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ESDU 92042

Issued December 1992
With Amendment B
March 2007
Supersedes ESDU 84029 and 88002
Re-issued June 2011

Ejectors and jet pumps:
Computer program for design and performance for compressible gas flow

Associated software: ESDUpac A9242

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We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

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:

Chairman	
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Mr D.A. Campbell	— Rolls-Royce Ltd, Derby
Mr J. Campbell	— Ove Arup and Partners
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This Item supersedes and incorporates the methods of ESDU 84029 and 88002. The work on ESDU 84029, for the design and performance of ejectors and jet pumps with compressible air flows, was monitored and guided in 1984 by the following Working Party†:

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The initial assessment of the available information on compressible air flows in ejectors and jet pumps and the subsequent development of ESDU 84029 was undertaken (under contract to ESDU) by†

Ms A.E. Gibson	— Atkins Research and Development
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(*Continued on inside back cover*)

† Affiliations at the time are given

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EJECTORS AND JET PUMPS
COMPUTER PROGRAM FOR DESIGN AND PERFORMANCE FOR COMPRESSIBLE GAS FLOW

ESDU 92042 describes a computer program for the design of gas ejectors and jet pumps to meet given requirements and for prediction of performance.

Two design methods are provided. A 'quick' method is based on data from a range of typical 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 prediction 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. An executable version of this program is available.

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EJECTORS AND JET PUMPS
Computer Program for Design and Performance for Compressible 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
C_D	primary-nozzle discharge coefficient	–	–
d	diameter	m	ft
i	defines user estimated 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†
n	number of user estimates of parameter, number of nozzles	–	–
PP	primary parameter: $C_D(p_{te}'/p_{te}'')/A_R$	–	–
p_t	absolute total pressure	‡kPa	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: $(p_{te}''/p_4)(A_R - 1)/A_R$	–	–

For footnotes see end of Notation Section.

Issued December 1992
With Amendment B – March 2007
Re-issued June 2011 – 54 pages

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T_t	absolute total temperature	K	K
V	stream velocity	m/s	ft/s
γ	ratio of specific heat capacity at constant pressure to that at constant volume (for air, $\gamma \approx 1.4$)	–	–
η_d	contraction or diffuser total-pressure recovery: p_{t5}/p_{t4}	–	–
η_i	secondary flow inlet efficiency: p''_{te}/p_{t0}	–	–
ϕ_d	contraction or diffuser wall angle	degrees	degrees
ϕ_m	mixing duct wall equivalent angle	degrees	degrees

* 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 5.1, 5.2, 5.3 and 5.4 and are displayed on-screen when running ESDUpac A9242 in ESDUview (see Section 4).

† 1 slug = 32.174 lb mass.

‡ 1 kPa = 1000 N/m^2

Subscripts

e	primary nozzle exit plane
th	primary nozzle throat
max	upper limit of parameter
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

