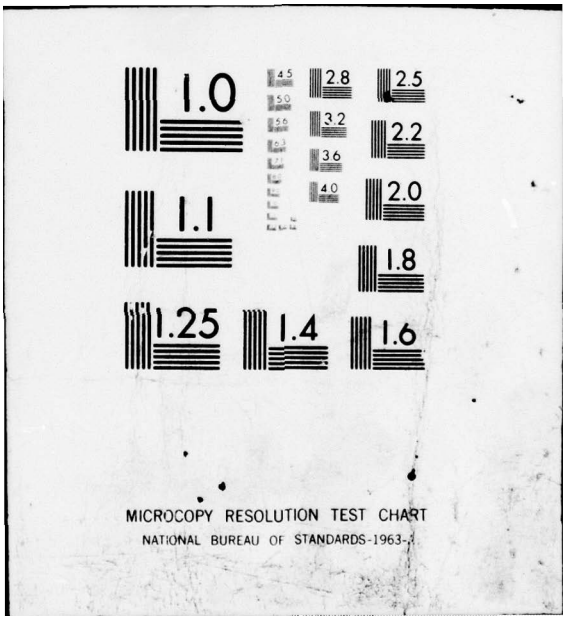
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ESTIMATES FOR HYDRAULIC EFFICIENCY AND BLADE CHARACTERISTICS FOR PRELIMINARY PUMPJET DESIGN EXERCISE.

(10) W. S. Gearhart and J. E. Fredley

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(U) A method is given for predicting hydraulic efficiency of a pumpjet as a function of ingested mass flow. This method is presented for a conventional pumpjet which has a stator aft of the rotor and a preswirl pumpjet which has a stator forward of the rotor. The approach uses mass averaged values of flow quantities to determine blade geometries and operating characteristics at a blade radius that is representative of the average energy input of the blade row. The space-to-chord ratio, lift coefficients, stage efficiency, and

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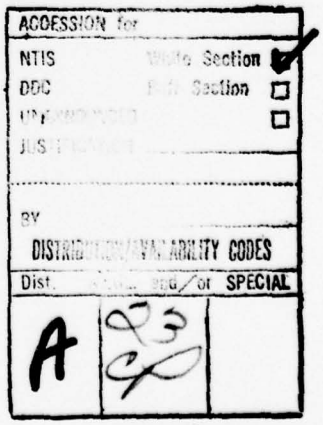
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Subject: Estimates for Hydraulic Efficiency and Blade Characteristics for Preliminary Pumpjet Design Exercise

References: See page 20

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Nomenclature

Letter Symbols

$\overline{H}$	the pressure head placed into the fluid, ft
J	the advance ratio based on body diameter, nondimensional
K	an inlet energy loss coefficient, nondimensional
P	the static pressure, lb/ft^2
P_∞	the free static pressure corresponding to the given submergence dept, lb/ft^2
P_v	the fluid vapor pressure at its bulk temperature, lb/ft^2
r_T	the rotor tip radius, ft
r_B	the maximum body radius of the vehicle, ft
S/C	the space-to-chord ratio, nondimensional
$\overline{U}$	the average peripheral blade velocity based on mass flow, ft/sec
$\overline{V}_m$	the average fluid meridional velocity component based on mass flow, ft/sec
$\Delta\overline{V}$	the average fluid velocity change between stations ① and ⑦ based on mass flow, ft/sec
$\overline{V}_\theta$	the average fluid peripheral velocity component based on mass flow, ft/sec
$\overline{V}$	the average absolute fluid velocity based on mass flow, ft/sec
V_∞	the vehicle forward velocity, ft/sec

Greek Letters

α	the absolute fluid angle, radians
β	the relative fluid angle, radians
ρ	the fluid density, $slug/ft^3$
σ	the cavitation index, nondimensional

Nomenclature (Continued)

Subscripts

1, 2, ... 7	indicates station location
m	indicates a mean value
R	indicates pertaining to the rotor
S	indicates pertaining to the stator

INTRODUCTION

The following outlines a method for determining the blade space-to-chord ratio to provide a prescribed blade cavitation index. It also indicates the hydraulic efficiency that would be obtained as a function of the advance ratio and the ingested mass flow of the pumpjet. This procedure has been added to the preliminary design process described in [1]*, which in the past, has assumed the hydraulic efficiency at some constant value typical of axial flow pumps. As a first check, the Akron propulsor of [1] is reviewed to see if the procedure can be applied with reasonable results. In addition, a series of runs were made for a body having a drag coefficient of 0.103 and at a number of advance ratios for both a preswirl and conventional pumpjet.

ESTIMATES OF EFFICIENCY AND BLADE CHARACTERISTICS FOR A CONVENTIONAL PUMPJET

The efficiency of a stage of an axial flow compressor is presented in [2] and shall be used as a basis to predict the efficiency of the pumpjet based on section characteristics of the rotor and stator blading at the mean radius, r_m. The conventional pumpjet geometry is decribed in Figure 1. In the preliminary design phase a very limited knowledge of the flow field characteristics and blade section parameters are known and, therefore, it is necessary to make some engineering approximations.

It is first necessary to obtain the space-to-chord ratio, or its inverse solidity, needed to satisfy the limits of cavitation that are desired. A conservative estimate is made that the static pressure forward of the rotor blade tip, P_2, is equal to the free-stream static pressure, P_∞.

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On this basis, the rotor blade pressure coefficient at cavitation inception, C_{b_R}, becomes

$$C_{b_R} \frac{P_2 - P_v}{\frac{\rho W_2^2}{2}} = \frac{P_\infty - P_v}{\frac{\rho W_1^2}{2}} = \sigma_R \left(\frac{V_\infty}{W_2}\right)^2 \quad . \tag{1}$$

The value of (W_2/V_∞) is the relative velocity ratio approaching the rotor blade at the $(0.9\ r_T/r_B)$ radius and is defined by Equation (6). The impulse momentum relation can be used to approximate the average differnce in static pressure across the blade as outlined in [1]:

$$\frac{\overline{\Delta p}}{\frac{\rho V_\infty^2}{2}} = 2 \left(\frac{S}{C}\right)_R \left(\frac{W_2}{\overline{V}_{m_2}}\right) \left(\frac{\overline{V}_{m_2}}{V_\infty}\right) \left(\frac{\Delta \overline{V}_{\theta_R}}{V_\infty}\right) \quad . \tag{2}$$

A review of a number of blade pressure diagrams has indicated the average pressure difference across a blade chord closely approximates the difference in pressure from blade inlet to the minimum pressure point on the blade. On this basis,

$$C_{b_R} = \frac{\overline{\Delta p}}{\frac{\rho V_\infty^2}{2}} \left(\frac{V_\infty}{\overline{W}_2}\right)^2 = 2 \left(\frac{S}{C}\right)_R \left(\frac{V_\infty}{\overline{W}_2}\right) \left(\frac{\Delta \overline{V}_{\theta_R}}{V_\infty}\right) \quad . \tag{3}$$

The value of $\Delta \overline{V}_{\theta_R}/V_\infty$ for any ingested mass flow can be evaluated from:

$$\frac{\overline{H}}{\frac{V_\infty^2}{2g}} = \left[2 \left(\frac{\overline{\Delta V}}{V_\infty}\right) \left(\frac{\overline{V}_{m_2}}{V_\infty}\right) + \left(\frac{\overline{\Delta V}}{V_\infty}\right)^2 + K \left(\frac{\overline{V}_{m_1}}{V_\infty}\right)^2 \right] = 2 \left(\frac{\overline{U}}{V_\infty}\right) \left(\frac{\Delta \overline{V}_{\theta_R}}{V_\infty}\right) \quad , \tag{4}$$

where all the quantities in the brackets are tabulated on the output of the preliminary pumpjet design program (PPDP) of [3]. The value $(\Delta\bar{V}_{\theta_R}/V_\infty)$ is confined to an upper limit of $(\bar{U}/V_\infty)$.

The quantity $\bar{U}/V_\infty$ can be expressed as:

$$\frac{\bar{U}}{V_\infty} = (0.9\,\frac{\pi}{J})\left(\frac{r_T}{r_B}\right) \quad , \tag{5}$$

where r_T/r_B is computed in the (PPDP) for each mass flow. The value of (W_2/V_∞) can be estimated as:

$$\frac{W_2}{V_\infty} = \left[\left(\frac{\bar{U}}{V_\infty}\right)^2 + \left(\frac{\bar{V}_{m_2}}{V_\infty}\right)^2\right]^{\frac{1}{2}} \quad . \tag{6}$$

The preceding provides the necessary data to determine (S/C) from Equation (3) that satisfy cavitation requirements. An upper limit of 1.8 is placed on this quantity.

The estimate of blade drag is obtained as outlined in [2] and consists of increments due to profile and secondary flow drag. The annulus wall drag is not included since this has already been considered in the shroud surface skin friction drag with was added to the required propulsor thrust as indicated in [1].

The rotor blade drag is then:

$$C_{D_R} = C_{D_P} + C_{D_S} \quad , \tag{7}$$

and

$$C_{D_P} = \text{blade profile drag} = 0.020 - 0.004\left(\frac{S}{C}\right)_R \quad ;$$

$$C_{D_S} = \text{secondary flow drag} = 0.018\,C_{L}{}^{2}{}_{R} \quad .$$

The value of the rotor lift coefficient C_{L_R} can be evaluated as:

$$C_{L_R} = 2 \left(\frac{\Delta \overline{V}_{\theta_R}}{W_2} \right) \left(\frac{S}{C} \right)_R \quad . \tag{8}$$

The total pressure loss coefficient through the rotor blade row can now be determined as outlined in [2] where:

$$\zeta_R = \frac{\Delta P_T}{\left(\frac{\rho W_2^2}{2} \right)_{loss}} = C_{D_R} \left(\frac{C}{S} \right)_R \frac{\cos^2 \beta_2}{\cos^3 \beta_m} \quad . \tag{9}$$

The values of β_2 and β_m in Equation (9) are estimated for the rotor in the following manner:

$$\tan \beta_2 = \left(\frac{\overline{U}}{V_\infty} \right) \left(\frac{V_\infty}{\overline{V}_{m_2}} \right) \quad ,$$

$$\tan \beta_3 = \left(\frac{\overline{U}}{V_\infty} - \frac{\overline{V}_{\theta_3}}{V_\infty} \right) \left(\frac{V_\infty}{1.15\ \overline{V}_{m_2}} \right) \quad ,$$

and

$$\tan \beta_m = \frac{1}{2} (\tan \beta_2 + \tan \beta_3) \quad .$$

It is assumed in the above that the meridional velocity accelerates by a factor of 1.15 in passing through the rotor. The preceding provides an estimate of total pressure loss through the rotor blade row and now it is necessary to perform a similar analysis for the stator.

The stator blade drag and solidity can be similarly evaluated, where in this case the stator is located behind the rotor. The relation for the average pressure difference over the stator blade is: (The subscript ④ denotes a station at the stator leading edge.)

$$\frac{\overline{\Delta P}}{\frac{\rho V_\infty^2}{2}} = 2 \left(\frac{S}{C}\right)_S \left[\frac{\overline{V}_4}{\overline{V}_{m_4}}\right]\left[\frac{\overline{V}_{m_4}}{V_\infty}\right]\left[\frac{\Delta\overline{V}_{\theta_S}}{V_\infty}\right] \tag{10}$$

where it shall be assumed that:

$$\frac{\overline{V}_{m_4}}{V_\infty} = 1.2 \frac{\overline{V}_{m_1}}{V_\infty} \quad ,$$

$$\frac{\overline{V}_{\theta_4}}{V_\infty} = 1.1 \frac{\overline{V}_{\theta_3}}{V_\infty} \quad ,$$

and

$$\frac{\overline{V}_4}{V_\infty} = \left[\left[\frac{\overline{V}_{\theta_4}}{V_\infty}\right]^2 + \left[\frac{\overline{V}_{m_4}}{V_\infty}\right]^2\right]^{\frac{1}{2}} \quad .$$

It is necessary to now relate Equation (10) to the cavitation index of the stator blade system. This can be approximated by writing the energy relation between far upstream of the pumpjet and the stator blade inlet:

$$P_\infty + \rho \frac{\overline{V}_{m_1}^2}{2} = P_4 + \rho \frac{\overline{V}_{m_4}^2}{2} + \rho \frac{\overline{V}_{\theta_4}^2}{2} - g\overline{H} \quad . \tag{11}$$

