NASA TECHNICAL NOTE

NASA TN D-8243

NASA TN D-8243

AERODYNAMIC DESIGN GUIDELINES AND COMPUTER PROGRAM FOR ESTIMATION OF SUBSONIC WIND TUNNEL PERFORMANCE

William T. Eckert, Kenneth W. Mort,
and Jean Jope

Ames Research Center
and U.S. Army Air Mobility R&D Laboratory
Moffett Field, Calif. 94035

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1976

1. Report No. TN D-8243	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle AERODYNAMIC DESIGN GUIDELINES AND COMPUTER PROGRAM FOR ESTIMATION OF SUBSONIC WIND TUNNEL PERFORMANCE		5. Report Date October 1976 6. Performing Organization Code
7. Author(s) William T. Eckert,* Kenneth W. Mort, and Jean Jope		8. Performing Organization Report No. A-5944
9. Performing Organization Name and Address NASA Ames Research Center and Ames Directorate, U.S. Army Air Mobility R&D Laboratory Moffett Field, CA 94035		10. Work Unit No. 505-06-31 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546 and U.S. Army Air Mobility R&D Laboratory, Moffett Field, CA 94035		13. Type of Report and Period Covered Technical Note 14. Sponsoring Agency Code

15. Supplementary Notes

*Ames Directorate, U.S. Army Air Mobility R&D Laboratory, Moffett Field, CA 94035

16. Abstract

This report brings together and refines the previously scattered and over-simplified techniques for the aerodynamic design and loss prediction of the components of subsonic wind tunnels. General guidelines are given for the design of diffusers, contractions, corners, and the inlets and exits of non-return tunnels. A system of equations, reflecting the current technology, has been compiled and assembled into a computer program (a user's manual for this program is included) for determining the total pressure losses. The formulation presented is applicable to compressible flow through most closed- or open-throat, single-, double-, or non-return wind tunnels. A comparison of estimated performance with that actually achieved by several existing facilities produced generally good agreement.

17. Key Words (Suggested by Author(s))		18. Distribution Statement	
Wind tunnel design (subsonic) Wind tunnel (subsonic) Duct flow Duct losses Wind tunnel performance Aircraft testing Energy use analysis Power consumption analysis		Unlimited STAR Category - 02	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 197	22. Price* $7.00

*For sale by the National Technical Information Service, Springfield, Virginia 22161

TABLE OF CONTENTS

	Page
NOTATION (Engineering Symbols)	v
SUMMARY	1
INTRODUCTION	1
CAUTIONARY DESIGN GUIDELINES	2
Diffusers	2
Contractions	3
Corners	3
Non-Return Wind Tunnels	4
PERFORMANCE ESTIMATION	4
General Approach	4
Problem Restrictions	5
Computation Formulas	5
Flow-state parameters	5
Local conditions	5
Section pressure losses	6
COMPUTER PROGRAM DESCRIPTION	11
Method of Solution	11
Computing Equipment Required	12
Hardware and machine components	12
Software	13
Programming Techniques	14
Source Code	15
Operating Instructions	15
Input	15
Output	16
Computer system restrictions	17
Optional inputs	18
Diagnostic messages	18
Test Case	21
DISCUSSION AND APPLICATIONS	22
Results	23
Evaluation	24
APPENDIX A - NON-STANDARD FUNCTIONAL FORMS	26
Local Flow-State Parameters	26
Mach number	26
Reynolds number	27
Friction coefficient	27
Section Pressure Losses	27
Corners (constant area)	27
Corners (diffusing)	28
Diffusers	29
Exit	30
Flow straighteners: airfoil members (thick)	31
Internal flow obstruction: drag item	32
Vaned diffusers	32
Loss value transferred to reference location	32
Wall pressure differential	33
Input power required	34

	Page
APPENDIX B - NUMERICAL FUNCTION-APPROXIMATIONS	35
Corners	35
Diffusers	35
Mesh Screen	38
Vaned Diffusers	38
APPENDIX C - COMPUTER PROGRAM FØRTRAN CODES	39
Notation (FØRTRAN)	40
PERFØRM	52
DATACK	79
SPEED	97
FRICTN	98
ØUTPUT	99
PLØTIT	104
APPENDIX D - INPUT AND OUTPUT FOR SAMPLE CASES	107
REFERENCES	142
TABLES	144
FIGURES	153

NOTATION

(Engineering Symbols)

Symbol	FØRTRAN[1] name	Description
A	A	cross-sectional area of local section, m^2 (ft^2)
A_F		total cross-sectional flow area at drive fan(s), m^2 (ft^2)
A_{FLOW}	AL	cross-sectional area of local flow, m^2 (ft^2)
A_o	AO	cross-sectional flow area of test section at upstream end, m^2 (ft^2)
A_1	A1	cross-sectional flow area of section at upstream end, m^2 (ft^2)
A_2	A2	cross-sectional flow area of section at downstream end, m^2 (ft^2)
A_*	ASTAR	cross-sectional area for sonic flow at specified flow conditions, m^2 (ft^2)
AR	AR	cross-sectional flow area ratio of upstream and downstream ends of section
a_T	AT	speed of sound in still gas, computed at total (stagnation) conditions, m/sec (ft/sec)
a_o	ASO	speed of sound in moving flow at upstream end of test section, m/sec (ft/sec)
B		dummy constraint used in defining the friction term of turning vane loss function
C_D	CD	drag coefficient of flow obstructions: drag/qS
c_v	CHØRD	chord of turning vanes, m (ft)
D	D	cross-sectional diameter of circular duct, m (ft)
De_1		cross-section diameter at the upstream end of an equivalent circular duct with equal area, m (ft)

[1]Note that in this section, as throughout the report, all letter O's occurring in FØRTRAN names are shown with slashes, as Ø; all number zeros are shown without slashes.

Symbol	FØRTRAN name	Description
D_{e_2}		cross-section diameter at the downstream end of an equivalent circular duct with equal area, m (ft)
D_h	DH	hydraulic diameter: $\frac{4 \times (\text{cross-sectional area})}{\text{perimeter}}$, m (ft)
ER	ER	energy ratio: ratio of energy of flow at the test section to the output energy of the fans
f(Ø)	FKTV1 FKTV2	function defining turning vane loss parameter K_{TV}
K	EK	local total pressure loss coefficient of section: $\frac{\Delta p_T}{q}$
$K_{CONTRACTION}$	EKCNTR	local total pressure loss coefficient from contracting portion of thick-airfoil flow straighteners
$K_{DIFFUSION}$	EKD	local total pressure loss coefficient from diffusing portion of multi-loss-type sections
K_{EXP}	EKEXP	net expansion loss coefficient for diffusers
$K_{EXP_{Additional}}$	EKADD	additional diffuser expansion loss coefficient due only to more diffusion in one plane than the other
$K_{EXP_{Basic}}$	EKBASE	basic diffuser expansion loss factor coefficient for three-dimensional diffusion
$K_{EXP_{Circular}}$	EKC	expansion loss coefficient for conical diffusers
$K_{EXP_{Rectangular}}$	EK2DR	expansion loss coefficient for a two-dimensional, rectangular cross-section diffuser
$K_{EXP_{Square}}$	EKS	expansion loss coefficient for three-dimensional expansion in square cross-section diffusers
$K_{EXP_{2D_{Average}}}$	EK2DCS	estimated expansion loss value for a two-dimensional diffuser (one with expansion in only one plane) with cross-section shape of some square/circular hybrid

Symbol	FØRTRAN name	Description
$K_{EXP_{2D_{Circular}}}$	EK2DC	estimated expansion loss value for a hypothetical two-dimensional diffuser with circular sides: $K_{EXP_{2D_{Rectangular}}} \left(\frac{K_{EXP_{Circular}}}{K_{EXP_{Square}}}\right)$
$K_{EXP_{3D_{Average}}}$	EKCSAV	estimated expansion loss coefficient for three-dimensional, combination circular and square cross-section diffuser
$K_{EXPANSION}$		diffuser loss coefficient due to expansion: $K_{EXP} \left(\frac{AR - 1}{AR}\right)^2$
$K_{FRICTION}$		turning vane loss due to friction
$K_{FRICTION(CONICAL)}$		diffuser loss due to friction for the equivalent conical diffuser
K_{MESH}	EKMESH	mesh screen-type loss parameter
$K_{Ref.\ 9}$		diffuser loss factor presented in reference 9: $\frac{\Delta p/q}{[(AR - 1)/AR]^2}$
K_{RN}		mesh screen Reynolds number sensitivity factor
$K_{ROTATION}$		turning vane loss coefficient due to rotation
K_{TV}	EKTV	turning vane loss coefficient
$K_{TV_{90}}$	EKTV90	turning vane loss parameter for given vanes at a 90° turn
K_v	EKV	local total pressure loss coefficient for vaned diffusers
$K_{VANED\ DIFFUSER}$		local total pressure loss coefficient for vaned diffuser, $K_v \left(\frac{AR - 1}{AR}\right)^2$
K_o	EKO	section total pressure loss coefficient referred to test section conditions: $\frac{\Delta p_T}{q_o}$

Symbol	FØRTRAN name	Description
$K_{o_{DRAG}}$		flow obstruction (drag item) total pressure loss coefficient referred to test section conditions
L	EL	centerline length of section, m (ft)
ℓ		characteristic dimension on which Reynolds number is based
M	AMACH	local Mach number
M_o	EMO	Mach number at upstream end of test section
N	N	section assigned sequence number for order of occurrence in circuit
P_{DRAG}		power loss due to drag of flow obstruction, W (hp)
P_{INPUT}	PWRIP	tunnel drive power required to be input to flow by the fans, W (hp)
$P_{INPUT_{DRAG}}$		power input required to overcome drag of flow obstruction, W (hp)
$P_{REQUIRED}$	PWRØP	total fan motor output power required to drive wind tunnel at specified speed, W (hp)
p		local static pressure, N/m^2 (lb/ft^2)
p_T	PT	tunnel total (stagnation) pressure, N/m^2 (lb/ft^2)
$p_{T_{ATM}}$	PATM	atmospheric (barometric) pressure, N/m^2 (lb/ft^2)
$p_{T_{SC}}$		total (stagnation) pressure in the circuit settling chamber, N/m^2 (lb/ft^2)
q		local dynamic pressure: $\frac{\rho V^2}{2}$, N/m^2 (lb/ft^2)
q_o	QO	test section dynamic pressure: $\frac{\rho_o V_o{}^2}{2}$, N/m^2 (lb/ft^2)
R	R	gas constant, $m^2/sec^2\ {}^\circ K$ ($ft^2/sec^2\ {}^\circ R$)
R_e		equivalent radius: $\sqrt{A/\pi}$, m (ft)

Symbol	FØRTRAN name	Description
RN	RN	Reynolds number: $\frac{\rho V \ell}{\mu}$
RN_{REF}	RNREF	reference Reynolds number at which turning vane 90° loss parameter, $K_{TV_{90}}$, was determined
S		drag area of flow obstruction (i.e., area for which C_D is determined), m^2 (ft^2)
s		distance along diffuser wall, m (ft)
s_2		length of diffuser, taken along wall, m (ft)
T		tunnel temperature in moving flow, °K (°R)
T_T	TT	tunnel total (stagnation) temperature, °K (°R)
V	V	local flow velocity, m/sec (ft/sec)
V_F		flow velocity at the drive fan(s), m/sec (ft/sec)
V_{SYSTEM}		flow velocity in a multiple-duct section, m/sec (ft/sec)
V_o	VO	test section upstream-end flow velocity, m/sec (ft/sec)
X		location of inflection point in contraction wall (distance from upstream end), m (ft)
γ	G	specific heat ratio of gas
Δ	RUFNES	surface roughness in honeycomb cells, m (ft)
ΔER		difference between estimated and true circuit energy ratios; i.e., error in energy ratio estimate
Δp_F		static pressure rise across the fan(s), N/m^2 (lb/ft^2)
Δp_T		total pressure drop through a section, N/m^2 (lb/ft^2)
$\Delta p_{T_{DUCT}}$		total pressure drop through a single duct of a multiple-duct section, N/m^2 (lb/ft^2)
Δp_{T_F}		total pressure rise across the fan(s), N/m^2 (lb/ft^2)

Symbol	FØRTRAN name	Description
$\Delta p_{T_{F_{DUCT}}}$		average total pressure rise across a single fan, N/m^2 (lb/ft^2)
$\Delta p_{T_{SYSTEM}}$		total pressure drop through a multiple-duct section, N/m^2 (lb/ft^2)
$\Delta p_{T_{TOTAL}}$		summation of all total pressure drops through the wind tunnel circuit, N/m^2 (lb/ft^2)
Δp_{W_i}	DELP	local pressure difference across wind tunnel wall, N/m^2 (lb/ft^2)
$\Delta P_{REQUIRED}$		difference between true and estimated required drive power levels for given levels of operating velocity and fan efficiency; i.e., error in required power estimate, W (hp)
ΔV_o		difference between estimated and true test section operating velocity for given power and fan efficiency levels; i.e., error in operating velocity estimate, m/sec (ft/sec)
$\Delta\varepsilon$		increment of flow-obstruction downstream influence factor greater than unity: $\varepsilon - 1$ (greater than or equal to zero)
δ_s	SLR	diffuser side length ratio: ratio of change in height to change in width from upstream to downstream end, or its inverse, whichever is less than or equal to unity
ε	EPS	flow-obstruction downstream influence coefficient (greater than or equal to unity)
η_E		drive motor electrical efficiency, percent
η_F	ETAFAN	fan aerodynamic efficiency, percent
θ	TH	diffuser half-angle, rad
λ	SLAMDA	friction coefficient for smooth pipes
μ	EMU	flow viscosity, N sec/m^2 (lb sec/ft^2)
μ_{std}	EMUSTD	standard-day value of viscosity, N sec/m^2 (lb sec/ft^2)
μ_T	EMUT	reference viscosity at a known temperature, computed for still gas (stagnation conditions), N sec/m^2 (lb sec/ft^2)

Symbol	FØRTRAN name	Description
ν	ENU	kinetic viscosity of gas, m^2/sec (ft^2/sec)
ρ	RHØS	local static density, N sec^2/m^4 (lb sec^2/ft^4)
ρ_F	RHØSF	static density at the fan(s), N sec^2/m^4 (lb sec^2/ft^4)
ρ_T	RHØT	density computed for total (stagnation) conditions, N sec^2/m^4 (lb sec^2/ft^4)
ρ_o	RHØSO	static density at upstream end of test section, N sec^2/m^4 (lb sec^2/ft^4)
$\sum_{i=1}^{N} K_{o_i}$	SUMEKO	summation of section total pressure losses referenced to test section conditions
$\sum_{i=1}^{N} L_i$	SUMEL	summation of section centerline lengths, m (ft)
ϕ	PHI	corner flow turning angle, deg
2θ	TH2	diffuser equivalent cone angle: $2\tan^{-1}\left(\frac{\sqrt{A_2}-\sqrt{A_1}}{L\sqrt{\pi}}\right)$, deg

AERODYNAMIC DESIGN GUIDELINES AND COMPUTER PROGRAM FOR ESTIMATION OF SUBSONIC WIND TUNNEL PERFORMANCE

William T. Eckert, Kenneth W. Mort, and Jean Jope

Ames Research Center
and
Ames Directorate, U.S. Army Air Mobility R&D Laboratory

SUMMARY

This report brings together and refines the previously scattered and over-simplified techniques for the aerodynamic design and loss prediction of the components of subsonic wind tunnels. General guidelines are given for the design of diffusers, contractions, corners, and the inlets and exits of non-return tunnels. A system of equations, reflecting the current technology, has been compiled and assembled into a computer program (a user's manual for this program is included) for determining the total pressure losses. The formulation presented is applicable to compressible flow through most closed- or open-throat, single-, double-, or non-return wind tunnels. A comparison of estimated performance with that actually achieved by several existing facilities produced generally good agreement.

INTRODUCTION

In the past, most of the work on the design of ducts and wind tunnels and on the determination of their pressure (and power) losses has been either highly specialized, considering only one type of component, or over-simplified, covering several types of components but giving only a superficial idea of what parameters are important. However, for the recent NASA studies directed toward new and modified wind tunnel facilities, it has been necessary to do a careful job of estimating, easily and quickly, the performance of all circuit components. This report brings together, revises, and updates the techniques for the aerodynamic design and performance prediction of subsonic wind tunnels.

The basic procedures and guidelines for the aerodynamic design of critical wind tunnel components, as presented in references 1 through 3, have been revised and updated, as required. The diffuser and contraction design curves developed and suggested herein show the relative design points for several existing facilities. Also provided are recommendations derived from recent NASA studies on end treatments for non-return wind tunnels.

The method of loss analysis presented is a synthesis of theoretical and empirical techniques. Generally, the algorithms used were those substantiated by experimental results. The methods of references 4 through 11 for predicting component losses have been refined and incorporated. The performance calculations, based on user-selected flow conditions at the test section, assume that the circuit geometry has been predetermined.

The comparison of the actual and predicted performance for several existing wind tunnel facilities shows generally good agreement.

CAUTIONARY DESIGN GUIDELINES

This report presents the means for rapidly estimating the performance of a wind tunnel circuit after its geometry has been determined. However, an improper design of any of its several components (diffusers, contractions, or corners, for example) could result in performance penalties caused by interaction with the flow in other components; such penalties cannot be predicted. In addition, improper design could cause poor test-section flow quality which would not be indicated by the performance analysis. Therefore, the purposes of this section are to point out critical areas of concern in wind tunnel design and to attempt to establish proper design criteria.

Diffusers

Diffusers, especially those just downstream of high-speed sections, are very sensitive to design errors which may cause flow separation. The equivalent cone angle and area ratio must be properly selected to avoid steady-state or intermittent separation of the flow from the diffuser walls. (This separation can cause vibration, oscillatory fan loading, oscillations in test section velocity, and higher losses in downstream components.) Generally, proper diffuser design requires that, for a given area ratio, the equivalent cone angle be constrained below a certain value. ("Equivalent" denotes an imaginary conical section with length and with inlet and exit areas identical to the actual section.) This cone angle should probably be held 0.5° to 1° lower for diffusers with sharp corners than for those with a rounded cross section.

Since the portion of the wind tunnel between the test section and the fans is usually the higher-loss segment, it is the most critical in affecting circuit performance. Therefore, it was used as a basis for establishing recommended design limits as a guide to diffuser selection. It was assumed that the fans serve to reenergize the boundary layer of downstream sections and that the fans and the upstream and downstream components have no interaction that affects their losses; this may or may not be true (see ref. 12). The overall area ratio and cone angle between the test section and fan contraction were examined for several wind tunnels. This analysis used the centerline lengths of all intervening components, including corners. (The actual effect of corners is unknown: they may alter the onset of separation somewhat.) Figure 1(a) compares curves for the first appreciable stall for flows with thin inlet boundary layers, from references 1 and 2, with the design points of selected existing wind tunnels. These curves were used to aid in defining the separation trend; good correlation with the symbols is not necessarily expected. Figure 1(a) shows that most of these wind tunnels were designed beyond (above) the two-dimensional stall curve but below the conical stall curve. (Some of these diffusers are far from conical.) The recommended design region, shown in figure 1(b), was positioned with the prior knowledge that the NASA-Ames 7- by 10-Foot Wind Tunnel has a partially separated diffuser just downstream of the test section, and that the NASA-Ames 40- by 80-Foot Wind Tunnel has some local separation in the corners of the primary diffuser. The upper portion of the design region is recommended for diffusers with rounded corners, and the lower portion for diffusers with sharp corners.

Contractions

Contracting sections are subject to separation in the same manner as diffusers; however, the penalties are usually much less severe in the contracting sections. Separation of the flow can occur if the contraction is too short for the amount of area reduction. Figure 2(a) presents the general wall shapes suggested in reference 3 and figure 2(b) shows the design boundary for these shapes in comparison with the designs of several selected wind tunnel facilities.

From this comparison it is evident that, while some facilities were designed more conservatively than others, no design severely exceeds the design boundary. Since none of the facilities considered has shown significant contraction-caused flow problems, the design boundary may be considered empirically reasonable. Further, reference 13 generally tends to support the positioning of the suggested design curve. However, the criteria of reference 13 are more conservative due to consideration of viscous effects which were neglected in the study of reference 3.

Corners

The corner losses in a wind tunnel can be large. To minimize them, turning vanes should be used for more efficient turning. Also, as with any other high-loss item corners should, where possible, be located in a large-area section where the flow speed is low. Corner vane losses can be minimized in two additional ways: (1) by selecting an efficient vane cross-sectional shape and adjusting it for proper alignment with the flow, and (2) by choosing the best chord-to-gap spacing.

With reference to item (1), turning vane shapes can vary from bent plates to highly-cambered airfoils. Some sources favor airfoil vanes as being more efficient (ref. 4, p. 63) while others claim that thin vanes can have lower losses (ref. 5, p. 93). But airfoil vanes with blunted leading edges may be more forgiving of misalignment with the flow. The thicker vanes may, therefore, hold some advantage.

When considering item (2), the best chord-to-gap ratio depends on the vane type. For thick vanes, a ratio of about 2.5-to-1 is recommended (ref. 4, p. 62) and for thin vanes a ratio of about 4-to-1 is suggested (ref. 5, p. 92).

Non-Return Wind Tunnels

Non-return wind tunnels have presented some interesting problems in tunnel design. This type of wind tunnel has the advantages of less structure (and therefore lower construction costs) and of no exhaust-gas-purging or air-exchange requirement. Careful design can make the non-return circuit operating power competitive with that of closed-return wind tunnels (the corner losses can be traded for inlet and exit losses). However, an area of concern for the non-return tunnel is its potential sensitivity to external winds which could affect both the required power and the test section flow quality.

A recent series of NASA studies, which dealt with wind sensitivity problems, showed that a non-return wind tunnel should have three features: (1) a vertical exit system, (2) a horizontal inlet, and (3) an enclosed area of protection, with a solid roof, at the inlet. References 14 and 15 detail the development work for the end treatment considered in those studies.

Reference 16 describes an inlet geometry that was developed to reduce the effects of wind. (This reference also presents a set of test-section flow-quality requirements by which the characteristics of any inlet treatment may be evaluated.) Although the end treatment designs shown in references 14 through 16 could be revised or refined for additional wind protection, any additional inlet treatment would increase the structural cost and could increase the power requirement.

PERFORMANCE ESTIMATION

Although the performance analysis presented in this report was systematized and automated for rapid calculation of numerous cases or iterations (by the computer program described in the following sections), the equations presented are equally amenable to manual calculation methods.

General Approach

The equations were derived in forms that use the most common and convenient defining parameters. The equations are listed and explained below and may be used for component after component, each in turn.

The total pressure losses (proportional to power losses) of each component are calculated and summed to give the total circuit loss and operating power required. The computation technique is applicable to either closed- or non-return circuit types made up of any combination of standard wind tunnel components in any order. The flow conditions in the test section (velocity, and stagnation temperature and pressure) and the external atmospheric pressure are variable as required.

Problem Restrictions

Three restrictions were found to be necessary in order to allow rapid solution of most cases with a minimum amount of effort. First, the cross-sectional geometries were limited to the most common shapes: circular, rectangular, and flat-oval (semi-circular side walls with flat floor and ceiling). Second, air exchangers were omitted from this analysis due to lack of uniformity of configuration and a lack of definition as to the proper method of computing the losses. Finally, the drive system was assumed to be located in one or more parallel, annular ducts.

Computation Formulas

The equations used in this performance analysis were synthesized from various sources. Some were used in their original (source) form and others were modified to make them more convenient for use in this analysis. The equations used are presented below.

Flow-state parameters- The basic flow-state parameters were determined from input information about the reference control station and the test section. These parameters were derived from standard relationships for compressible flow.

$$\rho_T = \frac{P_T}{RT_T} \qquad \text{(ref. 17, p. 8)}$$

$$a_T = \sqrt{\gamma R T_T} \qquad \text{(ref. 17, p. 51)}$$

$$\mu_T = \mu_{STD}\left(\frac{T_T}{T_{STD}}\right)^{0.76} \qquad \text{(ref. 18, p. 19)}$$

$$a_o = \frac{a_T}{\sqrt{1+\left(\frac{\gamma-1}{2} M_o^2\right)}} \qquad \text{(ref. 18, p. 4)}$$

$$\rho_o = \frac{\rho_T}{\left[1+\left(\frac{\gamma-1}{2} M_o^2\right)\right]^{\frac{1}{\gamma-1}}} \qquad \text{(ref. 18, p. 4)}$$

$$A_* = M_o A_o \left\{\frac{\gamma+1}{2\left[1+\left(\frac{\gamma-1}{2} M_o^2\right)\right]}\right\}^{\frac{\gamma+1}{2(\gamma-1)}} \qquad \text{(appendix A)}$$

Local conditions- The local flow conditions were determined for each end of each section.

1. Mach number: The local Mach number was found from a Newton's-method solution of the relationship

$$M^2 - \left[\frac{\gamma + 1}{\gamma - 1}\left(\frac{A}{A_*} M\right)^{\frac{2(\gamma-1)}{\gamma+1}}\right] + \frac{2}{\gamma - 1} = 0 \qquad \text{(appendix A)}$$

2. Reynolds number: The Reynolds number based on the characteristic length ℓ, usually the local hydraulic diameter, was determined from

$$RN = \frac{\rho_o V_o \ell}{\mu_T}\left(\frac{A_o}{A}\right)\left[1 + \left(\frac{\gamma - 1}{2} M^2\right)\right]^{0.76} \qquad \text{(appendix A)}$$

3. Friction coefficient: A Newton's-method solution was used to determine the friction coefficient for smooth walls from the expression

$$[\log_{10}(\lambda RN^2) - 0.8]^{-2} - \lambda = 0 \qquad \text{(appendix A)}$$

Section pressure losses- The loss in total pressure caused by each section was calculated in a form non-dimensionalized by local dynamic pressure: $K = \Delta p_T/q$. (In this study the smallest-area end of each section was used as the local reference position.) The individual losses were based on the nature of the section, local flow conditions, and input geometry and parameter information. The most appropriate loss forms for typical wind tunnel sections are catalogued on the following pages. The nonstandard formulas, those which are not directly attributable to the literature, are developed in appendix A. The precise equations, which were developed from various curve-fitting and interpolation techniques based on the plots presented in certain figures, are given in appendix B.

1. Constant-area ducts: For closed, constant-area sections the pressure loss due to friction is given by

$$K = \frac{\lambda L}{D_h} \qquad \text{(ref. 7, p. 53)}$$

2. Open-throat duct: The losses from an open-throat test section may be found from the expression

$$K = 0.0845 \frac{L}{D_h} - 0.0053 \left(\frac{L}{D_h}\right)^2 \qquad \text{(ref. 7, p. 150)}$$

3. Contractions: In contracting sections, where the major part of the losses is due to friction, the local loss may be approximated as

$$K = 0.32 \frac{\lambda L}{D_h} \qquad \text{(ref. 6, p. 528)}$$

4. Corners with no net area change ("constant area"): A duct can change direction with or without the aid of flow guide vanes. For a constant-area turn employing turning vanes for efficiency, with a "normal" number of vanes (ref. 7, p. 241), and with chord-to-gap ratios between 2-to-1 and 4-to-1, the losses resulting from friction and rotation caused by the vanes are

$$K = \frac{K_{TV}}{3}\left[2 + \left(\frac{\log_{10} RN_{REF}}{\log_{10} RN}\right)^{2.58}\right] \qquad \text{(appendix A)}$$

The Reynolds number used for the turning vane loss should be based on vane chord. The turning vane loss parameter K_{TV} is plotted as a function of turning angle in figure 3(a), with the assumption that $K_{TV} = 0.15$ is a reasonable value for a 90° corner. Corners without turning vanes are less efficient and the loss function may be approximated by a sixth-order polynomial as shown in figure 3(b):

$$K = 4.313761\times10^{-5} - 6.021515\times10^{-4}\ \phi + 1.693778\times10^{-4}\ \phi^2 - 2.755078\times10^{-6}\ \phi^3$$

$$+2.323170\times10^{-7}\ \phi^4 - 3.775568\times10^{-9}\ \phi^5 + 1.796817\times10^{-11}\ \phi^6$$

(appendix B)

This function assumes a loss value of about $K = 1.8$ for a 90° turn. The foregoing losses are those associated with the turning of the flow only. The losses for a corner system (with or without vanes), with the walls of the duct to be considered as well, requires an additional term for the frictional loss of the constant-area duct based on the centerline length.

5. Corners (diffusing): Corners with diffusion may well employ longer vanes in order to improve the efficiency of the diffusion process. For this reason they were treated as vaned diffusers with the addition of the rotational loss term of the turning vane function:

$$K = \left\{0.3 + [0.006(2\theta - 21.5^\circ)u(2\theta - 21.5^\circ)]\right\}\left(\frac{AR - 1}{AR}\right)^2 + \frac{2}{3}K_{TV}$$

(appendix A)

where $u(2\theta - 21.5^\circ)$ is the unit step function and the turning vane loss parameter is defined as for a constant-area corner. This loss function includes the effects of friction.

6. Diffusers: Diffusion produces both expansion and friction losses in the duct given by

$$K = \left[K_{EXP} + \left(\frac{\lambda}{8 \sin\theta}\,\frac{AR + 1}{AR - 1}\right)\right]\left(\frac{AR - 1}{AR}\right)^2 \qquad \text{(appendix A)}$$

where the expansion parameter values, K_{EXP}, are plotted against equivalent cone angle in figure 4 and the technique used for estimating the K_{EXP} values is described in appendix A.

(It should be noted that there are more sophisticated techniques for estimating diffuser performance than the one presented here. However, they require boundary-layer calculations; for example, see reference 19. Experience with both the simple technique described herein and more complex techniques indicates that the two produce comparable results. Generally, little is gained by the significant additional effort required to use the more complex approaches.)

7. Exit: The total pressure loss at the exit of a non-return wind tunnel, or of any expelled flow, is due to the loss of the kinetic energy of the exiting flow. This is given by

$$K = \frac{2\left\{\left[1 + \left(\frac{\gamma - 1}{2} M^2\right)\right]^{\frac{\gamma}{\gamma - 1}} - 1\right\}}{\gamma M^2} \qquad \text{(appendix A)}$$

8. Fan (power) section: Fan drive sections are commonly made up of contractions, constant-area annular ducts, and diffusers. Analysis should be handled by dividing the fan section into these three component parts.

9. Flow straighteners - honeycomb (thin walls): The loss through thin flow-straightener or honeycomb systems may be expressed as

$$K = \lambda\left(3 + \frac{L}{D_h}\right)\left(\frac{A}{A_{FLOW}}\right)^2 + \left(\frac{A}{A_{FLOW}} - 1\right)^2 \qquad \text{(ref. 7, p. 478)}$$

where the hydraulic diameter is that of the honeycomb cell. The friction coefficient is determined from a Reynolds number based on the surface roughness of the honeycomb:

for $RN \leq 275$, $\qquad \lambda = 0.375\ RN^{-0.1}\left(\frac{\Delta}{D_h}\right)^{0.4}$

and for $RN > 275$, $\qquad \lambda = 0.214\left(\frac{\Delta}{D_h}\right)^{0.4}$

10. Flow straighteners - airfoil members (thick walls): Flow through adjacent airfoils will first contract and then diffuse. It was assumed that the point of minimum distance between parallel members would be at 30 percent of the straightener length back from the leading edge. The forward 30 percent was treated as a contraction and the aft 70 percent as a vaned diffuser. Thus,

$$K = 0.096\,\frac{\lambda L}{D_h} + \left\{0.3 + \left[0.006(2\theta - 21.5°)u(2\theta - 21.5°)\right]\right\}\left(\frac{AR - 1}{AR}\right)^2$$

(appendix A)

where the hydraulic diameter is that of each cell of the flow straightener, the friction coefficient is determined from a Reynolds number based on that hydraulic diameter, the area ratio and equivalent cone angle are based on the exit and minimum flow areas, and $u(2\theta - 21.5°)$ is the unit step function.

11. Internal flow obstruction - drag item: The loss due to the drag of internal structure such as struts or models has the form

$$K = C_D \frac{S}{A_{FLOW}} \varepsilon \qquad \text{(appendix A)}$$

12. Perforated plate: Perforated plate with sharp-edged orifices, used as protection screen or as screen around the inlet of a non-return tunnel, produces losses given by

$$K = \left\{\left[\sqrt{\frac{1}{2}}\left(1 - \frac{A_{FLOW}}{A}\right) + \left(1 - \frac{A_{FLOW}}{A}\right)\right]\frac{A}{A_{FLOW}}\right\}^2 \qquad \text{(ref. 7, p. 321)}$$

13. Mesh screen: The losses produced by a mesh screen may be expressed as

$$K = K_{RN}K_{MESH}\left(1 - \frac{A_{FLOW}}{A}\right) + \left(\frac{A}{A_{FLOW}} - 1\right)^2 \qquad \text{(ref. 7, p. 308)}$$

where the Reynolds number influence factor, K_{RN}, is plotted against Reynolds number (based on mesh diameter) in figure 5, and the mesh constant, K_{MESH}, is 1.3 for average circular metal wire, 1.0 for new metal wire, and 2.1 for silk thread.

14. Sudden expansion: For a sudden expansion with ducting downstream (to allow reattachment of the flow and maximize the pressure recovery) the loss is

$$K = \left(\frac{AR - 1}{AR}\right)^2 \qquad \text{(ref. 7, p. 128)}$$

15. Vaned diffusers: The pressure loss of a vaned diffuser, one in which splitter vanes are used to improve the performance of a short diffuser by decreasing the effective equivalent cone angle of each chamber, may be determined from

$$K = \left\{0.3 + [0.006(2\theta - 21.5°)u(2\theta - 21.5°)]\right\}\left(\frac{AR - 1}{AR}\right)^2$$

(appendix A)

where $u(2\theta - 21.5°)$ is the unit step function. (See fig. 6.)

16. Fixed, known loss: For a fixed loss item where the pressure loss value is known, that value may be used directly by definition:

$$K = \frac{\Delta p_T}{q}$$

17. Multiple ducts: In a system of multiple ducts, where the local flow passes through two or more separate, identical passages at the same time, the losses have the same value as those for the same type of single duct. Some of the pertinent parameters, such as hydraulic diameter and equivalent cone angle, should be based on the geometry of one of the individual ducts. The loss for the system of ducts may then be determined from the loss for a single duct:

$$K = \frac{\Delta p_{T_{SYSTEM}}}{q} = \frac{\Delta p_{T_{DUCT}}}{q}$$

18. Loss value transferred to reference location: Each local loss parameter is calculated based on local conditions at the smallest-area end of each section and may then be referenced to the test section conditions by the formula

$$K_o = K \left[\frac{A_o M}{A M_o} \bigg/ \frac{1 + \left(\frac{\gamma - 1}{2} M_o^2\right)}{1 + \left(\frac{\gamma - 1}{2} M^2\right)} \right] \qquad \text{(appendix A)}$$

19. Overall and summary performance: The energy ratio of the wind tunnel under consideration is given by

$$ER = \frac{1}{\sum_{i=1}^{N} K_{o_i}} \qquad \text{(ref. 4, p. 69)}$$

The pressure difference across the wind tunnel walls, determining the minimum required structural strength for each section, is given by

$$\Delta p_{W_i} = p_{T_{ATM}} - \left\{ \frac{p_{T_{SC}} - \left(q_o \sum_{j=1}^{i} K_{o_j}\right)}{\left[1 + \left(\frac{\gamma - 1}{2} M_i^2\right)\right]^{\frac{\gamma}{\gamma - 1}}} \right\} \qquad \text{(appendix A)}$$

The power required to be input into the flow in order to drive the flow through the wind tunnel at a specified test section speed is expressed as

$$P_{INPUT} = \frac{\left(\sum_{i=1}^{N} K_{o_i}\right) \rho_o{}^2 A_o V_o{}^3}{2\rho_F} \qquad \text{(appendix A)}$$

The actual drive power required is dependent on the efficiency of the fan/motor system:

$$P_{REQUIRED} = \frac{P_{INPUT}}{\eta_F}$$

COMPUTER PROGRAM DESCRIPTION

The computer program was written in FØRTRAN IV language. It consists of a main program which calls five subroutines and/or six library routines, as required. Two of the subroutines are optional and may be abbreviated and simulated in order to save execution time and/or memory storage space.

Method of Solution

The general technique used is outlined in the computer program functional flow chart in figure 7. The program was developed in six functional units: a main program and five specialized subroutines. The main program retains general control over the computational flow and calls the subprograms as required.

In the main portion (designated PERFØRM), at first entry into the program, various section-shape geometry relationships and certain semi-empirical diffuser, turning vane, and honeycomb loss functions are defined. The case title card is read and checked for validity by specified code. The tunnel master data control card is then read, checked for validity, and checked for content of pertinent data by the data-checking subroutine. If any errors are found in either of these two preliminary cards, error messages will be printed. Although detected errors will not abort the computer run (unless a card of improper format is encountered where not expected), the case under current consideration will not be computed - only the checking of input errors will then be performed on each section card. Prior to reading the section cards, the units of measure (International System or U.S. Customary System) to be used for the particular case are read. These units of measure are used as the basis for the development of the appropriate flow parameters and test section conditions.

The section cards are read and operated on one at a time. They are checked for validity and input errors by the data-checking subroutine (called DATACK) and the input information, if sufficiently complete, is then used in the computation of the section upstream- and downstream-end geometries. Adjustments to these geometry calculations are made for any multiple-ducted sections. For diffusing sections where the expansion loss parameter was not input by the user, that parameter is generated from predefined functions. Branching of the computational flow then transfers control to the appropriate block of instructions for the remainder of the calculations which are peculiar to the particular section under consideration.

After all section cards have been read in and operated on, each in turn, a case termination card is encountered. The termination card specifies the optional summary operations to be performed. The encounter of this card signals the end of a case and triggers the final calculations. The codes contained on this card determine the printing of velocity-optimizing and circuit summary information, the plotting of the summary information, and the return to the beginning for another case.

The data-checking subroutine evaluates the master and section input cards for completeness of data (based on the requirements for the type of section). Then, if any error was detected during computation of a case or if the appropriate termination code was specified by the user, the complete set of input data is tabulated. Messages about errors, omissions, or superfluous information are included.

The subroutine SPEED computes the local Mach number based on local cross-sectional area and determines the local flow velocity.

The subroutine FRICTN calculates the local Reynolds number, usually based on the local duct hydraulic diameter, and the local friction coefficient for smooth pipes.

The subroutine ØUTPUT accepts the calculated section parameters along with the section type codes describing the types of information to be output and prints the section information according to the appropriate format.

The subroutine PLØTIT plots the summary information (cummulative total pressure losses and/or wall pressure differential) versus circuit centerline length if requested. The plot is scaled for centimeter or inch plot paper, determined by whether International or U.S. Customary units are used for computation.

The program is terminated after the last operations on a case for which a no-return instruction on the termination card was given by the user.

Computing Equipment Required

Hardware and machine components- Although this program was written for use on an IBM 360/67 with TSS Monitor, batch mode, an attempt was made to keep it compatible with any system that uses FØRTRAN IV. No magnetic tapes were used. In this version, input is made by cards and the data to be plotted are stored on a disc file for plotting at a later time in an off-line mode. However, it is possible to use a typewriter-type terminal for conversational or real-time computation, typing the data by card-image format, and plotting immediately after the computation has been completed for a case.

The total core required for compilation on the IBM 360/67 was approximately 82 000 (decimal) bytes. If necessary this figure can be reduced by eliminating two subroutines, DATACK and PLØTIT. The sizes of the main program and of each subroutine were approximately as follows:

PERFØRM	38 800 bytes
DATACK	25 700
SPEED	800
FRICTN	900
ØUTPUT	12 900
PLØTIT	2 900

The program was executed on an IBM 360/67, writing plot data on a disc, logical unit 10. Later the data file was accessed from a 14.8 character-per-second binary-coded-decimal terminal and plotted on a Zeta plotter with 0.005-in. step increments. The plot page size was programmed not to exceed 25 by 38 cm (or 10 by 15 in.).

Software- This program was written for use on any computer with sufficient core and with a standard FØRTRAN IV compiler.

The Zeta plotter routines, with minor exceptions, are compatible with the Calcomp routines. The subroutines AXIS, FACTØR, LINE, PLØT, SCALE and SYMBØL are alike in both Calcomp and Zeta plotting.

CALL AXIS - draws the axis line and annotates the divisions at every two centimeters or each inch (depending on the units of measure specified).

CALL FACTØR - enables the user to produce normal size drawings with plotters which have either 0.01- or 0.005-in. increment size. The variable FACT must be set to 1.0 for 0.01-in. increments and to 2.0 for 0.005-in. increment plotters.

CALL LINE - plots centered squares connected by straight lines through the coordinate pairs of data values.

CALL PLØT - is used to establish a new point of origin for the pen and paper movements. Before plotting commences, the pen must be positioned where desired along the X-axis. The program will position it along the Y-axis. The plot-page size is defined by the values of YLEN and XLEN which are equated to 25 and 38 cm or 10 and 15 in., as required.

CALL PLØTF - is an alternate plotting initialization routine which is available in the Zeta but not Calcomp plot package. It is used in place of PLØTS whenever deferred plotting is desired. The first argument in the call statement indicates the speed of the terminal with which the plotter is interfaced. The second argument is the logical-device number of the plot file.

CALL SCALE - examines the data and determines the proper scaling for the given dimensions of the plotter paper, 25 by 38 cm or 10 by 15 in.

CALL SMØDE - is available only in the Zeta plot package. It permits the user to choose from extensive capabilities which affect several of the plotter routines. In this program the options have been set equal to the usage found in the Calcomp routines, and therefore, if Zeta plotter routines are not available, the call to SMØDE should be eliminated.

CALL SYMBØL - prints the input case title at the top left of each plot page as it appears in columns 2 through 80 of the title card. For reference purposes, it also draws a small plus sign at the origin of the plot.

The library routines used are standard FØRTRAN routines:

ABS - Absolute value

ALØG10 - Common logarithm, base ten

ATAN - Arctangent (result in radians)

EXP - Exponential of the natural number e

IFIX - Convert from real number to integer

SIN - Trigonometric sine (argument in radians)

SQRT - Square root

Programming Techniques

It was intended that this program be usable on as many different computer systems as possible. Therefore, in order to make them applicable to some machines, certain statements were forced into particular forms which would be less efficient on other systems (e.g., Hollerith instead of literals in format statements).

CØMMØN and DATA statements were used as much as possible to simplify the definition of parameter values. In the main program, arithmetic statement functions were used for three purposes: (1) for the definition of section hydraulic diameter, area, and equivalent cone angle geometry functions; (2) for the conversion function from local to reference-section pressure losses; and (3) for the definition of the least-squares-polynomial-curve-fit functions. The last group of functions includes: (1) the corner turning-loss parameters as functions of turning angle (see fig. 3); (2) the diffuser expansion loss parameters for the different cross-section shapes as functions of equivalent cone angle (see fig. 4); and (3) the mesh screen Reynolds number sensitivity factor as a function of mesh-diameter-based Reynolds number (see fig. 5).

Certain functions not easily solvable in closed form were solved iteratively (some by Newton's method) to 0.01 percent accuracy. These functions include test section Mach number, local section Mach number, and local section friction coefficient.

Numeric codes were used for specifying such things as section type, section end-shape types, and system of computational units; for decisions on requirements for inputs to each section type; and for case-termination procedures and outputs desired. The various important input codes are listed in tables 1 and 4. All sections of the multiple-ducted type were assigned high code numbers for simplicity in selecting them for special handling. The various section types were grouped in code decades for reasonable association of section code and component function. Where possible, the second digit of the code (if that second digit is not zero) reflects the basic characteristic of the section: constant area, contracting, or diffusing.

The information input fields on the master data and section cards were arranged in three basic groups: (1) qualitative information (type and shape); (2) quantitative geometry information (number of ducts, cross-sectional end dimensions, and length); and (3) loss-related parameters. The case termination card employs the same format as the section cards so that it may be encountered at random intervals without causing a program crash. For the tabulation of the input data (for error-location and record-keeping purposes), object-time formatting was used to compile the combination input and annotation data set for a convenient output.

Much of the output of the program was set up on a demand (i.e., optional) basis. A section-by-section performance analysis is automatically provided. A brief summary of the variation of selected parameters through the circuit, and plots of those parameters, may be selected if desired. An annotated listing of the inputs may be requested or, if errors are detected, the listing is internally forced in order to provide a simple means of error-detection and correction and/or simplified record-keeping of case data.

Source Code

A source code listing of the performance estimation program is provided in appendix C along with the associated notation definitions. The source code includes the use of comment cards throughout the program for identification of the operations carried out by each set of instructions.

Operating Instructions

The basic source program deck arrangement is shown in figure 8.

Input- Sample coding forms for the four types of input cards required are presented in figure 9. The special symbols required in the first columns of the title and master data cards are included.

1. Title card: For the title labeling card, with the exception of the first column which must contain an asterisk (*), the entire card may be used as desired. This title was programmed to appear at the top of each page of the case to which the title refers, including the plots. Only one title card per case may be used.

2. Master card: The tunnel master control data card provides sufficient information for defining conditions in the test section (which is the reference section for all calculations) and conditions of the surrounding external atmosphere. Table 2 details the inputs included on the master data card. The first column must contain a minus sign in order to identify the card as a valid master card. The remainder of the inputs should be positive, with

columns 2 through 6 containing five fields of integers only (no decimal points). Columns 7 through 10 were not used on this card and should be left blank. Columns 11 through 50 should contain floating-point numbers. These columns were divided into eight parameters of five columns each, including decimal point.

3. Section cards: The individual section information cards were based on the same format as the master card, except that the section cards require no special identifying code. Table 3 details the inputs contained on the section cards. The first six columns, containing four data fields, require integer inputs. The remaining 74 columns were divided into two real number fields of two columns each (with the assumed default decimal points to the right of the second columns), and 14 real number fields of five columns each (with the assumed default decimal point between the third and fourth columns of each field).

Although the input parameter requirements vary from section to section, certain requirements are basic to all sections. These items include: (1) the section type code, (2) the section end shape codes, and (3) the section dimensions (end height(s) and width(s) and/or diameter(s) and usually length). A detailed list of the additional, specialized requirements for each section is presented in table 4.

Although not mandatory in order to obtain a correct total power estimation, it is advisable to input the section data cards in the actual section order so that the summary calculations and plots have relevance to the actual circuit.

4. Termination card: The case termination card, which signals the end of the section inputs for a particular case, is identified by the constraint of blanks in card columns 3 and 4. The numbers contained on this card are used strictly as task codes; table 5 shows the details of these codes. In the event of a request for plotted information, the code determines the type(s) of information to be presented. For all other tasks the codes dictate a simple yes/no decision.

As many cases as desired may be input in a single job submission. The same system of units need not be used in all cases. Any parameters may be changed as desired from case-to-case since there are no forced carry-overs (except the specific heat ratio, γ, which is fixed at the time of program compilation).

Output- Based on the foregoing input information the results may be calculated and tabulated in five different types of information groups.

1. Section performance analysis: The section performance tabulation fully describes the performance-related parameters of the wind tunnel circuit. Atmospheric and test section flow reference conditions are stated at the top of the first page. The various parameters are tabulated for each section in the order of computation with the upstream end information on the first and the downstream information on the second of the two lines for each section. The section sequence number and type (a translation of the code) and the end

shapes are given first. The geometry and local velocity information are presented next, followed by the section length and calculated total pressure loss values.

2. Overall performance: If no input errors are encountered during the analysis of a case, overall performance values are presented at the end of the section performance tabulation. This includes the total circuit length, the total pressure losses and energy ratio for the circuit, and the total operating power required.

3. Summary characteristics: If requested on the termination card and barring any errors, a summary of the circuit characteristics is tabulated on a separate page. This tabulation includes section sequence numbers, Mach numbers, cumulative pressure losses, and local wall pressures, all as functions of distance through the circuit.

4. Plots: Under proper condition codes, the cumulative pressure losses and/or the wall pressure differentials will be plotted as functions of distance through the circuit (centerline length). The straight lines that appear on the plots connecting the points are for reference only and do not represent the actual distribution in a component.

5. Input data tabulation: Finally, if an input error was encountered during the analysis of the circuit, or if such information was requested by the user, the input cards are tabulated with annotations regarding missing or superfluous inputs. A careful look at this section should allow the user to discover why a given set of input data did not produce the expected type of results.

All of the foregoing types of output are shown for the test case.

Computer system restrictions- Certain restrictions and/or assumptions had to be imposed on the computer system and its methods and abilities in order to perform the performance analysis within reasonable time, effort, and money constraints.

1. Hardware: This analysis was programmed for a moderate-sized system with common components. No special hardware is required with the exception of a plotter if the plotting option is used. The output printing device is assumed to have available a minimum capacity of 120 characters per line, but the number of lines per page may be set by means of the LINEMX parameter in the main program. (Barring any special requirements, 45 lines for an 8.5-in. page or 60 lines for an 11-in. page are recommended.)

2. Software: Certain software restrictions were imposed simply as a starting point to the problem solution. The input card formats were fixed as shown in figure 9. The specific heat ratio (γ) and the number of lines per output page were fixed for each compilation of the source deck, although changes can be made by altering the values of G and/or LINEMX, respectively, near the beginning of the main program.

For reasons of possible memory limitations on smaller systems, the number of wind tunnel components in each circuit case was limited to 30 sections. This limit may be changed by assigning a new value to LMTSEC in the main program and by re-dimensioning the following variables as denoted by "XX": in the main program (PERFØRM), DELP(XX+2), SEKO(XX), SEL(XX), SMACH(XX), SSUMEL(XX+2) and SSUMKO(XX+2); in the data-checking subroutine (DATACK), ENDATA(XX,20), NCHECK(XX,20) and NDATA(XX,4); and in the plotting subroutine (PLØTIT), DELP(XX+2), SSUMEL(XX+2) and SSUMKO(XX+2). If memory limitations are a severe problem and/or if computer-controlled plotting facilities are not available to the user, the data-checking and/or plotting subroutines may be "removed" by inserting dummy, one-card subroutines with the same arguments which would have no effect on the calculations. This would decrease the utility and power of the program, but would retain the basic performance estimation capabilities without crippling them altogether.

The plotting routines were written according to the requirements for a plotter with 0.005-in. increments.

Optional inputs- Certain of the parameter inputs are designated as optional and have built-in assumed default values in the event that the user knows no better values than the ones provided in the sources referenced herein. These optional parameters are shown in tables 2 through 4.

On the master card (see table 2), the units of measure should be specified and an error message will be given if they are specified erroneously (other than as type 1 or 2). However, the units code will default to 1 (the International System) and case execution will continue. The test section and atmospheric total pressures will default to one atmosphere if not specified.

On the section cards (see table 3), the number of items in the duct will default to unity if not specified. The expansion loss parameter for diffusers defaults to a value based on figure 4. (It is computed by determining the shape of each end, the extent to which the diffuser is two-dimensional in nature (i.e., changing cross-sectional size in height or width only), and the equivalent cone angle, and then interpolating between the curves of figure 4. See appendix A.) The mesh screen loss constant defaults to 1.3, the value for an average-condition metal mesh screen (ref. 6, p. 527), and the reference Reynolds number for turning vanes defaults to 0.5 million (ref. 6, p. 527). The surface roughness for honeycombs defaults to the appropriate equivalent of 0.00001 m, the value for new, commercially smooth, non-steel pipe (ref. 7, p. 62). The factor for the additional influence of a blockage on downstream sections ($\Delta\varepsilon$) defaults to zero.

Diagnostic messages- There are a limited number of error diagnostic messages which were built in to handle many, but not all, of the potential user errors. The causes and appropriate corrections of these errors should be evident in each message.

1. Title card: If a card is in the position of a title card and does not begin with an asterisk as required, the following message will appear:

TITLE ('...(invalid title)...') IS INCORRECT OR IMPROPER AS IT EXISTS. THE FIRST CARD COLUMN MUST CONTAIN AN ASTERISK (*) TO BE IDENTIFIED AS A VALID TITLE CARD.

2. Master card: An invalid master card is denoted by:

MASTER CONTROL DATA ('...(card image)...') IS INCORRECT OR IMPROPER AS IT EXISTS. THE FIRST TWO CARD COLUMNS MUST CONTAIN A NEGATIVE NUMBER (-1 TO -9) TO BE IDENTIFIED AS A VALID MASTER CARD. THIS CASE WILL BE SKIPPED.

A general omission from the master card of required information produces:

CRITICAL OMISSION(S) IN TUNNEL MASTER CONTROL DATA PREVENT EXECUTION OF THIS CASE. ANY SUCCEEDING CASES WILL NOT BE AFFECTED.

Two master cards, back-to-back, for a given case are identified by:

MORE THAN ONE MASTER CONTROL CARD EXISTS FOR THIS CASE OR INPUT CARDS ARE OUT OF ORDER. CHECK DECK SET-UP. THE LAST MASTER CARD ENCOUNTERED WILL BE ASSUMED AS THE CORRECT MASTER CARD FOR THE SECTION CARDS WHICH FOLLOW.

Encountering a master card where not expected (generally indicating missing case termination and title cards) causes this message:

MASTER CONTROL CARD HAS BEEN ENCOUNTERED BEFORE CASE TERMINATION AND TITLE CARDS. CHECK DECK SET-UP. ERROR-MESSAGE TITLE WILL BE GENERATED AND SUMMARY OUTPUT, NO-PLOT, INPUT DATA TABULATION, AND NEXT-CASE RETURN TERMINATION PARAMETERS WILL BE ASSUMED.

If an invalid test section upstream end shape geometry is specified, one which the program cannot handle, an error results:

**ERROR -- INVALID TEST SECTION UPSTREAM END SHAPE CODE WAS SPECIFIED AS (code used) (SHOULD BE 1, 2 OR 3). THIS CASE CANNOT BE EXECUTED.

If an invalid units code is specified the message is:

THE UNITS OF MEASURE CODE IS IMPROPERLY SPECIFIED AS (code used), (SHOULD BE 1 OR 2). CHECK MASTER CARD (COLUMN 4). SEE THE DATA TABULATION AT THE END OF THIS CASE. THE INTERNATIONAL SYSTEM OF UNITS WILL BE ASSUMED FOR THIS CASE.

