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Ejectors and jet pumps: computer program for design and performance for steam/gas flow

Associated software: ESDUpac A9446

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Internal Flow Panel, which first met in 1979 and had the following membership:

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This Item supersedes in part and incorporates the methods of ESDU 86030. The work on ESDU 86030, for the design and performance of ejectors and jet pumps with steam driven flows, was monitored and guided in 1986 by the following Working Party[†]:

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(Continued on inside back cover)

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EJECTORS AND JET PUMPS: COMPUTER PROGRAM FOR DESIGN AND PERFORMANCE FOR STEAM/GAS FLOW

ESDU 94046 is one of a group of Data Items on the design and performance prediction of ejectors and jet pumps. A computer program, referred to as ESDUpac A93446, is presented for the design and performance prediction of ejectors where both the primary is steam and secondary is gas.

Three calculation procedures are provided within the program. A 'quick' design method is based on data from a range of single nozzle ejectors and requires a minimum of input data. A detailed design method is also provided (based on a one-dimensional flow theory given in the Appendix) which enables a more detailed assessment of the effects of internal losses to be made. This method may also be applied to multi-nozzle or annular nozzle designs. The performance predicted method is also based on the one-dimensional theory and calculates the flow conditions throughout the ejector given the dimensions, loss factors and entry flow conditions. The use of the program is illustrated by three worked examples. The program is provided to run within ESDUview, a user-friendly environment for personal computer users. The FORTRAN source code is also provided.

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EJECTORS AND JET PUMPS:

Computer Program for Design and Performance for Steam/gas Flow

1. NOTATION AND UNITS

Any consistent system of units may be used in the equations in this Item*.

		Units	
		SI	British
A	cross-sectional area	m^2	ft^2
A_{ME}	area ratio, A_4/A_e	—	—
A_R	area ratio, A_4/A'_e	—	—
A_R^*	area ratio, A_4/A_{th}	—	—
a	sonic velocity	m/s	ft/s
b_1, b_2	gradients of ejector characteristics	—	—
C_D	primary-nozzle discharge coefficient	—	—
C_{pr}	diffuser static pressure recovery	—	—
c_1, c_2	intercepts of ejector characteristics (see Section 6.1.2)	—	—
d	diameter	m	ft
i	indicator of parameter	—	—
K	mixing duct momentum loss factor	—	—
L	length of mixing duct	m	ft
L_d	length of contraction or diffuser	m	ft
M	Mach number: V/a	—	—
$\dot{m}$	mass flow rate	kg/s	slug/s [†]
$\tilde{m}$	molar mass	kg/kmol	kg/kmol
N_s	pressure ratio for component of multi-stage ejector: p_{t5}/p_{t0}	—	—
n	number of values of parameter, or number of stages, or number of nozzles	—	—
PP	primary parameter: $C_D(p'_{te}/p''_{te})/A_R$	—	—

For footnotes see end of notation section.

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p	absolute static pressure	Pa	lbf/ft ²
p_t	absolute total pressure	Pa	lbf/ft ²
R	gas constant (for air, $R \approx 287$ J/kg K, 3090 ft lbf/slug K)	J/kg K	ft lbf/slug K [†]
r_m	mass flow ratio: $\dot{m}''/\dot{m}'$	—	—
S	length of mixing duct entry	m	ft
SP	secondary parameter: $(p_{te}''/p_4)(A_R - 1)/A_R$	—	—
T_t	absolute total temperature	K	K
V	stream velocity	m/s	ft/s
W	mass flow ratio for component of multi-stage ejector: $1/r_m$	—	—
γ	ratio of specific heat capacity at constant pressure to that at constant volume (for superheated steam, $\gamma \approx 1.3$)	—	—
η_d	contraction or diffuser total-pressure recovery: p_{t5}/p_{t4}	—	—
η_i	secondary flow inlet efficiency: p_{te}''/p_{t0}	—	—
ρ	fluid density	kg/m ³	†slug/ft ³
ϕ_d	contraction or diffuser wall angle	degree	degree
ϕ_m	mixing duct wall equivalent angle	degree	degree

* For many parameters, ESDUpac A9242 uses non-consistent, but more commonly-used, units to simplify the use of the program. The units required by the program are shown in Tables 5.2a-d and are displayed on-screen when running VIEWpac A9242 in ESDUview (see Section 4).

† 1 slug = 32.174 lb mass.