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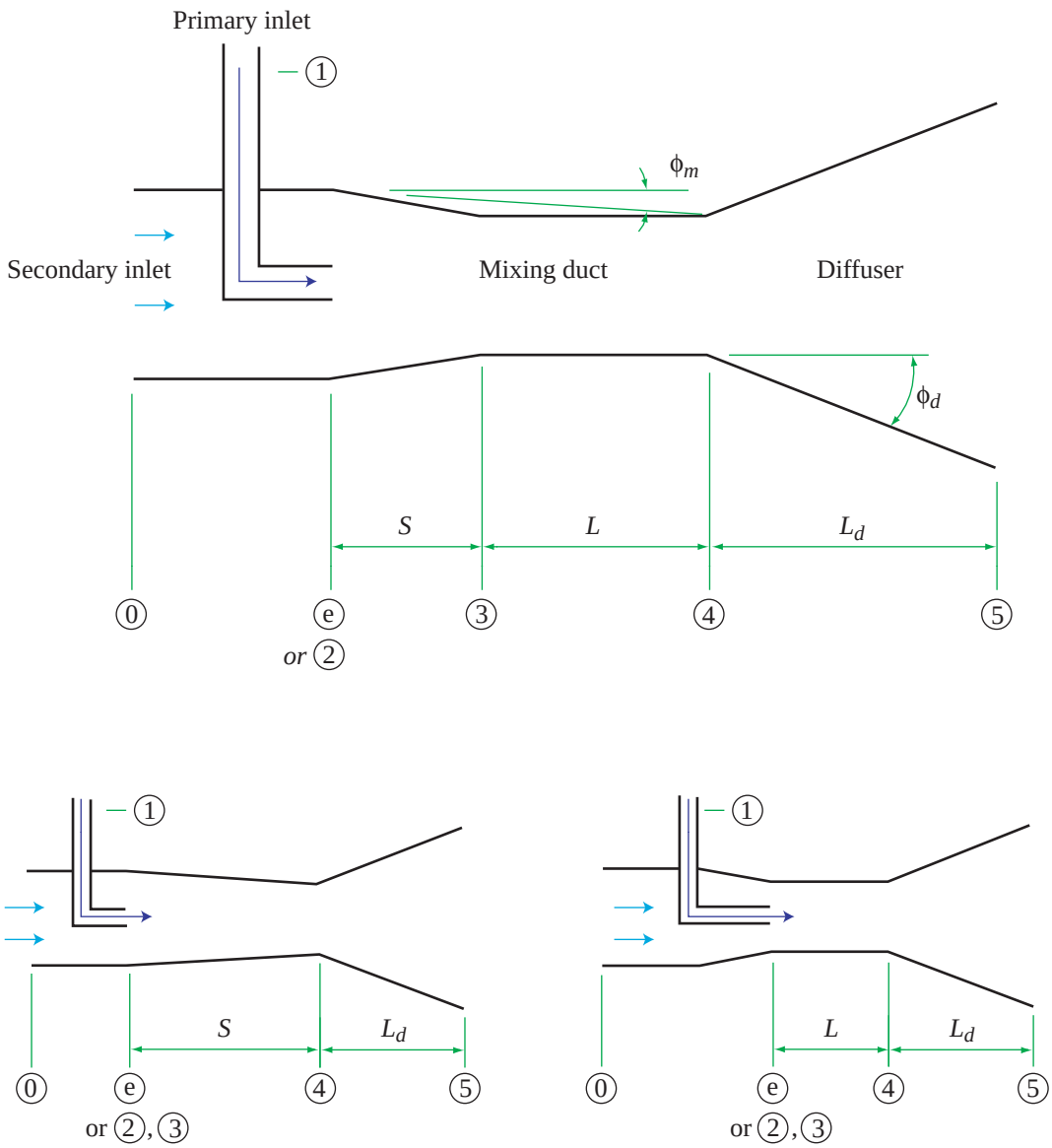

(i) Convergent mixing duct.
In this case, the mixing duct length, L, is effectively zero

(ii) Parallel sided mixing duct.
In this case, the mixing duct entry length, S, is effectively zero

Sketch 1.1 Ejector configuration and typical cases.

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2. INTRODUCTION

ESDU 92042 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.

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	✓	✓	ESDUpac A9242	ESDUpac A9242
Steam	Gas	Any (saturated gas, saturated steam)	✓	✓	86030	86030
Steam	Liquid	Any (saturated steam)	✓	✓	86030	86030
Liquid	Liquid	N/A	✓	✓	ESDUpac A9322 and 85032	ESDUpac A9322 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.

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3. PURPOSE AND SCOPE OF ESDUPAC A9242

ESDU 92042 provides details of a computer program, ESDUpac A9242, for use in the design and performance evaluation of ejectors and jet pumps in which the working fluids are gases.

ESDUpac A9242 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 air-air ejectors. Note that the scope of the Quick Design Method is restricted to ejectors with constant area mixing and air as both working fluids.

(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 A.12 of Appendix A.

(iii) **Performance Prediction Calculation.** Given the ejector dimensions, loss factors and a range of flow conditions at entry, the program will calculate the outlet conditions and the flow conditions throughout the ejector, using the procedure outlined in Section A.13 of Appendix A.

Section 5 describes the required input data. A number of examples which illustrate the use of the program are presented in Section 7. The full analysis for the computer program is presented in Appendix A.

In many ejectors, the primary fluid is compressed air or gas and the secondary inlet conditions are often set by existing 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.

Performance prediction can be considered as almost the reverse of the design process in that solutions to what were design criteria are now required, with the physical dimensions of the device being known.

The calculation procedure presented in Appendix A is applicable to non-reacting gases which 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.

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4. VERSIONS OF THE PROGRAM

ESDUpac A9242 is provided on disk in two versions, as described below. Example input and output files are included with both versions.

An interactive version is contained within ESDUview, a user-friendly 'windowing' environment for running ESDUpacs on personal computers. ESDUview manages all operations such as setting up input files, running the FORTRAN code and viewing the output files. On selecting ESDUpac A9242 from the menu of available programs, the user is prompted for all the input data. Guidance is provided on all the variables and on all the features of ESDUview in the context-sensitive HELP facility. At various points throughout operation 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 Section 1 of the Fluid Mechanics, Internal Flow series.

An executable version of this program is available. In order to run this the user creates a data file, which contains the input data required by the program, by following exactly the data input sequence of Section 5. 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

```
A9242 < EX1.IN > EX1.OUT
```

The ESDUview version of the program is recommended for its ease of operation. Instructions for creating the data input file are given in Section 5. Although the ESDUview 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.