If the termination code requests power-matching but the input power value is such that the calculation would be meaningless, a diagnostic of the following form is printed:

**ALTHOUGH VELOCITY-OPTIMIZING WAS REQUESTED BY TERMINATION CODE, THE INPUT POWER VALUE IS ILLEGAL (LESS THAN OR EQUAL TO ZERO). THEREFORE, NO VELOCITY-OPTIMIZING IS POSSIBLE. RECHECK INPUT VALUE ON MASTER DATA CARD.

3. Section card: A general omission of required data from a section card will cause this message:

> **ERROR -- CRITICAL OMISSION(S) IN SECTION INPUT DATA. SEE DATA TABULATION AT END OF OUTPUT FOR THIS CASE.**

If an invalid section shape code is specified it is not possible for the program to properly compute section end geometries; as a result an error occurs:

> **ERROR -- INVALID SECTION SHAPE CODE WAS SPECIFIED AS (input code) (SHOULD BE 1, 2 OR 3). THIS SECTION WILL BE SKIPPED.

An error which arises during computation and causes a non-positive total pressure loss for a given section prevents completion of the case analysis and gives rise to an error message:

> **ERROR -- SOME INCORRECT COMBINATION OF INPUTS OR UNANTICIPATED SITUATION HAS CAUSED AN INVALID (NON-POSITIVE) TOTAL LOSS LEVEL. RECHECK SECTION (section number) INPUT DATA.

If the maximum allowable number of circuit sections written into the program is exceeded by placing too many section cards together in one case, or without termination, title, and master cards between cases, this diagnostic will appear:

> MAXIMUM LIMIT ON THE NUMBER OF SECTIONS (...(maximum allowable number of section)...) HAS BEEN REACHED. EITHER A CASE TERMINATION CARD HAS BEEN OMITTED (ALONG WITH TITLE AND MASTER CARDS TO BEGIN A NEW CASE) OR THIS CASE IS TOO LONG FOR THE PROGRAMMED ALLOWABLE NUMBER OF SECTIONS. THE CASE HAS BEEN TERMINATED AT THIS POINT.

In this instance, the inputs from the group of sections for which the limit was exceeded will be tabulated and the remaining section inputs will be evaluated and tabulated. If the user fails to cause the test section blockage amounts specified on the master control card to coincide with that of the test section card, erroneous analysis may result since inconsistent flow areas would be calculated. The section card value will be used (since the discrepancy may be desired) and this notice is given:

> **NOTE -- TEST SECTION BLOCKAGE FROM SECTION CARD INPUT (...(section input value)...PERCENT) DOES NOT EQUAL THAT OF THE MASTER CARD INPUT (...(master input value)...PERCENT). CHECK DATA DECK. SECTION CARD VALUE WILL BE ASSUMED AS CORRECT AND EXECUTION WILL CONTINUE.

An invalid section type code will cause a section to be skipped and a message to be printed:

> *ERROR -- INPUT SECTION TYPE CODE (CARD COLUMNS 3 AND 4) CALLS INVALID SECTION TYPE. DATA CARD IGNORED.**

Any input errors were deemed justifiable cause for judgment as an incomplete case. As a result, reliable overall and summary information cannot be calculated. To assist the user in locating the error(s), the input values will be forced to be tabulated and the following explanation appears:

> ***DUE TO ERROR(S) IN INPUT CARD(S), VALID SUMMARY INFORMATION IS NOT AVAILABLE. REFER TO THE TABULATION OF INPUT DATA ON THE FOLLOWING PAGES. CORRECT THE ERROR(S) AND RESUBMIT THIS CASE. SUBSEQUENT CASES WILL NOT BE AFFECTED.

4. Possible errors lacking diagnostics: Certain potential problem areas remain unprotected by diagnostic and error-recovery systems.

No special provision was made for two test sections in the same circuit case. As long as the blockage values for both test sections match the one from the master card, no message will be printed. In any event, the execution will not be terminated. The test section shapes and dimensions from the master card are not checked against those of the test section card. Although a mismatch of these values could cause a mass-flow error, including and enforcing such a check could inhibit any meaningful tandem-test section cases. These problems could be avoided, however, by naming only one working section as a test section and referring to the other by general type.

Also, there was no provision for checking the specified tunnel type against the types of sections actually used (e.g., checking a non-return, or open-test-section tunnel for exit or open-throat test section input cards). This check is not critical and was left to the user.

One error-check was not included due to the program complications which would have resulted. If a case termination card is omitted at the end of a case and a computer-system control card or a title card is encountered, the error will be disastrous due to mismatched format types. Execution and calculations will be immediately aborted by the computer.

Test Case

The NASA-Ames Research Center 40- by 80-Foot Wind Tunnel was used as an example of a typical wind tunnel. This tunnel, illustrated in figure 10, is of the single-return, closed-test-section, continuous-running type. It has a flat-oval test section 12.2 m (40 ft) high by 24.4 m (80 ft) wide and is powered by six 12.2-m (40 ft) diameter, six-bladed fans. It has an eight-to-one overall contraction ratio and uses multiple-circular-arc type turning vanes in each of the four 90° corners.

A complete list of the test case inputs and computed information outputs are presented in figure 11. The machine computing time for this test case (without plots) was about 7 sec on an IBM 360/67.

Although this test case was not an exhaustive exercise of all possible tunnel components, it does include most of the basic section types: diffusing test section, single-duct contraction and diffuser, constant-area single duct, constant-area corner with turning vanes, and multiple-duct fan sections (contraction, constant-area annulus, and diffuser). Examples of other types of components are shown in the sample cases which follow.

DISCUSSION AND APPLICATIONS

Wind tunnel energy ratio, required power, and operating velocity are interdependent. The energy ratio is affected by velocity through the effect of velocity on the Reynolds number. The required drive power, influenced directly by operating velocity and inversely by energy ratio, is also controlled by the fan system efficiency which is often only an estimated quantity. Any estimate of operating velocity for a given power level is, then, dependent on the basic efficiency of the circuit (energy ratio) and drive system efficiency, assuming the best power estimate available to be that delivered to the fans. This interdependency means that an error in the prediction of energy ratio (and/or in the estimation of fan efficiency) will cause corresponding errors in power and velocity estimates.

These errors resulting from an erroneous prediction of the circuit energy ratio can be found from the relationship governing required power, test section velocity, and energy ratio, assuming given motor electrical and fan efficiencies. For a fixed test section velocity,

$$\frac{\Delta P_{REQUIRED}}{P_{REQUIRED}} = \frac{1}{1 - \frac{\Delta ER}{ER}} - 1$$

and, for constant power, an error in energy ratio yields the performance penalty

$$\frac{\Delta V_o}{V_o} = 1 - \left(1 - \frac{\Delta ER}{ER}\right)^{1/3}$$

The expected true power and velocity levels can thus be obtained from the performance estimate:

$$P_{REQUIRED} = \left(\frac{1}{1 - \frac{\Delta ER}{ER}}\right) P_{REQUIRED_{Estimate}}$$

for a given set of test section conditions, and from

$$V_o \approx \left(1 - \frac{\Delta ER}{ER}\right)^{1/3} V_{o_{Estimate}}$$

for a given level of required power.

This adjustment of the estimated performance values is pointless for a known, existing wind tunnel, but necessary for new, or proposed facilities. Before the adjustment can be made the probable error in the energy ratio estimate must be determined. It is desirable, therefore, to consider several existing facilities of different circuit types in order to gain a degree of confidence in the performance estimation routine.

Results

The input parameters and output performance values for the several sample cases, other than the test case shown in figure 11, are compiled in appendix D. The estimated energy ratios for the seven sample wind tunnels are presented in table 6. The corresponding sketches for all these sample tunnel circuits are shown in figures 10 and 12.

The actual energy ratios for the first three wind tunnels presented in table 6 were estimated from the best available information on fan and electrical efficiencies from known input power levels. The actual performance of the other four facilities was taken from measured data.

The test case and first sample case was the circuit of the NASA-Ames Research Center 40- by 80-Foot Wind Tunnel as described previously in the test case discussion. The predicted energy ratio for this rather conventional tunnel was only 1 percent higher than the actual value when new.

The performance of the NASA-Ames 7- by 10-Foot Tunnel was predicted at a slightly optimistic level. However, this tunnel is one with several known problems which complicate the prediction process. With the air exchanger operating, the primary diffuser is known to have some local flow separation, having been designed at a 6° equivalent cone angle, an angle too great for its cross-sectional shape and length (see fig. 1). Also, the drive fan is stalled from the centerbody out to about 45 percent of the fan radius, causing some back-flow along the nacelle centerbody. (The impact of the stall on the fan efficiency has only been estimated; it was assumed that the fan efficiency would suffer by about an additional 10 percent.) In spite of these things, the predicted energy ratio was only about 3 percent too high relative to the original value of approximately 7.85, both values taken in the zero-air-exchange configuration. This agreement may indicate that much of the above-mentioned off-design performance is triggered by the air exchanger operation and is not as significant with the air exchanger closed. Although insufficient data are available to resolve this question, the fact remains that the prediction accuracy, for the stated conditions, was good.

The Lockheed-Georgia Low-Speed Wind Tunnel employs a tandem test section design. For this analysis, the larger, V/STOL test section was used as the only reference station. Because of the two area restrictions to cross sections smaller than that of the reference area (those of the smaller test section and of the fan), the tunnel efficiency would be expected to be low. (This in no way reflects on the tunnel's usefulness as a research tool or on its design or capabilities. The "low efficiency" value results only from the point of reference used in the calculations.) In other than these features the facility is basically of conventional design. The computerized performance prediction was in error by less than 2 percent from the true value of about 1.10.

The Indian Institute of Science 14- by 9-Foot Tunnel at Bangalore stands out among non-return wind tunnels as a facility with an unusually high energy ratio. Although the determination of circuit dimensions for the program input was somewhat hampered by the limitations of small drawings, the estimated energy ratio was within 1 percent of the true facility value of 6.85. It is interesting to note that the fan performance data of reference 23 would indicate a fan design efficiency of about 69 percent. The power requirement calculations based on energy ratio and test section maximum velocity, however, show that the fan efficiency must be higher than was expected; in fact, greater than 90 percent.

The Hawker Siddeley 15-Foot V/STOL Tunnel at Hatfield, England was constructed under economy constraints and is a compact, cost-effective facility. The estimated performance was about 1.6 energy ratios higher (i.e., more optimistic) than the actual value of 2.38. This is an error of about 67 percent. The primary performance difference was probably caused by the fan system. The losses of the ducting in this area are difficult to predict because the area changes are not gradual and are even difficult to define.

The University of Washington 8- by 12-Foot Double-Return Tunnel has a surprisingly high measured energy ratio of 8.3. This would indicate a very carefully designed circuit powered by carefully designed fans. The performance estimate produced by the computer program is lower than the actual energy ratio by about 13 percent, showing that the achieved performance level is higher than would normally be expected.

The NASA-Langley Research Center 30- by 60-Foot Open-Throat Tunnel is unusual in configuration, having a double-return system with the twin fans located less than two fan-diameters downstream of the test section. The location of the data point for this tunnel on the diffuser design curves of figure 1 would not indicate that any diffuser-related problems should be expected forward of the fans. The diffuser between the fans and the first corner, however, does have a rather large equivalent cone angle (more than 8°). If the fans cause or contribute to diffuser flow problems (see the Cautionary Design Guidelines for Diffusers) and if those problems lead to corner flow inefficiency in a region critical to overall performance, then the circuit energy ratio may be well below the normal estimated level. Although it is not clear whether this is the case in the NASA-Langley 30- by 60-Foot Tunnel, the performance estimate was about 27 percent higher than the actual value of about 3.71.

Evaluation

To summarize what may be learned from the sample cases:

1. The Ames 40- by 80-Foot and 7- by 10-Foot Tunnels and the Lockheed-Georgia Low-Speed Tunnel, although at opposite ends of the energy ratio

spectrum, are all basically standard, single return, closed-test-section facilities; the computer program estimates of actual performance were good.

2. The Indian Institute of Science Bangalore tunnel, being of the non-return variety, is a different and less common type of facility; the computer program closely estimated its actual performance.

3. The University of Washington double-return tunnel is a third major circuit type; the program produced a reasonably accurate prediction of its performance.

4. The Hawker Siddeley V/STOL and Langley 30- by 60-Foot Tunnels are examples of facilities which may have flow problems due to too-rapid area changes and, as a result, lower than optimum performance levels for their respective circuit types. For these tunnels, because of their flow quality and not because of their circuit types, the program provided a poor estimate of actual performance.

Based on these results one thing is immediately clear: the performance of a wind tunnel of conventional, conservative design can be evaluated accurately. On the other hand, the performance of a tunnel whose design generates or contributes to flow problems (separation or grossly non-uniform) will be overestimated by the loss equations and computer program.

Flow peculiarities and off-optimum designs, even though seemingly only slight, can cause operational performance to fall significantly below the predicted levels. Such problems can be expensive whether considered in terms of modifying the facility or in such terms as reduced testing capability and increased power costs. Judicious, iterative use of the estimation techniques presented in this report, simplified by computerized automation, can lead to the improvement of an existing facility through guidance of design changes or to the optimization of a proposed new wind tunnel design.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California 94035, January 8, 1976

APPENDIX A

NON-STANDARD FUNCTIONAL FORMS

Due to the nature of this analysis, certain of the local flow-state, section loss, and summary parameter formulas were used in a form more convenient than that usually found in the literature. The relationships which were altered or derived are outlined on the following pages.

Local Flow-State Parameters

The calculation of several local parameters was based on the local Mach number, determined from the relationship between the local area and the area for choked flow:

$$\frac{A_*}{A} = \left(\frac{\gamma + 1}{2}\right)^{\frac{\gamma+1}{2(\gamma-1)}} M\left[1 + \left(\frac{\gamma - 1}{2} M^2\right)\right]^{-\frac{\gamma+1}{2(\gamma-1)}} \qquad \text{(ref. 18, p. 6)}$$

Solving for the area for choked flow, knowing the test section area and Mach number,

$$A_* = M_o A_o \left\{\frac{\gamma + 1}{2\left[1 + \left(\frac{\gamma - 1}{2} M_o^2\right)\right]}\right\}^{\frac{\gamma+1}{2(\gamma-1)}}$$

Mach number- Another form of the same area relationship,

$$\left(\frac{A}{A_*}\right)^2 = \frac{1}{M^2}\left\{\frac{2}{\gamma + 1}\left[1 + \left(\frac{\gamma - 1}{2} M^2\right)\right]\right\}^{\frac{\gamma+1}{\gamma-1}} \qquad \text{(ref. 17, p. 126)}$$

can be rewritten to produce a polynomial equation in Mach number which may be solved by Newton's method if the areas are known:

$$\left[\left(\frac{A}{A_*}\right)^2 M^2\right]^{\frac{\gamma-1}{\gamma+1}} = \frac{2}{\gamma + 1}\left[1 + \left(\frac{\gamma - 1}{2} M^2\right)\right]$$

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

$$M^2 - \left[\frac{\gamma + 1}{\gamma - 1}\left(\frac{A}{A_*} M\right)^{\frac{2(\gamma-1)}{\gamma+1}}\right] + \frac{2}{\gamma - 1} = 0$$

Reynolds number- The local Reynolds number was calculated based on other, known, local conditions and from basic principles:

$$RN = \frac{\rho V \ell}{\mu}$$

$$\rho VA = \rho_o A_o V_o \qquad \text{(conservation of mass)}$$

$$\mu = \mu_T \left(\frac{T}{T_T}\right)^{0.76} \qquad \text{(ref. 18, p. 19)}$$

$$\frac{T}{T_T} = \left[1 + \left(\frac{\gamma - 1}{2} M^2\right)\right]^{-1} \qquad \text{(ref. 18, p. 4)}$$

$$RN = \frac{\rho_o V_o \ell}{\mu_T} \frac{A_o}{A} \left[1 + \left(\frac{\gamma - 1}{2} M^2\right)\right]^{0.76}$$

Friction coefficient- The Reynolds number-friction coefficient function used was

$$\frac{1}{\sqrt{\lambda}} = 2 \log_{10}(RN\sqrt{\lambda}) - 0.8 \qquad \text{(ref. 6, p. 70)}$$

A Newton's method solution was performed on a rewritten form of the equation:

$$[\log_{10}(\lambda RN^2) - 0.8]^{-2} - \lambda = 0$$

Section Pressure Losses

The losses for some types of sections were derived in forms not found in the literature. For others, a curve-fit of data points or a simplification of analysis was performed.

Corners (constant area)- The frictional and rotational losses through turning vanes are additive: $K = K_{FRICTION} + K_{ROTATION}$. Also,

$$K_{FRICTION} = \frac{1}{3} K_{TV} \quad \text{and} \quad K_{ROTATION} = \frac{2}{3} K_{TV} \qquad \text{(ref. 6, p. 527)}$$

Assuming that the frictional loss value has a form similar to that for a flat plate, then at 90°:

$$K_{FRICTION} = \frac{1}{3} K_{TV_{90}} = \frac{0.455B}{(\log_{10} RN)^{2.58}} \qquad \text{(ref. 6, p. 527)}$$

Thus, the constant B is dependent on the turning vane loss constant and the reference Reynolds number at which that constant was determined:

$$B = \frac{\frac{1}{3} K_{TV_{90}} \left(\log_{10} RN_{REF}\right)^{2.58}}{0.455}$$

Therefore,

$$K_{FRICTION} = \frac{1}{3} K_{TV_{90}} \left(\frac{\log_{10} RN_{REF}}{\log_{10} RN}\right)^{2.58}$$

Since the rotational term is assumed independent of Reynolds number, $K_{ROTATION} = (2/3)K_{TV_{90}}$. The additional complication of loss parameter variation with turning angle is presented in figure 3 for a loss parameter at 90° equal to 0.15. It was assumed that the relationship between the actual and reference loss constants is linear:

$$K_{TV} = K_{TV_{90}} \left[\frac{f(\phi)}{0.15}\right]$$

where $f(\phi)$ is the functional relationship plotted in figure 3. The complete turning vane loss function then becomes

$$K = K_{TV} \left\{\frac{2}{3} + \left[\frac{1}{3} \left(\frac{\log_{10} RN_{REF}}{\log_{10} RN}\right)^{2.58}\right]\right\}$$

Corners (diffusing)- Diffusing corners were treated as vaned diffusers with the addition of rotational losses dependent on the turning angle. The expansion and frictional losses used were those for a vaned diffuser:

$$K_{VANED\ DIFFUSER} = \left\{0.3 + [0.006(2\theta - 21.5°)u(2\theta - 21.5°)]\right\} \left(\frac{AR - 1}{AR}\right)^2$$

The rotational loss is as for a constant-area corner where

$$K_{ROTATION} = \frac{2}{3} K_{TV} = \frac{2}{3} K_{TV_{90}} \left[\frac{f(\phi)}{0.15}\right]$$

The diffusing corner loss function is then

$$K = \left\{0.3 + [0.006(2\theta - 21.5°)u(2\theta - 21.5°)]\right\} \left(\frac{AR - 1}{AR}\right)^2 + \frac{2}{3} K_{TV}$$

where $u(2\theta - 21.5°)$ is the unit step function.

Diffusers- The diffuser losses are due to both friction and expansion. The friction term may be derived theoretically from

$$K_{FRICTION} = \left.\frac{\Delta p_T}{q}\right|_{FRICTION} = \int_o^{s_2} \frac{\lambda \rho V^2}{\rho_1 V_1{}^2 D_h}\, ds$$

Making the simplifying assumptions that the density and the friction coefficient are approximately constant and applying conservation of mass,

$$K_{FRICTION} = \lambda A_1{}^2 \int_o^{s_2} \frac{ds}{D_h A^2}$$

which, for a conical diffuser, becomes

$$K_{FRICTION} = \frac{16 A_1{}^2 \lambda}{\pi^2} \int_o^{s_2} \frac{ds}{D^5}$$

and transforming variables from surface to centerline distances,

$$K_{FRICTION} = \frac{16 A_1{}^2 \lambda}{\pi^2 \cos\theta} \int_o^{L} \frac{dx}{(D_1 + 2x \tan\theta)^5}$$

Completing this integration the friction loss becomes

$$K_{FRICTION} = \frac{\lambda}{8 \sin\theta}\left(1 - \frac{1}{AR^2}\right)$$

The influence of the expansion term is given by

$$K = K_{EXPANSION} + K_{FRICTION}$$

Thus, it may be rewritten:

$$K = \frac{K_{EXPANSION} + K_{FRICTION}}{\left(1 - \frac{1}{AR}\right)^2}\left(1 - \frac{1}{AR}\right)^2$$

$$K = \left\{K_{EXP} + \left[\frac{\lambda}{8 \sin\theta}\, \frac{\frac{AR^2 - 1}{AR^2}}{\left(\frac{AR - 1}{AR}\right)^2}\right]\right\}\left(\frac{AR - 1}{AR}\right)^2$$

$$K = \left\{K_{EXP} + \left[\frac{\lambda}{8 \sin\theta}\left(\frac{AR + 1}{AR - 1}\right)\right]\right\}\left(\frac{AR - 1}{AR}\right)^2$$

$$K_{EXP} = \frac{K_{EXPANSION}}{\left(\frac{AR - 1}{AR}\right)^2}$$

$$K_{EXP} = \frac{K - K_{FRICTION}}{\left(\frac{AR - 1}{AR}\right)^2}$$

The expansion loss parameter curves shown in figure 4 were determined using the approximation

$$K_{EXP} = \frac{K - K_{FRICTION(CONICAL)}}{\left(\frac{AR - 1}{AR}\right)^2}$$

$$K_{EXP} = \frac{K - \left[\frac{\lambda}{8 \sin \theta}\left(1 - \frac{1}{AR^2}\right)\right]}{\left(\frac{AR - 1}{AR}\right)^2}$$

and figure 5(a) of reference 9, which shows complete diffuser losses plotted as functions of equivalent cone angle and independent of area ratio for circular, square and rectangular, and two-dimensional diffusers. (This implies an assumption that the expansion part of the losses is dependent only on cross-sectional shape, the extent to which the diffusion takes place in only one direction, and the equivalent cone angle.) Thus, the complete loss for diffusers is given as

$$K = \left\{K_{EXP} + \left[\frac{\lambda}{8 \sin \theta}\left(\frac{AR + 1}{AR - 1}\right)\right]\right\}\left(\frac{AR - 1}{AR}\right)^2$$

using K_{EXP} from figure 4.

Exit- The kinetic energy loss at an exit of a non-return wind tunnel was derived from basic compressibility relationships and with the assumptions that the exit flow static pressure is equal to the atmospheric pressure and that the exit velocity is uniform.

$$\frac{p_T}{p} = \left[1 - \left(\frac{\gamma - 1}{2} M^2\right)\right]^{\frac{\gamma}{\gamma - 1}}$$ (rewritten from ref. 17, p. 53)

Rewriting, the local total pressure is

$$p_T = p\left[1 - \left(\frac{\gamma - 1}{2} M^2\right)\right]^{\frac{\gamma}{\gamma - 1}}$$

Also, since $\Delta p_T = p_T - p_{T_{ATM}} = p_T - p$, the total loss parameter is

$$K = \frac{\Delta p_T}{q} = \frac{p\left\{\left[1 + \left(\frac{\gamma - 1}{2} M^2\right)\right]^{\frac{\gamma}{\gamma - 1}} - 1\right\}}{\frac{1}{2} \gamma p M^2}$$

since

$$q = \frac{1}{2} \rho V^2 = \frac{1}{2} \gamma p M^2 \qquad \text{(ref. 17, p. 55)}$$

Simplifying, the exit loss becomes

$$K = \frac{2}{\gamma M^2}\left\{\left[1 + \left(\frac{\gamma - 1}{2} M^2\right)\right]^{\frac{\gamma}{\gamma - 1}} - 1\right\}$$

Flow straighteners: airfoil members (thick)- Thick flow straightener losses were assumed to be made up of two parts: contraction and subsequent diffusion:

$$K = K_{CONTRACTION} + K_{DIFFUSION}$$

The contraction was estimated as being about 30 percent of the length of the straighteners:

$$K_{CONTRACTION} = \frac{0.32\lambda(0.30L)}{D_h}$$

$$K_{CONTRACTION} = \frac{0.096\lambda L}{D_h}$$

The diffusion portion was based on the aft 70 percent of the length and on the exit and minimum areas for the computation of the area ratio and equivalent cone angle. As for a vaned diffuser,

$$K_{DIFFUSION} = \left\{0.3 + [0.006(2\theta - 21.5°)u(2\theta - 21.5°)]\right\}\left(\frac{AR - 1}{AR}\right)^2$$

Hence the loss for thick flow straighteners becomes

$$K = 0.096 \frac{\lambda L}{D_h} + \left\{0.3 + [0.006(2\theta - 21.5°)u(2\theta - 21.5°)]\right\}\left(\frac{AR - 1}{AR}\right)^2$$

Internal flow obstruction: drag item- The loss due to internal structure may be derived from the relationships governing power losses:

$$P_{INPUT_{DRAG}} = \frac{K_{o_{DRAG}} \rho_o^{\,2} A_o V_o^{\,3}}{2\rho_F}$$

and $P_{DRAG} = DV\varepsilon = (1/2)\rho V^3 S C_D \varepsilon$, where ε is the factor accounting for additional effects on downstream sections. Since $P_{INPUT_{DRAG}} = P_{DRAG}$, the loss becomes

$$K_o = \frac{q}{q_o} \frac{S}{A_o} C_D \varepsilon \frac{\rho_F V}{\rho_o V_o}$$

and therefore

$$K = C_D \frac{S}{A} \varepsilon \frac{\rho_F}{\rho} \frac{\rho V A}{\rho_o V_o A_o}$$

$$K = C_D \frac{S}{A} \varepsilon \frac{\rho_F}{\rho}$$

Since in general the flow density at the fans is unknown at the time a given section loss is calculated, and since for incompressible flow the density ratio is unity, the ratio of the densities at the fan and the local station was assumed as unity for the analysis. (If the user prefers not to make such an assumption, an approximation of the ratio may be made by way of a change in the downstream influence factor ε.) The loss due to a flow obstruction is

$$K = C_D \frac{S}{A} \varepsilon$$

Vaned diffusers- The expansion and friction losses for vaned diffusers were combined into one parameter which is reasonably independent of area ratio and is presented in figure 6. The loss curves shown were approximated by a two-segment, straight-line curve fit so that, for vaned diffusers

$$K = K_v \left(\frac{AR - 1}{AR}\right)^2$$

and

$$K = \left\{0.3 + [0.006(2\theta - 21.5^\circ)u(2\theta - 21.5^\circ)]\right\}\left(\frac{AR - 1}{AR}\right)^2$$

where $u(2\theta - 21.5^\circ)$ is the unit step function.

Loss value transferred to reference location- The change of reference for loss values is defined as

$$K_o = \frac{\Delta p_T}{q}\left(\frac{q}{q_o}\right) = K\left(\frac{q}{q_o}\right)$$

Using the law of conservation of mass, this may be rewritten in terms of areas and Mach numbers:

$$\rho VA = \rho_o V_o A_o$$

$$\frac{q}{q_o} = \frac{\frac{1}{2}\rho V^2}{\frac{1}{2}\rho_o V_o^2} = \frac{A_o V}{AV_o}$$

$$\frac{q}{q_o} = \frac{A_o}{A}\frac{M}{M_o}\sqrt{\frac{1+\left(\frac{\gamma-1}{2}M_o^2\right)}{1+\left(\frac{\gamma-1}{2}M^2\right)}}$$

and

$$K_o = K\left[\frac{A_o}{A}\frac{M}{M_o}\sqrt{\frac{1+\left(\frac{\gamma-1}{2}M_o^2\right)}{1+\left(\frac{\gamma-1}{2}M^2\right)}}\right]$$

Wall pressure differential- The pressure across a section of wall was determined from the exterior atmospheric pressure, internal static pressure, and cumulative pressure losses through the circuit. Since the wall pressure differential for a given section is $\Delta p_{W_i} = p_{T_{ATM}} - p_i$ and

$$p_i = \frac{p_{T_i}}{\left[1+\left(\frac{\gamma-1}{2}M_i^2\right)\right]^{\frac{\gamma}{\gamma-1}}}$$

and, using the test section as the reference location,

$$p_{T_i} = p_{T_{SC}} - \sum_{j=1}^{i} K_{o_j}$$

The wall pressure differential may be written as

$$\Delta p_{W_i} = p_{T_{ATM}} - \left\{\frac{p_{T_{SC}} - q_o\sum_{j=1}^{i} K_{o_j}}{\left[1+\left(\frac{\gamma-1}{2}M_i^2\right)\right]^{\frac{\gamma}{\gamma-1}}}\right\}$$

Input power required- The power input to the flow required for operation of a wind tunnel circuit having predetermined losses was calculated from the pressure rise required at the fans, with the simplifying assumption that the static and total pressure rises across the fan are equal.

$$P_{INPUT} = \Delta p_F A_F V_F$$

$$P_{INPUT} = \Delta p_{T_F} A_F V_F \frac{\rho_F \rho_o A_o V_o}{\rho_F \rho_o A_o V_o}$$

Considering conservation of mass,

$$P_{INPUT} = \Delta p_{T_F} A_o V_o \frac{\rho_o}{\rho_F}$$

Also,

$$\Delta p_{T_F} = \Delta p_T = q_o \sum_{i=1}^{N} K_{o_i}$$

Thus,

$$P_{INPUT} = \left(\sum_{i=1}^{N} K_{o_i}\right) \frac{1}{2} \rho_o A_o V_o^3 \frac{\rho_o}{\rho_F}$$

$$P_{INPUT} = \frac{\left(\sum_{i=1}^{N} K_{o_i}\right) \rho_o^2 A_o V_o^3}{2\rho_F}$$

APPENDIX B

NUMERICAL FUNCTION-APPROXIMATIONS

The formulas that follow resulted from curve-fitting and/or interpolation techniques applied to certain functions arising from the loss analysis.

Corners

The corner loss parameters for corners with and without turning vanes are shown in figure 3. For a corner with vanes, using least-squares polynomial curve-fitting techniques, the turning vane loss function of figure 3(a) becomes, for $0° \leq \phi \leq 30°$:

$$K_{TV} = 1.395066\times10^{-2} + 5.672649\times10^{-4}\,\phi + 7.081591\times10^{-5}\,\phi^2 + 1.394685\times10^{-6}\,\phi^3 - 4.885101\times10^{-8}\,\phi^4 \qquad \text{(B1)}$$

and for $30° < \phi \leq 90°$:

$$K_{TV} = -1.605670\times10^{-1} + 1.446753\times10^{-2}\,\phi - 2.570748\times10^{-4}\,\phi^2 + 2.066207\times10^{-6}\,\phi^3 - 6.335764\times10^{-9}\,\phi^4 \qquad \text{(B2)}$$

For a corner without turning vanes the local loss function of figure 3(b) was found using a least-squares polynomial technique and is given by

$$K = 4.313761\times10^{-5} - 6.021515\times10^{-4}\,\phi + 1.693778\times10^{-4}\,\phi^2 - 2.755078\times10^{-6}\,\phi^3 + 2.323170\times10^{-7}\,\phi^4 - 3.775568\times10^{-9}\,\phi^5 + 1.796817\times10^{-11}\,\phi^6 \qquad \text{(B3)}$$

For all the above equations, ϕ is the flow turning angle in degrees.

Diffusers

The determination of the diffuser loss parameter is a complex operation. It depends on the cross-sectional shape and equivalent cone angle of the section. For a conical diffuser the expansion functions are, for $3° \leq 2\theta \leq 10°$:

$$K_{EXP_{Circular}} = 1.70925\times10^{-1} - 5.84932\times10^{-2}\ (2\theta) + 8.14936\times10^{-3}\ (2\theta)^2 + 1.34777\times10^{-4}\ (2\theta)^3 - 5.67258\times10^{-5}\ (2\theta)^4 - 4.15879\times10^{-7}\ (2\theta)^5 + 2.10219\times10^{-7}\ (2\theta)^6 \tag{B4}$$

for $0° < 2\theta < 3°$:

$$K_{EXP_{Circular}} = 1.033395\times10^{-1} - 1.19465\times10^{-2}\ (2\theta) \tag{B5}$$

and for $2\theta > 10°$:

$$K_{EXP_{Circular}} = -9.66135\times10^{-2} + 2.336135\times10^{-2}\ (2\theta) \tag{B6}$$

For a square cross-section diffuser the expressions are, for $3° \leq 2\theta \leq 10°$:

$$K_{EXP_{Square}} = 1.22156\times10^{-1} - 2.29480\times10^{-2}\ (2\theta) + 5.50704\times10^{-3}\ (2\theta)^2 - 4.08644\times10^{-4}\ (2\theta)^3 - 3.84056\times10^{-5}\ (2\theta)^4 + 8.74969\times10^{-6}\ (2\theta)^5 - 3.65217\times10^{-7}\ (2\theta)^6 \tag{B7}$$

for $0° < 2\theta < 3°$:

$$K_{EXP_{Square}} = 9.62274\times10^{-2} - 2.07582\times10^{-3}\ (2\theta) \tag{B8}$$

and for $2\theta > 10°$:

$$K_{EXP_{Square}} = -1.321685\times10^{-1} + 2.93315\times10^{-2}\ (2\theta) \tag{B9}$$

For a two-dimensional diffuser with a square upstream-end cross section the expansion loss functions are, for $3° \leq 2\theta \leq 9°$:

$$K_{EXP_{2D_{Rectangular}}} = 3.23334\times10^{-1} - 5.82939\times10^{-2}\ (2\theta) - 4.97151\times10^{-2}\ (2\theta)^2 + 1.99093\times10^{-2}\ (2\theta)^3 - 1.98630\times10^{-3}\ (2\theta)^4 + 2.06857\times10^{-5}\ (2\theta)^5 + 3.81387\times10^{-6}\ (2\theta)^6 \tag{B10}$$

for $9° \leq 2\theta \leq 10°$:

$$K_{EXP_{2D_{Rectangular}}} = 5.72853 - 1.21832\ (2\theta) + 7.08483\times10^{-2}\ (2\theta)^2 \tag{B11}$$

for $0° < 2\theta < 3°$:

$$K_{EXP_{2D_{Rectangular}}} = 1.0\times10^{-1} - 5.333333\times10^{-3}\ (2\theta) \qquad \text{(B12)}$$

and for $2\theta > 10°$:

$$K_{EXP_{2D_{Rectangular}}} = -1.36146 + 1.986460\times10^{-1}\ (2\theta) \qquad \text{(B13)}$$

Since the expansion function for a two-dimensional diffuser with circular sides was not given (and is not defined), it was assumed for computational purposes that this value would be the same fraction of that for a two-dimensional rectangular diffuser as the loss of a conical is of that for a three-dimensional square diffuser:

$$K_{EXP_{2D_{Circular}}} = K_{EXP_{2D_{Rectangular}}} \left(\frac{K_{EXP_{Circular}}}{K_{EXP_{Square}}} \right)$$

For cross-section shapes somewhere between rectangular and circular, such as flat oval (flat ceiling and floor with semi-circular sidewalls), or for diffusers which have one end rectangular and one end either circular or flat oval, a loss value between that for circular and rectangular may be more appropriate; thus,

$$K_{EXP_{2D_{Average}}} = \frac{K_{EXP_{2D_{Rectangular}}} + K_{EXP_{2D_{Circular}}}}{2}$$

and

$$K_{EXP_{3D_{Average}}} = \frac{K_{EXP_{Square}} + K_{EXP_{Circular}}}{2}$$

The extent to which a diffuser is planar in nature was computed from the ratio of the changes in size of the two characteristic dimensions from end to end:

$$\delta_s = \text{smaller of } \frac{h_2 - h_1}{w_2 - w_1} \text{ or } \frac{w_2 - w_1}{h_2 - h_1}$$

or if the ratio is negative,

$$\delta_s \equiv 0$$

Then, based on the geometries of each end, the basic loss constant, $K_{EXP_{Basic}}$, may be selected from $K_{EXP_{Circular}}$, $K_{EXP_{3D_{Average}}}$ or $K_{EXP_{Square}}$ and the additional loss fact. $K_{EXP_{Additional}}$, may be selected from the corresponding

$K_{EXP_{2D_{Circular}}}$, $K_{EXP_{2D_{Average}}}$ or $K_{EXP_{2D_{Rectangular}}}$. Finally, the applicable diffuser expansion loss coefficient is given by

$$K_{EXP} = K_{EXP_{Basic}} + (1 - \delta_s)\left(K_{EXP_{Additional}} - K_{EXP_{Basic}}\right) \tag{B14}$$

Mesh Screen

The mesh screen Reynolds number sensitivity factor plotted in figure 5 can be expressed in functional form as, for $0 \leq RN < 400$:

$$K_{RN} = \frac{78.5\left(1 - \frac{RN}{354}\right)}{100} + 1.01 \tag{B15}$$

and for $RN \geq 400$:

$$K_{RN} \equiv 1.0$$

Vaned Diffusers

The vaned diffuser loss coefficient functions plotted in figure 6 were approximated by two line segments; for $2\theta < 21.5°$:

$$K_v = 0.3$$

and for $21.5° \leq 2\theta \leq 90°$:

$$K_v = 0.3 + [0.006(2\theta - 21.5°)]$$

Thus, over the entire range of equivalent cone angles of interest,

$$K_v = 0.3 + [0.006(2\theta - 21.5°)u(2\theta - 21.5°)] \tag{B16}$$

where $u(2\theta - 21.5°)$ is the unit step function.

APPENDIX C

COMPUTER PROGRAM FØRTRAN CODES

The following pages contain the FØRTRAN codes developed to implement the wind tunnel performance analysis techniques presented in this report.

The Notation section explains the variable names used in the program. (Note that in the notation sections, as throughout this report, all letter O's occurring in FØRTRAN names are shown with slashes, as Ø; all number zeros are shown unslashed.) This notation section is similar to that for engineering symbols presented in the main body of the report, but this section was changed in two respects. First, it was rearranged alphabetically by FØRTRAN variable name. Second, it was expanded to include many variable names which were not used elsewhere and which have significance only in the context of the computer program. The "titles" shown in parentheses in the first column of this notation section are column heading titles which appear on the program output pages.

Immediately following the Notation are the listings of the six actual FØRTRAN program codes: the main program (PERFØRM) and the five subroutines (DATACK, SPEED, FRICTN, ØUTPUT, AND PLØTIT). Each program routine page is titled and numbered for clarity. The last seven columns of each line on each page contain a two-letter program routine name abbreviation and a line sequence number (in ten-count increments). Thus, the user can know at a glance to which routine (and where within that routine) any given line or instruction belongs. Each instruction line in the program is uniquely identified.

NOTATION (FØRTRAN)

FØRTRAN name and/or (title)	Engineering symbol	Description
A	A	cross-sectional area of local section, m^2 (ft^2)
AI1		cross-sectional area of individual duct at upstream end, m^2 (ft^2)
AI2		cross-sectional area of individual duct at downstream end, m^2 (ft^2)
AL	A_{FLOW}	cross-sectional area of local flow, m^2 (ft^2)
AMACH	M	local Mach number
AMACH1 (MACH1)		Mach number at section upstream end
AMACH2 (MACH2)		Mach number at section downstream end
AR (AR,CR)	AR	ratio of cross-sectional areas at upstream and downstream ends of section
ASL		speed of sound in moving flow at local section, m/sec (ft/sec)
ASTAR	A_*	cross-sectional area for sonic flow at specified flow conditions, m^2 (ft^2)
ASO	a_o	speed of sound in moving flow at upstream end of test section, m/sec (ft/sec)
AT	a_T	speed of sound in still gas, computed at total (stagnation) conditions, m/sec (ft/sec)
AVGPWR		average power consumed by each drive fan at specified conditions: PWRØP/ENFAN, W (hp)
AO	A_o	cross-sectional flow area of test section at upstream end, m^2 (ft^2)
A1 (AREA1)	A_1	cross-sectional flow area of section at upstream end, m^2 (ft^2)

FØRTRAN name and/or (title)	Engineering symbol	Description
A1ØA0 (A1/A0)		ratio of local section upstream area to test section area, m^2 (ft^2)
A2 (AREA2)	A_2	cross-sectional flow area of section at downstream end, m^2 (ft^2)
A2ØA0 (A2/A0)		ratio of local section downstream area to test section area, m^2 (ft^2)
BLKAGE		blockage to flow in local section (at upstream end for all applicable sections except fan contraction, for which it is at downstream end), fraction of local area
(BLKGE)		blockage to flow in local section (at upstream end for all applicable sections except fan contraction, for which it is at downstream end), percent of local area
CD	C_D	drag coefficient of flow obstruction, $\frac{\text{drag}}{qS}$
CHØRD	c_v	chord of turning vanes, m (ft)
D	D	diameter of circular duct, m (ft)
DATA		data array of master, section, and termination card floating-point inputs
DELP	Δp_{W_i}	local pressure difference across wind tunnel wall, N/m^2 (lb/ft^2)
(D EPS)	$\Delta\varepsilon$	increment of flow-obstruction downstream influence factor greater than unity: $\varepsilon - 1$, (greater than or equal to zero)
DFAN		drive fan diameter, m (ft)
DH	D_h	hydraulic diameter: $\frac{4 \times (\text{cross-sectional area})}{\text{perimeter}}$, m (ft)
DHL		hydraulic diameter of single cell in flow straightener, m (ft)

FØRTRAN name and/or (title)	Engineering symbol	Description
DHUB		diameter of drive fan hub and/or spinner, m (ft)
DHO		hydraulic diameter of test section, m (ft)
DH1		hydraulic diameter of upstream end of local section, m (ft)
DH2		hydraulic diameter of downstream end of local section, m (ft)
DMESH		diameter of mesh element in woven-mesh screen, m (ft)
D1		diameter of upstream end of circular section, m (ft)
D2		diameter of downstream end of circular section, m (ft)
EK (DP/QL)	K	local total pressure loss of section: $\frac{\Delta p_T}{q}$
EKADD	$K_{EXP_{Additional}}$	additional diffuser expansion loss factor due to more diffusion in one plane than in another (i.e., partially two-dimensional diffusion)
EKBASE	$K_{EXP_{Basic}}$	basic diffuser expansion loss factor for purely three-dimensional diffusion
EKC	$K_{EXP_{Circular}}$	expansion loss value for conical diffusers
EKCNTR	$K_{CONTRACTION}$	local total pressure loss from contracting portion of thick-airfoil flow straighteners
EKCSAV	$K_{EXP_{3D_{Average}}}$	estimated expansion loss coefficient for three-dimensional, combination circular and square cross-section diffuser
EKD	$K_{DIFFUSION}$	local total pressure loss from diffusing portion of multi-loss-type sections
EKEXP (KEXP)		net expansion loss coefficient for diffusers

FØRTRAN name and/or (title)	Engineering symbols	Description
EKMESH (KMESH)	K_{MESH}	mesh screen-type loss constant
EKS	$K_{EXP_{Square}}$	expansion loss value for three-dimensional expansion in square cross-section diffusers
EKSTRT		local total pressure loss coefficient due to strut drag in fan section
EKTE		local total pressure loss parameter for corners without turning vanes
EKTE90 (KT 90)		vaneless-corner loss parameter for given corner at a 90° turn
EKTV	K_{TV}	turning vane loss coefficient
EKTV90 (KT 90)	$K_{TV_{90}}$	turning vane loss parameter for given vanes at a 90° turn
EKV	K_v	local total pressure loss coefficient for vaned diffusers
EKO (DP/QO)	K_o	section total pressure loss referred to test section conditions: $\frac{\Delta p_T}{q_o}$
EK1		local total pressure loss coefficient due to diffusion and vanes in a diffusing corner
EK2		local total pressure loss coefficient due to rotational flow in a diffusiing corner
EK2DC	$K_{EXP_{2D_{Circular}}}$	estimated expansion loss coefficient for hypothetical, two-dimensional diffusion with circular sides: $K_{EXP_{2D_{Rectangular}}} \left(\frac{K_{EXP_{Circular}}}{K_{EXP_{Square}}}\right)$
EK2DCS	$K_{EXP_{2D_{Average}}}$	estimated expansion loss coefficient for two-dimensional diffuser with cross-section shape of some square/circular hybrid

FØRTRAN name and/or (title)	Engineering symbol	Description
EK2DR	$K_{EXP_{2D_{Rectangular}}}$	expansion loss coefficient for two-dimensional rectangular cross-section diffusers
EL (L)	L	centerline length of section, m (ft)
ELC		length of contracting portion of thick-airfoil flow straighteners, m (ft)
ELD		length of diffusing portion of thick-airfoil flow straighteners, m (ft)
ELØDH (L/DH)		length-to-hydraulic-diameter ratio of flow straightener cell
EMDATA		data array containing master-card floating-point inputs
EMF		Mach number at the fan section
EMU	μ	flow viscosity, N sec/m^2 (lb sec/ft^2)
EMUSTD	μ_{std}	standard-day value of viscosity, N sec/m^2 (lb sec/ft^2)
EMUT	μ_T	reference viscosity at a known temperature, computed for a still gas (stagnation conditions), N sec/m^2 (lb sec/ft^2)
EMWRIT		master card output array containing data and/or annotation(s)
EMO	M_o	Mach number at upstream end of test section
ENDATA		data array containing section-card floating-point input
ENDUCT		number of ducts in multiple-duct sections
ENFAN		number of fans in fan drive section
ENITEM		number of drag or blockage items in each local duct
ENU	ν	kinematic viscosity of gas, m^2/sec (ft^2/sec)

FØRTRAN name and/or (title)	Engineering system	Description
ENWRIT		section-card output array containing data and/or annotation(s)
EPS	ε	flow-obstruction downstream influence factor (greater than or equal to unity)
ER	ER	energy ratio: ratio of energy of flow at test section to the output energy of the fans
ETAFAN (ETA)	η_F	fan aerodynamic efficiency, percent
ETWRIT		case termination-card output array containing termination request de-codings
FAC		function defining the area of sections with circular cross sections
FACT		scaling factor for plot size
FAFØ		function defining the area of sections with flat-oval cross sections (flat floor and ceiling, semi-circular walls)
FAR		function defining the area of sections with rectangular cross sections
FDHC		function defining the hydraulic diameter of sections with circular cross sections
FDHFØ		function defining the hydraulic diameter of sections with flat-oval cross sections
FDHR		function defining the hydraulic diameter of sections with rectangular cross sections
FEKC		function defining the diffuser expansion loss for three-dimensional, circular cross-section diffusers
FEKCH		function defining the diffuser expansion loss for three-dimensional, circular cross-section diffusers at high diffusion angles (TH2 > 10°)

FØRTRAN name and/or (title)	Engineering system	Description
FEKCS		function defining the diffuser expansion loss for three-dimensional, circular cross-section diffusers at small diffusion angles (TH2 < 3°)
FEKS		function defining the diffuser expansion loss for three-dimensional, square cross-section diffusers
FEKSH		function defining the diffuser expansion loss for three-dimensional, cross-section diffusers at high diffusion angles (TH2 > 10°)
FEKSS		function defining the diffuser expansion loss for three-dimensional, square cross-section diffusers at small diffusion angles (TH2 < 3°)
FEKO		function defining the change-of-reference station for total pressure losses from local section to test section
FEK2DL		function defining "two-dimensional" (rectangular) diffuser expansion loss for low diffuser angle range (TH2 < 9°)
FEK2DU		function defining "two-dimensional" (rectangular) diffuser expansion loss for high diffuser angle range (TH2 ≥ 9°)
FKTE		function defining corner turning loss parameter EKTE for corners without turning vanes (based on a value of EKTE = 1.80 at PHI = 90°)
FKTV1	$f(\phi)$	function defining turning vane loss parameter EKTV (based on a value of EKTV = 0.15 at PHI = 90°) for lower turning angle range (PHI ≤ 30°)
FKTV2	$f(\phi)$	function defining turning vane loss parameter EKTV (based on a value of EKTV = 0.15 at PHI = 90°) for upper turning angle range (30° < PHI ≤ 90°)
FTH		function converting diffuser equivalent cone angle, TH2, in degrees to half-angle, TH, in radians

FØRTRAN name and/or (title)	Engineering symbol	Description
FTH2		function defining diffuser equivalent cone angle, TH2
G	γ	specific heat ratio of gas
H1	h_1	height at the upstream end of a non-circular section
H2	h_2	height at the downstream end of a non-circular section
IFLAG		parameter indicating the sequence number assigned to the fan section
IPLØT		decision parameter for selecting which (if any) plots are to be plotted
IPRINT		decision parameter for requesting or omitting output of summary characteristics page
ISEC		section type-description code
ISEQ		input section sequence number
ISHAP1		section upstream-end cross-sectional shape code
ISHAP2		section downstream-end cross-sectional shape code
ITITLA		assumed case-title array in the event the title card is omitted
ITITLE		input case-title array
ITUNNL		wind tunnel circuit-type code
ITYPE		code for type of output format required for printing section information
IU		units-of-measure type code
LINEMX		maximum number of output lines per page
LMTSEC		limit for maximum number of sections in any given case

FØRTRAN name and/or (title)	Engineering system	Description
MCHECK		master-card input-requirement checking code array
MDATA		master-card integer input data array
MFØRMT		master-card output format array
MWRITE		master-card output array containing data and/or annotation(s)
N	N	section assigned sequence number for order of occurrence in circuit
NCHECK		section-card input-requirement checking code array
NDATA		section-card integer input data array
NFØRMT		section-card output format array
NN		section type number for printing proper section title
NWRITE		section-card output array containing data and/or annotation(s)
P		input tunnel total (stagnation) pressure, standard atmospheres
PA		input atmospheric (barometric) pressure, standard atmospheres
PATM (P ATM)	$p_{T_{ATM}}$	atmospheric (barometric) pressure, N/m^2 (lb/ft^2)
PHI	ϕ	corner flow turning angle, deg
PI	π	ratio of the area of a circle to the square of its radius
PRSTY		porosity of certain non-solid flow obstructions: AL/A
PT	p_T	tunnel total (stagnation) pressure, N/m^2 (lb/ft^2)
PWRI		decision parameter for requesting or omitting the matching of power consumption with given input value

FØRTRAN name and/or (title)	Engineering system	Description
PWRIP		power required to be input to flow in order to drive wind tunnel at specified speed, W (hp)
PWRMCH		total power value for which the maximum test section velocity is to be determined (if requested), W (hp)
PWRØP	$P_{REQUIRED}$	total fan motor output power required to drive wind tunnel at specified speed, W (hp)
QO	q_o	test section upstream-end dynamic pressure: $\frac{\rho_o V_o^2}{2}$, N/m^2 (lb/ft^2)
R	R	gas constant, m^2/sec^2 °K (ft^2/sec^2 °R)
RHØS	ρ	local static density, N sec^2/m^4 (lb sec^2/ft^4)
RHØSF	ρ_F	static density at the fans, N sec^2/m^4 (lb sec^2/ft^4)
RHØSO	ρ_o	static density at upstream end of test section, N sec^2/m^4 (lb sec^2/ft^4)
RHØT	ρ_T	density computed for total (stagnation) conditions, N sec^2/m^4 (lb sec^2/ft^4)
RN	RN	Reynolds number: $\frac{\rho V \ell}{\mu}$
RNREF	RN_{REF}	reference Reynolds number at which turning vane 90°-loss constant, EKTV90, was determined
RNV		Reynolds number for turning vanes based on vane chord: $\frac{\rho V c_v}{\mu}$
RUFNES	Δ	surface roughness in honeycomb cells, m (ft)
(RUFNES)		surface roughness in honeycomb cells, 10^{-6} m (10^{-6} ft)
SEKO		section total pressure loss array (referenced to test section conditions) used in summary calculations

FØRTRAN name and/or (title)	Engineering symbol	Description
SEL		section centerline length array used in summary calculations, m (ft)
SERRØR		section input error occurrence code
SLAMDA		friction coefficient for smooth pipes
SLMDAE		calculated friction coefficient in test section at the requested power-matching condition
SLMDA1		friction coefficient at section upstream end
SLMDA2		friction coefficient at section downstream end
SLR	δ_s	diffuser side length ratio: ratio of change in height to change in width from upstream to downstream end, or its inverse, whichever is less than or equal to unity
SMACH		section downstream-end Mach number array used in summary calculations
SØA (S/AL)		ratio of flow-obstruction drag area to local flow area
SSUMEL		summation array of total centerline length from start of circuit to end of local section
SSUMKO		summation array of total pressure losses from start of circuit to end of local section
SUMEKO	$\sum_{i=1}^{N} K_{o_i}$	summation of all section total pressure losses referenced to test section conditions
SUMEL	$\sum_{i=1}^{N} L_i$	summation of all section centerline lengths (total circuit flow length), m (ft)
T		tunnel total (stagnation) temperature, °C (°F)
TH	θ	diffuser half-angle, rad