The quantity (P_v) can be subtracted from each side of Equation (11) and the relation rearranged to give:

$$\sigma_S = C_{b_S} \left(\frac{\overline{V}_4}{V_\infty}\right)^2 + \left(\frac{\overline{V}_{m_3}}{V_\infty}\right)^2 - \left(\frac{\overline{V}_{m_1}}{V_\infty}\right)^2 + \left(\frac{\overline{V}_{\theta_4}}{V_\infty}\right)^2 - \frac{\overline{H}}{\frac{V_\infty^2}{2g}} \quad . \tag{12}$$

The quantity C_{b_S} is now expressed as,

$$C_{b_S} = 2 \left(\frac{S}{C}\right)_S \left(\frac{V_\infty}{V_4}\right)\left(\frac{V_{\theta_4}}{V_\infty}\right)$$

and can be substituted into Equation (12) to give:

$$\left(\frac{S}{C}\right)_S = \left[\sigma_S - \left(\frac{\overline{V}_{m_4}}{V_\infty}\right)^2 + \left(\frac{\overline{V}_{m_1}}{V_\infty}\right)^2 - \left(\frac{\overline{V}_{\theta_4}}{V_\infty}\right)^2 + \frac{\overline{H}}{\frac{V_\infty^2}{2g}}\right] \frac{1}{2} \left(\frac{V_\infty}{\overline{V}_{\theta_4}}\right)\left(\frac{V_\infty}{\overline{V}_4}\right) \quad . \tag{13}$$

The cavitation index substituted in Equation (13) is that value calculated in the program for the rotor at the mass flow coefficient considered and assumes no acceleration or deceleration of the flow as it approaches the rotor. An upper limit for the space-to-chord ratio of 2.0 has been imposed on the output. The stator blade drag can be estimated where:

$$C_D = C_{D_P} + C_{D_S} \quad , \tag{14}$$

where

$$C_{D_P} = 0.020 - 0.004 \left(\frac{S}{C}\right)_S \quad ,$$

and

$$C_{D_S} = 0.018 \, C_{L_S}^2 \quad .$$

For the stator assume:

$$C_{L_S} = 2 \left(\frac{S}{C}\right)_S \left(\frac{\Delta \bar{V}_{\theta_S}}{V_4}\right) \quad . \tag{15}$$

The total pressure loss coefficient for the stator is then:

$$\zeta_S = \left(\frac{\Delta P_T}{\frac{\rho \bar{V}_4^2}{2}}\right) = C_D \left(\frac{C}{S}\right)_S \frac{\cos^2 \alpha_4}{\cos^3 \alpha_m} \quad , \tag{16}$$

where:

$$\tan \alpha_4 = \frac{1.1 \frac{\bar{V}_{\theta_3}}{V_\infty}}{1.2 \frac{\bar{V}_{m_1}}{V_\infty}} \quad ;$$

$$\tan \alpha_5 = 0.0 \quad ;$$

and

$$\tan \alpha_m = \frac{1}{2} \tan \alpha_4 \quad .$$

The hydraulic efficiency is then computed as:

$$\eta_H = 1 - \left\{ \frac{\zeta_R + \zeta_S \left(\frac{\bar{V}_3}{\bar{W}_2}\right)}{\frac{\bar{H}}{\frac{V_\infty^2}{2g}} \left(\frac{V_\infty}{\bar{W}_2}\right)^2} \right\} \quad . \tag{17}$$

The preceding shall be applied to the pumpjet designed in [1] to determine efficiency, lift coefficient, etc., as determined by this technique and compared to that obtained in the Akron exercise at the selected design point.

Appendix (I) lists the input data for the Akron pumpjet analysis and the new program. The output is also listed and consists of an output identical to that of [3] plus the output which indicates computed hydraulic efficiency, the rotor and stator space-to-chord, and their respective lift coefficients. The use of the rotor lift coefficient in conjunction with Figure 2, which is an empirical correlation of lift coefficient and achievable blade pressure coefficient, will aid in selecting the optimum rotor tip diameter. The estimated hydraulic efficiency for the Akron pumpjet in [1] was 0.89, which closely agrees with that computed and listed as EFF-TOT in Appendix (I) at a r_T/r_B of 0.414. The lift coefficient of the rotor and stator is listed in Appendix (I) as 0.34 and 1.02 respectively. The values computed in [1] for the rotor and stator near the 0.9 r_T are 0.3 and 1.0.

ESTIMATES OF EFFICIENCY AND BLADE CHARACTERISTICS FOR A PRESWIRL PUMPJET

As depicted in Figure 3, this pumpjet arrangement would consist of a stator system upstream of a rotor. The stator places swirl in the flow counter to rotor rotation. In the case of the stator vanes, since the velocity over their surfaces is relatively low, the blade solidity is a function of blade loading rather than cavitation performance. On this basis, the upper limit of lift coefficient for the stators is assumed at 1.4. The output from the PPDP provides data to compute $\Delta\bar{V}_{\theta_S}/V_\infty$ for each mass flow from:

$$\Delta\bar{V}_{\theta_S}/V_\infty = \frac{\left[2 \left(\frac{\Delta\bar{V}}{V_\infty}\right)\left(\frac{\bar{V}_{m_2}}{V_\infty}\right) + \left(\frac{\Delta\bar{V}}{V_\infty}\right)^2 + K \left(\frac{\bar{V}_{m_1}}{V_\infty}\right)^2 \right]}{(2)\ (0.9)\ \left(\frac{\pi}{J}\right)\left(\frac{r_T}{r_B}\right)} \quad . \qquad (18)$$

An upper limit has been imposed on $\bar{V}_{\theta_3}/V_\infty$ so as not to permit it to exceed the blade speed at $0.9\ r_T/r_B$.

The relation for the lift coefficient permits computing $(S/C)_S$, assuming the relative velocity ratio over the stator blade surface $(\bar{V}_2/V_\infty)$ is unity.

$$\left(\frac{S}{C}\right)_S = \left(\frac{C_{L_S}}{2}\right)\left(\frac{\frac{\bar{V}_2}{V_\infty}}{\frac{\bar{V}_{\theta_3}}{V_\infty}}\right) = \frac{0.7}{\frac{\bar{V}_{\theta_3}}{V_\infty}} \quad . \qquad (19)$$

At the larger values of ingested mass the values of $(S/C)_S$ will be greater than 2.0. However, an upper limit of 2.0 has been imposed on this quantity. The preceding provides data to compute the profile and secondary drag coefficients for the stator. The profile drag coefficient for the preswirl stator blade row is lower than that estimated for the stator of the conventional pumpjet because it is in an assumed uniform flow field that enters the blade row at zero incidence. On this basis, the drag coefficient is lower as indicated by [4].

$$C_D = C_{D_P} + C_{D_S} \quad ,$$

where:

$$C_{D_P} = 0.012 - 0.004 \left(\frac{S}{C}\right)_S \quad ;$$

$$C_{D_S} = 0.018\ C_{L_S}^2 \quad .$$

The angles α_2 and α_m are approximated for inclusion in Equation (16) to compute the total pressure loss coefficient through the stator as:

$$\alpha_2 = 0 \; ; \; \tan \alpha_3 = \frac{\frac{\overline{V}_{\theta_3}}{V_\infty}}{\frac{\overline{V}_{m_3}}{V_\infty}} \; ; \; \tan \alpha_m = \frac{1}{2} \tan \alpha_3 \quad .$$

The rotor solidity shall be estimated assuming that the relative velocity near the blade tip is:

$$\left(\frac{W_4}{V_\infty}\right)^2 = \left[\left(0.9 \, \frac{\pi}{J} \, \frac{r_T}{r_B}\right) + \left(\frac{\overline{V}_{\theta_4}}{V_\infty}\right)\right]^2 + \left(\frac{\overline{V}_{m_4}}{V_\infty}\right)^2 \quad . \tag{20}$$

The value of $\overline{V}_{\theta_4}/V_\infty$ is the same as computed for insertion in Equation (19).

The energy equation from upstream of the preswirl vanes to the inlet of the rotor, assuming the same meridional velocity at both stations can be expressed:

$$P_\infty = P_4 + \rho \, \frac{\overline{V}_{\theta_4}^{\,2}}{2} \quad . \tag{21}$$

By subtracting vapor pressire (P_v) from both sides of Equation (21) and using the relation given by Equation (3) the value of $(S/C)_R$ can be written as:

$$\left(\frac{S}{C}\right)_R = \frac{\sigma_R - \left(\frac{\overline{V}_{\theta_4}}{V_\infty}\right)^2}{2 \, \frac{\overline{V}_{\theta_4}}{V_\infty} \left(\frac{W_4}{V_\infty}\right)} \quad . \tag{22}$$

It is assumed that zero acceleration or deceleration of the flow, from upstream to the rotor inlet, occurs when computing (σ_R) for insertion in Equation (22). On this basis, the energy equation can be written between these two stations and, using the relations for the minimum pressure coefficient, the cavitation index at rotor inlet is computed as:

$$\sigma_R = C_{b_R} \left(\frac{W_4}{V_\infty}\right)^2 + \left(\frac{\bar{V}_{\theta_4}}{V_\infty}\right)^2 + K \left(\frac{\bar{V}_{m_4}}{V_\infty}\right)^2 \quad . \tag{23}$$

An upper limit was placed on the above $(S/C)_R$ value of 1.8. The lift coefficient for both the stator and rotor is estimated based on the relation:

$$C_{L_S} = 2 \left(\frac{S}{C}\right)_S \left(\frac{\Delta\bar{V}_{\theta_S}}{V_\infty}\right) \qquad \text{(for stator)} \quad ,$$

$$C_{L_R} = 2 \left(\frac{S}{C}\right)_R \left(\frac{\Delta\bar{V}_{\theta_R}}{W_4}\right) \qquad \text{(for rotor)} \quad ,$$

where the respective (S/C) of stator and rotor are inserted.

The values of β_4 and β_m can be estimated for evaluation of Equation (9) by the following:

$$\tan \beta_4 = \frac{0.9 \frac{\pi}{J} \frac{r_T}{r_B} + \frac{\bar{V}_{\theta_4}}{V_\infty}}{\frac{\bar{V}_{m_4}}{V_\infty}} \; ; \; \tan \beta_5 = \frac{0.9 \frac{\pi}{J} \frac{r_T}{r_B}}{1.25 \frac{\bar{V}_{m_4}}{V_\infty}} \; ; \; \tan \beta_m = \frac{1}{2} (\tan \beta_4 + \beta_5)$$

where:

$$\left(\frac{W_4}{V_\infty}\right)^2 = \left(0.9\,\frac{\pi}{J}\,\frac{r_T}{r_B} + \frac{\overline{V}_{\theta_4}}{V_\infty}\right)^2 + \left(\frac{\overline{V}_{m_4}}{V_\infty}\right)^2 \quad .$$

The preceding values are used to compute the drag coefficient of the preswirl rotor as:

$$C_{D_R} = C_{D_P} + C_{D_S} \quad ,$$

where

$$C_{D_P} = 0.020 - 0.004\left(\frac{S}{C}\right)_R \quad ,$$

and

$$C_{S_S} = 0.018\ C_{L_R}^2 \quad .$$

The preceding quantities are then used to compute the total pressure loss coefficient indicated by Equation (9). The hydraulic efficiency of this preswirl stage is expressed as:

$$\eta_H = 1 - \left\{ \frac{\zeta_R + \zeta_S \left(\frac{\overline{V}_2}{W_4}\right)^2}{\left(\frac{\overline{H}}{\frac{V_\infty^2}{2g}}\right)\left(\frac{V_\infty}{W_4}\right)^2} \right\} \quad . \qquad (24)$$

A flow diagram of the preliminary design procedure is outlined in Appendix (II) for both the conventional and preswirl pumpjet configurations.

A sample problem has been run for the preswirl pumpjet configuration and the conventional pumpjet. The input data and a listing of the program and output are shown in Appendix (III) for both types of pumpjets at advance ratios of 0.675, 0.844, and 1.125. The power requirements that would be obtained assuming a hydraulic efficiency of 88 percent versus that obtained from the described methods are plotted in Figure 4 for the conventional pumpjet and Figure 5 for the preswirl pumpjet. It is apparent from these plots that the optimum tip diameter and the efficiency varies with advance ratio for both types of pumpjets.

The preswirl and conventional pumpjet are approximately equal in efficiency for a given advance ratio. The efficiency of either type of pumpjet tends to decrease at low values of advance ratio. This loss in efficiency is associated with higher blade surface velocities due to the higher shaft speeds at the lower advance ratios.

SUMMARY

The results of the preliminary design procedure described within provides data indicating the hydraulic efficiency and power requirements of a pumpjet operating on a given body at a specified advance ratio as a function of ingested mass flow. The space-to-chord ratio and lift coefficient of the blading near the tip ($0.9\ r_T/r_B$) is computed and can be used in selecting blade chord, if blade number is known. The lift coefficient has been empirically correlated with achievable minimum blade pressure coefficients as indicated by Figure 2. This correlation in combination with the program output provides a guide in selecting the mass flow and lift coefficient that will provide the desired cavitation performance.

