C     PRINT ONE PAGE OF GEOMETRIC DATA -------------------------------
      DO 10 J=1,40
      LPT=LPT+1
      IF(LPT .GT . NMACH) RETURN
      WRITE(6,220) XMACH(LPT),BETA(LPT),TOB(LPT),WSB(LPT),EARCL(LPT),
     1             FCLR(LPT),FCLD(LPT)
   10 CONTINUE
   20 CONTINUE
      RETURN
C     FORMAT STATEMENTS ----------------------------------------------
  100 FORMAT(1H1,T24,A32,T73,'PAGE')
  110 FORMAT(1H ,T17,A46,T72,I2,' /',I2)
  120 FORMAT(1H ,5A15)
  130 FORMAT(1H ,A75)
  140 FORMAT(1H ,A33)
  150 FORMAT(1H ,T10,A50,3X,F10.4,1X,A2)
  160 FORMAT(1H ,T10,A50,3X,F10.4,1X,'B/2')
  170 FORMAT(1H ,T10,A50,3X,F10.4,1X,'   ')
  180 FORMAT(1H ,T10,A50,3X,F10.4,1X,'DEG')
  190 FORMAT(1H ,T3,A37,A37)
  200 FORMAT(1H ,T22,A52)
  210 FORMAT(1H ,T3,A6,2X,A6,2X,A10,2X,A10,2X,A10,2X,A10,2X,A10)
  220 FORMAT(1H ,1X,2(F6.4,2X),2(F10.4,2X),3(F10.6,2X))
      END
```