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DYNJET, A MATLAB PROGRAM FOR CALCULATING STEADY-STATE PERFORMANCE OF ONE-SPOOL TURBOJET ENGINES - (A) GRAPHICAL (POLAR) PRESENTATION OF COMPRESSOR MAP

by

Michael Lichtsinder and Yeshayahou Levy
Faculty of Aerospace Engineering
Technion - Israel Institute of Technology
Haifa 32000, Israel

TAE No. 833

For students learning course "Jet Engines" by Prof. Yeshayahou Levy

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INTRODUCTION

DYNJET is a Technion Matlab program for analyzing the steady-state performance of one-spool turbojet engines with divergent nozzles without afterburners. The program will be continued for transient performance calculation, engine control system design and analyzing two spool engines.

The program input data are: Compressor/Turbine/Nozzle Maps; reference data; $M, P_a, T_a, \eta_n, P_{04} / P_{03}$ and operating line rotational speed points. Output is the steady-state operating line and all the relevant engine parameters: $T, SFC, u_a, u_e, mdot_a, f, T_{02}, T_{03}, P_{02}, P_{03}, \eta_e, T_{04}, T_{05}, P_{04}, P_{05}, \eta_t, T_{07}, P_{07}$. The graphs are plotted vs. rotational speed in dimension form. All parameters are presented in IS units.

DYNJET uses normalized (dimensionless) maps and normalized equations to generalize solution.

The program contains the normalized "standard" maps to estimate engine parameters at the preliminary design stage. The real engines maps are calculated using "Standard" Maps and the engine reference data.

Existence of the equation solution and the continuation of the solving process depend on initial solution values to a marked degree. The initial values are introduced in DYNJET for the design point. The initial parameter values for each rotational speed calculations equal to solution for the previous rotational speed.

DYNJET uses the Polar Coordinate for Compressor Map description to increase accuracy of engine steady-state calculations (error less than 0.2%):

a) The Polar Coordinate Maps are described by one-mean functions while the Cartesian Coordinate Efficiency Compressor Map is described by two-mean functions (see Figs. 3.1 and 3.2).

b) The map point numbers are increased significantly for each argument of the Polar Coordinate Compressor Map. It leads to the use of the Matlab "look-up table" functions for the map data interpolation (for comparison, there is one point only to each point of mass flow: 0.11, 0.13, 0.22, 0.25, 0.27 ... [Kg/s] in Fig. 3.1). It is known that a polynomial approximation provides the two arguments function interpolations with less precision in comparison to the "look-up table" interpolation.

DYNJET uses the default Gauss-Newton Least Squares Method to solve the equations. Optional Matlab methods can be used. Default parameter/function tolerance is 0.001 and can be changed by the user.

DYNJET can be used without modification to the basic program. The user can change and introduce other equations in DYNJET at the same time.

The program is written in MATLAB 5.2.

The intention of this report is to describe DYNJET for students learning the "Jet Engines" course and also for other researchers.

A complete MATLAB program listing, a brief description of the program/symbols and example calculations are given in the Appendix.

1. ONE-SPOOL ENGINE STEADY-STATE EQUATIONS

1.1 Map Equations

Compressor/Turbine/Nozzle Maps are described by the following functions:

a) Compressor Map:

$$\frac{P_{03}}{P_{02}} \; vs. \; \frac{\dot{m}\sqrt{T_{02}}}{P_{02}}; \frac{N}{\sqrt{T_{02}}} = \text{parameter} \tag{1.1}$$

$$\eta_c \text{ vs. } \frac{\dot{m}\sqrt{T_{02}}}{P_{02}} \quad ; \quad \frac{N}{\sqrt{T_{02}}} = \text{parameter} \tag{1.2}$$

b) Turbine Map:

$$\frac{P_{04}}{P_{05}} \text{ vs. } \frac{\dot{m}\sqrt{T_{04}}}{P_{04}} \quad ; \quad \frac{N}{\sqrt{T_{04}}} = \text{parameter} \tag{1.3}$$

$$\eta_t \text{ vs. } \frac{\dot{m}\sqrt{T_{04}}}{P_{04}} \quad ; \quad \frac{N}{\sqrt{T_{04}}} = \text{parameter} \tag{1.4}$$

c) Nozzle Map:

$$\frac{\dot{m}\sqrt{T_{07}}}{P_{07}} \quad \text{vs.} \quad \frac{P_{07}}{P_a} \tag{1.5}$$

1.2 Engine Equations

Equations for operating line calculations for a one-spool jet engine without an afterburner, are:

$$\frac{N}{\sqrt{T_{04}}} = \frac{N}{\sqrt{T_{02}}}\sqrt{\frac{T_{02}}{T_{04}}} \tag{1.6}$$

$$\frac{\dot{m}\sqrt{T_{04}}}{P_{04}} = \frac{\dot{m}\sqrt{T_{02}}}{P_{02}}\frac{P_{02}}{P_{03}}\frac{P_{03}}{P_{04}}\sqrt{\frac{T_{04}}{T_{02}}} \tag{1.7}$$

$$\frac{\Delta T_{04-5}}{T_{04}} = \frac{\Delta T_{03-2}}{T_{02}}\frac{T_{02}}{T_{04}}\frac{C_{P_a}}{C_{P_g}\eta_m} \tag{1.8}$$

$$\frac{\Delta T_{04-5}}{T_{04}} = \eta_t \left[1 - \frac{1}{\left(\frac{P_{04}}{P_{05}} \right)^{\frac{\gamma-1}{\gamma}}} \right] \tag{1.9}$$

$$\frac{\Delta T_{03-2}}{T_{02}} = \frac{1}{\eta_c} \left[\left(\frac{P_{03}}{P_{02}} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \tag{1.10}$$

$$\frac{\dot{m}\sqrt{T_{07}}}{P_{07}} = \frac{\dot{m}\sqrt{T_{04}}}{P_{04}} \frac{P_{04}}{P_{07}} \sqrt{\frac{T_{07}}{T_{04}}} \tag{1.11}$$

$$\sqrt{\frac{T_{07}}{T_{04}}}\Bigg|_{\text{no afterburner}} = \sqrt{\frac{T_{05}}{T_{04}}} = \sqrt{1 - \frac{\Delta T_{04-5}}{T_{04}}} \tag{1.12}$$

$$\frac{P_{97}}{P_a} = \frac{P_{05}}{P_{04}} \frac{P_{04}}{P_{03}} \frac{P_{03}}{P_{02}} \frac{P_{02}}{P_a} \tag{1.13}$$

$$\frac{P_{04}}{P_{05}} = \frac{P_{04}}{P_{07}}\,. \tag{1.15}$$

2. NORMALIZED EQUATIONS

2.1 Reference Data

Define the following reference data:

$$\dot{m}_{ref}\,,\ N_{ref}\,,\ T_{02,ref}\,,\ T_{03,ref}\,,\ T_{04,ref}\,,\ T_{05,ref} = T_{07,ref}$$

$$P_{02,ref}\,,\ \frac{P_{03,ref}}{P_{02,ref}},\ P_{04,ref}\,,\ \frac{P_{04,ref}}{P_{05,ref}},\ \frac{P_{07,ref}}{P_{a,ref}}.$$

2.2 Normalized Parameters

Let us define the following normalized parameters:

$$\mu_{S2} = \frac{\dot{m}\sqrt{T_{02}}}{P_{02}} \Bigg/ \frac{\dot{m}_{ref}\sqrt{T_{02,ref}}}{P_{02,ref}};$$

$$\mu_{S4} = \frac{\dot{m}\sqrt{T_{04}}}{P_{04}} \Bigg/ \frac{\dot{m}_{ref}\sqrt{T_{04,ref}}}{P_{04,ref}};$$

$$\mu_{S7} = \frac{\dot{m}\sqrt{T_{07}}}{P_{07}} \Bigg/ \frac{\dot{m}_{ref}\sqrt{T_{07,ref}}}{P_{07,ref}}$$

$$\nu_{S2} = \frac{N}{\sqrt{T_{02}}} \Bigg/ \frac{N_{ref}}{\sqrt{T_{02,ref}}};$$

$$\nu_{S4} = \frac{N}{\sqrt{T_{04}}} \Bigg/ \frac{N_{ref}}{\sqrt{T_{04,ref}}};$$

$$\pi_{S32} = \frac{P_{03}}{P_{02}} \Bigg/ \frac{P_{03,ref}}{P_{02,ref}};$$

$$\pi_{S45} = \frac{P_{04}}{P_{05}} \Bigg/ \frac{P_{04,ref}}{P_{05,ref}};$$

$$\pi_{S7a} = \frac{P_{07}}{P_{a}} \Bigg/ \frac{P_{07,ref}}{P_{0,ref}}$$

Let us introduce the following dimensionless parameters:

$$\pi_{32} = \frac{P_{03}}{P_{02}};\ \pi_{45} = \frac{P_{04}}{P_{05}};\ \pi_{7a} = \frac{P_{07}}{P_a};$$

$$\pi_{2a} = \frac{P_{02}}{P_a};\ \pi_{47} = \frac{P_{04}}{P_{07}};\ \pi_{34} = \frac{P_{03}}{P_{04}};$$

$$\theta_{24} = \frac{T_{02}}{T_{04}};\ \theta_{74} = \frac{T_{07}}{T_{04}};$$

$$\Delta\theta_{454} = \frac{\Delta T_{04-5}}{T_{04}};$$

$$\Delta\theta_{322} = \frac{\Delta T_{03-2}}{T_{02}}.$$

Mark: The parameters with subscript S are Standard Map normalized parameters.

2.3 Standard Normalized Maps

The Normalized Standard Map (or shorter Standard Map) definitions follow from (1.1) - (1.5) and from the normalized parameter definitions of section 2.2.

a) Substitute the standard parameters μ_{S2}, ν_{S2} and π_{S32} in the Compressor Map functions (1.1), (1.2):

$$\pi_{S32} \cdot \frac{P_{03,ref}}{P_{02,ref}} \text{ vs. } \mu_{S2} \frac{\dot{m}_{ref} \cdot \sqrt{T_{02,ref}}}{P_{02,ref}} \quad ; \quad \nu_{S2} \cdot \frac{N_{ref}}{\sqrt{T_{02,ref}}} - \text{parameter} \tag{1.1a}$$

$$\eta_C \text{ vs. } \mu_{S2} \frac{\dot{m}_{ref} \cdot \sqrt{T_{02,ref}}}{P_{02,ref}} \nu_{S2} \frac{N_{ref}}{\sqrt{T_{02,ref}}} - \text{parameter} \tag{1.2a}$$

Let us define the Standard Normalized Compressor Map (or shorter Standard Compressor Map) by the following functions:

$$\pi_{S32} \text{ vs. } \mu_{S2} \quad ; \quad \nu_{S2} - \text{parameter} \tag{2.1}$$

$$\eta_C \text{ vs. } \mu_{S2} \quad ; \quad \nu_{S2} - \text{parameter} \tag{2.2}$$

Mark: Function

$$\pi_{S32} \text{ vs. } \mu_{S2} \quad ; \quad \eta_C \text{ -- parameter} \tag{2.2a}$$

is used instead of (2.2) in the DYNJET.

b) The Turbine Map (1.3), (1.4), expressed by the standard parameters μ_{S4}, ν_{S4} and π_{S45},

is:

$$\pi_{S45} \cdot \frac{P_{04,ref}}{P_{05,ref}} \text{ vs. } \mu_{S4} \frac{\dot{m}_{ref} \cdot \sqrt{T_{04,ref}}}{P_{04,ref}} ; \nu_{S4} \cdot \frac{N_{ref}}{\sqrt{T_{04,ref}}} \text{ -- parameter} \tag{1.3a}$$

$$\eta_t \text{ vs. } \mu_{S4} \frac{\dot{m}_{ref} \cdot \sqrt{T_{04,ref}}}{P_{04,ref}} ; \nu_{S4} \frac{N_{ref}}{\sqrt{T_{04,ref}}} \text{ -- parameter} \tag{1.4a}$$

Let us define the Standard Normalized Turbine Map (or shorter Standard Turbine Map) by the following functions:

$$\pi_{S45} \text{ vs. } \mu_{S4} \quad ; \quad \nu_{S4} \text{ -- parameter} \tag{2.3}$$

$$\eta_t \text{ vs. } \mu_{S4} \quad ; \quad \nu_{S4} \text{ -- parameter .} \tag{2.4}$$

c) The Nozzle Map (4.5), expressed by the parameters μ_{S7} and π_{S7a}, is

$$\mu_{S7} \cdot \frac{\dot{m}_{ref} \cdot \sqrt{T_{07,ref}}}{P_{07,ref}} \text{ vs. } \pi_{S7a} \cdot \frac{P_{07,ref}}{P_{a,ref}} . \tag{1.5a}$$

Let us define the Standard Normalized Nozzle Map (or shorter Standard Nozzle Map) by the following function:

$$\mu_{S7} \text{ vs. } \pi_{S7a} \tag{2.5}$$

d) Parameters of "usual" maps are expressed with Standard Map parameters according to the following expressions:

For Compressor Map:

$$\frac{P_{03}}{P_{02}} = \pi_{S32} \cdot \frac{P_{03,ref}}{P_{02,ref}}; \tag{2.6}$$

$$\frac{\dot{m}\sqrt{T_{02}}}{P_{02}} = \mu_{S2} \frac{\dot{m}_{ref} \cdot \sqrt{T_{02,ref}}}{P_{02,ref}}; \tag{2.7}$$

$$\frac{N}{\sqrt{T_{02}}} = \nu_{S2} \cdot \frac{N_{ref}}{\sqrt{T_{02,ref}}}; \tag{2.8}$$

For Turbine Map:

$$\frac{P_{04}}{P_{05}} = \pi_{S45} \cdot \frac{P_{04,ref}}{P_{05,ref}}; \tag{2.9}$$

$$\frac{\dot{m}\sqrt{T_{04}}}{P_{04}} = \mu_{S4} \frac{\dot{m}_{ref} \cdot \sqrt{T_{04,ref}}}{P_{04,ref}}; \tag{2.10}$$

$$\frac{\dot{m}\sqrt{T_{04} / T_{04,ref}}}{P_{04} / P_{07,ref}} = \mu_{S4} \cdot \dot{m}_{ref}; \tag{2.10a}$$

$$\frac{N}{\sqrt{T_{04}}} = \nu_{S4} \cdot \frac{N_{ref}}{\sqrt{T_{04,ref}}}. \tag{2.11}$$

For Nozzle Map:

$$\frac{\dot{m}\sqrt{T_{07}}}{P_{07}} = \mu_{S7} \frac{\dot{m}_{ref} \cdot \sqrt{T_{07,ref}}}{P_{07,ref}}; \tag{2.12}$$

$$\frac{\dot{m}\sqrt{T_{07} / T_{07,ref}}}{P_{07} / P_{07,ref}} = \mu_{S7} \cdot \dot{m}_{ref}; \tag{2.12a}$$

$$\frac{P_{07}}{P_a} = \pi_{S7a} \cdot \frac{P_{07,ref}}{P_{a,ref}}. \tag{2.13}$$

Expressions (2.6) - (2.13) are used in DYNJET for the Standard Map translation to real engine maps using the reference data.

2.4 Normalized Equation System

Substitution of (2.7), (2.8), (2.10), (2.11) and (2.12) into the equations (1.6) - (1.14) leads to the following normalized equation system:

$$\nu_{S4} = \nu_{S2} \cdot \sqrt{\theta_{24} / SF1}\,; \tag{2.14}$$

$$\mu_{S4} = \mu_{S2} \frac{\pi_{34}}{\pi_{32}\sqrt{\theta_{24}}} \cdot SF2\,; \tag{2.15}$$

$$\Delta\theta_{454} = \Delta\theta_{322} \cdot \theta_2 \cdot \frac{C_{pa}}{C_{pg}\eta_m}\,; \tag{2.16}$$

$$\Delta\theta_{454} = \eta_t \cdot \left(1 - \frac{1}{\pi_{45}^{\frac{\gamma-1}{\gamma}}}\right); \tag{2.17}$$

$$\Delta\theta_{322} = \frac{1}{\eta_C}\left(\pi_{32}^{\frac{\gamma-1}{\gamma}} - 1\right); \tag{2.18}$$

$$\mu_{S7} = \mu_{S4} \cdot \pi_{47} \cdot \sqrt{\theta_{74}} \cdot SF3\,; \tag{2.19}$$

$$\theta_{74} = 1 - \Delta\theta_{454}\,; \tag{2.20}$$

$$\pi_{7a} = \frac{\pi_{43} \cdot \pi_{32} \cdot \pi_{2a}}{\pi_{45}}\,; \tag{2.21}$$

$$\pi_{45} = \pi_{47}\,, \tag{2.22}$$

where

$$SF1 = \frac{T_{02,ref}}{T_{04,ref}}\,;$$

$$SF2 = \frac{P_{04,ref}}{P_{02,ref}} * \sqrt{\frac{T_{02,ref}}{T_{04,ref}}}\,;$$

$$SF3 = \frac{P_{a,ref}}{P_{4,ref}} \cdot \sqrt{\frac{T_{04,ref}}{T_{07,ref}}}$$

are the reference scale coefficients.

The 9 equations (2.14) - (2.22) and the 5 standard map equations (2.1) - (2.5) are engine steady state dimensionless mathematical models.

Parameters $\nu_{S2}, \pi_{34}, \pi_{2a}, C_{pa}, C_{pg}, \eta_m$ and the reference parameters are input data. Pay attention that equations (2.14) - (2.22) do not depend on $\dot{m}_{ref}$.

3. COMPRESSOR/TURBINE/NOZZLE MAPS INTRODUCING in DYNJET

3.1 The Polar Coordinate for Compressor Map Description

High accuracy is required for engine steady-state calculations (error less than 0.2%).

The description of the Compressor Map in the Cartesian Coordinate has two general disadvantages:

a) The Efficiency Compressor Map is described by two-mean functions (see Fig.3.2).

b) The Rotational Speed Compressor Map is defined for only one rotational speed value for some arguments in the graphs (for example, for mass flow: 0.11, 0.13, 0.22, 0.25, 0.27 [kg/s] in Fig.3.1). This is insufficient for the function interpolation.

These disadvantages decrease the Compressor Map accuracy significantly.

The Compressor Map in the Polar Coordinate is described by one-mean functions. The map points number for each argument increases substantially and accuracy increases accordingly. It allows use of the Matlab look-up table function, Table 2, for the map data interpolation. It is known that the polynomial approximation provides less precision for the two argument function interpolation.

The typical Compressor Map (1.1) and (1.2) in the Cartesian and in the Polar Coordinates is shown in Figs. 3.1 and 3.2.