Subscripts

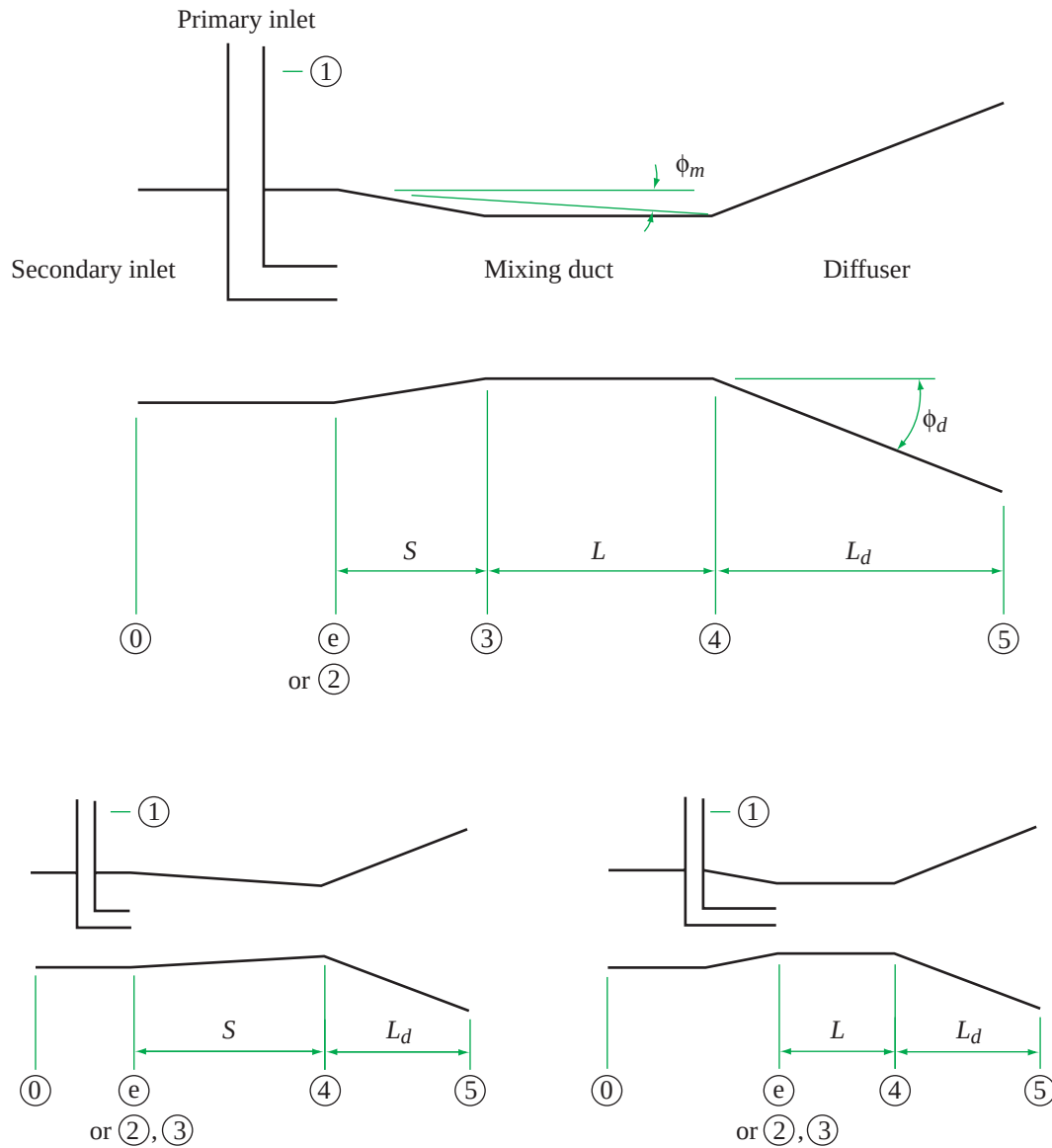
e	primary nozzle exit plane
th	primary nozzle throat
max	upper limit of parameter
T	refers to total steam consumption of multi-stage unit (see Section 6.2.1)
u	denotes multi-stage unit
0	secondary flow entry plane
1	primary nozzle entry plane
3	mixing duct entry plane

- 4 mixing duct exit plane
- 5 contraction or diffuser exit plane

The reference planes are defined in Sketch 1.1. Note that, for constant area mixing, planes 2 and 3 are coincident and are referred to by subscript e .