FØRTRAN name and/or (title)	Engineering symbol	Description
TH2 (2 THETA)	2θ	diffuser equivalent cone angle, deg
TLIST		case-fatal error occurrence code
TLISTI		decision parameter for requesting or omitting tabulation of input data
TRETRN		decision parameter for requesting return for additional case or final termination
TSBLKG		test section blockage used for computation of basic test section conditions, percent of test section cross-sectional area
TT	T_T	tunnel total (stagnation) temperature, °K (°R)
V	V	local flow velocity, m/sec (ft/sec)
VOC		calculated test section velocity at adjusted power level, m/sec (ft/sec)
VOK		test section flow velocity at input conditions, knots
V1		section upstream-end flow velocity, m/sec (ft/sec)
V2		section downstream-end flow velocity, m/sec (ft/sec)
W1	w_1	width of upstream end of non-circular section, m (ft)
W2	w_2	width of downstream end of non-circular section, m (ft)

```
C     MAIN PROGRAM PERFORM                                 (SEE NASA TN D-8243)
C***********************************************************************
C***********************************************************************
C  THIS PROGRAM CALCULATES THE PERFORMANCE EFFICIENCY LEVEL (ENERGY
C  RATIO), POWER REQUIREMENTS, AND VELOCITY CAPABILITIES OF WIND TUNNEL
C  CIRCUITS OF A VARIABLE NUMBER OF INDIVIDUAL COMPONENT SECTIONS AND
C  WITH ANY OF 36 DIFFERENT TYPES OF COMPONENTS FOR SELECTED INPUTS OF
C  SECTION GEOMETRIES AND TEST SECTION FLOW CONDITIONS.
C  THIS MAIN PROGRAM CALLS THE FOLLOWING PERFORMANCE-RELATED, VERY
C  SPECIALIZED SUBROUTINES -- DATACK, SPEED, FRICTN, OUTPUT, AND PLOTIT.
C  A FURTHER EXPLANATION OF THE DETAILS, PURPOSES, APPROACH, AND
C  RESTRICTIONS OF THIS PROGRAM ARE PRESENTED, ALONG WITH AN OPERATING
C  MANUAL, IN THE NASA TECHNICAL NOTE TN D-8243, ENTITLED 'AERODYNAMIC
C  DESIGN GUIDELINES AND COMPUTER PROGRAM FOR ESTIMATION OF SUBSONIC
C  WIND TUNNEL PERFORMANCE,' BY WILLIAM T. ECKERT, KENNETH W. MORT, AND
C  JEAN JOPE, PUBLISHED IN 1976.
C***********************************************************************
C***********************************************************************
      COMMON/BLOCKA/ISEQ,ISHAP1,ISHAP2,N
      COMMON/BLOCKB/DATA(16),ITITLE(21),IPAGE,IPLOT,IPRINT,ISEC,ITUNNL,
     1  IU,LINECT,LINEMX,PWRT,SERROR,TLIST,TLISTI,TRETRN
      COMMON/BLOCKC/ ASTAR,AT,G
      COMMON/BLOCKD/ RNOC
      COMMON/BLOCKE/ AMACH1,AMACH2,AR,A1,A1OA0,A2,A2OA0,D1,D2,EK,EKO,EL,
     1  H1,H2,TH2,V1,V2,W1,W2
      DIMENSION DELP(32),ITITLA(21),LTITLA(15),LTITLE(9),SEKO(30),
     1  SEL(30),SMACH(30),SSUMEL(32),SSUMKO(32)
C.....
C..            ERROR-DEFAULT OMITTED-CASE-TITLE ARRAY
C..
      DATA ITID,ITITLA/1H*,1H*,3H  E,4HRROR,4H -- ,4HTITL,4HE CA,4HRD O,
     1  4HMITT,4HED. ,4H ***,4H****,4H****,4H****,4H    ,4H    ,4H    ,
     2  4H    ,4H    ,4H    ,4H    ,4H    /
C.....
C..            TUNNEL-TYPE TITLE ARRAY
C..
      DATA LTITLA/4H  SI,4HNGLE,4H  DO,4HUBLE,4H    ,4H NON,4H-RET,
     1  4HURN,,4H CLO,4HSED-,4H   O,4HPEN-,4HTEST,4H-SEC,4HTION/
C..........
C....SECTION GEOMETRY FUNCTIONS
C...
      FAC(D) = ATAN(1.)*D**2
      FAR(H,W) = H*W
      FAFO(H,W) = ATAN(1.)*H**2+H*(W-H)
      FDHC(D,A) = A/D/ATAN(1.)
      FDHR(H,W,A) = 2.*A/(H+W)
      FDHFO(H,W,A) = 2.*A/(W-H+2.*ATAN(1.)*H)
      FTH(TH2) = TH2*ATAN(1.)/90.
      FTH2(A2,A1,EL) = ATAN((SQRT(A2)-SQRT(A1))/(SQRT(4.*ATAN(1.))*EL))*
     1  90./ATAN(1.)
```

```
C..........
C....PRESSURE LOSS REFERENCE-STATION TRANSFER FUNCTION
C...
      FEKO(EK,AO,A,EMO,AMACH,EMOSQ,G) = EK*(AO/A)*(AMACH/EMO)*
     1  SQRT(EMOSQ/(1.+(G-1.)/2.*AMACH**2))
C..........
C....LOSS PARAMETER CURVE-FIT FUNCTIONS
C...
      FEKC(TH2) = .170925-.384932E-1*TH2+.814936E-2*TH2**2
     1  +.134777E-3*TH2**3-.567258E-4*TH2**4-.415879E-6*TH2**5
     2  +.210219E-6*TH2**6
      FEKS(TH2) = .122156-.229480E-1*TH2+.550704E-2*TH2**2
     1  -.408644E-3*TH2**3-.384056E-4*TH2**4+.874969E-5*TH2**5
     2  -.365217E-6*TH2**6
      FEK2DL(TH2) = .323334-.582939E-1*TH2-.497151E-1*TH2**2
     1  +.199093E-1*TH2**3-.198630E-2*TH2**4+.206857E-4*TH2**5
     2  +.381387E-5*TH2**6
      FEK2DU(TH2) = .572853E1-.121832E1*TH2+.708483E-1*TH2**2
      FEKCS(TH2) = .1033395-.119465E-1*TH2
      FEKSS(TH2) = .962274E-1-.207582E-2*TH2
      FEK2DS(TH2) = .1-.5333333E-2*TH2
      FEKCH(TH2) = -.966135E-1+.2336135E-1*TH2
      FEKSH(TH2) = -.1321685+.293315E-1*TH2
      FEK2DH(TH2) = -1.36146+.1986460*TH2
      FKTE(P) = .4313761E-4-.6021515E-3*P+.1693778E-3*P**2-
     1  .2755078E-5*P**3+.2323170E-6*P**4-.3775568E-8*P**5+
     2  .1796817E-10*P**6
      FKTV1(P) = .1395066E-1+.5672649E-3*P+.7081591E-4*P**2+
     1  .1394685E-5*P**3-.4885101E-7*P**4
      FKTV2(P) = -.1605670E0+.1446753E-1*P-.2570748E-3*P**2+
     1  .2066207E-5*P**3-.6335764E-8*P**4
C..........
C....COMPILE-TIME PARAMETER DEFINITIONS
C...
C.....
C..            FIXED PARAMETER DEFINITIONS
C..
      PI = 4.*ATAN(1.)
      PLOTON = 0.0
C.....
C..            OPTIONAL PARAMETER SELECTION
C..
      G = 1.4
      LINEMX = 45
      LMTSEC = 30
C....................
C..THERE IS NO RETURN TO THE PREVIOUS INSTRUCTIONS.
C...
C***********************************************************************
C
```

```
C...................
C..TITLE CARD OPERATIONS
C...
  100 READ(5,7000) ITITLE
      IPAGE = 1
      N = 0
      SUMEKO = 0.0
      SUMEL = 0.0
      TLIST = 0.0
C.....
C..         TITLE CARD VALIDITY CHECK
C..
      IF (ITITLE(1) .EQ. ITID) GO TO 101
      TLIST = -4.
      WRITE(6,9500)
      WRITE(6,9502) ITITLE
C...................
C..WIND TUNNEL MASTER CONTROL DATA CARD OPERATIONS
C...
  101 READ(5,7001) ISEQ,ITUNNL,IU,ISHAP1,ISHAP2,(DATA(I),I=3,10)
C.....
C..         MASTER CARD VALIDITY CHECK
C..
      IF (ISEQ .LT. 0) GO TO 102
      IF (TLIST .GT. -3.5) WRITE(6,9500)
      IF (TLIST .GT. -3.5) TLIST = -3.
      WRITE(6,9503) ISEQ,ITUNNL,IU,ISHAP1,ISHAP2,(DATA(I),I=3,10)
      GO TO 201
C..........
C....MASTER CARD ERROR-CHECK AND BASIC PARAMETER DEFINITION
C...
  102 CALL DATACK(1)
      IPAGE = 1
      N = 0
      SUMEKO = 0.0
      SUMEL = 0.0
      IF (TLIST .LT. -2.5) WRITE(6,9004)
      IF (TLIST .LT. -2.5 .AND. IU .EQ. 1) WRITE(6,9005)
      IF (TLIST .LT. -2.5 .AND. IU .EQ. 2) WRITE(6,9006)
      IF (TLIST .LT. -2.5) GO TO 200
      TLIST = 0.0
      P = DATA(8)
      IF (P .LT. 1.E-6) P = 1.
      T = DATA(9)
      PA = DATA(10)
      IF (PA .LT. 1.E-6) PA = 1.
C..........
C....BASIC DIMENSIONAL FLOW PARAMETERS DEPENDING ON UNITS-OF-MEASURE
C...
      IF (IU .EQ. 2) GO TO 103
```

```
C.....
C...        INTERNATIONAL SYSTEM OF UNITS (SI)
C...
      EMUSTD = 1.7807E-5
      PT = P*101325.
      PATM = PA*101325.
      R = 286.79
      TT = T+273.15
      EMUT = EMUSTD*(TT/288.0)**.76
      PWRMCH = DATA(7)*1.E6
      GO TO 104
C.....
C...        U.S. CUSTOMARY UNITS
C...
  103 EMUSTD = 3.719E-7
      PT = P*2116.217
      PATM = PA*2116.217
      R = 1715.0
      TT = T+459.6
      EMUT = EMUSTD*(TT/518.4)**.76
      PWRMCH = DATA(7)*1.E3
C..........
C....GENERAL-FORM DIMENSIONAL PARAMETERS
C...
  104 AT = SQRT(G*R*TT)
      RHOT = PT/(R*TT)
C..........
C....TEST-SECTION MACH NUMBER NEWTON'S METHOD ITERATION
C...
      V0 = DATA(6)
  105 IF (IU .EQ. 1) V0K = V0*1.9438
      IF (IU .EQ. 2) V0K = V0*.59248
      EM0 = V0/AT
  106 AS0 = AT/SQRT(1.+(G-1.)/2.*EM0**2)
      EM = V0/AS0
      IF (ABS(EM0-EM)/EM0 .LT. 1.E-4) GO TO 107
      EM0 = EM
      GO TO 106
  107 EM0 = EM
C..........
C....MACH-NUMBER-DEPENDENT PARAMETERS
C...
      EM0SQ = 1.+(G-1.)/2.*EM0**2
      RHOS0 = RHOT/EM0SQ**(1./(G-1.))
      Q0 = RHOS0*V0**2/2.
C..........
C....TEST SECTION THROAT SIZE AND THROAT-AREA-DEPENDENT PARAMETERS
C...
      TSBLKG = DATA(5)
      A0 = FAR(DATA(3),DATA(4))*(1.-TSBLKG/100.)
```

```
      IF (ISHAP1 .EQ. 3) A0 = FAFO(DATA(3),DATA(4))*(1.-TSBLKG/100.)
      IF (ISHAP1 .EQ. 1) A0 = FAC(DATA(4))*(1.-TSBLKG/100.)
      DH0 = FDHR(DATA(3),DATA(4),A0)
      IF (ISHAP1 .EQ. 3) DH0 = FDHFO(DATA(3),DATA(4),A0)
      IF (ISHAP2 .EQ. 1) DH0 = FDHC(DATA(4),A0)
      ASTAR = EM0*A0*((G+1.)/2./EM0SQ)**((G+1.)/2./(G-1.))
      RNOC = RHOS0*V0*A0/EMUT
C..........
C....TUNNEL-TYPE NAME ASSIGNMENT
C...
      IF (ITUNNL .GE. 1 .AND. ITUNNL .LE. 6) GO TO 109
      DO 108 I = 1,9
      LTITLE(I) = LTITLA(5)
  108 CONTINUE
      GO TO 112
  109 LTITLE(3) = LTITLA(7)
      LTITLE(4) = LTITLA(8)
      LTITLE(7) = LTITLA(13)
      LTITLE(8) = LTITLA(14)
      LTITLE(9) = LTITLA(15)
      IF (ITUNNL .NE. 1 .AND. ITUNNL .NE. 4) GO TO 110
      LTITLE(1) = LTITLA(1)
      LTITLE(2) = LTITLA(2)
      GO TO 112
  110 IF (ITUNNL .NE. 2 .AND. ITUNNL .NE. 5) GO TO 111
      LTITLE(1) = LTITLA(3)
      LTITLE(2) = LTITLA(4)
      GO TO 112
  111 LTITLE(1) = LTITLA(5)
      LTITLE(2) = LTITLA(6)
  112 IF (ITUNNL .GT. 4) GO TO 113
      LTITLE(5) = LTITLA( 9)
      LTITLE(6) = LTITLA(10)
      GO TO 114
  113 LTITLE(5) = LTITLA(11)
      LTITLE(6) = LTITLA(12)
C..........
C....OUTPUT OF CASE PAGE 1 TITLE, HEADINGS AND DEFINING PARAMETERS
C...
  114 WRITE(6,9000) ITITLE,IPAGE,LTITLE
      IF (IU .EQ. 1) WRITE(6,9002) PA,PATM,P,PT,T,TT,V0,V0K,Q0
      IF (IU .EQ. 2) WRITE(6,9003) PA,PATM,P,PT,T,TT,V0,V0K,Q0
      WRITE(6,9004)
      IF (IU .EQ. 1) WRITE(6,9005)
      IF (IU .EQ. 2) WRITE(6,9006)
      LINECT = 17
C..................
C..RETURN TO THE PREVIOUS PORTION ONLY FOR BEGINNING CALCULATIONS FOR A
C..NEW WIND TUNNEL CIRCUIT
C...
```

```
C*********************************************************************
C
C.....
C..       MAXIMUM NUMBER OF SECTIONS PER CASE LIMIT-CHECK AND MESSAGE
C..
  200 IF (N .LT. LMTSEC) GO TO 201
      IF (LINECT .GE. (LINEMX-7)) IPAGE = IPAGE+1
      IF (LINECT .GE. (LINEMX-7)) WRITE(6,9001) ITITLE,IPAGE
      WRITE(6,9505) LMTSEC
      WRITE(6,9501)
      CALL DATACK(3)
      TLIST = -4.
      N = 0
      IPAGE = IPAGE+1
      WRITE(6,9001) ITITLE,IPAGE
      WRITE(6,9004)
      IF (IU .EQ. 1) WRITE(6,9005)
      IF (IU .EQ. 2) WRITE(6,9006)
      LINECT = 9
C.....................
C..SECTION DATA OPERATIONS
C..
  201 READ(5,7002) ISEQ,ISEC,ISHAP1,ISHAP2,(DATA(I),I=1,16)
      IF (ISEQ .GE. 0) GO TO 204
      TLIST = -2.
      IF (N .NE. 0) GO TO 202
      WRITE(6,9504)
      LINECT = LINECT+5
      GO TO 102
  202 WRITE(6,9506)
      LINECT = LINECT+5
      DO 203 I = 1,21
      ITITLE(I) = ITITLA(I)
  203 CONTINUE
C.....
C..       DEFINITION OF ASSUMED TERMINATION PARAMETERS FOR OMITTED
C..       TERMINATION CARD
C..
      IPRINT = 1
      IPLOT = 0
      TLISTI = 1.
      PWRI = 0.0
      TRETRN = -1.
      GO TO 2002
  204 IF (ISEC .NE. 0 .AND. TLIST .LT. -2.5) GO TO 205
      IF (ISEC .NE. 0 .AND. TLIST .GT. -2.5) GO TO 206
C.....
C..       DEFINITION OF TERMINATION TASK-REQUEST PARAMETERS
C..
      IPRINT = ISHAP2
```

```
      IPLOT = IFIX(ABS(DATA(1)))
      TLISTI = ABS(DATA(2))
      PWRI = ABS(DATA(3))
      TRETRN = ABS(DATA(4))
      GO TO 2002
C.....
C..          CASE-SKIP SECTION CHECK
C..
  205 N = N+1
      CALL DATACK(2)
      GO TO 200
C.....
C..          NORMAL SECTION CHECK
C..
  206 N = N+1
      CALL DATACK(2)
      IF (SERROR .LT. -1.) GO TO 200
      EL = DATA(5)
      SEL(N) = EL
      SUMEL = SUMEL+EL
C..........
C....SECTION UPSTREAM END (INLET OR END 1) GEOMETRY COMPUTATIONS
C...
      BLKAGE = DATA(10)
      IF (ISEC .GE. 60 .AND. DATA(2) .GT. 1.E-6) BLKAGE = BLKAGE*DATA(2)
      IF (ISEC .LE. 6 .AND. ABS(TSBLKG-DATA(10)) .GT. 1.E-6)
     1 WRITE(6,9507) BLKAGE,TSBLKG
      IF (ISEC .LE. 6 .AND. ABS(TSBLKG-DATA(10)) .GT. 1.E-6)
     1 LINECT = LINECT+3
      IF (ISHAP1 .EQ. 2) GO TO 207
      IF (ISHAP1 .EQ. 3) GO TO 208
      D1 = DATA(4)
      A1 = FAC(D1)
      IF (ISEC .EQ. 2 .OR. ISEC .EQ. 4 .OR. ISEC .EQ. 56 .OR.
     1 ISEC .EQ. 96) A1 = A1*(1.-BLKAGE/100.)
      DH1 = FDHC(D1,A1)
      GO TO 209
  207 H1 = DATA(3)
      W1 = DATA(4)
      A1 = FAR(H1,W1)
      IF (ISEC .EQ. 2 .OR. ISEC .EQ. 4 .OR. ISEC .EQ. 56 .OR.
     1 ISEC .EQ. 96) A1 = A1*(1.-BLKAGE/100.)
      DH1 = FDHR(H1,W1,A1)
      GO TO 209
  208 H1 = DATA(3)
      W1 = DATA(4)
      A1 = FAFO(H1,W1)
      IF (ISEC .EQ. 2 .OR. ISEC .EQ. 4 .OR. ISEC .EQ. 56 .OR.
     1 ISEC .EQ. 96) A1 = A1*(1.-BLKAGE/100.)
      DH1 = FDHFO(H1,W1,A1)
```

```
C..........
C....SECTION DOWNSTREAM (EXIT OR END 2) GEOMETRY COMPUTATIONS
C...
  209 IF (ISHAP2 .EQ. 3) GO TO 211
      IF (ISHAP2 .EQ. 2) GO TO 210
      D2 = DATA(7)
      A2 = FAC(D2)
      DH2 = D2
      GO TO 212
  210 H2 = DATA(6)
      W2 = DATA(7)
      A2 = FAR(H2,W2)
      DH2 = FDHR(H2,W2,A2)
      GO TO 212
  211 H2 = DATA(6)
      W2 = DATA(7)
      A2 = FAFO(H2,W2)
      DH2 = FDHFO(H2,W2,A2)
C..........
C....ALTERATIONS TO GEOMETRY DEFINITIONS DUE TO MULTIPLE DUCTING
C...
  212 IF (ISEC .LT. 60 .OR. ISEC .EQ. 85) GO TO 215
      ENDUCT = DATA(1)
      IF (ISEC .GE. 91 .AND. ISEC .LE. 94. .AND. ENDUCT .LT. 1.E-6)
     1 ENDUCT = 1.
      AI1 = A1
      AI2 = A2
      A1 = AI1*ENDUCT
      IF (ISEC .NE. 86) A2 = AI2*ENDUCT
      IF (ISEC .LT. 91 .OR. ISEC .GE. 95) GO TO 215
C.....
C..            FAN SECTION GEOMETRY
C..
      DHUB = DATA(9)
      IF (ISEC .NE. 91) GO TO 213
      DFAN = DATA(4)
      DH1 = DFAN-DHUB
      DH2 = DH1
      A1 = PI*(DFAN**2-DHUB**2)/4.*(1.-BLKAGE/100.)*ENDUCT
      A2 = PI*(D2**2-DHUB**2)/4.*(1.-BLKAGE/100.)*ENDUCT
      GO TO 215
  213 IF (ISEC .NE. 92) GO TO 214
      DFAN = DATA(7)
      DH2 = DFAN-DHUB
      A2 = PI*(DFAN**2-DHUB**2)/4.*ENDUCT*(1.-BLKAGE/100.)
      AI1 = A1/ENDUCT
      AI2 = A2/ENDUCT
      GO TO 215
  214 DFAN = DATA(4)
      DH1 = DFAN-DHUB
```

```
      A1 = PI*(DFAN**2-DHUB**2)/4.*(1.-BLKAGE/100.)*ENDUCT
      AI1 = A1/ENDUCT
C..........
C....SECTION AREA-RATIOS, VELOCITIES AND MACH NUMBERS AT BOTH ENDS
C...
  215 A1OA0 = A1/A0
      A2OA0 = A2/A0
      AR = A2/A1
      IF (AR .LT. 1.) AR = A1/A2
      CALL SPEED(A1,AMACH,V)
      CALL FRICTN(DH1,A1,AMACH,SLAMDA)
      AMACH1 = AMACH
      V1 = V
      SLMDA1 = SLAMDA
      CALL SPEED(A2,AMACH,V)
      CALL FRICTN(DH2,A2,AMACH,SLAMDA)
      AMACH2 = AMACH
      SMACH(N) = AMACH2
      V2 = V
      SLMDA2 = SLAMDA
      IF (ISEC .NE. 3 .AND. ISEC .NE. 4 .AND. ISEC .NE. 40 .AND.
     1 ISEC .NE. 84 .AND. (ISEC .NE. 91 .OR. (A2/A1-1.) .LT. 1.E-6)
     2 .AND. ISEC .NE. 94) GO TO 224
C..........
C....DEFINITION OF DIFFUSER-ONLY PARAMETERS
C...
      TH2 = FTH2(A2,A1,EL)
      IF (ISEC .GE. 60 .AND. ISEC .NE. 85) TH2 = FTH2(AI2,AI1,EL)
      TH = FTH(TH2)
      EKEXP = DATA(12)
      IF (EKEXP .GT. 1.E-6) GO TO 224
C.....
C..         DEFAULT-CAUSED DETERMINATION OF DIFFUSER EXPANSION LOSS
C..         PARAMETER
C..
      EKC = FEKC(TH2)
      IF (TH2 .LT. 3.) EKC = FEKCS(TH2)
      IF (TH2 .GT. 10.) EKC = FEKCH(TH2)
      EKS = FEKS(TH2)
      IF (TH2 .LT. 3.) EKS = FEKSS(TH2)
      IF (TH2 .GT. 10.) EKS = FEKSH(TH2)
      EK2DR = FEK2DL(TH2)
      IF (TH2 .LT. 3.) EK2DR = FEK2DS(TH2)
      IF (TH2 .GE. 9.) EK2DR = FEK2DU(TH2)
      IF (TH2 .GT. 10.) EK2DR = FEK2DH(TH2)
      EKCSAV = (EKC+EKS)/2.
      EK2DC = EK2DR*EKC/EKS
      EK2DCS = (EK2DR+EK2DC)/2.
      IF (ISHAP1 .NE. 1 .OR. ISHAP2 .NE. 1) GO TO 216
C...
```

```
C..             BOTH ENDS CIRCULAR
C..
      SLR = 1.
      EKBASE = EKC
      EKADD = EK2DC
      GO TO 223
  216 IF (ISHAP1 .NE. 1 .OR. ISHAP2 .EQ. 1) GO TO 219
C..
C..             UPSTREAM END ONLY CIRCULAR
C..
      IF ((H2-D1) .GT. 0.0 .AND. (W2-D1) .GT. 0.0) GO TO 217
      SLR = 0.0
      GO TO 218
  217 SLR = (H2-D1)/(W2-D1)
      IF (SLR .GT. 1.) SLR = 1./SLR
  218 IF (ISHAP2 .EQ. 2) EKBASE = EKCSAV
      IF (ISHAP2 .EQ. 2) EKADD = EK2DCS
      IF (ISHAP2 .EQ. 3) EKBASE = EKC
      IF (ISHAP2 .EQ. 3) EKADD = EK2DC
      GO TO 223
  219 IF (ISHAP2 .NE. 1) GO TO 220
C..
C..             DOWNSTREAM ONLY CIRCULAR
C..
      SLR = 1.
      IF (ISHAP1 .EQ. 2) EKBASE = EKCSAV
      IF (ISHAP1 .EQ. 2) EKADD = EK2DCS
      IF (ISHAP1 .EQ. 3) EKBASE = EKC
      IF (ISHAP1 .EQ. 3) EKADD = EK2DC
      GO TO 223
C..
C..             BOTH ENDS NON-CIRCULAR
C..
  220 IF ((H2-H1) .EQ. (W2-W1)) SLR = 1.
      IF ((H2-H1) .EQ. (W2-W1)) GO TO 222
      IF ((H2-H1) .GT. 0.0 .AND. (W2-W1) .GT. 0.0) GO TO 221
      SLR = 0.0
      GO TO 222
  221 SLR = (H2-H1)/(W2-W1)
      IF (SLR .GT. 1.) SLR = 1./SLR
  222 EKBASE = EKCSAV
      EKADD = EK2DCS
      IF (ISHAP1 .EQ. 2 .AND. ISHAP2 .EQ. 2) EKBASE = EKS
      IF (ISHAP1 .EQ. 2 .AND. ISHAP2 .EQ. 2) EKADD = EK2DR
      IF (ISHAP1 .EQ. 3 .AND. ISHAP2 .EQ. 3) EKBASE = EKC
      IF (ISHAP1 .EQ. 3 .AND. ISHAP2 .EQ. 3) EKADD = EK2DC
  223 EKEXP = EKBASE+(1.-SLR)*(EKADD-EKBASE)
C.....
C..          PAGING-CHECK BEFORE SECTION INFORMATION OUTPUT
C..
```

```
  224 IF (LINECT .LT. (LINEMX-2)) GO TO 225
      IPAGE = IPAGE+1
      WRITE(6,9001) ITITLE,IPAGE
      WRITE(6,9004)
      IF (IU .EQ. 1) WRITE(6,9005)
      IF (IU .EQ. 2) WRITE(6,9006)
      LINECT = 9
C..........
C....SECTION-TYPE BRANCHING
C...
  225 IF (ISEC .EQ.  1) GO TO 1010
      IF (ISEC .EQ.  2) GO TO 1010
      IF (ISEC .EQ.  3) GO TO 1030
      IF (ISEC .EQ.  4) GO TO 1030
      IF (ISEC .EQ.  5) GO TO 1050
      IF (ISEC .EQ.  6) GO TO 1050
      IF (ISEC .EQ. 10) GO TO 1100
      IF (ISEC .EQ. 20) GO TO 1200
      IF (ISEC .EQ. 30) GO TO 1300
      IF (ISEC .EQ. 32) GO TO 1300
      IF (ISEC .EQ. 33) GO TO 1330
      IF (ISEC .EQ. 34) GO TO 1340
      IF (ISEC .EQ. 40) GO TO 1400
      IF (ISEC .EQ. 45) GO TO 1450
      IF (ISEC .EQ. 46) GO TO 1460
      IF (ISEC .EQ. 51) GO TO 1510
      IF (ISEC .EQ. 52) GO TO 1520
      IF (ISEC .EQ. 53) GO TO 1530
      IF (ISEC .EQ. 54) GO TO 1540
      IF (ISEC .EQ. 56) GO TO 1560
      IF (ISEC .EQ. 57) GO TO 1570
      IF (ISEC .EQ. 61) GO TO 1610
      IF (ISEC .EQ. 62) GO TO 1620
      IF (ISEC .EQ. 70) GO TO 1700
      IF (ISEC .EQ. 71) GO TO 1700
      IF (ISEC .EQ. 72) GO TO 1700
      IF (ISEC .EQ. 73) GO TO 1730
      IF (ISEC .EQ. 74) GO TO 1740
      IF (ISEC .EQ. 75) GO TO 1740
      IF (ISEC .EQ. 84) GO TO 1840
      IF (ISEC .EQ. 85) GO TO 1850
      IF (ISEC .EQ. 86) GO TO 1860
      IF (ISEC .EQ. 87) GO TO 1860
      IF (ISEC .EQ. 91) GO TO 1910
      IF (ISEC .EQ. 92) GO TO 1920
      IF (ISEC .EQ. 94) GO TO 1940
      IF (ISEC .EQ. 96) GO TO 1960
      IF (ISEC .EQ. 97) GO TO 1970
C..........
C....SINGLE-DUCT SECTIONS TOTAL-PRESSURE LOSSES
```

```
C...
C.....
C..         TEST SECTIONS
C..
C..
C..              CLOSED, CONSTANT-AREA TEST SECTION
C..
 1010 EK = SLMDA1*EL/DH1
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      SEKO(N) = EKO
      SUMEKO = SUMEKO+EKO
      CALL OUTPUT(1,1)
      LINECT = LINECT+3
      IF (ISEC .EQ. 1) GO TO 200
C..
C..              MODEL IN THE TEST SECTION
C..
 1020 SOA = DATA(8)
      CD = DATA(13)
      EPS = 1.+DATA(16)/100.
      EK = CD*SOA*EPS
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      SEKO(N) = SEKO(N)+EKO
      SUMEKO = SUMEKO+EKO
      CALL OUTPUT(2,3)
      LINECT = LINECT+3
      GO TO 200
C..
C..              CLOSED, DIFFUSING TEST SECTION
C..
 1030 EK = (EKEXP+SLMDA1/(8.*SIN(TH))*(AR+1.)/(AR-1.))*((AR-1.)/AR)**2
      IF (EK .LT. (SLMDA1*EL/DH1)) EK = SLMDA1*EL/DH1
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      SEKO(N) = EKO
      SUMEKO = SUMEKO+EKO
      CALL OUTPUT(3,2)
      LINECT = LINECT+3
      IF (ISEC .EQ. 3) GO TO 200
      GO TO 1020
C..
C..              OPEN-THROAT TEST SECTION
C..
 1050 EK = .0845*EL/DH1-.0053*(EL/DH1)**2
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      SEKO(N) = EKO
      SUMEKO = SUMEKO+EKO
      TH2 = FTH2(A2,A1,EL)
      CALL OUTPUT(3,4)
      LINECT = LINECT+3
      IF (ISEC .EQ. 5) GO TO 200
```

```
      GO TO 1020
C.....
C..          STRAIGHT, NON-DIFFUSING DUCTS
C..
C..
C..             CONSTANT-AREA DUCT
C..
 1100 NN = 5
      EK = SLMDA1*EL/DH1
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 1
      GO TO 2000
C..
C..             CONTRACTION
C..
 1200 NN = 6
      TH2 = FTH2(A1,A2,EL)
      EK = .32*SLMDA2*EL/DH2
      EK0 = FEK0(EK,A0,A2,EM0,AMACH2,EM0SQ,G)
      ITYPE = 4
      GO TO 2000
C.....
C..          CORNERS AND TURNS
C..
C..
C..             CONSTANT-AREA CORNER -- TURNING VANES ONLY
C..
 1300 NN = 7
      CHORD = DATA(9)
      PHI = ABS(DATA(11))
      EKTV90 = DATA(12)
      RNREF = DATA(14)*10.**6
      IF (DATA(14) .LT. 1.E-6) RNREF = .5*10.**6
      IF (EKTV90 .LT. 1.E-6) EKTV90 = .15
      IF (PHI .LE. 30.) EKTV = FKTV1(PHI)*EKTV90/.15
      IF (PHI .GT. 30.) EKTV = FKTV2(PHI)*EKTV90/.15
      RNV = RNOC*CHORD/A1*(1.+(G-1.)/2.*AMACH1**2)**.76
      EK = EKTV*(2.+(ALOG10(RNREF)/ALOG10(RNV))**2.58)/3.
      IF (ISEC .EQ. 30) GO TO 1301
C..
C..             CONSTANT-AREA CORNER WITH TURNING VANES AND WALLS
C..
      NN = 8
      EK = EK+SLMDA1*EL/DH1
 1301 EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 1
      GO TO 2000
C..
C..             CONSTANT-AREA CORNER WITH WALLS AND WITHOUT TURNING VANES
C..
```

```
 1330 NN = 9
      PHI = ABS(DATA(11))
      EKTE90 = DATA(12)
      IF (EKTE90 .LT. 1.E-6) EKTE90 = 1.80
      EKTE = FKTE(PHI)*EKTE90/1.80
      EK = EKTE+SLMDA1*EL/DH1
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 1
      GO TO 2000
C..
C..             DIFFUSING CORNER WITH TURNING VANES AND WALLS
C..
 1340 NN = 10
      CHORD = DATA(9)
      PHI = ABS(DATA(11))
      EKTV90 = DATA(12)
      RNREF = DATA(14)*10.**6
      IF (EKTV90 .LT. 1.E-6) EKTV90 = .15
      IF (DATA(14) .LT. 1.E-6) RNREF = .5*10.**6
      IF (PHI .LE. 30.) EKTV = FKTV1(PHI)*EKTV90/.15
      IF (PHI .GT. 30.) EKTV = FKTV2(PHI)*EKTV90/.15
      TH2 = FTH2(A2,A1,EL)
      RNV = RNOC*CHORD/A1*(1.+(G-1.)/2.*AMACH1**2)**.76
      EKV = .3
      IF (TH2 .GE. 21.5) EKV = EKV+.006*(TH2-21.5)
      EK1 = EKV*((AR-1.)/AR)**2
      EK2 = EKTV*2./3.
      CALL FRICTN(CHORD,A1,AMACH1,SLAMDA)
      EK = EK1+EK2
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 3
      GO TO 2000
C.....
C..          DIFFUSION
C..
C..
C..             DIFFUSER
C..
 1400 NN = 11
      EK = (EKEXP+SLMDA1/(8.*SIN(TH))*(AR+1.)/(AR-1.))*((AR-1.)/AR)**2
      IF (EK .LT. (SLMDA1*EL/DH1)) EK = SLMDA1*EL/DH1
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 3
      GO TO 2000
C..
C..             EXIT KINETIC ENERGY FROM FLOW DUMP
C..
 1450 NN = 12
      EK = 2.*((1.+(G-1.)/2.*AMACH1**2)**(G/(G-1.))-1.)/(G*AMACH1**2)
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
```

```
      ITYPE = 2
      GO TO 2000
C..
C..            SUDDEN EXPANSION
C..
 1460 NN = 13
      TH2 = 90.
      EK = ((AR-1.)/AR)**2
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 3
      GO TO 2000
C.....
C..         FLOW OBSTRUCTIONS
C..
C..
C..            HONEYCOMB THIN FLOW STRAIGHTENERS
C..
 1510 NN = 14
      ELODH = DATA(8)
      PRSTY = DATA(10)
      RUFNES = DATA(14)*10.**(-6)
      IF (DATA(14) .LT. 1.E-6 .AND. IU .EQ. 1) RUFNES = .00001
      IF (DATA(14) .LT. 1.E-6 .AND. IU .EQ. 2) RUFNES = .000032808
      DHL = EL/ELODH
      AL = PRSTY*A1/100.
      CALL SPEED(AL,AMACH,V)
      RHOS = RHOT/(1.+(G-1.)/2.*AMACH**2)**(1./(G-1.))
      EMU = EMUT/(1.+(G-1.)/2.*AMACH**2)**.76
      ENU = EMU/RHOS
      RN = V*RUFNES/DHL/ENU
      SLAMDA = .375*(RUFNES/DHL)**.4/RN**.1
      IF (RN .GT. 275.) SLAMDA = .214*(RUFNES/DHL)**.4
      EK = SLAMDA*(ELODH+3.)*(100./PRSTY)**2+(100./PRSTY-1.)**2
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 1
      GO TO 2000
C..
C..            AIRFOIL THICK FLOW STRAIGHTENERS
C..
 1520 NN = 15
      ELODH = DATA(8)
      PRSTY = DATA(10)
      IF (ELODH .LE. 0.0) ELODH = 2.
      ELC = .3*EL
      ELD = EL-ELC
      AL = PRSTY/100.*A1
      AR = A2/AL
      DHL = EL/ELODH
      CALL SPEED(AL,AMACH,V)
      CALL FRICTN(DHL,AL,AMACH,SLAMDA)
```

```
      EKCNTR = .32*ELC/DHL*SLAMDA
      TH2 = FTH2(A2,AL,ELD)
      EKV = .3
      IF (TH2 .GE. 21.5) EKV = EKV+.006*(TH2-21.5)
      EKD = EKV*((AR-1.)/AR)**2
      EK = EKCNTR+EKD
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 3
      GO TO 2000
C...
C...               PERFORATED PLATE WITH SHARP-EDGED ORIFICES
C...
 1530 NN = 16
      PRSTY = DATA(10)
      EK = ((SQRT(.5-PRSTY/200.)+1.-PRSTY/100.)*100./PRSTY)**2
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 2
      GO TO 2000
C...
C...               WOVEN MESH SCREEN
C...
 1540 NN = 17
      DMESH = DATA(9)
      PRSTY = DATA(10)
      EKMESH = DATA(12)
      IF (EKMESH .LT. 1.E-6) EKMESH = 1.3
      RHOS = RHOT/(1.+(G-1.)/2.*AMACH1**2)**(1./(G-1.))
      EMU = EMUT/(1.+(G-1.)/2.*AMACH1**2)**.76
      ENU = EMU/RHOS
      RN = V1*DMESH/ENU
      EK = EKMESH*(1.-PRSTY/100.)+(100./PRSTY-1.)**2
      IF (RN .LT. 400. .AND.
     1  EK .LT. (EK*(78.5**(1.-RN/354.)/100.+1.01)))
     1  EK = EK*(78.5**(1.-RN/354.)/100.+1.01)
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 2
      GO TO 2000
C...
C...               INTERNAL STRUCTURE (DRAG ITEM(S)) AT UPSTREAM END OF A
C...               SECTION
C...
 1560 NN = 18
      ENITEM = DATA(2)
      SOA = DATA(8)
      CD = DATA(13)
      EPS = 1.+DATA(16)/100.
      IF (ABS(ENITEM) .LT. 1.E-6) ENITEM = 1.
      EK = CD*SOA*EPS*ENITEM
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 2
```

```
      GO TO 2000
C..
C..            FIXED, KNOWN-LOCAL-LOSS ITEM AT THE UPSTREAM END OF A
C..            SECTION
C..
 1570 NN = 19
      EK = DATA(13)
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 2
      GO TO 2000
C.........
C....MULTIPLE-DUCT SECTIONS TOTAL-PRESSURE LOSSES
C...
C.....
C..          STRAIGHT, NON-DIFFUSING DUCTS
C..
C..
C..            CONSTANT-AREA DUCTS
C..
 1610 NN = 20
      EK = SLMDA1*EL/DH1
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 1
      GO TO 2000
C..
C..            CONTRACTIONS
C..
 1620 NN = 21
      TH2 = FTH2(AI1,AI2,EL)
      EK = .32*SLMDA1*EL/DH2
      EK0 = FEK0(EK,A0,A2,EM0,AMACH2,EM0SQ,G)
      ITYPE = 4
      GO TO 2000
C.....
C..          CORNERS AND TURNS
C..
C..
C..            CONSTANT-AREA CORNERS -- TURNING VANES ONLY
C..
 1700 NN = 22
      CHORD = DATA(9)
      PHI = ABS(DATA(11))
      EKTV90 = DATA(12)
      RNREF = DATA(14)*10.**6
      IF (EKTV90 .LT. 1.E-6) EKTV90 = .15
      IF (DATA(14) .LT. 1.E-6) RNREF = .5*10.**6
      IF (PHI .LE. 30.) EKTV = FKTV1(PHI)*EKTV90/.15
      IF (PHI .GT. 30.) EKTV = FKTV2(PHI)*EKTV90/.15
      RNV = RNOC*CHORD/A1*(1.+(G-1.)/2.*AMACH1**2)**.76
      EK = EKTV*(2.+(ALOG10(RNREF)/ALOG10(RNV))**2.58)/3.
```

```
      IF (ISEC .EQ. 70) GO TO 1701
C..
C..              CONSTANT-AREA CORNERS WITH TURNING VANES AND WALLS
C..
      NN = 24
      EK = EK+SLMDA1*EL/DH1
      IF (ISEC .EQ. 71) NN = 23
C..
C..              CONSTANT-AREA CORNERS WITH TURNING VANES AND ONLY ONE
C..              SIDE-WALL EACH
C..
      IF (ISEC .EQ. 71) EK = EK*3./4.
 1701 EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 1
      GO TO 2000
C..
C..              CONSTANT-AREA CORNER WITH WALLS AND WITHOUT TURNING VANES
C..
 1730 NN = 25
      PHI = ABS(DATA(11))
      EKTE90 = DATA(12)
      IF (EKTE90 .LT. 1.E-6) EKTE90 = 1.80
      EKTE = FKTE(PHI)*EKTE90/1.80
      EK = EKTE+SLMDA1*EL/DH1
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 1
      GO TO 2000
C..
C..              DIFFUSING CORNERS WITH TURNING VANES AND WALLS
C..
 1740 NN = 26
      CHORD = DATA(9)
      PHI = ABS(DATA(11))
      EKTV90 = DATA(12)
      RNREF = DATA(14)*10.**6
      IF (DATA(14) .LT. 1.E-6) RNREF = .5*10.**6
      IF (EKTV90 .LT. 1.E-6) EKTV90 = .15
      IF (PHI .LE. 30.) EKTV = FKTV1(PHI)*EKTV90/.15
      IF (PHI .GT. 30.) EKTV = FKTV2(PHI)*EKTV90/.15
      TH2 = FTH2(A2,A1,EL)
      RNV = RNOC*CHORD/A1*(1.+(G-1.)/2.*AMACH1**2)**.76
      EKV = .3
      IF (TH2 .GE. 21.5) EKV = EKV+.006*(TH2-21.5)
      EK1 = EKV*((AR-1.)/AR)**2
      EK2 = EKTV*2./3.
      CALL FRICTN(CHORD,A1,AMACH1,SLAMDA)
C..
C..              DIFFUSING CORNERS WITH TURNING VANES AND ONLY ONE
C..              SIDE-WALL EACH
C..
```

```
      IF (ISEC .EQ. 74) EK1 = EK1-EL*SLAMDA/DH1/4.
      IF (ISEC .EQ. 75) NN = 27
      EK = EK1+EK2
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 3
      GO TO 2000
C.....
C..             DIFFUSION
C..
C..
C..                DIFFUSERS
C..
 1840 NN = 28
      EK = (EKEXP+SLMDA1/(8.*SIN(TH))*(AR+1.)/(AR-1.))*((AR-1.)/AR)**2
      IF (EK .LT. (SLMDA1*EL/DH1)) EK = SLMDA1*EL/DH1
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 3
      GO TO 2000
C.....
C..                VANED DIFFUSERS
C..
 1850 NN = 29
      EKV = .3
      TH2 = FTH2(A2,A1,EL)
      IF (TH2 .GE. 21.5) EKV = EKV+.006*(TH2-21.5)
      EK = EKV*((AR-1.)/AR)**2
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      ITYPE = 3
      GO TO 2000
C..             SUDDEN EXPANSION FROM MULTIPLE DUCTS TO SINGLE DUCT
C..
 1860 NN = 30
      TH2 = 90.
      EK = ((AR-1.)/AR)**2
      EK0 = FEK0(EK,A0,A1,EM0,AMACH1,EM0SQ,G)
      IF (ISEC .EQ. 87) NN = 31
      ITYPE = 3
      GO TO 2000
C.....
C..             DRIVE-FAN SYSTEM
C..
C..
C..                FAN ANNULAR DUCT(S) WITH MOTOR-SUPPORT STRUT(S)
C..
 1910 NN = 32
      ENITEM = DATA(2)
      SPA = DATA(8)
      CD = DATA(13)
      ETAFAN = DATA(15)
      EPS = 1.+DATA(16)/100.
```

```
      IF (ENITEM .LT. 1.E-6) ENITEM = 1.
      IF (ETAFAN .LT. 1.E-6) ETAFAN = 100.
      EMF = AMACH1
      ENFAN = ENDUCT
      IFLAG = N
      RHOSF = RHOT/(1.+(G-1.)/2.*AMACH1**2)**(1./(G-1.))
      EKD = SLMDA1*EL/DH1
      IF ((A2/A1-1.) .GT. 1.E-6) EKD = (EKEXP+SLMDA1/(8.*SIN(TH))*
     1  (AR+1.)/(AR-1.))*((AR-1.)/AR)**2
      IF (EKD .LT. (SLMDA1*EL/DH1)) EKD = SLMDA1*EL/DH1
      EKSTRT = CD*SOA*EPS*ENITEM
      EK = EKD+EKSTRT
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 1
      IF ((A2/A1-1.) .GT. 1.E-6) ITYPE = 3
      GO TO 2000
C..
C..            FAN CONTRACTION(S) TO ANNULAR DUCT(S) WITH MOTOR-SUPPORT
C..            STRUT(S)
C..
 1920 NN = 33
      TH2 = FTH2(AI1,AI2,EL)
      EK = .32*SLMDA1*EL/DH2
      EKO = FEKO(EK,A0,A2,EMO,AMACH2,EMOSQ,G)
      ITYPE = 4
      GO TO 2000
C..
C..            FAN DIFFUSER(S) FROM ANNULAR DUCT(S), EACH WITH TAPERING,
C..            CONE-SHAPED CENTERBODY
C..
 1940 NN = 34
      EK = (EKEXP+SLMDA1/(8.*SIN(TH))*(AR+1.)/(AR-1.))*((AR-1.)/AR)**2
      IF (EK .LT. (SLMDA1*EL/DH1)) EK = SLMDA1*EL/DH1
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 3
      GO TO 2000
C.....
C..         FLOW OBSTRUCTIONS
C..
C..
C..            INTERNAL STRUCTURE (DRAG ITEM(S)) AT UPSTREAM END OF EACH
C..            DUCT
C..
 1960 NN = 35
      ENITEM = DATA(2)
      SOA = DATA(8)
      CD = DATA(13)
      EPS = 1+DATA(16)/100.
      IF (ENITEM .LT. 1.E-6) ENITEM = 1.
      EK = CD*SOA*EPS*ENITEM
```

```
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 2
      GO TO 2000
C..
C..            FIXED, KNOWN-LOCAL-LOSS ITEM AT UPSTREAM END OF EACH DUCT
C..
 1970 NN = 36
      EK = DATA(13)
      EKO = FEKO(EK,A0,A1,EMO,AMACH1,EMOSQ,G)
      ITYPE = 2
C..........
C....COMPONENT TEST-SECTION-REFERENCED LOSS SUMMATION
C...
 2000 SEKO(N) = EKO
      SUMEKO = SUMEKO+EKO
C..........
C....SECTION PERFORMANCE INFORMATION OUTPUT
C...
      IF (EKO .GT. 0.0) GO TO 2001
      WRITE(6,9509) N
      TLIST = -2.
      LINECT = LINECT+3
      GO TO 200
 2001 CALL OUTPUT(ITYPE,NN)
      LINECT = LINECT+3
      GO TO 200
C
C*****************************************************************************
C...................
C..CASE TERMINATION TASKS
C...
C..........
C....SUMMARY AND OVERALL PERFORMANCE CALCULATIONS
C...
C.....
C..           ERROR-CAUSED SKIP AND MESSAGE
C..
 2002 IF ((TLIST .LT. -1. .OR. ABS(SUMEKO) .LT. 1.E-6) .AND.
     1  LINECT .GE. (LINEMX-1)) IPAGE = IPAGE+1
      IF ((TLIST .LT. -1. .OR. ABS(SUMEKO) .LT. 1.E-6) .AND.
     1  LINECT .GE. (LINEMX-1)) WRITE(6,9001) ITITLE,IPAGE
      IF ((TLIST .LT. -1. .OR. ABS(SUMEKO) .LT. 1.E-6) .AND.
     1  LINECT .GE. (LINEMX-1)) WRITE(6,9004)
      IF ((TLIST .LT. -1. .OR. ABS(SUMEKO) .LT. 1.E-6) .AND.
     1  LINECT .GE. (LINEMX-1) .AND. IU .EQ. 1) WRITE(6,9005)
      IF ((TLIST .LT. -1. .OR. ABS(SUMEKO) .LT. 1.E-6) .AND.
     1  LINECT .GE. (LINEMX-1) .AND. IU .EQ. 2) WRITE(6,9006)
      IF ((TLIST .LT. -1. .OR. ABS(SUMEKO) .LT. 1.E-6) .AND.
     1  LINECT .GE. (LINEMX-1)) LINECT = 10
      IF (TLIST .LT. -1. .OR. ABS(SUMEKO) .LT. 1.E-6) WRITE(6,9501)
```

```
      IF (TLIST .LT. -1. .OR. ABS(SUMEKO) .LT. 1.E-6) LINECT = LINECT+3
      IF (TLIST .LT. -1. .OR. ABS(SUMEKO) .LT. 1.E-6) GO TO 2015
C.....
C..            ENERGY RATIO
C..
      ER = 1./SUMEKO
C.....
C..            PRESSURE DIFFERENTIAL ACROSS SECTION WALLS (COMPUTED AT THE
C..            DOWNSTREAM END OF EACH SECTION)
C..
      DO 2005 I = 1,N
      IF (I .NE. 1) GO TO 2003
      SSUMEL(1) = SEL(1)
      SSUMKO(1) = SEKO(1)
      GO TO 2004
 2003 SSUMEL(I) = SSUMEL(I-1)+SEL(I)
      SSUMKO(I) = SSUMKO(I-1)+SEKO(I)
 2004 IF (IFLAG .EQ. I) SSUMKO(I) = SSUMKO(I)-SUMEKO
 2005 DELP(I) = PATM-((PT-Q0*SSUMKO(I))/(1.+(G-1.)/2.*SMACH(I)**2)**
     1  (G/(G-1.)))
      IF (LINECT .LT. (LINEMX-1)) GO TO 2006
      IPAGE = IPAGE+1
      WRITE(6,9001) ITITLE,IPAGE
      LINECT = 6
 2006 IF (IU .EQ. 1) WRITE(6,9300) SUMEL
      IF (IU .EQ. 2) WRITE(6,9301) SUMEL
      LINECT = LINECT+2
C.....
C..            PAGING-CHECK PRIOR TO OUTPUT OF SUMMARY PERFORMANCE
C..            INFORMATION
C..
      IF (LINECT .LT. (LINEMX-4)) GO TO 2007
      IPAGE = IPAGE+1
      WRITE(6,9001) ITITLE,IPAGE
      LINECT = 6
 2007 IF (IU .EQ. 2) GO TO 2008
C.....
C..            POWER CALCULATIONS FOR SI UNITS
C..
      PWRIP = A0*V0**3*SUMEKO*RHOS0**2/2./RHOSF
      PWROP = PWRIP*100./ETAFAN
      AVGPWR = PWROP/ENFAN
      WRITE(6,9302) SUMEKO,ER,PWRIP,PWROP,AVGPWR,ETAFAN,ENFAN
      LINECT = LINECT+5
      GO TO 2009
C.....
C..            POWER CALCULATIONS FOR U.S. CUSTOMARY UNITS
C..
 2008 PWRIP = A0*V0**3*SUMEKO*RHOS0**2/1100./RHOSF
      PWROP = PWRIP*100./ETAFAN
```

```
      AVGPWR = PWROP/ENFAN
      WRITE(6,9303) SUMEK0,ER,PWRIP,PWROP,AVGPWR,ETAFAN,ENFAN
      LINECT = LINECT+5
 2009 IF (PWRI .LT. 1.E-6) GO TO 2011
C..........
C....VELOCITY ADJUSTMENT CALCULATIONS FOR POWER-MATCHING WITH INPUT
C....POWER VALUE -- DETERMINES APPROXIMATE MAXIMUM TEST SECTION VELOCTY
C....FOR THE SPECIFIED POWER LEVEL
C...
      CALL FRICTN(DH0,A0,EM0,SLMDAC)
      V0C = V0
      V0 = V0*(PWRMCH/PWROP)**(1./3.)
      EMF = EMF*V0/V0C
      EM0 = EM0*V0/V0C
      RHOSF = RHOT/(1.+(G-1.)/2.*EMF**2)**(1./(G-1.))
      RHOS0 = RHOT/(1.+(G-1.)/2.*EM0**2)**(1./(G-1.))
      RN0C = RHOS0*V0*A0/EMUT
      CALL FRICTN(DH0,A0,EM0,SLMDAE)
      IF (IU .EQ. 1) PWROP = A0*V0**3*SUMEK0*SLMDAE*RHOS0**2/SLMDAC*50./
     1 RHOSF/ETAFAN
      IF (IU .EQ. 2) PWROP = A0*V0**3*SUMEK0*SLMDAE*RHOS0**2/SLMDAC/11.
     1 /RHOSF/ETAFAN
      IF (ABS((PWRMCH-PWROP)/PWRMCH) .GT. 1.E-6) GO TO 2009
      IF (IU .EQ. 1) V0K = V0*1.9438
      IF (IU .EQ. 2) V0K = V0*.59248
      Q0 = RHOS0*V0**2/2.
      IF (LINECT .LT. (LINEMX-10)) GO TO 2010
      IPAGE = IPAGE+1
      WRITE(6,9001) ITITLE,IPAGE
 2010 IF (IU .EQ. 1) WRITE(6,9304) PWROP,V0,V0K,EM0,Q0
      IF (IU .EQ. 2) WRITE(6,9305) PWROP,V0,V0K,EM0,Q0
 2011 IF (IPRINT .EQ. 0) GO TO 2014
C..........
C....CIRCUIT SUMMARY CHARACTERISTICS PAGE OUTPUT
C...
      LINECT = 100
      DO 2013 I = 1,N
      IF (LINECT .LT. LINEMX) GO TO 2012
      IPAGE = IPAGE+1
      WRITE(6,9001) ITITLE,IPAGE
      WRITE(6,9401)
      IF (IU .EQ. 1) WRITE(6,9402)
      IF (IU .EQ. 2) WRITE(6,9403)
      LINECT = 15
 2012 WRITE(6,9400) I,SSUMEL(I),SMACH(I),SSUMK0(I),DELP(I)
      LINECT = LINECT+1
 2013 CONTINUE
 2014 IF (IPLOT .EQ. 0) GO TO 2015
C..........
C....CIRCUIT SUMMARY CHARACTERISTICS PLOT(S)
```

```
C...
      CALL PLOTIT(N,DELP,SSUMEL,SSUMKU,IU,IPLOT,ITITLE,TRETRN,PLOTON)
C..........
C....ANNOTATED TABULATION OF INPUT DATA CARDS FOR CURRENT CASE
C...
 2015 IF (TLISTI .GT. 1.E-6 .OR. TLIST .LT. -.6) CALL DATACK(3)
C..........
C....END-OF-CASES OR RETURN CHECK
C...
      WRITE(6,9007) ITITLE
      IF (TRETRN .GT. 1.E-6) GO TO 100
      IF (TRETRN .LT. -.5) GO TO 102
      STOP 1066
C
C**********************************************************************
C...................
C..INPUT READ FORMATS
C...
 7000 FORMAT (A1,19A4,A3)
 7001 FORMAT (I2,4I1,4X,8F5.2)
 7002 FORMAT (2I2,2I1,2F2.0,14F5.2)
C...................
C..OUTPUT FORMATS
C...
C..........
C....PERFORMANCE INFORMATION LABELLING AND OUTPUT FORMATS
C...
 9000 FORMAT (1H1//20X,A1,19A4,A3,13X,4HPAGE,I3//
     1  26X,9A4,24H WIND-TUNNEL PERFORMANCE/)
 9001 FORMAT (1H1//5X,A1,19A4,A3,6X,16H...CONTINUED...,6X,4HPAGE,I3//)
 9002 FORMAT (24H ATMOSPHERIC PRESSURE = ,F6.3,15H ATMOSPHERES = ,F9.1,
     A  8H N/SQ M./
     B  27H TEST SECTION CONDITIONS -- /
     C  21H    TOTAL PRESSURE = ,F6.3,15H ATMOSPHERES = ,F9.1,
     D  8H N/SQ M./
     E  24H    TOTAL TEMPERATURE = ,F6.2,9H DEG C = ,F7.2,7H DEG K./
     F  15H    VELOCITY = ,F7.2,9H M/SEC = ,F7.2,28H KNOTS,  DYNAMIC PRE
     GSSURE = ,F9.2,8H N/SQ M./)
 9003 FORMAT (24H ATMOSPHERIC PRESSURE = ,F6.3,15H ATMOSPHERES = ,F8.2,
     A  10H LB/SQ FT./
     B  27H TEST SECTION CONDITIONS -- /
     C  21H    TOTAL PRESSURE = ,F6.3,15H ATMOSPHERES = ,F8.2,
     D  10H LB/SQ FT./
     E  24H    TOTAL TEMPERATURE = ,F6.2,9H DEG F = ,F7.2,7H DEG R./
     F  15H    VELOCITY = ,F7.2,10H FT/SEC = ,F7.2,28H KNOTS,  DYNAMIC P
     GRESSURE = ,F7.2,10H LB/SQ FT./)
 9004 FORMAT (120H NO.   SECTION TYPE    SHAPE    H1     W1,D1     AREA1
     A  A1/A0  AR,CR  2 THETA    V1    MACH1   LENGTH   DP/QL    DP/Q0
     B / 30X, 33H  H2     W2,D2     AREA2   A2/A0  ,17X,
     C 22H  V2    MACH2       )
```

```
 9005 FORMAT(28X,26H METERS   METERS      SQ M, 17X, 32HDEGREES   M/SEC
     A          METERS /120H ++      +===========+      +====+ +=====+      +====+
     B    +====+    +====+   +====+   +======+   +=====+   +====+    +=====+     +====+
     C    +====+  )
 9006 FORMAT (30X, 26H FEET      FEET      SQ FT      , 15X,31HDEGREES  FT/
     ASEC            FEET   /120H ++      +===========+       +====+     +===+     +
     B====+      +====+    +====+   +====+   +======+   +=====+   +====+     +=====+    +
     C====+      +====+   )
 9007 FORMAT (/6H  ** ',A1,19A4,A3,34H' CASE COMPLETED OR TERMINATED. **
     A  )
C..........
C....SUMMARY PERFORMANCE LABELLING AND OUTPUT FORMATS
C...
 9300 FORMAT (94X,8H========/68X,26H TOTAL CENTERLINE LENGTH = , F8.2,
     A   7H METERS)
 9301 FORMAT (94X,8H========/68X,26H TOTAL CENTERLINE LENGTH = , F8.2,
     A   6H FEET )
 9302 FORMAT (23H0PERFORMANCE SUMMARY ==/
     A   3X,30H TOTAL PRESSURE LOSS (DP/Q0) =,F8.5,6X,14HENERGY RATIO =,
     B   F7.3/
     C   4X,14HTOTAL POWER ==/
     D   120H        INPUT TO FLOW       OUTPUT REQUIRED       AVERAGE PER FAN
     E          FAN EFFICIENCY        TOTAL NUMBER OF FANS               /
     F   F15.0,6H WATTS,F13.0,6H WATTS,F14.0,6H WATTS,F11.2,9H  PERCENT,
     G   F16.0)
 9303 FORMAT (23H0PERFORMANCE SUMMARY ==/
     A   3X,30H TOTAL PRESSURE LOSS (DP/Q0) =,F8.5,6X,14HENERGY RATIO =,
     B   F7.3/
     C   4X,14HTOTAL POWER ==/
     D   120H        INPUT TO FLOW       OUTPUT REQUIRED       AVERAGE PER FAN
     E          FAN EFFICIENCY        TOTAL NUMBER OF FANS               /
     F   F15.0,4H  HP,F15.0,4H  HP,F16.0,4H  HP,F13.2,9H  PERCENT,F16.0)
 9304 FORMAT (///35X,50HMAXIMUM VELOCITY FOR A SPECIFIED POWER CONSUMPTI
     AON //46H THE MAXIMUM TEST SECTION FLOW ACHIEVABLE WITH,F10.0,
     B   56H WATTS OF POWER AVAILABLE IS APPROXIMATELY AS FOLLOWS ==/
     C   15X,13H VELOCITY == ,F8.2,8H M/SEC =,F8.2,6H KNOTS/
     D   15X,16H MACH NUMBER == ,F5.2/
     E   15X,21H DYNAMIC PRESSURE == ,F9.2,7H N/SQ M)
 9305 FORMAT (///35X,50HMAXIMUM VELOCITY FOR A SPECIFIED POWER CONSUMPTI
     AON //46H THE MAXIMUM TEST SECTION FLOW ACHIEVABLE WITH,F8.0,
     B   52H HORSEPOWER AVAILABLE IS APPROXIMATELY AS FOLLOWS ==/
     C   15X,13H VELOCITY == ,F8.2,9H FT/SEC =,F8.2,6H KNOTS/
     D   15X,16H MACH NUMBER == ,F5.2/
     E   15X,21H DYNAMIC PRESSURE == ,F7.2,9H LB/SQ FT)
C..........
C....CIRCUIT SUMMARY INFORMATION PAGE FORMATS
C...
 9400 FORMAT (25X,I5,F17.2,F14.3,F15.5,F17.1)
 9401 FORMAT (38X,44H WIND-TUNNEL CIRCUIT CHARACTERISTICS SUMMARY/
     A   40X,40H TAKEN AT DOWNSTREAM END OF EACH SECTION//
```

```
     B  25X,71H SECTION          CUMULATIVE          MACH          CUMULATIVE          PM12510
     C WALL PRESSURE/                                                                  PM12520
     D  25X,71HASSIGNED           CIRCUIT          NUMBER          PRESSURE            PM12530
     E DIFFERENTIAL/                                                                   PM12540
     F  25X,71HSEQUENCE           LENGTH                            LOSS               PM12550
     G (ATMOSPHERIC /                                                                  PM12560
     H  69X,27H(DP/Q0)          - INTERNAL))                                           PM12570
 9402 FORMAT (25X,70H                        METERS                                    PM12580
     A                N/SQ M   /                                                       PM12590
     B  25X,71H+-------+         +---------+          +-----+        +---------+       PM12600
     C +------------+/)                                                                PM12610
 9403 FORMAT (25X,70H                        FEET                                      PM12620
     A                LB/SQ FT /                                                       PM12630
     B  25X,71H+-------+         +---------+          +-----+        +---------+       PM12640
     C +------------+/)                                                                PM12650
C..........                                                                            PM12660
C....ERROR-DIAGNOSTIC MESSAGES AND FORMATS                                             PM12670
C...                                                                                   PM12680
 9500 FORMAT (1H1)                                                                     PM12690
 9501 FORMAT (/118H *** DUE TO ERROR(S) IN INPUT CARD(S), VALID SUMMARY   PM12700
     AINFORMATION IS NOT AVAILABLE.  REFER TO THE TABULATION OF INPUT   / PM12710
     B 120H      DATA ON THE FOLLOWING PAGES.  CORRECT THE ERROR(S) AND  PM12720
     C RESUBMIT THIS CASE.  SUBSEQUENT CASES WILL NOT BE AFFECTED.)       PM12730
 9502 FORMAT (//10H  TITLE (1,A1,1944,A3,27H1) IS INCORRECT OR IMPROPER/ PM12740
     A 120H   AS IT EXISTS.  THE FIRST CARD COLUMN MUST CONTAIN AN ASTER PM12750
     BISK (*) TO BE IDENTIFIED AS A VALID TITLE CARD.              /     PM12760
     C  28H  THIS CASE WILL BE SKIPPED./)                                 PM12770
 9503 FORMAT (//24H  MASTER CONTROL DATA (1,I2,4I1,4X,7F5.2,61H1) IS INC PM12780
     AORRECT OR IMPROPER AS IT EXISTS.  THE FIRST TWO CARD/               PM12790
     B 120H  COLUMNS MUST CONTAIN A NEGATIVE NUMBER (-1 TO -9) TO BE ID  PM12800
     CENTIFIED AS A VALID MASTER CARD.  THIS CASE WILL BE SKIPPED./)     PM12810
 9504 FORMAT (//117H  MORE THAN ONE MASTER CONTROL CARD EXISTS FOR THIS  PM12820
     A CASE OR INPUT CARDS ARE OUT OF ORDER.  CHECK DECK SET-UP.       / PM12830
     B  120H  THE LAST MASTER CARD ENCOUNTERED WILL BE ASSUMED AS THE CO PM12840
     CRRECT MASTER CARD FOR THE SECTION CARDS WHICH FOLLOW.          /)  PM12850
 9505 FORMAT (/43H  MAXIMUM LIMIT ON THE NUMBER OF SECTIONS (,I3,69H) HA PM12860
     AS BEEN  REACHED.  EITHER A CASE TERMINATION CARD HAS BEEN OMITTED/ PM12870
     C  120H  (ALONG WITH TITLE AND MASTER CARDS TO BEGIN A NEW CASE) OR PM12880
     D THIS CASE IS TOO LONG FOR THE PROGRAMMED ALLOWABLE NUMBER   /     PM12890
     E  59H  OF SECTIONS.  THE CASE HAS BEEN TERMINATED AT THIS POINT./) PM12900
 9506 FORMAT (/118H  MASTER CONTROL CARD HAS BEEN ENCOUNTERED BEFORE CAS PM12910
     AE TERMINATION AND TITLE CARDS.  CHECK DECK SET-UP.               / PM12920
     B  120H  ERROR-MESSAGE TITLE WILL BE GENERATED AND SUMMARY OUTPUT,  PM12930
     CNO-PLOT, INPUT DATA TABULATION, AND NEXT-CASE RETURN /              PM12940
     D  41H  TERMINATION PARAMETERS WILL BE ASSUMED.//)                  PM12950
 9507 FORMAT (/60H  ** NOTE -- TEST SECTION BLOCKAGE FROM SECTION CARD I PM12960
     ANPUT (,F5.3,49H PERCENT)  DOES NOT EQUAL THAT OF THE MASTER CARD/  PM12970
     B  8H INPUT (,F5.3,109H PERCENT).  CHECK DATA DECK.  SECTION CARD V PM12980
     CALUE WILL BE ASSUMED AS CORRECT AND EXECUTION WILL CONTINUE.     ) PM12990
 9508 FORMAT (/117H  ** ALTHOUGH VELOCITY-OPTIMIZATION WAS REQUESTED BY  PM13000
```

```
     ATERMINATION CODE, THE INPUT POWER VALUE IS ILLEGAL (LESS THAN OR/  PM13010
     B  120H    EQUAL TO ZERO). THEREFORE, NO VELOCITY-OPTIMIZING IS PO PM13020
     CSSIBLE. RECHECK INPUT VALUE ON MASTER DATA CARD.          )       PM13030
9509 FORMAT (/115H ** ERROR - SOME INCORRECT COMBINATION OF INPUTS OR   PM13040
     AUNANTICIPATED SITUATION HAS CAUSED AN INVALID (NON-POSITIVE)  /   PM13050
     B  39H     TOTAL LOSS LEVEL. RECHECK SECTION,I3,12H INPUT DATA./)  PM13060
     END                                                                PM13070
```

```
      SUBROUTINE DATACK(NLIST)
C*********************************************************************
C*********************************************************************
C  THIS ROUTINE, A SUBROUTINE OF THE MAIN PROGRAM PERFORM, CHECKS FOR
C  ERRORS IN INPUTS OF MASTER CONTROL CARD AND SECTION CARDS, AND, IF
C  REQUESTED, IT CONTROLS THE ASSEMBLY AND PRINTING OF THE ANNOTATED
C  TABULATION OF THE INPUT INFORMATION.
C*********************************************************************
C*********************************************************************
      COMMON/BLOCKA/ISEQ,ISHAP1,ISHAP2,N
      COMMON/BLOCKB/DATA(16),ITITLE(21),IPAGE,IPLOT,IPRINT,ISEC,ITUNNL,
     1  IU,LINECT,LINEMX,PWRI,SERROR,TLIST,TLISTI,TRETRN
      DIMENSION EMDATA(13),EMWRIT(26),ENDATA(30,20),ENWRIT(40),
     1  ETWRIT(12),MCHECK(13),MDATA(5),MFORMT(30),MWRITE(12),
     2  NCHECK(30,20),NDATA(30,4),NFORMT(42),NWRITE(8)
C..........
C....OBJECT-TIME FORMATTING ARRAYS
C..
      DATA MLEFT,NLEFT,IAFLD2,IAFLD4,IIFLD5,IFLD0,IFFLD0,IFFLD1,IFFLD2,
     1  IFFLD3,IFFLD4,ICOMMA,ISPACC,ISPAC1,IRIGHT/
     2  4H(19X,4H(   ,3HA2,,3HA4,,2HI5,4HF5.0,4HF6.0,4HF6.1,4HF6.2,
     3  4HF6.3,4HF6.4,1H,,4H,1X,,3H1X,,2H/)/
C..........
C....INPUT TABULATION ANNOTATION MESSAGE ARRAY (INTEGER VALUES)
C...
      DATA IBLNK2,IBLNK4,IMSG1,IMSG2,IMSG3,IMSG4,IMSG5,IMSG6,IMSG7,
     1  IMSG8/2H  ,4H    ,2H E,4HXTRA,2H E,4HRROR,2H O,4HPTIN,2H E,
     2  4HMPTY/
C..........
C....INPUT TABULATION ANNOTATION MESSAGE ARRAY (FLOATING POINT VALUES)
C...
      DATA RBLNK2,RBLNK4,RMSG1,RMSG2,RMSG3,RMSG4,RMSG5,RMSG6,RMSG7,
     1  RMSG8/2H  ,4H    ,2H E,4HXTRA,2H E,4HRROR,2H O,4HPTIN,2H E,
     2  4HMPTY/
C..........
C....TERMINATION CARD PARAMETER TRANSLATION ARRAY
C...
      DATA TMSG1,TMSG2,TMSG3,TMSG4,TMSG5,TMSG6A,TMSG6B,TMSG7,TMSG8,
     1  TMSG9,TMSG10,TMSG11,TMSG12,TMSG13/
     2  4HYES ,4H NO ,4HNONE,4HPRES,4HS, L,4HOSS ,4HOSS.,4H WAL,4HL PR,
     3  4HESS.,4H(CHO,4HSEN),4H(FOR,4HCED)/
C..........
C....TRANSFER TO APPLICABLE SECTION OF SUBROUTINE --
C..          PART 1 (STATEMENT 1000) FOR MASTER CONTROL CARD CHECK-OUT
C..          PART 2 (STATEMENT 2000) FOR SECTION CARD CHECK-OUT
C..          PART 3 (STATEMENT 4000) FOR OUTPUT TABULATION OF INPUT CARDS
C...
      GO TO (1000,2000,4000), NLIST
C
C*********************************************************************
```

```
C....................
C..DEFINITION OF MASTER CONTROL INPUT REQUIREMENTS --
C..         CODE '0' INDICATES INPUT WHICH IS NOT REQUIRED FOR ANY
C                    PURPOSE AND WHICH MAY BE OMITTED FROM INPUT CARD
C..         CODE '1' INDICATES MANDATORY INPUT
C..         CODE '2' INDICATES OPTIONAL INPUT WITH DEFAULT PROVISION
C..         CODE '3' INDICATES NON-REQUIRED, CONVENIENCE INPUT OR
C                    OPTIONAL INPUT WHICH MAY BE CORRECT AS ZERO
C...
C..........
C....INTEGER DATA
C...
 1000 MDATA(1) = ISEQ
      MDATA(2) = ITUNNL
      MDATA(3) = IU
      MDATA(4) = ISHAP1
      MDATA(5) = ISHAP2
C..........
C....FLOATING POINT DATA
C...
      DO 1001 I = 6,13
      EMDATA(I) = DATA(I-3)
 1001 CONTINUE
C..........
C....INPUT REQUIREMENT DEFINITIONS
C...
      DO 1002 I = 1,13
      MCHECK(I) = 1
 1002 CONTINUE
      MCHECK( 2) = 2
      MCHECK( 5) = 3
      IF (ISHAP1 .EQ. 1) MCHECK( 6) = 0
      MCHECK( 8) = 3
      MCHECK(10) = 3
      MCHECK(11) = 2
      MCHECK(12) = 3
      MCHECK(13) = 2
C..........
C....INTEGER INPUT ERROR-CHECK
C...
      DO 1003 I = 1,5
      IF (MCHECK(I) .NE. 0 .AND. MDATA(I) .EQ. 0 .AND. TLIST .GT. -.5)
     1 TLIST = -.5
      IF (MCHECK(I) .EQ. 1 .AND. MDATA(I) .EQ. 0) TLIST = -1.
 1003 CONTINUE
C.....
C..          UNITS-OF-MEASURE ERROR DETECTION
C..
      EMERR = 0.0
      IF (((IU-1)*(IU-2)) .EQ. 0) GO TO 1004
```

```
      WRITE(6,8006) ITITLE,IPAGE
      WRITE(6,8002) IU
      LINECT = 8
      IU = 1
      EMERR = 3.
 1004 IF (((ISHAP1-1)*(ISHAP1-2)*(ISHAP1-3)) .EQ. 0) GO TO 1006
      IF (EMERR .GT. 2.5) GO TO 1005
      WRITE(6,8006) ITITLE,IPAGE
      LINECT = 4
      EMERR = 3.
 1005 WRITE(6,8001) ISHAP1
      LINECT = LINECT+4
      TLIST = -3.
 1006 IF (((ISHAP2-1)*(ISHAP2-2)*(ISHAP2-3)) .NE. 0) TLIST = -.5
C..........
C....FLOATING POINT INPUT ERROR-CHECK
C...
      DO 1007 I = 6,13
      IF (MCHECK(I) .NE. 0 .AND. ABS(EMDATA(I)) .LT. 1.E-6 .AND.
     1 TLIST .GT. -.5) TLIST = -.5
      IF (MCHECK(I) .EQ. 1 .AND. ABS(EMDATA(I)) .LT. 1.E-6) TLIST = -3.
 1007 CONTINUE
      IF (TLIST .GT. -2.5 .OR. TLIST .LT. -3.5) RETURN
      WRITE(6,8000)