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 ESDUview 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 ESDUview version but wish to compile the Fortran source code and run the resulting executable code (file A9242.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 input procedure.

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.

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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*
	Title of the run (3 lines of text of up to 72 characters each).			
(1a)	Enter text for first line of title.	–	–	CHAR
(1b)	Enter text for second line of title.	–	–	CHAR
(1c)	Enter text for third line of title.	–	–	CHAR
(2)	Enter 1 or 2 as required, where 1 is for SI units, and 2 is for British units.	–	–	INT
(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.	–	–	INT

The data entry sequence continues as follows.

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For Entry at (3)	*Go to Entry*
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" (for air-air ejectors only)

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 pressure 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 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.

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*
	If 1 was entered in (3)			
(Q4)	*Either* enter secondary stream entry total pressure, p_{t0}, *or* enter 0 if this pressure is unknown (see above).	kPa	psi	REAL
(Q5)	*Either* enter primary stream entry total pressure, p_{t1}, *or* enter 0 if this pressure is unknown (see above).	kPa	psi	REAL
(Q6)	*Either* enter contraction or diffuser exit total pressure, p_{t5}, *or* enter 0 if this pressure is unknown (see above).	kPa	psi	REAL
(Q7)	*Either* enter secondary stream mass flow rate, $\dot{m}''$, *or* enter 0 if this mass flow rate is unknown (see above).	kg/s	lb/s	REAL
(Q8)	*Either* enter primary stream mass flow rate, $\dot{m}'$, *or* enter 0 if this mass flow rate is unknown (see above).	kg/s	lb/s	REAL
(Q9)	*Either* enter mixing duct mass flow rate, $\dot{m}'' + \dot{m}'$, *or* enter 0 if this mass flow rate is unknown (see above).	kg/s	lb/s	REAL

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If option (i) is chosen (that is 2 pressures and 2 mass flow rates are input) the data entry sequence continues at Entry (Q13).

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 (Q11).

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 (Q10).

TABLE 5.20 Data for Quick Design Procedure (Continued)

Entry order	*Input parameter*	*SI units*	*British units*	*Variable type*
(Q10)	**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 (Q10) go to Entry (Q13).	–	–	INT
(Q11)	**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 $\dot{m}'' + \dot{m}'$.	–	–	INT
(Q12)	Enter *n* estimates of parameter defined in (Q11).	kPa or kg/s	psi or lb/s	REAL
(Q13)	Enter secondary flow entry total temperature, T_{t0}.	K	K	REAL
(Q14)	Enter primary flow entry total temperature, T_{t1}.	K	K	REAL
(Q15)	Enter mixing duct length/diameter ratio, $(S + L)/d_4$. A value in the range $8 \le (S + L)/d_4 \le 10$ is recommended (see Section 6.4).	–	–	REAL

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TABLE 5.20 Data for Quick Design Procedure (Continued)

Entry order	*Input parameter*	*SI units*	*British units*	*Variable type*
(Q16)	Enter contraction or diffuser exit diameter, d_5	m	in	REAL
(Q17)	Enter modulus of contraction or diffuser wall angle $\lvert\phi_d\rvert$. A value in the range $3 \le \phi_d \le 5$ is recommended (see Section 6.5). Note that the program will determine whether a contraction or a diffuser is appropriate.	degrees	degrees	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 primary gas.	–	–	REAL
(D5)	Enter R', the gas constant of the primary gas.	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" which 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

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defined by the equation

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

which is reduced to Equation (A.33) in Appendix A of Section A.10. 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 0.75-0.95. 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

$$\eta_d = p_{t5}/p_{t4} \ . \tag{5.2}$$

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

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

can be related to η_d by

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

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.

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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

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

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.

TABLE 5.30 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 5.30 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_{Rmax}. 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° (ϕ_d = 3° 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.

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TABLE 5.30 Data for Detailed Design Procedure (continued)

Entry order	*Input parameter*	*SI units*	*British units*	*Variable type*
(D13)	Enter primary nozzle entry pressure limit, p_{t1max}.	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_{Rmax}.	–	–	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_{t0}, 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 5.30 Data for Detailed Design Procedure (continued)

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

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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 5.30 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).	–	–	INT
(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 $\dot{m}'' + \dot{m}'$.	–	–	INT
(D25)	Enter n estimates of parameter defined in (D24).	kPa or kg/s	psi or lb/s	REAL
(D26)	Enter secondary flow entry total temperature, T_{t0}.	K	K	REAL
(D27)	Enter primary flow entry total temperature, T_{t1}.	K	K	REAL
(D28)	Enter mixing duct length/diameter ratio, $(S + L)/d_4$. A value in the range $8 \le (S + L)/d_4 \le 10$ is recommended (see Section 6.4).	–	–	REAL

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