Superscripts

- ' refers to primary stream or primary nozzle
- " refers to secondary stream or secondary inlet



Sketch 1.1 Ejector configuration and typical cases

2. INTRODUCTION

ESDU 94046 is one of a group of ESDU Data Items concerned with the design and performance of ejectors and jet pumps. Such devices are characterised by the use of the kinetic energy of a fluid stream (the primary flow) to impart momentum to a second fluid stream (the secondary flow) by direct mixing. Each Data Item in the group treats the different combinations of working fluids (which can be gases, liquids or solids in suspension); their applicability is outlined below.

TABLE 2.1 Applicability of Data Items in the Group on Ejectors and Jet Pumps

Fluid		Fluid temperatures	Mixing chamber		Design methods	Performance prediction
Primary flow	Secondary flow		Constant area	Conical		
Gas	Gas	Any	✓	✓	92042	92042
Steam	Gas	Any (saturated gas, saturated steam)	✓	✓	94046	94046
Steam	Liquid	Any (saturated steam)	✓	✓	86030	–
Liquid	Liquid	N/A	✓	✓	93022 and 85032	93022 and 85032

The terms “ejector” and “jet pump” are synonymous, and the term “injector” is also commonly used. Guidance on the applications of ejectors (as pressure boosters, compressors, vacuum pumps or in ventilation and air conditioning, for example) and on the principles of operation is given in the Data Items within the group.

3. PURPOSE AND SCOPE OF ESDUpac A9446 and VIEWpac 9446A

ESDU 94046 provides details of a Fortran computer program, ESDUpac A9446, for use in the design and performance evaluation of ejectors and jet pumps in which the working fluids are gases. A user-friendly version, referred to as VIEWpac 9446A, is also available, and is described in Section 4

ESDUpac A9446 provides the following design and performance prediction procedures.

- (i) **Quick Design Procedure.** Given a selection of entry and required exit pressures, temperatures, mass flow rates and dimensions, the program will calculate primary nozzle and exit dimensions, using empirical data for steam-air ejectors. Note that the scope of the Quick Design Method is restricted to ejectors with constant area mixing and air as the secondary fluid.
- (ii) **Detailed Design Procedure.** Given a selection of entry and required exit pressures, temperatures, mass flow rates, dimensions and loss factors as well as four user defined constraints on the flow conditions, the program will calculate primary nozzle and exit dimensions and flow conditions throughout the ejector using the procedure outlined in Section A1 of Appendix A.
- (iii) **Performance Prediction Calculation.** Given the ejector dimensions, loss factors and a range of flow conditions at the entry, the program will calculate the outlet conditions and the flow conditions throughout the ejector, using the procedure outlined in Section A13 of Appendix A.

Section 5 describes the required input data. Section 6 provides notes on the design and operation of steam/gas ejectors. A number of examples that illustrate the use of the program are presented in Section 7. The full analysis for the computer program appears in Appendix A.

In many ejectors, the secondary inlet conditions are set by existing upstream pipework. In the design procedure, the program optimises for the shortest mixing duct length for complete mixing of the primary and secondary fluids and for the highest efficiency. The program allows a design requirement for a particular pressure and/or mass flow characteristic at the exit of the ejector to be met.

The ejector design procedures determine performance at the primary nozzle 'on-design' point. There are a number of situations in which this approach will be inadequate. The ejector may be required to operate over a range of primary pressures or secondary Mach numbers, in which case estimates of 'off-design' performance must be sought. Performance prediction is also necessary if an existing plant item, with all physical dimensions known, needs to be assessed for a particular application.

The performance prediction procedure calculates the flow conditions in an ejector of known physical dimensions.

The calculation procedure presented in Appendix A is applicable to non-reacting gases that can be modelled as ideal and to ejectors with mixing ducts of circular (either cylindrical or conical) section. The methods are based on the equations of continuity and of momentum and energy conservation.

4. VERSIONS OF THE PROGRAM

*ESDUpac A9446 is provided on disk and can be accessed in two ways.