      IF (EMERR .LT. 2.5) WRITE(6,8006) ITITLE,IPAGE
      IF (EMERR .GT. 2.5) LINECT = LINECT+4
      IF (EMERR .LT. 2.5) LINECT = 9
      RETURN
C
C***********************************************************************
C....................
C..DEFINITION OF SECTION INPUT REQUIREMENTS
C..        CODE '0' INDICATES INPUT WHICH IS NOT REQUIRED FOR ANY
C..                 PURPOSE AND WHICH MAY BE OMITTED FROM INPUT CARD
C..        CODE '1' INDICATES MANDATORY INPUT
C..        CODE '2' INDICATES OPTIONAL INPUT WITH DEFAULT PROVISION
C..        CODE '3' INDICATES NON-REQUIRED, CONVENIENCE INPUT OR
C..                 OPTIONAL INPUT WHICH MAY BE CORRECT AS ZERO
C...
 2000 SERROR = 0.0
C..........
C....INTEGER DATA
C...
      NDATA(N,1) = ISEQ
      NDATA(N,2) = ISEC
      NDATA(N,3) = ISHAP1
      NDATA(N,4) = ISHAP2
C..........
C....FLOATING POINT DATA
C...
```

```
      DO 2001 I = 5,20
      ENDATA(N,I) = DATA(I-4)
 2001 CONTINUE
C..........
C....GENERAL INPUT REQUIREMENT DEFINITIONS
C...
      DO 2002 I = 1,20
      NCHECK(N,I) = 0
 2002 CONTINUE
      NCHECK(N, 1) = 2
      NCHECK(N, 2) = 1
      NCHECK(N, 3) = 1
      NCHECK(N, 4) = 1
      IF (ISHAP1 .NE. 1) NCHECK(N, 7) = 1
      NCHECK(N, 8) = 1
      NCHECK(N, 9) = 1
      IF (ISHAP2 .NE. 1) NCHECK(N,10) = 1
      NCHECK(N,11) = 1
C..........
C....SECTION TYPE BRANCHING
C...
      IF (ISEC .EQ.  1) GO TO 3000
      IF (ISEC .EQ.  2) GO TO 2020
      IF (ISEC .EQ.  3) GO TO 2030
      IF (ISEC .EQ.  4) GO TO 2040
      IF (ISEC .EQ.  5) GO TO 3000
      IF (ISEC .EQ.  6) GO TO 2060
      IF (ISEC .EQ. 10) GO TO 3000
      IF (ISEC .EQ. 20) GO TO 3000
      IF (ISEC .EQ. 30) GO TO 2300
      IF (ISEC .EQ. 32) GO TO 2300
      IF (ISEC .EQ. 33) GO TO 2330
      IF (ISEC .EQ. 34) GO TO 2340
      IF (ISEC .EQ. 40) GO TO 2400
      IF (ISEC .EQ. 45) GO TO 2450
      IF (ISEC .EQ. 46) GO TO 2460
      IF (ISEC .EQ. 51) GO TO 2510
      IF (ISEC .EQ. 52) GO TO 2520
      IF (ISEC .EQ. 53) GO TO 2530
      IF (ISEC .EQ. 54) GO TO 2540
      IF (ISEC .EQ. 56) GO TO 2560
      IF (ISEC .EQ. 57) GO TO 2570
      NCHECK(N, 5) = 1
      IF (ISEC .EQ. 61) GO TO 3000
      IF (ISEC .EQ. 62) GO TO 3000
      IF (ISEC .EQ. 70) GO TO 2700
      IF (ISEC .EQ. 71) GO TO 2700
      IF (ISEC .EQ. 72) GO TO 2700
      IF (ISEC .EQ. 73) GO TO 2730
      IF (ISEC .EQ. 74) GO TO 2740
```

```
      IF (ISEC .EQ. 75) GO TO 2740                                      DK 2010
      IF (ISEC .EQ. 84) GO TO 2840                                      DK 2020
      IF (ISEC .EQ. 85) GO TO 3000                                      DK 2030
      IF (ISEC .EQ. 86) GO TO 2860                                      DK 2040
      IF (ISEC .EQ. 87) GO TO 2860                                      DK 2050
      IF (ISEC .EQ. 91) GO TO 2910                                      DK 2060
      IF (ISEC .EQ. 92) GO TO 2920                                      DK 2070
      IF (ISEC .EQ. 94) GO TO 2940                                      DK 2080
      IF (ISEC .EQ. 96) GO TO 2960                                      DK 2090
      IF (ISEC .EQ. 97) GO TO 2970                                      DK 2100
C.....                                                                  DK 2110
C..               INVALID SECTION TYPE-CODE MESSAGE                     DK 2120
C..                                                                     DK 2130
      IF (LINECT .LT. (LINEMX-2)) GO TO 2003                            DK 2140
      IPAGE = IPAGE+1                                                   DK 2150
      WRITE(6,8111) ITITLE,IPAGE                                        DK 2160
      LINECT = 5                                                        DK 2170
 2003 WRITE(6,8004) N                                                   DK 2180
      LINECT = LINECT+3                                                 DK 2190
      SERROR = -2.                                                      DK 2200
      GO TO 3003                                                        DK 2210
C..........                                                             DK 2220
C....SINGLE-DUCT SPECIALIZED INPUT REQUIREMENTS DEFINITIONS              DK 2230
C...                                                                    DK 2240
C.....                                                                  DK 2250
C..                 TEST SECTIONS                                       DK 2260
C..                                                                     DK 2270
C..                                                                     DK 2280
C..                 CONSTANT-AREA TEST SECTION WITH MODEL               DK 2290
C..                                                                     DK 2300
 2020 NCHECK(N,12) = 1                                                  DK 2310
      NCHECK(N,14) = 3                                                  DK 2320
      NCHECK(N,17) = 1                                                  DK 2330
      NCHECK(N,20) = 3                                                  DK 2340
      GO TO 3000                                                        DK 2350
C..                                                                     DK 2360
C..                 DIFFUSING TEST SECTION -- EMPTY                     DK 2370
C..                                                                     DK 2380
 2030 NCHECK(N,16) = 2                                                  DK 2390
      GO TO 3000                                                        DK 2400
C..                                                                     DK 2410
C..                 DIFFUSING TEST SECTION WITH MODEL                   DK 2420
C..                                                                     DK 2430
 2040 NCHECK(N,12) = 1                                                  DK 2440
      NCHECK(N,14) = 3                                                  DK 2450
      NCHECK(N,16) = 2                                                  DK 2460
      NCHECK(N,17) = 1                                                  DK 2470
      NCHECK(N,20) = 3                                                  DK 2480
      GO TO 3000                                                        DK 2490
C..                                                                     DK 2500
```

```
C..              OPEN-THROAT TEST SECTION WITH MODEL
C..
 2060 NCHECK(N,12) = 1
      NCHECK(N,14) = 3
      NCHECK(N,17) = 1
      NCHECK(N,20) = 3
      GO TO 3000
C.....
C..           CORNERS AND TURNS
C..
C..
C..              CONSTANT-AREA TURN WITH VANES
C..
 2300 NCHECK(N,13) = 1
      NCHECK(N,15) = 1
      NCHECK(N,16) = 2
      NCHECK(N,18) = 2
      GO TO 3000
C..
C..              CONSTANT-AREA TURN WITHOUT VANES
C..
 2330 NCHECK(N,15) = 1
      NCHECK(N,16) = 2
      GO TO 3000
C.....
C..
C..              DIFFUSING CORNER
C..
 2340 NCHECK(N,13) = 1
      NCHECK(N,15) = 1
      NCHECK(N,16) = 2
      NCHECK(N,18) = 2
      GO TO 3000
C.....
C..           DIFFUSION
C..
C..
C..              DIFFUSER
C..
 2400 NCHECK(N,16) = 2
      GO TO 3000
C..              EXIT-FLOW KINETIC ENERGY
C..
 2450 NCHECK(N, 9) = 0
      GO TO 3000
C..
C..              SUDDEN EXPANSION
C..
 2460 NCHECK(N, 9) = 0
      GO TO 3000
```

```
C.....
C..          FLOW OBSTRUCTIONS
C..
C..
C..             HONEYCOMB THIN FLOW STRAIGHTENERS
C..
 2510 NCHECK(N,12) = 1
      NCHECK(N,14) = 1
      NCHECK(N,18) = 2
      GO TO 3000
C..
C..             AIRFOIL THICK FLOW STRAIGHTENERS
C..
 2520 NCHECK(N,12) = 2
      NCHECK(N,14) = 1
      GO TO 3000
C..
C..             PERFORATED PLATE
C..
 2530 NCHECK(N, 9) = 0
      NCHECK(N,14) = 1
      GO TO 3000
C..
C..             MESH SCREEN
C..
 2540 NCHECK(N, 9) = 0
      NCHECK(N,13) = 1
      NCHECK(N,14) = 1
      NCHECK(N,16) = 2
      GO TO 3000
C..
C..             INTERNAL STRUCTURE
C..
 2560 NCHECK(N, 6) = 2
      NCHECK(N, 9) = 0
      NCHECK(N,12) = 1
      NCHECK(N,14) = 3
      NCHECK(N,17) = 1
      NCHECK(N,20) = 3
      GO TO 3000
C..
C..             FIXED, KNOWN LOCAL LOSS
C..
 2570 NCHECK(N, 9) = 0
      NCHECK(N,17) = 1
      GO TO 3000
C..........
C....MULTIPLE-DUCT SPECIALIZED INPUT REQUIREMENTS DEFINITIONS
C...
C.....
```

```
C..             CORNERS AND TURNS                                  DK 3510
C..                                                                DK 3520
C..                                                                DK 3530
C..                CONSTANT-AREA CORNERS WITH VANES                DK 3540
C..                                                                DK 3550
 2700 NCHECK(N,13) = 1                                             DK 3560
      NCHECK(N,15) = 1                                             DK 3570
      NCHECK(N,16) = 2                                             DK 3580
      NCHECK(N,18) = 2                                             DK 3590
      GO TO 3000                                                   DK 3600
C..                                                                DK 3610
C..                CONSTANT-AREA CORNERS WITHOUT VANES             DK 3620
C..                                                                DK 3630
 2730 NCHECK(N,15) = 1                                             DK 3640
      NCHECK(N,16) = 2                                             DK 3650
      GO TO 3000                                                   DK 3660
C..                                                                DK 3670
C..                DIFFUSING CORNERS                               DK 3680
C..                                                                DK 3690
 2740 NCHECK(N,13) = 1                                             DK 3700
      NCHECK(N,15) = 1                                             DK 3710
      NCHECK(N,16) = 2                                             DK 3720
      NCHECK(N,18) = 2                                             DK 3730
      GO TO 3000                                                   DK 3740
C.....                                                             DK 3750
C..             DIFFUSION                                          DK 3760
C..                                                                DK 3770
C..                                                                DK 3780
C..                DIFFUSERS                                       DK 3790
C..                                                                DK 3800
 2840 NCHECK(N,16) = 2                                             DK 3810
      GO TO 3000                                                   DK 3820
C..                                                                DK 3830
C..                SUDDEN EXPANSION                                DK 3840
C..                                                                DK 3850
 2860 NCHECK(N, 9) = 0                                             DK 3860
      GO TO 3000                                                   DK 3870
C.....                                                             DK 3880
C..             DRIVE-FAN SYSTEM                                   DK 3890
C..                                                                DK 3900
C..                                                                DK 3910
C..                FAN ANNULAR DUCT(8)                             DK 3920
C..                                                                DK 3930
 2910 NCHECK(N, 5) = 2                                             DK 3940
      NCHECK(N, 6) = 2                                             DK 3950
      NCHECK(N,12) = 1                                             DK 3960
      NCHECK(N,13) = 1                                             DK 3970
      NCHECK(N,14) = 3                                             DK 3980
      NCHECK(N,17) = 1                                             DK 3990
      NCHECK(N,19) = 2                                             DK 4000
```

```
      NCHECK(N,20) = 3
      GO TO 3000
C..             FAN CONTRACTION(S)
C..
 2920 NCHECK(N, 5) = 2
      NCHECK(N, 6) = 2
      NCHECK(N,13) = 1
      NCHECK(N,14) = 3
      GO TO 3000
C..             FAN DIFFUSER(S)
C..
 2940 NCHECK(N, 5) = 2
      NCHECK(N, 6) = 2
      NCHECK(N,13) = 1
      NCHECK(N,14) = 3
      NCHECK(N,16) = 2
      GO TO 3000
C.....
C..          FLOW OBSTRUCTIONS
C..
C..
C..             INTERNAL STRUCTURE
C..
 2960 NCHECK(N, 6) = 2
      NCHECK(N, 9) = 0
      NCHECK(N,12) = 1
      NCHECK(N,14) = 3
      NCHECK(N,17) = 1
      NCHECK(N,20) = 3
      GO TO 3000
C..
C..             FIXED, KNOWN LOSS
C..
 2970 NCHECK(N, 9) = 0
      NCHECK(N,17) = 1
C..........
C....INTEGER INPUT ERROR-CHECK AND SETTING OF ERROR FLAG
C...
 3000 DO 3001 I =1,4
      IF (NCHECK(N,I) .NE. 0 .AND. NDATA(N,I) .EQ. 0 .AND.
     1 SERROR .GT. -.5) SERROR = -.5
      IF (NCHECK(N,I) .EQ. 1 .AND. NDATA(N,I) .EQ. 0) SERROR = -2.
 3001 CONTINUE
C..........
C....FLOATING-POINT INPUT ERROR-CHECK AND SETTING OF ERROR FLAG
C...
      DO 3002 I = 5,20
      IF (NCHECK(N,I) .NE. 0 .AND. ABS(ENDATA(N,I)) .LT. 1.E-6 .AND.
     1 SERROR .GT. -.5) SERROR = -.5
      IF (NCHECK(N,I) .EQ. 1 .AND. ABS(ENDATA(N,I)) .LT. 1.E-6)
```

```
    1 SERROR = -2.                                                          DK 4510
 3002 CONTINUE                                                              DK 4520
C.....                                                                      DK 4530
C..             INVALID SECTION SHAPE CHECK AND MESSAGE                     DK 4540
C..                                                                         DK 4550
 3003 IF (((ISHAP1-1)*(ISHAP1-2)*(ISHAP1-3)) .EQ. 0) GO TO 3005             DK 4560
      IF (LINECT .LT. (LINEMX-2)) GO TO 3004                                DK 4570
      IPAGE = IPAGE+1                                                       DK 4580
      WRITE(6,8111) ITITLE,IPAGE                                            DK 4590
      WRITE(6,8007)                                                         DK 4600
      IF (IU .EQ. 1) WRITE(6,8008)                                          DK 4610
      IF (IU .EQ. 2) WRITE(6,8009)                                          DK 4620
      LINECT = 9                                                            DK 4630
 3004 WRITE(6,8003) N,ISHAP1                                                DK 4640
      LINECT = LINECT+3                                                     DK 4650
      SERROR = -2.                                                          DK 4660
 3005 IF (((ISHAP2-1)*(ISHAP2-2)*(ISHAP2-3)) .EQ. 0) GO TO 3007             DK 4670
      IF (LINECT .LT. (LINEMX-2)) GO TO 3006                                DK 4680
      IPAGE = IPAGE+1                                                       DK 4690
      WRITE(6,8111) ITITLE,IPAGE                                            DK 4700
      WRITE(6,8007)                                                         DK 4710
      IF (IU .EQ. 1) WRITE(6,8008)                                          DK 4720
      IF (IU .EQ. 2) WRITE(6,8009)                                          DK 4730
      LINECT = 9                                                            DK 4740
 3006 WRITE(6,8003) N,ISHAP2                                                DK 4750
      LINECT = LINECT+3                                                     DK 4760
      SERROR = -2.                                                          DK 4770
 3007 IF (SERROR .GT. -1.) GO TO 3009                                       DK 4780
      IF (LINECT .LT. (LINEMX-3)) GO TO 3008                                DK 4790
      IPAGE = IPAGE+1                                                       DK 4800
      WRITE(6,8111) ITITLE,IPAGE                                            DK 4810
      WRITE(6,8007)                                                         DK 4820
      IF (IU .EQ. 1) WRITE(6,8008)                                          DK 4830
      IF (IU .EQ. 2) WRITE(6,8009)                                          DK 4840
      LINECT = 9                                                            DK 4850
 3008 WRITE(6,8005) N                                                       DK 4860
      LINECT = LINECT+3                                                     DK 4870
 3009 IF (TLIST .GT. SERROR) TLIST = SERROR                                 DK 4880
      RETURN                                                                DK 4890
C                                                                           DK 4900
C*************************************************************************  DK 4910
C....................                                                       DK 4920
C..PRINTED TABULATION OF INPUT DATA WITH ANNOTATIONS AS REQUIRED             DK 4930
C...                                                                        DK 4940
C..........                                                                 DK 4950
C....LABELLING OF MASTER AND TERMINATION DATA PAGE                          DK 4960
C...                                                                        DK 4970
 4000 IPAGE = IPAGE+1                                                       DK 4980
      WRITE(6,8100) ITITLE,IPAGE                                            DK 4990
      WRITE(6,8101)                                                         DK 5000
```

```
      IF (IU .EQ. 1) WRITE(6,8102)
      IF (IU .EQ. 2) WRITE(6,8103)
      WRITE(6,8104)
C..........
C....DEFINITION OF MASTER DATA INFORMATION AND FORMAT ARRAYS
C...
C.....
C..            INTEGER INFORMATION
C..
      MFORMT( 1) = MLEFT
      MFORMT( 2) = ICOMMA
      MFORMT(13) = ISPAC1
      MFORMT(30) = IRIGHT
      IOV = 1
      IOF = 3
      DO 4007 I = 1,5
      IF (MCHECK(I) .NE. 0) GO TO 4001
      MWRITE(IOV) = IBLNK2
      MWRITE(IOV+1) = IBLNK4
      IF (MDATA(I) .EQ. 0) GO TO 4005
      MWRITE(IOV) = IMSG1
      MWRITE(IOV+1) = IMSG2
      GO TO 4005
 4001 IF (MCHECK(I) .EQ. 0 .OR. MDATA(I) .EQ. 0) GO TO 4002
      MWRITE(IOV) = MDATA(I)
      IOV = IOV+1
      MFORMT(IOF) = IIFLDS
      MFORMT(IOF+1) = ISPACC
      GO TO 4006
 4002 IF (MCHECK(I) .NE. 1 .OR. MDATA(I) .NE. 0) GO TO 4003
      MWRITE(IOV) = IMSG3
      MWRITE(IOV+1) = IMSG4
      GO TO 4005
 4003 IF (MCHECK(I) .NE. 2 .OR. MDATA(I) .NE. 0) GO TO 4004
      MWRITE(IOV) = IMSG5
      MWRITE(IOV+1) = IMSG6
      GO TO 4005
 4004 MWRITE(IOV) = IMSG7
      MWRITE(IOV+1) = IMSG8
 4005 IOV = IOV+2
      MFORMT(IOF) = IAFLD2
      MFORMT(IOF+1) = IAFLD4
 4006 IOF = IOF+2
 4007 CONTINUE
      IOF = IOF+1
      IOVI = IOV-1
      IOVR = IOVI+1
C.....
C..            FLOATING-POINT INFORMATION
C..
```

```
      DO 4014 I = 6,13
      IF (MCHECK(I) .NE. 0) GO TO 4008
      EMWRIT(IOV) = RBLNK2
      EMWRIT(IOV+1) = RBLNK4
      IF (ABS(EMDATA(I)) .LT. 1.E-6) GO TO 4012
      EMWRIT(IOV) = RMSG1
      EMWRIT(IOV+1) = RMSG2
      GO TO 4012
 4008 IF (MCHECK(I) .EQ. 0 .OR. ABS(EMDATA(I)) .LT. 1.E-6) GO TO 4009
      EMWRIT(IOV) = EMDATA(I)
      IOV = IOV+1
C.....
C..          DATA-MAGNITUDE-CONTROLLED FORMATTING
C..
      MFORMT(IOF) = IFFLD0
      IF (EMDATA(I) .LT. 1000.) MFORMT(IOF) = IFFLD1
      IF (EMDATA(I) .LT. 100.) MFORMT(IOF) = IFFLD2
      IF (EMDATA(I) .LT. 10.) MFORMT(IOF) = IFFLD3
      IF (EMDATA(I) .LT. 1.) MFORMT(IOF) = IFFLD4
      MFORMT(IOF+1) = ICOMMA
      GO TO 4013
 4009 IF (MCHECK(I) .NE. 1 .OR. ABS(EMDATA(I)) .GT. 1.E-6) GO TO 4010
      EMWRIT(IOV) = RMSG3
      EMWRIT(IOV+1) = RMSG4
      GO TO 4012
 4010 IF (MCHECK(I) .NE. 2 .OR. ABS(EMDATA(I)) .GT. 1.E-6) GO TO 4011
      EMWRIT(IOV) = RMSG5
      EMWRIT(IOV+1) = RMSG6
      GO TO 4012
 4011 EMWRIT(IOV) = RMSG7
      EMWRIT(IOV+1) = RMSG8
 4012 IOV = IOV+2
      MFORMT(IOF) = IAFLD2
      MFORMT(IOF+1) = IAFLD4
 4013 IOF = IOF+2
 4014 CONTINUE
      IOV = IOV-1
      WRITE(6,MFORMT) (MWRITE(I),I = 1,IOVI),(EMWRIT(I),I = IOVR,IOV)
C..........
C....DEFINITION OF TERMINATION CONTROL CODES
C...
C...
C.....
C..          SUMMARY INFORMATION PRINT
C..
      ETWRIT( 1) = TMSG2
      IF (IPRINT .NE. 0) ETWRIT( 1) = TMSG1
C.....
C..          SUMMARY PLOTS
C..
      IF (IPLOT .NE. 0) GO TO 4015
```

```
      ETWRIT( 2) = RBLNK4
      ETWRIT( 3) = TMSG3
      ETWRIT( 4) = RBLNK4
      GO TO 4017
 4015 IF (IPLOT .NE. 1 .AND. IPLOT .NE. 3) GO TO 4016
      ETWRIT( 2) = TMSG4
      ETWRIT( 3) = TMSG5
      ETWRIT( 4) = TMSG6A
      IF (IPLOT .GT. 2) ETWRIT( 4) = TMSG6B
      GO TO 4017
 4016 ETWRIT( 2) = TMSG7
      ETWRIT( 3) = TMSG8
      ETWRIT( 4) = TMSG9
 4017 IF (IPLOT .GT. 2) GO TO 4019
      DO 4018 I = 10,12
 4018 ETWRIT(I) = RBLNK4
      GO TO 4020
 4019 ETWRIT(10) = TMSG7
      ETWRIT(11) = TMSG8
      ETWRIT(12) = TMSG9
C.....
C..            ANNOTATED TABULATION OF INPUT DATA
C..
 4020 ETWRIT( 5) = TMSG1
      IF (TLIST .GT. -.6) GO TO 4021
      ETWRIT( 6) = TMSG12
      ETWRIT( 7) = TMSG13
      GO TO 4022
 4021 ETWRIT( 6) = TMSG10
      ETWRIT( 7) = TMSG11
 4022 ETWRIT( 8) = TMSG2
C.....
C..            POWER-MATCHING AND VELOCITY-OPTIMIZATION REQUEST
C..
      IF (PWRI .GT. 1.E-6) ETWRIT( 8) = TMSG1
      ETWRIT( 9) = TMSG2
C.....
C..            NEXT-CASE-RETURN OR TERMINATION REQUEST
C..
      IF (TRETRN .GT. 1.E-6) ETWRIT( 9) = TMSG1
      WRITE(6,8105) N
      WRITE(6,8106) ETWRIT
C..........
C....HEADINGS FOR LISTING OF SECTION DATA INPUTS
C...
      IPAGE = IPAGE+1
      WRITE(6,8100) ITITLE,IPAGE
      WRITE(6,8107)
      IF (IU .EQ. 1) WRITE (6,8108)
      IF (IU .EQ. 2) WRITE (6,8109)
```

```
      WRITE(6,8110)
      LINECT = 27
      DO 4039 I = 1,N
      IF (LINECT .LT. (LINEMX-1)) GO TO 4023
      IPAGE = IPAGE+1
      WRITE(6,8111) ITITLE,IPAGE
      WRITE(6,8107)
      IF (IU .EQ. 1) WRITE (6,8108)
      IF (IU .EQ. 2) WRITE (6,8109)
      WRITE(6,8110)
      LINECT = 19
C..........
C....DEFINITION OF SECTION DATA INFORMATION AND FORMAT ARRAYS
C...
 4023 NFORMT( 1) = NLEFT
      NFORMT(42) = IRIGHT
      IOV = 1
      IOF = 2
C.....
C..          INTEGER INFORMATION
C..
      DO 4030 J = 1,4
      IF (NCHECK(I,J) .NE. 0) GO TO 4024
      NWRITE(IOV) = IBLNK2
      NWRITE(IOV+1) = IBLNK4
      IF (NDATA(I,J) .EQ. 0) GO TO 4028
      NWRITE(IOV) = IMSG1
      NWRITE(IOV+1) = IMSG2
      GO TO 4028
 4024 IF (NCHECK(I,J) .EQ. 0 .OR. NDATA(I,J) .EQ. 0) GO TO 4025
      NWRITE(IOV) = NDATA(I,J)
      IOV = IOV+1
      NFORMT(IOF) = IIFLD5
      NFORMT(IOF+1) = ISPACC
      GO TO 4029
 4025 IF (NCHECK(I,J) .NE. 1 .OR. NDATA(I,J) .NE. 0) GO TO 4026
      NWRITE(IOV) = IMSG3
      NWRITE(IOV+1) = IMSG4
      GO TO 4028
 4026 IF (NCHECK(I,J) .NE. 2 .OR. NDATA(I,J) .NE. 0) GO TO 4027
      NWRITE(IOV) = IMSG5
      NWRITE(IOV+1) = IMSG6
      GO TO 4028
 4027 NWRITE(IOV) = IMSG7
      NWRITE(IOV+1) = IMSG8
 4028 IOV = IOV+2
      NFORMT(IOF) = IAFLD2
      NFORMT(IOF+1) = IAFLD4
 4029 IOF = IOF+2
 4030 CONTINUE
```

```
      IOVI = IOV-1
      IOVR = IOVI+1
C.....
C..           FLOATING-POINT INFORMATION
C..
      DO 4038 J = 5,20
      IF (NCHECK(I,J) .NE. 0) GO TO 4031
      ENWRIT(IOV) = RBLNK2
      ENWRIT(IOV+1) = RBLNK4
      IF (ABS(ENDATA(I,J)) .LT. 1.E-6) GO TO 4036
      ENWRIT(IOV) = RMSG1
      ENWRIT(IOV+1) = RMSG2
      GO TO 4036
 4031 IF (NCHECK(I,J) .EQ. 0 .OR. ABS(ENDATA(I,J)) .LT. 1.E-6)
     1  GO TO 4033
      ENWRIT(IOV) = ENDATA(I,J)
      IOV = IOV+1
      IF (J .NE. 5 .AND. J .NE. 6) GO TO 4032
      NFORMT(IOF) = IFLD0
      NFORMT(IOF+1) = ISPACC
      GO TO 4037
C.....
C..           DATA-MAGNITUDE-CONTROLLED FORMATTING
C..
 4032 NFORMT(IOF) = IFFLD0
      IF (ENDATA(I,J) .LT. 1000.) NFORMT(IOF) = IFFLD1
      IF (ENDATA(I,J) .LT. 100.) NFORMT(IOF) = IFFLD2
      IF (ENDATA(I,J) .LT. 10.) NFORMT(IOF) = IFFLD3
      IF (ENDATA(I,J) .LT. 1.) NFORMT(IOF) = IFFLD4
      NFORMT(IOF+1) = ICOMMA
      GO TO 4037
 4033 IF (NCHECK(I,J) .NE. 1 .OR. ABS(ENDATA(I,J)) .GE. 1.E-6)
     1  GO TO 4034
      ENWRIT(IOV) = RMSG3
      ENWRIT(IOV+1) = RMSG4
      GO TO 4036
 4034 IF (NCHECK(I,J) .NE. 2 .OR. ABS(ENDATA(I,J)) .GE. 1.E-6)
     1  GO TO 4035
      ENWRIT(IOV) = RMSG5
      ENWRIT(IOV+1) = RMSG6
      GO TO 4036
 4035 ENWRIT(IOV) = RMSG7
      ENWRIT(IOV+1) = RMSG8
 4036 IOV = IOV+2
      NFORMT(IOF) = IAFLD2
      NFORMT(IOF+1) = IAFLD4
 4037 IOF = IOF+2
 4038 CONTINUE
      IOV = IOV-1
      WRITE(6,NFORMT) (NWRITE(J),J = 1,IOVI),(ENWRIT(J),J = IOVR,IOV)
```

```
      LINECT = LINECT+2                                                  DK 7510
 4039 CONTINUE                                                           DK 7520
      RETURN                                                             DK 7530
C....................                                                    DK 7540
C..DATA ERROR MESSAGE FORMATS                                            DK 7550
C...                                                                     DK 7560
 6000 FORMAT (/10X,82HCRITICAL OMISSION(S) IN TUNNEL MASTER CONTROL DATA DK 7570
     A PREVENT EXECUTION OF THIS CASE./10X,41HANY SUCEEDING CASES WILL N DK 7580
     BOT BE AFFECTED./)                                                  DK 7590
 8001 FORMAT (/10X,73H** ERROR -- INVALID TEST SECTION UPSTREAM END SHAP DK 7600
     AE CODE WAS SPECIFIED AS,I2,23H (SHOULD BE 1, 2 OR 3)./             DK 7610
     B 13X,29HTHIS CASE CANNOT BE EXECUTED./)                            DK 7620
 8002 FORMAT (/54H  THE UNITS OF MEASURE CODE IS IMPROPERLY SPECIFIED AS DK 7630
     A,I2,54H (SHOULD BE 1 OR 2).  CHECK MASTER CARD (COLUMN 4).     /   DK 7640
     B 120H  SEE THE DATA TABULATION AT THE END OF THIS CASE.  THE INTE  DK 7650
     CRNATIONAL SYSTEM OF UNITS WILL BE ASSUMED FOR THIS CASE.      /)   DK 7660
 8003 FORMAT (/I3,2X,55H** ERROR -- INVALID SECTION SHAPE CODE WAS SPECI DK 7670
     AFIED AS,I2,54H (SHOULD BE 1, 2 OR 3).  THIS SECTION WILL BE SKIPPE DK 7680
     BD./)                                                               DK 7690
 8004 FORMAT (/I3,2X,109H** ERROR -- INPUT SECTION TYPE CODE (CARD COLUM DK 7700
     ANS 3 AND 4) CALLS INVALID SECTION TYPE.  DATA CARD IGNORED. **/)   DK 7710
 8005 FORMAT (/I3,2X,111H** ERROR -- CRITICAL OMISSION(S) IN SECTION INP DK 7720
     AUT DATA.  SEE DATA TABULATION AT END OF OUTPUT FOR THIS CASE. **/) DK 7730
 8006 FORMAT (1H1//5X,A1,19A4,A3,28X,4HPAGE,I3)                          DK 7740
 8007 FORMAT (120H NO.   SECTION TYPE     SHAPE      H1      W1,D1   AREA1 DK 7750
     A   A1/A0  AR,CR  2 THETA    V1     MACH1   LENGTH   DP/QL    DP/Q0 DK 7760
     B / 30X, 33H  H2      W2,D2      AREA2    A2/A0   ,17X,             DK 7770
     C 22H  V2     MACH2         )                                       DK 7780
 8008 FORMAT(28X,26H METERS    METERS       SQ M, 17X, 32HDEGREES   M/SEC DK 7790
     A          METERS /120H ++    +-----------+      +---+ +-----+   +-----+ DK 7800
     B    +----+  +----+  +----+  +------+  +-----+  +----+   +-----+   +----+ DK 7810
     C    +----+  )                                                      DK 7820
 8009 FORMAT (30X, 26H FEET      FEET      SQ FT      , 15X,31HDEGREES  FT/ DK 7830
     ASEC           FEET   /120H ++    +-----------+      +----+  +---+   + DK 7840
     B---+    +----+    +----+  +----+  +------+  +-----+  +----+  +-----+  + DK 7850
     C---+    +----+  )                                                  DK 7860
C....................                                                    DK 7870
C..ANNOTATED TABULATION LABELLING AND DATA FORMATS                       DK 7880
C...                                                                     DK 7890
 8100 FORMAT (1H1//5X,A1,19A4,A3,6X,16H...CONTINUED.....,6X,4HPAGE,I3/// DK 7900
     A  44X,32H ANNOTATED INPUT DATA TABULATION//                        DK 7910
     B 120H  'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER H  DK 7920
     CAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.     /        DK 7930
     C 120H  'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITT  DK 7940
     EED.  THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE. /      DK 7950
     F 120H  'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNN  DK 7960
     GECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.     /        DK 7970
     H 120H  'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND  DK 7980
     I THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.      //)     DK 7990
 8101 FORMAT (47X,26HTUNNEL MASTER CONTROL DATA//                        DK 8000
```

```
      A 20X,78H CASE TUNNEL UNITS SECT, SECT,    H1    W1   MODEL   VO  PO
      BWER  PT    TT  P ATM /
      C 20X,61H SEQ, TYPE        INLET EXIT            D1  BLKGE      LE
      DVEL )
 8102 FORMAT (21X,4H NO.,13X,12H SHAPE SHAPE,13X,17H PER-        MEGA-/
      A 50X,47H    M      M     CENT M/SEC WATTS  ATM  DEG C  ATM )
 8103 FORMAT (21X,4H NO.,13X,12H SHAPE SHAPE,13X,17H PER- FT/    10(3)/
      A 50X,47H  FEET  FEET  CENT   SEC   HP   ATM  DEG F  ATM )
 8104 FORMAT (18H DATA FIELD BEGINS/
      A 18H IN CARD COLUMN --,78H   1    3    4    5    6   11
      B16   21   26   31   36   41   46  /
      C 20X,78H ++     +    +    +    +    +-----+ +----+ +----+ +----+ +-
      D--+ +----+ +----+ +----+/)
 8105 FORMAT (//44X,32HCASE TERMINATION CONDITIONS DATA//
      A 27X,66H CASE TERMINATION OCCURRED (DUE TO BLANKS IN CARD COLUMNS
      B 3 AND 4)/
      C 25X,6H AFTER,I3,61H INPUT SECTIONS, AND ACCORDING TO THE FOLLOWI
      DNG CONDITIONS --//
      E 20X,81H    SUMMARY              PLOTTING AS          INPUT       V
      FELOCITY-        RETURN    /
      G 20X,81HCHARACTERISTICS       A FUNCTION          DATA       OP
      HTIMIZATION     FOR NEXT /
      I 20X,81H     OUTPUT           OF LENGTH      TABULATION     (FI
      JXED POWER)      CASE    /
      K 17H TERMINATION-CODE/
      L 14H DATA FIELD IS,13H CONTAINED IN/
      M 16H CARD COLUMNS --,10X,74H5-6                7-8            9-
      N10           11-15          16-20/
      O 20X,81H+-------------+     +---------+     +--------+       +--
      P---------+     +-------+ /)
 8106 FORMAT (26X,A4,10X,3A4,5X,3A4,10X,A4,13X,A4/40X,3A4)
 8107 FORMAT (48X,24HSECTION DESCRIPTION DATA//
      A 120H SECT. SECT. SECT. SECT. TOTAL ITEMS   H1    W1    L     H2
      B  W2  L/DH. CHORD BLKGE PHI   KEXP   CD  RNREF. ETA D EPS/
      C 120H SEQ. TYPE  INLET EXIT   NO.   PER             D1
      D  D2  S/AL  DHUB PRSTY      KMESH   K   RUFNES             /
      E 120H INPUT       SHAPE SHAPE DUCTS  DUCT
      F          DMESH               KT 90                       )
 8108 FORMAT (67X,42H M/M,                               10(6), /
      A 67X,53HSQ M/         PER-                     10(-6) PER-  PER-/
      B 24X,96H NO.   NO.     M     M     M     M     M   SQ M    M    C
      CENT DEG            METERS CENT  CENT )
 8109 FORMAT (67X,42HFT/FT,                               10(6), /
      A 67X,53HSQ FT/        PER-                     10(-6) PER-  PER-/
      B 24X,96H NO.   NO.  FEET  FEET  FEET  FEET  FEET SQ FT  FEET  C
      CENT DEG            FEET  CENT  CENT)
 8110 FORMAT (18H DATA FIELD BEGINS/
      A 18H IN CARD COLUMN --/
      B 120H   1    3    5    6    7    9   11   16   21   26
      C 31   36   41   46   51   56   61   66   71   76  /
```

```
      D  120H   ◆◆     ◆◆     ◆     ◆     ◆◆     ◆◆   ◆■■■◆ ◆■■■◆ ◆■■■◆ ◆■■■◆ DK 8510
      E ◆■■■◆ ◆■■■◆ ◆■■■◆ ◆■■■◆ ◆■■■◆ ◆■■■◆ ◆■■■◆ ◆■■■◆ ◆■■■◆ ◆■■■◆ /)      DK 8520
 8111 FORMAT (1H1//5X,A1,19A4,A3,6X,16H...CONTINUED.....,6X,4HPAGE,I3//)  DK 8530
      END                                                                  DK 8540
```

```
      SUBROUTINE SPEED(A,AMACH,V)
C*****************************************************************************
C*****************************************************************************
C  THIS ROUTINE, A SUBROUTINE OF THE MAIN PROGRAM PERFORM, COMPUTES THE
C  LOCAL MACH NUMBERS AND VELOCITIES.
C*****************************************************************************
C*****************************************************************************
      COMMON/BLOCKC/ ASTAR,AT,G
C.....................
C...NEWTON'S METHOD ITERATION FOR MACH NUMBER
C...
      EMT = .1
    1 EMN = EMT-(ASTAR/A*(2./(G+1.))**((G+1.)/2./(G-1.))*
     1  (1.+(G-1.)/2.*EMT**2)**((G+1.)/2./(G-1.))-EMT)/
     2  (ASTAR/A*EMT*(2./(G+1.))**((3.-G)/2./(G-1.))*
     3  (1.+(G-1.)/2.*EMT**2)**((3.-G)/2./(G-1.))-1.)
      IF (ABS(EMN-EMT)/EMN .LT. 1.E-4) GC TO 2
      EMT = EMN
      GO TO 1
    2 AMACH = EMN
C.....................
C...LOCAL FLOW VELOCITY
C...
      ASL = AT/SQRT(1.+(G-1.)/2.*AMACH**2)
      V = AMACH*ASL
      RETURN
      END
```

```
      SUBROUTINE FRICTN(DH,A,AMACH,SLAMDA)
C***********************************************************************
C***********************************************************************
C  THIS ROUTINE, A SUBROUTINE OF THE MAIN PROGRAM PERFORM, COMPUTES THE
C  LOCAL REYNOLDS NUMBERS AND SMOOTH=PIPE FRICTION COEFFICIENTS.
C***********************************************************************
C***********************************************************************
      COMMON/BLOCKC/ ASTAR,AT,G
      COMMON/BLOCKD/ RNOC
C....................
C..REYNOLDS NUMBER BASED ON THE CHARACTERISTIC DIMENSION DH (USUALLY BUT
C..NOT ALWAYS THE HYDRAULIC DIAMETER OF THE LOCAL DUCT)
C...
      RN ■ RNOC*DH/A*(1.+(G=1.)/2.*AMACH**2)**.76
      IF (RN .GE. 4.E3) GO TO 1
C....................
C..FRICTION COEFFICIENT
C...
C..........
C....FOR REYNOLDS NUMBERS LESS THAN 4000
C...
      SLAMDA ■ .3164/RN**.25
C..........
C....FOR REYNOLDS NUMBERS LESS THAN 2000
C...
      IF (RN .LT. 2.E3) SLAMDA ■ 64./RN
      GO TO 4
C..........
C....NEWTON'S METHOD ITERATION FOR FRICTION COEFFICIENT AT REYNOLDS
C....NUMBERS GREATER THAN OR EQUAL TO 4000
C...
    1 SLAMT ■ .005
    2 SLAMN ■ SLAMT+((1./(ALOG10(SLAMT*RN**2)=.8))**2=SLAMT)/
     1   (2.*ALOG10(EXP(1.))/(SLAMT*(ALOG10(SLAMT*RN**2)=.8)**3)+1.)
      IF (ABS(SLAMN=SLAMT)/SLAMN .LT. 1.E=4) GO TO 3
      SLAMT ■ SLAMN
      GO TO 2
    3 SLAMDA ■ SLAMN
    4 RETURN
      END
```

```
      SUBROUTINE OUTPUT(ITYPE,NN)
C************************************************************************
C************************************************************************
C  THIS ROUTINE, A SUBROUTINE OF THE MAIN PROGRAM PERFORM, HANDLES THE
C  OUTPUT FORMATTING OF CALCULATED SECTION PERFORMANCE INFORMATION.
C************************************************************************
C************************************************************************
      COMMON/BLOCKA/ISEQ,ISHAP1,ISHAP2,N
      COMMON/BLOCKE/ AMACH1,AMACH2,AR,A1,A10A0,A2,A2DA0,D1,D2,EK,EK0,EL,
     1 H1,H2,TH2,V1,V2,W1,W2
      DIMENSION NSECT(180),NSHAPE(3)
C..........
C....SECTION-TYPE NAME DEFINITIONS
C....
      DATA NSECT(  1),NSECT(  2),NSECT(  3),NSECT(  4),NSECT(  5)/
     1  4HTEST, 4H SEC, 4HT, C, 4HONST, 2H A/
      DATA NSECT(  6),NSECT(  7),NSECT(  8),NSECT(  9),NSECT( 10)/
     1  4HTEST, 4H SEC, 4HT, D, 4HIFSN, 2H  /
      DATA NSECT( 11),NSECT( 12),NSECT( 13),NSECT( 14),NSECT( 15)/
     1  4HMODE, 4HL IN, 4H TES, 4HT SE, 2HCT/
      DATA NSECT( 16),NSECT( 17),NSECT( 18),NSECT( 19),NSECT( 20)/
     1  4HOPEN, 4H-THR, 4HOAT , 4HT SE, 2HCT/
      DATA NSECT( 21),NSECT( 22),NSECT( 23),NSECT( 24),NSECT( 25)/
     1  4HCONS, 4HTANT, 4H ARE, 4HA DU, 2HCT/
      DATA NSECT( 26),NSECT( 27),NSECT( 28),NSECT( 29),NSECT( 30)/
     1  4HCONT, 4HRACT, 4HN, S, 4HING , 2HE /
      DATA NSECT( 31),NSECT( 32),NSECT( 33),NSECT( 34),NSECT( 35)/
     1  4HTURN, 4HING , 4HVANE, 4HS   , 2H  /
      DATA NSECT( 36),NSECT( 37),NSECT( 38),NSECT( 39),NSECT( 40)/
     1  4HCORN, 4HER W, 4HITH , 4HVANE, 2HS /
      DATA NSECT( 41),NSECT( 42),NSECT( 43),NSECT( 44),NSECT( 45)/
     1  4HCORN, 4HER, , 4HNO V, 4HANES, 2H  /
      DATA NSECT( 46),NSECT( 47),NSECT( 48),NSECT( 49),NSECT( 50)/
     1  4HCRNR, 4H,DIF, 4HSN &, 4H VAN, 2HES/
      DATA NSECT( 51),NSECT( 52),NSECT( 53),NSECT( 54),NSECT( 55)/
     1  4HDIFF, 4HUSER, 4H    , 4H    , 2H  /
      DATA NSECT( 56),NSECT( 57),NSECT( 58),NSECT( 59),NSECT( 60)/
     1  4HEXIT, 4H KIN, 4HETIC, 4H ENR, 2HGY/
      DATA NSECT( 61),NSECT( 62),NSECT( 63),NSECT( 64),NSECT( 65)/
     1  4HSUDD, 4HEN E, 4HXPAN, 4HSION, 2H  /
      DATA NSECT( 66),NSECT( 67),NSECT( 68),NSECT( 69),NSECT( 70)/
     1  4HHONE, 4HYCOM, 4HB FL, 4HOW S, 2HTR/
      DATA NSECT( 71),NSECT( 72),NSECT( 73),NSECT( 74),NSECT( 75)/
     1  4HAIRF, 4HOIL , 4HFLOW, 4H STR, 2H  /
      DATA NSECT( 76),NSECT( 77),NSECT( 78),NSECT( 79),NSECT( 80)/
     1  4HSCRE, 4HEN, , 4HPERF, 4H PLA, 2HTE/
      DATA NSECT( 81),NSECT( 82),NSECT( 83),NSECT( 84),NSECT( 85)/
     1  4HSCRE, 4HEN, , 4HWIRE, 4H MES, 2HH /
      DATA NSECT( 86),NSECT( 87),NSECT( 88),NSECT( 89),NSECT( 90)/
     1  4HINTE, 4HRNAL, 4H STR, 4HUCTU, 2HRE/
```

```
      DATA NSECT( 91),NSECT( 92),NSECT( 93),NSECT( 94),NSECT( 95)/
     1 4HSING, 4HLE F, 4HIXED, 4H LOS, 2HS /
      DATA NSECT( 96),NSECT( 97),NSECT( 98),NSECT( 99),NSECT(100)/
     1 4HMULT, 4H DUC, 4HTS , 4HCNST, 2H A/
      DATA NSECT(101),NSECT(102),NSECT(103),NSECT(104),NSECT(105)/
     1 4HMULT, 4H DUC, 4HT CO, 4HNTRA, 2HCT/
      DATA NSECT(106),NSECT(107),NSECT(108),NSECT(109),NSECT(110)/
     1 4HMULT, 4H DUC, 4HT T., 4H VAN, 2HES /
      DATA NSECT(111),NSECT(112),NSECT(113),NSECT(114),NSECT(115)/
     1 4HMULT, 4H D 1, 4H-WAL, 4HL CR, 2HNR /
      DATA NSECT(116),NSECT(117),NSECT(118),NSECT(119),NSECT(120)/
     1 4HMULT, 4H D 2, 4H-WAL, 4HL CR, 2HNR /
      DATA NSECT(121),NSECT(122),NSECT(123),NSECT(124),NSECT(125)/
     1 4HM D , 4H CRN, 4HR, N, 4HO VA, 2HNE/
      DATA NSECT(126),NSECT(127),NSECT(128),NSECT(129),NSECT(130)/
     1 4HM D , 4H1-WA, 4HLL D, 4HIF C, 2HNR /
      DATA NSECT(131),NSECT(132),NSECT(133),NSECT(134),NSECT(135)/
     1 4HM D , 4H2-WA, 4HLL D, 4HIF C, 2HNR /
      DATA NSECT(136),NSECT(137),NSECT(138),NSECT(139),NSECT(140)/
     1 4HMULT, 4H DUC, 4HT DI, 4HFFUS, 2HER/
      DATA NSECT(141),NSECT(142),NSECT(143),NSECT(144),NSECT(145)/
     1 4HVANE, 4HD DI, 4HFFUS, 4HER  , 2H  /
      DATA NSECT(146),NSECT(147),NSECT(148),NSECT(149),NSECT(150)/
     1 4HSUD , 4HEXP , 4HM D , 4H- SN, 2HGL/
      DATA NSECT(151),NSECT(152),NSECT(153),NSECT(154),NSECT(155)/
     1 4HSUD , 4HEXP , 4HM D , 4H- M , 2HD /
      DATA NSECT(156),NSECT(157),NSECT(158),NSECT(159),NSECT(160)/
     1 4HFAN , 4HDUCT, 4H , S, 4HTRUT, 2HS /
      DATA NSECT(161),NSECT(162),NSECT(163),NSECT(164),NSECT(165)/
     1 4HFAN , 4HCONT, 4HRACT, 4HION , 2H  /
      DATA NSECT(166),NSECT(167),NSECT(168),NSECT(169),NSECT(170)/
     1 4HFAN , 4HDIFS, 4HR,CN, 4HTR B, 2HDY/
      DATA NSECT(171),NSECT(172),NSECT(173),NSECT(174),NSECT(175)/
     1 4HMULT, 4H INT, 4HRNL , 4HSTRC, 2HTR/
      DATA NSECT(176),NSECT(177),NSECT(178),NSECT(179),NSECT(180)/
     1 4HMULT, 4HIPL , 4HFIXE, 4HD LO, 2HSS/
C..........
C....SECTION END-SHAPE NAME DEFINITIONS
C...
      DATA NSHAPE(1),NSHAPE(2),NSHAPE(3)/ 4HCIRC, 4HRECT, 4HEL O/
      N1 = NN*5-4
      N5 = N1+4
      IF (ISHAP1 .NE. 1 .OR. ISHAP2 .NE. 1) GO TO 1
C.................
C..WRITE STATEMENTS FOR SECTIONS WHICH HAVE CIRCULAR CROSS-SECTIONS
C..AT BOTH ENDS
C...
      IF (ITYPE .EQ. 1)
     1 WRITE(6,9111) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),D1,A1,A1OA0,
     2 V1,AMACH1,EL,EK,EK0,NSHAPE(ISHAP2),D2,A2,A2OA0,V2,AMACH2
```

```
      IF (ITYPE .EQ. 2)
     1 WRITE(6,9121) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),D1,A1,A10A0,
     2 V1,AMACH1,EK,EK0,NSHAPE(ISHAP2),D2,A2,A20A0,V2,AMACH2
      IF (ITYPE .EQ. 3)
     1 WRITE(6,9131) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),D1,A1,A10A0,
     2 AR,TH2,V1,AMACH1,EL,EK,EK0,NSHAPE(ISHAP2),D2,A2,A20A0,V2,AMACH2
      IF (ITYPE .EQ. 4)
     1 WRITE(6,9132) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),D1,A1,A10A0,
     2 AR,TH2,V1,AMACH1,EL,NSHAPE(ISHAP2),D2,A2,A20A0,V2,AMACH2,EK,EK0
      GO TO 4
    1 IF (ISHAP1 .EQ. 1 .OR. ISHAP2 .EQ. 1) GO TO 2
C....................
C..WRITE STATEMENTS FOR SECTIONS WHICH HAVE NON-CIRCULAR CROSS-SECTIONS
C..AT BOTH ENDS
C...
      IF (ITYPE .EQ. 1)
     1 WRITE(6,9141) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),H1,W1,A1,
     2 A10A0,V1,AMACH1,EL,EK,EK0,NSHAPE(ISHAP2),H2,W2,A2,A20A0,V2,
     3 AMACH2
      IF (ITYPE .EQ. 2)
     1 WRITE(6,9151) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),H1,W1,A1,
     2 A10A0,V1,AMACH1,EK,EK0,NSHAPE(ISHAP2),H2,W2,A2,A20A0,V2,AMACH2
      IF (ITYPE .EQ. 3)
     1 WRITE(6,9161) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),H1,W1,A1,
     2 A10A0,AR,TH2,V1,AMACH1,EL,EK,EK0,NSHAPE(ISHAP2),H2,W2,A2,A20A0,
     3 V2,AMACH2
      IF (ITYPE .EQ. 4)
     1 WRITE(6,9162) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),H1,W1,A1,
     2 A10A0,AR,TH2,V1,AMACH1,EL,NSHAPE(ISHAP2),H2,W2,A2,A20A0,V2,
     3 AMACH2,EK,EK0
      GO TO 4
    2 IF (ISHAP1 .NE. 1 .OR. ISHAP2 .EQ. 1) GO TO 3
C....................
C..WRITE STATEMENTS FOR SECTIONS WHICH HAVE A CIRCULAR CROSS-SECTION AT
C..THE UPSTREAM END AND A NON-CIRCULAR CROSS-SECTION AT THE DOWNSTREAM
C..END
C...
      IF (ITYPE .EQ. 1)
     1 WRITE(6,9171) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),D1,A1,A10A0,
     2 V1,AMACH1,EL,EK,EK0,NSHAPE(ISHAP2),H2,W2,A2,A20A0,V2,AMACH2
      IF (ITYPE .EQ. 2)
     1 WRITE(6,9181) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),D1,A1,A10A0,
     2 V1,AMACH1,EK,EK0,NSHAPE(ISHAP2),H2,W2,A2,A20A0,V2,AMACH2
      IF (ITYPE .EQ. 3)
     1 WRITE(6,9191) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),D1,A1,A10A0,
     2 AR,TH2,V1,AMACH1,EL,EK,EK0,NSHAPE(ISHAP2),H2,W2,A2,A20A0,V2,
     3 AMACH2
      IF (ITYPE .EQ. 4)
     1 WRITE(6,9192) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),D1,A1,A10A0,
     2 AR,TH2,V1,AMACH1,EL,NSHAPE(ISHAP2),H2,W2,A2,A20A0,V2,AMACH2,
```

```
    3  EK,EKO
       GO TO 4
C...................
C..WRITE STATEMENTS FOR SECTIONS WHICH HAVE A NON-CIRCULAR CROSS-SECTION
C..AT THE UPSTREAM END AND A CIRCULAR CROSS-SECTION AT THE DOWNSTREAM
C..END
C...
    3 IF (ITYPE .EQ. 1)
     1 WRITE(6,9201) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),H1,W1,A1,
     2 A1OA0,V1,AMACH1,EL,EK,EKO,NSHAPE(ISHAP2),D2,A2,A2OA0,V2,AMACH2
      IF (ITYPE .EQ. 2)
     1 WRITE(6,9211) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),H1,W1,A1,
     2 A1OA0,V1,AMACH1,EK,EKO,NSHAPE(ISHAP2),D2,A2,A2OA0,V2,AMACH2
      IF (ITYPE .EQ. 3)
     1 WRITE(6,9221) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),H1,W1,A1,
     2 A1OA0,AR,TH2,V1,AMACH1,EL,EK,EKO,NSHAPE(ISHAP2),D2,A2,A2OA0,V2,
     3 AMACH2
      IF (ITYPE .EQ. 4)
     1 WRITE(6,9222) N,(NSECT(I),I=N1,N5),NSHAPE(ISHAP1),H1,W1,A1,
     2 A1OA0,AR,TH2,V1,AMACH1,EL,NSHAPE(ISHAP2),D2,A2,A2OA0,V2,AMACH2,
     3 EK,EKO
    4 RETURN
C.........
C....SECTION PERFORMANCE CALCULATION OUTPUT WRITE FORMATS
C...
 9111 FORMAT (/I3,1X,4A4,A2,1X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3,
     A F9.2,2F9.5/23X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9121 FORMAT (/I3,1X,4A4,A2,1X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3,
     A 9X,2F9.5/23X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9131 FORMAT (/I3,1X,4A4,A2,1X,A4,8X,F9.2,F11.2,2F7.2,F9.2,F8.1,F7.3,
     A F9.2,2F9.5/23X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9132 FORMAT (/I3,1X,4A4,A2,1X,A4,8X,F9.2,F11.2,2F7.2,F9.2,F8.1,F7.3,
     A F9.2/23X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3,9X,2F9.5)
 9141 FORMAT (/I3,1X,4A4,A2,1X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3,
     A F9.2,2F9.5/23X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9151 FORMAT (/I3,1X,4A4,A2,1X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3,
     A 9X,2F9.5/23X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9161 FORMAT (/I3,1X,4A4,A2,1X,A4,F8.2,F9.2,F11.2,2F7.2,F9.2,F8.1,F7.3,
     A F9.2,2F9.5/23X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9162 FORMAT (/I3,1X,4A4,A2,1X,A4,F8.2,F9.2,F11.2,2F7.2,F9.2,F8.1,F7.3,
     A F9.2/23X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3,9X,2F9.5)
 9171 FORMAT (/I3,1X,4A4,A2,1X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3,F9.2,
     A 2F9.5/23X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9181 FORMAT (/I3,1X,4A4,A2,1X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3,9X,
     A 2F9.5/23X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9191 FORMAT (/I3,1X,4A4,A2,1X,A4,8X,F9.2,F11.2,2F7.2,F9.2,F8.1,F7.3,
     A F9.2,2F9.5/23X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9192 FORMAT (/I3,1X,4A4,A2,1X,A4,8X,F9.2,F11.2,2F7.2,F9.2,F8.1,F7.3,
     A F9.2/23X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3,9X,2F9.5)
 9201 FORMAT (/I3,1X,4A4,A2,1X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3,
```

```
      A  F9.2,2F9.5/23X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9211 FORMAT (/I3,1X,4A4,A2,1X,A4,F8.2,F9.2,F11.2,F7.2,16X,F8.1,F7.3,9X,
      A  2F9.5/23X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9221 FORMAT (/I3,1X,4A4,A2,1X,A4,F8.2,F9.2,F11.2,2F7.2,F9.2,F8.1,F7.3,
      A  F9.2,2F9.5/23X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3)
 9222 FORMAT (/I3,1X,4A4,A2,1X,A4,F8.2,F9.2,F11.2,2F7.2,F9.2,F8.1,F7.3,
      A  F9.2/23X,A4,8X,F9.2,F11.2,F7.2,16X,F8.1,F7.3,9X,2F9.5)
      END
```

```
      SUBROUTINE PLOTIT(N,DELP,SSUMEL,SSUMKO,IU,IPLOT,ITITLE,TRETRN,
     1 PLOTON)
C***********************************************************************
C***********************************************************************
C  THIS ROUTINE, A SUBROUTINE OF THE MAIN PROGRAM PERFORM, PLOTS WALL
C  PRESSURE DIFFERENTIAL AND/OR CUMMULATIVE, NONDIMENSIONAL PRESSURE
C  LOSSES AGAINST CUMMULATIVE CIRCUIT CENTERLINE LENGTH.  THIS PLOT
C  SUBROUTINE WAS WRITTEN FOR A ZETA PLOTTER WITH 0.005-INCH INCREMENTS.
C  NOTE... WHEN PLOTTING IN SI UNITS, CENTIMETER SCALES WILL RESULT.
C***********************************************************************
C***********************************************************************
      DIMENSION DELP(32),ITITLE(21),SSUMEL(32),SSUMKO(32)
      DIMENSION IX(6),IXN(6),IXNM(6),IY(6),IYN(6),IYNM(6)
C.....
C..          PLOT AXIS LABELS ARRAYS
C..
      DATA IXN(1),IXN(2),IXN(3),IXN(4),IXN(5),IXN(6)/ 4HCIRC,4HUIT ,
     1  4HLENG,4HTH (,4HFEET,4H)    /
      DATA IXNM(1),IXNM(2),IXNM(3),IXNM(4),IXNM(5),IXNM(6)/ 4HCIRC,
     1  4HUIT ,4HLENG,4HTH (,4HMETE,4HRS) /
      DATA IYN(1),IYN(2),IYN(3),IYN(4),IYN(5),IYN(6)/ 4HWALL,4H PRE,
     1  4HSSUR,4HE (L,4HB/SQ,4H FT)/
      DATA IYNM(1),IYNM(2),IYNM(3),IYNM(4),IYNM(5),IYNM(6)/ 4HWALL,
     1  4H PRE,4HSSUR,4HE (N,4H/SQ ,4HM)  /
C..........
C.....READYING OF THE PLOTTER AND ESTABLISHMENT OF THE ORIGIN
C...
      IF (ABS(PLOTON) .LT. 1.E-6) CALL PLOTF(15,10)
C..........
C.....DEFINITION OF PLOTTER PARAMETERS IN STANDARD PLOTTER UNITS (INCHES)
C...
      N1 = N+1
      N2 = N+2
      FACT = 2.
      XLEN = 15.
      YLEN = 10.
      PYLEN = YLEN-.5
      YLAB = YLEN+.1
      XNEXT = 17.
      YMAX = 11.
      YMARG = .5
C.....
C..          DEFINITION OF AXIS LABELS
C..
      DO 50 I = 1,6
      IY(I) = IYN(I)
      IX(I) = IXN(I)
   50 CONTINUE
C..........
C.....TEST FOR TYPE OF UNITS
```

```
C...
      IF (IU .NE. 2) GO TO 3000
C..........
C....ASSIGNMENT OF DESIGNATED SCALE FACTOR AND PLOTTING OF A SMALL + AT
C....THE ORIGIN
C...
 1000 CONTINUE
      CALL FACTOR(FACT)
      CALL SMODE(0,1.)
      CALL PLOT(0.0,-YMAX,-3)
      CALL PLOT(0.0,YMARG,-3)
      CALL SYMBOL(0.0,0.0,.001,3,0.0,-1)
C..........
C....DETERMINATION OF SCALE FOR CIRCUIT LENGTH ON X AXIS
C...
      CALL SCALE (SSUMEL,XLEN,N,1)
C.....
C..             TRANSFER IF PRESSURE-LOSS PLOT ONLY
C..
      IF (IPLOT .EQ. 2) GO TO 2000
C..................
C..WALL PRESSURE DIFFERENTIAL PLOTTED AGAINST CIRCUIT LENGTH
C...
      CALL AXIS(0.0,0.0,IX,-24,XLEN,0.0,SSUMEL(N1),SSUMEL(N2))
      CALL SYMBOL(0.5,YLAB,.1,ITITLE,0.0,79)
      CALL SCALE(SSUMKO,YLEN,N,1)
      CALL AXIS(0.0,0.0,13HPRESSURE LOSS,13,PYLEN,90.,SSUMKO(N1),
     2 SSUMKO(N2))
      CALL LINE(SSUMEL,SSUMKO,N,1,1,0)
      IF (IPLOT .EQ. 1) GO TO 2500
C..........
C....DEFINITION OF LOCATION OF ORIGIN FOR NEW PLOT
C...
      CALL PLOT(0.0,-YMAX,-3)
      CALL PLOT(0.0,YMARG,-3)
      CALL PLOT(XNEXT,0.0,-3)
      CALL SYMBOL(0.0,0.0,.001,3,0.0,-1)
C..................
C..CUMMULATIVE PRESSURE LOSS PLOTTED AGAINST CIRCUIT LENGTH
C...
 2000 CONTINUE
      CALL AXIS(0.0,0.0,IX,-24,XLEN,0.0,SSUMEL(N1),SSUMEL(N2))
      CALL SYMBOL(.5,YLAB,.1,ITITLE,0.0,79)
      CALL SCALE(DELP,YLEN,N,1)
      CALL AXIS(0.0,0.0,IY,24,PYLEN,90.,DELP(N1),DELP(N2))
      CALL LINE(SSUMEL,DELP,N,1,1,0)
C..........
C....DEFINITION OF LOCATION OF ORIGIN FOR NEXT PLOT
C...
 2500 CONTINUE
```

```
      CALL PLOT(0.,0.,-YMAX,-3)
      CALL PLOT(0.,0.,YMARG,-3)
      CALL PLOT(XNEXT,0.,0,-3)
      PLOTON = 1.
C..........
C.....IF NO MORE CASES, CONTROL PERMANENTLY TAKEN FROM PLOTTER
C...
      IF (ABS(TRETRN) .LT. 1.E-6) CALL PLOT(0.,0.,0.,999)
      RETURN
C..........
C.....PARAMETER CONVERSION TO SI UNITS
C...
 3000 CONTINUE
      FACT = 2./1.26999
      XLEN = 15.*1.26999
      YLEN = 10.*1.26999
      YLAB = YLEN+.1
      XNEXT = 17.*1.26999
      YMAX = 11.*1.26999
      YMARG = .5*1.26999
      DO 3500 I = 1,6
      IY(I) = IYNM(I)
 3500 IX(I) = IXNM(I)
      GO TO 1000
      END
```