The results of the described preliminary design procedure indicates that the maximum efficiency and the associated mass flow and tip radius of the pumpjet changes as a function of advance ratio. This is contrasted to past preliminary design procedures which assumed the hydraulic efficiency constant as a function of ingested mass flow.

References

1. Bruce, E. P., et al., "The Design of Pumpjets for Hydrodynamic Propulsion," NASA SP-304, 1974.

2. Howell, A. R., "Fluid Dynamics of Axial Compressors," Proc. Instn. Mech. Engrs., London, 153 (1945).

3. Treaster, A. L., "Computerization of the Preliminary Pumpjet Design Procedure," ARL/PSU Technical Memorandum, File No. 506-04, March 20, 1970.

4. Klein, A., "Aerodynamics of Cascades," AGARD-AG-220, 1977.

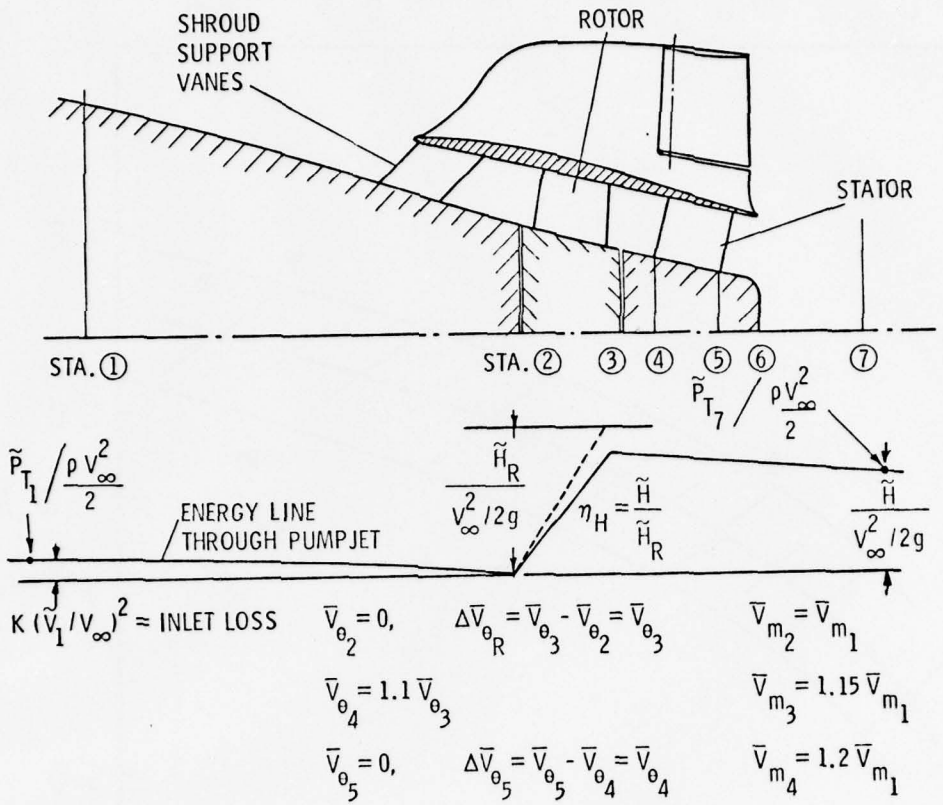


Figure 1. Conventional Pumpjet Geometry and Energy Distribution

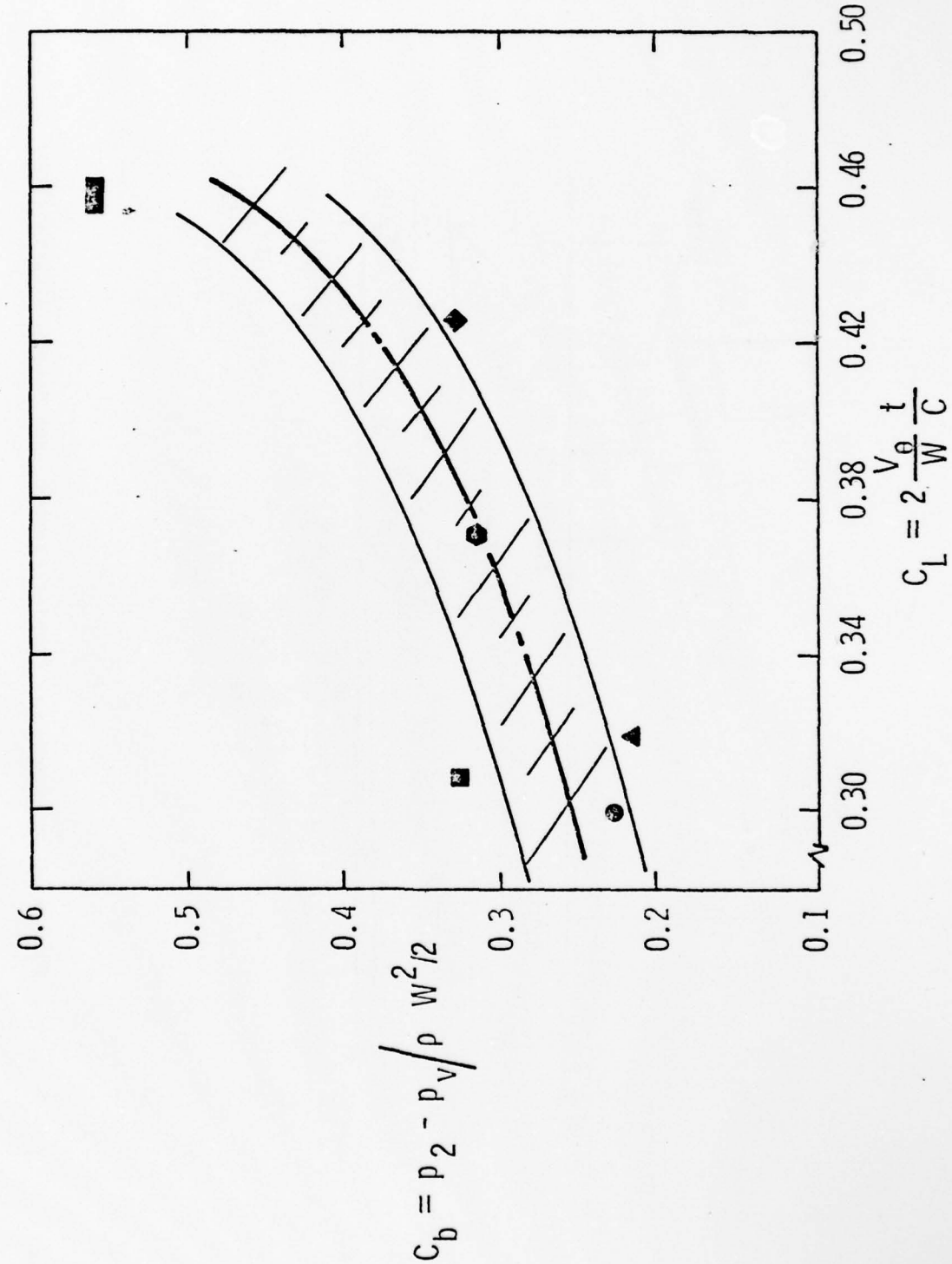


Figure 2. Experimental Minimum Pressure Coefficient of the Leakage Vortex Versus Blade Tip Lift Coefficient

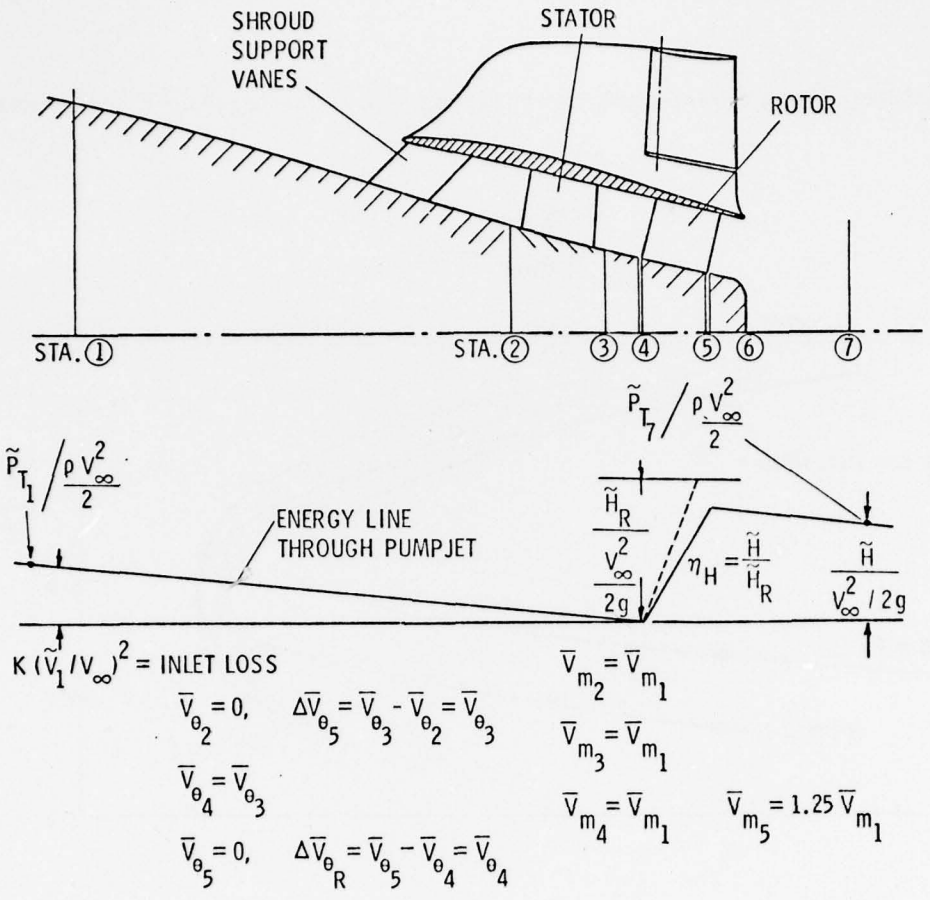


Figure 3. Preswirl Pumpjet Geometry and Energy Distribution

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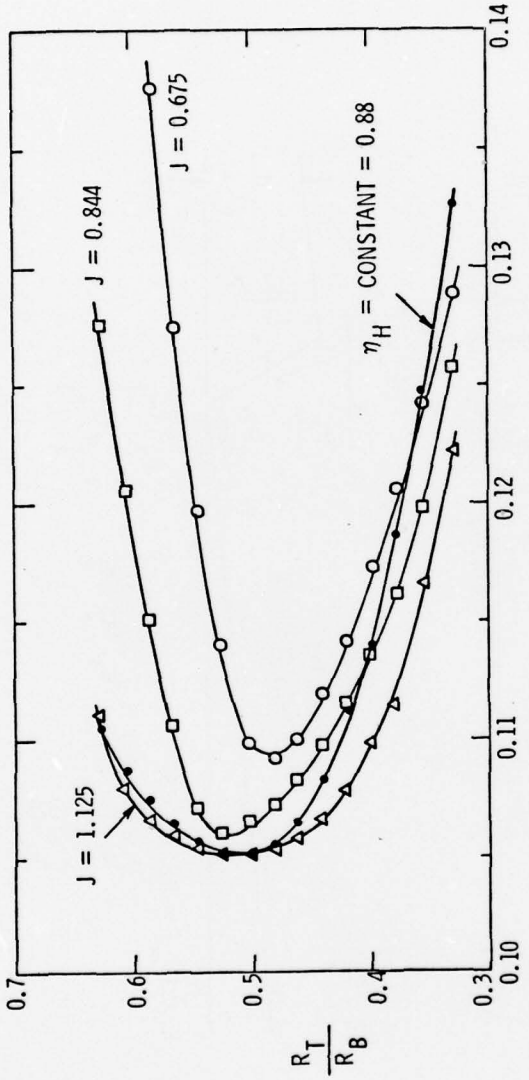