The interactive version, VIEWpac 9446A, is contained within ESDUview, a user-friendly ‘windowing’ environment for running ESDUpacs. ESDUview manages all operations such as setting up input files, running the Fortran ESDUpac code and viewing the output files. On opening *VIEWpac 9446A from the menu of available VIEWpacs, the user is prompted for all the input data. Context-sensitive help is available on all the parameters of the program. At various points throughout operation of the program a number of checks are carried out on the entered data. Error messages alert the user to incorrect numerical values and guide in their correction; other potential problems are highlighted by warning messages.

The features of ESDUview are described fully in the Fluid Mechanics, Internal Flow Software Volume.

The source code is contained in the Fluid Mechanics, Internal Flow Software Volume. An executable version of this program can be obtained by compiling[†] the code, which is written in ANSI standard Fortran 77. By compiling the source code the program can be operated on a range of computers. To run the executable version of the program from the keyboard, the name of the data input file and the name of the output file must be specified on the command line using the operating system redirection symbols, for example

```
A9446V10 < EX1.IN > EX1.OUT
```

The VIEWpac version is recommended for its ease of operation. Instructions for creating the data input file are given in Section 5 for users who wish to compile the source code and run the program directly. Although the VIEWpac version can be operated without reference to this Data Item, the user may find in Section 5 additional useful guidance (complementary to that in the ESDUview HELP facility) on the program variables and model details.

The scope of the program is described in Section 3. Guidance on the input and output files is given in Section 5. Section 7 presents a selection of worked examples, with full input and output file listings.

5. DESCRIPTION OF INPUT AND OUTPUT DATA

5.1 Program Input

At run time, the program reads from a text data input file all the information necessary to define the nature of the problem and control the analysis. When using the VIEWpac version of the program, this data file is generated automatically and the program operates when the user selects RUN from an on-screen menu (provided all the pre-run checks are satisfied). If you do not intend to use the VIEWpac version but wish to compile the Fortran source code and run the resulting executable code (*e.g.* file A9446V10.EXE), this data file must be constructed (outside the program) using a text editor. The order in which data variables are required by the program in data input files is shown in Section 5.2; this data entry sequence must be followed exactly. Example data input files and corresponding output files are discussed in Section 7. The user should note, however, that these examples cover only three of the large number of possible routes through the data program.

* In addition to a core reference number based on the number of this Item, ESDUpac and VIEWpac names include version numbers. At first issue, the ESDUpac is named ESDUpac A9442V10 and the VIEWpac is named VIEWpac 9442AV10. See “Using ESDUview” for further information on these numbering systems.

† Guidance on the compilation and running of the program is given in the “Introduction to ESDUpacs” in the Fluid Mechanics, Internal Flow Software Volume.

The controlling data input file contains information on the type of analysis required (that is the design or performance prediction methods), the flow conditions and the geometry of the ejector.

The use of data input files allows the information to be checked before each run and edited if necessary.

5.2 Data Input Files

The data input sequence of this Section must be followed.

5.2.1 General data input

TABLE 5.1 General Data for the Analysis

Entry order	Input parameter	SI units	British units	Variable type
(1a) (1b) (1c)	Title of the run (3 lines of text of up to 72 characters each). Enter text for first line of title. Enter text for second line of title. Enter text for third line of title.	— — —	— — —	Character Character Character
(2)	Enter 1 or 2 as required, where 1 is for SI units, and 2 is for British units.	—	—	Integer
(3)	Enter 1, 2 or 3 as required, where 1 instructs program to use Quick Design Procedure, 2 instructs program to use Detailed Design Procedure, 3 instructs program to use Performance Prediction Procedure.	—	—	Integer

The data entry sequence continues as follows.

<i>For Entry at (3)</i>	<i>Go to Entry</i>
1	(Q4) in Table 5.2 of Section 5.2.2
2	(D4) in Table 5.3 of Section 5.2.3
3	(P4) in Table 5.4 of Section 5.2.4

5.2.2 Data input for “Quick Design Procedure”

The Quick Design Procedure is based on data obtained for steam ejectors pumping air at 20°C. If other gases are to be handled, it is necessary to convert the secondary mass flow rate to an equivalent value for air at 20°C. The program performs this conversion using the molar mass of the secondary gas. A value of 29 kg/kmol may be assumed (in both unit systems) for the molar mass of air. This parameter is entered at Entry (Q4).

In the Quick Design Procedure, the program requires as input values of any two of the three pressures p_{t0} , p_{t1} and p_{t5} and any two of the mass flow rates $\dot{m}''$, $\dot{m}'$ and $\dot{m}'' + \dot{m}'$. It subsequently calculates the two pressures ratios p_{t1}/p_{t5} , p_{t5}/p_{t0} and the mass flow ratio, r_m . The following options are provided to allow the user flexibility to input combinations of known values of the pressures and mass flow rates.