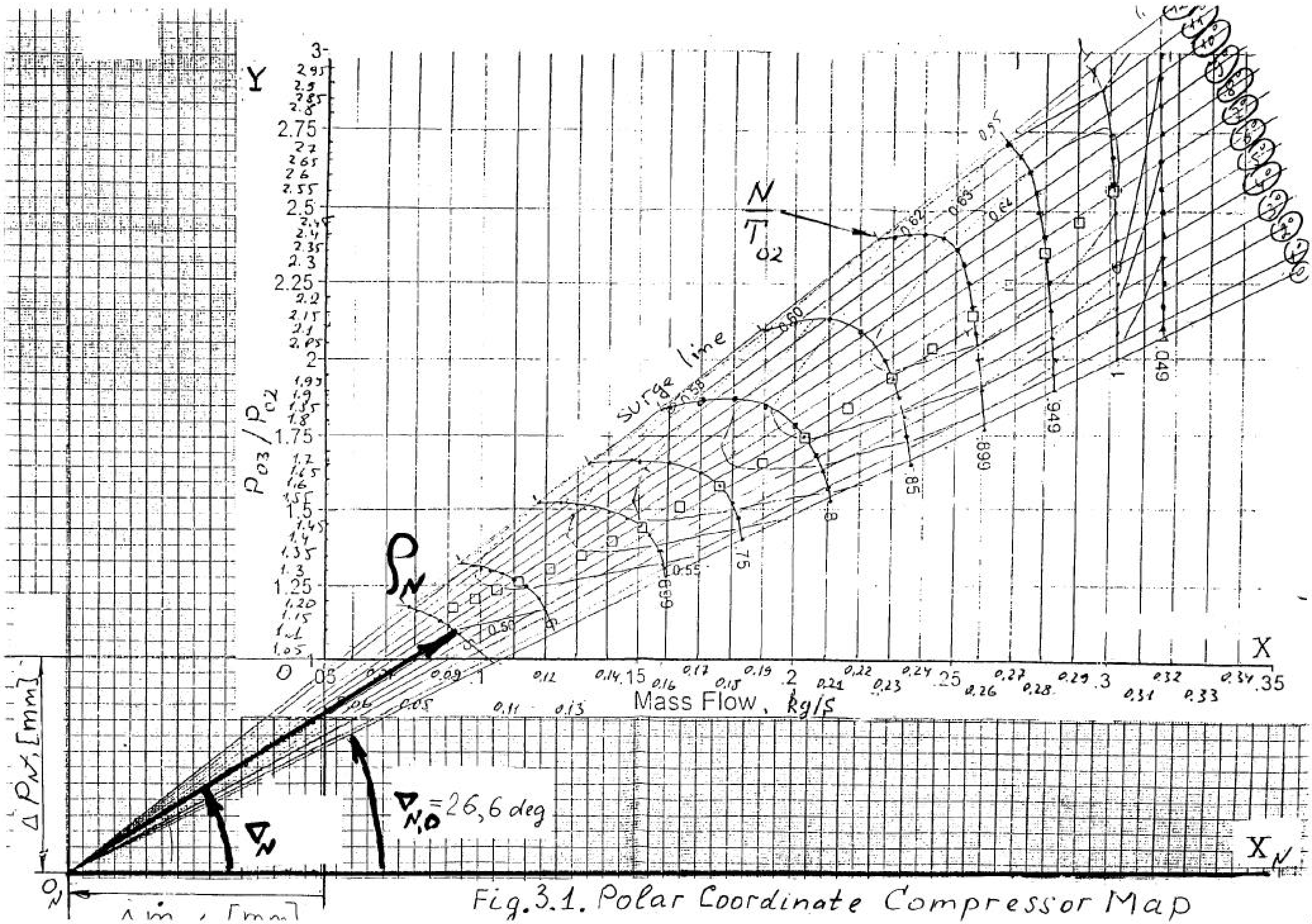


Fig.3.1. Polar Coordinate Compressor Map

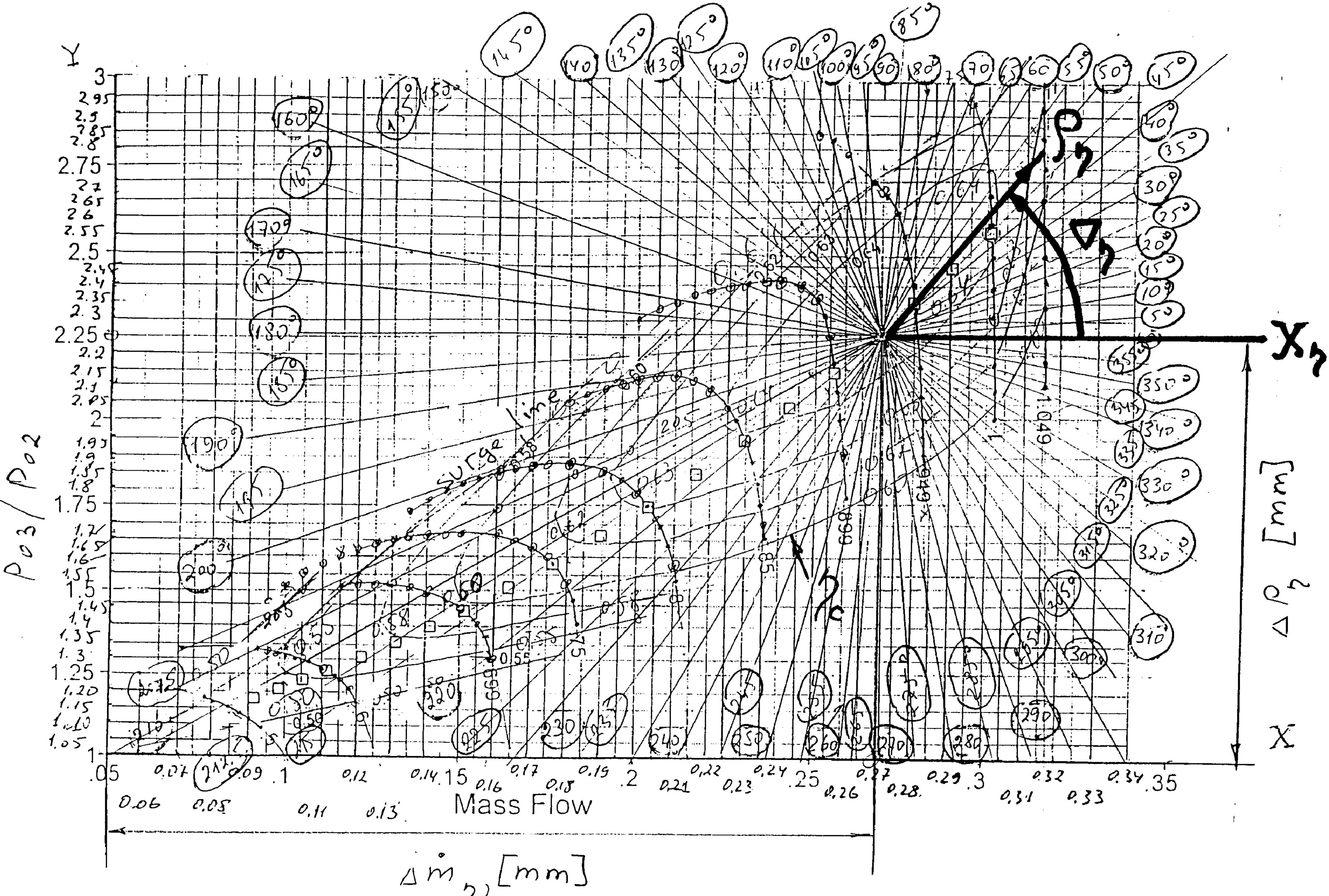


Fig. 3.2 Polar Coordinate Compressor Map

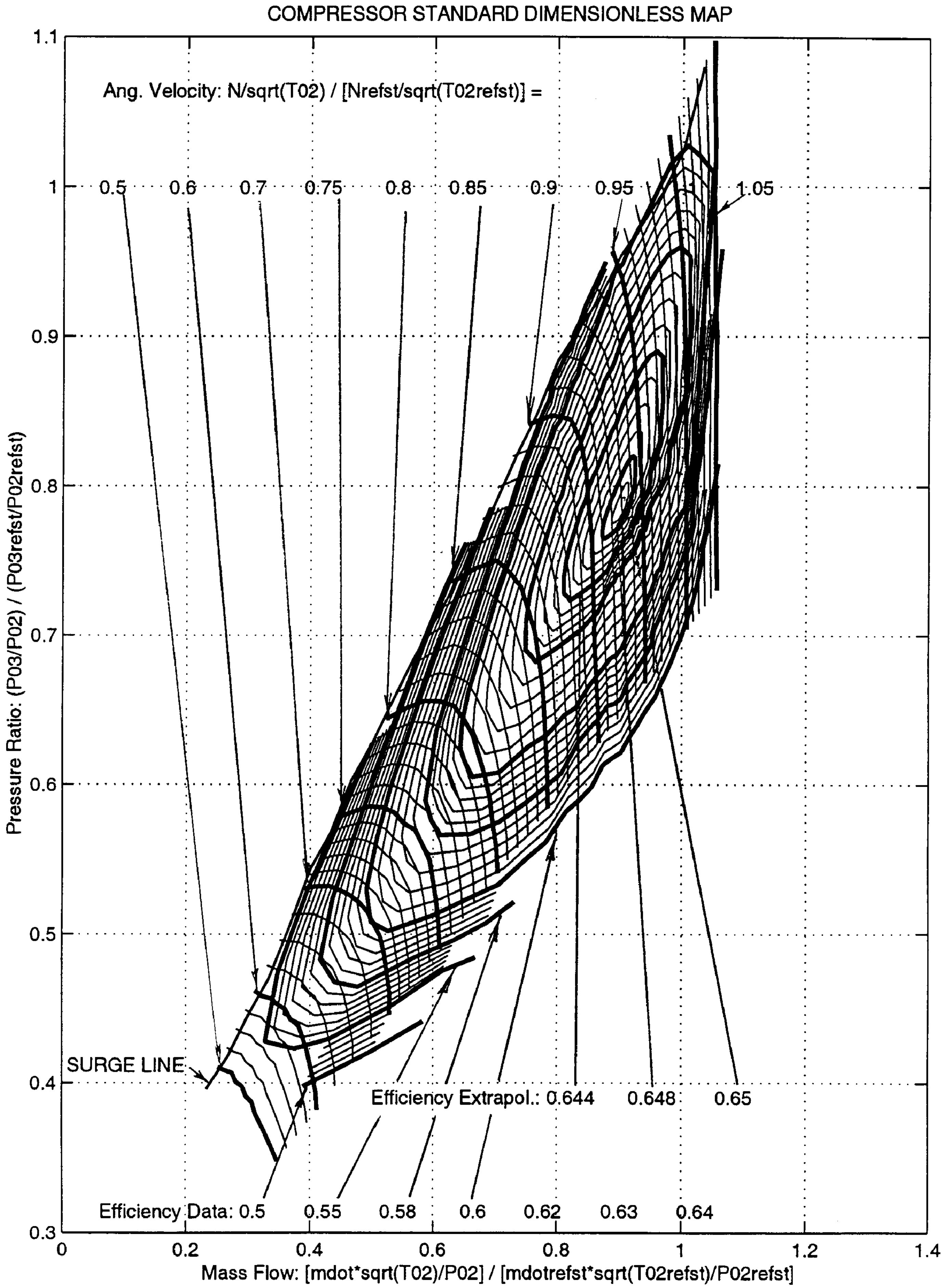

COMPRESSOR STANDARD DIMENSIONLESS MAP
Ang. Velocity: N/sqrt(T02) / [Nrefst/sqrt(T02refst)] =
0.5
0.6
0.7
0.75
0.8
0.85
0.9
0.95
1.05
SURGE LINE
Efficiency Extrapol.: 0.644
0.648
0.65
Efficiency Data: 0.5
0.55
0.58
0.6
0.62
0.63
0.64
Pressure Ratio: (P03/P02) / (P03refst/P02refst)
Mass Flow: [mdot*sqrt(T02)/P02] / [mdotrefst*sqrt(T02refst)/P02refst]
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
0.2
0.4
0.6
0.8
1
1.2
1.4

Fig. 3.3

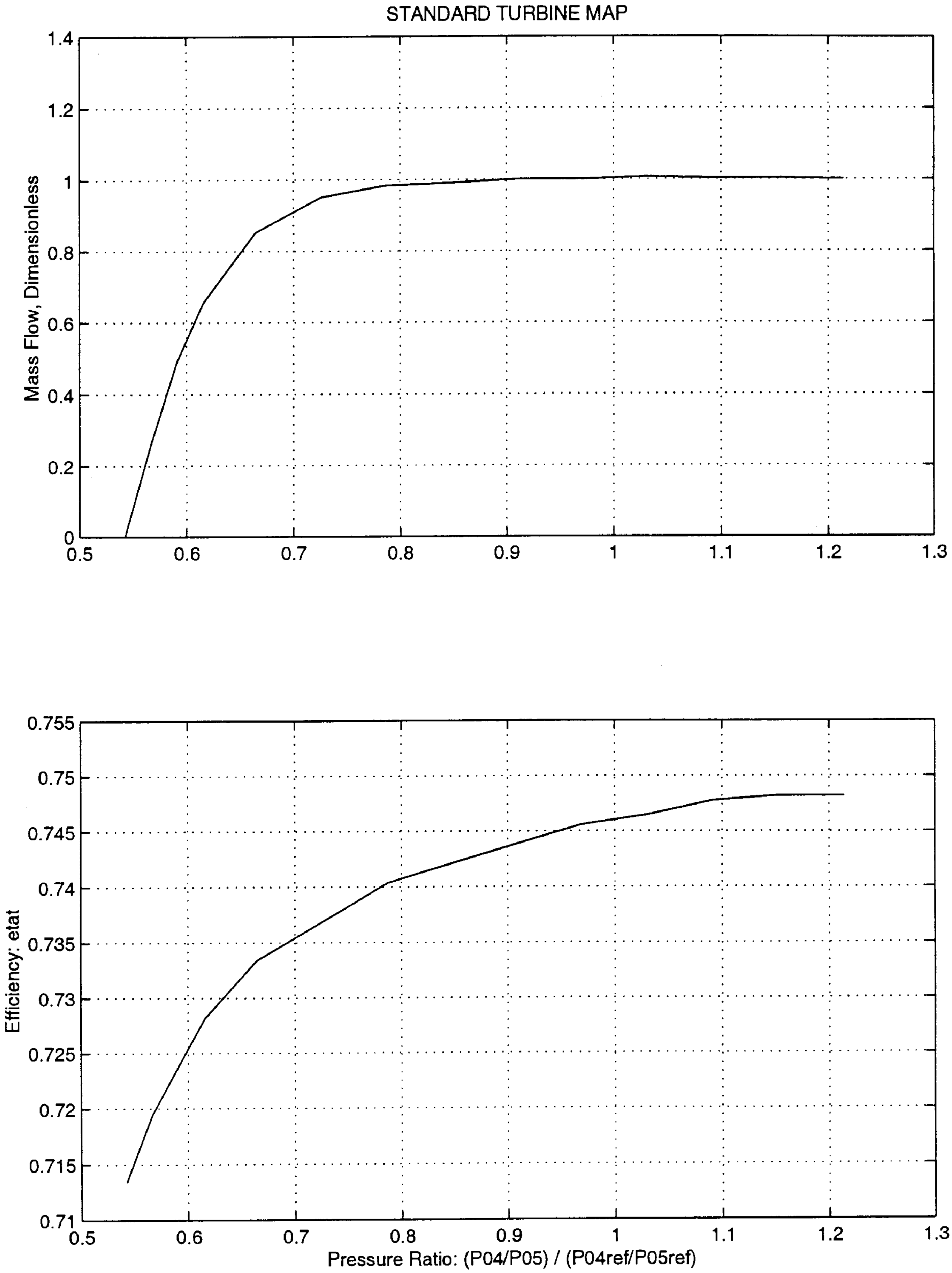
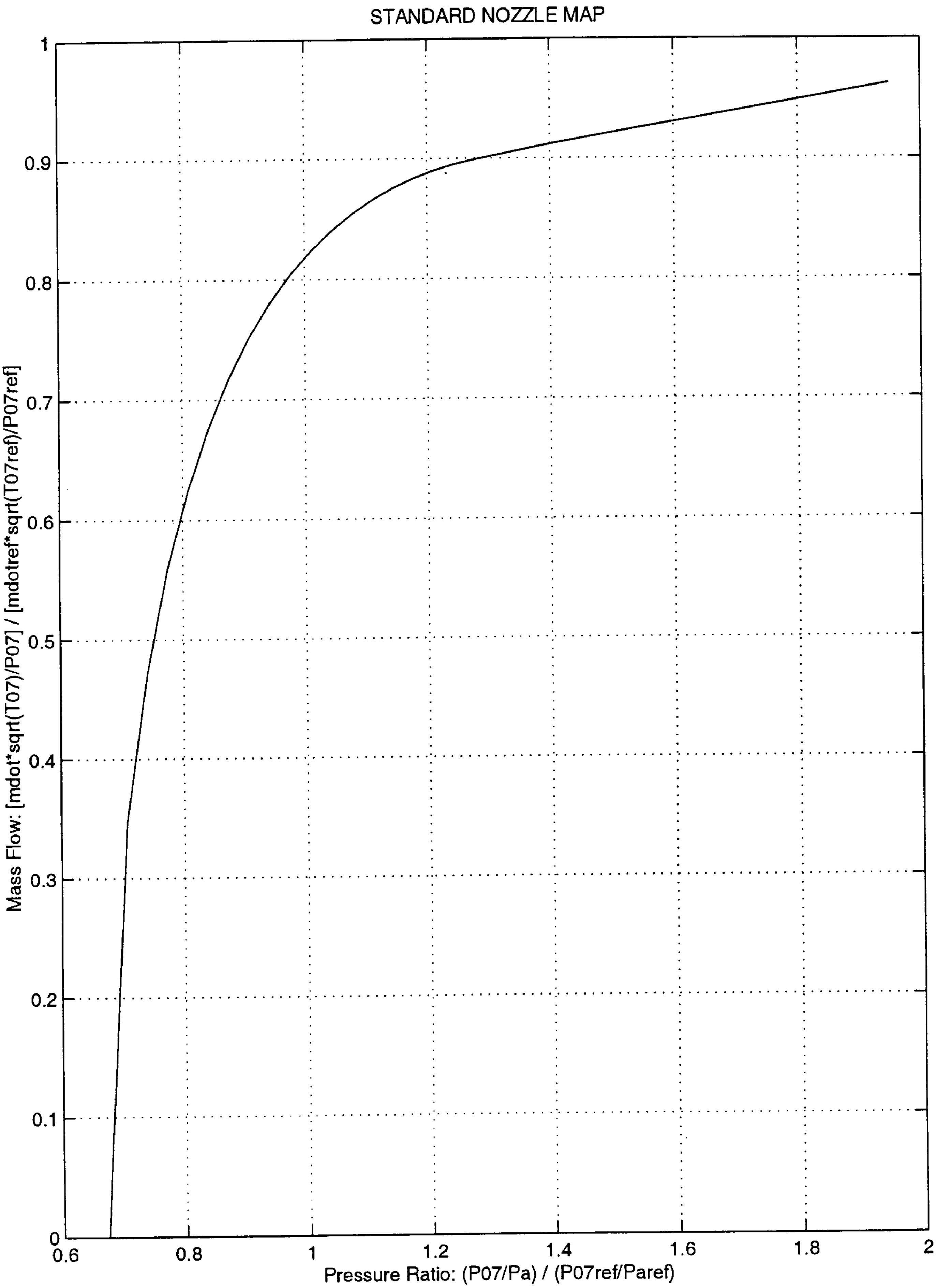

STANDARD TURBINE MAP
Mass Flow, Dimensionless
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
Efficiency: etat
0.755
0.75
0.745
0.74
0.735
0.73
0.725
0.72
0.715
0.71
Pressure Ratio: (P04/P05) / (P04ref/P05ref)

Fig. 3.4



STANDARD NOZZLE MAP
Mass Flow: [mdot*sqrt(T07)/P07] / [mdotref*sqrt(T07ref)/P07ref]
Pressure Ratio: (P07/Pa) / (P07ref/Paref)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Fig. 3.5

The Polar system map functions are:

$$\rho_N \text{ vs. } \nabla_N, N/T_{02} = \text{parameter} \tag{3.1}$$

$$\rho_{\eta_C} \text{ vs. } \nabla_{\eta_C}, \eta_C = \text{parameter} \tag{3.2}$$

The Polar systems Compressor Map is transformed into the "usual" Cartesian system Compressor Map by the following expressions:

For (1.1) (Fig. 3.1, N/T_{02} - parameter):

$$\frac{P_{03}}{P_{02}} = \left(\rho_N \cdot \sin\nabla_N + \Delta P_N\right)\cdot mash_{(P_{03}/P_{02})} + \left(\frac{P_{03}}{P_{02}}\right)_0; \tag{3.3}$$

$$\frac{\dot{m}\sqrt{T_{02}}}{P_{02}}\cdot\frac{P_{02,ref}}{\sqrt{T_{02,ref}}} = \left(\rho_N \cos\nabla_N + \Delta\dot{m}_N\right)\cdot mash_{\dot{m}} + \dot{m}_0 \tag{3.4}$$

For (1.2) (Fig. 3.2, η_C - parameter):

$$\frac{P_{03}}{P_{02}} = \left(\rho_{\eta_C} \cdot \sin\nabla_{\eta_C} + \Delta P_{\eta_C}\right)\cdot mash_{(P_{03}/P_{022})} + \left(\frac{P_{03}}{P_{02}}\right)_0; \tag{3.5}$$

$$\frac{\dot{m}\sqrt{T_{02}}}{P_{02}}\cdot\frac{P_{02,ref}}{\sqrt{T_{02,ref}}} = \left(\rho_{\eta_C} \cos\nabla_{\eta_C} + \Delta\dot{m}_{\eta_C}\right)\cdot mash_{\dot{m}} + \dot{m}_0 \tag{3.6}$$

where:

ρ_N, ρ_{η_C} = Polar coordinate radius-vector, mm ;

$\nabla_N, \nabla_{\eta_C}$ = Polar coordinate argument, rad or deg ;

$\Delta P_N, \Delta\dot{m}_N, \Delta P_{\eta_C}, \Delta m_{\eta_C}$ = the Polar Coordinates shifting relative to the Cartesian Coordinates, mm:

$mash_{(P_{03}/P_{02})}, mash_{\dot{m}}$ = mashtab of P_{03}/P_{02} or $\frac{\dot{m}\sqrt{T_{02}}}{P_{02}}\cdot\frac{P_{02,ref}}{\sqrt{T_{02,ref}}}$,

$[1/mm$ or (kg/s)/mm];

$\left(\frac{P_{03}}{P_{02}}\right)_0, \dot{m}_0$ = initial data, [dimensionless or kg/s].