Figure 4. r_T/r_B Versus Power Coefficient for Conventional Pumpjet

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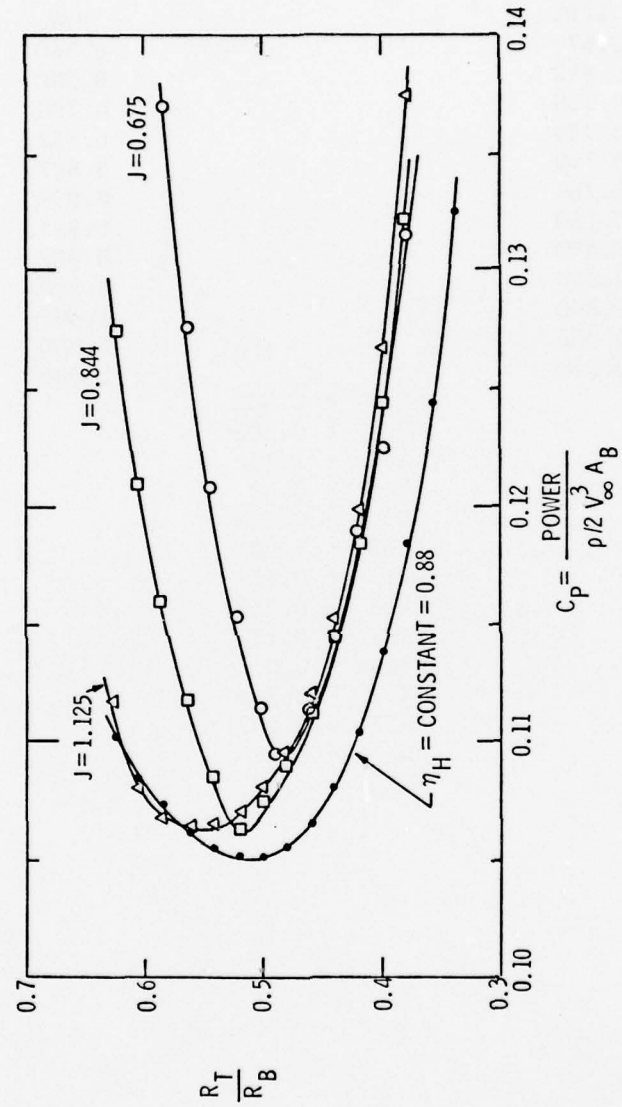


Figure 5. r_T/r_B Versus Power Coefficient for Preswirl Pumpjet

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Appendix I

AKRON input data

N = 12

R/RB	V/V_∞
0.677	0.540
0.692	0.700
0.708	0.790
0.724	0.852
0.740	0.897
0.760	0.938
0.780	0.965
0.800	0.982
0.830	0.998
0.860	1.000
0.900	1.000
0.940	1.000

CDBB = 0.052
CDS = 0.003
V1OV2 = 1.15
ETAH = 0.89
PHI = 0.175
LORB = 1.00
RH1 = 0.677
RH2 = 0.250
XXK = 0.13
PRCNT = 0.0
CB = 0.3
PHI2 = 0.262
NN = 1.0
ADRAT = 1.0

THE LOSS COEFFICIENT, K, IS 0.13000

K/PI	V/VREF	A/AR	FMASS	CT	VBAR/VREF	DELV/VREF	CP	VMOM/VREF	VENG/VREF
0.57703	0.56400	0.00000	0.00000	0.05500					
0.63225	0.60157	0.00726	0.00415	0.05519	0.57095	6.74043	0.24783	0.57262	0.57345
0.63752	0.60665	0.01458	0.00876	0.05537	0.60273	3.19503	0.13896	0.60366	0.60510
0.64278	0.61167	0.02185	0.01335	0.05555	0.62551	2.00076	0.10408	0.64221	0.64560
0.64804	0.61664	0.02933	0.01959	0.05571	0.65675	1.42464	0.08366	0.67588	0.68025
0.70330	0.66947	0.03676	0.02541	0.05587	0.68424	1.10066	0.08066	0.69920	0.70378
0.70856	0.67422	0.04441	0.03141	0.05603	0.70730	0.89278	0.07603	0.71741	0.72223
0.71382	0.67894	0.05200	0.03758	0.05618	0.72269	0.74810	0.07324	0.73324	0.73797
0.71908	0.68362	0.05960	0.04383	0.05633	0.73535	0.64168	0.07157	0.74711	0.75177
0.72434	0.68825	0.06737	0.05044	0.05647	0.74978	0.56020	0.07064	0.75976	0.76446
0.72960	0.69287	0.07513	0.05712	0.05661	0.76029	0.49589	0.07022	0.77148	0.77624
0.73486	0.69744	0.08295	0.06395	0.05675	0.77102	0.44388	0.07018	0.78247	0.78731
0.74012	0.70198	0.09084	0.07096	0.05688	0.78114	0.40102	0.07043	0.79285	0.79778
0.74538	0.70646	0.09877	0.07810	0.05701	0.79072	0.36512	0.07090	0.80269	0.80771
0.75064	0.71095	0.10676	0.08539	0.05714	0.79981	0.33465	0.07155	0.81204	0.81715
0.75590	0.71539	0.11481	0.09282	0.05727	0.80845	0.30850	0.07234	0.82093	0.82614
0.76116	0.71980	0.12291	0.10038	0.05739	0.81668	0.28584	0.07325	0.82940	0.83469
0.76642	0.72419	0.13107	0.10807	0.05751	0.82451	0.26604	0.07426	0.83744	0.84231
0.77168	0.72854	0.13929	0.11588	0.05763	0.83195	0.24860	0.07535	0.84508	0.85052
0.77694	0.73286	0.14756	0.12381	0.05775	0.83902	0.23315	0.07651	0.85231	0.85781
0.78220	0.73715	0.15589	0.13184	0.05787	0.84572	0.21939	0.07773	0.85914	0.86466
0.78746	0.74142	0.16427	0.13997	0.05798	0.85206	0.20705	0.07899	0.86557	0.87114
0.79272	0.74565	0.17271	0.14819	0.05810	0.85804	0.19595	0.08029	0.87162	0.87729
0.79798	0.74985	0.18121	0.15651	0.05821	0.86370	0.18591	0.08163	0.87730	0.88288
0.80324	0.75403	0.18976	0.16491	0.05832	0.86905	0.17679	0.08299	0.88265	0.88822
0.80850	0.75818	0.19837	0.17340	0.05843	0.87412	0.16848	0.08438	0.88772	0.89325
0.81376	0.76230	0.20704	0.18197	0.05854	0.87894	0.16086	0.08580	0.89250	0.89801
0.81902	0.76639	0.21576	0.19063	0.05865	0.88352	0.15395	0.08723	0.89703	0.90250
0.82428	0.77046	0.22454	0.19936	0.05875	0.88787	0.14741	0.08869	0.90132	0.90674
0.82954	0.77451	0.23337	0.20817	0.05886	0.89200	0.14145	0.09016	0.90536	0.91074
0.83480	0.77853	0.24226	0.21704	0.05896	0.89591	0.13593	0.09165	0.90917	0.91449
0.84006	0.78253	0.25121	0.22599	0.05907	0.89960	0.13081	0.09314	0.91274	0.91801
0.84532	0.78650	0.26021	0.23499	0.05917	0.90307	0.12604	0.09465	0.91609	0.92128
0.85058	0.79045	0.26927	0.24405	0.05927	0.90634	0.12160	0.09615	0.91921	0.92433
0.85584	0.79438	0.27838	0.25317	0.05938	0.90941	0.11744	0.09765	0.92212	0.92717
0.86110	0.79827	0.28755	0.26234	0.05948	0.91230	0.11355	0.09917	0.92485	0.92981
0.86636	0.80214	0.29678	0.27156	0.05958	0.91503	0.10991	0.10069	0.92740	0.93228
0.87162	0.80598	0.30607	0.28085	0.05968	0.91760	0.10648	0.10221	0.92979	0.93459
0.87688	0.80979	0.31541	0.29018	0.05977	0.92003	0.10324	0.10374	0.93205	0.93676
0.88214	0.81358	0.32480	0.29958	0.05987	0.92234	0.10019	0.10527	0.93417	0.93881
0.88740	0.81734	0.33425	0.30903	0.05997	0.92454	0.09731	0.10680	0.93618	0.94073
0.89266	0.82107	0.34375	0.31854	0.06007	0.92662	0.09458	0.10835	0.93808	0.94255
0.89792	0.82478	0.35333	0.32810	0.06016	0.92861	0.09199	0.10989	0.93989	0.94427
0.90318	1.00000	0.36295	0.33772	0.06026	0.93050	0.08953	0.11145	0.94162	0.94591
0.90844	1.00000	0.37262	0.34740	0.06035	0.93230	0.08719	0.11301	0.94328	0.94746
0.91370	1.00000	0.38235	0.35713	0.06045	0.93403	0.08496	0.11457	0.94488	0.94893
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0.92422	1.00000	0.40199	0.37677	0.06063	0.93725	0.08082	0.11772	0.94794	0.95169
0.92948	1.00000	0.41189	0.38667	0.06073	0.93876	0.07888	0.11931	0.94940	0.95299
0.93474	1.00000	0.42185	0.39663	0.06082	0.94021	0.07704	0.12090	0.95082	0.95424
0.94000	1.00000	0.43186	0.40664	0.06091	0.94160	0.07527	0.12250	0.95219	0.95544

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THE MINIMUM VALUE OF CP IS 0.0701597 THE CORRESPONDING AREA RATIO IS 0.0800346

AND THE MASS FLOW RATE COEFFICIENT IS 0.0613241

THE AREA RATIO IS INCREASED BY 0.000000PERCENT TO THE DESIGN VALUE 0.0800346

CP AND MASS ARE 0.0701597 AND 0.0613241 RESPECTIVELY

THE ADVANCE RATIO IS 1.00000

RT/RJ	SIGMA
0.3139435	2.4599422
0.3299726	2.0040512
0.3414854	1.4391794
0.3526225	1.0305902
0.3634194	0.8419351
0.3739026	0.6777433
0.3841009	0.5522197
0.3940353	0.4738307
0.4037253	0.4207986
0.4131880	0.3736673
0.4224369	0.3491094

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THE ADVANCE RATIO IS 1.00000