- Either* (i) enter 2 of the 3 pressures *and* 2 of the 3 mass flow rates,
or (ii) enter 2 of the 3 pressures *and* 1 of the 3 mass flow rates,
or (iii) enter 1 of the 3 pressures *and* 2 of the 3 mass flow rates.

When too few data are available to define the flow conditions fully (that is in options (ii) and (iii)), the user must in addition enter estimated values of one further parameter defining a range of ejector flow conditions.

The data entry sequence continues at Entry (Q4).

TABLE 5.2 Data for Quick Design Procedure

Entry order	Input parameter	SI units	British units	Variable type
(Q4)	If 1 was entered in (3) Enter molar mass of secondary gas.	kg/kmol	kg/kmol	Real
(Q5)	<i>Either</i> enter secondary stream entry total pressure, p_{t0} , <i>or</i> enter 0 if this pressure is unknown (see above).	kPa	psi	Real
(Q6)	<i>Either</i> enter primary stream entry total pressure, p_{t1} , <i>or</i> enter 0 if this pressure is unknown (see above).	kPa	psi	Real
(Q7)	<i>Either</i> enter contraction or diffuser exit total pressure, p_{t5} , <i>or</i> enter 0 if this pressure is unknown (see above).	kPa	psi	Real
(Q8)	<i>Either</i> enter secondary stream mass flow rate, $\dot{m}''$, <i>or</i> enter 0 if this mass flow rate is unknown (see above).	kg/s	lb/s	Real
(Q9)	<i>Either</i> enter primary stream mass flow rate, $\dot{m}'$, <i>or</i> enter 0 if this mass flow rate is unknown (see above).	kg/s	lb/s	Real
(Q10)	<i>Either</i> enter mixing duct mass flow rate, $\dot{m}'' + \dot{m}'$, <i>or</i> enter 0 if this mass flow rate is unknown (see above).	kg/s	lb/s	Real

If option (i) is chosen (that is 2 pressures and 2 mass flow rates are input) the data entry sequence continues at Entry (Q14).

If option (ii) or option (iii) is chosen, further input data are required as one more parameter needs to be defined in order to run the program. The user is provided with the following options.

Either to enter any number of values (up to 9) of an undefined mass flow (for option (ii)) or an undefined pressure (for option (iii)) as appropriate. The range of values must be within the practical range defined by Figure 1. The choice of the defined parameter is made at Entry (Q12).

Or to instruct the program to operate using a range of values of an undefined parameter. For option (iii) the program uses a range of values of the pressure ratio p_{t1}/p_{t5} to define the input data fully. For option (ii) a range of values of the mass flow ratio, r_m , is used to define the input data fully. These values will be calculated by the program and cover the suggested practical range shown in Figure 1.

If option (ii) or option (iii) is followed, the data entry sequence continues at Entry (Q11).

TABLE 5.2 Data Quick Design Procedure (continued)

Entry order	Input parameter	SI units	British units	Variable type
(Q11)	Number of user estimates, n, of the undefined parameter (number in range 0 to 9). Enter n . A value of $n = 0$ instructs the program to generate 9 estimates of an undefined mass flow or pressure ratio (see above). If 0 was entered in (Q11) go to Entry (Q14).	—	—	Integer
(Q12)	Undefined parameters Enter i , where i defines parameter to be estimated by user; $i = 1$ corresponds to estimates of p_{t0} $i = 2$ corresponds to estimates of p_{t1} $i = 3$ corresponds to estimates of p_{t5} $i = 4$ corresponds to estimates of $\dot{m}''$ $i = 5$ corresponds to estimates of $\dot{m}'$ $i = 6$ corresponds to estimates of $\dot{m}'' + \dot{m}'$.	—	—	Integer
(Q13)	Enter n estimates of parameter defined in (Q11).	kPa or kg/s	psi or lb/s	Real
(Q14)	Enter secondary flow entry total temperature, T_{t0} .	K	K	Real
(Q15)	Enter primary flow entry total temperature, T_{t1} .	K	K	Real

TABLE 5.2 Data Quick Design Procedure (continued)

Entry order	Input parameter	SI units	British units	Variable type
(Q16)	Enter mixing duct length/diameter ratio, $(S + L)/d_4$. A value in the range $8 \leq (S + L)/d_4 \leq 10$ is recommended (see Section 6.1.4).	—	—	Real
(Q17)	Enter contraction or diffuser exit diameter, d_5 .	m	in	Real
(Q18)	Enter modulus of contraction or diffuser wall angle, $ \phi_d $. A value in the range $3 \leq \phi_d \leq 5$ is recommended (see Section 6.1.5). Note that the program will determine whether a contraction or a diffuser is appropriate.	degree	degree	Real

No further entries are required for the Quick Design Procedure.