Equations (3.1) - (3.6) is our Compressor Map mathematical description in the "usual" form.

For the standard parameters the equations are:

$$\rho_N \text{ vs. } \nabla_N; \nu_{S2} = \text{parameter} \tag{3.7}$$

$$\rho_{\eta_c} \text{ vs. } \nabla_{\eta c}; \eta_c - \text{parameter} \tag{3.8}$$

$$\pi_{32} = \left[\left(\rho_N \sin\nabla_N + \Delta P_N\right) mash_{\pi_{32}} + \left(\pi_{32}\right)_0\right] \cdot SF4 \tag{3.9}$$

$$\mu_{S2} = \left[\left(\rho_N \cdot \cos\nabla_N + \Delta\dot{m}_N\right) \cdot mash_{\dot{m}} + \dot{m}_0\right] / SF7 \tag{3.10}$$

$$\pi_{32} = \left[\left(\rho_{\eta c} \sin\Delta_{\eta c} + \Delta P_{\eta c}\right) \cdot mash_{\pi_{32}} + \left(\pi_{32}\right)_0\right] \cdot SF4 \tag{3.11}$$

$$\mu_{S2} = \left[\left(\rho_{\eta c} \cdot \cos\nabla_{\eta c} + \Delta\dot{m}_{\eta c}\right) \cdot mash_{\dot{m}} + \dot{m}_0\right] / SF7, \tag{3.12}$$

where

$$SF4 = \pi_{32,ref} / \pi_{32,ref,st}$$

$$SF5 = \pi_{45,ref} / \pi_{45,ref,st}$$

$$SF6 = \pi_{7a,ref} / \pi_{7a,ref,st}$$

$$SF7 = \dot{m}_{ref,st}$$

Subscript st relates to the Standard Map reference parameters

Standard Compressor Map is shown in Fig. 3.3

3.2 Standard Turbine Map

The typical normalized Turbine Map is shown in Fig. 3.4 The Standard Turbine map in DYNJET is described in the Cartesian Coordinates by (2.3) and (2.4).

3.3 Standard Nozzle Map

The typical normalized Nozzle Map is shown in Fig. 3.5. The standard Nozzle Map in DYNJET is presented in (2.5).

4. DESCRIPTION OF THE MATHEMATICAL PROBLEM

The compressor-turbine-nozzle matching problem is described by the following dimensionless equations:

(2.14) - (2.22) for an engine;

(3.7) - (3.12) for the Standard Compressor Map;

(2.3) - (2.4) for the Standard Turbine Map;

(2.5) – for the Standard Nozzle Map;

(You can see the equations in APPENDIX D).

The 18 equations contain the 18 unknown dimensionless variables:

$$\mu_{S2}, \mu_{S4}, \mu_{S7}, \nu_{S4}$$

$$\pi_{32}, \pi_{45}, \pi_{7a}, \pi_{47}$$

$$\theta_{24}, \theta_{74}, \Delta\theta_{454}, \Delta\theta_{322}$$

$$\eta_C, \eta_t$$

$$\rho_N, \nabla_N, \rho_{\eta_C}, \nabla_{\eta_C}$$

Variables ν_{S2}, π_{43} and π_{2a} are given.

The DYNJET input is:

$$P_a, T_a, M_a, \eta_n, P_{o4} / P_{03},$$

$$\nu_{S2,max}, \Delta\nu_{S2}, \nu_{S2,min},$$

$$\eta_m, \eta_d, \eta_n,$$

$$C_{P_g}, C_{P_a}, \gamma, R, Q_R, C_p$$

Reference data are:

$$\dot{m}_{ref}, N_{ref}, T_{02,ref}, T_{04,ref}, T_{05,ref} = T_{07,ref};$$

$$P_{02,erf}; \frac{P_{03,ref}}{P_{02,ref}}; P_{4,ref}; \frac{P_{04,ref}}{P_{05,ref}}; \frac{P_{07,ref}}{P_{a,ref}}.$$

Calculated input variables are:

$$P_{02} = P_a\left[1 + \eta_d \frac{\gamma - 1}{2} M_a^2\right]^{\frac{\gamma}{\gamma-1}}$$

$$T_{02} = T_a\left[1 + \left(\frac{\gamma - 1}{2}\right) \cdot M_a^2\right].$$

The operating line is plotted at the Compressor Map.

The output variables

$$\dot{m}, T(\text{thrust}), SFC, u_a, u_e, f,$$

$$T_{02,} T_{03}, T_{04}, T_{05}, T_{07},$$

$$P_{02,} P_{03}, P_{04}, P_{05}, P_{07}$$

are plotted vs. rotational speed in SI units.

The equation solution program listing is presented in function STENGD of Appendix B.

5. DESCRIPTION OF DYNJET

The DYNJET flow chart is shown in Fig. 5.1. The program M-files and M-functions are presented in Appendix A. The program listing is presented in Appendix B, the symbols-in Appendix C, expressions for output parameters calculations-in Appendix D and example calculations for jet engine SR-30 –in Appendix E.

6. EXAMPLE CALCULATIONS

In order to show DYNJET capability, examples for steady state operating line one-spool SR-30 jet engine calculations are presented in Figs. E.1 - E.13 of Appendix E. Input data are contained in files STARTD.M and REFDATD.M of Appendix B.

REFERENCES

1. Y. Levy, Learning Course, "Jet Engines", 1999.
2. H. Cohen, G.F.C. Rogers, J.I.H. Saravanamutto, "Gas Turbine Theory", 1982.
3. P.G. Hill, C.R. Peterson, "Mechanics and Thermodynamics of Propulsion", 1992.

APPENDIX A - SYMBOLS

a, NaN	=	unavailable number
Cpa	=	C_{pa}
Cpg	=	C_{pg}
Cp	=	C_p
CPR, mashpco$\overline{m}$	=	Compressor Map pressure mashtab, [1/mm]
Cmdot, mashmco$\overline{m}$	=	Compressor Map flow rate mashtab, [kg/(s·mm)]
delpeco$\overline{m}$, delPR	=	Polar Coordinate vertical zero shifting for efficiency Compressor Map, [mm]
delmvco$\overline{m}$, delmdot	=	Polar Coordinate horizontal zero shifting for Rotational Speed Compressor Map, [mm]
delpvco$\overline{m}$, delPR	=	Polar Coordinate vertical zero shifting for Rotational Speed Compressor Map, [mm]
delmeco$\overline{m}$, delmdot	=	Polar Coordinate horizontal zero shifting for Efficiency Compressor Map, [mm]
etac	=	compressor efficiency
etat	=	turbine efficiency
etad	=	entrance efficiency
etan	=	nozzle efficiency
eta$\overline{m}$	=	mechanical efficiency
etatdat	=	Turbine Map efficiency data
etacdat	=	Compressor Map efficiency data
Efdat	=	efficiency data vector for Compressor Map
Efdat1	=	efficiency data + extrapolation data vector

Efextr	=	efficiency extrapolation vector data
Efint	=	efficiency interpolation data vector
Efdatstr	=	string vector for Efdat
gamma	=	γ
initpcom,PRØ	=	initial P_{03} / P_{02} Cartesian coordinate value for Compressor Map
initmcom,mdotØ	=	initial flow rate Cartesian Coordinate for Compressor Map, [kg/s]
Kmdotcom̅	=	$\mathrm{sqrt}(T_{02,ref}) / P_{02,ref}$
Kvelcom̅	=	$N_{ref} / \mathrm{sqrt}(T_{02,ref})$
mdotint	=	mass flow vector for interpolation, [kg/s]
mdot	=	flow rate, [kg/s]
mdotØ, initmcom̅	=	initial flow rate Cartesian Coordinate for Compressor Map, [kg/s]
mdotref	=	reference flow rate, [kg/s]
miu2	=	compressor dimensionless flow rate
miu4	=	turbine dimensionless flow rate
miu7	=	nozzle dimensionless flow rate
m7datkgs	=	Nozzle Map flow rate data, [kg/s]
m7datdim	=	nozzle dimensionless flow rate data
m4datkgs	=	Turbine Map flow rate, [kg/s]
m4datdim	=	turbine dimensionless flow rate data
mashpcom,CPR	=	Compressor Map pressure mashtab, [1/mm]
mashmcom,emdot	=	Compressor Map flow rate mashtab [kg/(s·mm)]

mRodat	=	Rodat rows number
N	=	rotational speed ,[RPM]
NaN or a	=	unavailable number
$N_{ref} = N_{max}$	=	reference rotational speed, RPM
niu2	=	compressor dimensionless rotational speed
niu4	=	turbine dimensionless rotational speed
niumin	=	minimal niu2
nabvcom	=	Polar Coordinate argument for Velocity Compressor Map, [rad]
nabefcom	=	Polar Coordinate argument for Efficiency Compressor Map, [rad]
Nkdat	=	vector dimensionless rotational speed data for Compressor Map
Nklnt	=	vector dimensionless rotational speed of interpolation
nablaØ	=	initial polar argument for rotational speed data of Compressor Map, [deg]
nabladat	=	polar argument for rotational speed data of Compressor Map, [deg]
nabvrad	=	nabladat/rad, [rad]
neff	=	efficiency data vector size
nnabla	=	polar argument vector size
nROdat	=	Rodat columns number
NaNstr	=	string of NaN
N	=	rotational speed, [RPM]
Nref	=	reference rotational speed, [RPM]

paref	=	P_a reference [Pa]
p2ref	=	P_{02} reference [Pa]
p3ref	=	P_{03} reference [Pa]
p4ref	=	P_{04} reference [Pa]
p7ref	=	P_{07} reference [Pa]
pi42ref	=	$P_{04,ref} / P_{02,ref}$
p43	=	P_{04} / P_{03}
pi43	=	p43
pi32	=	P_{03} / P_{02}
pi45	=	P_{04} / P_{05}
pi7a	=	P_{07} / P_a
pi2a	=	P_{02} / P_a
pi47	=	P_{04} / P_{07}
p45dat	=	P_{04} / P_{05} Turbine Map data
p7adat	=	P_{07} / P_a Nozzle Map data
p32dat	=	P_{03} / P_{02} Compressor Map data
pa	=	P_a [K]
PRO,unitpcom	=	initial P_{03} / P_{03} Cartesian coordinate value for Compressor Map
PRTABLE	=	Polar Coordinate Rotational Speed Compressor Map data matrix for look-up table Matlab function Table 2
PPP1	=	polynomial coefficients vector for rotational speed line extrapolations: output of POLYFIT Matlab function

QR	=	Q_R ,[J / kg]
rad	=	180/π
roefcom	=	Polar Coordinate radius-vector for Efficiency Compressor Map, [mm]
rovcom	=	Polar Coordinate radius-vector for Rotational Speed Compressor Map, [mm]
R	=	R,[J/(kg·K)]
ROdat	=	radius vector matrix data for Rotational Speed Compressor Map, [mm]
SF1,SF2,SF3	=	reference scale factors
SteadØ	=	equation solution matrix
sur	=	surge line data vector for Compressor Map
steady	=	pressure ratio vector for example
T2ref	=	T_{02} reference [K]
T4ref	=	T_{04} reference [K]
T7ref	=	T_{07} reference [K]
tet24ref	=	$T_{02,ref} / T_{04,ref}$
tet42ref	=	1/tet24ref
tet74ref	=	$T_{07,ref} / T_{04,ref}$
tet47ref	=	1/tet74ref
TABEFCOM	=	Polar Coordinate Efficiency Compressor Map data matrix for look-up table Matlab function Table 2

TABVCOM = dimensionless rotational speed Polar Coordinate Compressor Map data matrix for look-up table Matlab function Table 2

Ta = T_a, [K]

ue = u_e,[m / s]

ua = u_a,[m / s]

vw = Polar Coordinate interpolated data matrix for Compressor Map plotting

xmiu = initial value vector for miu2, miu4, miu7

xniu = initial niu4

xeta = initial value vector for etae, etat

xpi = initial value vector for pi32, pi45, pi7a, pi2a, pi47

xtet = initial value vector for tet24, tet74, tet454, tet322

xvmap = initial value vector for nabefec$\overline{m}$, roefcom

x=[xmiu xniu xeta xpi xtet xvmap xefmap] = initial value vector for equation systems

x,xx = flow rate vector for Compressor Map plotting [kg/s]

x,xx = dimensionless flow rate vector for Compressor Map plotting

xy = polar coordinate data matrix for Compressor Map plotting

y,yy = pressure ratio vector for Compressor Map plotting

APPENDIX B - DYNJET M-FILES AND THEIR DESCRIPTIONS

COMPEFD	performs interpolation/extrapolation data and plots constant efficiency lines of Compressor Map in the Cartesian Coordinates, uses DATCOMED
COMPEFF	performs interpolation/extrapolation data and plots constant efficiency lines for Standard Compressor Map in the Cartesian Coordinates, uses DATCOMEF
COMPVELD	performs interpolation/extrapolation data and plots constant rotational speed lines for Compressor Map in the Cartesian Coordinates, uses DATCOMVD
COMPVELF	performs interpolation/extrapolation data and plots constant rotational speed lines for Standard Compressor Map in the Cartesian Coordinates, uses DATCOMVF
COMPSURD	plots surge line for Compressor Map
COMPSURF	plots surge line for Standard Compressor Map
COMPSTD	plots SR-30 operating line (example from literature)
COMPLOTD	plots Compressor Map
DATNOZLD	input data for Nozzle Map
DATNOZLF	input data for Standard Nozzle Map
DATTURD	input data for Turbine Map
DATTURF	input data for standard Turbine Map
DATCOMUD	input polar coordinate data for constant rotational speed lines of Compressor Map (radius-vector [mm] vs. polar angle [deg])
DATCOMVF	= DATCOMVD
DATCOMED	input polar coordinate data for constant efficiency lines of Compressor Map (radius-vector [mm] vs. polar angle [deg])

DATCOMEF = DATCOMED

DATCOMSD input data surge line

DATCOMSF = DATCOMSD

DATSTD input data for SR-30 engine operating line (example from the literature)

NOZZLED plots Nozzle Map

NOZZLEF plots Standard Nozzle Map

PLOTMAPD plots Compressor/Turbine/Nozzle Maps; uses COMPVELD, COMPEFD, COMPSURD, TURBD, NOZZLED

PLOTMAPF plots compressor/turbine/nozzle Standard Maps; uses COMPVELF, COMPEFF, COMPSURF, TURBF, NOZZZLEF

PLOTUNIT plots DYNJET dimension output (with units)

REFDATD reference data for dimensionless parameter calculations; calculates scale coefficients (SF) for function STENGD

STENGD compressor-turbine-nozzle steady state equations for standard MATLAB FSOLF functions

STARTD start file for steady state equation solution; uses standard MATLAB FSOLVE function; contains aerodynamic/thermodynamic input data and output data in matrix STEADØ

TURBD plots Turbine Map, uses DATTURD

TRUBF plots standard Turbine Map

APPENDIX C – M-FILE LISTINGS

```
%Standard Compressor map at the polar coordinates
Nkdat=[.5 .6 .7 .75 .8 .85 .9 .95 1 1.05];%Velocity dimensionless
nabla0=26.6; %initial nabla, deg
nabladat=[0:1:12]+nabla0; %Polar angle, deg
Nkint=[.525 .550 .575 .625 .650 .675 .71 .72 .73 .74 .76 .77...
 .78 .79 .81 .82 .83 .84...
 .86 .87 .88 .89 .91 .92 .93 .94 .96 .97 .98 .99 1.01 1.02 1.03 1.04];
mdotint=[.05:.01:.33];
rad=180/pi
%nablarad=nabladat./rad; %Polar angle, rad
nabvrad=nabladat/rad;
ROdat=...
 [149   170   209   236   267   293.6 320.5  345   367   383
 148   171   211   237.5 268.5 296   323   348   370   386
 147   171   211.5 238.5 269   298   325   351   373.5 389.5
 146   171   212   239   270   300   327.25 354  377   393
 145   171   212   239.5 270   302   330   357   381   397
 144   170.5 210.5 238   269.5 303   333   360   384.5 401.5
 143.8 170   209   236.5 269   304   336   363   388.5 406
 142   167.5 206.5 232.5 267   303.5 338   366   392.5 409.5
 141.5 166.5 203.5 230   264.5 303   340.5 369   396.5 414.5
 139.5 164   200   226   259.5 300   341.5 371.5 400   419
 139   162   196.5 221   253.5 296.5 340   373.5 403   425
 136.5 159   192   214.5 245.5 287.5 333.5 374.5 405.5 430
 134.5 157   187   208   237   277   323.5 374   408.2 436];
mashmcom=.3/295; %.3/298 Mdot mashtab, (kg/s)/mm;
mashpcom=2/192; % PR mashtab, 1/mm;
delpvcom=-67.5; %-67.5 the polar coordinate  y-shifting, mm; (minus-down);
delmvcom=-80; %-80 the polar coordinate  x-shifting, mm; (minus-left);
initpcom=1; %y-initial cartesian coordinate, dimensionless;
initmcom=.05; % 0.05! initial x-cartesian coordinate, kg/s
%
Nmax=Nrefst; %RPM
Kmdotcom=sqrt(T2refst)/p2refst; %sqrt(T02ref,st)/P02ref,st;
Kvelcom=Nmax/sqrt(T2refst);
delPR=delpvcom;
delmdot=delmvcom;
CPR=mashpcom;
Cmdot=mashmcom;
PR0=initpcom;
mdot0=initmcom;
```

```
%Compressor map via efficiency data at the polar coordinates
Efdat=[.5 .55 .58 .60 .62 .63 .64];%Efficiency data dimensionless
nabla0=0; %initial nabla, deg
nabladat=[0:5:205 207.5 210 212.5 215:05:360]+nabla0; %Polar angle, deg
rad=180/pi
nablarad=nabladat./rad; %Polar angle, rad
a=NaN;
ROdat0=...
[a      a      a      42.6  34.0  30.0  13.5
 a      a      a      44.0  35.2  31.2  15.1
 a      a      a      46.6  36.8  32.9  18.1
 a      a      a       a    39.0  34.8  22.0
 a      a      a       a    41.2  36.9  24.0
 a      a      a       a    44.2  38.2  25.1
 a      a      a       a    48.2  41.9  30.3
 a      a      a       a    51.6  45.0  37.5
 a      a      a       a    58.6  50.2  40.6
 a      a      a       a    66.9  55.6  45.9
 a      a      a       a     a    64.8  50.0
 a      a      a       a     a    75.0  56.2
 a      a      a       a     a    74.2  55.2
 a      a      a       a     a    73.2  51.1
 a      a      a       a     a    67.1  45.8
 a      a      a       a     a    59.0  41.0
 a      a      a       a     a    53.1  36.0
 a      a      a       a     a    48.8  33.5
 a      a      a       a     a    44.6  31.0
 a      a      a       a     a    43.2  28.2
 a      a      a       a    45.6  39.1  26.2
 a      a      a       a    43.5  37.1  25.3
 a      a      a       a    42.0  35.3  24.6
 a      a      a       a    40.8  34.2  23.4
 a      a      a       a    39.5  33.2  23.0
 a      a      a       a    39.2  32.9  22.4
 a      a      a       a    38.1  32.0  22.6
 a      a      a       a    38.6  32.4  22.2
 a      a      a       a    39.1  32.5  22.3
 a      a      a       a    40.1  32.5  22.6
 a      a      a       a    39.7  32.9  22.9
 a      a      a       a    41.2  34.8  24.1
 a      a      a       a    42.8  35.8  24.9
 a      a      a       a    44.6  37.3  26.2
 a      a      a       a    47.1  39.7  27.2
 a      a      a       a    49.7  42.0  28.2
 a      a      a      62.0  53.1  45.0  31.1
 a      a      74.2   68.4  58.3  49.2  33.6
 a      a      85.2   75.5  64.2  53.6  36.9
 a      a      98.6   87.2  72.0  60.8  41.2
 a      126.2  115.0 101.4  82.6  68.8  46.1
 a      164.2  139.0 120.8  96.8  80.1  49.8
 a      184.3  155.0 131.0 101.5  85.0  51.0
 a      195.8  165.5 140.0 107.3  88.2  52.2
 a      184.6  161.8 141.2 106.8  87.4  50.4
 185    169.8  153.0 135.2 104.6  86.0  49.3
 155.0  141.8  128.1 116.1  93.1  75.5  40.1
 133.2  120.0  112.0 101.0  81.4  61.8  33.5
 a      107.5   99.3  90.2  70.8  54.3  29.0
 a      a       88.2  78.8  62.6  46.3  24.8
 a      a      a      70.8  56.2  42.2  22.2
 a      a      a      61.5  47.4  36.1  17.6
 a      a      a      57.0  42.9  32.6  15.0
 a      a      a      53.0  39.9  30.0  14.1
 a      a      a      47.8  36.8  27.9  12.5
 a      a      a      46.0  36.0  27.1  12.2
```

```
a        a        a        44.8  34.9  25.8  11.9
a        a        a        42.3  32.3  24.2  10.4
a        a        a        40.8  31.1  22.8  10.3
a        a        a        39.4  30.3  21.9   9.9
a        a        a        38.6  29.5  21.2   9.9
a        a        a        38.2  29.2  20.9   9.9
a        a        a        37.3  28.8  20.9   9.9
a        a        a        37.0  27.2  20.8  10.0
a        a        a        36.8  27.1  20.7  10.0
a        a        a        36.6  27.1  20.6  10.0
a        a        a        36.9  27.1  20.6  10.1
a        a        a        37.1  27.4  20.6  10.1
a        a        a        37.6  28.0  21.6  10.2
a        a        a        38.2  29.0  21.6  10.4
a        a        a        38.6  30.0  22.3  11.9
a        a        a        39.2  31.2  22.9  12.2
a        a        a        39.6  32.5  24.3  12.8
a        a        a        41.1  33.8  25.9  13.1
a        a        a        42.6  34.0  30.0  13.5];

Cmdot=.3/295; %.3/298 Mdot mashtab, (kg/s)/mm;
CPR=2/192; % PR mashtab, 1/mm;
delpecom=119; % the  polar coordinate  y-shifting, mm; plus up
delmecom=217; %the polar coordinate  x-shifting, mm; plus right
PR0=1; %y-cartesian coordinate initial value, dimensionless;
mdot0=.05; % 0.05! x-cartesian coordinate initial value, kg/s
delPR=delpecom;
delmdot=delmecom;
```