APPENDIX D

INPUT AND OUTPUT FOR SAMPLE CASES

Six wind tunnels were used, in addition to the test case (fig. 11), as sample cases to establish the reliability and accuracy of the computer program analysis technique for the various types of duct components and wind tunnel circuits. Each case included here is titled with the appropriate wind tunnel name and its pages are numbered. The performance analyses are presented on the first two to three pages of each case. The summary characteristics tabulations and the plotted information were omitted. The annotated tabulations of the input data were included for reference.

The results of the performance analyses are summarized in table 6. They are discussed and critiqued in the Results and Evaluation sections of this report.

SINGLE-RETURN, CLOSED-TEST-SECTION WIND-TUNNEL PERFORMANCE

ATMOSPHERIC PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TEST SECTION CONDITIONS --
TOTAL PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TOTAL TEMPERATURE = 14.85 DEG C = 288.00 DEG K.
VELOCITY = 133.00 M/SEC = 258.53 KNOTS. DYNAMIC PRESSURE = 10039.16 N/SQ M.

NO.	SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	2 THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/Q0
1	CONSTANT AREA DUCT	RECT	9.14	10.06	91.99	14.14			8.7	0.026	6.10	0.00560	0.00003
		RECT	9.14	10.06	91.99	14.14			8.7	0.026			
2	CONTRACTN, SINGLE	RECT	9.14	10.06	91.99	14.14	14.14	33.71	8.7	0.026	13.11		
		RECT	2.13	3.05	6.50	1.00			133.0	0.397		0.01213	0.01213
3	TEST SECT, DIFSN	RECT	2.13	3.05	6.50	1.00	1.01	0.24	133.0	0.397	4.57	0.01322	0.01322
		RECT	2.13	3.09	6.59	1.01			131.0	0.391			
4	DIFFUSER	RECT	2.13	3.09	6.59	1.01	1.01	3.09	131.0	0.391	0.34	0.00099	0.00096
		RECT	2.15	3.11	6.67	1.03			129.0	0.385			
5	INTERNAL STRUCTURE	RECT	2.13	3.09	6.26	0.96			139.2	0.416		0.00224	0.00244
		RECT	2.15	3.11	6.67	1.03			129.0	0.385			
6	DIFFUSER	RECT	2.15	3.11	6.67	1.03	4.17	6.00	129.0	0.385	28.96	0.08292	0.07838
		RECT	4.84	5.75	27.82	4.28			28.9	0.085			
7	CORNER WITH VANES	RECT	4.84	5.75	27.82	4.28			28.9	0.085	6.21	0.15748	0.00799
		RECT	4.84	5.75	27.82	4.28			28.9	0.085			
8	DIFFUSER	RECT	4.84	5.75	27.82	4.28	1.35	5.98	28.9	0.085	9.14	0.01500	0.00076
		RECT	5.68	6.60	37.47	5.76			21.4	0.063			
9	CORNER WITH VANES	RECT	5.68	6.60	37.47	5.76			21.4	0.063	7.04	0.16035	0.00448
		RECT	5.68	6.60	37.47	5.76			21.4	0.063			

NO.	SECTION TYPE	SHAPE	H1 / H2 METERS	W1,D1 / W2,D2 METERS	AREA1 / AREA2 SQ M	A1/A0 / A2/A0	AR,CR	2 THETA DEGREES	V1 / V2 M/SEC	MACH1 / MACH2	LENGTH METERS	DP/QL	DP/Q0
10	DIFFUSER	RECT	5.68	6.60	37.47	5.76	1.59	6.01	21.4	0.063	17.16	0.02364	0.00066
		CIRC		8.71	59.56	9.16			13.5	0.040			
11	FAN CONTRACTION	CIRC		8.71	59.56	9.16	1.29	38.48	13.5	0.040	1.51		
		CIRC		8.87	46.04	7.08			17.4	0.051		0.00066	0.00001
12	FAN DUCT & STRUTS	CIRC		8.87	46.04	7.08			17.4	0.051	0.61	0.00914	0.00017
		CIRC		8.87	46.04	7.08			17.4	0.051			
13	MULT INTRNL STRCTR	CIRC		8.87	46.13	7.09			17.4	0.051		0.01129	0.00021
		CIRC		8.87	61.75	9.49			13.0	0.038			
14	FAN DIFSR&CNTR BDY	CIRC		8.87	55.84	8.59	1.65	7.54	14.3	0.042	18.14	0.05617	0.00071
		RECT	9.14	10.06	91.99	14.14			8.7	0.026			
15	CONTRACTN, SINGLE	RECT	9.14	10.06	91.99	14.14	1.23	11.51	8.7	0.026	5.33		
		RECT	8.19	9.11	74.61	11.47			10.7	0.032		0.00171	0.00001
16	DIFFUSER	RECT	8.19	9.11	74.61	11.47	1.08	6.93	10.7	0.032	3.05	0.00306	0.00002
		RECT	8.52	9.43	80.37	12.36			10.0	0.029			
17	DIFFUSER	RECT	8.52	9.43	80.37	12.36	1.14	7.58	10.0	0.029	5.33	0.00565	0.00003
		RECT	9.14	10.06	91.99	14.14			8.7	0.026			
18	CONSTANT AREA DUCT	RECT	9.14	10.06	91.99	14.14			8.7	0.026	1.52	0.00140	0.00001
		RECT	9.14	10.06	91.99	14.14			8.7	0.026			
19	CORNER WITH VANES	RECT	9.14	10.06	91.99	14.14			8.7	0.026	10.52	0.17085	0.00079
		RECT	9.14	10.06	91.99	14.14			8.7	0.026			
20	CONSTANT AREA DUCT	RECT	9.14	10.06	91.99	14.14			8.7	0.026	5.38	0.00494	0.00002
		RECT	9.14	10.06	91.99	14.14			8.7	0.026			
21	CORNER WITH VANES	RECT	9.14	10.06	91.99	14.14			8.7	0.026	10.29	0.18071	0.00084
		RECT	9.14	10.06	91.99	14.14			8.7	0.026			

TOTAL CENTERLINE LENGTH = 154.32 METERS

PERFORMANCE SUMMARY --
TOTAL PRESSURE LOSS (DP/QO) = 0.12387 ENERGY RATIO = 8.073
TOTAL POWER --

INPUT TO FLOW	OUTPUT REQUIRED	AVERAGE PER FAN	FAN EFFICIENCY	TOTAL NUMBER OF FANS
996651. WATTS	1172530. WATTS	1172530. WATTS	85.00 PERCENT	1.

MAXIMUM VELOCITY FOR A SPECIFIED POWER CONSUMPTION

THE MAXIMUM TEST SECTION FLOW ACHIEVABLE WITH 1110000. WATTS OF POWER AVAILABLE IS APPROXIMATELY AS FOLLOWS --
VELOCITY -- 130.33 M/SEC = 253.34 KNOTS
MACH NUMBER -- 0.39
DYNAMIC PRESSURE -- 9669.53 N/SQ M

ANNOTATED INPUT DATA TABULATION

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

TUNNEL MASTER CONTROL DATA

	CASE SEQ. NO.	TUNNEL TYPE	UNITS	SECT. INLET SHAPE	SECT. EXIT SHAPE	H1 M	W1 D1 M	MODEL BLKGE PER-CENT	VO M/SEC	POWER LEVEL MEGA-WATTS	PT ATM	TT DEG C	P ATM ATM
DATA FIELD BEGINS IN CARD COLUMN --	1	3	4	5	6	11	16	21	26	31	36	41	46
	++	+	+	+	+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+
	-2	1	1	2	2	2.134	3.048	EMPTY	133.0	1.110	1.000	14.85	1.000

CASE TERMINATION CONDITIONS DATA

CASE TERMINATION OCCURRED (DUE TO BLANKS IN CARD COLUMNS 3 AND 4)
AFTER 21 INPUT SECTIONS, AND ACCORDING TO THE FOLLOWING CONDITIONS --

	SUMMARY CHARACTERISTICS OUTPUT	PLOTTING AS A FUNCTION OF LENGTH	INPUT DATA TABULATION	VELOCITY-OPTIMIZATION (FIXED POWER)	RETURN FOR NEXT CASE
TERMINATION-CODE DATA FIELD IS CONTAINED IN CARD COLUMNS --	5-6	7-8	9-10	11-15	16-20
	+-------------+	+---------+	+--------+	+-----------+	+------+
	NO	NONE	YES (CHOSEN)	YES	YES

ANNOTATED INPUT DATA TABULATION

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER- CENT	DEG			10(6), 10(-6) METERS	PER- CENT	PER- CENT
DATA FIELD BEGINS IN CARD COLUMN -- 1	3	5	6	7	9	11	16	21	26	31	36	41	46	51	56	61	66	71	76
++	++	+	+	++	++	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+
1	10	2	2			9.144	10.06	6.096	9.144	10.06									
2	20	2	2			9.144	10.06	13.11	2.134	3.048									
3	3	2	2			2.134	3.048	4.572	2.134	3.088					OPT'N				
4	40	2	2			2.134	3.088	0.3447	2.149	3.106					OPT'N				
5	56	2	2		2.	2.134	3.088		2.149	3.106	0.1121		4.954			0.0100			EMPTY
6	40	2	2			2.149	3.106	28.96	4.837	5.752					OPT'N				
7	32	2	2			4.837	5.752	6.209	4.837	5.752		0.3048		90.00	OPT'N		OPT'N		
8	40	2	2			4.837	5.752	9.144	5.681	6.596					OPT'N				
9	32	2	2			5.681	6.596	7.045	5.681	6.596		0.3048		90.00	OPT'N		OPT'N		

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER- CENT	DEG			10(6), 10(-6) METERS	PER- CENT	PER- CENT
DATA FIELD BEGINS IN CARD COLUMN --																			
1 ++	3 ++	5 +	6 +	7 ++	9 ++	11 +---+	16 +---+	21 +---+	26 +---+	31 +---+	36 +---+	41 +---+	46 +---+	51 +---+	56 +---+	61 +---+	66 +---+	71 +---+	76 +---+
10	4C	2	1			5.681	6.596	17.16		8.708					OPT'N				
11	92	1	1	1.	2.		8.708	1.507		8.667		2.743	8.780						
12	91	1	1	1.	2.		8.867	0.6096		8.867	0.4149	2.743	8.780			0.0100		85.00	EMPTY
13	96	1	1	1.	9.		8.867			8.867	0.1254		2.811			0.0100			EMPTY
14	94	1	2	1.	OPT'N		8.867	18.14	9.144	10.06		2.743	EMPTY		OPT'N				
15	20	2	2			9.144	10.06	5.334	8.193	9.107									
16	40	2	2			8.193	9.107	3.048	8.519	9.434					OPT'N				
17	40	2	2			8.519	9.434	5.334	9.144	10.06					OPT'N				
18	10	2	2			9.144	10.06	1.524	9.144	10.06									
19	32	2	2			9.144	10.06	10.52	9.144	10.06		0.3048		90.00	OPT'N		OPT'N		
20	1C	2	2			9.144	10.06	5.377	9.144	10.06									
21	32	2	2			9.144	10.06	10.29	9.144	10.06		0.1524		90.00	OPT'N		OPT'N		

** '* NASA-AMES RESEARCH CENTER 7- BY 10-FOOT WIND TUNNEL *' CASE COMPLETED OR TERMINATED. **

SINGLE-RETURN, CLOSED-TEST-SECTION WIND-TUNNEL PERFORMANCE

ATMOSPHERIC PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TEST SECTION CONDITIONS --
TOTAL PRESSURE = 1.019 ATMOSPHERES = 103250.1 N/SQ M.
TOTAL TEMPERATURE = 14.85 DEG C = 288.00 DEG K.
VELOCITY = 52.27 M/SEC = 101.60 KNOTS. DYNAMIC PRESSURE = 1687.59 N/SQ M.

NO.	SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	∠ THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/Q0
1	CONSTANT AREA DUCT	RECT	15.70	15.70	246.49	3.40			15.2	0.045	6.10	0.00292	0.00025
		RECT	15.70	15.70	246.49	3.40			15.2	0.045			
2	CONTRACTN, SINGLE	RECT	15.70	15.70	246.49	3.40	3.40	40.57	15.2	0.045	10.97		
		RECT	9.14	7.92	72.47	1.00			52.3	0.154		0.00286	0.00286
3	TEST SECT, DIFSN	RECT	9.14	7.92	72.47	1.00	1.02	0.35	52.3	0.154	19.20	0.01565	0.01565
		RECT	9.14	8.12	74.22	1.02			51.0	0.150			
4	CONTRACTN, SINGLE	RECT	9.14	8.12	74.22	1.02	2.11	24.44	51.0	0.150	7.01		
		RECT	4.95	7.09	35.10	0.48			112.7	0.335		0.00254	0.01130
5	DIFFUSER	RECT	4.95	7.09	35.10	0.48	1.02	0.26	112.7	0.335	13.11	0.01483	0.06602
		RECT	4.95	7.21	35.74	0.49			110.5	0.328			
6	DIFFUSER	RECT	4.95	7.21	35.74	0.49	2.11	5.87	110.5	0.328	29.79	0.06272	0.26884
		RECT	8.69	8.69	75.46	1.04			50.1	0.148			
7	CORNER WITH VANES	RECT	8.69	8.69	75.46	1.04			50.1	0.148	9.75	0.14222	0.13102
		RECT	8.69	8.69	75.46	1.04			50.1	0.148			
8	DIFFUSER	RECT	8.69	8.69	75.46	1.04	1.26	6.51	50.1	0.148	10.59	0.00990	0.00912
		RECT	9.75	9.75	95.14	1.31			39.6	0.117			
9	CORNER WITH VANES	RECT	9.75	9.75	95.14	1.31			39.6	0.117	10.82	0.14366	0.08292
		RECT	9.75	9.75	95.14	1.31			39.6	0.117			

NO.	SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	2 THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/Q0
10	SCREEN, WIRE MESH	RECT RECT	9.75 9.75	9.75 9.75	95.14 95.14	1.31 1.31			39.6 39.6	0.117 0.117		0.06777	0.03912
11	DIFFUSER	RECT CIRC	9.75	9.75 11.58	95.14 105.32	1.31 1.45	1.11	8.57	39.6 35.7	0.117 0.105	3.83	0.00327	0.00189
12	FAN CONTRACTION	CIRC CIRC		11.58 11.89	105.32 69.62	1.45 0.96	1.51	15.75	35.7 54.5	0.105 0.161	7.83	0.00244	0.00265
13	FAN DUCT & STRUTS	CIRC CIRC		11.89 11.89	69.62 69.62	0.96 0.96			54.5 54.5	0.161 0.161	5.64	0.02219	0.02407
14	FAN DIFSR&CNTR BDY	CIRC CIRC		11.89 11.89	69.62 111.03	0.96 1.53	1.59	11.18	54.5 33.9	0.161 0.100	12.65	0.02837	0.03077
15	DIFFUSER	CIRC RECT	15.70	11.89 15.70	111.03 246.49	1.53 3.40	2.22	6.04	33.9 15.2	0.100 0.045	55.17	0.03921	0.01659
16	CORNER WITH VANES	RECT RECT	15.70 15.70	15.70 15.70	246.49 246.49	3.40 3.40			15.2 15.2	0.045 0.045	17.53	0.14696	0.01257
17	CONSTANT AREA DUCT	RECT RECT	15.70 15.70	15.70 15.70	246.49 246.49	3.40 3.40			15.2 15.2	0.045 0.045	3.35	0.00161	0.00014
18	CORNER WITH VANES	RECT RECT	15.70 15.70	15.70 15.70	246.49 246.49	3.40 3.40			15.2 15.2	0.045 0.045	17.53	0.14696	0.01257
19	SCREEN, WIRE MESH	RECT RECT	15.70 15.70	15.70 15.70	246.49 246.49	3.40 3.40			15.2 15.2	0.045 0.045		1.96061	0.16763

TOTAL CENTERLINE LENGTH = 240.87 METERS

```
PERFORMANCE SUMMARY --
   TOTAL PRESSURE LOSS (DP/QO) = 0.89596       ENERGY RATIO =  1.116
   TOTAL POWER --
       INPUT TO FLOW      OUTPUT REQUIRED      AVERAGE PER FAN      FAN EFFICIENCY      TOTAL NUMBER OF FANS
       5733046. WATTS     6034785. WATTS       6034785. WATTS       95.00  PERCENT              1.

                              MAXIMUM VELOCITY FOR A SPECIFIED POWER CONSUMPTION

THE MAXIMUM TEST SECTION FLOW ACHIEVABLE WITH  6058999. WATTS OF POWER AVAILABLE IS APPROXIMATELY AS FOLLOWS --
            VELOCITY --     52.34 M/SEC =  101.74 KNOTS
            MACH NUMBER --  0.15
            DYNAMIC PRESSURE --    1692.08 N/SQ M
```

ANNOTATED INPUT DATA TABULATION

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

TUNNEL MASTER CONTROL DATA

	CASE SEQ. NO.	TUNNEL TYPE	UNITS	SECT. INLET SHAPE	SECT. EXIT SHAPE	H1	W1 D1	MODEL BLKGE PER-	VO	POWER LEVEL MEGA-	PT	TT	P ATM
						M	M	CENT	M/SEC	WATTS	ATM	DEG C	ATM
DATA FIELD BEGINS IN CARD COLUMN --	1	3	4	5	6	11	16	21	26	31	36	41	46
	++	+	+	+	+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+
	-3	1	1	2	2	9.144	7.925	EMPTY	52.27	6.059	1.019	14.85	1.000

CASE TERMINATION CONDITIONS DATA

CASE TERMINATION OCCURRED (DUE TO BLANKS IN CARD COLUMNS 3 AND 4)
AFTER 19 INPUT SECTIONS, AND ACCORDING TO THE FOLLOWING CONDITIONS --

TERMINATION-CODE	SUMMARY CHARACTERISTICS OUTPUT	PLOTTING AS A FUNCTION OF LENGTH	INPUT DATA TABULATION	VELOCITY-OPTIMIZATION (FIXED POWER)	RETURN FOR NEXT CASE
DATA FIELD IS CONTAINED IN CARD COLUMNS --	5-6	7-8	9-10	11-15	16-20
	+-------------+	+---------+	+---------+	+-----------+	+-------+
	NO	NONE	YES (CHOSEN)	YES	YES

ANNOTATED INPUT DATA TABULATICN

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			10(6), 10(-6) METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARD COLUMN -- 1	3	5	6	7	9	11	16	21	26	31	36	41	46	51	56	61	66	71	76
++	++	+	+	++	++	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+
1	10	2	2			15.70	15.70	6.096	15.70	15.70									
2	20	2	2			15.70	15.70	10.97	9.144	7.925									
3	3	2	2			9.144	7.925	19.20	9.144	8.117					OPT'N				
4	20	2	2			9.144	8.117	7.010	4.953	7.087									
5	40	2	2			4.953	7.087	13.11	4.953	7.215					OPT'N				
6	40	2	2			4.953	7.215	29.79	8.687	8.687					OPT'N				
7	32	2	2			8.687	8.687	9.754	8.687	8.687		1.067		90.00	OPT'N		OPT'N		
8	40	2	2			8.687	6.687	10.59	9.754	9.754					OPT'N				
9	32	2	2			9.754	9.754	10.82	9.754	9.754		1.067		90.00	OPT'N		OPT'N		

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			10(6), 10(-6) METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARD COLUMN -- 1 ++	3 ++	5 +	6 +	7 ++	9 ++	11 +---+	16 +---+	21 +---+	26 +---+	31 +---+	36 +---+	41 +---+	46 +---+	51 +---+	56 +---+	61 +---+	66 +---+	71 +---+	76 +---+
10	54	2	2			9.754	9.754		9.754	9.754		0.0030	95.00		OPT'N				
11	40	2	1			9.754	9.754	3.831		11.58					OPT'N				
12	92	1	1	1.	5.		11.58	7.827		11.89		4.724	5.110						
13	91	1	1	1.	5.		11.89	5.639		11.89	0.3329	4.724	5.110			0.0100		95.00	EMPTY
14	94	1	1	1.	5.		11.89	12.65		11.89		4.724	5.110		OPT'N				
15	40	1	2				11.89	55.17	15.70	15.70					OPT'N				
16	32	2	2			15.70	15.70	17.53	15.70	15.70		1.829		90.00	OPT'N		OPT'N		
17	10	2	2			15.70	15.70	3.353	15.70	15.70									
18	32	2	2			15.70	15.70	17.53	15.70	15.70		1.829		90.00	OPT'N		OPT'N		
19	54	2	2			15.70	15.70		15.70	15.70		0.0015	47.00		OPT'N				

** '* LOCKHEED-GEORGIA LOW-SPEED WIND TUNNEL, V/STOL TEST SECTION *' CASE COMPLETED OR TERMINATED. **

NON-RETURN, CLOSED-TEST-SECTION WIND-TUNNEL PERFORMANCE

ATMOSPHERIC PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TEST SECTION CONDITIONS --
TOTAL PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TOTAL TEMPERATURE = 14.85 DEG C = 288.00 DEG K.
VELOCITY = 96.32 M/SEC = 187.23 KNOTS. DYNAMIC PRESSURE = 5465.13 N/SQ M.

NO.	SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	2 THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/Q0
1	SCREEN, WIRE MESH	RECT	6.10	24.38	148.62	14.10			6.6	0.019		0.25621	0.00124
		RECT	6.10	24.38	148.62	14.10			6.6	0.019			
2	SCREEN, WIRE MESH	RECT	6.10	24.38	148.62	14.10			6.6	0.019		0.25621	0.00124
		RECT	6.10	24.38	148.62	14.10			6.6	0.019			
3	SCREEN, WIRE MESH	RECT	6.10	24.38	148.62	14.10			6.6	0.019		0.25621	0.00124
		RECT	6.10	24.38	148.62	14.10			6.6	0.019			
4	SCREEN, WIRE MESH	RECT	6.10	24.38	148.62	14.10			6.6	0.019		0.25621	0.00124
		RECT	6.10	24.38	148.62	14.10			6.6	0.019			
5	SCREEN, WIRE MESH	RECT	6.10	24.38	148.62	14.10			6.6	0.019		0.25621	0.00124
		RECT	6.10	24.38	148.62	14.10			6.6	0.019			
6	CONTRACTN, SINGLE	RECT	6.10	24.38	148.62	14.10	8.17	28.11	6.6	0.019	17.86		
		FL O	3.47	5.99	18.19	1.73			54.3	0.160		0.00941	0.00307
7	CONTRACTN, SINGLE	FL O	3.47	5.99	18.19	1.73	1.73	11.96	54.3	0.160	5.49		
		FL O	2.82	4.34	10.54	1.00			96.3	0.286		0.00357	0.00357
8	TEST SECT, DIFSN	FL O	2.82	4.34	10.54	1.00	1.07	1.26	96.3	0.286	6.10	0.01241	0.01241
		FL O	2.95	4.47	11.33	1.07			89.1	0.264			
9	DIFFUSER	FL O	2.95	4.47	11.33	1.07	3.67	5.40	89.1	0.264	36.85	0.08077	0.06953
		FL O	4.72	9.80	41.53	3.94			23.5	0.069			

NO.	SECTION TYPE	SHAPE	H1 / H2 METERS	W1,D1 / W2,D2 METERS	AREA1 / AREA2 SQ M	A1/AO / A2/AO	AR,CR	2 THETA DEGREES	V1 / V2 M/SEC	MACH1 / MACH2	LENGTH METERS	DP/QL	DP/QO
10	FAN CONTRACTION	FL O	4.72	5.41	41.54	3.94	1.28	11.11	23.5	0.069	3.05		
		CIRC		4.88	32.51	3.08			30.1	0.089		0.00238	0.00024
11	FAN DUCT & STRUTS	CIRC		4.88	32.51	3.08			30.1	0.089	0.61	0.00626	0.00063
		CIRC		4.88	32.51	3.08			30.1	0.089			
12	FAN DIFSR&CNTR BDY	CIRC		4.88	34.00	3.22	1.63	13.69	28.8	0.085	5.33	0.13864	0.01285
		FL O	5.26	6.39	55.29	5.24			17.7	0.052			
13	SUD EXP M C - SNGL	FL O	5.26	6.39	55.29	5.24	1.09	90.00	17.7	0.052	0.00	0.00747	0.00026
		RECT	5.26	11.51	60.52	5.74			16.1	0.047			
14	CORNER, NO VANES	RECT	5.26	11.51	60.52	5.74			16.1	0.047	6.10	0.60893	0.01777
		RECT	6.32	11.58	73.24	6.95			13.3	0.039			
15	EXIT KINETIC ENRGY	RECT	6.32	11.58	73.24	6.95			13.3	0.039		0.99942	0.01991
		RECT	6.32	11.58	73.24	6.95			13.3	0.039			

TOTAL CENTERLINE LENGTH = 81.38 METERS

PERFORMANCE SUMMARY --
TOTAL PRESSURE LOSS (DP/QO) = 0.14644   ENERGY RATIO = 6.829
TOTAL POWER --

INPUT TO FLOW	OUTPUT REQUIRED	AVERAGE PER FAN	FAN EFFICIENCY	TOTAL NUMBER OF FANS
783658. WATTS	1135735. WATTS	567868. WATTS	69.00 PERCENT	2.