5.2.3 Data input for “Detailed Design Procedure”

For this procedure the data entry sequence continues after Table 5.1 at Entry (D4).

TABLE 5.3 Data for Detailed Design Procedure

Entry order	Input parameter	SI units	British units	Variable type
(D4)	If 2 was entered in (3) Enter γ' , the ratio of the specific heat capacities of the steam in the primary stream.	—	—	Real
(D5)	Enter R' , the gas constant of the steam in the primary stream.	J/kg K	ft lbf/ slug K	Real
(D6)	Enter γ'' , the ratio of the specific heat capacities of the secondary gas.	—	—	Real
(D7)	Enter R'' , the gas constant of the secondary gas.	J/kg K	ft lbf/ slug K	Real

The Quick Design Procedure incorporates losses by using empirical results. In order to refine the design it is necessary to break the overall loss down into constituent parts and to attempt to identify their sources. The Detailed Design Procedure involves the use of four “loss factors” that are used to characterise the main sources of loss in ejector performance. These loss factors are defined below.

- (i) The primary nozzle discharge coefficient, C_D , accounts for losses in the primary nozzle. Information on nozzle design and corresponding C_D values is given in References 2, 3, 4, 9 and 12. A well-designed nozzle can achieve a C_D value greater than 0.95.
- (ii) The mixing duct momentum loss factor, K , allows for all losses in the mixing duct. This factor is defined by the equation

$$1 + \frac{\gamma_4}{K} M_4^2 = \frac{PP(1 + \gamma' M_3'^2)}{\left[1 + \frac{(\gamma' - 1)}{2} M_3'^2\right]^{\frac{\gamma'}{\gamma' - 1}}} + \frac{SP(1 + \gamma'' M_3''^2)}{\left[1 + \frac{(\gamma'' - 1)}{2} M_3''^2\right]^{\frac{\gamma''}{\gamma'' - 1}}}, \quad (5.1)$$

which is reduced to Equation (A10.1) in Appendix Section A10. The maximum theoretical value of K is unity. The momentum loss may be caused by:

- (a) primary/secondary energy transfer inefficiency,
- (b) skin friction at the mixing duct wall,
- (c) secondary flow non-uniformity due to blockage by the primary nozzle support/feed assembly (most significant for multi-nozzle arrangements),
- (d) non-ideal gas and non-isentropic flow effects.

The energy losses occurring in the mixing duct are the most significant in terms of ejector design. The magnitude of these losses can vary considerably from one ejector to another and so the factor K can vary appreciably in different designs. For most types of ejector, K falls within the range 0.75 to 0.95. A value lower than 0.75 indicates excessive losses. Conversely, a value close to 0.95 denotes a highly efficient design. Table 9.1 gives a number of ranges of values of K derived from experimental data for a variety of configurations. However, for general purpose single nozzle ejectors, a value of $K = 0.87$ may be taken as typical.

- (iii) Losses in the exit diffuser or contraction are represented by the pressure recovery term, η_d , defined by

$$\eta_d = p_{t5}/p_{t4}. \quad (5.2)$$

For a well-designed contraction, η_d is unity. For a diffuser, the static pressure recovery coefficient,

$$C_{pr} = (p_5 - p_4)/[\frac{1}{2}\rho_4(\dot{m}/\rho_4 A_4)^2], \quad (5.3)$$

can be related to η_d by

$$\eta_d = (1 + \frac{1}{2}\gamma_4 M_4^2 C_{pr})((p_{t5}/p_5)/(p_{t4}/p_4)). \quad (5.4)$$

Ideally, a pressure recovery coefficient for compressible flow should be used, but data on this topic are not readily available. However, an incompressible value for the coefficient should be sufficiently accurate for values of M_4 up to about 0.7. Data for diffusers in incompressible flow

may be found from References 14 to 16 and some information on diffusers in compressible flow from Reference 5. Typical values of η_d for the recommended diffuser geometries lie in the range 0.9 to 0.96.