datturf.m


```
%SR-30 Turbine Map Estimation for all speed
%Mass Flow
p45dat=[1 1.1 1.2 1.3 1.4 1.5 1.75 2.0 2.25 2.5...
 2.75 3.00];% 3.25 3.5 3.75 4.00 4.25 4.5 4.75 5]; %for data processing
p45dadim=p45dat/p45refst; %p45refst=(p2refst*p32refst*.96/p5refst);
m4datkgs=[0 .130 .205 .245 .26 .27 .29 .30 .302 .305...
 .305 .307];% .307 .305 .305 .304];% .303 .302 .301 .300]; %kg/s
m4datdim=m4datkgs/mdotrefs;
etatdat=[.82 .827 .832 .837 .84 .843 .847 .849 .852...dattur
.854 .856 .858];% .861 .8615 .8615  .8615]; for data processing
```


datnozlf.m


```
%SR-30 Nozzle Map Estimation for the the speeds
%Mass Flow
p7adat=[1 1.1 1.2 1.3 1.4 1.5 1.75 2.0 2.25 2.5...
 2.75]; % 3.00 3.25 3.5 3.75 4.00 4.25 4.5 4.75 5]; %for data processing
p7adadim=p7adat/p7arefst;
m7datkgs=[0 .06 .13 .17 .21 .23 .27 .29 .304 .308...
 .310]; % .31 .31 .31 .31 .31 .31 .308 .306 .304 ]; %kg/s
m7datdim=m7datkgs/mdotrefs;
```


datcomsf.m


```
%%Surge line data
sur=[NaN NaN 1.13 1.19 1.27 1.34 1.44 1.55 1.62 1.72 1.79 1.87 1.95 2.02...
      2.09 2.17 2.25 2.34 2.42 2.52 2.58 2.64 2.72 2.78 2.84 2.92 3.08...
      NaN NaN NaN NaN];
mas=[.05:.01:.35];%kg/s
```


datcostf.m


```
%%Steady state of compressor/turbine system
steady=[NaN NaN NaN NaN 1.17 1.22 1.27 1.3 1.36 1.4 1.43 1.47 1.53 1.59...
1.66 1.72 1.81 1.87 1.94 2.01 2.08 2.17 2.25 2.35 2.43 2.56...
NaN NaN NaN NaN NaN];
mas=.05:.01:.35;
```

```
%THE STANDARD ENGINE REFERENCE DATA:
p2refst=101000; %Pa, P02 reference for standard map;
p32refst=2.8515;%P03refst/P02ef,st;
p4refst=276480; %Pa, P02 reference for standard map;
p45refst=1.8432; %P04refst/P05refst;
parefst=101000;
p7arefst=1.485;%P07refst/Parefst;
mdotrefs=.3; %kg/s - mass flow reference for standard map
Nrefst=82000; %RPM
T2refst=300; %K, T02 reference

%THE SR-30 ENGINE REFERENCE DATA:
%mdotref=.3; %kg/s
%Nref=82000; %RPM
%T2ref=300; %K, T02 reference
%T3ref=485; %K
%T4ref=1000; %K, T02 reference
%T5ref=750; 7ref=750; %K
%Paref=101000; %Pa, Pa reference
%P2ref=101000; %Pa, P02 reference;
%P3ref=288000; %Pa, P03 reference
%P4ref=276480; % %P04 ref, P43=P04/P03 is datum;
%P5ref=150000; %Pa, P05ref
%P7ref=P5ref; %Pa, P07 ref.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%tet24ref=T2ref/T4ref; %Theta24ref=T02ref/T04ref;
%tet42ref=1/tet24ref;
%tet74ref=T7ref/T4ref; %Theta74ref=T07ref/T04ref;
%tet47ref=1/tet74ref;
%pi32ref=P3ref/P2ref;
%pi42ref=P4ref/P2ref;%pi42ref=p04ref/p02ref;
%pi45ref=P4ref/P5ref;
%pia4ref=Paref/P4ref;     %pia4ref=pa/p04ref;
%pi7aref=P7ref/Paref;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%Compressor map at the polar coordinates
datcomvf
PRTABLE=[NaN       Nkdat*Kvelcom
         nabvrad' ROdat];
TABVCOM=[NaN       Nkdat
        nabvrad'  ROdat];
%data ploting:
rad=180/pi;
ii=size(Nkdat);
for i=1:ii(2) %Nk number
xy=[nabvrad' ROdat(:,i)];
y=(xy(:,2).*sin(xy(:,1))+delPR)*CPR+PR0; %PR-vector;
x=(xy(:,2).*cos(xy(:,1))+delmdot)*Cmdot+mdot0;%mdot-vector,kg/s
x=x/mdotrefs; %x is mius2 dimensionless; 0.3 is mdotref for SR-30
y=y/p32refst; %y is pis32; P03,ref,st/P02ref,st=(288000/101000);
plot(x,y,'lineWidth',2);
hold on;
grid
end
xlabel('Mass Flow: [mdot*sqrt(T02)/P02] / [mdotrefst*sqrt(T02refst)/P02refst]');
ylabel('Pressure Ratio: (P03/P02) / (P03refst/P02refst)');
title('STANDARD DIMENSIONLESS COMPRESSOR MAP');
ll=size(Nkint);
for j=1:ll(2)
vw=[nabvrad' table2(PRTABLE,nabvrad',Nkint(j)*Kvelcom)];
yy=(vw(:,2).*sin(vw(:,1))+delPR)*CPR+PR0;
xx=(vw(:,2).*cos(vw(:,1))+delmdot)*Cmdot+mdot0;
%xx=xx*Kmdotcom;
xx=xx/mdotrefs;
yy=yy/p32refst; %y is pis32; P03ref/P02ref=(288000/101000);
plot(xx,yy);
hold on
end
Nkdatstr=num2str(Nkdat);
Nkstr=['Ang. Velocity: N/sqrt(T02) / [Nrefst/sqrt(T02refst)] ='];
'Plot Dimensionless N Data'
gtext(Nkstr)
gtext(Nkdatstr);
grid
grid
grid
```

```
%Compressor efficiency data extrapolation and plotting
datcomef
%%%%%% Data extrapolation;
Efextr=[0.644 .648 .65]; % .643 is Extrapolation input for eff
Efint=[.51 .52 .53 .54 .555 .56 .565 .57 .575 .584 .588 .592...
 .596 .604 .608 .612 .616 .622 .624 .626 .628 .632 .634 .636...
 .638  .641 .642  .643 .645 .646 .647 .649];
ii=size(Efdat);
neff=ii(2); % efficiency data size;
ii=size(nabladat);
nnabla=ii(2); % nabla data size
ii=size(ROdat0);
mROdat=ii(1); % ROdat rows number
nROdat=ii(2); % ROdat colomns number
NaNstr=num2str(NaN);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
ROdat1=[ROdat0 ROdat0(:,7)*0.6 ROdat0(:,7)*0.2 ROdat0(:,7)*0 ];
Efdat1=[Efdat 0.644 0.648 0.65];
%%%%%%%%%%%
TABEFCOM=[NaN        Efdat1
          nablarad' ROdat1];
%%%%%%DATA/EXTRAPOL. PLOTTING:
rad=180/pi;
ii=size(Efdat1);
for i=1:ii(2) % with approx. counture
xy=[nablarad' ROdat1(:,i)];
y=(xy(:,2).*sin(xy(:,1))+delPR)*CPR+PR0; %PR-vector;
x=(xy(:,2).*cos(xy(:,1))+delmdot)*Cmdot+mdot0;%mdot-vector,kg/s
x=x/mdotrefs; %x is mius2;
y=y/p32refst; %y is pis32; P03,ref/P02ref
plot(x,y,'lineWidth',2); hold on;
grid
end
%%%INTERPOLATION PLOTTING:
mdotint=[.05:.01:.33];
jj=size(Efint);
for j=1:jj(2)
vw=[nablarad' table2(TABEFCOM,nablarad',Efint(j))];
yy=(vw(:,2).*sin(vw(:,1))+delPR)*CPR+PR0;
xx=(vw(:,2).*cos(vw(:,1))+delmdot)*Cmdot+mdot0;
xx=xx/mdotrefs;
yy=yy/p32refst; %y is pis32; P03,ref,st/P02ref,st
plot(xx,yy);
grid
hold on
end
Efdatstr=num2str(Efdat);
Efint=num2str(Efint);
Efexstr=num2str(Efextr);
Efdatstr=['Efficiency Data: ' Efdatstr];
Efint=['Eff. int.: ' Efint];
Efexstr=['Efficiency Extrapol.: ' Efexstr];
'Plot Efficiency Data'
gtext(Efdatstr)
'Plot Efficiency for Extrapolation'
gtext(Efexstr)
grid
hold on
```

02/02/99
14:10:27

turbf.m

1

```
%SR-30 Turbine Map Estimation for the all speeds
%Mass Flow
datturf
subplot(2,1,1)
plot(p45dadim,m4datdim)
ylabel('Mass Flow, Dimensionless');
title('TURBINE STANDARD DIMENSIONLESS MAP')
grid
subplot(2,1,2)
plot(p45dadim,etatdat)
xlabel('Pressure Ratio: (P04/P05) / (P04refst/P05refst)')
ylabel('Turbine Efficiency')
grid
```

02/02/99
14:11:06

complotf.m

1

```
%%%compressor-turbine-nozzle steady state matching. Input: datenstd.m
global SC1 SC2 SC3 SC4 SC5 SC6 SC7 SC8
global TABVCOM delpvcom mashpcom initpcom mdotref delmvcom mashmcom initmcom
global TABEFCOM delpecom delmecom p45dat m4datdim etatdat p7adat m7datdim
%%%%%
refdatd
figure(1)
compvelf
compeff
compsurf
%compstd
hold off
```

```
%Compressor map at the polar coordinates
Nkdat=[.5 .6 .7 .75 .8 .85 .9 .95 1 1.05];%Velocity dimensionless
nabla0=26.6; %initial nabla, deg
nabladat=[0:1:12]+nabla0; %Polar angle, deg
Nkint=[.525 .550 .575 .625 .650 .675 .71 .72 .73 .74 .76 .77 .78 .79...
   .81 .82 .83 .84 .86 .87 .88 .89 .91 .92 .93...
   .94 .96 .97 .98 .99 1.01 1.02 1.03 1.04];
mdotint=[.05:.01:.33];
rad=180/pi
%nablarad=nabladat./rad; %Polar angle, rad
nabvrad=nabladat/rad;
ROdat=...
 [149  170   209   236   267   293.6 320.5  345   367   383
 148   171   211   237.5 268.5 296   323   348   370   386
 147   171   211.5 238.5 269   298   325   351   373.5 389.5
 146   171   212   239   270   300   327.25 354  377   393
 145   171   212   239.5 270   302   330   357   381   397
 144   170.5 210.5 238   269.5 303   333   360   384.5 401.5
 143.8 170   209   236.5 269   304   336   363   388.5 406
 142   167.5 206.5 232.5 267   303.5 338   366   392.5 409.5
 141.5 166.5 203.5 230   264.5 303   340.5 369   396.5 414.5
 139.5 164   200   226   259.5 300   341.5 371.5 400   419
 139   162   196.5 221   253.5 296.5 340   373.5 403   425
 136.5 159   192   214.5 245.5 287.5 333.5 374.5 405.5 430
 134.5 157   187   208   237   277   323.5 374   408.2 436];
mashmcom=.3/295; %.3/298 Mdot mashtab, (kg/s)/mm;
mashpcom=2/192; % PR mashtab, 1/mm;
delpvcom=-67.5; %-67.5 the polar coordinate  y-shifting, mm; (minus-down);
delmvcom=-80; %-80 the polar coordinate  x-shifting, mm; (minus-left);
initpcom=1; %y-initial cartesian coordinate, dimensionless;
initmcom=.05; % 0.05! initial x-cartesian coordinate, kg/s
%%%
Nmax=Nref; %RPM
Kmdotcom=sqrt(T2ref)/p2ref; %sqrt(T02ref)/P02ref;
Kvelcom=Nmax/sqrt(T2ref);
delPR=delpvcom;
delmdot=delmvcom;
CPR=mashpcom;
Cmdot=mashmcom;
PR0=initpcom;
mdot0=initmcom;
```

```
%Compressor map via efficiency data in the polar coordinates
Efdat=[.5 .55 .58 .60 .62 .63 .64];%Efficiency data dimensionless
nabla0=0; %initial nabla, deg
nabladat=[0:5:205 207.5 210 212.5 215:05:360]+nabla0; %Polar angle, deg
rad=180/pi
nablarad=nabladat./rad; %Polar angle, rad
a=NaN;
ROdat0=...
[a      a      a      42.6   34.0   30.0   13.5
 a      a      a      44.0   35.2   31.2   15.1
 a      a      a      46.6   36.8   32.9   18.1
 a      a      a      a      39.0   34.8   22.0
 a      a      a      a      41.2   36.9   24.0
 a      a      a      a      44.2   38.2   25.1
 a      a      a      a      48.2   41.9   30.3
 a      a      a      a      51.6   45.0   37.5
 a      a      a      a      58.6   50.2   40.6
 a      a      a      a      66.9   55.6   45.9
 a      a      a      a      a      64.8   50.0
 a      a      a      a      a      75.0   56.2
 a      a      a      a      a      74.2   55.2
 a      a      a      a      a      73.2   51.1
 a      a      a      a      a      67.1   45.8
 a      a      a      a      a      59.0   41.0
 a      a      a      a      a      53.1   36.0
 a      a      a      a      a      48.8   33.5
 a      a      a      a      a      44.6   31.0
 a      a      a      a      a      43.2   28.2
 a      a      a      a      45.6   39.1   26.2
 a      a      a      a      43.5   37.1   25.3
 a      a      a      a      42.0   35.3   24.6
 a      a      a      a      40.8   34.2   23.4
 a      a      a      a      39.5   33.2   23.0
 a      a      a      a      39.2   32.9   22.4
 a      a      a      a      38.1   32.0   22.6
 a      a      a      a      38.6   32.4   22.2
 a      a      a      a      39.1   32.5   22.3
 a      a      a      a      40.1   32.5   22.6
 a      a      a      a      39.7   32.9   22.9
 a      a      a      a      41.2   34.8   24.1
 a      a      a      a      42.8   35.8   24.9
 a      a      a      a      44.6   37.3   26.2
 a      a      a      a      47.1   39.7   27.2
 a      a      a      a      49.7   42.0   28.2
 a      a      a      62.0   53.1   45.0   31.1
 a      a      74.2   68.4   58.3   49.2   33.6
 a      a      85.2   75.5   64.2   53.6   36.9
 a      a      98.6   87.2   72.0   60.8   41.2
 a      126.2  115.0  101.4  82.6   68.8   46.1
 a      164.2  139.0  120.8  96.8   80.1   49.8
 a      184.3  155.0  131.0  101.5  85.0   51.0
 a      195.8  165.5  140.0  107.3  88.2   52.2
 a      184.6  161.8  141.2  106.8  87.4   50.4
185     169.8  153.0  135.2  104.6  86.0   49.3
155.0   141.8  128.1  116.1  93.1   75.5   40.1
133.2   120.0  112.0  101.0  81.4   61.8   33.5
a       107.5  99.3   90.2   70.8   54.3   29.0
a       a      88.2   78.8   62.6   46.3   24.8
a       a      a      70.8   56.2   42.2   22.2
a       a      a      61.5   47.4   36.1   17.6
a       a      a      57.0   42.9   32.6   15.0
a       a      a      53.0   39.9   30.0   14.1
a       a      a      47.8   36.8   27.9   12.5
a       a      a      46.0   36.0   27.1   12.2
```

```
a      a      a      44.8  34.9  25.8  11.9
a      a      a      42.3  32.3  24.2  10.4
a      a      a      40.8  31.1  22.8  10.3
a      a      a      39.4  30.3  21.9   9.9
a      a      a      38.6  29.5  21.2   9.9
a      a      a      38.2  29.2  20.9   9.9
a      a      a      37.3  28.8  20.9   9.9
a      a      a      37.0  27.2  20.8  10.0
a      a      a      36.8  27.1  20.7  10.0
a      a      a      36.6  27.1  20.6  10.0
a      a      a      36.9  27.1  20.6  10.1
a      a      a      37.1  27.4  20.6  10.1
a      a      a      37.6  28.0  21.6  10.2
a      a      a      38.2  29.0  21.6  10.4
a      a      a      38.6  30.0  22.3  11.9
a      a      a      39.2  31.2  22.9  12.2
a      a      a      39.6  32.5  24.3  12.8
a      a      a      41.1  33.8  25.9  13.1
a      a      a      42.6  34.0  30.0  13.5];

Cmdot=.3/295; %.3/298 Mdot mashtab, (kg/s)/mm;
CPR=2/192; % PR mashtab, 1/mm;
delpecom=119; % the  polar coordinate  y-shifting, mm; plus up
delmecom=217; %the polar coordinate  x-shifting, mm; plus right
PR0=1; %y-cartesian coordinate initial value, dimensionless;
mdot0=.05; % 0.05! x-cartesian coordinate initial value, kg/s
delPR=delpecom;
delmdot=delmecom;
```

02/02/99
14:10:03

datturd.m

1

```
%SR-30 Turbine Map Estimation for all speed
%Mass Flow
p45dat=[1 1.1 1.2 1.3 1.4 1.5 1.75 2.0 2.25 2.5...
      2.75 3.00]/p45refst*p45ref;% 3.25 3.5 3.75 4.00 4.25 4.5 4.75 5];
                                    %for data processing
m4datkgs=[0 .130 .205 .245 .26 .27 .29 .30 .302 .305...
 .305 .307];% .307 .305 .305 .304];% .303 .302 .301 .300]; %kg/s
m4datdim=m4datkgs/mdotrefs;
etatdat=[.82 .827 .832 .837 .84 .843 .847 .849 .852...dattur
   .854 .856 .858]*1.075;% .861 .8615 .8615  .8615] for data processing
```

?/02/99
14:10:05

datnozld.m

1

```
%SR-30 Nozzle Map Estimation for the all speeds
%Mass Flow
p7adat=[1 1.1 1.2 1.3 1.4 1.5 1.75 2.0 2.25 2.5...
 2.75 3.00]/p7arefst*p7aref; % 3.25 3.5 3.75 4.00 4.25 4.5 4.75 5]; %for data processing
m7datkgs=[0 .06 .13 .17 .21 .23 .27 .29 .304 .308...
 .310 .310]; %.31 .31 .31 .31 .308 .306 .304 ]; %kg/s
m7datdim=m7datkgs/mdotref;
```

02/02/99
14:10:11

datcomsd.m

1

```
%%Surge line data
sur=[NaN NaN 1.13 1.19 1.27 1.34 1.44 1.55 1.62 1.72 1.79 1.87 1.95 2.02...
      2.09 2.17 2.25 2.34 2.42 2.52 2.58 2.64 2.72 2.78 2.84 2.92 3.08...
      NaN NaN NaN NaN];
mas=[.05:.01:.35];%kg/s
mdotsur=mas/mdotref;
```