MAXIMUM VELOCITY FOR A SPECIFIED POWER CONSUMPTION

THE MAXIMUM TEST SECTION FLOW ACHIEVABLE WITH 862800. WATTS OF POWER AVAILABLE IS APPROXIMATELY AS FOLLOWS --
VELOCITY -- 87.50 M/SEC = 170.08 KNOTS
MACH NUMBER -- 0.26
DYNAMIC PRESSURE -- 4541.55 N/SQ M

ANNCTATED INPUT DATA TABULATION

'EMPTY' INCICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INCICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

TUNNEL MASTER CONTROL DATA

	CASE SEQ. NC.	TUNNEL TYPE	UNITS	SECT. INLET SHAPE	SECT. EXIT SHAPE	HI M	WI DI M	MODEL BLKGE PER-CENT	VO M/SEC	POWER LEVEL MEGA-WATTS	PT ATM	TT DEG C	P ATM ATM
DATA FIELD BEGINS IN CARD CCLUMN --	1	3	4	5	6	11	16	21	26	31	36	41	46
	-4	3	1	3	3	2.821	4.343	EMPTY	96.32	0.8628	1.000	14.85	1.000

CASE TERMINATION CONDITIONS DATA

CASE TERMINATION OCCURRED (DUE TO BLANKS IN CARD COLUMNS 3 AND 4)
AFTER 15 INPUT SECTIONS, AND ACCORDING TO THE FOLLOWING CONDITIONS --

TERMINATICN-CCDE	SUMMARY CHARACTERISTICS OUTPUT	PLOTTING AS A FUNCTION OF LENGTH	INPUT DATA TABULATION	VELOCITY-OPTIMIZATION (FIXED POWER)	RETURN FOR NEXT CASE
DATA FIELD IS CONTAINED IN CARD CCLUMNS --	5-6	7-8	9-10	11-15	16-20
	NO	NONE	YES (CHOSEN)	YES	YES

ANNOTATED INPUT DATA TABULATION

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			10(6), 10(-6) METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARD COLUMN -- 1	3	5	6	7	9	11	16	21	26	31	36	41	46	51	56	61	66	71	76
++	++	+	+	++	++	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+
1	54	2	2			6.096	24.38		6.096	24.38		0.0005	84.12		OPT'N				
2	54	2	2			6.096	24.38		6.096	24.38		0.0005	84.12		OPT'N				
3	54	2	2			6.096	24.38		6.096	24.38		0.0005	84.12		OPT'N				
4	54	2	2			6.096	24.38		6.096	24.38		0.0005	84.12		OPT'N				
5	54	2	2			6.096	24.38		6.096	24.38		0.0005	84.12		OPT'N				
6	20	2	3			6.096	24.38	17.86	3.469	5.989									
7	20	3	3			3.469	5.989	5.486	2.821	4.343									
8	3	3	3			2.821	4.343	6.096	2.950	4.474					OPT'N				
9	40	3	3			2.950	4.474	36.85	4.724	9.805					OPT'N				

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			10(6), 10(-6) METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARD COLUMN -- 1 ++	3 ++	5 +	6 +	7 ++	9 ++	11 +----+	16 +----+	21 +----+	26 +----+	31 +----+	36 +----+	41 +----+	46 +----+	51 +----+	56 +----+	61 +----+	66 +----+	71 +----+	76 +----+
10	92	3	1	2.	2.	4.724	5.410	3.048		4.877		1.463	2.186						
11	91	1	1	2.	2.		4.877	0.6096		4.877	0.2369	1.463	2.186			0.0100		69.00	EMPTY
12	94	1	3	2.	OPT'N		4.877	5.334	5.258	6.386		1.463	EMPTY		OPT'N				
13	86	3	2	2.		5.258	6.386		5.258	11.51									
14	33	2	2			5.258	11.51	6.096	6.325	11.58				50.00	OPT'N				
15	45	2	2			6.325	11.58		6.325	11.58									

** ** INDIAN INSTITUTE OF SCIENCE 14- BY 9-FOOT WIND TUNNEL AT BANGALORE ** CASE COMPLETED OR TERMINATED. **

HAWKER SIDDELEY AIRCRAFT 15-FOOT V/STOL WIND TUNNEL AT HATFIELD *

NON-RETURN, CLOSED-TEST-SECTION WIND-TUNNEL PERFORMANCE

ATMOSPHERIC PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TEST SECTION CONDITIONS --
TOTAL PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TOTAL TEMPERATURE = 14.85 DEG C = 288.00 DEG K.
VELOCITY = 45.72 M/SEC = 88.87 KNOTS. DYNAMIC PRESSURE = 1270.61 N/SQ M.

NO. SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	2 THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/QO
1 SCREEN, PERF PLATE	RECT	11.13	39.32	437.63	20.94			2.2	0.006		20.66628	0.04672
	RECT	11.13	39.32	437.63	20.94			2.2	0.006			
2 CONTRACTN, SINGLE	RECT	11.13	39.32	437.63	20.94	3.23	59.55	2.2	0.006	9.14	0.00222	0.00005
	RECT	11.13	12.19	135.67	6.49			7.0	0.021			
3 HONEYCOMB FLOW STR	RECT	11.13	10.06	111.97	5.36			8.5	0.025	0.91	0.02985	0.00103
	RECT	11.13	10.06	111.97	5.36			8.5	0.025			
4 CONTRACTN, SINGLE	RECT	11.13	12.19	135.67	6.49	6.49	47.17	7.0	0.021	9.14	0.00493	0.00493
	RECT	4.57	4.57	20.90	1.00			45.7	0.135			
5 CONSTANT AREA DUCT	RECT	4.57	4.57	20.90	1.00			45.7	0.135	2.44	0.00410	0.00410
	RECT	4.57	4.57	20.90	1.00			45.7	0.135			
6 TEST SECT, CONST A	RECT	4.57	4.57	20.90	1.00			45.7	0.135	7.31	0.01232	0.01232
	RECT	4.57	4.57	20.90	1.00			45.7	0.135			
7 CONSTANT AREA DUCT	RECT	4.57	4.57	20.90	1.00			45.7	0.135	2.44	0.00410	0.00410
	RECT	4.57	4.57	20.90	1.00			45.7	0.135			
8 CONSTANT AREA DUCT	RECT	4.57	4.57	20.90	1.00			45.7	0.135	1.83	0.00308	0.00308
	CIRC		5.16	20.89	1.00			45.8	0.135			
9 DIFFUSER	CIRC		5.16	20.89	1.00	2.14	8.15	45.8	0.135	16.76	0.04015	0.04021
	CIRC		7.54	44.70	2.14			21.2	0.062			

* HAWKER SIDDELEY AIRCRAFT 15-FOOT V/STOL WIND TUNNEL AT HATFIELD * ...CONTINUED.... PAGE 2

NO.	SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	2 THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/Q0
++	+-----------+	+---+	+-----+	+-----+	+---+	+---+	+---+	+-----+	+----+	+---+	+-----+	+---+	+---+
10	DIFFUSER	CIRC CIRC		7.54 8.78	44.70 60.56	2.14 2.90	1.35	22.94	21.2 15.7	0.062 0.046	3.05	0.03242	0.00704
11	FAN CONTRACTION	CIRC CIRC		3.31 3.05	60.23 34.40	2.88 1.65	1.75	82.97	15.7 27.6	0.046 0.081	0.46	0.00057	0.00021
12	FAN DUCT & STRUTS	CIRC CIRC		3.05 3.05	45.78 45.78	2.19 2.19			20.7 20.7	0.061 0.061	1.52	0.05900	0.01221
13	SUD EXP M D - SNGL	CIRC CIRC		2.89 8.78	45.79 60.56	2.19 2.90	1.32	90.00	20.7 15.7	0.061 0.046	0.00	0.05947	0.01230
14	CONSTANT AREA DUCT	CIRC CIRC		8.78 8.78	60.56 60.56	2.90 2.90			15.7 15.7	0.046 0.046	2.59	0.00241	0.00028
15	SUDDEN EXPANSION	CIRC RECT	 10.36	8.78 14.02	60.56 145.25	2.90 6.95	2.40	90.00	15.7 6.5	0.046 0.019	0.00	0.33996	0.04018
16	CORNER, NO VANES	RECT RECT	10.36 10.36	14.02 12.50	145.25 129.50	6.95 6.20			6.5 7.3	0.019 0.022	9.75	1.81366	0.03723
17	EXIT KINETIC ENRGY	RECT RECT	10.36 10.36	12.50 12.50	129.50 129.50	6.20 6.20			7.3 7.3	0.022 0.022		1.00090	0.02585

TOTAL CENTERLINE LENGTH = 67.36 METERS

PERFORMANCE SUMMARY --

TOTAL PRESSURE LOSS (DP/Q0) = 0.25186 ENERGY RATIO = 3.971

TOTAL POWER --

INPUT TO FLOW	OUTPUT REQUIRED	AVERAGE PER FAN	FAN EFFICIENCY	TOTAL NUMBER OF FANS
303640. WATTS	319620. WATTS	45660. WATTS	95.00 PERCENT	7.

MAXIMUM VELOCITY FOR A SPECIFIED POWER CONSUMPTION

THE MAXIMUM TEST SECTION FLOW ACHIEVABLE WITH 522200. WATTS OF POWER AVAILABLE IS APPROXIMATELY AS FOLLOWS --

VELOCITY -- 53.96 M/SEC = 104.89 KNOTS
MACH NUMBER -- 0.16
DYNAMIC PRESSURE -- 1763.80 N/SQ M

ANNOTATED INPUT DATA TABULATION

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

TUNNEL MASTER CONTROL DATA

	CASE SEQ. NO.	TUNNEL TYPE	UNITS	SECT. INLET SHAPE	SECT. EXIT SHAPE	H1 M	W1 D1 M	MODEL BLKGE PER-CENT	VO M/SEC	POWER LEVEL MEGA-WATTS	PT ATM	TT DEG C	P ATM ATM
DATA FIELD BEGINS IN CARD COLUMN --	1	3	4	5	6	11	16	21	26	31	36	41	46
	++	+	+	+	+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+
	-5	3	1	2	2	4.572	4.572	EMPTY	45.720	.5222	1.000	14.85	1.000

CASE TERMINATION CONDITIONS DATA

CASE TERMINATION OCCURRED (DUE TO BLANKS IN CARD COLUMNS 3 AND 4)
AFTER 17 INPUT SECTIONS, AND ACCORDING TO THE FOLLOWING CONDITIONS --

	SUMMARY CHARACTERISTICS OUTPUT	PLOTTING AS A FUNCTION OF LENGTH	INPUT DATA TABULATION	VELOCITY-OPTIMIZATION (FIXED POWER)	RETURN FOR NEXT CASE
TERMINATION-CODE DATA FIELD IS CONTAINED IN CARD COLUMNS --	5-6	7-8	9-10	11-15	16-20
	+------------+	+---------+	+--------+	+-----------+	+------+
	NO	NONE	YES (CHOSEN)	YES	YES

ANNCTATED INPUT DATA TABULATION

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERC.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			10(6), 10(-6) METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARD CCLUMN -- 1	3	5	6	7	9	11	16	21	26	31	36	41	46	51	56	61	66	71	76
++	++	+	+	++	++	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+
1	53	2	2			11.13	39.32		11.13	39.32			28.79						
2	20	2	2			11.13	39.32	9.144	11.13	12.19									
3	51	2	2			11.13	10.06	0.9144	11.13	10.06	1.200		90.00				OPT'N		
4	2C	2	2			11.13	12.19	9.144	4.572	4.572									
5	10	2	2			4.572	4.572	2.438	4.572	4.572									
6	1	2	2			4.572	4.572	7.315	4.572	4.572									
7	10	2	2			4.572	4.572	2.438	4.572	4.572									
8	10	2	1			4.572	4.572	1.829		5.157									
9	40	1	1				5.157	16.76		7.544					OPT'N				

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			10(6), 10(-6) METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARD CCLUMN -- 1 ++	3 ++	5 +	6 +	7 ++	9 ++	11 +----+	16 +----+	21 +----+	26 +----+	31 +----+	36 +----+	41 +----+	46 +----+	51 +----+	56 +----+	61 +----+	66 +----+	71 +----+	76 +----+
10	40	1	1				7.544	3.048		8.781					OPT'N				
11	92	1	1	7.	9.		3.310	0.4572		3.048		0.6096	3.316						
12	91	1	1	7.	2.		3.048	1.524		3.048	2.653	0.6096	3.316			0.0100		95.00	EMPTY
13	86	1	1	7.			2.886			8.781									
14	10	1	1				8.781	2.591		8.781									
15	46	1	2				8.781		10.36	14.02									
16	33	2	2			10.36	14.02	9.754	10.36	12.50				90.00	OPT'N				
17	45	2	2			10.36	12.50		10.36	12.50									

** '* HAWKER SIDDELEY AIRCRAFT 15-FOOT V/STOL WIND TUNNEL AT HATFIELD *' CASE COMPLETED OR TERMINATED. **

DOUBLE-RETURN, CLOSED-TEST-SECTION WIND-TUNNEL PERFORMANCE

ATMOSPHERIC PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TEST SECTION CONDITIONS --
TOTAL PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TOTAL TEMPERATURE = 14.85 DEG C = 288.00 DEG K.
VELOCITY = 117.70 M/SEC = 228.79 KNOTS. DYNAMIC PRESSURE = 7997.46 N/SQ M.

NO.	SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	2 THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/Q0
1	CONSTANT AREA DUCT	RECT	5.94	8.99	53.45	6.29			17.6	0.052	0.76	0.00088	0.00002
		RECT	5.94	8.99	53.45	6.29			17.6	0.052			
2	CONTRACTN, SINGLE	RECT	5.94	8.99	53.45	6.29	6.14	44.45	17.6	0.052	6.02		
		RECT	2.41	3.61	8.71	1.02			114.5	0.341		0.00483	0.00459
3	CONSTANT AREA DUCT	RECT	2.38	3.57	8.50	1.00			117.7	0.350	1.52	0.00386	0.00386
		RECT	2.38	3.57	8.50	1.00			117.7	0.350			
4	TEST SECT, CONST A	RECT	2.38	3.57	8.50	1.00			117.7	0.350	3.35	0.00850	0.00850
		RECT	2.38	3.57	8.50	1.00			117.7	0.350			
5	DIFFUSER	RECT	2.38	3.57	8.50	1.00	2.70	7.42	117.7	0.350	16.31	0.08428	0.08428
		RECT	3.96	5.79	22.94	2.70			41.4	0.122			
6	MULT D 1-WALL CRNR	RECT	3.96	2.90	22.95	2.70			41.3	0.122	2.90	0.10780	0.01403
		RECT	3.96	2.90	22.95	2.70			41.3	0.122			
7	MULT DUCT DIFFUSER	RECT	3.96	2.90	22.95	2.70	1.05	1.96	41.3	0.122	2.90	0.00707	0.00092
		RECT	3.96	3.05	24.15	2.84			39.3	0.116			
8	MULT D 1-WALL CRNR	RECT	3.96	3.05	24.15	2.84			39.3	0.116	3.05	0.10818	0.01270
		RECT	3.96	3.05	24.15	2.84			39.3	0.116			
9	MULT DUCT DIFFUSER	RECT	3.96	3.05	24.15	2.84	1.31	4.91	39.3	0.116	6.71	0.01595	0.00187
		CIRC		4.50	31.75	3.73			29.8	0.088			

* UNIVERSITY OF WASHINGTON 8- BY 12-FOOT WIND TUNNEL * ...CONTINUED.... PAGE 2

NO.	SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	2 THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/Q0
10	FAN CONTRACTION	CIRC CIRC		4.50 4.50	31.75 27.95	3.73 3.29	1.14	33.80	29.8 33.9	0.088 0.100	0.46	0.00034	0.00003
11	FAN DUCT & STRUTS	CIRC CIRC		4.50 4.50	27.95 27.95	3.29 3.29			33.9 33.9	0.100 0.100	1.22	0.005C6	0.00044
12	FAN DIFSR&CATR BDY	CIRC CIRC		4.50 4.50	30.44 31.75	3.58 3.73	1.04	3.21	31.1 29.8	0.091 0.088	1.68	0.00394	0.00029
13	MULT DUCT DIFFUSER	CIRC RECT	 4.50	4.50 4.50	31.75 40.43	3.73 4.76	1.27	5.16	29.8 23.3	0.088 0.069	6.40	0.01563	0.00106
14	MULT DUCT DIFFUSER	RECT RECT	4.50 5.94	4.50 4.50	40.43 53.45	4.76 6.29	1.32	4.11	23.3 17.6	0.069 0.052	10.59	0.02002	0.00084
15	MULT DLCTS, CNST A	RECT RECT	5.94 5.94	4.50 4.50	53.45 53.45	6.29 6.29			17.6 17.6	0.052 0.052	0.76	0.00129	0.00003
16	MULT D 1-WALL CRNR	RECT RECT	5.94 5.94	4.50 4.50	53.45 53.45	6.29 6.29			17.6 17.6	0.052 0.052	4.50	0.11603	0.00277
17	MULT DUCTS, CNST A	RECT RECT	5.94 5.94	4.50 4.50	53.45 53.45	6.29 6.29			17.6 17.6	0.052 0.052	0.57	0.00097	0.00002
18	MULT D 1-WALL CRNR	RECT RECT	5.94 5.94	4.50 4.50	53.45 53.45	6.29 6.29			17.6 17.6	0.052 0.052	4.50	0.11319	0.00270

TOTAL CENTERLINE LENGTH = 74.18 METERS

PERFORMANCE SUMMARY --
TOTAL PRESSURE LOSS (DP/Q0) = 0.13895 ENERGY RATIO = 7.197
TOTAL POWER --

INPUT TC FLOW	OUTPUT REQUIRED	AVERAGE PER FAN	FAN EFFICIENCY	TOTAL NUMBER OF FANS
1051693. WATTS	1107045. WATTS	553523. WATTS	95.00 PERCENT	2.

MAXIMUM VELOCITY FOR A SPECIFIED POWER CONSUMPTION

THE MAXIMLM TEST SECTICN FLOW ACHIEVABLE WITH 1076999. WATTS OF POWER AVAILABLE IS APPROXIMATELY AS FOLLOWS --

VELOCITY -- 116.54 M/SEC = 226.53 KNOTS
MACH NUMBER -- 0.35
DYNAMIC PRESSURE -- 7849.53 N/SQ M

ANNOTATED INPUT DATA TABULATION

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

TUNNEL MASTER CONTROL DATA

	CASE SEQ. NO.	TUNNEL TYPE	UNITS	SECT. INLET SHAPE	SECT. EXIT SHAPE	H1 M	W1 D1 M	MODEL BLKGE PER-CENT	VO M/SEC	POWER LEVEL MEGA-WATTS	PT ATM	TT DEG C	P ATM ATM
DATA FIELD BEGINS IN CARD COLUMN --	1	3	4	5	6	11	16	21	26	31	36	41	46
	++	+	+	+	+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+
	-6	2	1	2	2	2.380	3.572	EMPTY	117.7	1.077	1.000	14.85	1.000

CASE TERMINATION CONDITIONS DATA

CASE TERMINATION OCCURRED (DUE TO BLANKS IN CARD COLUMNS 3 AND 4)
AFTER 18 INPUT SECTIONS, AND ACCORDING TO THE FOLLOWING CONDITIONS --

TERMINATION-CODE	SUMMARY CHARACTERISTICS OUTPUT	PLOTTING AS A FUNCTION OF LENGTH	INPUT DATA TABULATION	VELOCITY-OPTIMIZATION (FIXED POWER)	RETURN FOR NEXT CASE
DATA FIELD IS CONTAINED IN CARD COLUMNS --	5-6	7-8	9-10	11-15	16-20
	+-------------+	+---------+	+--------+	+-----------+	+------+
	NO	NONE	YES (CHOSEN)	YES	YES

ANNCTATED INPUT DATA TABULATION

'EMPTY' INCICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED CR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INCICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			10(6), 10(-6) METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARC CCLUMN -- 1	3	5	6	7	9	11	16	21	26	31	36	41	46	51	56	61	66	71	76
++	++	+	+	++	++	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+
1	10	2	2			5.944	8.992	0.7620	5.944	8.992									
2	20	2	2			5.944	8.992	6.020	2.409	3.615									
3	10	2	2			2.380	3.572	1.524	2.380	3.572									
4	1	2	2			2.380	3.572	3.353	2.380	3.572									
5	40	2	2			2.380	3.572	16.31	3.962	5.791					OPT'N				
6	71	2	2	2.		3.962	2.896	2.896	3.962	2.896		0.9144		90.00	OPT'N		OPT'N		
7	84	2	2	2.		3.962	2.896	2.896	3.962	3.048					OPT'N				
8	71	2	2	2.		3.962	3.048	3.048	3.962	3.048		0.9144		90.00	OPT'N		OPT'N		
9	84	2	1	2.		3.962	3.048	6.706		4.496					OPT'N				

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES 10(6), 10(-6)	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARD COLUMN -- 1 ++	3 ++	5 +	6 +	7 ++	9 ++	11 +---+	16 +---+	21 +---+	26 +---+	31 +---+	36 +---+	41 +---+	46 +---+	51 +---+	56 +---+	61 +---+	66 +---+	71 +---+	76 +---+
10	92	1	1	2.	4.		4.496	0.4572		4.496		0.9144	2.045						
11	91	1	1	2.	4.		4.496	1.219		4.496	0.0556	0.9144	2.045			0.0100		95.00	EMPTY
12	94	1	1	2.	OPT'N		4.496	1.676		4.496		0.9144	EMPTY		OPT'N				
13	84	1	2	2.			4.496	6.401	4.496	4.496					OPT'N				
14	84	2	2	2.		4.496	4.496	10.59	5.944	4.496					OPT'N				
15	61	2	2	2.		5.944	4.496	0.7620	5.944	4.496									
16	71	2	2	2.		5.944	4.496	4.496	5.944	4.496		0.5486		90.00	OPT'N		OPT'N		
17	61	2	2	2.		5.944	4.496	0.5715	5.944	4.496									
18	71	2	2	2.		5.944	4.496	4.496	5.944	4.496		0.8534		90.00	OPT'N		OPT'N		

DOUBLE-RETURN, OPEN-TEST-SECTION WIND-TUNNEL PERFORMANCE

ATMOSPHERIC PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TEST SECTION CONDITIONS --
TOTAL PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TOTAL TEMPERATURE = 14.85 DEG C = 288.00 DEG K.
VELOCITY = 52.73 M/SEC = 102.50 KNOTS. DYNAMIC PRESSURE = 1685.05 N/SQ M.

NO.	SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	2 THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/QO
1	CONTRACTN, SINGLE	RECT	21.95	33.52	735.76	4.93	4.93	39.99	10.6	0.031	23.11		
		FL O	9.14	18.29	149.30	1.00			52.7	0.155		0.00382	0.00382
2	OPEN-THROAT T SECT	FL O	9.14	18.29	149.30	1.00	1.84	16.45	52.7	0.155	17.07	0.10399	0.10399
		FL O	13.72	23.01	275.30	1.84			28.4	0.083			
3	CONTRACTN, SINGLE	FL O	13.72	23.01	275.30	1.84	1.67	49.83	28.4	0.083	4.57		
		FL O	9.60	19.20	164.56	1.10			47.7	0.141		0.00073	0.00060
4	DIFFUSER	FL O	9.60	19.20	164.56	1.10	1.16	12.61	47.7	0.141	5.18	0.01578	0.01296
		FL O	10.21	20.96	191.63	1.28			40.9	0.120			
5	FAN CONTRACTION	FL O	10.21	11.57	191.52	1.28	1.22	6.35	40.9	0.120	9.45		
		CIRC		10.80	156.89	1.05			50.1	0.148		0.00285	0.00258
6	FAN DUCT & STRUTS	CIRC		10.80	156.89	1.05			50.1	0.148	3.81	0.01708	0.01545
		CIRC		10.80	156.89	1.05			50.1	0.148			
7	FAN DIFSR&CNTR BDY	CIRC		10.80	160.02	1.07	1.25	11.74	49.1	0.145	5.77	0.01019	0.00885
		CIRC		11.28	199.87	1.34			39.2	0.115			
8	MULT DUCT DIFFUSER	CIRC		11.28	199.87	1.34	1.97	8.23	39.2	0.115	31.55	0.03618	0.02008
		RECT	14.02	14.02	393.12	2.63			19.8	0.058			
9	M D 2-WALL DIF CNR	RECT	14.02	14.02	393.12	2.63	1.04	1.79	19.8	0.058	15.39	0.10037	0.01433
		RECT	14.02	14.63	410.23	2.75			19.0	0.056			

NO.	SECTION TYPE	SHAPE	H1 / H2 METERS	W1,D1 / W2,D2 METERS	AREA1 / AREA2 SQ M	A1/A0 / A2/A0	AR,CR	2 THETA DEGREES	V1 / V2 M/SEC	MACH1 / MACH2	LENGTH METERS	DP/QL	DP/Q0
10	MULT DUCTS, CNST A	RECT	14.02	14.63	410.23	2.75			19.0	0.056	2.59	0.00134	0.00018
		RECT	14.02	14.63	410.23	2.75			19.0	0.056			
11	M D 2-WALL CIF CNR	RECT	14.02	14.63	410.23	2.75	1.04	1.69	19.0	0.056	16.00	0.10033	0.01315
		RECT	14.02	15.24	427.33	2.86			18.2	0.054			
12	MULT DUCT CIFFUSER	RECT	14.02	15.24	427.33	2.86	1.57	2.36	18.2	0.054	100.60	0.05122	0.00619
		RECT	21.95	15.24	669.04	4.48			11.6	0.034			
13	M D 2-WALL CIF CNR	RECT	21.95	15.24	669.04	4.48	1.05	2.55	11.6	0.034	16.15	0.10053	0.00495
		RECT	21.95	16.00	702.40	4.70			11.1	0.033			
14	MULT DUCTS, CNST A	RECT	21.95	16.00	702.40	4.70			11.1	0.033	0.53	0.00022	0.00001
		RECT	21.95	16.00	702.40	4.70			11.1	0.033			
15	M D 1-WALL CIF CNR	RECT	21.95	16.00	702.40	4.70	1.05	2.38	11.1	0.033	16.92	0.09771	0.00436
		RECT	21.95	16.76	735.76	4.93			10.6	0.031			

TOTAL CENTERLINE LENGTH = 268.70 METERS

PERFORMANCE SUMMARY --
TOTAL PRESSURE LOSS (DP/Q0) = 0.21149 ENERGY RATIO = 4.728
TOTAL POWER --

INPUT TC FLOW	OUTPUT REQUIRED	AVERAGE PER FAN	FAN EFFICIENCY	TOTAL NUMBER OF FANS
2802290. WATTS	3113654. WATTS	1556827. WATTS	90.00 PERCENT	2.

MAXIMUM VELOCITY FOR A SPECIFIED POWER CONSUMPTION

THE MAXIMUM TEST SECTION FLOW ACHIEVABLE WITH 5967994. WATTS OF POWER AVAILABLE IS APPROXIMATELY AS FOLLOWS --
VELOCITY -- 65.66 M/SEC = 127.63 KNOTS
MACH NUMBER -- 0.19
DYNAMIC PRESSURE -- 2595.44 N/SQ M

ANNCTATED INPUT DATA TABULATION

'EMPTY' INCICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED CR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INCICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

TUNNEL MASTER CONTROL DATA

	CASE SEQ. NC.	TUNNEL TYPE	UNITS	SECT. INLET SHAPE	SECT. EXIT SHAPE	H1 M	W1 D1 M	MODEL BLKGE PER-CENT	VO M/SEC	POWER LEVEL MEGA-WATTS	PT ATM	TT DEG C	P ATM ATM
DATA FIELC BEGINS IN CARD CCLUMN --	1	3	4	5	6	11	16	21	26	31	36	41	46
	++	+	+	+	+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+
	-7	5	1	3	3	9.144	18.29	EMPTY	52.73	5.968	1.000	14.85	OPT'N

CASE TERMINATION CONDITIONS DATA

CASE TERMINATION OCCURRED (DUE TC BLANKS IN CARD COLUMNS 3 AND 4)
AFTER 15 INPUT SECTIONS, AND ACCORDING TO THE FOLLOWING CONDITIONS --

TERMINATICN-CCDE	SUMMARY CHARACTERISTICS OUTPUT	PLOTTING AS A FUNCTION OF LENGTH	INPUT DATA TABULATION	VELOCITY-OPTIMIZATION (FIXED POWER)	RETURN FOR NEXT CASE
DATA FIELD IS CONTAINED IN CARD CCLUMNS --	5-6	7-8	9-10	11-15	16-20
	+-------------+	+---------+	+--------+	+-----------+	+------+
	NO	NONE	YES (CHOSEN)	YES	YES

ANNOTATED INPUT DATA TABULATION

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			10(6), 10(-6) METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARD COLUMN -- 1	3	5	6	7	9	11	16	21	26	31	36	41	46	51	56	61	66	71	76
++	++	+	+	++	++	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+	+----+
1	20	2	3			21.95	33.52	23.11	9.144	18.29									
2	5	3	3			9.144	18.29	17.07	13.72	23.01									
3	20	3	3			13.72	23.01	4.572	9.601	19.20									
4	40	3	3			9.601	19.20	5.182	10.21	20.96					OPT'N				
5	92	3	1	2.	2.	10.21	11.57	9.449		10.80		3.453	2.310						
6	91	1	1	2.	2.		10.80	3.810		10.80	0.6693	3.453	2.310			0.0100		90.00	EMPTY
7	94	1	1	2.	2.		10.80	5.773		11.28		3.453	1.357		OPT'N				
8	84	1	2	2.			11.28	31.55	14.02	14.02					OPT'N				
9	75	2	2	2.		14.02	14.02	15.39	14.02	14.63		2.134		90.00	OPT'N		OPT'N		

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA D	EPS
											M/M, SQ M/		PER-				10(6), 10(-6)	PER-	PER-
				NO.	NO.	M	M	M	M	M	SQ M	M	CENT	DEG			METERS	CENT	CENT
DATA FIELD BEGINS IN CARD COLUMN --																			
1	3	5	6	7	9	11	16	21	26	31	36	41	46	51	56	61	66	71	76
++	++	+	+	++	++	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+
10	61	2	2	2.		14.02	14.63	2.591	14.02	14.63									
11	75	2	2	2.		14.02	14.63	16.00	14.02	15.24		2.134		90.00	OPT'N		OPT'N		
12	84	2	2	2.		14.02	15.24	100.6	21.95	15.24					OPT'N				
13	75	2	2	2.		21.95	15.24	16.15	21.95	16.00		1.067		90.00	OPT'N		OPT'N		
14	61	2	2	2.		21.95	16.00	0.5334	21.95	16.00									
15	74	2	2	2.		21.95	16.00	16.92	21.95	16.76		1.067		90.00	OPT'N		OPT'N		

REFERENCES

1. McDonald, Alan T.; and Fox, Robert W.: Incompressible Flow in Conical Diffusers. Tech. Rep. No. 1, Army Research Office (Durham), Project No. 4332, 1964. (Available from Armed Services Technical Information Agency, U.S. Department of Defense.)

2. Reneau, L. R.; Johnston, J. P.; and Kline, S. J.: Performance and Design of Straight, Two-Dimensional Diffusers. Trans. ASME, Journal of Basic Engineering, Vol. 89, March 1967, pp. 141-150.

3. Rouse, Hunter; and Hassan, M. M.: Cavitation-Free Inlets and Contractions. Mechanical Engineering, Vol. 71, March 1949, pp. 213-216.

4. Pope, Alan; and Harper, John J.: Low-Speed Wind Tunnel Testing. John Wiley & Sons, Inc., N. Y., 1966.

5. Pankhurst, R. C.; and Holder, D. W.: Wind-Tunnel Technique. Sir Isaac Pitman & Sons Ltd., 1952.

6. Wattendorf, Frank L.: Factors Influencing the Energy Ratio of Return Flow Wind Tunnels. Fifth International Congress for Applied Mechanics, Cambridge, 1938, pp. 526-530.

7. Idel'chik, I. E.: Handbook of Hydraulic Resistance. AEC-TR-6630, The Israel Program for Scientific Translations Ltd., 1966. (Available from Clearinghouse for Federal Scientific and Technical Information, U.S. Department of Commerce.)

8. Kröber, G.; (translated by Dwight M. Miner): Guide Vanes for Deflecting Fluid Currents With Small Loss of Energy. NACA TM-722, 1933. (Transl. into Engligh of "Schaufelgitter zur Umlenkung von Flüssigkeitsstromungen mit geringem Energieverlust," Ingenieur-Arkiv, Vol. 3, 1932, pp. 516-541.)

9. Henry, John R.; Wood, Charles C.; and Wilbur, Stafford W.: Summary of Subsonic-Diffuser Data. NACA RM L56F05, 1956.

10. Moore, Carl A., Jr.; and Kline, Stephen J.: Some Effects of Vanes and of Turbulence in Two-Dimensional Wide-Angle Subsonic Diffusers. NACA TN 4080, 1958.

11. Cochran, D. L.; and Kline, S. J.: Use of Short Flat Vanes for Producing Efficient Wide-Angle Two-Dimensional Subsonic Diffusers. NASA TN 4309, 1958.

12. Wallis, R. A.: Axial Flow Fans. Academic Press, N. Y., 1961.

13. Chmielewski, G. E.: Boundary-Layer Considerations in the Design of Aerodynamic Contractions. J. of Aircraft, Vol. 11, No. 8, Aug. 1974, pp. 435-438.

14. Eckert, William T.; Mort, Kenneth W.; and Piazza, J. E.: Wind-Sensitivity Studies of a Non-Return Wind Tunnel With a 216- by 432-mm (8.5- by 17.0-in.) Test Section - Phase I. NASA TM X-62,171, 1972.

15. Eckert, William T.; Mort, Kenneth W.; and Piazza, J. E.: Wind-Sensitivity Studies of a Non-Return Wind Tunnel With a 216- by 432-mm (8.5- by 17.0-in.) Test Section - Phase II. NASA TM X-62,307, 1973.

16. Mort, K. W.; Eckert, W. T.; and Kelly, M. W.: The Steady-State Flow Quality of an Open Return Wind Tunnel Model. Canadian Aeronautics and Space Journal, Vol. 18, No. 9, Nov. 1972, pp. 285-289. (Also NASA TM X-62,170, 1972.)

17. Liepmann, H. W.; and Roshko, A.: Elements of Gasdynamics. John Wiley & Sons, Inc., N. Y., 1957.

18. Staff of Ames Research Center: Equations, Tables, and Charts for Compressible Flow. NACA Report 1135, 1953.

19. Sovran, Gino; and Klomp, Edward D.: Experimentally Determined Optimum Geometries for Rectilinear Diffusers with Rectangular, Conical or Annular Cross-Section. Fluid Mechanics of Internal Flow, Gino Sovran, ed., Elsevier Publishing Co., Amsterdam, 1967, pp. 270-319.

20. Annon: Low-Speed Wind Tunnel User Manual. Lockheed-Georgia Company, ER-11,000, 1970.

21. Krishnaswamy, T. N.; Ramachandra, S. M.; and Krishnamoorthy, V.: Design and Characteristics of the 14' × 9' Open Circuit Wind Tunnel. Proc. of the 11th Seminar on Aeronautical Sciences, National Aeronautics Lab., Bangalore, 1961, pp. 417-434.

22. Krishnaswamy, T. N.: Selection of the Electric Drive for the 14' × 9' Wind Tunnel. Journal of the Aeronautical Society of India, Vol. 7, No. 2, May 1955, pp. 19-28.

23. Krishnaswamy, T. N.; and Ramachandra, S. M.: Fan System of the 14' × 9' Open Circuit Wind Tunnel of the Indian Institute of Science. Journal of the Aeronautical Society of India, Vol. 18, No. 2, May 1966, pp. 47-61.

24. Kirk, J. A.: Experience With a V/STOL Tunnel. Journal of the Royal Aeronautical Society, Vol. 71, Sept. 1967, pp. 606-622.

25. DeFrance, Smith J.: The N.A.C.A. Full-Scale Wind Tunnel. NACA Report 459, 1933.

TABLE 1.- NUMERIC INPUT CODE DEFINITIONS

Code type	Code value	Description of code meaning
Tunnel type	1	Closed test section, single-return tunnel
	2	Closed test section, double-return tunnel
	3	Closed test section, non-return tunnel
	4	Open-throat, single-return tunnel
	5	Open-throat, double-return tunnel
	6	Open-throat, non-return tunnel
Units of measure	1	International System of Units (SI)
	2	U.S. Customary Units
Section shape	1	Circular cross section
	2	Rectangular cross section
	3	Flat oval cross section (ceiling and floor parallel with semicircular sidewalls)
Section type		(See table 4)
Plot type	≤0.0	No plots
	1.0	Cummulative pressure losses vs circuit length
	2.0	Wall pressure differential vs circuit length
	>2.0	Cummulative pressure losses and wall pressure differential vs circuit length (on separate plots)

TABLE 2.- TUNNEL MASTER CONTROL INPUT DATA DESCRIPTIONS

Card column(s)	Field title(s)	Requirement?[a]	Input type	Description(s)	Units
1	CASE SEQ.	Required	Minus sign	Master card identifier	---
2		Optional	Integer	Arbitrary user case number	---
3	TUNNEL TYPE	Optional	Integer	Tunnel type code (see table 1)	---
4	UNITS	Default(1)	Integer	Units of measure code (see table 1)	---
5	SECT. INLET SHAPE	Required	Integer	Test section upstream end shape code (see table 1)	---
6	SECT. EXIT SHAPE	Optional	Integer	Test section downstream end shape code (see table 1)	---
11-15	H1	Geom. Dep.	Real	Height of rectangular or flat oval test section at upstream end	m or ft
16-20	W1, D1	Required	Real	Width of rectangular or flat oval,or diameter of circular test section at upstream end	m or ft
21-25	MODEL BLKGE	Optional	Real	Blockage factor of the model in the test section (if model is to be included)	% of test section area
26-30	V0	Required	Real	Test section velocity for which power calculation is to be made	m/sec or ft/sec
31-35	POWER LEVEL	Optional	Real	Power for which maximum attainable velocity is to be calculated (if velocity-optimizing is requested)	10^6 W or 10^3 hp
36-40	PT	Default(1.0)	Real	Test section total (stagnation) pressure	ATM
41-45	TT	Required	Real	Test section total (stagnation) temperature	°C or °F
46-50	P ATM	Default(1.0)	Real	External atmospheric pressure	ATM

[a]"Default(X)" indicates the input is optional and defaults to X if omitted.
"Geom. Dep." indicates the input requirement is dependent on section geometry.
"Optional" indicates the input may be selected and included as desired.
"Required" indicates the input must be non-zero and included for all cases or the case will terminate due to input error.

TABLE 3.- SECTION INPUT DATA DESCRIPTIONS

Card column(s)	Field title(s)	Requirement?[a]	Input type	Description(s)	Units
1-2	SECT. SEQ.	Optional	Integer	Arbitrary section order number	---
3-4	SECT.TYPE	Required	Integer	Section type code (see table 4)	---
5	SECT. INLET SHAPE	Required	Integer	Section upstream end shape code (see table 1)	---
6	SECT. EXIT SHAPE	Required	Integer	Section downstream end shape code (see table 1)	---
7-8	TOTAL NO. DUCTS	Default(1.0)	Real	Number of multiple ducts	---
9-10	ITEMS PER DUCT	Default(1.0)	Real	Number of individual, flow obstruction, drag loss items in local duct	---
11-15	H1	Geom. Dep.	Real	Height of upstream end of non-circular section	m or ft
16-20	W1, D1	Required	Real	Width of non-circular, or diameter of circular section at upstream end	m or ft
21-25	L	Sect. Dep.	Real	Centerline length of section	m or ft
26-30	H2	Geom. Dep.	Real	Height of downstream end of non-circular section	m or ft
31-35	W2, D2	Required	Real	Width of non-circular, or diameter of circular section at downstream end	m or ft
36-40	L/DH, S/AL	Sect. Dep.	Real	Length-to-hydraulic diameter, ratio of flow straightener cells, or drag-area-to-local-duct-flow-area ratio for each flow obstruction drag item	m/m or ft/ft, m^2/m^2 or ft^2/ft^2
41-45	DHUB, CHORD, DMESH	Sect. Dep.	Real	Hub diameter of fan-drive section, or turning vane chord length, or mesh screen wire diameter	m or ft

TABLE 3.- SECTION INPUT DATA DESCRIPTIONS - Concluded.

Card column(s)	Field title(s)	Requirement?[a]	Input type	Description(s)	Units
46-50	BLKGE PRSTY	Sect. Dep.	Real	Local flow area blockage due to each obstruction in the local duct, or porosity of flow straighteners, screen, perforated plate	% of local area
51-55	PHI	Sect. Dep.	Real	Corner flow centerline turning angle, $0° \leq \phi \leq 90°$	deg
56-60	KEXP KMESH KT 90	Default(INT) Default(1.3) Default(0.15) Default(1.80)	Real	Diffuser expansion loss parameter (see fig. 4), or mesh screen loss constant, or turning vane loss parameter at $\phi = 90°$ empty corner loss parameter at $\phi = 90°$	---
61-65	CD K	Sect. Dep.	Real	Drag coefficient of flow obstruction, or fixed, known local loss value	---
66-70	RNREF, RUFNESS	Default(0.5) Default(.0001m)	Real	Reference Reynolds number for which 90° corner loss value is given, or surface roughness of flow straightener material	10^6, 10^{-6} m or 10^{-6} ft
71-75	ETA	Default(100.0)	Real	Efficiency of fan drive system	%
76-80	D EPS	Sect. Dep.	Real	Additional (amount over 100%) downstream influence factor for flow obstruction items	% over 100%

[a]"Default(INT)" indicates optional input, dependent on section type, which defaults to an internally-generated, geometry-dependent value if omitted.
"Default(X)" indicates optional input, dependent on section type, which defaults to X if omitted.
"Geom. Dep." indicates the input requirement is dependent on section geometry.
"Optional" indicates the input may be selected and included as desired.
"Required" indicates the input must be non-zero and included for all sections or section will be skipped and case terminated due to input error.
"Sect. Dep." indicates the input requirement is dependent on section type.

TABLE 4.- ADDITIONAL, SECTION-DEPENDENT INPUT REQUIREMENTS

Section		Additional input title(s)	Requirement?[a]	Card column(s)
Type description	Type code			
Single ducts:				
Test section, closed, constant area, empty	01	---		
Test section, closed, constant area with model	02	S/AL	Required	36-40
		BLKGE	Optional	46-50
		CD	Required	61-65
		D EPS	Optional	76-80
Test section, closed, diffusing, empty	03	KEXP	Default	56-60
Test section, closed diffusing, with model	04	S/AL	Required	36-40
		BLKGE	Optional	46-50
		KEXP	Default	56-60
		CD	Required	61-65
		D EPS	Optional	76-80
Test section, open-throat, empty	05	---		
Test section, open-throat, with model	06	S/AL	Required	36-40
		BLKGE	Optional	46-50
		CD	Required	61-65
		D EPS	Optional	76-80
Constant-area duct	10	---		
Contraction	20	---		
Corner, constant-area, turning vanes only	30	CHORD	Required	41-45
		PHI	Required	51-55
		KT 90	Default	56-60
		RNREF	Default	66-70
Corner, constant-area, with turning vanes and walls	32	CHORD	Required	41-45
		PHI	Required	51-55
		KT 90	Default	56-60
		RNREF	Default	66-70
Corner, constant-area, with walls and without turning vanes	33	PHI	Required	51-55
		KT 90	Default	56-60
Corner, diffusing, with turning vanes and walls	34	CHORD	Required	41-45
		PHI	Required	51-55
		KT 90	Default	56-60
		RNREF	Default	66-70
Diffuser	40	KEXP	Default	56-60
Exit kinetic energy from flow dump	45	---		
Sudden expansion	46	---		

TABLE 4.- ADDITIONAL, SECTION-DEPENDENT INPUT REQUIREMENTS - Continued.

Section		Additional input title(s)	Requirement?[a]	Card column(s)
Type description	Type code			
Flow straighteners, thin honeycomb	51	L/DH	Required	36-40
		PRSTY	Required	46-50
		RUFNESS	Default	66-70
Flow straighteners, thick airfoils	52	L/DH	Default	36-40
		PRSTY	Required	46-50
Perforated plate with sharp-edged orifices	53	PRSTY	Required	46-50
Woven mesh screen	54	DMESH	Required	41-45
		PRSTY	Required	46-50
		KMESH	Default	56-60
Internal structure (drag item(s)) at upstream end of section	56	ITEMS	Default	9-10
		S/AL	Required	36-40
		BLKGE	Optional	46-50
		CD	Required	61-65
		D EPS	Optional	75-80
Fixed, known local loss item at upstream end of section	57	K	Required	61-65
<u>Multiple ducts</u>:				
Constant-area ducts	61	DUCTS	Required	7-8
Contractions	62	DUCTS	Required	7-8
Corners, constant-area; turning vanes only	70	DUCTS	Required	7-8
		CHORD	Required	41-45
		PHI	Required	51-55
		KT 90	Default	56-60
		RNREF	Default	66-70
Corners, constant-area, with turning vanes and only one side-wall each	71	DUCTS	Required	7-8
		CHORD	Required	41-45
		PHI	Required	51-55
		KT 90	Default	56-60
		RNREF	Default	66-70
Corners, constant-area, with turning vanes and walls	72	DUCTS	Required	7-8
		CHORD	Required	41-45
		PHI	Required	51-55
		KT 90	Default	56-60
		RNREF	Default	66-70
Corners, constant-area, with walls and without turning vanes	73	DUCTS	Required	7-8
		PHI	Required	51-55
		KT 90	Default	56-60
Corners, diffusing, with turning vanes and only one side-wall each	74	DUCTS	Required	7-8
		CHORD	Required	41-45
		PHI	Required	51-55
		KT 90	Default	56-60
		RNREF	Default	66-70

TABLE 4.- ADDITIONAL, SECTION-DEPENDENT INPUT REQUIREMENTS - Concluded.

Section		Additional input title(s)	Requirement?[a]	Card column(s)
Type description	Type code			
Corners, diffusing, with turning vanes and walls	75	DUCTS	Required	7-8
		CHORD	Required	41-45
		PHI	Required	51-55
		KT 90	Default	56-60
		RNREF	Default	66-70
Diffusers	84	DUCTS	Required	7-8
		KEXP	Default	56-60
Vaned diffuser	85	---		
Sudden expansion from multiple ducts to single duct	86	DUCTS	Required	7-8
Sudden expansion from multiple ducts to multiple ducts	87	DUCTS	Required	7-8
Fan, constant-area annular duct(s) with motor-support strut(s)	91	DUCTS	Default	7-8
		ITEMS	Default	9-10
		S/AL	Required	36-40
		DHUB	Required	41-45
		BLKGE	Optional	46-50
		CD	Required	61-65
		ETA	Default	71-75
		D EPS	Optional	75-80
Fan contraction(s) to annular duct(s) with motor-support strut(s)	92	DUCTS	Default	7-8
		ITEMS	Default	9-10
		DHUB	Required	41-45
		BLKGE	Optional	46-50
Fan diffuser(s) from annular duct(s), each with tapering, cone-shaped centerbody	94	DUCTS	Default	7-8
		DHUB	Required	41-45
		BLKGE	Optional	46-50
		KEXP	Default	56-60
Internal structure (drag item(s)) at upstream end of each duct	96	DUCTS	Required	7-8
		ITEMS	Default	9-10
		S/AL	Required	36-40
		BLKGE	Optional	46-50
		CD	Required	61-65
		D EPS	Optional	75-80
Fixed, known local loss item at upstream end of each duct	97	DUCTS	Required	7-8
		K	Required	61-65

[a]"Default" indicates the input is optional and has a default value if omitted (see table 3).
"Optional" indicates the input may be selected and included as desired.
"Required" indicates the input must be non-zero and included for all sections of the specified type or the section will be skipped and the case not completed due to input error.

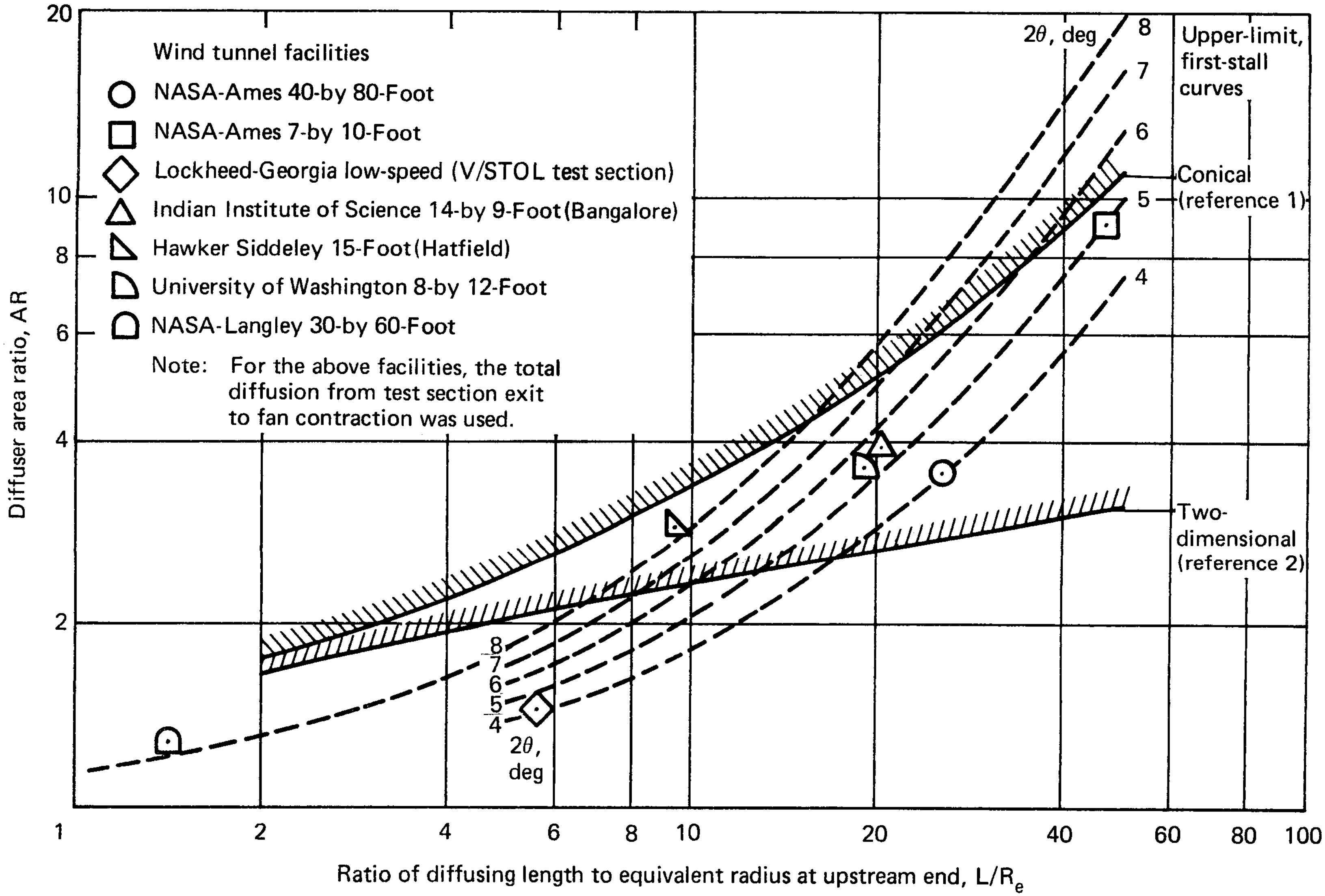
TABLE 5.- CASE TERMINATION TASK DESCRIPTIONS

Card column(s)	Input type	Input value	Task description
3-4	Blanks	Blanks	Case termination card identification
6	Integer		Summary characteristics page(s):
		0	Non-print
		≠0	Print
7-8	Real		Plotting of summary information as a function of distance through circuit:
		≤0.0	No plots
		1.	Cummulative pressure loss
		2.	Wall pressure differential
		>2.	Cummulative pressure loss and wall pressure differential
9-10	Real		Complete, annotated tabulation of input values:
		0.0	No print unless internally forced by omission of required inputs
		≠0.0	"Chosen" tabulation
11-15	Real		Power-matching (optimizing velocity for a specified power level):
		0.0	No velocity optimization
		≠0.0	Velocity optimization
16-20	Real		Return to beginning for evaluation of another case:
		0.0	No return, program termination
		≠0.0	Return

TABLE 6.- COMPARISON OF PREDICTED WITH ACTUAL PERFORMANCE LEVELS FOR SEVERAL EXISTING WIND TUNNEL FACILITIES

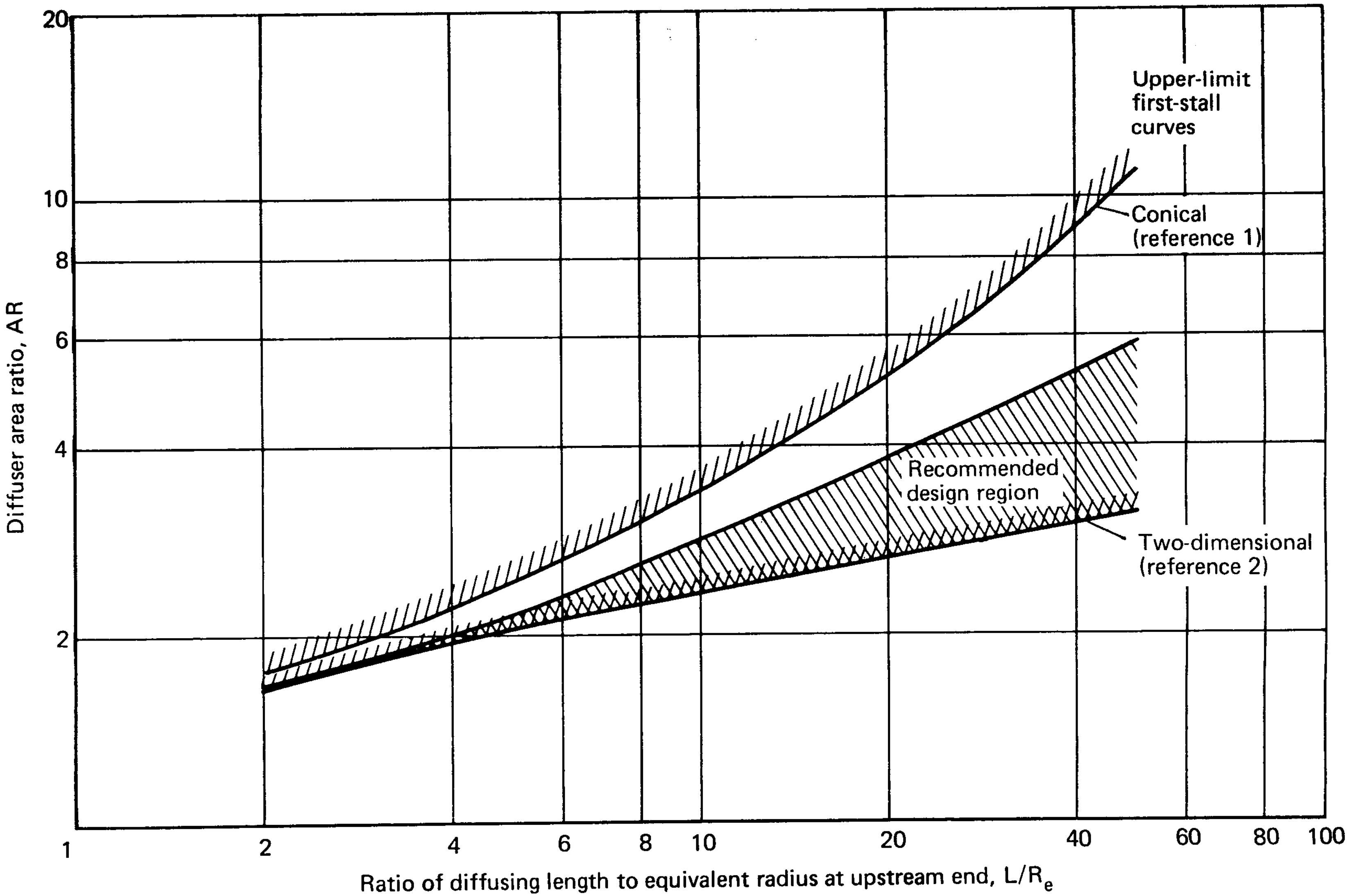
Wind tunnel description				Reference condition	Basis of actual energy ratio				Energy ratio		
					Drive power						
Facility	Return circuit type/basic cross-section shape	Test section type/shape	Comments	Test section velocity, m/sec	Motor input	Motor output (fan input)	Fan output	Circuit losses	Actual[a]	Estimated by computer program	Error, %
NASA-Ames Research Center 40- by 80-Foot	Single, closed/ rectangular	Closed/ flat oval	Conventional tunnel; multiple circular-arc turning vanes	107.3	Measured	Estimated from measured motor losses	Estimated from assumed η_F = 97%	---	7.88	7.96	1.0
NASA-Ames Research Center 7- by 10-Foot	Single, closed/ rectangular	Closed/ rectangular	Some separation in primary diffuser; partial fan stall; multiple-circular-arc turning vanes; air exchanger available	133.0	Measured	Estimated from measured motor losses	Estimated from assumed η_F = 85%	---	7.85	8.07	2.8
Lockheed-Georgia Low-Speed (V/STOL Test Section) (ref. 20)	Single, closed/ rectangular	Closed/ rectangular	The larger of two tandem test sections was considered; test section vented	52.3	Measured	Estimated from assumed η_E = 95%	Estimated from assumed η_F = 95%	---	1.10	1.12	1.8
Indian Institute of Science 14- by 9-Foot (at Bangalore) (refs. 21-23)	Non-return/ flat oval	Closed/ rectangular with corner fillets	Some dimensions for the estimate were scaled off of small drawings	96.3	---	---	---	---	6.85 (ref. 21)	6.83	-0.3
Hawker Siddeley Aviation 15-Foot V/STOL (at Hatfield) (ref. 24)	Non-return/ rectangular and circular	Closed/ rectangular	Basically a cost-effective facility; some dimensions for the estimate were scaled off of small drawings	45.7	---	---	---	Measured (ref. 24)	2.38	3.97	66.8
University of Washington 8- by 12-Foot	Double, closed/ rectangular	Closed/ rectangular with corner fillets	Surprisingly high measured energy ratio	117.7	---	---	---	Measured	8.3	7.20	-13.3
NASA-Langley Research Center 30- by 60-Foot (ref. 25)	Double, closed/ rectangular	Open/flat oval	High diffusion rates in some important components	52.7	Measured	Estimated from assumed η_E = 85%	Estimated from assumed η_F = 90%	---	3.71	4.73	27.4

[a]The quoted energy ratios are the best available and best achieved for each facility. The energy ratios of some facilities have dropped over the years due to deterioration, leaks, soot build-up, etc.