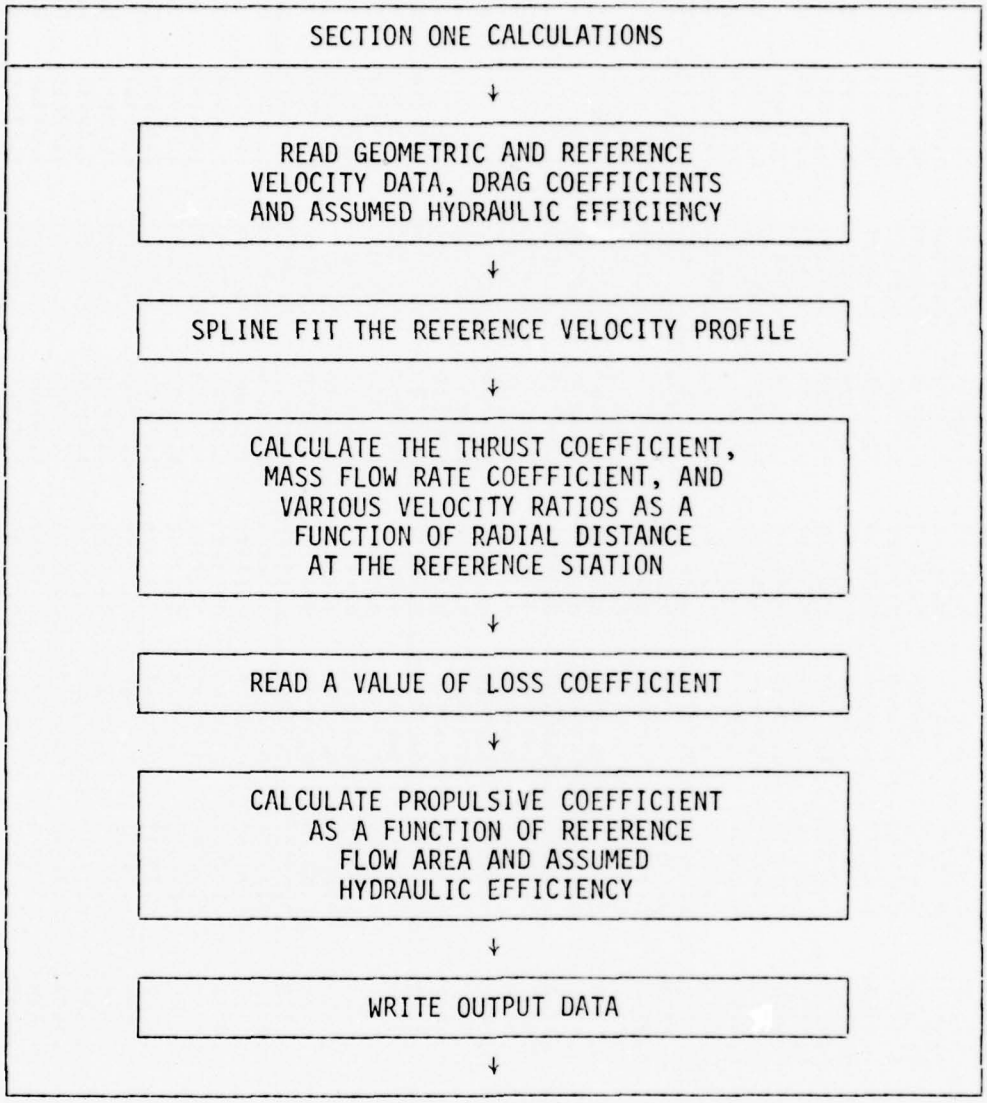
R/D	CP-ACT	EFF-ACT	EFF-STAT	EFF-TOT	CL-STAT	CL-ACT	S/C-ACT	S/C-STAT	SIGMA	RT/RS
0.63225	0.22115	0.78307	0.99072	0.99769	3.07301	0.34761	0.21332	2.00000	0.38941	0.25564
0.63752	0.12433	0.89569	0.99491	0.99832	3.03351	0.34739	0.21789	2.00000	0.34390	0.28052
0.63278	0.08437	0.93081	0.99725	0.99719	3.07510	0.34780	0.21869	2.00000	0.38204	0.29476
0.63204	0.06182	0.94852	0.99849	0.99631	3.10341	0.34796	0.21900	1.87301	0.41932	0.30344
0.70330	0.07556	0.93143	0.99747	0.99048	1.20578	0.34743	0.21797	0.78293	0.45238	0.32163
0.70650	0.07286	0.93369	0.99775	0.99375	0.72499	0.34665	0.21645	0.46798	0.48331	0.33440
0.71382	0.07154	0.93482	0.99106	0.99119	0.54235	0.34576	0.24166	0.48312	0.51301	0.34679
0.71903	0.07017	0.93956	0.99815	0.99775	0.42269	0.34485	0.30732	0.62230	0.54197	0.35384
0.72434	0.06962	0.93382	0.99831	0.99237	0.32275	0.34395	0.37367	0.79352	0.57045	0.37058
0.72960	0.06932	0.92743	0.99805	0.98893	0.20815	0.34307	0.45533	0.96130	0.59860	0.38204
0.73485	0.06972	0.92372	0.99890	0.98592	1.01649	0.34221	0.53594	1.11417	0.62651	0.39325
0.74012	0.07312	0.92083	0.99072	0.98387	1.02460	0.34139	0.62326	1.26027	0.65425	0.40422
0.74538	0.07069	0.91875	0.99154	0.98261	1.02193	0.34060	0.71394	1.40235	0.68187	0.41498
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0.77168	0.07501	0.91650	0.99569	0.98404	0.97220	0.33705	1.22414	2.00000	0.81857	0.46606
0.77694	0.07602	0.91714	0.99591	0.98505	0.85234	0.33640	1.33593	2.00000	0.84569	0.47582
0.78220	0.07713	0.91803	0.99620	0.98618	0.79289	0.33577	1.45064	2.00000	0.87273	0.48544
0.78746	0.07834	0.91915	0.99636	0.98742	0.74051	0.33516	1.56797	2.00000	0.89969	0.49494
0.79272	0.07951	0.92047	0.99643	0.98877	0.69413	0.33456	1.68783	2.00000	0.92657	0.50432
0.79798	0.08075	0.92144	0.99642	0.98971	0.65233	0.33210	1.80000	2.00000	0.95340	0.51359
0.80324	0.08255	0.91838	0.99634	0.98970	0.61588	0.31018	1.80000	2.00000	0.98017	0.52276
0.80850	0.08444	0.91109	0.99621	0.98942	0.58267	0.29060	1.80000	2.00000	1.00690	0.53183
0.81376	0.08639	0.90559	0.99603	0.98889	0.55267	0.27304	1.80000	2.00000	1.03362	0.54080
0.81902	0.08841	0.89983	0.99582	0.98812	0.52548	0.25720	1.80000	2.00000	1.06033	0.54969
0.82428	0.09051	0.89397	0.99557	0.98713	0.50074	0.24287	1.80000	2.00000	1.08703	0.55848
0.82954	0.09267	0.88796	0.99530	0.98593	0.47815	0.22984	1.80000	2.00000	1.11372	0.56720
0.83480	0.09490	0.88156	0.99501	0.98452	0.45747	0.21796	1.80000	2.00000	1.14041	0.57584
0.84006	0.09717	0.87505	0.99470	0.98292	0.43847	0.20709	1.80000	2.00000	1.16709	0.58441
0.84532	0.09955	0.86837	0.99438	0.98112	0.42096	0.19711	1.80000	2.00000	1.19376	0.59290
0.85058	0.10197	0.86143	0.99405	0.97912	0.40479	0.18792	1.80000	2.00000	1.22044	0.60132
0.85584	0.10444	0.85441	0.99371	0.97694	0.38980	0.17943	1.80000	2.00000	1.24712	0.60969
0.86110	0.10704	0.84714	0.99336	0.97454	0.37589	0.17157	1.80000	2.00000	1.27381	0.61798
0.86636	0.10968	0.83958	0.99302	0.97193	0.36293	0.16427	1.80000	2.00000	1.30053	0.62622
0.87162	0.11240	0.83204	0.99267	0.96929	0.35084	0.15749	1.80000	2.00000	1.32729	0.63440
0.87688	0.11521	0.82420	0.99231	0.96638	0.33956	0.15115	1.80000	2.00000	1.35410	0.64252
0.88214	0.11810	0.81613	0.99195	0.96329	0.32904	0.14525	1.80000	2.00000	1.38095	0.65060
0.88740	0.12109	0.80775	0.99161	0.95992	0.31922	0.13972	1.80000	2.00000	1.40788	0.65861
0.89266	0.12417	0.79906	0.99125	0.95627	0.30963	0.13453	1.80000	2.00000	1.43486	0.66658
0.89792	0.12735	0.79007	0.99090	0.95235	0.30091	0.12966	1.80000	2.00000	1.46193	0.67451
0.90318	0.13066	0.78078	0.99055	0.94815	0.29248	0.12508	1.80000	2.00000	1.48907	0.68238
0.90844	0.13407	0.77121	0.99020	0.94367	0.28461	0.12076	1.80000	2.00000	1.51630	0.69021
0.91370	0.13761	0.76135	0.98985	0.93892	0.27716	0.11669	1.80000	2.00000	1.54361	0.69800
0.91896	0.14128	0.75120	0.98951	0.93389	0.27010	0.11284	1.80000	2.00000	1.57101	0.70575
0.92422	0.14508	0.74076	0.98917	0.92858	0.26339	0.10920	1.80000	2.00000	1.59851	0.71345
0.92948	0.14903	0.73002	0.98883	0.92298	0.25702	0.10576	1.80000	2.00000	1.62610	0.72112
0.93474	0.15314	0.71899	0.98849	0.91709	0.25096	0.10249	1.80000	2.00000	1.65380	0.72875
0.94000	0.15741	0.70767	0.98816	0.91090	0.24518	0.09939	1.80000	2.00000	1.68160	0.73634

May 3, 1979
WSG:JEH:mmj

May 3, 1979
WSG:JEF:mmj

Appendix II

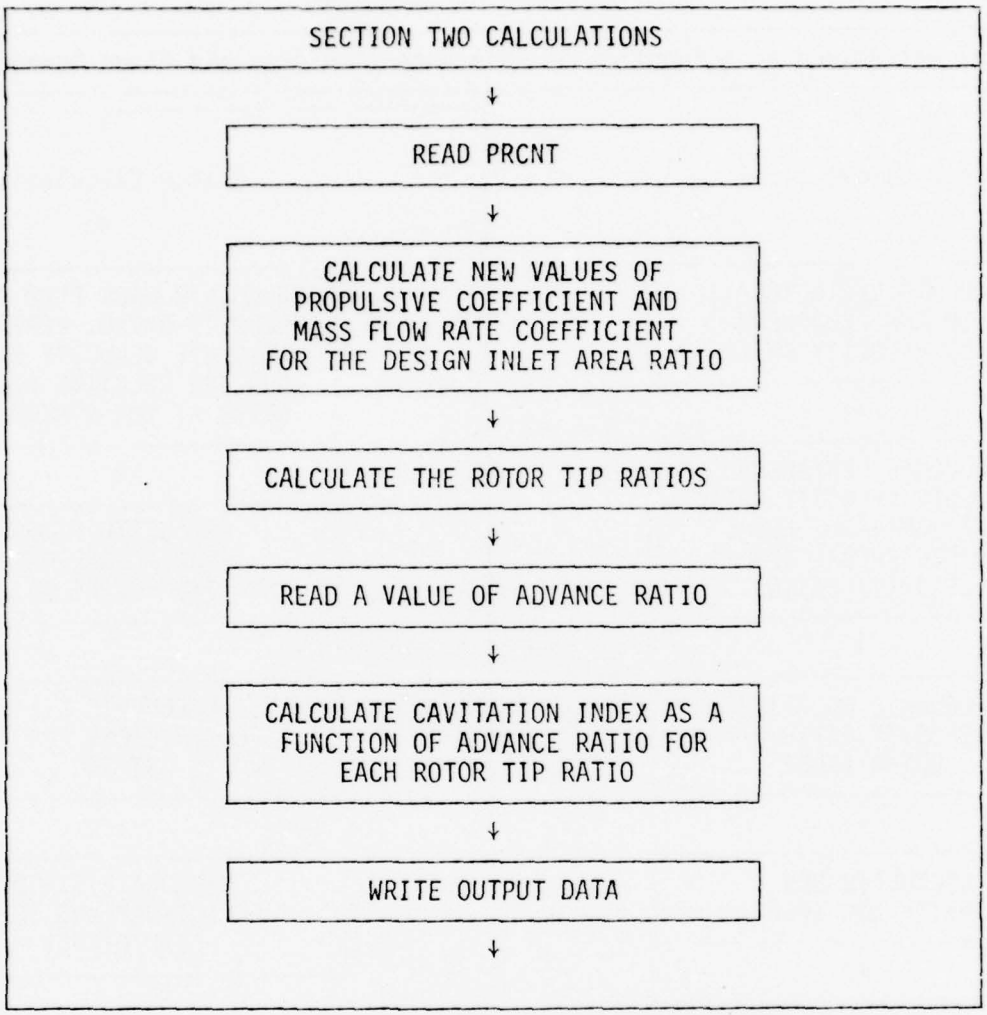
Conventional Pumpjet Functional Diagram



Proceed to Section Two Calculations

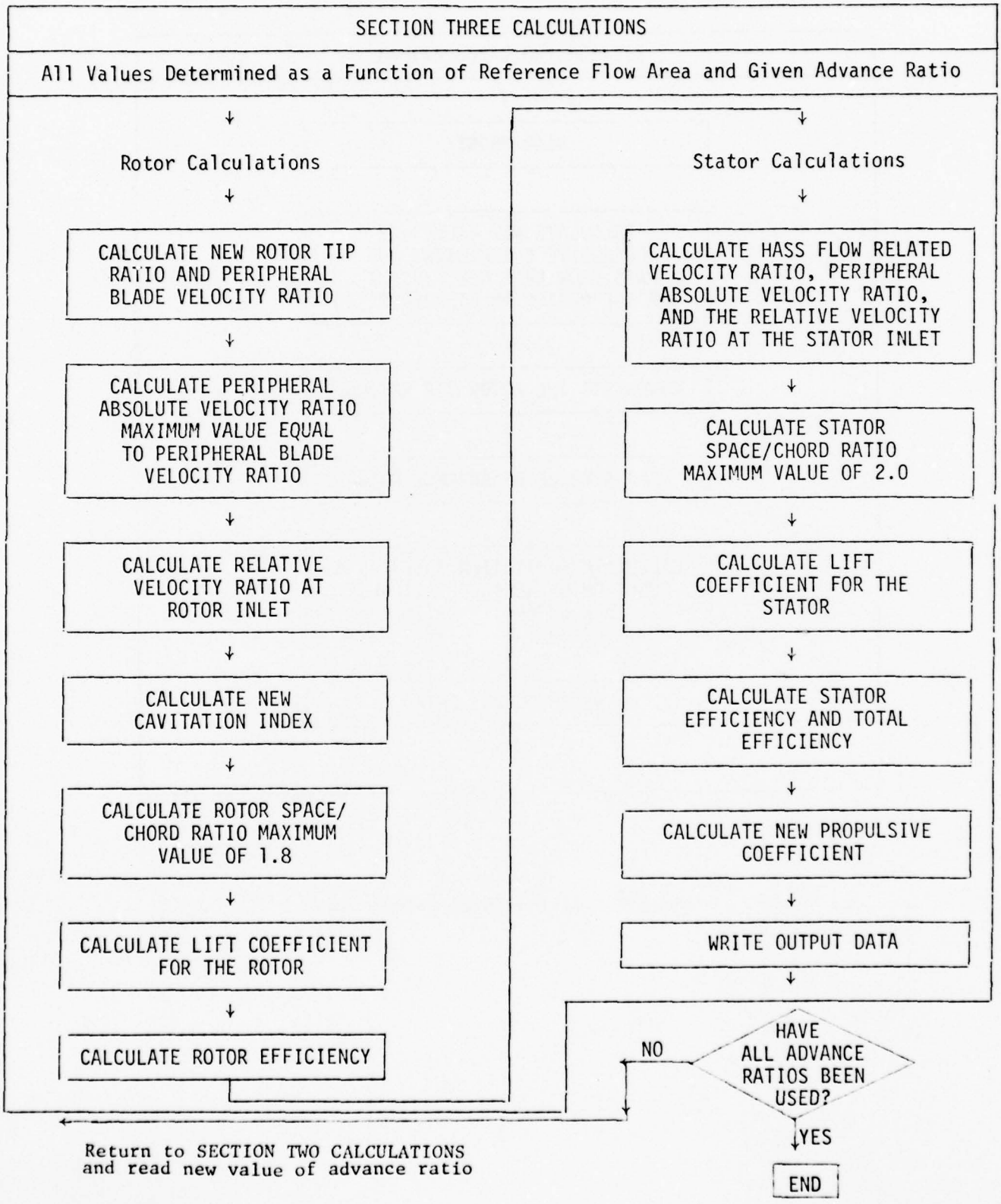
May 3, 1979
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Conventional Pumpjet Functional Diagram