Note that Equations (5.3) and (5.4) assume uniform flow across the duct.

In the Detailed Design Procedure, unless the diffuser geometry is fixed, it may be necessary on completion of the procedure to check that the diffuser geometry required is compatible with the value chosen for η_d .

- (iv) Losses in the secondary flow inlet are represented by the secondary inlet efficiency, η_i , defined by

$$\eta_i = p''_{te} / p_{t0}. \quad (5.5)$$

Losses in the secondary flow inlet are usually negligible but blockage by the primary nozzle support/feed assembly can cause significant losses, especially for multi-nozzle arrangements.

The loss factors are Entries (D8) to (D11).

TABLE 5.3 Data for Detailed Design Procedure (continued)

Entry order	Input parameter	SI units	British units	Variable type
(D8)	Enter primary nozzle discharge coefficient, C_D .	—	—	Real
(D9)	Enter mixing duct momentum loss factor, K .	—	—	Real
(D10)	Enter contraction or diffuser total pressure recovery, η_d .	—	—	Real
(D11)	Enter secondary flow inlet efficiency, η_i .	—	—	Real

The program requires an input to determine the convergence of the mixing duct. This is the area ratio $A_{ME} = A_4/A_e$. Note that this ratio, taken with the ratio $(S + L)/d_4$ (see Entry (D28)) determines the mixing duct wall equivalent angle, ϕ_m .

TABLE 5.3 Data for Detailed Design Procedure (continued)

Entry order	Input parameter	SI units	British units	Variable type
(D12)	Enter area ratio, A_{ME} .	—	—	Real

The following design constraints ensure that the final design does not exceed design limits and that the ejector will not be running in a high-loss mode.

- Maximum primary pressure limit, p_{t1max} : the maximum primary flow pressure available less all losses upstream of the primary nozzle exit plane.

- Maximum secondary Mach number, $M''_{e\max}$. It is advisable to minimise secondary fluid inlet velocities so that inlet losses are minimised. This effectively imposes a limit on the secondary flow Mach number, M''_e .
- Maximum allowable area ratio, $A_{R\max}$. The space available for the ejector sets a limit on the maximum cross-sectional area of the mixing duct. The primary flow Mach number, M'_e , determines the primary nozzle exit area for a given throat area. Hence a limit is placed on the area ratio, $A_R = A_4/A'_e$.
- Exit duct area ratio, A_5/A_4 . For a diffuser, an area ratio of 3 to 4 and an included angle of 6° to 10° ($\phi_d = 3^\circ$ to 5°) are desirable in the absence of other constraints. This may also influence the mixing duct diameter if connection is to be made to an existing system.

TABLE 5.3 Data for Detailed Design Procedure (continued)

Entry order	Input parameter	SI units	British units	Variable type
(D13)	Enter primary nozzle entry pressure limit, $p_{t1\max}$.	kPa	psi	Real
(D14)	Enter secondary flow mixing duct entry Mach number limit, $M''_{e\max}$.	—	—	Real
(D15)	Enter mixing duct area ratio limit, $A_{R\max}$.	—	—	Real
(D16)	Enter exit duct area ratio, A_5/A_4 .	—	—	Real

In the Detailed Design Procedure, the program requires any two of the three pressures p_{t0} , p_{t1} , p_{t5} and any two of the mass flow rates $\dot{m}''$, $\dot{m}'$ and $\dot{m}'' + \dot{m}'$. It subsequently calculates the two pressure ratios p_{t1}/p_{t5} , p_{t5}/p_0 , and the mass flow ratio, r_m . The following options are provided to allow the user flexibility to input combinations of the pressures and mass flow rates.

- Either (i) enter 2 of the 3 pressures *and* 2 of the 3 mass flow rates,
or (ii) enter 2 of the 3 pressures *and* 1 of the 3 mass flow rates,
or (iii) enter 1 of the 3 pressures *and* 2 of the 3 mass flow rates.

When insufficient data are available to define the flow conditions fully (in options (ii) and (iii)), the user must, in addition, enter estimated values of one further parameter, defining a range of ejector flow conditions.