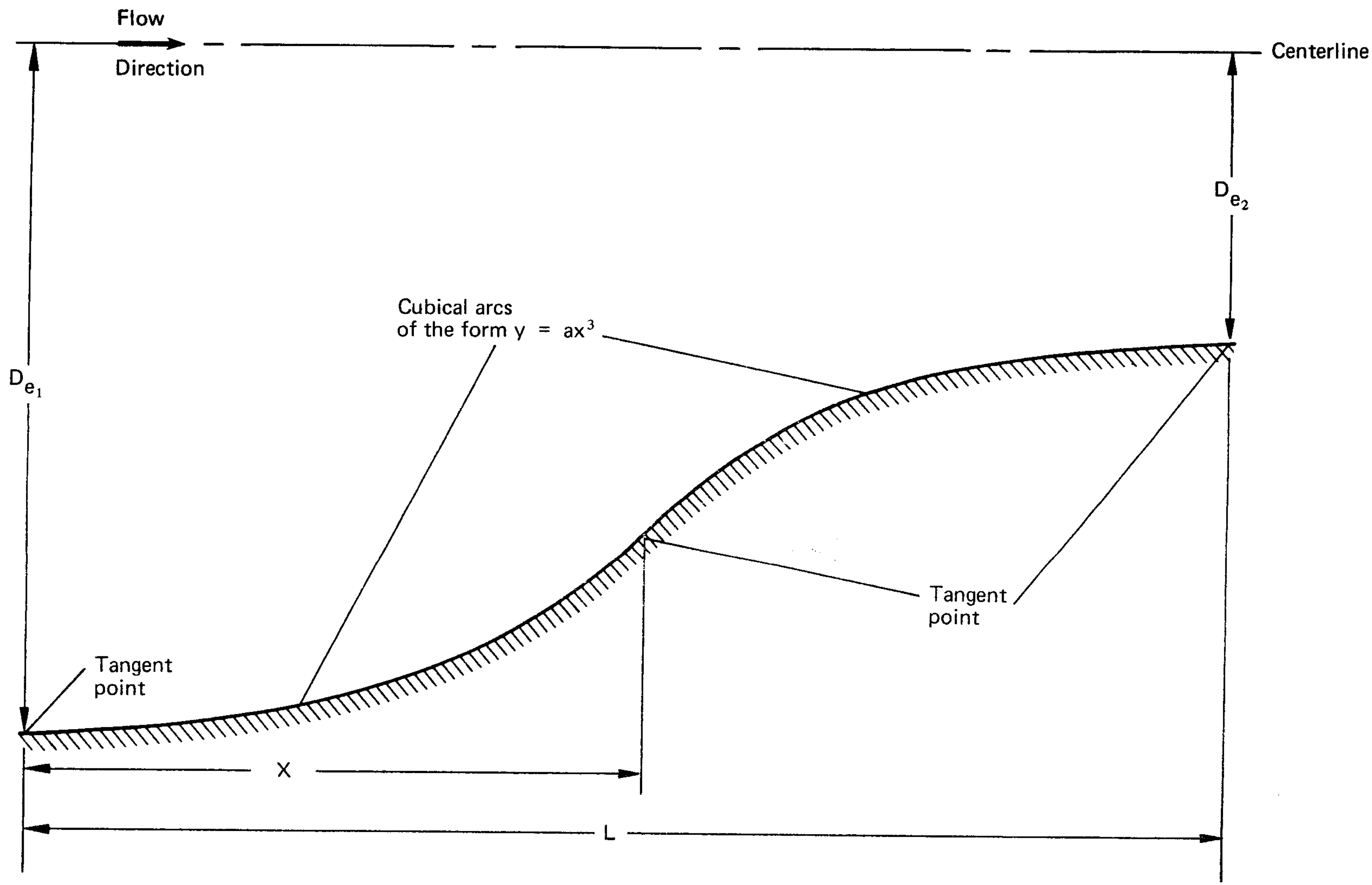
(a) Several existing facilities.

Figure 1.- Diffuser design parameters.



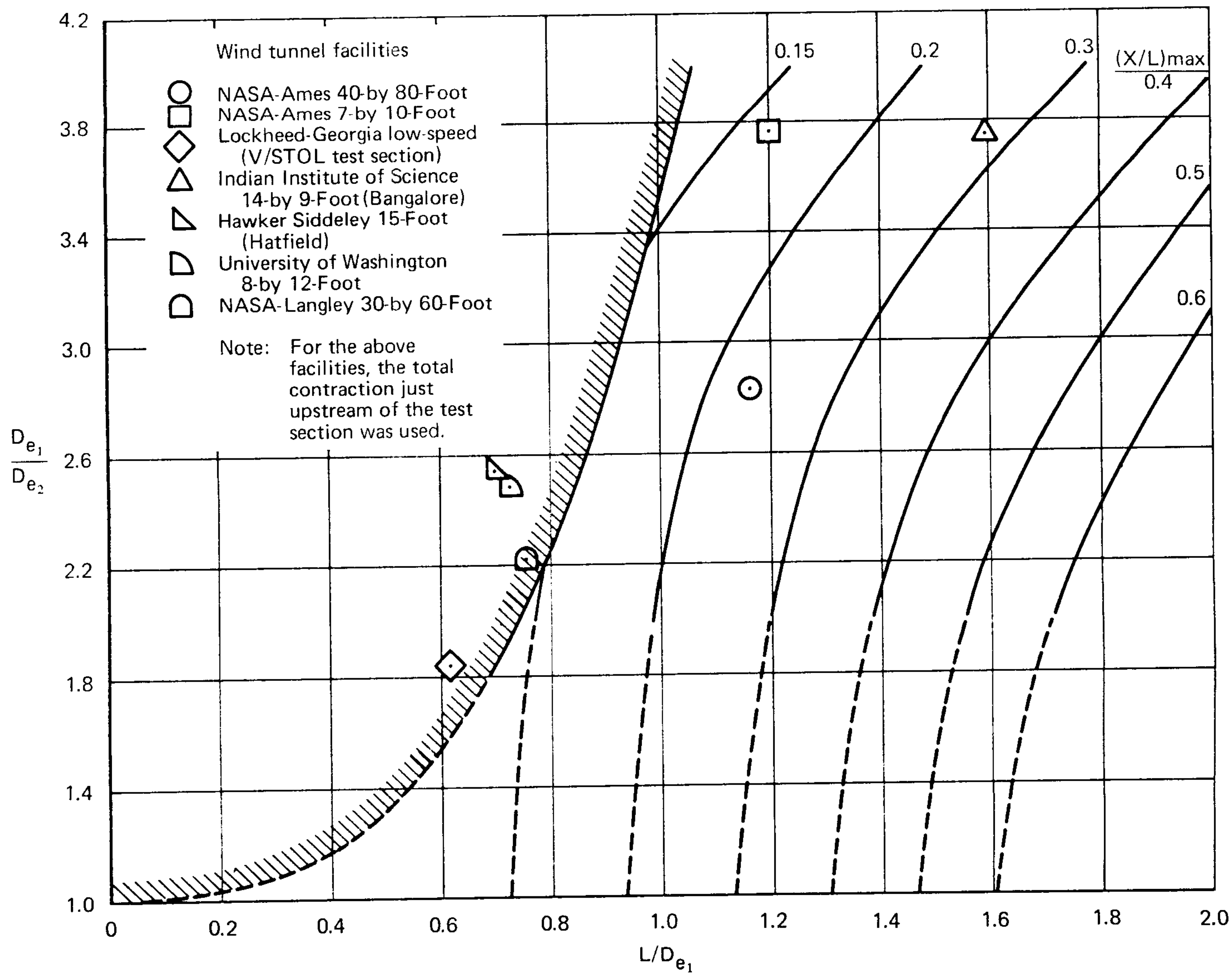
(b) Recommended design region.

Figure 1.- Concluded.



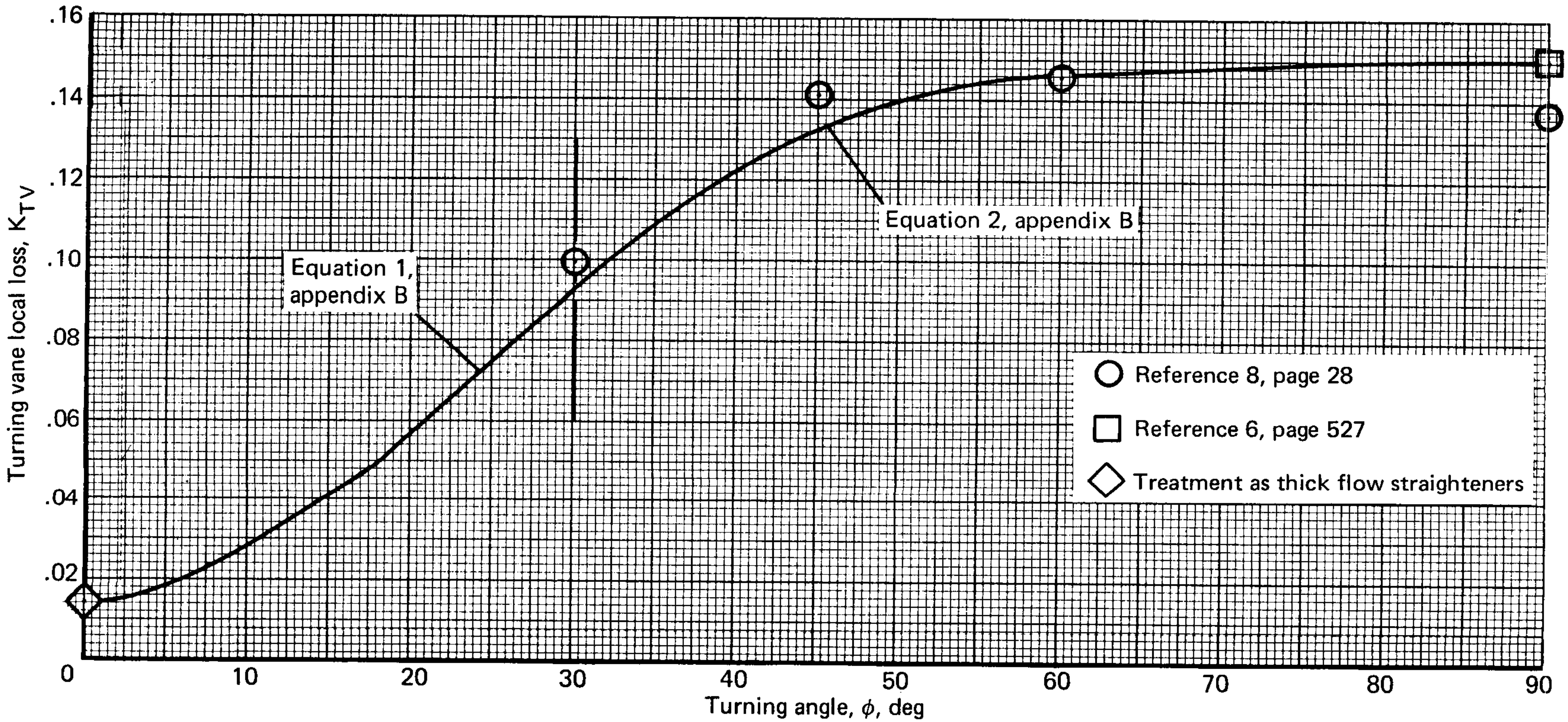
(a) Contraction geometry definition.

Figure 2.- Contraction design criteria.



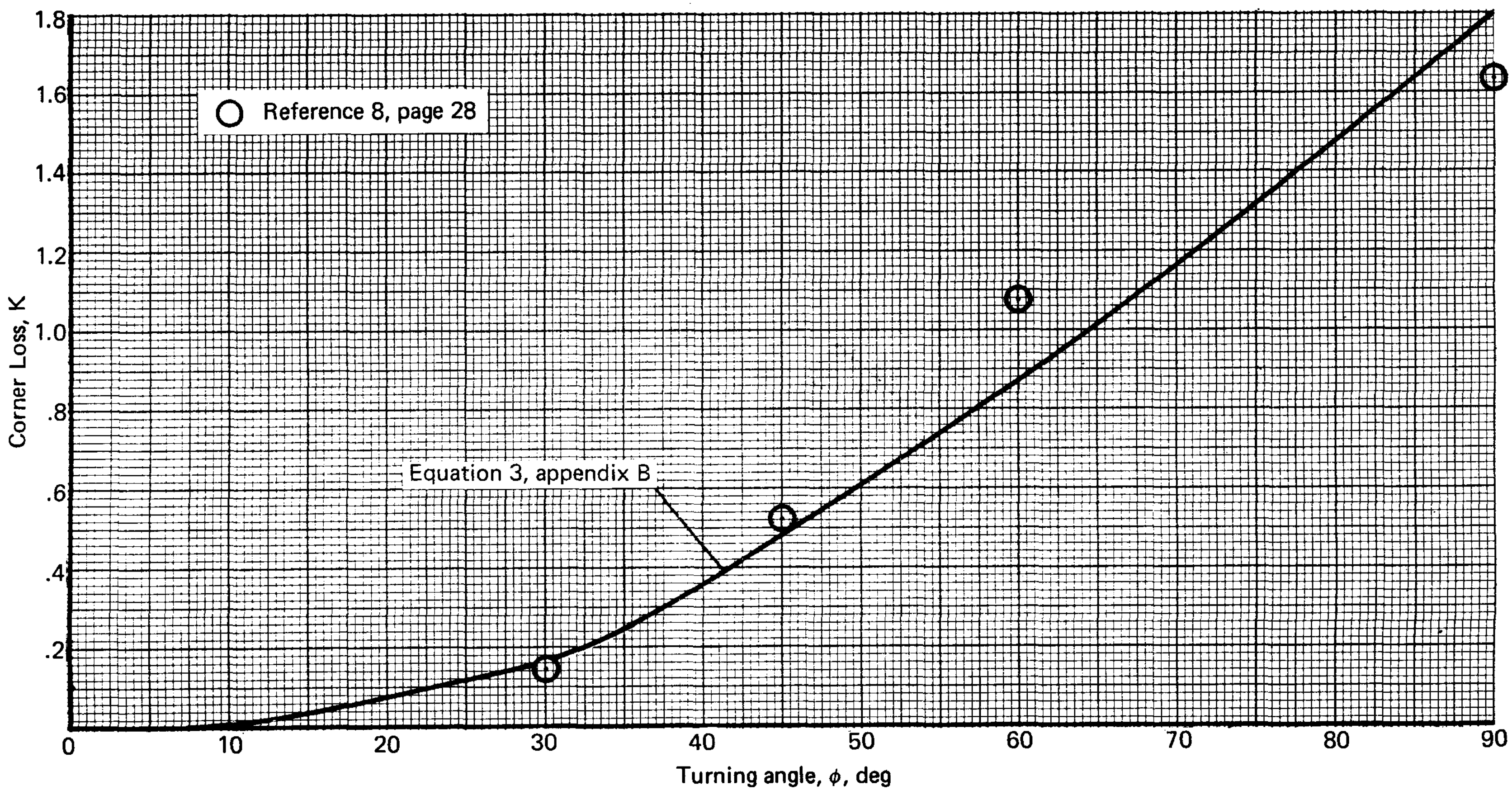
(b) Contraction design curves from reference 3.

Figure 2.- Concluded.



(a) Turns with turning guide vanes.

Figure 3.- Local losses for turns as functions of turning angle.



(b) Turns without vanes.

Figure 3.- Concluded.

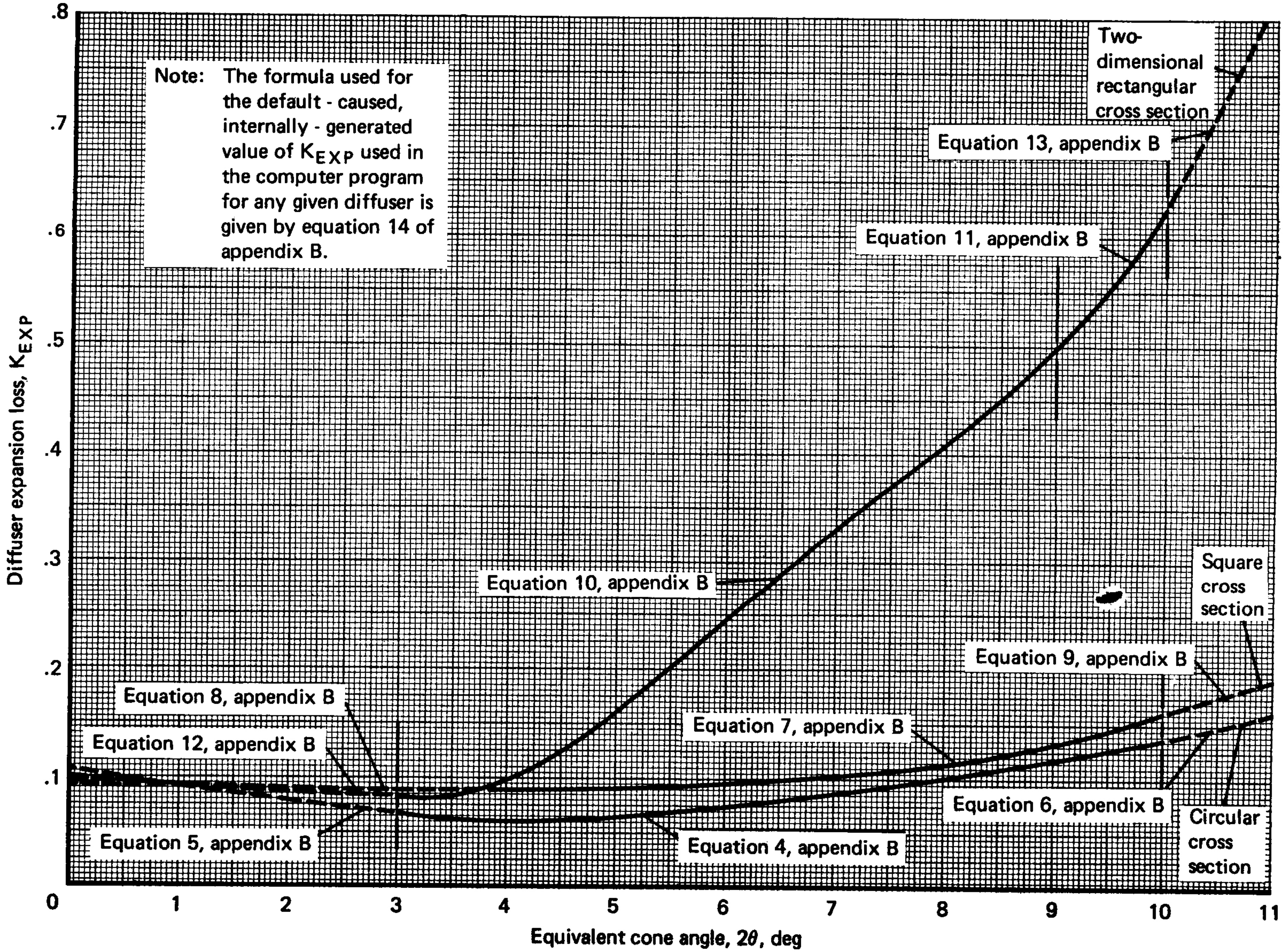


Figure 4.- Straight-walled diffuser expansion loss parameter variation with equivalent cone angle;

$$K_{EXP} = K_{Ref.\ 9} - \frac{\lambda}{8 \sin \theta}\left(\frac{AR + 1}{AR - 1}\right)$$

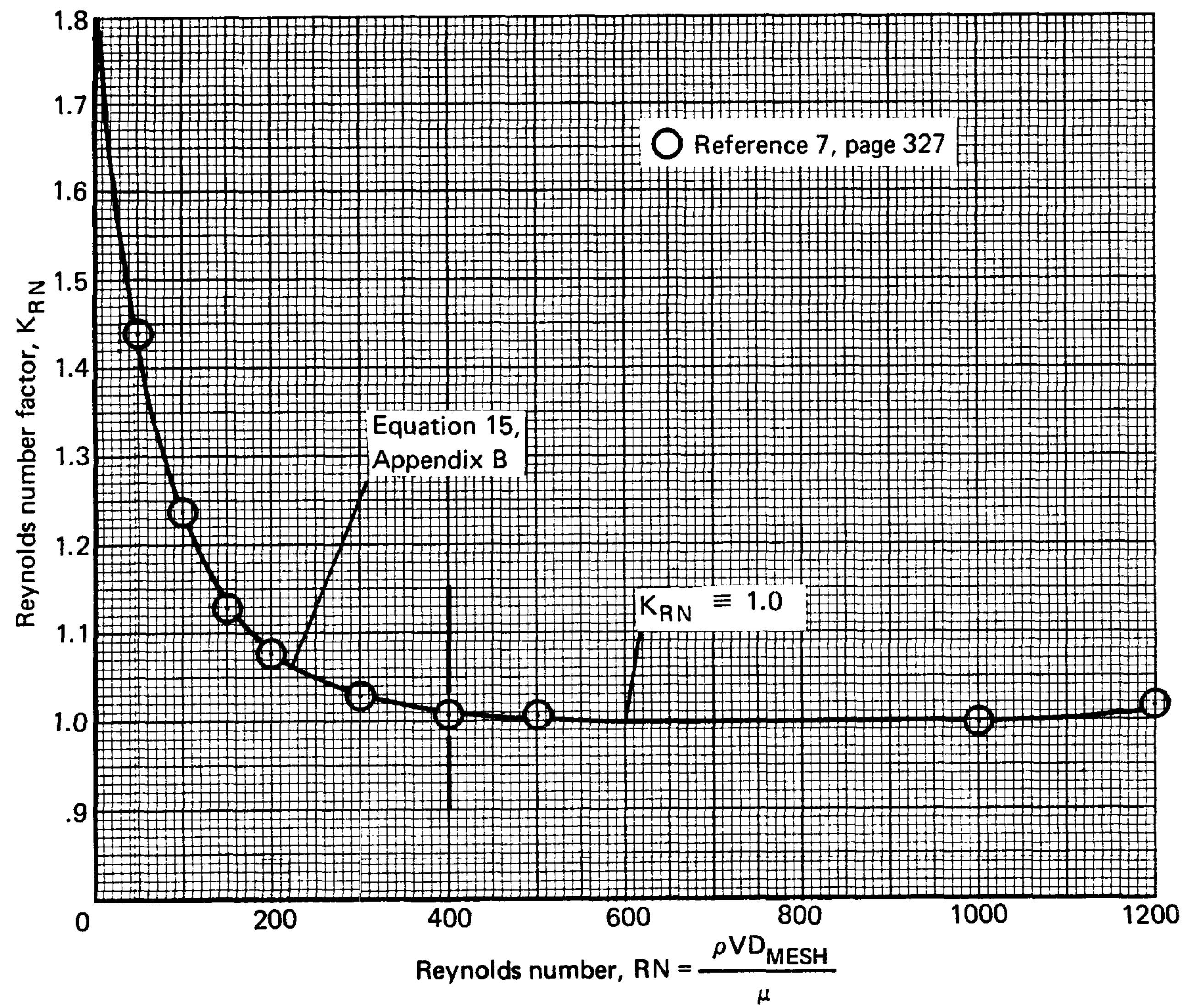


Figure 5.- Mesh screen Reynolds number sensitivity factor as a function of Reynolds number.

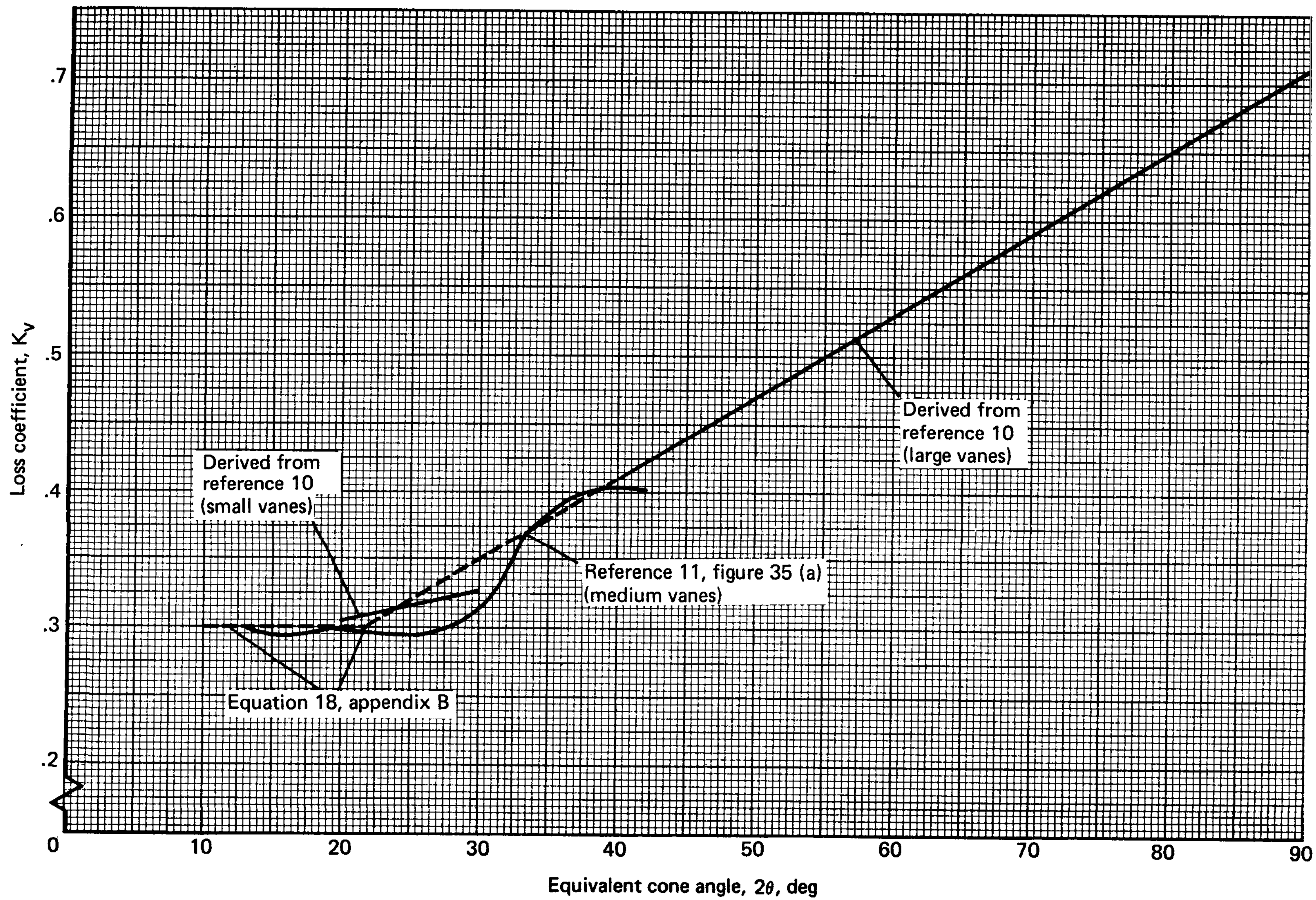
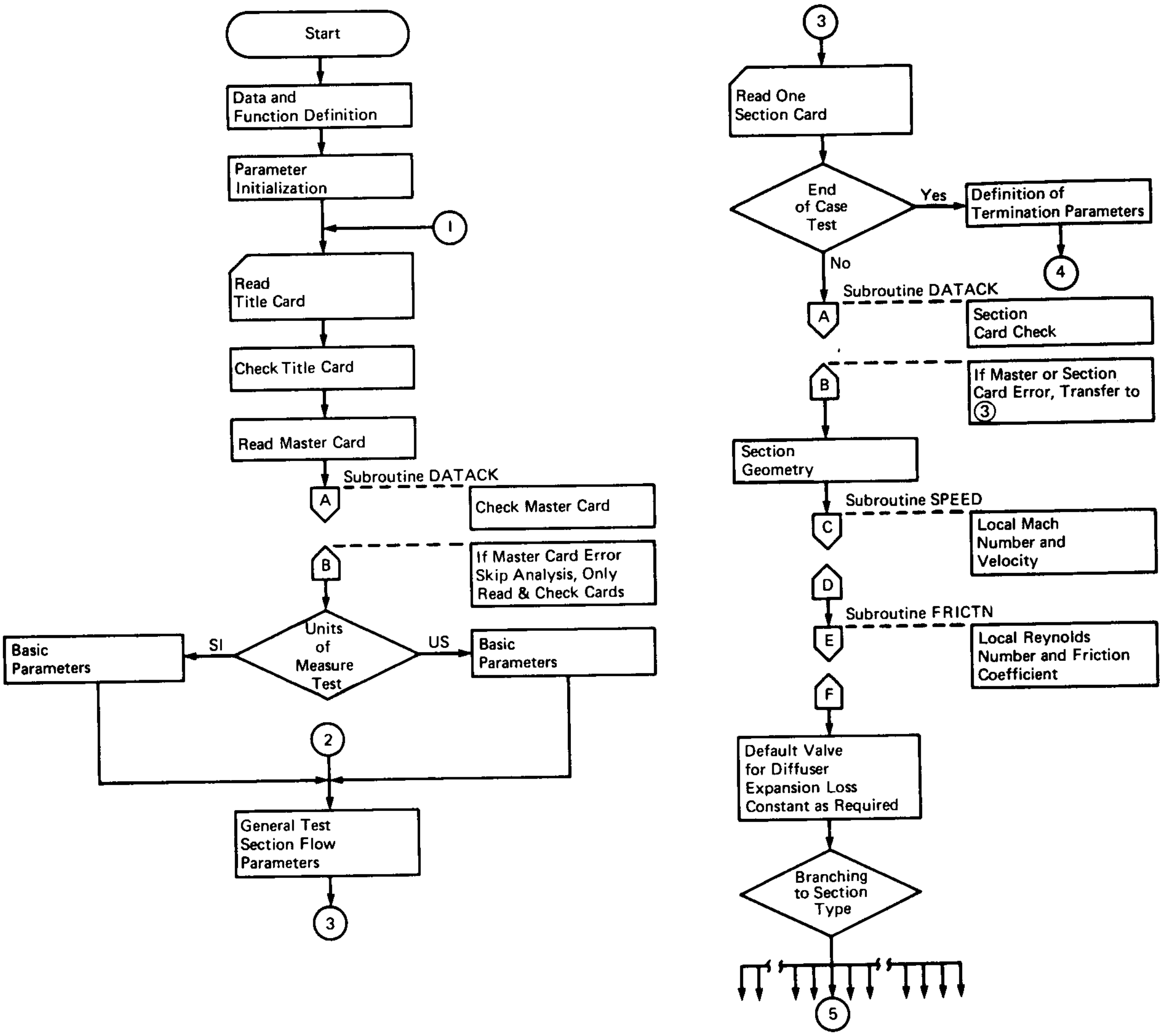


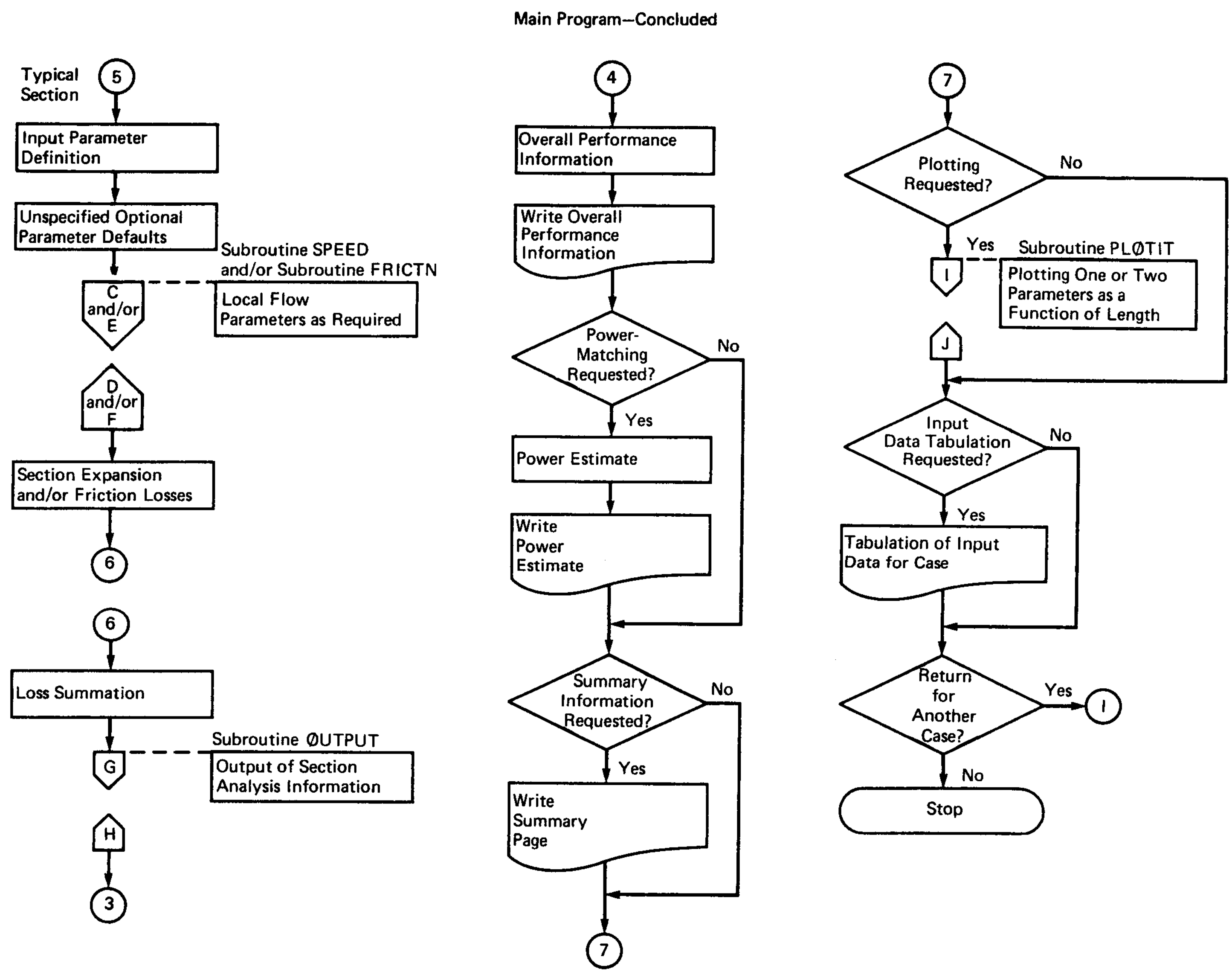
Figure 6.- Vaned diffuser loss coefficient as a function of equivalent cone angle.

Main Program (PERFØRM)



(a) Main program.

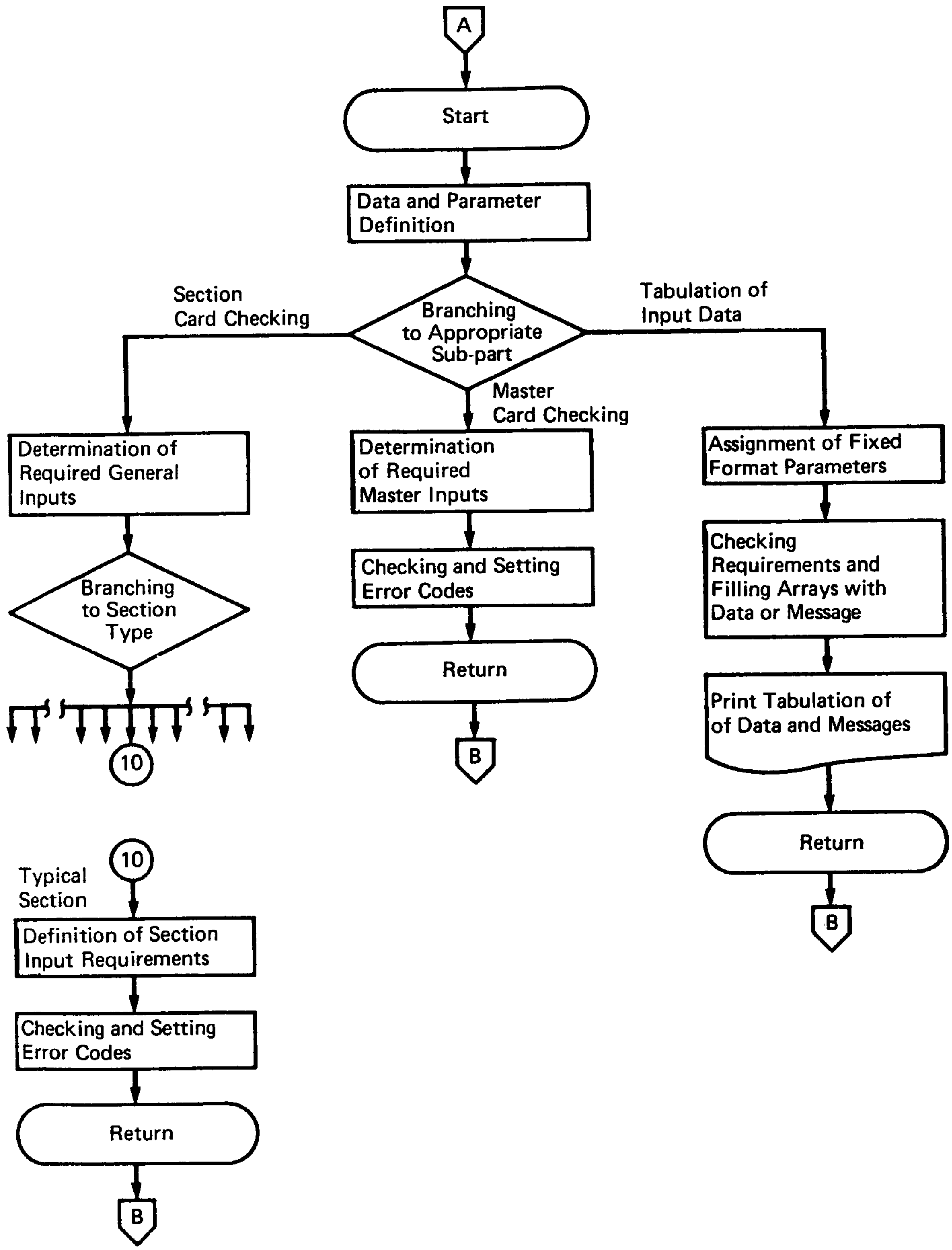
Figure 7.- Basic functional flow chart.



(a) Main program - Concluded.

Figure 7.- Continued.

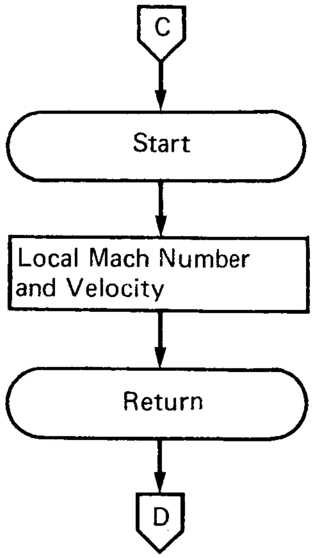
Data-Checking Subroutine (DATACK)



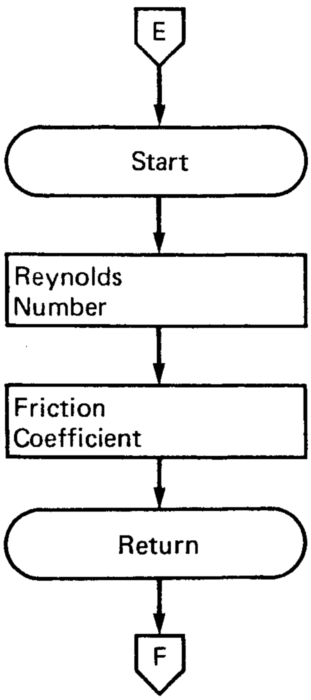
(b) Data-checking subroutine.

Figure 7.- Continued.

Local Speed Subroutine (SPEED)

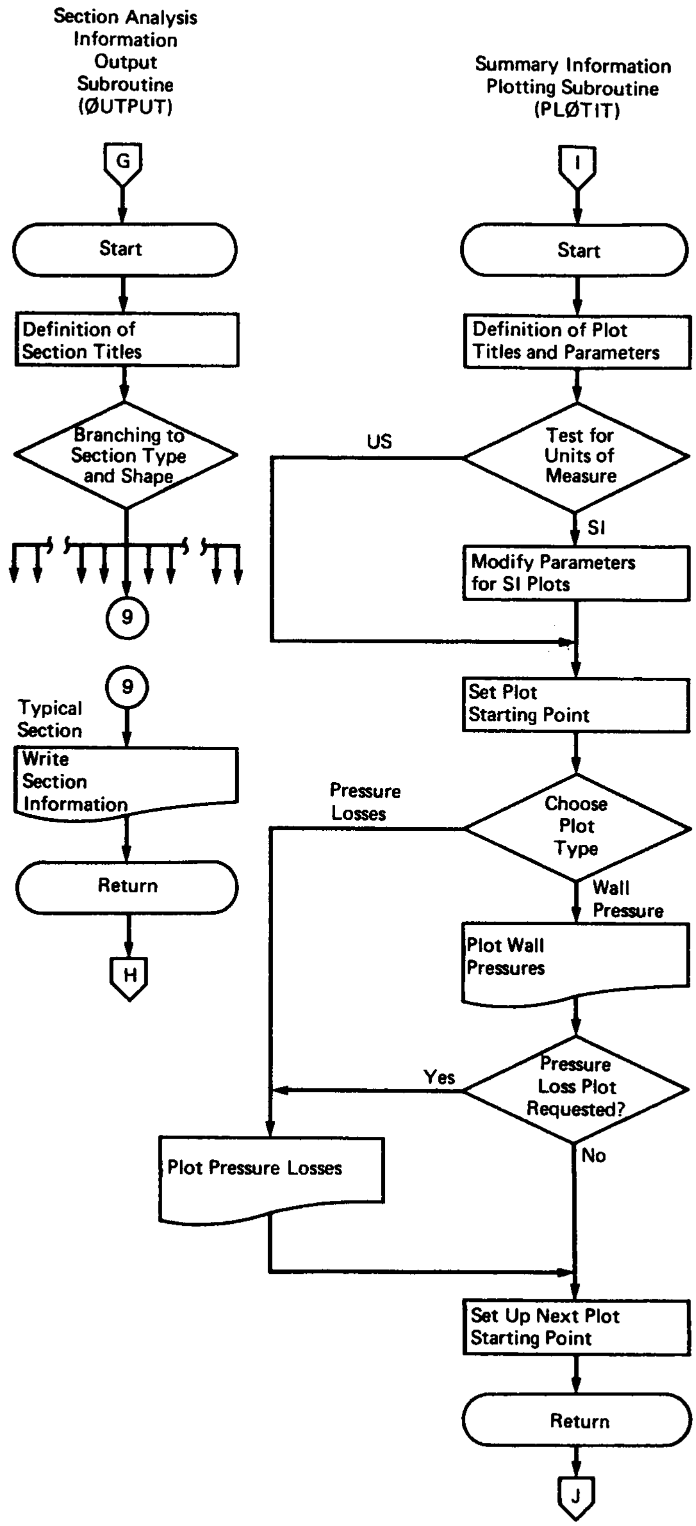


Local Reynolds Number and Friction Coefficient Subroutine (FRICTN)



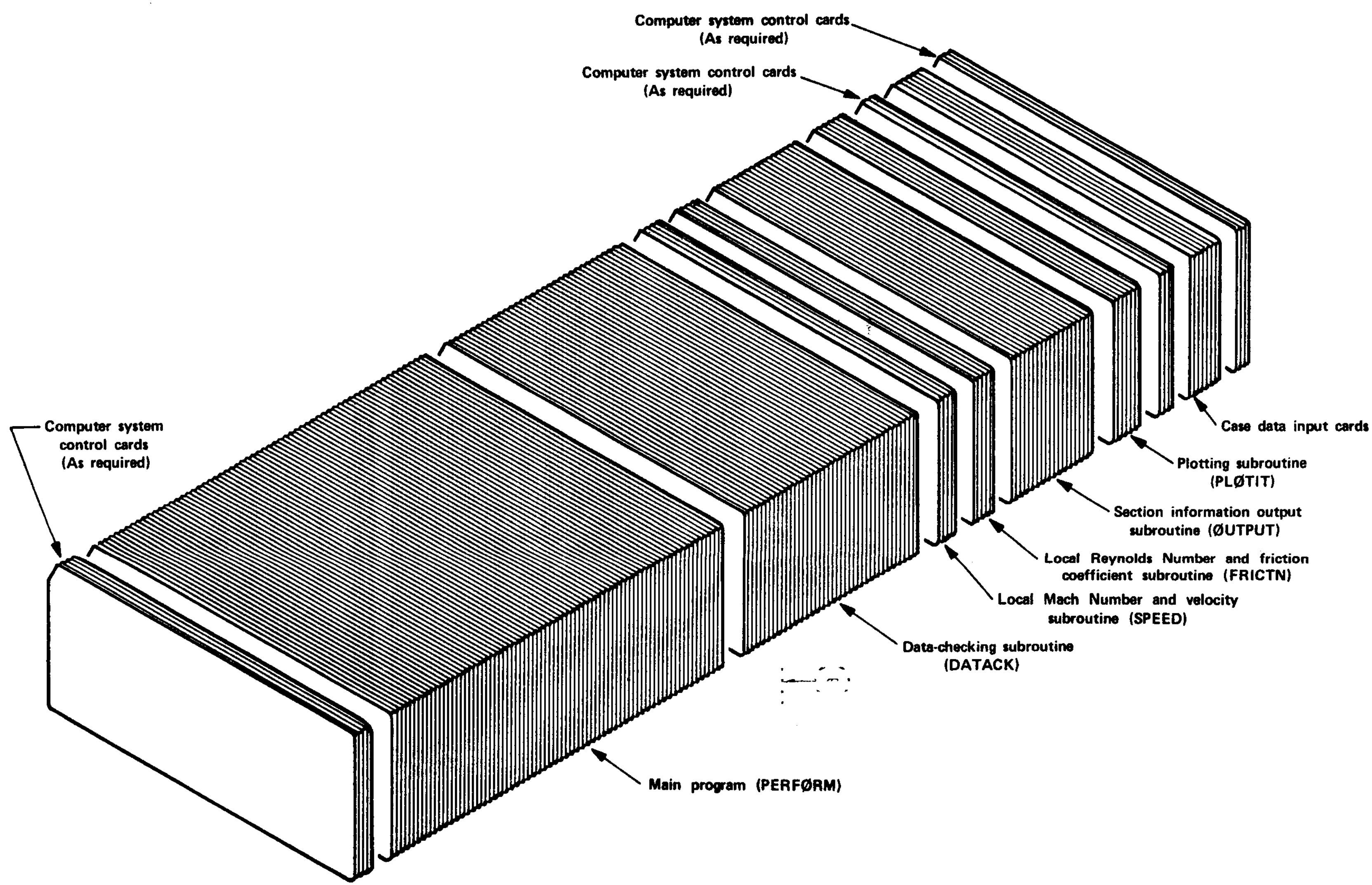
(c) Local speed and Reynolds number/friction coefficient subroutines.

Figure 7.- Continued.