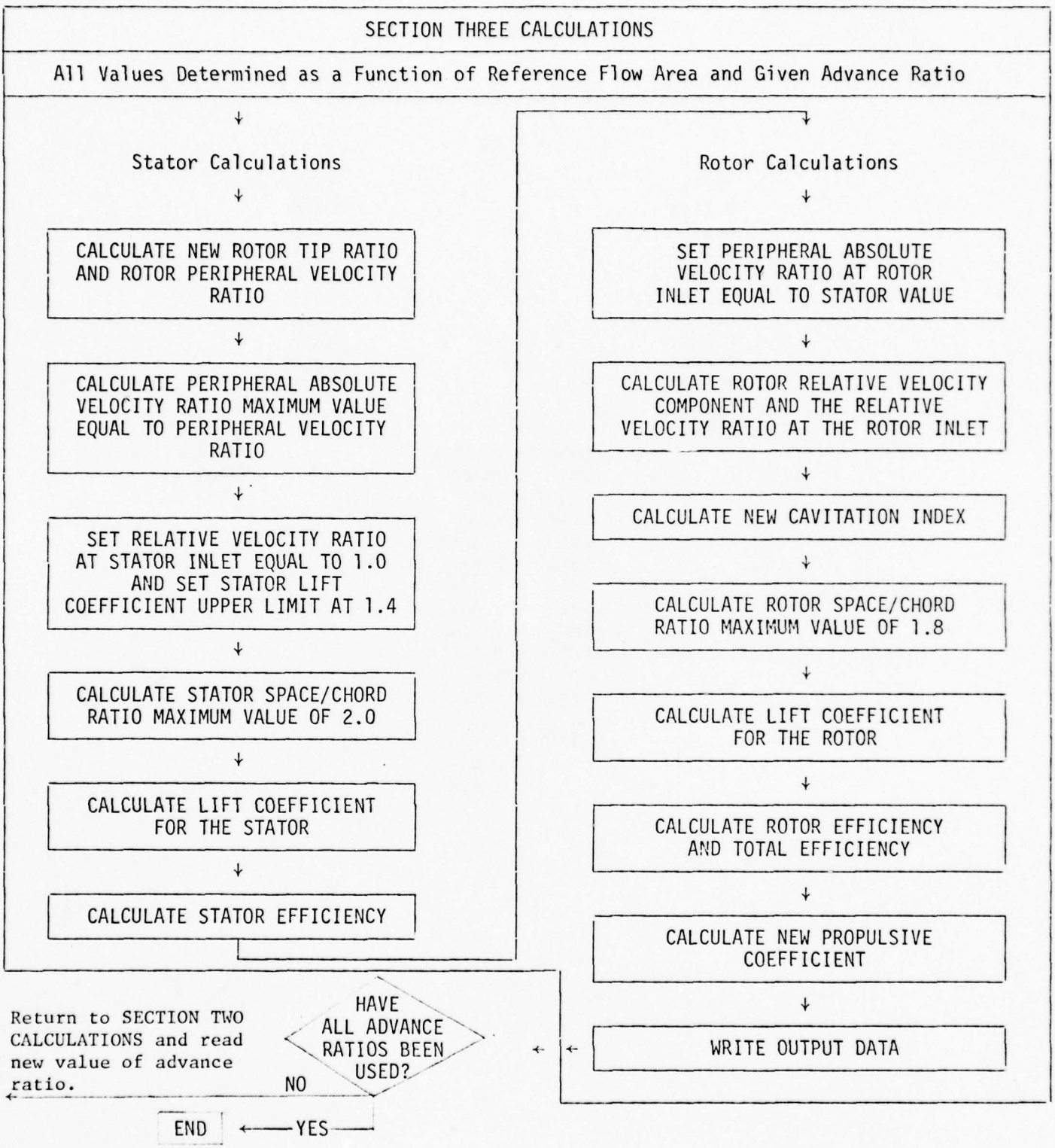
Proceed to Section Three Calculations

Conventional Pumpjet Functional Diagram



May 3, 1979
WSG:JEF:mmj

Preswirl Pumpjet Functional Diagram



May 3, 1979
WSG:JEF:mmj

Appendix III

With Drag Coefficient CDBB = 0.103

N = 11

R/RB	V/V_∞
0.1188	0.430
0.150	0.450
0.200	0.485
0.250	0.528
0.300	0.575
0.350	0.628
0.400	0.680
0.450	0.730
0.500	0.775
0.550	0.818
0.600	0.860

CDBB = 0.103
CDS = 0.003
V1OV2 = 1.15
ETAH = 0.88
PHI = 0.1396
LORB = 0.662
RH1 = 0.1188
RH2 = 0.11
XXK = 0.08
PRCNT = 0.0
CB = 0.3
PHI2 = 0.174
NN = 3.0
ADRAT = 0.675,
0.844,
1.125

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// READ DEVICE-SYSIN
// PRINT DEVICE-PRTR
*PROCESS MAP,LINK(X,LIB(JEFLIB)),SIZE(24)
      1           PROGRAM PROP
      2           REAL LOPP,MSFLG
      3           DIMENSION AA(60),A(60),ADAR(60),A2DAR(60),B(60),C(60),CP(60)
      4           DIMENSION CPP(60),CT(60),DLTAV(60),EL(60),EEE(60),EE(60),E(60)
      5           DIMENSION EMASS(60),RR(60),R(60),RT(60),SC(60),SIGMA(60),VV(60)
      6           DIMENSION V(60),V2AR(60),VMOM(60),VENG(60),VVMOM(60),VVENG(60)
      7           DIMENSION CPPP(60),RTRR(60),CLS(60),CLP(60),SOCR(60),SOCS(60)
      8           DIMENSION EROT(60),ESTAT(60),ETOT(60),SGMA(60)
      9           EQUIVALENCE (A(1),VVMOM(1)),(B(1),VVENG(1))
                C
                C     THE PRELIMINARY PUMPJET DESIGN COMPUTER PROGRAM SELECTS AN
                C     OPTIMUM FLOW AREA FROM THE REFERENCE VELOCITY PROFILE BASED ON
                C     A MINIMUM VALUE OF PROPULSIVE COEFFICIENT.  FROM THESE DATA THE
                C     PROGRAM ALSO PREDICTS THE CAVITATION PERFORMANCE AS A FUNCTION
                C     OF ADVANCE RATIO AND ROTOR TIP DIAMETER.
                C     ADDITIONALLY, THE PROGRAM COMPUTES THE SPACE TO CHORD RATIO,
                C     LIFT COEFFICIENT, STAGE EFFICIENCY, AND TOTAL PUMPJET
                C     EFFICIENCY AS A FUNCTION OF INGESTED MASS FLOW AND ADVANCE RATIO.
                C
     10           READ(4,100)N
     11           DO 1 I=1,N
     12         1 READ(4,101)R(I),V(I)
     13           READ(4,101)CDBB,CDS,V1OV2,ETAH
     14           READ(4,101)PHI,LOPP,RH1,RH2
     15           CALL SPEIT(N,R,V,SC,EL,A,B,C)
                C
                C     N IS THE NUMBER OF DATA POINTS DEFINING THE THE REFERENCE VELOCITY
                C     PROFILE
                C     R(I) AND V(I) ARE THE DATA POINTS DEFINING THE REFERENCE VELOCITY
                C     PROFILE
                C     CDBB IS THE BARE BODY DRAG COEFFICIENT
                C     CDS IS THE SKIN FRICTION DRAG COEFFICIENT
                C     V1OV2 IS A VELOCITY RATIO WHICH REPRESENTS THE ACCELERATION OF THE
                C     FLUID FROM THE REFERENCE STATION TO THE ROTOR DISK PLANE
                C     ETAH IS THE HYDRAULIC EFFICIENCY
                C     PHI IS THE LOCAL BODY ANGLE AT THE REFERENCE STATION WITH RESPECT
                C     TO THE VEHICLE CENTERLINE
                C     LOPP IS THE NONDIMENSIONAL SHROUD LENGTH
                C     RH1 IS THE NONDIMENSIONAL BODY RADIUS AT THE REFERENCE STATION
                C     RH2 IS THE NONDIMENSIONAL BODY RADIUS AT THE ROTOR HUB
                C
     16           DLTAR=(R(N)-R(1))/50.0
     17           RR(1)=R(1)
     18           DO 2 I=2,51
     19         2 RR(I)=RR(I-1)+DLTAR
     20           DO 3 I=1,51
     21           CALL SPDET(N,R,V,SC,EL,RR(I),VV(I),YP,DP)
```

```
      CT(I)=1.0)*CD3B+4.0*CD5*LOPB*SQRT(V1OV2*((RR(I))**2-RH1**2)+
     -RH2**2)
C
C     CT(I) IS THE REQUIRED THRUST COEFFICIENT
C
    3 F(I)=2.0*RR(I)/COS(PHI)
      AOAB(1)=0.0
      DO 4 I=2,51
    4 AOAB(I)=AOAB(I-1)+0.5*(F(I)+F(I-1))*(RR(I)-RR(I-1))
C
C     AOAB(I) IS THE FLOW AREA AT THE REFERENCE STATION AS A FUNCTION OF
C     P/P3
C
      DO 5 I=1,51
      F(I)=2.0*(VV(I)*RR(I)/COS(PHI))
      FF(I)=VV(I)*F(I)
    5 FFF(I)=VV(I)*FF(I)
      EMASS(1)=0.0
      VVMOM(1)=0.0
      VVENG(1)=0.0
      DO 6 I=2,51
      EMASS(I)=EMASS(I-1)+0.5*(F(I)+F(I-1))*(RR(I)-RR(I-1))
      VVMOM(I)=VVMOM(I-1)+0.5*(FF(I)+FF(I-1))*(RR(I)-RR(I-1))
      VVENG(I)=VVENG(I-1)+0.5*(FFF(I)+FFF(I-1))*(RR(I)-RR(I-1))
      VBAR(I)=EMASS(I)/AOAB(I)
      VMOM(I)=VVMOM(I)/EMASS(I)
      VENG(I)=SQRT(VVENG(I)/EMASS(I))
    6 DLTAV(I)=0.5*(CT(I)/(COS(PHI)*AOAB(I)*VMOM(I)))
C
C     EMASS(I) IS THE MASS FLOW RATE COEFFICIENT
C     VBAR(I) IS AN AVERAGE VELOCITY RATIO BASED ON MASS FLOW RATE
C     VENG(I) IS AN AVERAGE VELOCITY RATIO BASED ON ENERGY
C     DLTAV(I) IS THE NONDIMENSIONAL VELOCITY CHANGE BASED ON MOMENTUM
C     VMOM(I) IS AN AVERAGE VELOCITY RATIO BASED ON MOMENTUM
C
      READ(4,101)XXK
      WRITE(3,104)XXK
      WRITE(3,105)
C
C     XXK IS THE LOSS COEFFICIENT
C
      WRITE(3,102)RR(1),VV(1),AOAB(1),EMASS(1),CT(1)
      DO 7 I=2,51
      CP(I)=(2.0*DLTAV(I)*VENG(I)+DLTAV(I)**2+XXK*VENG(I)**2)
     -*AOAB(I)*VBAR(I)/ETAH
    7 WRITE(3,102)RR(I),VV(I),AOAB(I),EMASS(I),CT(I),VBAR(I),DLTAV(I),
     -CP(I),VMOM(I),VENG(I)
C
C     THE FOLLOWING STATEMENTS (THROUGH 12) LOCATE THE POINT OF
C     MINIMUM PROPULSIVE COEFFICIENT
C
```