02/02/99
14:10:06

datcostd.m

1

```
%%Steady state of compressor/turbine system
steady=[NaN NaN NaN NaN 1.17 1.22 1.27 1.3 1.36 1.4 1.43 1.47 1.53 1.59...
1.66 1.72 1.81 1.87 1.94 2.01 2.08 2.17 2.25 2.35 2.43 2.56...
NaN NaN NaN NaN NaN];
mas=.05:.01:.35;
mdotst=mas/mdotref;
```

```
%Reference data for the maps
global SF1 SF2 SF3 SF4 SF5 SF6 SF7
p43=.96; %P04/P03
pi43=p43;
%%%%%%%%%%%%%%%%%%%%%%%%%%
%REFERENCE DATA:
mdotref=.3; %kg/s
Nref=82000; %RPM
T2ref=300; %K, T02 reference
T4ref=1000; %K, T02 reference
T7ref=750; %K
paref=101000; %Pa, Pa reference
p2ref=101000; %Pa, P02 reference;
%p3ref=288000; %Pa, P03 reference
p32ref=2.8515;% for test*1.1
p45ref=1.8432;
p7aref=1.485;; %Pa,
p3ref=p2ref*p32ref;
p4ref=p3ref*p43; % %P04 ref, P43=P04/P03
p5ref=p4ref/p45ref;
p7ref=paref*p7aref;
%%%%%%%%%%%%%%%%%%%%%%%%%%%
tet24ref=T2ref/T4ref; %Theta24ref=T02ref/T04ref;
tet42ref=1/tet24ref;
tet74ref=T7ref/T4ref; %Theta74ref=T07ref/T04ref;
tet47ref=1/tet74ref;
pi42ref=p4ref/p2ref;  %pi42ref=p04ref/p02ref;
pia4ref=paref/p4ref;     %pia4ref=pa/p04ref;
%%%%%%%%%%%%%%%%%%%%%%%%%%%
%THE STANDARD ENGINE REFERENCE DATA:
p2refst=101000; %Pa, P02 reference for standard map;
p32refst=2.8515;%P03refst/P02ef,st;
p4refst=276480; %Pa, P02 reference for standard map;
%P04refst/P05refst;
p45refst=1.8432; %P04refst/P05refst;
p7arefst=1.485; %P07refst/Parefst;
mdotrefs=.3; %kg/s - mass flow reference for standard map
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Scaling Coefficients:
SF1=tet24ref;
SF2=pi42ref*sqrt(tet24ref);
SF3=pia4ref*sqrt(tet47ref);
SF4=p32ref/p32refst;
SF5=p45ref/p45refst;
SF6=p7aref/p7arefst;
SF7=mdotrefs;
```

```
%Compressor efficiency data extrapolation and plotting
datcomed
%%%%%% Data extrapolation;
Efextr=[0.644 .648 .65]; % .643 is Extrapolation input for eff
Efint=[.51 .52 .53 .54 .555 .56 .565 .57 .575 .584 .588...
.592 .596 .604 .608 .612 .616 .622 .624 .626 .628...
.632 .634 .636 .638  .641 .642  .643 .645 .646 .647 .649];
ii=size(Efdat);
neff=ii(2); % efficiency data matrix size;
ii=size(nabladat);
nnabla=ii(2); % nabla data size
ii=size(ROdat0);
mROdat=ii(1); % ROdat rows number
nROdat=ii(2); % ROdat colomns number
NaNstr=num2str(NaN);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
ROdat1=[ROdat0 ROdat0(:,7)*0.6 ROdat0(:,7)*0.2 ROdat0(:,7)*0 ];
Efdat1=[Efdat 0.644 0.648 0.65]; %.644 .648 .65
%ROdat1=[ROdat0 ROextrap'];
%Efdat1=[Efdat Efextr];
%%%%%%%%%%%
TABEFCOM=[NaN        Efdat1
         nablarad' ROdat1];
%%%%%%DATA/EXTRAPOL. PLOTTING:
rad=180/pi;
ii=size(Efdat1);
for i=1:ii(2) % with approx. counture
xy=[nablarad' ROdat1(:,i)];
y=(xy(:,2).*sin(xy(:,1))+delPR)*CPR+PR0; %PR-vector;
x=(xy(:,2).*cos(xy(:,1))+delmdot)*Cmdot+mdot0;%mdot-vector,kg/s
x=x/mdotrefs;
y=y/p32refst*p32ref;
plot(x,y,'lineWidth',2); hold on;
grid
end
%%%INTERPOLATION PLOTTING:
mdotint=[.05:.01:.33];
jj=size(Efint);
for j=1:jj(2)
vw=[nablarad' table2(TABEFCOM,nablarad',Efint(j))];
yy=(vw(:,2).*sin(vw(:,1))+delPR)*CPR+PR0;
xx=(vw(:,2).*cos(vw(:,1))+delmdot)*Cmdot+mdot0;
xx=xx/mdotrefs;
yy=yy/p32refst*p32ref;
plot(xx,yy);
grid
hold on
end
Efdatstr=num2str(Efdat);
Efint=num2str(Efint);
Efexstr=num2str(Efextr);
Efdatstr=['Efficiency Data: ' Efdatstr];
Efint=['Eff. int.: ' Efint];
Efexstr=['Efficiency Extrapol.: ' Efexstr];
'Plot Efficiency Data'
gtext(Efdatstr)
'Plot Efficiency for Extrapolation'
gtext(Efexstr)
grid
hold on
```

02/02/99
14:10:17

compsurd.m

1

```
%%Surge line plotting
datcomsd
sur=sur/p32refst*p32ref; %sur is pis32; ;
mdotsur=mas/mdotrefs;
plot(mdotsur,sur,'lineWidth',1);
'Plot Surge Line'
gtext('SURGE LINE')
grid
hold on
```

02/02/99
14:10:20

compstd.m

1

```
%%Steady state of compressor/turbine example
datcostd
steady=steady/p32refst*p32ref; %P03,ref/P02ref=(288000/101000);
mdotstea=mas/mdotrefs;
plot(mdotstea,steady,'ko')
'Plot Steady State'
gtext('COMPRESSOR/TURBINE STEADY STATE')
grid
hold off
```

02/02/99
14:10:22

complotd.m

1

```
%%%compressor-turbine-nozzle steady state matching. Input: datenstd.m
global SF1 SF2 SF3 SC4 SC5 SC6 SC7 SC8
global TABVCOM delpvcom mashpcom initpcom mdotref delmvcom mashmcom initmcom
global TABEFCOM delpecom delmecom p45dat m4datdim etatdat p7adat m7datdim
%%%%%
refdatd
figure(1)
compveld
compefd
compsurd
%compstd
hold off
```

turbd.m


```
%SR-30 Turbine Map Estimation for the all speeds
%Mass Flow
datturd
subplot(2,1,1)
plot(p45dat,m4datdim)
ylabel('Mass Flow, Dimensionless')
title('SR-30 TURBINE DIMENSIONLESS MAP ESTIMATION')
grid
subplot(2,1,2)
plot(p45dat,etatdat)
xlabel('Pressure: P04/P05')
ylabel('Efficiency: etat')
grid
```


plotmapd.m


```
%%%compressor-turbine-nozzle steady state matching. Input: datenstd.m
global SF1 SF2 SF3 SC4 SC5 SC6 SC7 SC8 TABVCOM TABEFCOM
global delpvcom mashpcom initpcom mdotref delmvcom mashmcom initmcom
global delpecom delmecom p45dat m4datdim etatdat p7adat m7datdim
tic,
%%%%%
refdatf
refdatd
figure(1)
compveld
compefd
compsurd
%compstd
hold off
figure(2)
turbd
figure(3)
nozzled
save plotmapd.mat
toc
```


nozzled.m


```
%SR-30 Nozzle Map Estimation Data Plotting for the all speeds
datnozld
plot(p7adat,m7datdim)
xlabel('Pressure: P07/Pa')
ylabel('Mass Flow, Dimensionless')
title('SR-30 NOZZLE DIMENSIONLESS MAP ESTIMATION')
grid
```