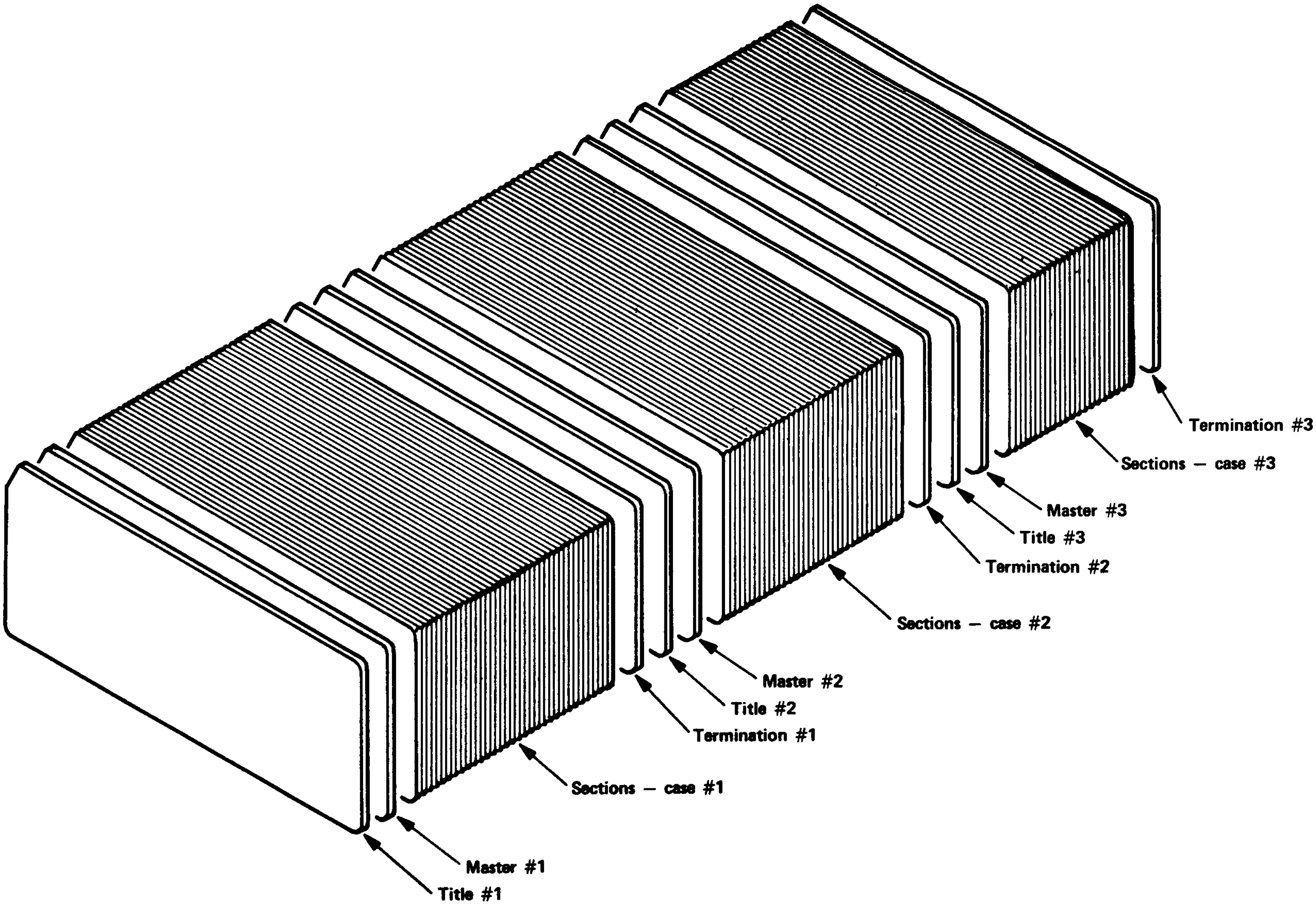
(d) Section information output and plotting subroutines.

Figure 7.- Concluded.



(a) Complete source and data decks.

Figure 8.- Input deck setup.



(b) Sample data deck for three cases.

Figure 8.- Concluded.

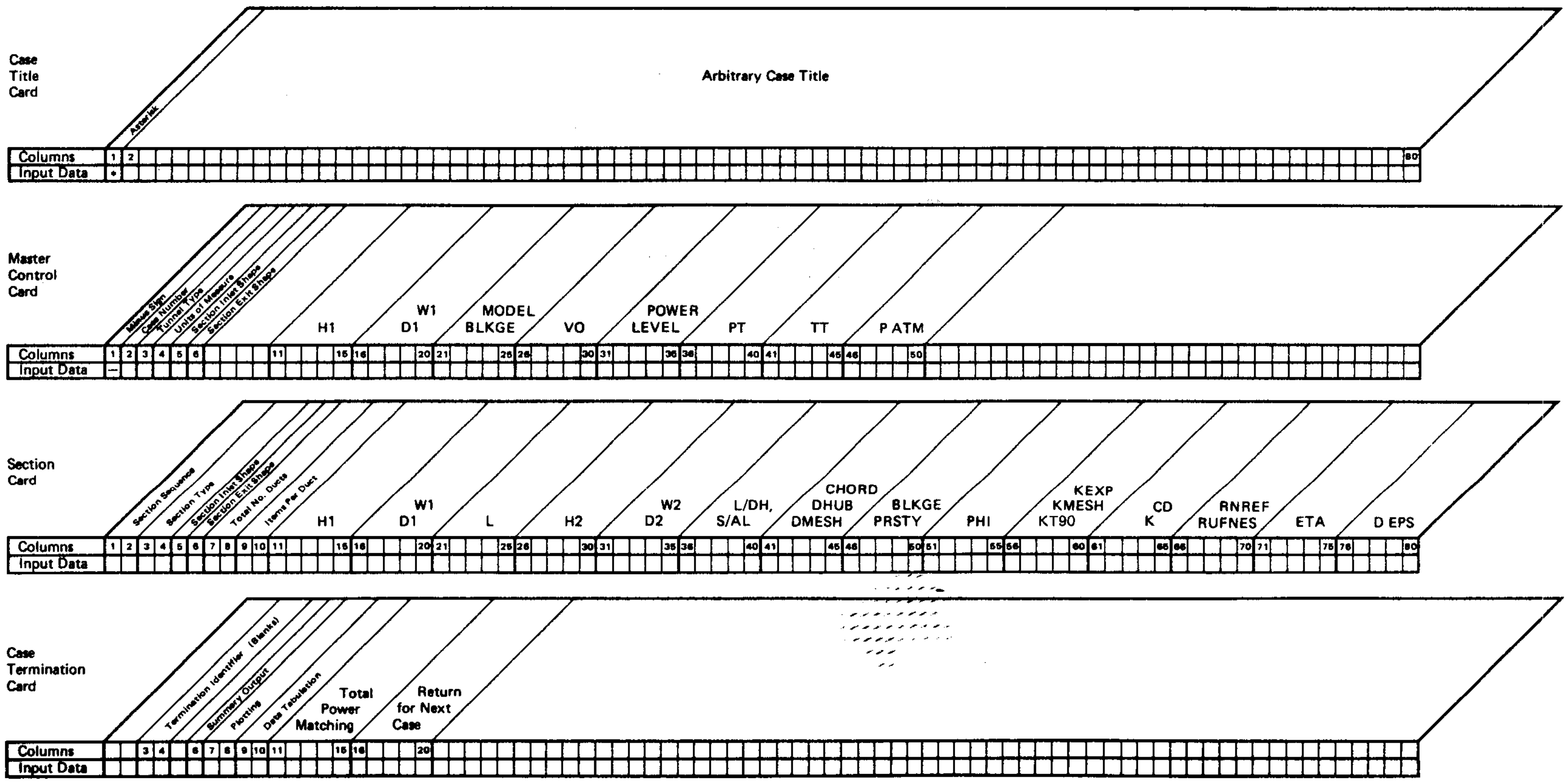


Figure 9.- Sample headings for input data sheets.

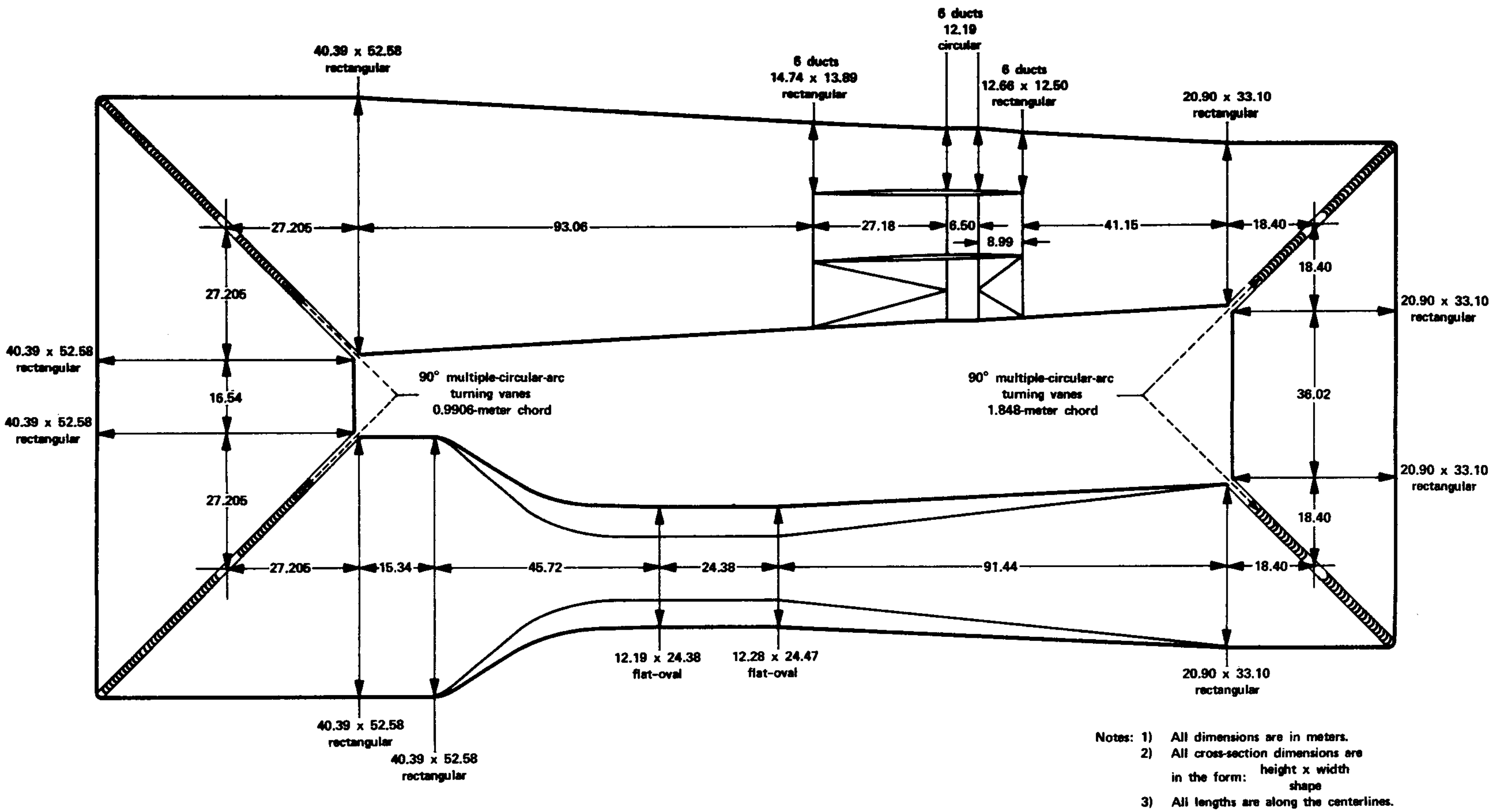


Figure 10.- Diagram of interior dimensions of NASA-Ames Research Center 40- by 80-Foot Wind Tunnel.

```
*             NASA-AMES RESEARCH CENTER 40- BY 80-FOOT WIND TUNNEL                *
-11133    12.1924.38      107.326.86  1.014.851.000
 11022    40.3952.5815.3440.3952.58
 22023    40.3952.5845.7212.1924.380
 3 333    12.1924.3824.3812.2824.47
 44032    12.2824.4791.4420.9033.10
 53222    20.9033.1036.8020.9033.10      1.848      90.00
 61022    20.9233.1036.0220.9233.10
 73222    20.9033.1036.8020.9033.10      1.848      90.00
 84022    20.9033.1041.1525.3237.52
 99221 6 212.6612.508.992      12.19     4.2671.797
109111 6 2     12.196.501     12.19.43204.2671.797          .0100     95.00
119412 6       12.1927.1814.7413.89      4.267
129612 6 3     12.19     14.7413.89.1027     5.365          .0100
134022    29.4841.6693.0640.3952.58
143222    40.3952.5854.4140.3952.58      .9906      90.00
151022    40.3952.5816.5440.3952.58
163222    40.3952.5854.4140.3952.58      .9906        90.
     1 3 1    1
```

(a) Listing of input data cards.

Figure 11.- Test case information details.

* NASA-AMES RESEARCH CENTER 40- BY 80-FOOT WIND TUNNEL * PAGE 1

SINGLE-RETURN, CLOSED-TEST-SECTION WIND-TUNNEL PERFORMANCE

ATMOSPHERIC PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TEST SECTION CONDITIONS --
TOTAL PRESSURE = 1.000 ATMOSPHERES = 101325.0 N/SQ M.
TOTAL TEMPERATURE = 14.85 DEG C = 288.00 DEG K.
VELOCITY = 107.30 M/SEC = 208.57 KNOTS. DYNAMIC PRESSURE = 6715.71 N/SQ M.

NO.	SECTION TYPE	SHAPE	H1 H2 METERS	W1,D1 W2,D2 METERS	AREA1 AREA2 SQ M	A1/A0 A2/A0	AR,CR	2 THETA DEGREES	V1 V2 M/SEC	MACH1 MACH2	LENGTH METERS	DP/QL	DP/Q0
1	CONSTANT AREA DUCT	RECT	40.39	52.58	2123.71	8.00			12.8	0.038	15.34	0.00224	0.00003
		RECT	40.39	52.58	2123.71	8.00			12.8	0.038			
2	CONTRACTN, SINGLE	RECT	40.39	52.58	2123.71	8.00	8.00	40.37	12.8	0.038	45.72		
		FL O	12.19	24.38	265.30	1.00			107.3	0.319		0.00501	0.00501
3	TEST SECT, DIFSN	FL O	12.19	24.38	265.30	1.00	1.01	0.23	107.3	0.319	24.38	0.00835	0.00835
		FL O	12.28	24.47	268.13	1.01			106.0	0.315			
4	DIFFUSER	FL O	12.28	24.47	268.13	1.01	2.58	7.01	106.0	0.315	91.44	0.04616	0.04514
		RECT	20.90	33.10	691.79	2.61			39.4	0.116			
5	CORNER WITH VANES	RECT	20.90	33.10	691.79	2.61			39.4	0.116	36.80	0.14170	0.01995
		RECT	20.90	33.10	691.79	2.61			39.4	0.116			
6	CONSTANT AREA DUCT	RECT	20.92	33.10	692.45	2.61			39.4	0.116	36.02	0.00875	0.00123
		RECT	20.92	33.10	692.45	2.61			39.4	0.116			
7	CORNER WITH VANES	RECT	20.90	33.10	691.79	2.61			39.4	0.116	36.80	0.14170	0.01995
		RECT	20.90	33.10	691.79	2.61			39.4	0.116			
8	DIFFUSER	RECT	20.90	33.10	691.79	2.61	1.37	7.09	39.4	0.116	41.15	0.01359	0.00191
		RECT	25.32	37.52	950.01	3.58			28.6	0.084			
9	FAN CONTRACTION	RECT	12.66	12.50	949.50	3.58	1.60	18.84	28.6	0.084	8.99		
		CIRC		12.19	592.36	2.23			46.1	0.136		0.00259	0.00050

(b) Wind tunnel section and overall performance information.

Figure 11.- Continued.

* NASA-AMES RESEARCH CENTER 40- BY 80-FOOT WIND TUNNEL * ...CONTINUED.... PAGE 2

NO.	SECTION TYPE	SHAPE	H1 / H2 METERS	W1,D1 / W2,D2 METERS	AREA1 / AREA2 SQ M	A1/A0 / A2/A0	AR,CR	2 THETA DEGREES	V1 / V2 M/SEC	MACH1 / MACH2	LENGTH METERS	DP/QL	DP/Q0
10	FAN DUCT & STRUTS	CIRC		12.19	592.36	2.23			46.1	0.136	6.50	0.01448	0.00279
		CIRC		12.19	592.36	2.23			46.1	0.136			
11	FAN DIFSR&CNTR BDY	CIRC		12.19	614.44	2.32	2.00	9.94	44.4	0.131	27.18	0.08002	0.01431
		RECT	14.74	13.89	1228.43	4.63			22.1	0.065			
12	MULT INTRNL STRCTR	CIRC		12.19	587.54	2.21			46.5	0.137		0.00308	0.00060
		RECT	14.74	13.89	1228.43	4.63			22.1	0.065			
13	DIFFUSER	RECT	29.48	41.66	1228.14	4.63	1.73	7.66	22.1	0.065	93.06	0.02774	0.00123
		RECT	40.39	52.58	2123.71	8.00			12.8	0.038			
14	CORNER WITH VANES	RECT	40.39	52.58	2123.71	8.00			12.8	0.038	54.41	0.15269	0.00227
		RECT	40.39	52.58	2123.71	8.00			12.8	0.038			
15	CONSTANT AREA DUCT	RECT	40.39	52.58	2123.71	8.00			12.8	0.038	16.54	0.00242	0.00004
		RECT	40.39	52.58	2123.71	8.00			12.8	0.038			
16	CORNER WITH VANES	RECT	40.39	52.58	2123.71	8.00			12.8	0.038	54.41	0.15269	0.00227
		RECT	40.39	52.58	2123.71	8.00			12.8	0.038			

TOTAL CENTERLINE LENGTH = 588.74 METERS

PERFORMANCE SUMMARY --
TOTAL PRESSURE LOSS (DP/Q0) = 0.12559 ENERGY RATIO = 7.962
TOTAL POWER --

INPUT TO FLOW	OUTPUT REQUIRED	AVERAGE PER FAN	FAN EFFICIENCY	TOTAL NUMBER OF FANS
23044272. WATTS	24257120. WATTS	4042853. WATTS	95.00 PERCENT	6.

(b) Wind tunnel section and overall performance information - Concluded.

Figure 11.- Continued.

```
*            NASA-AMES RESEARCH CENTER 40- BY 80-FOOT WIND TUNNEL          *      ...CONTINUED....      PAGE  3

                        MAXIMUM VELOCITY FOR A SPECIFIED POWER CONSUMPTION

THE MAXIMUM TEST SECTION FLOW ACHIEVABLE WITH 26860000. WATTS OF POWER AVAILABLE IS APPROXIMATELY AS FOLLOWS --
            VELOCITY --    111.26 M/SEC =  216.27 KNOTS
            MACH NUMBER --  0.33
            DYNAMIC PRESSURE --   7193.57 N/SQ M
```

(c) Velocity optimization information.

Figure 11.- Continued.

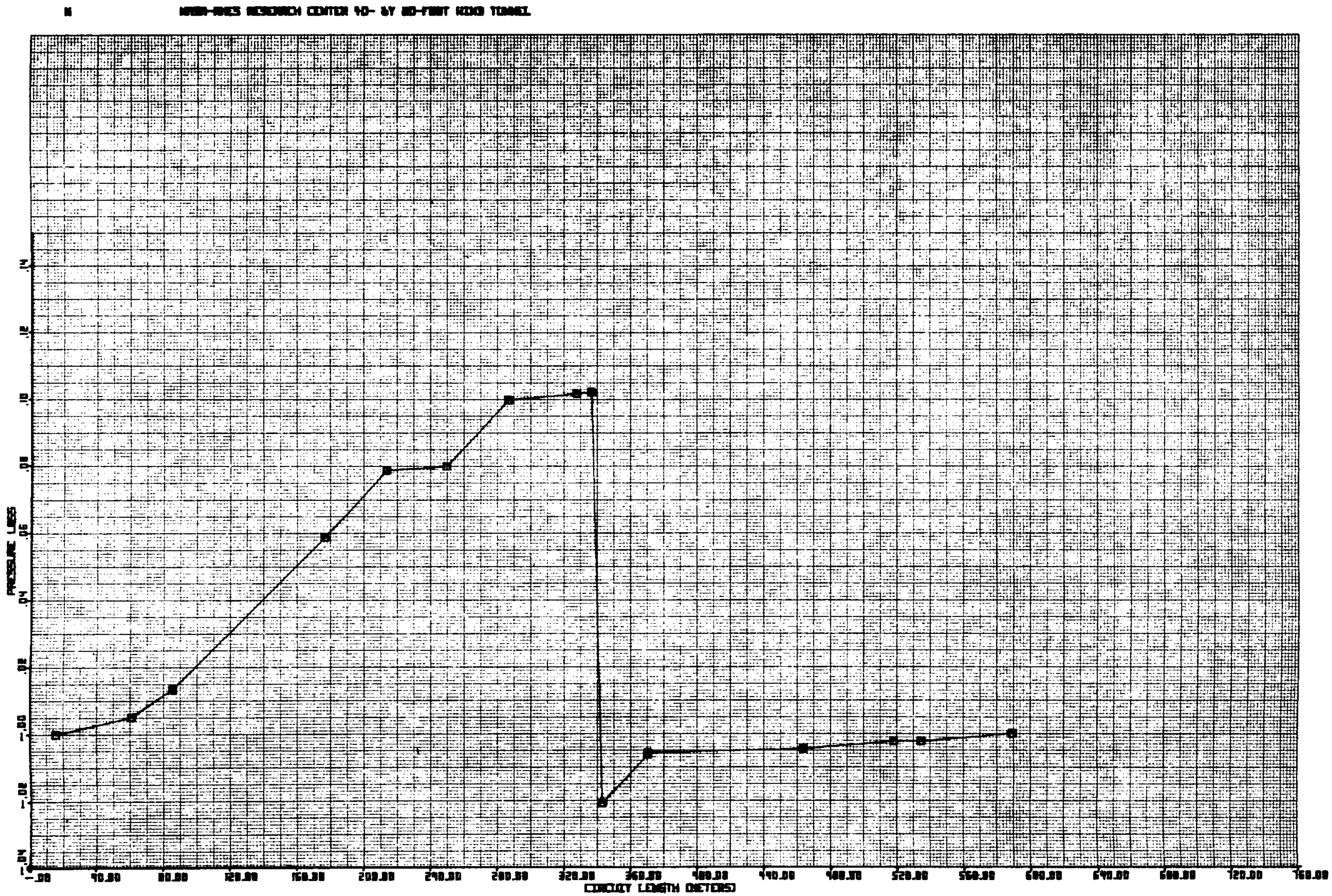
* NASA-AMES RESEARCH CENTER 40- BY 80-FOOT WIND TUNNEL * ...CONTINUED.... PAGE 4

WIND-TUNNEL CIRCUIT CHARACTERISTICS SUMMARY
TAKEN AT DOWNSTREAM END OF EACH SECTION

SECTION ASSIGNED SEQUENCE	CUMULATIVE CIRCUIT LENGTH METERS	MACH NUMBER	CUMULATIVE PRESSURE LOSS (DP/QO)	WALL PRESSURE DIFFERENTIAL (ATMOSPHERIC - INTERNAL) N/SQ M
1	15.34	0.038	0.00003	100.0
2	61.06	0.319	0.00505	6919.4
3	85.44	0.315	0.01340	6815.3
4	176.88	0.116	0.05854	1338.2
5	213.68	0.116	0.07850	1470.9
6	249.70	0.116	0.07972	1477.1
7	286.50	0.116	0.09968	1611.9
8	327.65	0.084	0.10159	1179.6
9	336.64	0.136	0.10209	1975.6
10	343.14	0.136	-0.02072	1161.5
11	370.32	0.065	-0.00641	255.9
12	370.32	0.065	-0.00580	260.0
13	463.38	0.038	-0.00457	69.1
14	517.79	0.038	-0.00230	84.3
15	534.33	0.038	-0.00227	84.6
16	588.74	0.038	0.00000	99.8

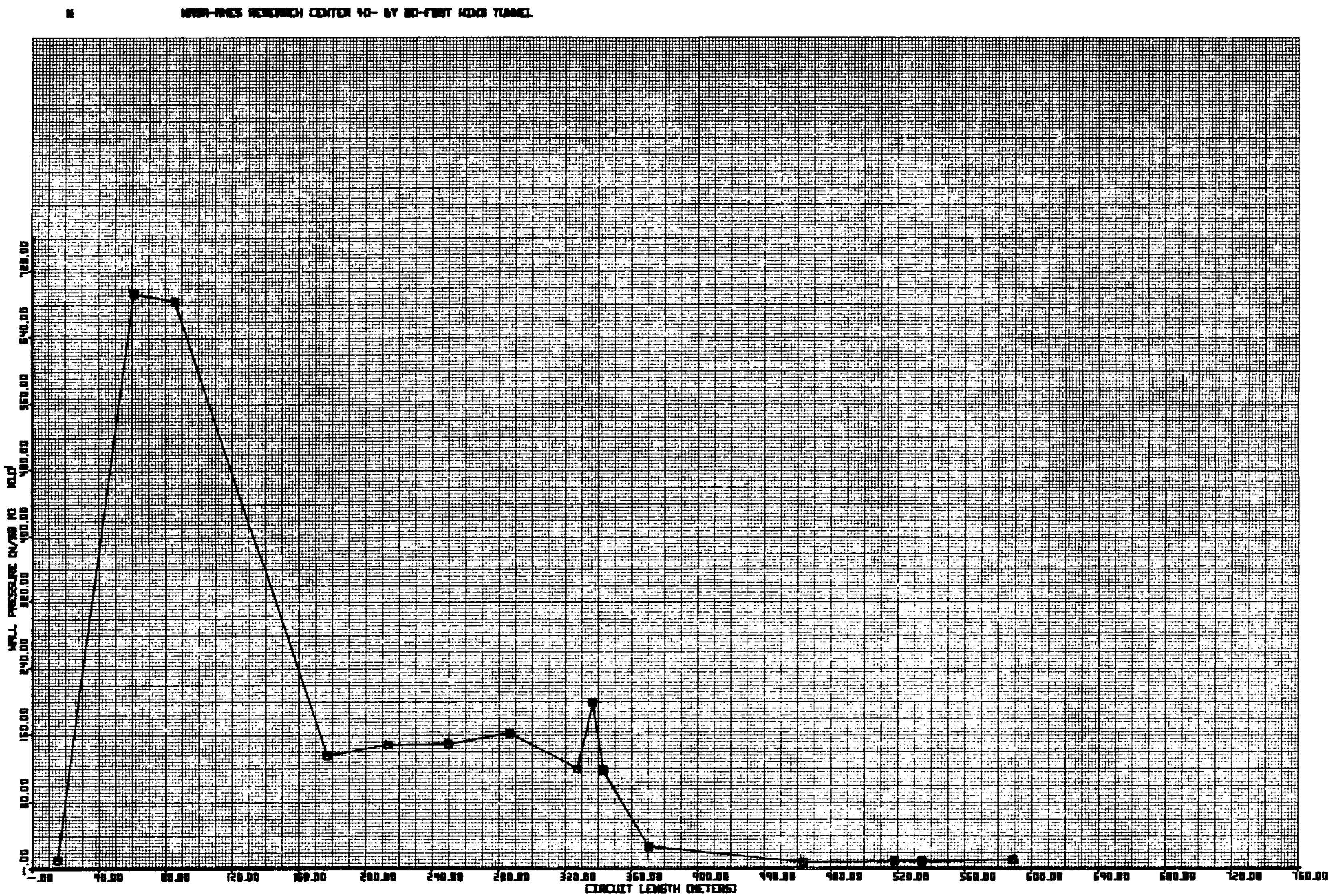
(d) Section summary characteristics information.

Figure 11.- Continued.



(e) Summary information plots.

Figure 11.- Continued.



(e) Summary information plots - Concluded.

Figure 11.- Continued.

* NASA-AMES RESEARCH CENTER 40- BY 80-FOOT WIND TUNNEL * ...CONTINUED.... PAGE 5

ANNCTATED INPUT DATA TABULATION

'EMPTY' INDICATES OPTIONAL, NON-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

TUNNEL MASTER CONTROL DATA

	CASE SEQ. NO.	TUNNEL TYPE	UNITS	SECT. INLET SHAPE	SECT. EXIT SHAPE	H1	W1 D1	MODEL BLKGE PER-	VO	POWER LEVEL MEGA-	PT	TT	P ATM
						M	M	CENT	M/SEC	WATTS	ATM	DEG C	ATM
DATA FIELD BEGINS IN CARD COLUMN --	1	3	4	5	6	11	16	21	26	31	36	41	46
	++	+	+	+	+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+
	-1	1	1	3	3	12.19	24.38	EMPTY	107.3	26.86	1.000	14.85	1.000

CASE TERMINATION CONDITIONS DATA

CASE TERMINATION OCCURRED (DUE TO BLANKS IN CARD COLUMNS 3 AND 4)
AFTER 16 INPUT SECTIONS, AND ACCORDING TO THE FOLLOWING CONDITIONS --

	SUMMARY CHARACTERISTICS OUTPUT	PLOTTING AS A FUNCTION OF LENGTH	INPUT DATA TABULATION	VELOCITY-OPTIMIZATION (FIXED POWER)	RETURN FOR NEXT CASE
TERMINATION-CODE DATA FIELD IS CONTAINED IN CARD COLUMNS --	5-6	7-8	9-10	11-15	16-20
	+-------------+	+---------+	+--------+	+-----------+	+------+
	YES	PRESS. LOSS, WALL PRESS.	YES (CHOSEN)	YES	NO

(f) Annotated tabulation of input data.

Figure 11.- Continued.

*   NASA-AMES RESEARCH CENTER 40- BY 80-FOOT WIND TUNNEL   *   ...CONTINUED....   PAGE 6

ANNOTATED INPUT DATA TABULATICN

'EMPTY' INDICATES OPTIONAL, NCN-REQUIRED INPUT PARAMETER HAS BEEN OMITTED OR PARAMETER MAY BE INTENDED AS ZERO.
'ERROR' INDICATES MANDATORY INPUT PARAMETER HAS BEEN OMITTED. THIS MUST BE CORRECTED BEFORE COMPUTATION IS POSSIBLE.
'EXTRA' INDICATES SUPERFLUOUS INPUT PARAMETER HAS BEEN UNNECESSARILY INCLUDED ON INPUT CARD AND MAY BE REMOVED.
'OPT'N' INDICATES OPTIONAL INPUT DATA HAS BEEN OMITTED AND THE PARAMETER WILL DEFAULT TO A PREDETERMINED VALUE.

SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER- CENT	DEG			10(6), 10(-6) METERS	PER- CENT	PER- CENT
DATA FIELD BEGINS IN CARD COLUMN -- 1	3	5	6	7	9	11	16	21	26	31	36	41	46	51	56	61	66	71	76
++	++	+	+	++	++	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+	+---+
1	10	2	2			40.39	52.58	15.34	40.39	52.58									
2	20	2	3			40.39	52.58	45.72	12.19	24.38									
3	3	3	3			12.19	24.38	24.38	12.28	24.47					OPT'N				
4	40	3	2			12.28	24.47	91.44	20.90	33.10					OPT'N				
5	32	2	2			20.90	33.10	36.80	20.90	33.10		1.848		90.00	OPT'N		OPT'N		
6	10	2	2			20.92	33.10	36.02	20.92	33.10									
7	32	2	2			20.90	33.10	36.80	20.90	33.10		1.848		90.00	OPT'N		OPT'N		
8	40	2	2			20.90	33.10	41.15	25.32	37.52					OPT'N				
9	92	2	1	6.	2.	12.66	12.50	8.992		12.19		4.267	1.797						

(f) Annotated tabulation of input data - Continued.

Figure 11.- Continued.

* NASA-AMES RESEARCH CENTER 40- BY 80-FOOT WIND TUNNEL * ...CONTINUED.... PAGE 7

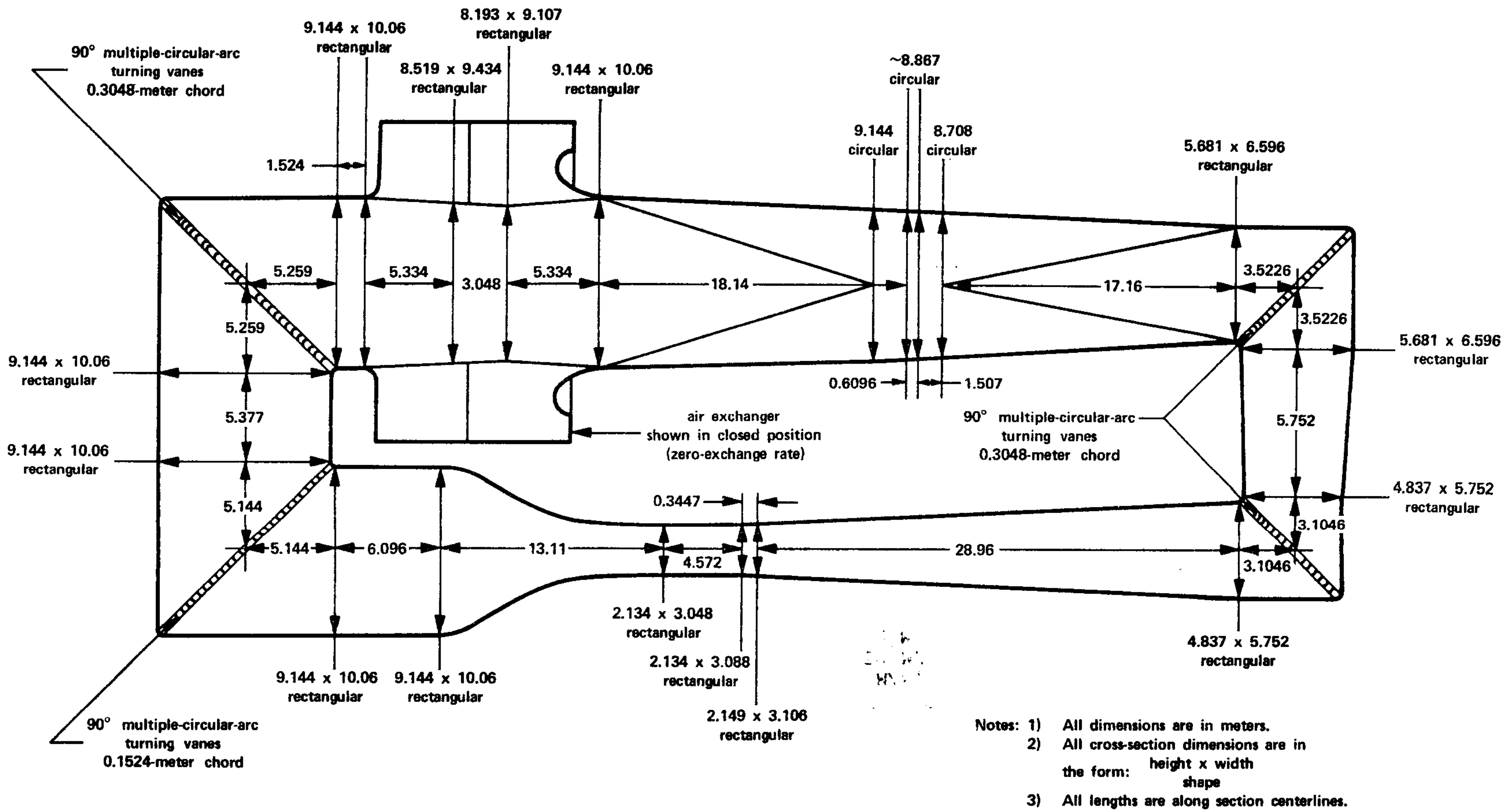
SECTION DESCRIPTION DATA

SECT. SEQ. INPUT	SECT. TYPE	SECT. INLET SHAPE	SECT. EXIT SHAPE	TOTAL NO. DUCTS	ITEMS PER DUCT	H1	W1 D1	L	H2	W2 D2	L/DH, S/AL	CHORD DHUB DMESH	BLKGE PRSTY	PHI	KEXP KMESH KT 90	CD K	RNREF, RUFNES	ETA	D EPS
				NO.	NO.	M	M	M	M	M	M/M, SQ M/ SQ M	M	PER-CENT	DEG			10(6), 10(-6) METERS	PER-CENT	PER-CENT
DATA FIELD BEGINS IN CARC CCLUMN --																			
1 ++	3 ++	5 +	6 +	7 ++	9 ++	11 +---+	16 +---+	21 +---+	26 +---+	31 +---+	36 +---+	41 +---+	46 +---+	51 +---+	56 +---+	61 +---+	66 +---+	71 +---+	76 +---+
10	91	1	1	6.	2.		12.19	6.501		12.19	0.4320	4.267	1.797			0.0100		95.00	EMPTY
11	94	1	2	6.	OPT'N		12.19	27.18	14.74	13.89		4.267	EMPTY		OPT'N				
12	96	1	2	6.	3.		12.19		14.74	13.89	0.1027		5.365			0.0100			EMPTY
13	40	2	2			29.48	41.66	93.06	40.39	52.58					OPT'N				
14	32	2	2			40.39	52.58	54.41	40.39	52.58		0.9906		90.00	OPT'N		OPT'N		
15	10	2	2			40.39	52.58	16.54	40.39	52.58									
16	32	2	2			40.39	52.58	54.41	40.39	52.58		0.9906		90.00	OPT'N		OPT'N		

** ** NASA-AMES RESEARCH CENTER 40- BY 80-FOOT WIND TUNNEL ** CASE COMPLETED OR TERMINATED. **

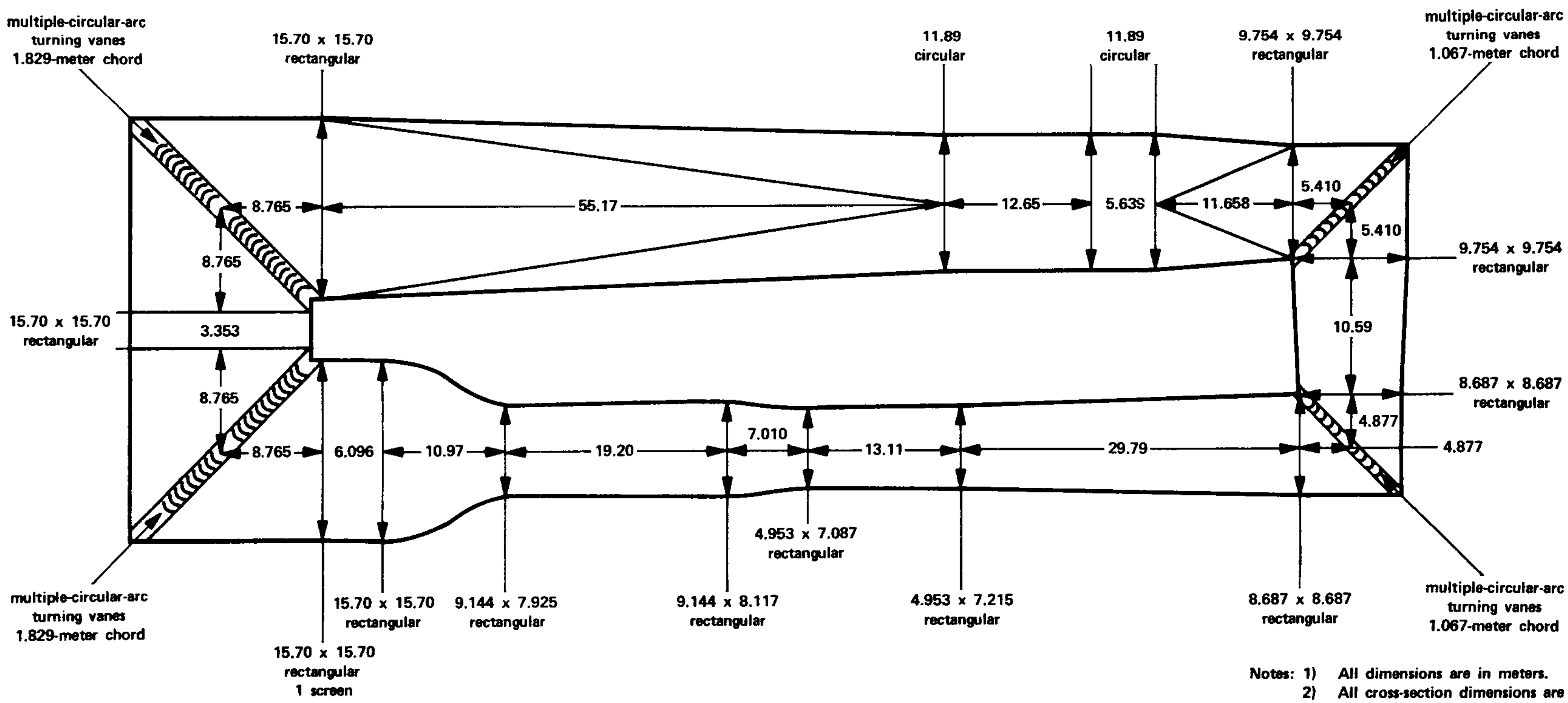
(f) Annotated tabulation of input data - Concluded.

Figure 11.- Concluded.



(a) NASA-Ames Research Center 7- by 10-Foot Wind Tunnel.

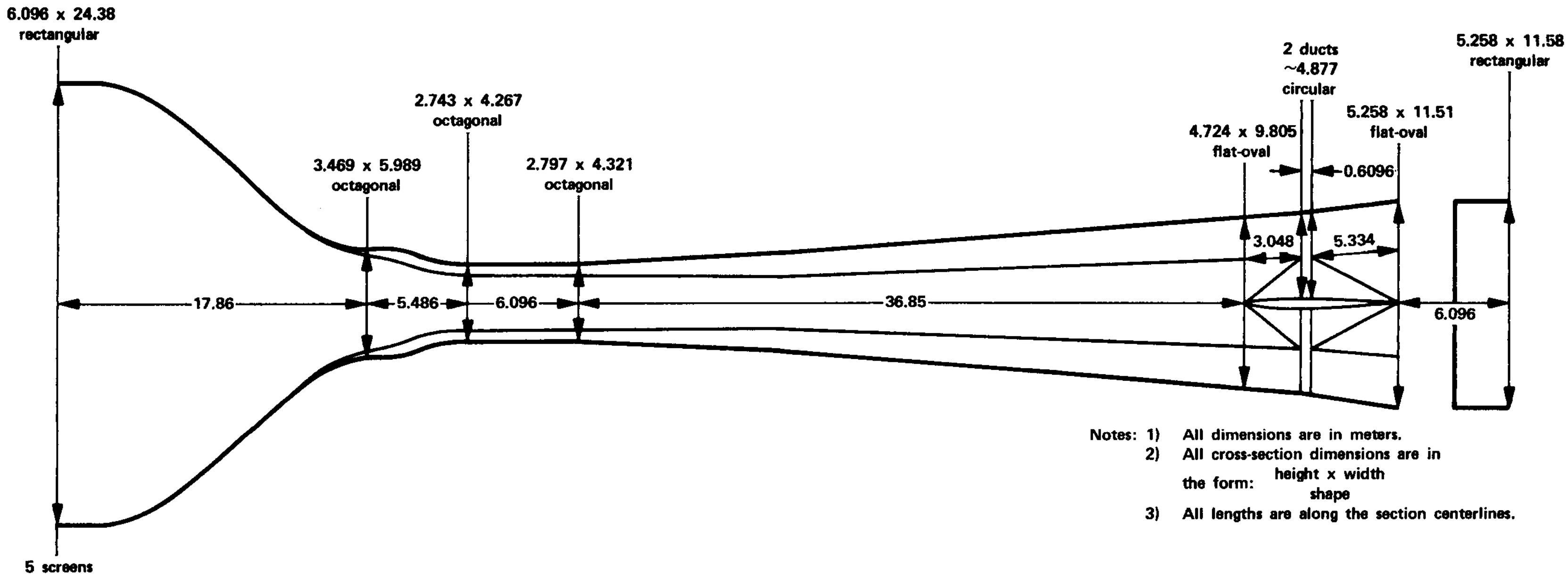
Figure 12.- Illustrations of several existing wind tunnel facilities used as sample cases.



Notes: 1) All dimensions are in meters.
2) All cross-section dimensions are in the form: $\frac{\text{height x width}}{\text{shape}}$
3) All lengths are along section centerlines.

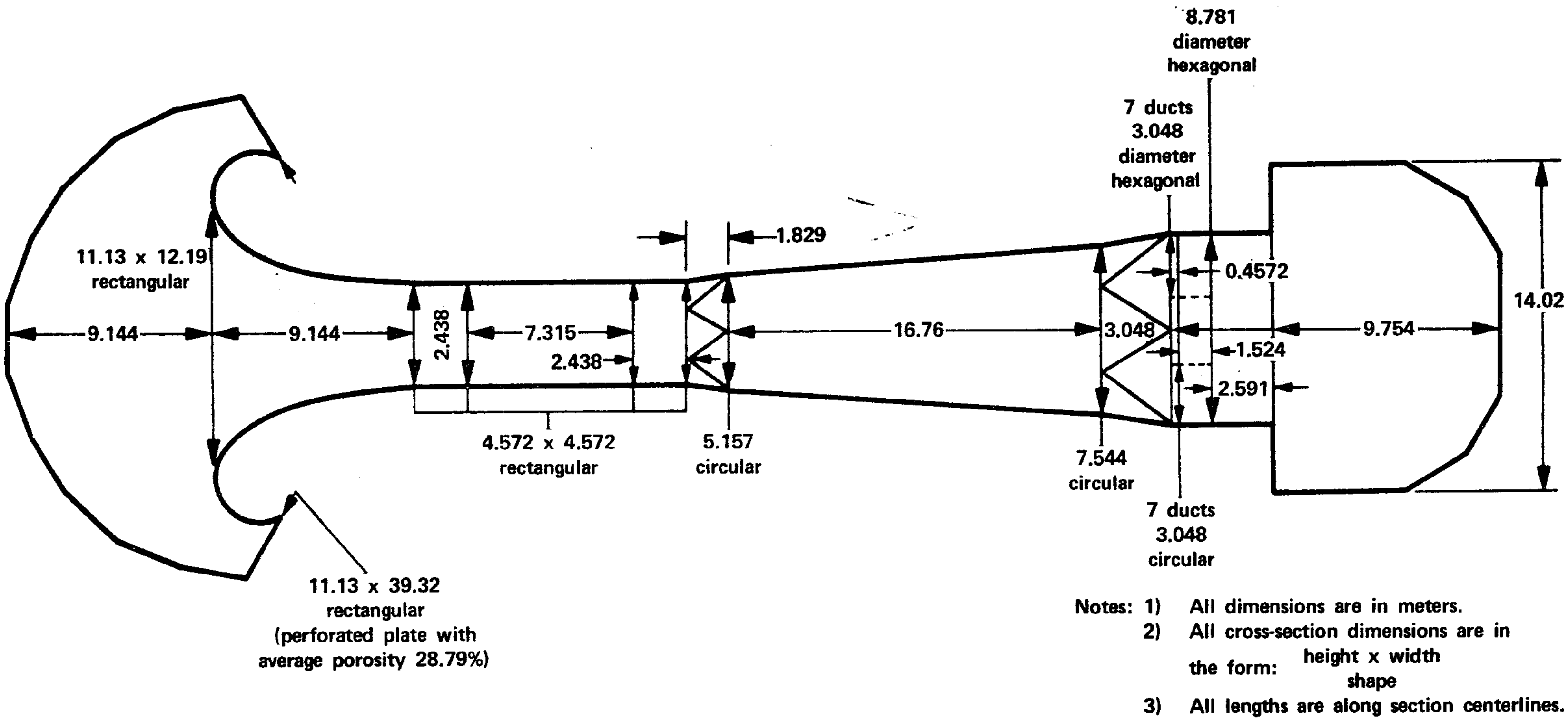
(b) Lockheed-Georgia Low-Speed Wind Tunnel.

Figure 12.- Continued.



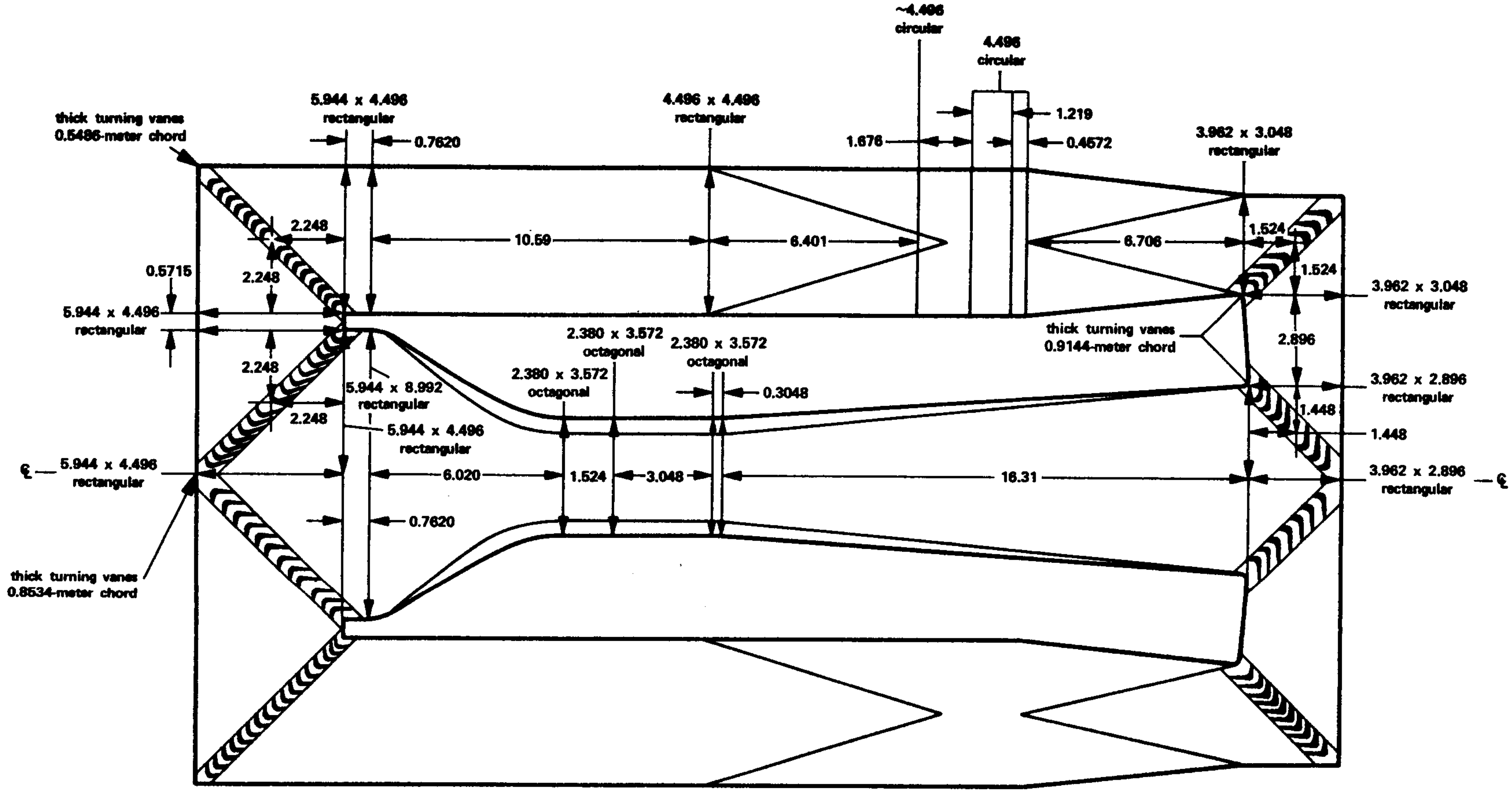
(c) Indian Institute of Science 14- by 9-Foot Wind Tunnel.

Figure 12.- Continued.



(d) Hawker-Siddeley Aviation 15-Foot V/STOL Wind Tunnel at Hatfield.

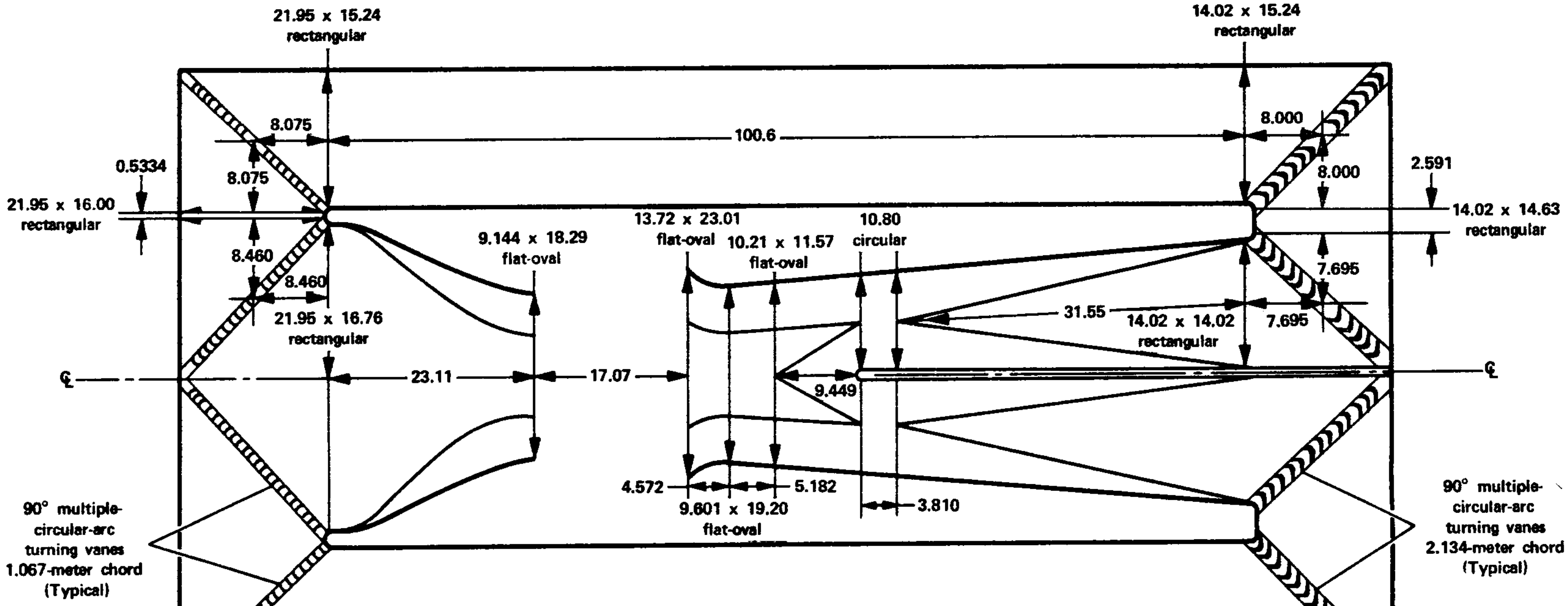
Figure 12.- Continued.



Notes: 1) All dimensions are in meters.
2) All cross-section dimensions are in the form: $\frac{\text{height x width}}{\text{shape}}$
3) The tunnel is symmetrical about the main longitudinal centerline.
4) All lengths are along section centerlines.

(e) University of Washington 8- by 12-Foot Wind Tunnel.

Figure 12.- Continued.



Notes: 1) All dimensions are in meters.
2) All cross-section dimensions are in the form: height x width / shape
3) The tunnel is symmetrical about the main longitudinal centerline.
4) All lengths are along section centerlines.

(f) NASA-Langley Research Center 30- by 60-Foot Wind Tunnel.

Figure 12.- Concluded.

*U.S. GOVERNMENT PRINTING OFFICE: 1976 - 635-275/120