TABLE 5.3 Data for Detailed Design Procedure (continued)

Entry order	Input parameter	SI units	British units	Variable type
(D17)	<i>Either or</i> enter secondary stream entry total pressure, p_{t0} , enter 0 if this pressure is unknown (see above).	kPa	psi	Real
(D18)	<i>Either or</i> enter primary stream entry total pressure, p_{t1} , enter 0 if this pressure is unknown (see above).	kPa	psi	Real
(D19)	<i>Either or</i> enter contraction or diffuser exit total pressure, p_{t5} , enter 0 if this pressure is unknown (see above).	kPa	psi	Real
(D20)	<i>Either or</i> enter secondary stream mass flow rate, $\dot{m}''$, enter 0 if this mass flow rate is unknown (see above).	kg/s	lb/s	Real
(D21)	<i>Either or</i> enter primary stream mass flow rate, $\dot{m}'$, enter 0 if this mass flow rate is unknown (see above).	kg/s	lb/s	Real
(D22)	<i>Either or</i> enter mixing duct mass flow rate, $\dot{m}'' + \dot{m}'$, enter 0 if this mass flow rate is unknown (see above).	kg/s	lb/s	Real

If option (i) is chosen (that is 2 pressures and 2 mass flow rates are input), the data entry sequence continues at Entry (D26).

If option (ii) or option (iii) is chosen, further input data are required as one more parameter needs to be defined in order to run the program. The user is provided with the following options.

Either to enter any number of values (up to 9) of an undefined mass flow (for option (ii)) or an undefined pressure (for option (iii)) as appropriate. The choice of the undefined parameter is made at Entry (D24).

Or to instruct the program to operate using a range of values of an undefined parameter. For option (iii), the program uses a range of values of the pressure ratio p_{t1}/p_{t5} to define the input data fully. For option (ii) a range of values of the mass flow ratio, r_m , is used to define the input data fully. These values will be calculated by the program.

If option (ii) or option (iii) is chosen, the data entry sequence continues at Entry (D23).

TABLE 5.3 Data for Detailed Design Procedure (continued)

Entry order	Input parameter	SI units	British units	Variable type
(D23)	Number of user estimates, n, of the undefined parameter (number in range 0 to 9)*. Enter n. A value of $n = 0$ instructs the program to generate 9 estimates of an undefined mass flow or pressure ratio (see above). If 0 was entered in (D23) go to Entry (D26).	—	—	Integer
(D24)	Undefined parameters Enter i, where i defines parameter to be estimated by user; $i = 1$ corresponds to estimates of p_{t0} $i = 2$ corresponds to estimates of p_{t1} $i = 3$ corresponds to estimates of p_{t5} $i = 4$ corresponds to estimates of $\dot{m}''$ $i = 5$ corresponds to estimates of $\dot{m}'$ $i = 6$ corresponds to estimates of $\dot{m}'' + \dot{m}'$	—	—	Integer
(D25)	Enter n estimates of parameter defined in (D24).	kPa or kg/s	psi or lb/s	Real
(D26)	Enter secondary stream entry total temperature, T_{t0} .	K	K	Real
(D27)	Enter primary stream entry total temperature, T_{t1} .	K	K	Real
(D28)	Enter mixing duct length/diameter ratio, $(S + L)/d_4$. A value in the range $8 \leq (S + L)/d_4 \leq 10$ is recommended (see Section 6.1.4).	—	—	Real
(D29)	Enter contraction or diffuser exit diameter, d_5 .	m	in	Real
(D30)	Enter modulus of contraction or diffuser wall angle, ϕ_d. A value in the range $3 \leq \phi_d \leq 5$ is recommended (see Section 6.1.5). Note that the program will determine whether a contraction or a diffuser is appropriate.	Degree	Degree	Real

* Care should be taken to avoid excessive output. The number of calculations performed by the Detailed Design Procedure is the product of Entries (D23) and (D31).

To calculate the mixing duct area, A_4 , from the area ratio, $A_R (= A_4 / A'_e)$, the program requires a value of the primary nozzle exit area, A'_e ; this is determined from the primary nozzle expansion ratio, A'_e / A_{th} . The primary nozzle throat area, A_{th} , is calculated from Equation (A4.2), using the primary flow Mach number, M'_e , and the assumption that the flow in the throat is choked.

The user may specify up to nine values for A'_e / A_{th} , or allow the program to calculate a value using a method employed by the Quick Design Procedure.