old file


```
%SR-30 compressr-turbine-nozzle steady state plotting
refdatf
refdatd
load steadso2
p7cr=[1-1/etan*(gamma-1)/(gamma+1)]^(gamma/(1-gamma)); %P07/Pcr=1.92
pcr7=1/p7cr;
K1=size(stead0);
K11=K1(2);
stead00=stead0;
for rr=1:K11    %
niu2abs(rr)=1-delniu2*(rr-1); niu2=niu2abs(rr);%niu2 vector, size=k11-1
unit(1,rr)=T02;
unit(2,rr)=P02;                                                          %P02
unit(3,rr)=Ma*sqrt(gamma*R*Ta); ua=unit(3,rr);                           %ua
unit(4,rr)=T02*(1+stead00(14,rr)); T03=unit(4,rr);                       %T03
unit(5,rr)=T02/stead00(11,rr); T04=unit(5,rr);                           %T04
unit(6,rr)=T04*(1-stead00(13,rr)); T05=unit(6,rr);                       %T05
unit(7,rr)=T04*stead00(12,rr);  T07=unit(7,rr);                          %T07
unit(8,rr)=P02*stead00(7,rr); P03=unit(8,rr);                            %P03
unit(9,rr)=P03/pi34; P04=unit(9,rr);                                     %P04
unit(10,rr)=P04/stead00(8,rr); P05=unit(10,rr);                          %P05
unit(11,rr)=Pa*stead00(9,rr); P07=unit(11,rr);                           %P07
unit(12,rr)=Nref*sqrt(T02/T2ref)*niu2abs(rr); N=unit(12,rr);             %N
unit(13,rr)=mdotref*stead00(1,rr)*P02/p2ref/sqrt(T02/T2ref); mdota=unit(13,rr); %mdota
unit(14,rr)=Cp*(T04-T03)/(QR-Cp*T04); f=unit(14,rr);                     %f
if P07/Pa<p7cr
unit(15,rr)=sqrt(2*etan*Cp*T05*(1-(Pa/P05)^((gamma-1)/gamma))); ue=unit(15,rr); %ue
elseif P07/Pa>=p7cr
unit(15,rr)=sqrt(2*etan*Cp*T05*(1-pcr7^((gamma-1)/gamma))); ue=unit(15,rr); %ue
end
unit(16,rr)=mdota*((1+f)*ue-ua); T=unit(16,rr); %Thrust                  %T
unit(17,rr)=f/( T/mdota); SFC=unit(17,rr);                               %SFC
unit(18,rr)=stead00(5,rr);                                               %etac
unit(19,rr)=stead00(6,rr);                                               %etat
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Compressor data plotting
Mstr=num2str(Ma);
figure(1)
subplot(5,1,1)
plot(unit(12,:),unit(1,:));
grid
ylabel('T02, K')
comstr=['SR-30 OPERATING LINE. COMPRESSOR DATA.  M= ' Mstr];
title(comstr);
subplot(5,1,2)
plot(unit(12,:),unit(4,:));
grid
ylabel('T03, K')
subplot(5,1,3)
plot(unit(12,:),unit(2,:));
grid
ylabel('P02, Pa')
subplot(5,1,4)
plot(unit(12,:),unit(8,:));
grid
ylabel('P03, Pa')
subplot(5,1,5)
plot(unit(12,:),unit(18,:));
grid
ylabel('Compr. Efficiency')
xlabel('Angular Velocity, RPM')
%%%%Turbine  data plotting
figure(2)
```

```
subplot(5,1,1)
plot(unit(12,:),unit(5,:));
grid
ylabel('T04, K')
turstr=['SR-30 OPERATING LINE. TURBINE DATA.  M= ' Mstr];
title(turstr);
%title('SR-30 OPERATING LINE. TURBINE DATA. M=0.5')
subplot(5,1,2)
plot(unit(12,:),unit(6,:));
grid
ylabel('T05, K')
subplot(5,1,3)
plot(unit(12,:),unit(9,:));
grid
ylabel('P04, Pa')
subplot(5,1,4)
plot(unit(12,:),unit(10,:));
grid
ylabel('P05, Pa')
subplot(5,1,5)
plot(unit(12,:),unit(19,:));
grid
ylabel('Turbine Efficiency')
xlabel('Angular Velocity, RPM')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Nozzle data plotting
figure(3)
subplot(2,1,1)
plot(unit(12,:),unit(7,:));
grid
ylabel('T07, K')
nozstr=['SR-30 OPERATING LINE. NOZZLE DATA.  M= ' Mstr];
title(nozstr);
%title('SR-30 OPERATING LINE. NOZZLE DATA. M=0.5')
subplot(2,1,2)
plot(unit(12,:),unit(11,:));
grid
ylabel('P07, Pa')
xlabel('Angular Velocity, RPM')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Engine data plotting
figure(4)
subplot(6,1,1)
plot(unit(12,:),unit(16,:));
grid
ylabel('Thrust, N')
opstr=['SR-30 OPERATING LINE. M= ' Mstr];
title(opstr);
%title('SR-30 OPERATING LINE. M=0.5')
subplot(6,1,2)
plot(unit(12,:),unit(17,:));
grid
ylabel('SFC, (kg/s)/N')
subplot(6,1,3)
plot(unit(12,:),unit(3,:));
grid
ylabel('ua, m/s')
subplot(6,1,4)
plot(unit(12,:),unit(15,:));
grid
ylabel('ue, m/s')
subplot(6,1,5)
plot(unit(12,:),unit(13,:));
grid
```

```
ylabel('mdota, kg/s')
subplot(6,1,6)
plot(unit(12,:),unit(14,:));
grid
ylabel('f=mdotf/mdota')
xlabel('Angular Velocity, RPM')
%Compressor map plotting:
figure(5)
compveld
%opstr=['SR-30 OPERATING LINE. M= ' Mstr];
title(opstr);
compefd
compsurd
compstdd %calculated
```

```
%start file for function: stengd.m
clear
global niu2 pi34 pi43 pi2a M etam etad Cpg Cpa gamma ppp1
tic,
delete steadso2.mat
load plotmapd
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%INPUT DATA:
niu2=1; %dimensionless compressor velocity;
delniu2=0.02; %velocity step
niumin=.65;  %minimal velocity .65
niu2=niu2+delniu2;
pi43=.96; %P04/P03;
pi34=1/pi43;
M=0.5; %.5
Ma=M;
etam=.95; %Mech. efficiency
etan=.98; %Nozzle efficiency
etad=1;%Entrance efficiency
Cpg=1.147;
Cpa=1.005;
gamma=1.4;
Pa=101000; %Pa 101000
Ta=300; %K 300
R=287; %J/(kg*K)
QR=41000000; %J/kg
Cp=1005; %J/(kg*K)
T02=Ta*(1+(gamma-1)/2*Ma^2);
P02=Pa*(1+etad*(gamma-1)/2*Ma^2)^(gamma/(gamma-1));
pi2a=P02/Pa;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%x is initial data for solution:
xmiu=[.9968 1.0014 .7864]; %.8 .8 .8
     % miu2  miu4  miu7
xniu=[1.0381]; %.87
      %niu4
xeta=[.6401 .8493]; %.6401 .8493
      %etac  etat
xpi= [2.7344   2.0255  1.5374          2.0255]; %2 1.3 1.56 1.0 2.34
      %pi32     pi45   pi7a     pi2a    pi47
xtet=[.3233 .8449  .1551   .5202]; %1.3=? 1.3=?;
     %tet24  tet74  tet454  tet322
xvmap=[.6242      400.3933]; %31.6/57.3
      %nabvcom     rovcom
xefmap=[1.0399 55.0896]; %220/57.3 38
      %nabefcom roefcom
x=[xmiu xniu xeta xpi xtet xvmap xefmap];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
ss=size(nabvrad);
sss=ss(2);
%roro=polyval(ppp1,.5)
options(2)=.001; options(3)=.001; options(14)=19*300;
%stead12(18,1)=zeros';
stead0=[];
iki=1;
while niu2>niumin
  if iki>1
  x=solution;
  end
niu2=niu2-delniu2;
 for i=1:(sss-1)