```
      DO 9 I=1,48
      CPP(I)=CP(I+3)
    9 AA(I)=AOAB(I+3)
      CALL SPFIT(48,AA,CPP,SC,EL,A,B,C)
      AINC=AOAB(51)/1000.0
      AAA=AOAB(4)
      CALL SPGET(48,AA,CPP,SC,EL,AAA,Y,YD,YDP)
      AQ=AAA
      YQ=Y
      DO 11 I=1,1000
      AAA=AAA+AINC
      CALL SPGET(48,AA,CPP,SC,EL,AAA,Y,YD,YDP)
      IF(Y-YQ)10,12,12
   10 AQ=AAA
      YQ=Y
   11 CONTINUE
   12 AMIN1=0.5*(AQ+AAA)
      READ(4,101)PRCNT
      AMIN2=(1.0+PRCNT)*AMIN1
C
C     AMIN1 IS THE FLOW AREA AT THE REFERENCE STATION CORRESPONDING TO
C     THE POINT OF MINIMUM PROPULSIVE COEFFICIENT
C     PRCNT IS THE AMOUNT BY WHICH THE DESIGNER INCREASES AMIN1 TO AMIN2
C     AMIN2 IS THE DESIGN VALUE OF THE FLOW AREA AT THE REFERENCE
C     STATION
C
      CALL SPGET(48,AA,CPP,SC,EL,AMIN1,Y1,YP,YDP)
      CALL SPGET(48,AA,CPP,SC,EL,AMIN2,Y2,YP,YDP)
      CALL SPFIT(51,AOAB,FMASS,SC,EL,A,B,C)
      CALL SPGET(51,AOAB,FMASS,SC,EL,AMIN1,Y3,YP,YDP)
      CALL SPGET(51,AOAB,FMASS,SC,EL,AMIN2,Y4,YP,YDP)
      WRITE(3,111)Y1,AMIN1,Y3
      P=100.0*PRCNT
      WRITE(3,112)P,AMIN2,Y2,Y4
      VENG(1)=0.0
      CALL SPFIT(51,AOAB,VENG,SC,EL,A,B,C)
      CALL SPGET(51,AOAB,VENG,SC,EL,AMIN2,Y5,YP,YDP)
      MSFLO=AMIN2*Y5
C
C     MSFLO IS A MASS FLOW RATE COEFFICIENT BASED ON VENG(I)
C     RT(I) IS THE NONDIMENSIONAL ROTOR TIP RADIUS
C     SIGMA(I) IS THE CAVITATION INDEX
C
      AINC2=AMIN2/10.0
      A2OA2(1)=AMIN2/2.0
      READ(4,101)CB,PHI2
C
C     CB IS AN ASSUMED VALUE OF THE MINIMUM PRESSURE COEFFICIENT OF THE
C     BLADE TIP SECTION
C     PH2 IS THE LOCAL FLOW ANGLE AT THE ROTOR HUB IN RADIANS
C
```

```
      RT(I)=SQRT(A2OAB(1)*COS(PHI2)+RH2**2)
      DO 13 I=2,11
      A2OAB(I)=A2OAB(I-1)+AINC2
   13 RT(I)=SQRT(A2OAB(I)*COS(PHI2)+RH2**2)
      READ(4,101)AN
      DO 22 J=1,NN
      READ(4,101)ADRAT
      IF(J.NE.1)GO TO 14
      WRITE(3,106)ADRAT
      GO TO 15
   14 WRITE(3,114)ADRAT
   15 WRITE(3,107)
      DO 16 I=1,11
      SIGMA(I)=CB*(MSFLO**2/(A2OAB(I)**2)+((3.1416/ADRAT)**2)*RT(I)**2)+
     -MSFLO**2*(1.0/(A2OAB(I)**2)-(1.0-XXK)/(AMIN2**2))
   16 WRITE(3,108)RT(I),SIGMA(I)
C
      WRITE(3,114)ADRAT
      WRITE(3,115)
      DO 21 I=2,51
C
C     ROTOR APPLICATION
C
      HBAR=2.*DLTAV(I)*VBAR(I)+DLTAV(I)**2+XXK*VBAR(I)**2
      RTB(I)=SQRT(A2OAB(I)*V10V2*COS(PHI2)+RH2**2)
      UBAR=0.9*3.1416*RTB(I)/ADRAT
      VTHV=HBAR/(2.*UBAR)
      IF(VTHV.LE.UBAR) GO TO 17
      VTHV=UBAR
   17 CONTINUE
      W10V=SQRT(UBAR**2+VBAR(I)**2)
      SIGMA(I)=CB*W10V**2+XXK*VBAR(I)**2
      SOCR(I)=SIGMA(I)/(2.*W10V*VTHV)
      IF(SOCR(I).LT.1.9) GO TO 18
      SOCR(I)=1.9
   18 CONTINUE
      CLR(I)=2.*VTHV*SOCR(I)/W10V
      CDPR=0.02-0.004*SOCR(I)
      CDSP=0.018*CLR(I)**2
      CDR=CDPR+CDSP
      ALP1R=ATAN(UBAR/VBAR(I))
      CA1R=COS(ALP1R)
      ALP2R=ATAN((UBAR-VTHV)/(V10V2*VBAR(I)))
      TN1=SIN(ALP1R)/COS(ALP1R)
      TN2=SIN(ALP2R)/COS(ALP2R)
      ALPMR=ATAN((TN1+TN2)/2.)
      CAMR=COS(ALPMR)
      PLOSR=CDR*CA1R**2/(SOCR(I)*CAMR**3)
      EROI(I)=1.-PLOSR*W10V**2/HBAR
C
C     STATOR APPLICATION
```

```
      C
  127         V3AR3=1.2*V3AR(I)
  128         VTHV3=1.1*VTHV
  129         W3OV=SQRT(VTHV3**2+V3AR3**2)
  130         SOCS(I)=(SGMA(I)-V3AR3**2+V3AR(I)**2-VTHV3**2+H3AR)/(2.*VTHV3*W3OV
     -)
  131         IF(SOCS(I).LT.2.) GO TO 19
  132         SOCS(I)=2.
  133      19 CONTINUE
  134         CLS(I)=2.*SOCS(I)*VTHV3/W3OV
  135         CDPS=0.02-0.004*SOCS(I)
  136         CDSS=0.018*CLS(I)**2
  137         CDS=CDPS+CDSS
  138         ALP1S=ATAN(VTHV3/V3AR3)
  139         CA1S=COS(ALP1S)
  140         ALPMS=ATAN(0.5*SIN(ALP1S)/COS(ALP1S))
  141         CAMS=COS(ALPMS)
  142         PLOSS=CDS*CA1S**2/(SOCS(I)*CAMS**3)
  143         ESTAT(I)=1.-PLOSS*W3OV**2/H3AR
  144         ETOT(I)=EROT(I)*ESTAT(I)
  145         CPPP(I)=CP(I)*ETAH/ETOT(I)
  146      21 WRITE(3,110)RR(I),CPPP(I),EROT(I),ESTAT(I),ETOT(I),CLS(I),CLR(I),
     -SOCR(I),SOCS(I),SGMA(I),RTRB(I)
  147      22 CONTINUE
         C
         C     HBAR IS THE NONDIMENSIONAL EXPRESSION FOR THE ENERGY
         C     PLACED IN THE FLUID
         C     U3AR IS AN AVERAGE PERIPHERAL BLADE VELOCITY RATIO
         C     RTRB(I) IS THE NONDIMENSIONAL ROTOR TIP RADIUS
         C     VTHV IS AN AVERAGE PERIPHERAL ABSOLUTE VELOCITY RATIO
         C     AT THE ROTOR LEADING EDGE
         C     W1OV IS AN AVERAGE RELATIVE VELOCITY RATIO AT THE
         C     ROTOR LEADING EDGE
         C     SOCR(I) IS THE BLADE SPACING TO CHORD RATIO FOR THE ROTOR
         C     CLR(I) IS THE ROTOR LIFT COEFFICIENT
         C     CDPR IS THE ROTOR PROFILE DRAG COEFFICIENT
         C     CDSR IS THE ROTOR SECONDARY FLOW DRAG COEFFICIENT
         C     CDR IS THE ROTOR DRAG COEFFICIENT
         C     EROT(I) IS THE ROTOR HYDRAULIC EFFICIENCY
         C     PLOSR IS THE PRESSURE LOSS THROUGH THE ROTOR
         C     V3AR3 IS AN AVERAGE VELOCITY RATIO AT THE STATOR INLET
         C     VTHV3 IS AN AVERAGE PERIPHERAL ABSOLUTE VELOCITY RATIO
         C     AT THE STATOR INLET
         C     W3OV IS AN AVERAGE RELATIVE VELOCITY RATIO AT THE STATOR INLET
         C     SOCS(I) IS THE BLADE SPACING TO CHORD RATIO FOR THE STATOR
         C     CLS(I) IS THE STATOR LIFT COEFFICIENT
         C     CDPS IS THE STATOR PROFILE DRAG COEFFICIENT
         C     CDSS IS THE STATOR SECONDARY FLOW DRAG COEFFICIENT
         C     CDS IS THE STATOR DRAG COEFFICIENT
         C     PLOSS IS THE PRESSURE LOSS THROUGH THE STATOR
         C     ESTAT(I) IS THE STATOR HYDRAULIC EFFICIENCY
```