rovcomnk(i)=table2(TABVCOM,nabvrad(i),niu2);
 nabvrad0(i)=nabvrad(i);
end
```

```
[ppp1,s1]=polyfit(nabvrad0,rovcomnk,5);
solution=fsolve('stengd',x,options)
stead0=[ stead0 solution']
iki=iki+1;
save steadso2.mat stead0;
end,
toc
```

```
%%compressor-turbine-nozzle steady state matching. Input: datenstd.m
%To run complotd.m for extrapolation data
%creation in the file: complotd.mat
function q=stengd(p);
global niu2 pi34 pi43 pi2a M etam etad Cpg Cpa gamma ppp1
global SF1 SF2 SF3 SF4 SF5 SF6 SF7 TABVCOM TABEFCOM
global  delpvcom mashpcom initpcom mdotref delmvcom mashmcom initmcom
global  delpecom delmecom p45dat m4datdim etatdat p7adat m7datdim
%datenstd %input data, m-file
%load complotd %efficiency extrapolation and another compressor data;
%complotd.mat is loaded after complotd.mat execution;
%datturd %turbine map data
%datnozld %nozzle map data
miu2=p(1); miu4=p(2); miu7=p(3);
niu4=p(4); %niu2 is given
etac=p(5); etat=p(6);
pi32=p(7); pi45=p(8); pi7a=p(9); %pi2a=p(10);
pi47=p(10); %pi34 is given
tet24=p(11); tet74=p(12); tet454=p(13); tet322=p(14);
nabvcom=p(15); %nabla [rad]!!! for compr. velocity map;
rovcom=p(16);   %radius-vector ro [mm] for compr.velocity map
nabefcom=p(17);% nabla [rad] for compr. efficincy map
roefcom=p(18); % radius-vector for compr.efficiency map
%%%%%%%%
q=zeros(18,1);
%%%%%%%%%
nabef888=nabefcom
if nabefcom<0
nabefcom=2*pi+nabefcom;
elseif nabefcom>2*pi
nabefcom=nabefcom-2*pi;
end
if etac>0.65  %.65
   etac=0.65; %.65
end
%%%%%%%%
q(1)=niu4-niu2*sqrt(tet24/SF1);
q(2)=miu4-miu2/pi32*pi34/sqrt(tet24)*SF2;
q(3)=tet454-tet322*tet24*Cpa/(Cpg*etam);
q(4)=tet454-etat*(1-1/pi45^((gamma-1)/gamma));
q(5)=tet322-(pi32^((gamma-1)/gamma)-1)/etac;
q(6)=miu7-miu4*pi47*sqrt(tet74)*SF3;
q(7)=tet74-(1-tet454);
q(8)=pi7a-pi43*pi32*pi2a/pi45; %D1.1.8,a
q(9)=pi45-pi47;
%%%%%%%%%
%%Compressor const. velocity map: (see compveld.m)
q(10)=rovcom-polyval(ppp1,nabvcom);
'%%%%%%%%%%%'
etacITER=etac
niu2ITER=niu2
'%%%%%%%%%%%'
q(11)=pi32-((rovcom.*sin(nabvcom)+delpvcom)*mashpcom+initpcom)*SF4;
q(12)=miu2-1/SF7*((rovcom.*cos(nabvcom)+delmvcom)...
   *mashmcom+initmcom);
%%Compressor const. efficiency map:
q(13)=roefcom-table2(TABEFCOM,nabefcom,etac)/SF7; %ro [mm]
q(14)=pi32-((roefcom.*sin(nabefcom)+delpecom)...
      *mashpcom+initpcom)*SF4;
%P03/P02;
q(15)=miu2-1/SF7*((roefcom.*cos(nabefcom)+delmecom)*mashmcom+initmcom); %miu2=mdotref;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Turbine map: miu4 vs pi45 for all niu4:
q(16)=miu4-spline(p45dat,m4datdim,pi45*SF5); %turbime mass flow dim.
```

```
%Turbine map: efficincy vs pi45 for all niu4;
q(17)=etat-spline(p45dat,etatdat,pi45*SF5); %turbine efficienty
%Nozzle map: miu7 vs pi7a:
q(18)= miu7-spline(p7adat,m7datdim,pi7a*SF6);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

APPENDIX D - EQUATION SYSTEM and OUTPUT PARAMETER CALCULATIONS

EQUATION SYSTEM (is contained in STENGD):

$$\nu_{S4} = \nu_{S2} \cdot \sqrt{\theta_{24} / \mathrm{SF1}}; \tag{2.14}$$

$$\mu_{S4} = \mu_{S2} \frac{\pi_{34}}{\pi_{32}\sqrt{\theta_{24}}} \cdot SF2; \tag{2.15}$$

$$\Delta\theta_{454} = \Delta\theta_{322} \cdot \theta_2 \cdot \frac{C_{pa}}{C_{pg}\eta_m}; \tag{2.16}$$

$$\Delta\theta_{454} = \eta_t \cdot \left(1 - \frac{1}{\pi_{45}^{\frac{\gamma-1}{\gamma}}}\right); \tag{2.17}$$

$$\Delta\theta_{322} = \frac{1}{\eta_C}\left(\pi_{32}^{\frac{\gamma-1}{\gamma}} - 1\right); \tag{2.18}$$

$$\mu_{S7} = \mu_{S4} \cdot \pi_{47} \cdot \sqrt{\theta_{74}} \cdot SF3; \tag{2.19}$$

$$\theta_{74} = 1 - \Delta\theta_{454}; \tag{2.20}$$

$$\pi_{7a} = \frac{\pi_{43} \cdot \pi_{32} \cdot \pi_{2a}}{\pi_{45}}; \tag{2.21}$$

$$\pi_{45} = \pi_{47}, \tag{2.22}$$

$$\rho_N \text{ vs. } \nabla_N; \nu_{S2} = \text{parameter} \tag{3.7}$$

$$\rho_{\eta_C} \text{ vs. } \nabla_{\eta_C}; \eta_c - \text{parameter} \tag{3.8}$$

$$\pi_{32} = \left[\left(\rho_N \sin\nabla_N + \Delta P_N\right) mash_{\pi_{32}} + \left(\pi_{32}\right)_0\right] \cdot SF4 \tag{3.9}$$

$$\mu_{S2} = \left[\left(\rho_N \cdot \cos\nabla_N + \Delta\dot{m}_N\right) \cdot mash_{\dot{m}} + \dot{m}_0\right] / SF7 \tag{3.10}$$

$$\pi_{32} = \left[\left(\rho_{\eta_C} \sin\Delta_{\eta_C} + \Delta P_{\eta_C}\right) \cdot mash_{\pi_{32}} + \left(\pi_{32}\right)_0\right] \cdot SF4 \tag{3.11}$$

$$\mu_{S2} = \left[\left(\rho_{\eta_C} \cdot \cos\nabla_{\eta_C} + \Delta\dot{m}_{\eta_C}\right) \cdot mash_{\dot{m}} + \dot{m}_0\right] / SF7, \tag{3.12}$$

π_{45} vs. μ_{S4} ; ν_{S4} – parameter (2.3)

η_t vs. μ_{S4} ; ν_{S4} – parameter . (2.4)

μ_{S7} vs. π_{7a} (2.5)

where

$$SF1 = \frac{T_{02,ref}}{T_{04,ref}};$$

$$SF2 = \frac{P_{04,ref}}{P_{02,ref}} * \sqrt{\frac{T_{02,ref}}{T_{04,ref}}};$$

$$SF3 = \frac{P_{a,ref}}{P_{4,ref}} \cdot \sqrt{\frac{T_{04,ref}}{T_{07,ref}}}$$

$$SF4 = \pi_{32,ref} / \pi_{32,ref,st}$$

$$SF5 = \pi_{45,ref} / \pi_{45,ref,st}$$

$$SF6 = \pi_{7a,ref} / \pi_{7a,ref,st}$$

$$SF7 = \dot{m}_{ref,st}$$

OUTPUT PARAMETER CALCULATIONS :

Dimension parameter calculations are executed with the following expressions contained in PLOTINIT:

$$\frac{P_{07}}{P_{cr}} = \left[1 - \frac{1}{\eta_n}\left(\frac{\gamma - 1}{\gamma + 1}\right)\right]^{\frac{\gamma}{1-\gamma}}$$

$$u_a = M_a \cdot \sqrt{\gamma \cdot R \cdot T_a};$$ (unit (3,rr))

$$T_{03} = T_{02} \cdot \left(1 + \frac{T_{03} - T_{02}}{T_{02}}\right)$$ (unit (4,rr))

$$T_{04} = T_{02} / (T_{02} / T_{04})$$ (unit (5,rr))

$$T_{05} = T_{04} \cdot \left(1 - \frac{T_{04} - T_{05}}{T_{04}}\right) \quad \text{(unit (6,rr))}$$

$$T_{07} = T_{04} \cdot (T_{07} / T_{04}) \quad \text{(unit (7,rr))}$$

$$P_{03} = P_{02} \cdot (P_{03} / P_{02}) \quad \text{(unit (8,rr))}$$

$$P_{04} = P_{03} / (P_{03} / P_{04}) \quad \text{(unit (9,rr))}$$

$$P_{05} = P_{04} / (P_{04} / P_{05}) \quad \text{(unit (10,rr))}$$

$$P_{07} = P_a \cdot (P_{07} / P_a) \quad \text{(unit (11,rr))}$$

$$N = N_{ref} \cdot \sqrt{\frac{T_{02}}{T_{02,ref}}} \cdot \left(\frac{N}{\sqrt{T_{02}}} \Big/ \frac{N_{ref}}{\sqrt{T_{02,ref}}} \right) \quad \text{(unit (12,rr)}$$

$$\dot{m}_a = \dot{m}_{ref} \cdot \left(\frac{\dot{m}_a \sqrt{T_{02}}}{P_{02}} \Big/ \frac{\dot{m}_{ref} \cdot \sqrt{T_{02,ref}}}{P_{02,ref}} \right) * P_{02} / P_{02,ref} \Big/ \sqrt{T_{02} / T_{02,ref}} \quad \text{(unit (13,rr))}$$

$$f = C_p \frac{T_{04} - T_{03}}{Q_R - C_p \cdot T_{04}} \quad \text{(unit (14,rr))}$$

(unit (15,rr)):

If $\frac{P_{07}}{P_a} < \frac{P_{07}}{P_{cr}}$,

$$u_e = \sqrt{2 \cdot \eta_n \cdot C_p \cdot T_{07} \cdot \left[1 - \left(\frac{P_a}{P_{07}} \right)^{\frac{\gamma - 1}{\gamma}} \right]}$$

If $\frac{P_{07}}{P_a} \geq \frac{P_{07}}{P_{cr}}$,

$$u_e = \sqrt{2 \cdot \eta_n \cdot C_p \cdot T_{07} \cdot \left[1 - \left(\frac{P_{cr}}{P_{07}} \right)^{\frac{\gamma - 1}{\gamma}} \right]}$$

$$T = \dot{m}_a * ((i + f) * u_e - u_a) \quad \text{(unit (16,rr))}$$

$$SFC = f / (T / \dot{m}_a) \quad \text{(unit (17,rr))}$$

The dimensionless equation system solution is contained in matrix steadØ (steadØØ) of STEADS02.MAT:

miu 2 in row 1

miu 4 in row 2

miu 7 in row 3

niu 4 in row 4

etac in row 5

etat in row 6

pi 32 in row 7

pi 45 in row 8

p7a in row 9

p47 in row 10

tet 24 in row 11

tet 74 in row 12

tet 454 in row 13

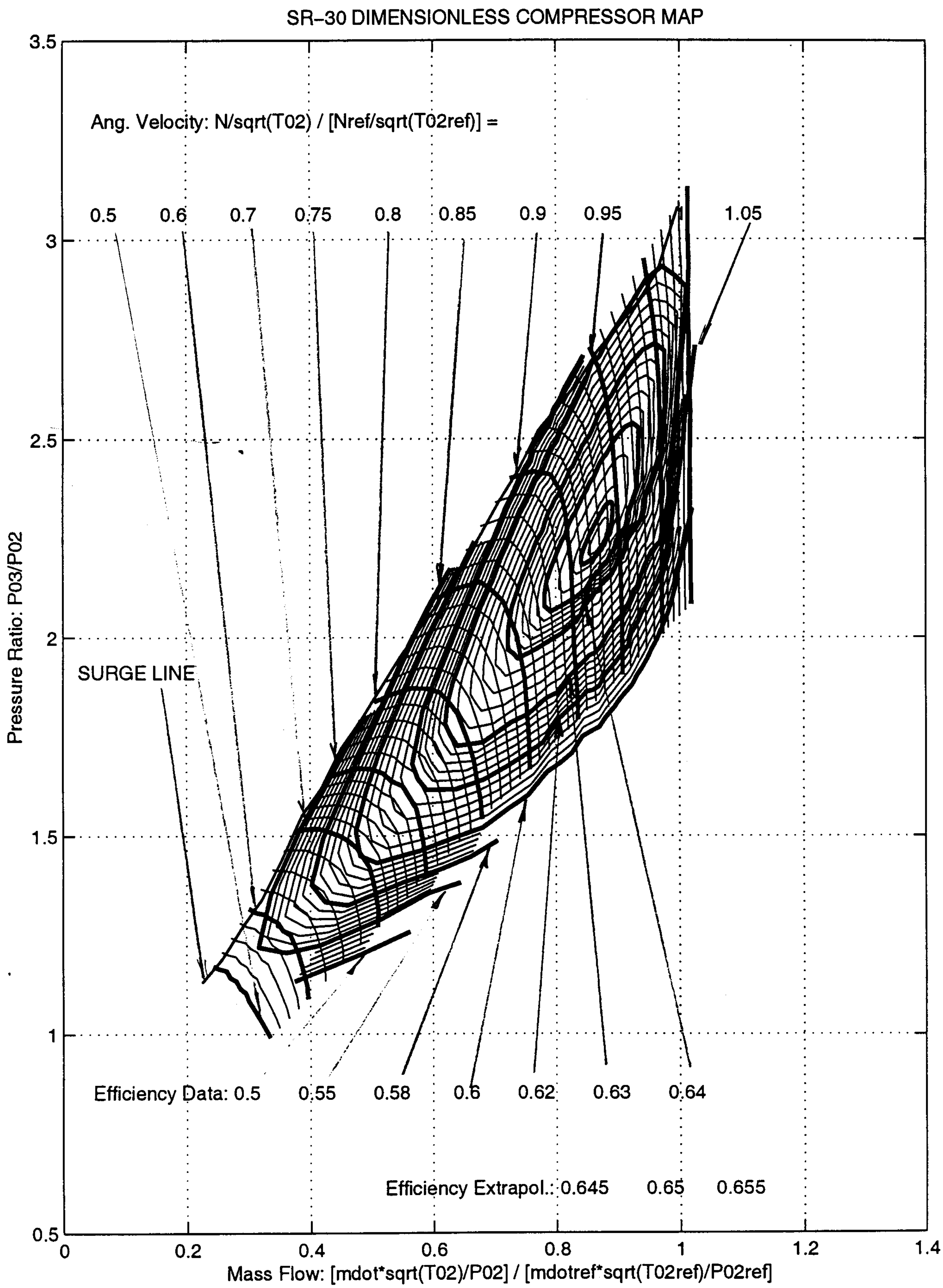
tet 322 in row 14

nabVcom in row 15

rovcom in row 16

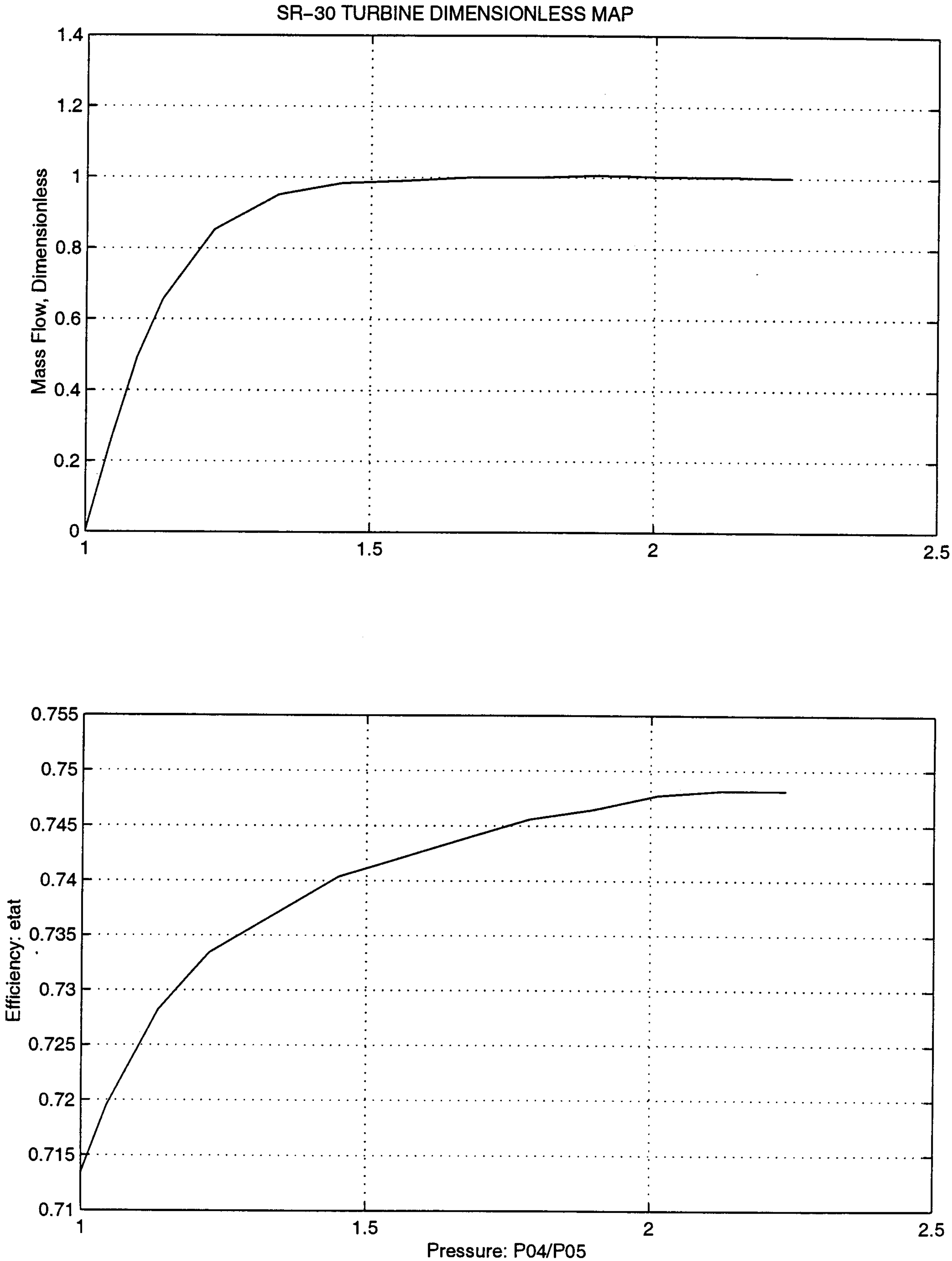
roefcom in row 18

APPENDIX E - EXAMPLE CALCULATIONS



SR–30 DIMENSIONLESS COMPRESSOR MAP
Ang. Velocity: N/sqrt(T02) / [Nref/sqrt(T02ref)] =
0.5 0.6 0.7 0.75 0.8 0.85 0.9 0.95 1 1.05
SURGE LINE
Efficiency Data: 0.5 0.55 0.58 0.6 0.62 0.63 0.64
Efficiency Extrapol.: 0.645 0.65 0.655
Pressure Ratio: P03/P02
Mass Flow: [mdot*sqrt(T02)/P02] / [mdotref*sqrt(T02ref)/P02ref]
3.5 3 2.5 2 1.5 1 0.5
0 0.2 0.4 0.6 0.8 1 1.2 1.4

Fig. E-1



SR-30 TURBINE DIMENSIONLESS MAP
Mass Flow, Dimensionless
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
1.5
2
2.5
Efficiency: etat
0.755
0.75
0.745
0.74
0.735
0.73
0.725
0.72
0.715
0.71
1
1.5
2
2.5
Pressure: P04/P05

Fig. E-2

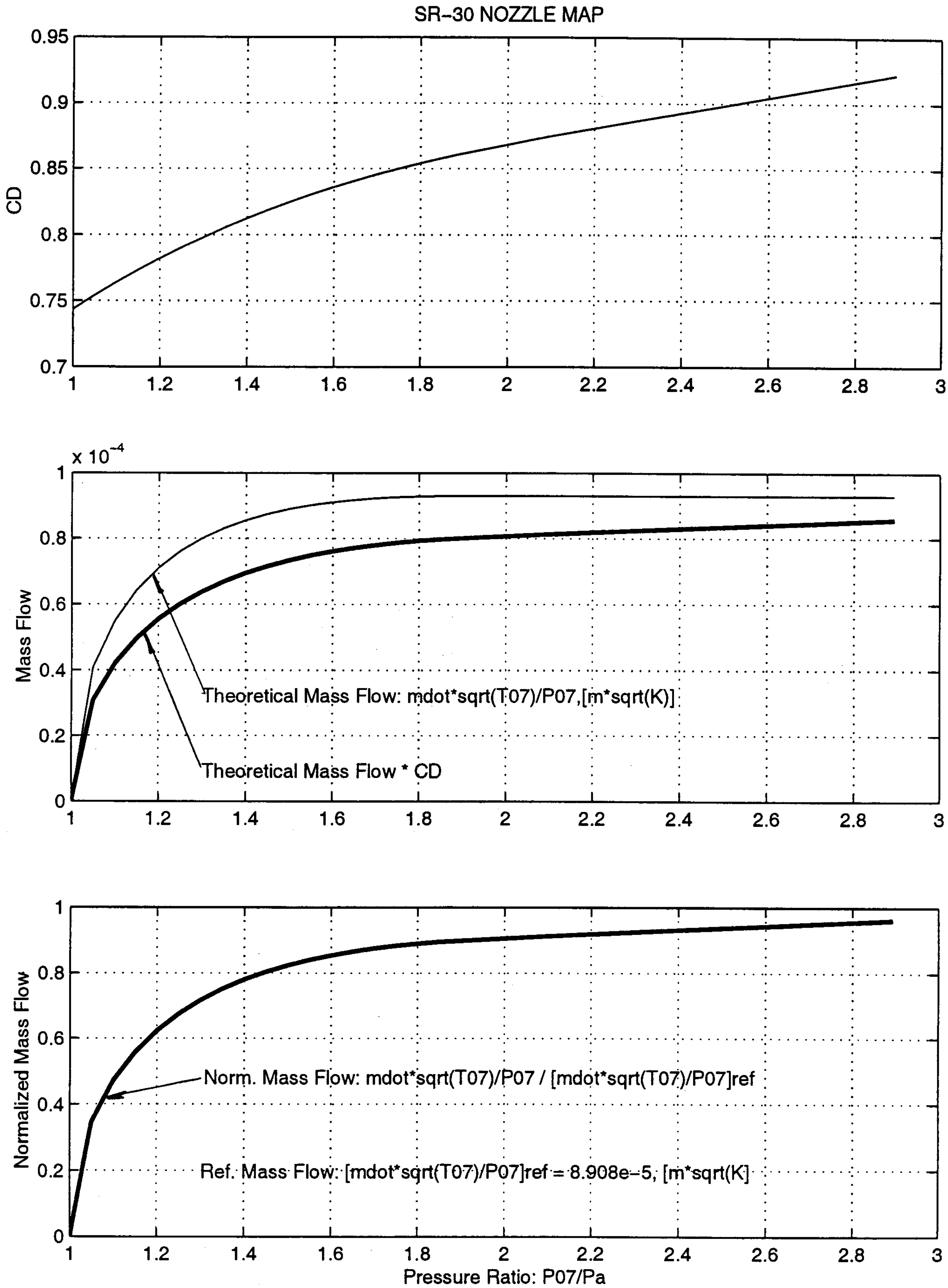
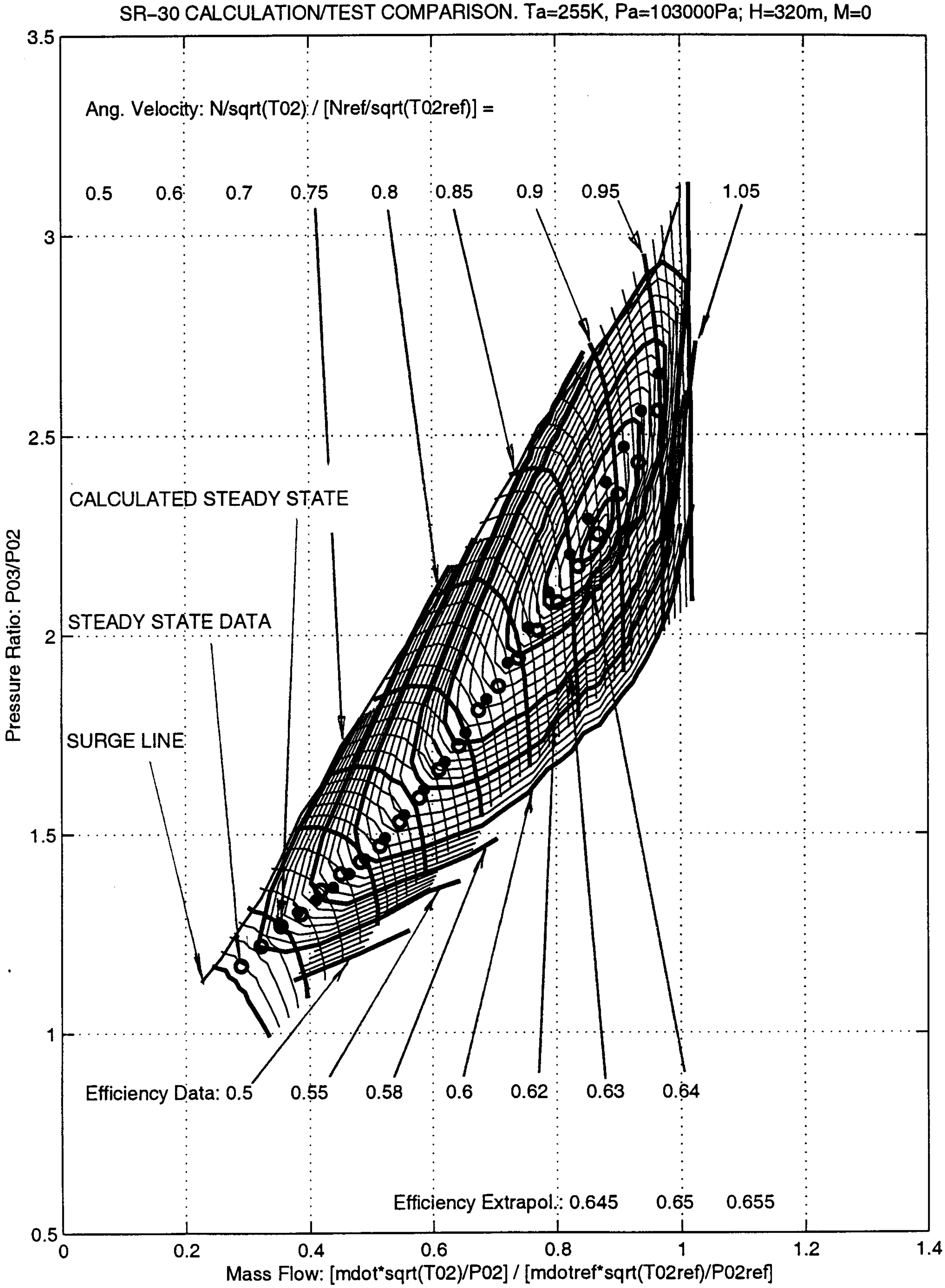

SR-30 NOZZLE MAP
CD
0.95
0.9
0.85
0.8
0.75
0.7
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
Mass Flow
x 10^-4
Theoretical Mass Flow: mdot*sqrt(T07)/P07,[m*sqrt(K)]
Theoretical Mass Flow * CD
Normalized Mass Flow
Norm. Mass Flow: mdot*sqrt(T07)/P07 / [mdot*sqrt(T07)/P07]ref
Ref. Mass Flow: [mdot*sqrt(T07)/P07]ref = 8.908e-5, [m*sqrt(K]
Pressure Ratio: P07/Pa

Fig. E-3



SR-30 CALCULATION/TEST COMPARISON. Ta=255K, Pa=103000Pa; H=320m, M=0
Ang. Velocity: N/sqrt(T02) / [Nref/sqrt(T02ref)] =
0.5 0.6 0.7 0.75 0.8 0.85 0.9 0.95 1 1.05
CALCULATED STEADY STATE
STEADY STATE DATA
SURGE LINE
Efficiency Data: 0.5 0.55 0.58 0.6 0.62 0.63 0.64
Efficiency Extrapol.: 0.645 0.65 0.655
Pressure Ratio: P03/P02
Mass Flow: [mdot*sqrt(T02)/P02] / [mdotref*sqrt(T02ref)/P02ref]
3.5
3
2.5
2
1.5
1
0.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4

Fig. E-4

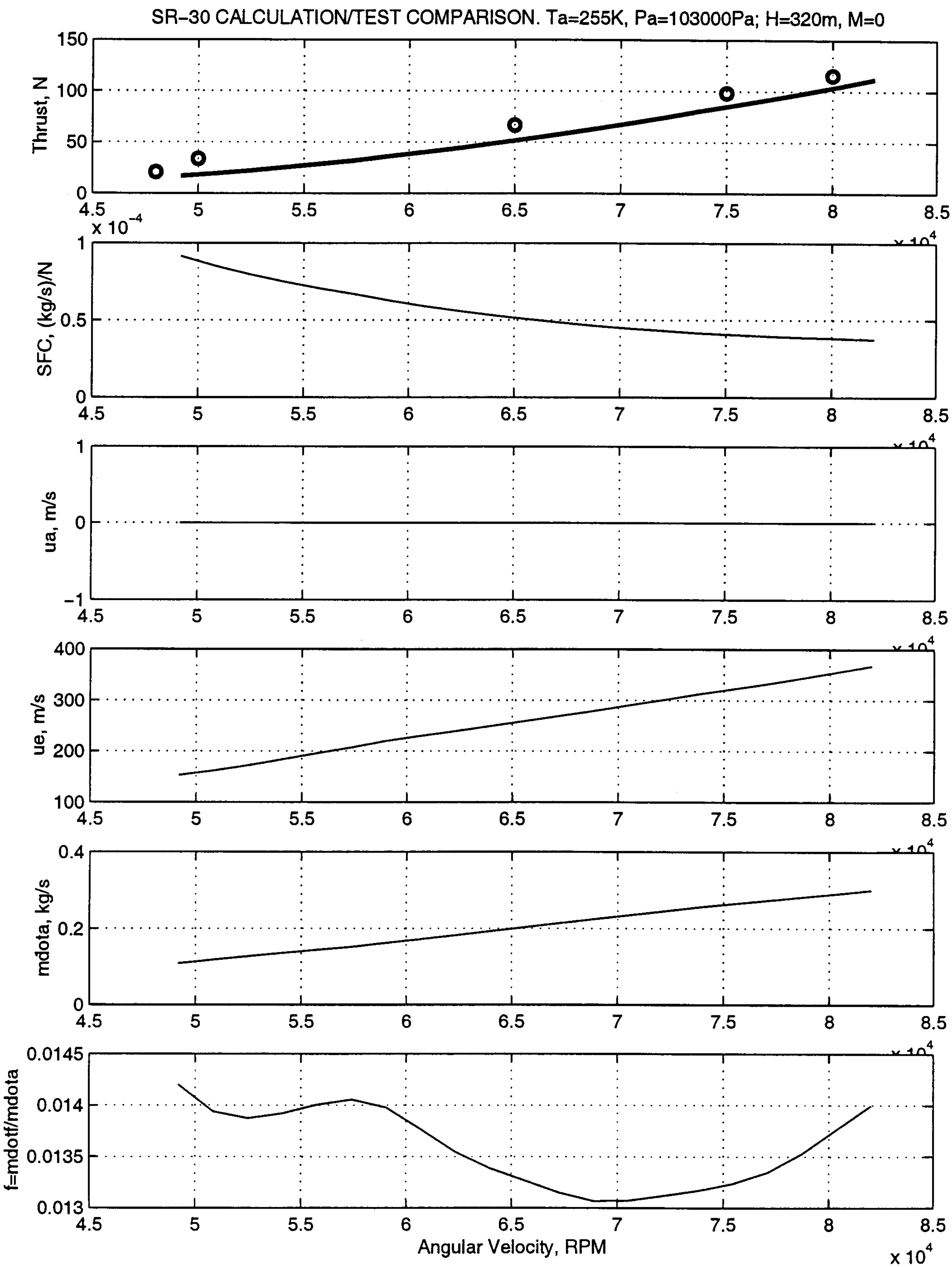
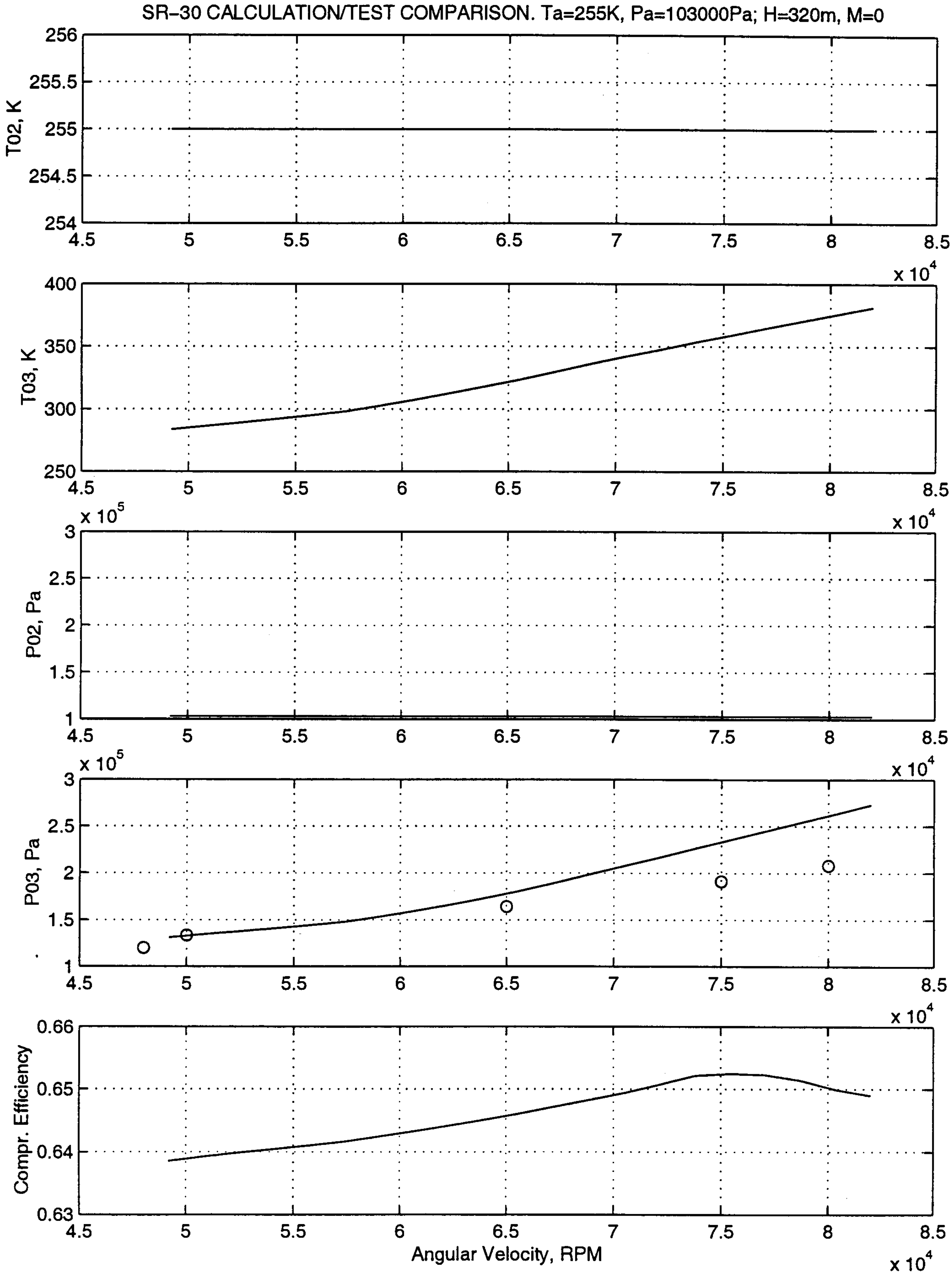

SR-30 CALCULATION/TEST COMPARISON. Ta=255K, Pa=103000Pa; H=320m, M=0
Thrust, N
x 10^-4
SFC, (kg/s)/N
ua, m/s
ue, m/s
mdota, kg/s
f=mdotf/mdota
Angular Velocity, RPM
x 10^4

Fig. E-5



SR–30 CALCULATION/TEST COMPARISON. Ta=255K, Pa=103000Pa; H=320m, M=0
T02, K
T03, K
P02, Pa
P03, Pa
Compr. Efficiency
x 10^5
x 10^4
Angular Velocity, RPM

Fig. E-6

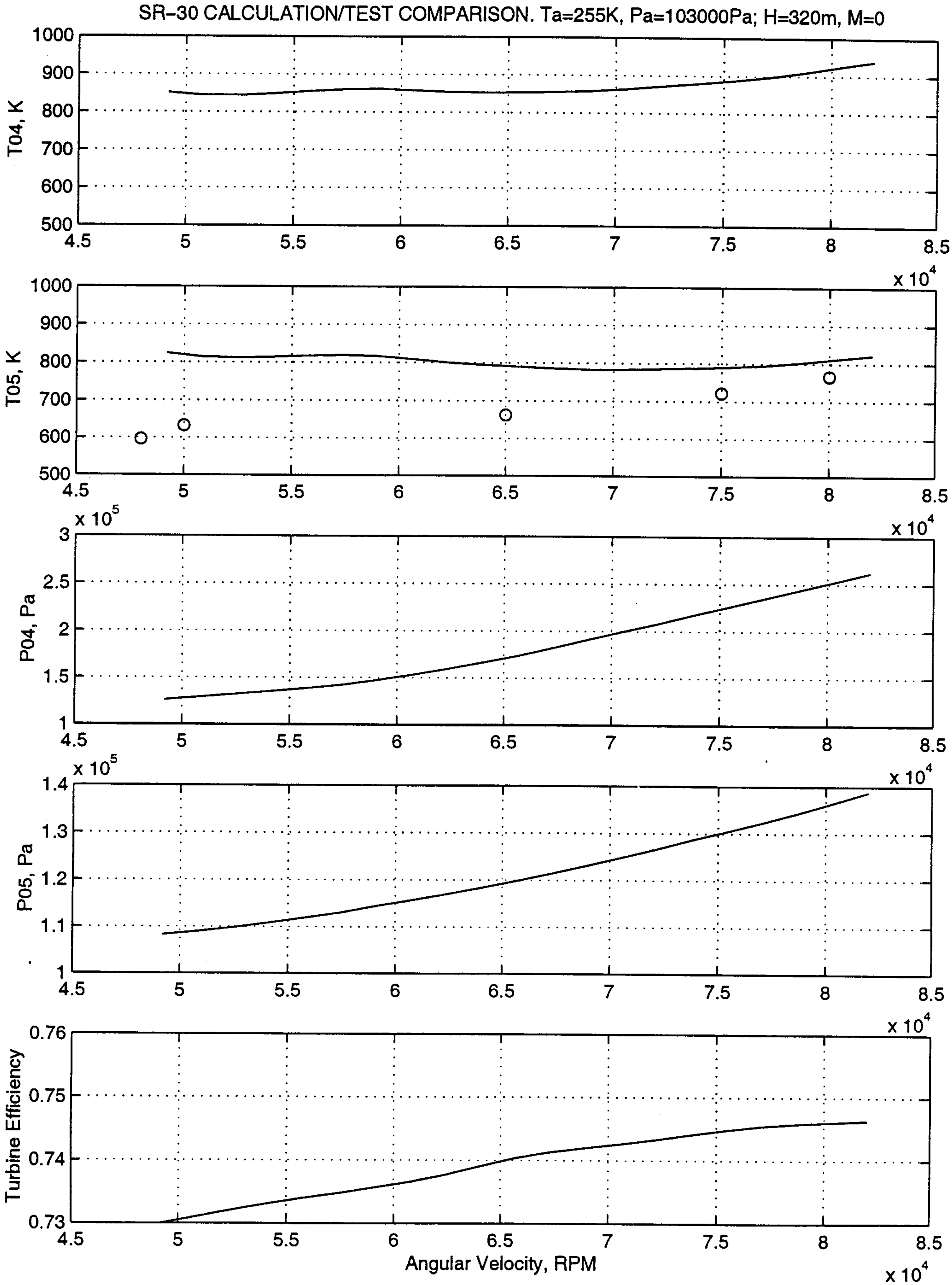

SR-30 CALCULATION/TEST COMPARISON. Ta=255K, Pa=103000Pa; H=320m, M=0
T04, K
T05, K
P04, Pa
P05, Pa
Turbine Efficiency
Angular Velocity, RPM
x 10^4
x 10^5

Fig. E-7

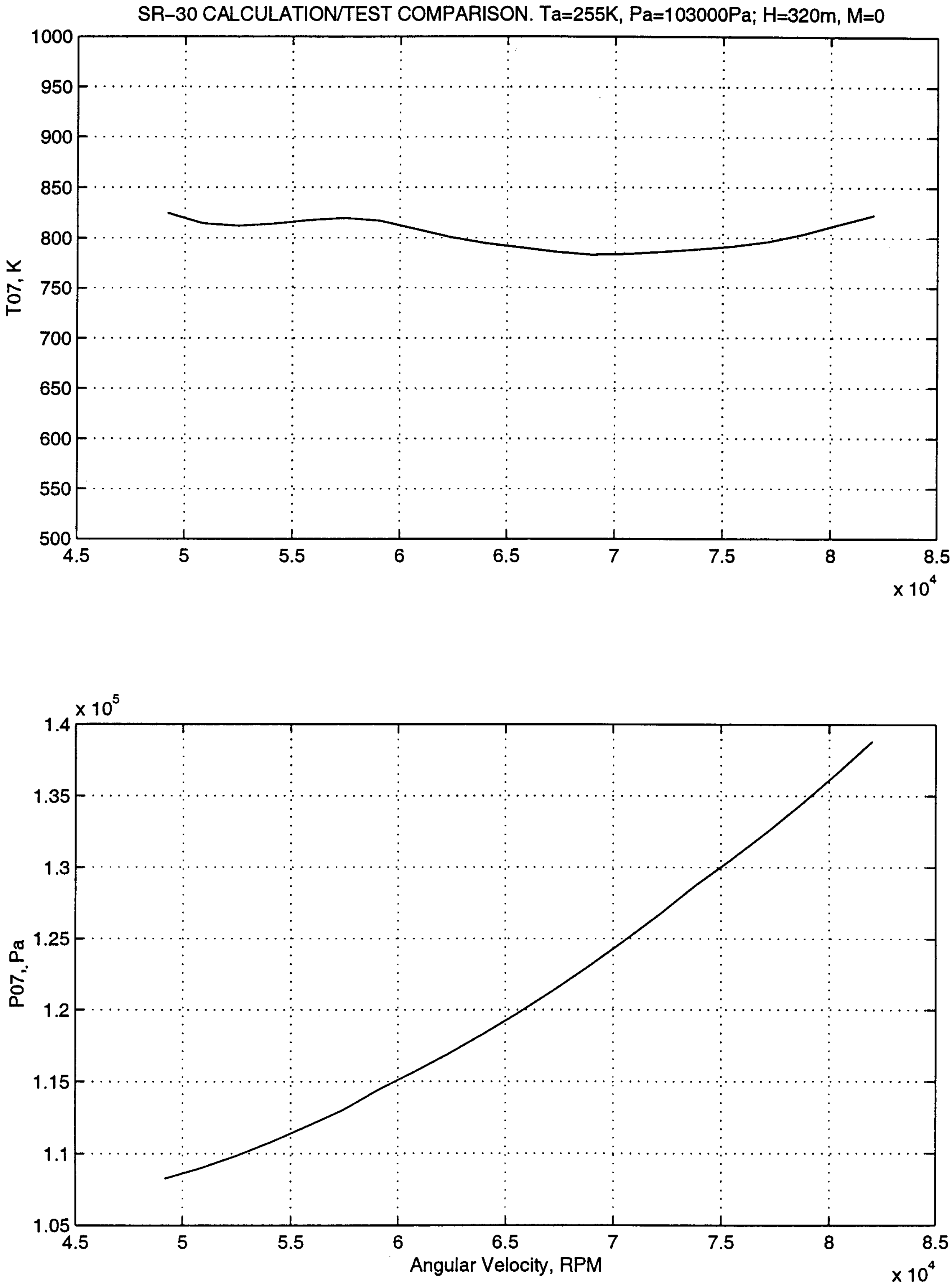

SR–30 CALCULATION/TEST COMPARISON. Ta=255K, Pa=103000Pa; H=320m, M=0
1000
950
900
850
800
750
700
650
600
550
500
T07, K
4.5
5
5.5
6
6.5
7
7.5
8
8.5
x 10^4
x 10^5
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
P07,, Pa
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Angular Velocity, RPM
x 10^4

Fig. E-8

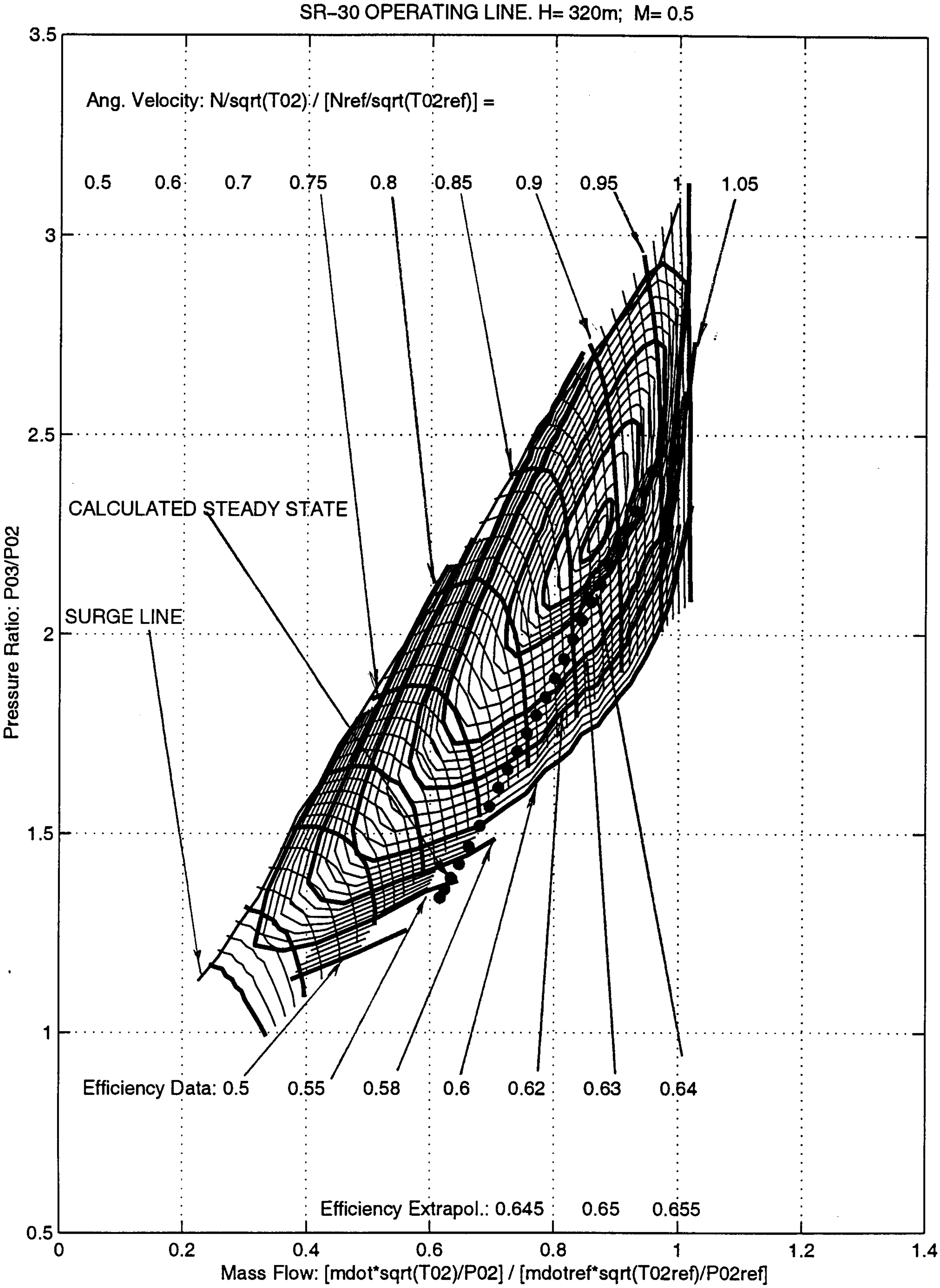

SR-30 OPERATING LINE. H= 320m; M= 0.5
Ang. Velocity: N/sqrt(T02) / [Nref/sqrt(T02ref)] =
0.5 0.6 0.7 0.75 0.8 0.85 0.9 0.95 1 1.05
CALCULATED STEADY STATE
SURGE LINE
Pressure Ratio: P03/P02
3.5
3
2.5
2
1.5
1
0.5
Efficiency Data: 0.5 0.55 0.58 0.6 0.62 0.63 0.64
Efficiency Extrapol.: 0.645 0.65 0.655
0 0.2 0.4 0.6 0.8 1 1.2 1.4
Mass Flow: [mdot*sqrt(T02)/P02] / [mdotref*sqrt(T02ref)/P02ref]

Fig. E-9

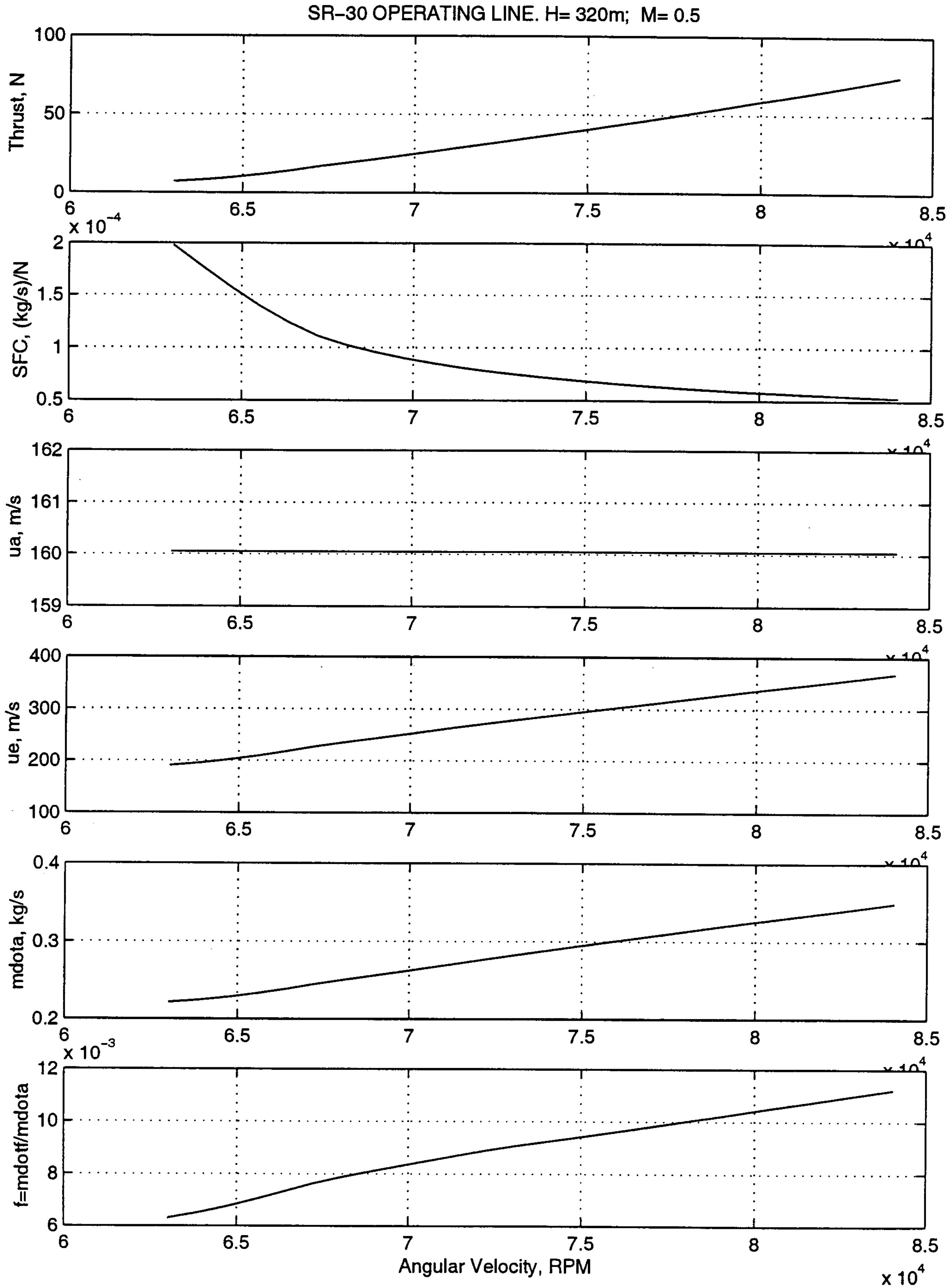

SR–30 OPERATING LINE. H= 320m; M= 0.5
Thrust, N
SFC, (kg/s)/N
x 10^-4
ua, m/s
ue, m/s
mdota, kg/s
f=mdotf/mdota
x 10^-3
Angular Velocity, RPM
x 10^4

Fig E-10

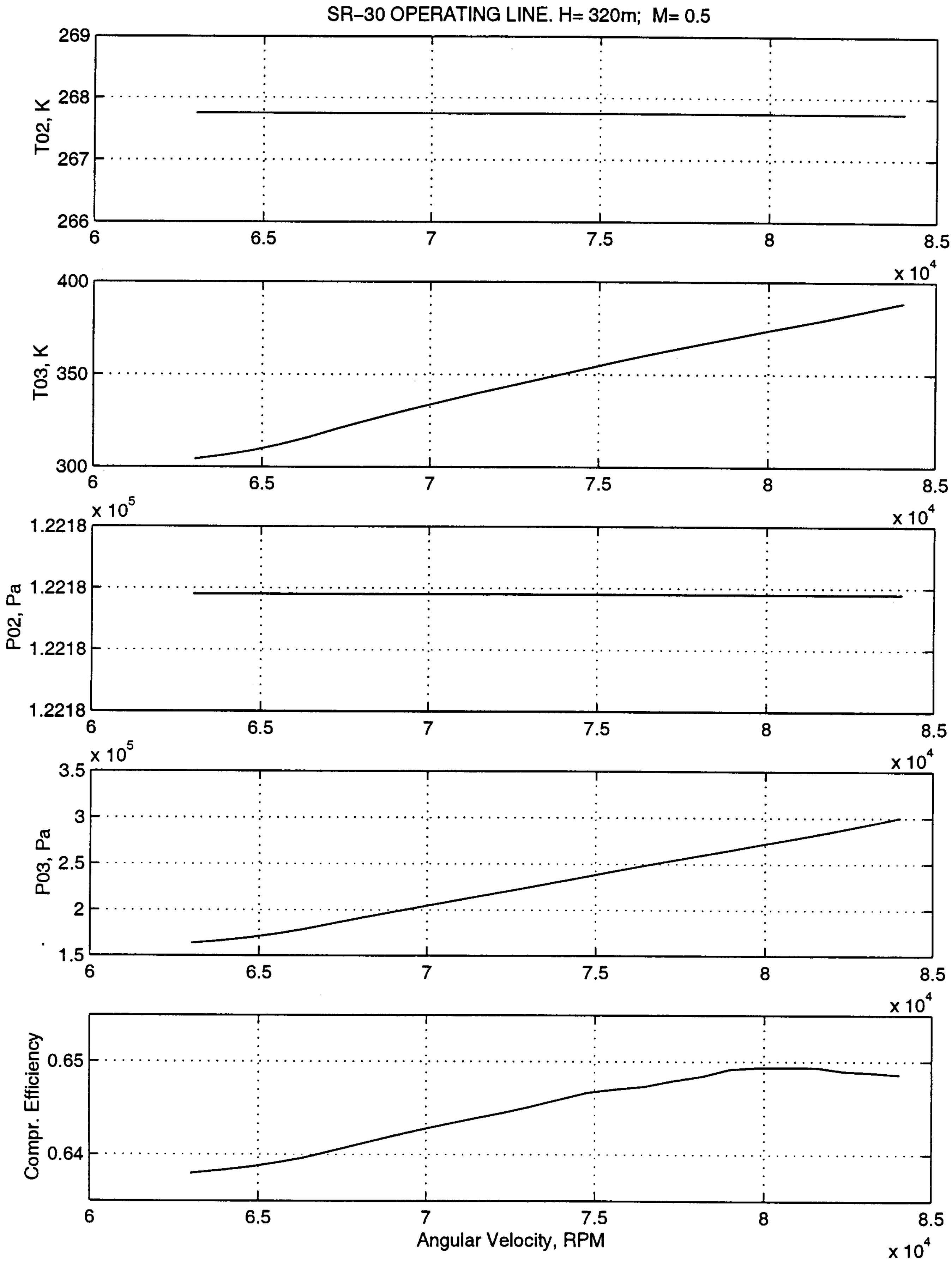
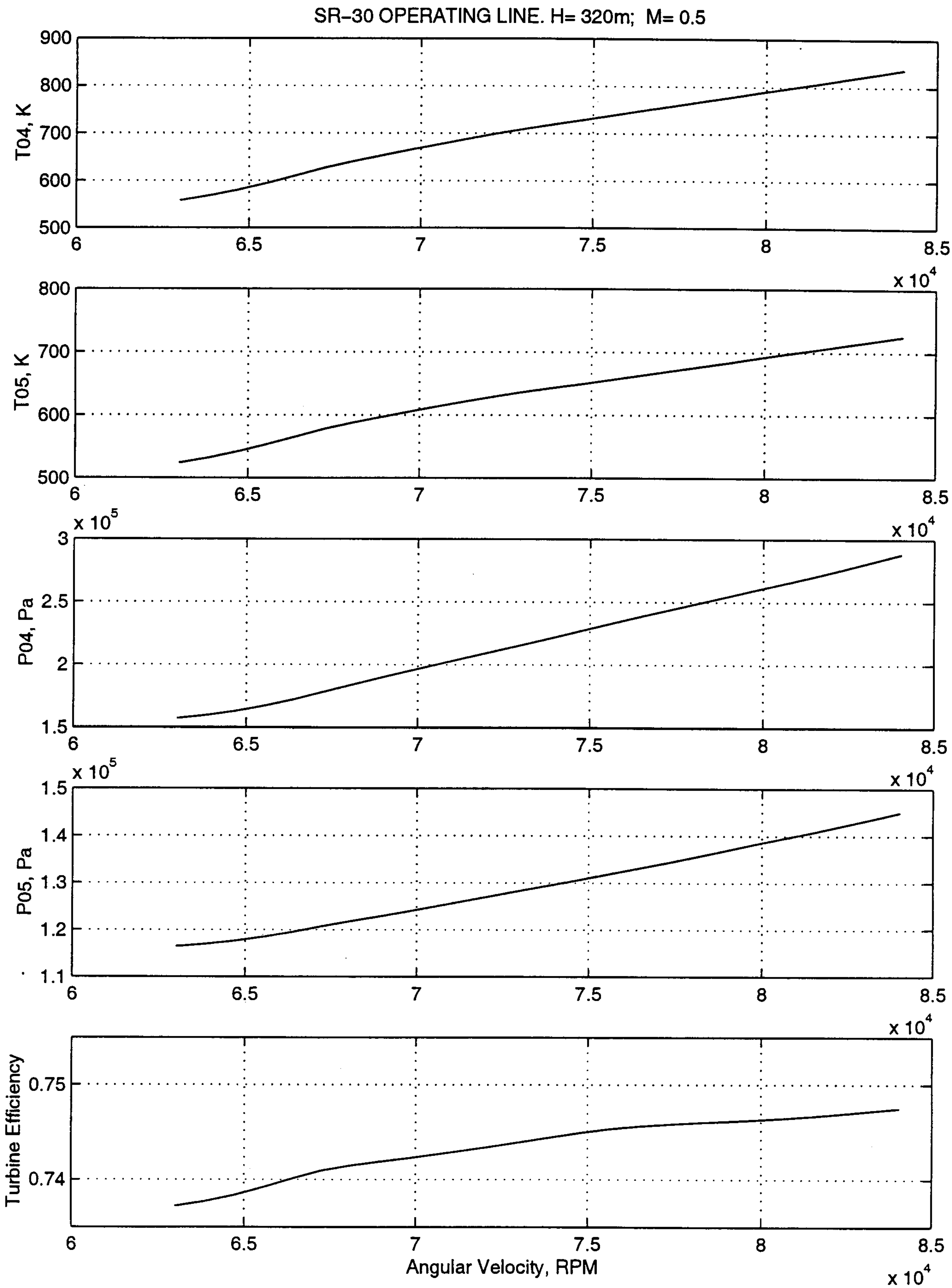
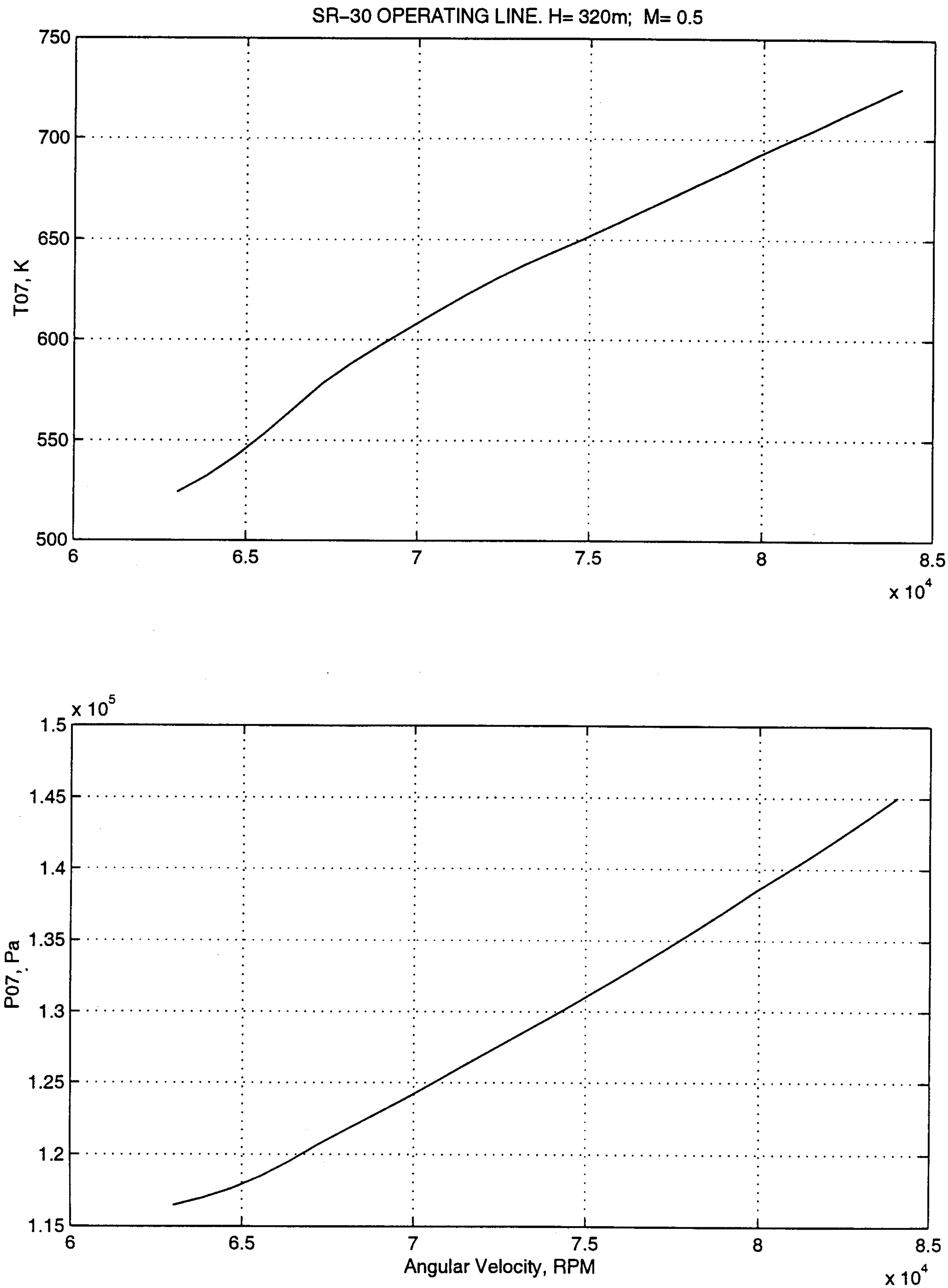

SR–30 OPERATING LINE. H= 320m; M= 0.5
T02, K
269
268
267
266
T03, K
400
350
300
x 10^5
P02, Pa
1.2218
x 10^5
P03, Pa
3.5
3
2.5
2
1.5
Compr. Efficiency
0.65
0.64
6
6.5
7
7.5
8
8.5
x 10^4
Angular Velocity, RPM

Fig. E-11



SR-30 OPERATING LINE. H= 320m; M= 0.5
T04, K
900
800
700
600
500
T05, K
800
700
600
500
P04, Pa
x 10^5
3
2.5
2
1.5
P05, Pa
x 10^5
1.5
1.4
1.3
1.2
1.1
Turbine Efficiency
0.75
0.74
6
6.5
7
7.5
8
8.5
x 10^4
Angular Velocity, RPM

Fig E-12



SR–30 OPERATING LINE. H= 320m; M= 0.5
750
700
650
600
550
500
T07, K
6
6.5
7
7.5
8
8.5
x 10^4
x 10^5
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
P07, Pa
6
6.5
7
7.5
8
8.5
Angular Velocity, RPM
x 10^4

Fig. E-13