```
      C     ETOT(I) IS THE TOTAL PUMPJET HYDRAULIC EFFICIENCY
      C     CPP(I) IS THE PROPULSIVE COEFFICIENT AS A FUNCTION
      C     OF CALCULATED TOTAL EFF. VS ASSUMED TOTAL EFF.
      C     SGMA(I) IS THE CAVITATION INDEX FOR A GIVEN MASS FLOW
      C
  148   100 FORMAT(I5)
  149   101 FORMAT(4F10.5)
  150   102 FORMAT(' ',10(F8.5,4X))
  151   104 FORMAT('1','THE LOSS COEFFICIENT, K, IS',F10.5)
  152   105 FORMAT(' ',1X,'R/RP',8X,'V/VREF',6X,'A/AP',8X,'EMASS',7X,'CT'
     -,9X,'VBAR/VREF',3X,'DELV/VREF',4X,'CP',9X,'VMOM/VREF',2X,
     -'VENG/VREF')
  153   106 FORMAT('0','THE ADVANCE RATIO IS',F10.5)
  154   107 FORMAT(' ',' RT/RP',7X,'SIGMA')
  155   108 FORMAT(' ',2(F10.7,3X))
  156   110 FORMAT(' ',10(F8.5,3X),F8.5)
  157   111 FORMAT('1','THE MINIMUM VALUE OF CP IS ',F10.7,' THE CORRESPONDING
     - AREA RATIO IS',F10.7,//' AND THE MASS FLOW RATE COEFFICIENT IS',
     -F10.7)
  158   112 FORMAT('0','THE AREA RATIO IS INCREASED BY',F10.5,'PERCENT TO THE
     -DESIGN VALUE ',F10.7,//' CP AND EMASS ARE',F10.7,' AND ',F10.7,
     -' RESPECTIVELY')
  159   114 FORMAT('1','THE ADVANCE RATIO IS',F10.5)
  160   115 FORMAT(' ',1X,'R/RP',7X,'CP-NEW',5X,'EFF-ROT',3X,'EFF-STAT',4X,'EF
     -F-TOT',4X,'CL-STAT',4X,'CL-ROT',5X,'S/C-ROT',3X,'S/C-STAT',4X,'SGM
     -A',7X,'RT/RP')
      C
  161         CALL EXIT
  162         END
```

VARIABLE ALLOCATION MAP

NAME	AT	HEX1	DEC1	HEX2	DEC2	NAME	AT	HEX1	DEC1	HEX2	DEC2
LJRB	R	0142	00322			MSELO	R	0181	00433		
AA	R	0185	00437	02A4	00676	ADAB	R	02A5	00677	0394	00916
A2DAB	R	0395	00917	0484	01156	C	R	0485	01157	0574	01396
CP	R	0575	01397	0664	01636	CPP	R	0665	01637	0754	01876
CT	R	0755	01877	0844	02116	DLTAV	R	0845	02117	0934	02356
EL	R	0935	02357	0A24	02596	EFF	R	0A25	02597	0B14	02836
FF	R	0B15	02837	0C04	03076	F	R	0C05	03077	0CF4	03316
FMASS	R	0CF5	03317	0DE4	03556	RR	R	0DE5	03557	0ED4	03796
R	R	0ED5	03797	0FC4	04036	RT	R	0FC5	04037	10B4	04276
SC	R	10B5	04277	11A4	04516	SIGMA	R	1145	04517	1294	04756
VV	R	1295	04757	1384	04996	V	R	1385	04997	1474	05236
VBAR	R	1475	05237	1564	05476	VMOM	R	1565	05477	1654	05716
VENG	R	1655	05717	1744	05956	CPPP	R	1745	05957	1834	06196
HTRB	R	1835	06197	1924	06436	CLS	R	1925	06437	1A14	06676
CLR	R	1A15	06677	1B04	06916	SOCR	R	1B05	06917	1BF4	07156
SOCS	R	1BF5	07157	1CE4	07396	EROT	R	1CE5	07397	1DD4	07636
ESTAT	R	1DD5	07637	1EC4	07876	ETOT	R	1EC5	07877	1FB4	08116

THE LOSS COEFFICIENT, K, IS 0.08000

R/RB	V/VREF	A/AB	FMASS	CT	VBAR/VREF	DELV/VREF	CP	VMOM/VREF	VENG/VREF
0.11880	0.43000	0.00000	0.00000	0.10387					
0.12342	0.43613	0.00040	0.00104	0.10397	0.43319	50.43454	3.06011	0.43321	0.43322
0.13805	0.44227	0.00087	0.00218	0.10406	0.43637	24.11546	1.49183	0.43641	0.43643
0.14767	0.44849	0.00777	0.00342	0.10415	0.43963	15.39349	0.97232	0.43971	0.43975
0.15730	0.45475	0.01073	0.00475	0.10424	0.44297	11.06691	0.71478	0.44310	0.44316
0.16592	0.46116	0.01389	0.00620	0.10433	0.44639	8.49567	0.56189	0.44657	0.44668
0.17654	0.46774	0.01722	0.00779	0.10441	0.44991	6.80000	0.46120	0.45019	0.45032
0.18617	0.47458	0.02075	0.00941	0.10450	0.45354	5.60299	0.39026	0.45391	0.45409
0.19577	0.48175	0.02446	0.01119	0.10459	0.45729	4.71637	0.33795	0.45778	0.45802
0.20542	0.48930	0.02836	0.01308	0.10467	0.46113	4.03566	0.29773	0.46181	0.46212
0.21504	0.49723	0.03244	0.01509	0.10476	0.46523	3.49832	0.26519	0.46603	0.46642
0.22466	0.50545	0.03672	0.01724	0.10484	0.46945	3.06472	0.24086	0.47043	0.47092
0.23429	0.51391	0.04118	0.01951	0.10493	0.47381	2.70856	0.22018	0.47502	0.47562
0.24391	0.52251	0.04583	0.02192	0.10501	0.47833	2.41167	0.20306	0.47978	0.48050
0.25354	0.53119	0.05066	0.02447	0.10510	0.48296	2.16114	0.18873	0.48469	0.48555
0.26316	0.53993	0.05563	0.02716	0.10519	0.48772	1.94753	0.17663	0.48974	0.49074
0.27278	0.54878	0.06089	0.02999	0.10527	0.49257	1.76373	0.16633	0.49492	0.49608
0.28241	0.55781	0.06629	0.03298	0.10535	0.49752	1.60429	0.15751	0.50021	0.50154
0.29203	0.56709	0.07187	0.03612	0.10543	0.50257	1.46497	0.14992	0.50564	0.50714
0.30165	0.57667	0.07764	0.03942	0.10552	0.50772	1.34243	0.14335	0.51119	0.51288
0.31128	0.58659	0.08359	0.04288	0.10560	0.51300	1.23399	0.13765	0.51689	0.51879
0.32090	0.59675	0.08974	0.04652	0.10569	0.51839	1.13754	0.13269	0.52275	0.52486
0.33053	0.60707	0.09607	0.05033	0.10577	0.52390	1.05134	0.12838	0.52875	0.53110
0.34015	0.61744	0.10259	0.05432	0.10585	0.52952	0.97400	0.12462	0.53489	0.53749
0.34977	0.62776	0.10929	0.05850	0.10594	0.53523	0.90436	0.12135	0.54116	0.54402
0.35940	0.63786	0.11618	0.06286	0.10602	0.54103	0.84148	0.11851	0.54753	0.55066
0.36902	0.64804	0.12326	0.06741	0.10610	0.54689	0.78452	0.11605	0.55399	0.55739
0.37865	0.65803	0.13053	0.07216	0.10618	0.55280	0.73281	0.11392	0.56051	0.56413
0.38827	0.66796	0.13798	0.07710	0.10627	0.55875	0.68572	0.11209	0.56703	0.57104
0.39789	0.67784	0.14562	0.08224	0.10635	0.56475	0.64274	0.11054	0.57371	0.57794
0.40752	0.68770	0.15345	0.08758	0.10643	0.57077	0.60343	0.10922	0.58037	0.58499
0.41714	0.69752	0.16146	0.09314	0.10652	0.57682	0.56733	0.10812	0.58706	0.59187
0.42677	0.70724	0.16967	0.09890	0.10660	0.58283	0.53425	0.10721	0.59379	0.59887
0.43639	0.71681	0.17805	0.10487	0.10668	0.58898	0.50376	0.10649	0.60053	0.60589
0.44601	0.72619	0.18663	0.11105	0.10677	0.59507	0.47564	0.10593	0.60727	0.61291
0.45564	0.73532	0.19539	0.11746	0.10685	0.60116	0.44963	0.10551	0.61401	0.61992
0.46526	0.74421	0.20434	0.12403	0.10693	0.60723	0.42556	0.10523	0.62072	0.62690
0.47489	0.75290	0.21348	0.13092	0.10701	0.61328	0.40341	0.10508	0.62740	0.63384
0.48451	0.76145	0.22280	0.13793	0.10710	0.61930	0.38278	0.10504	0.63405	0.64073
0.49413	0.76989	0.23231	0.14527	0.10718	0.62530	0.36360	0.10510	0.64065	0.64757
0.50376	0.77827	0.24201	0.15277	0.10726	0.63126	0.34576	0.10526	0.64721	0.65437
0.51338	0.78661	0.25190	0.16051	0.10734	0.63720	0.32913	0.10551	0.65373	0.66111
0.52301	0.79492	0.26197	0.16847	0.10743	0.64310	0.31361	0.10585	0.66021	0.66781
0.53263	0.80319	0.27223	0.17667	0.10751	0.64896	0.29911	0.10627	0.66665	0.67447
0.54225	0.81141	0.28267	0.18510	0.10759	0.65483	0.28553	0.10677	0.67306	0.68109
0.55188	0.81959	0.29331	0.19378	0.10767	0.66066	0.27280	0.10734	0.67944	0.68767
0.56150	0.82773	0.30413	0.20269	0.10776	0.66646	0.26086	0.10798	0.68579	0.69421
0.57113	0.83583	0.31514	0.21184	0.10784	0.67223	0.24955	0.10868	0.69210	0.70072
0.58075	0.84390	0.32633	0.22125	0.10792	0.67799	0.23910	0.10945	0.69838	0.70719
0.59037	0.85195	0.33771	0.23090	0.10800	0.68371	0.22916	0.11029	0.70463	0.71363
0.60000	0.86000	0.34928	0.24080	0.10809	0.68942	0.21980	0.11118	0.71086	0.72005

May 3, 1979
WSG:JEF:nmj

THE MINIMUM VALUE OF CP IS 0.1050347 THE CORRESPONDING AREA RATIO IS 0.2220265

AND THE MASS FLOW RATE COEFFICIENT IS 0.1373917

THE AREA RATIO IS INCREASED BY 0.00000PERCENT TO THE DESIGN VALUE 0.2220265

CP AND FMASS ARE 0.1050347 AND 0.1373917 RESPECTIVELY

THE ADVANCE RATIO IS 0.6750D

RT/RP	SIGMA
0.3484780	2.5431433
0.3785555	2.0341032
0.4064131	1.7335970
0.4324800	1.6708734
0.4570627	1.6382771
0.4803691	1.6554174
0.5026341	1.7050619
0.5239354	1.7768431
0.5444040	1.8642197
0.5641304	1.9629011
0.5831898	2.0699720

May 3, 1979
WSG:JEF:mmj

THE ADVANCE RATIO IS 0.67500

R/RR	CP-NEW	EFF-ROT	EFF-STAT	EFF-TOT	CL-STAT	CL-ROT	S/C-ROT	S/C-STAT	SGMA	RT/RR
0.12642	2.69296	0.99896	0.99999	0.99998	2.93304	0.33353	0.21881	2.00000	0.14932	0.12174
0.13335	1.31244	0.99895	0.99994	0.99988	3.04339	0.33035	0.20966	2.00000	0.16582	0.13325
0.14757	0.65581	0.99886	0.99983	0.99968	3.13569	0.32761	0.20242	2.00000	0.18346	0.14457
0.15736	0.42343	0.99867	0.99963	0.99932	3.21424	0.32524	0.19657	2.00000	0.20225	0.15574
0.16692	0.49508	0.99844	0.99931	0.99875	3.28164	0.32319	0.19176	2.00000	0.22219	0.16681
0.17554	0.40672	0.99805	0.99883	0.99788	3.33986	0.32139	0.18775	2.00000	0.24329	0.17778
0.18517	0.34453	0.99749	0.99814	0.99664	3.39042	0.31982	0.18437	2.00000	0.26555	0.18868
0.19579	0.29832	0.99673	0.99718	0.99491	3.43460	0.31843	0.18150	2.00000	0.28898	0.19951
0.20542	0.26375	0.99569	0.99589	0.99259	3.47336	0.31721	0.17903	2.00000	0.31358	0.21028
0.21504	0.23672	0.99433	0.99418	0.98954	3.50751	0.31613	0.17690	2.00000	0.33937	0.22101
0.22466	0.21505	0.99257	0.99199	0.98561	3.53772	0.31517	0.17505	2.00000	0.36634	0.23171
0.23429	0.19758	0.99034	0.98920	0.98064	3.56457	0.31431	0.17343	2.00000	0.39450	0.24236
0.24391	0.18332	0.98755	0.98572	0.97444	3.58854	0.31354	0.17200	2.00000	0.42384	0.25299
0.25354	0.17141	0.98411	0.98139	0.96684	3.12174	0.31285	0.17073	1.72948	0.45436	0.26359
0.26316	0.16115	0.98092	0.97330	0.95454	2.32009	0.31222	0.16961	1.27349	0.48605	0.27416
0.27278	0.15268	0.97588	0.98238	0.95869	1.71882	0.31166	0.16860	0.94261	0.51891	0.28472
0.28241	0.14579	0.96995	0.98026	0.95071	1.26087	0.31114	0.16769	0.69347	0.55294	0.29526
0.29203	0.14043	0.96275	0.97581	0.93946	0.90719	0.31067	0.16687	0.49340	0.58814	0.30578
0.30165	0.13583	0.95203	0.97544	0.92469	0.91952	0.31024	0.16305	0.50565	0.62452	0.31628
0.31128	0.13138	0.93959	0.97855	0.91845	1.25865	0.30995	0.22064	0.71679	0.66208	0.32677
0.32090	0.12283	0.92565	0.97921	0.90541	1.50398	0.30949	0.26371	0.95236	0.70082	0.33725
0.33053	0.12431	0.91372	0.97885	0.89439	1.93960	0.30916	0.31273	1.21049	0.74075	0.34772
0.34015	0.12416	0.90305	0.97904	0.88322	2.25119	0.30886	0.36317	1.48868	0.78186	0.35818
0.34977	0.12228	0.89372	0.97712	0.87327	2.52744	0.30858	0.43048	1.78435	0.82414	0.36863
0.35940	0.12050	0.88574	0.97711	0.86546	2.63583	0.30832	0.50014	2.00000	0.86760	0.37907
0.36902	0.11867	0.87903	0.97704	0.86057	2.43382	0.30808	0.57759	2.00000	0.91223	0.38950
0.37865	0.11702	0.87367	0.93057	0.85669	2.24657	0.30786	0.66327	2.00000	0.95803	0.39993
0.38827	0.11553	0.86945	0.98202	0.85392	2.06304	0.30765	0.75764	2.00000	1.00498	0.41035
0.39789	0.11419	0.86637	0.98330	0.85190	1.89042	0.30745	0.86111	2.00000	1.05309	0.42076
0.40752	0.11295	0.86435	0.98442	0.85089	1.73020	0.30726	0.97413	2.00000	1.10235	0.43116
0.41714	0.11183	0.86336	0.98540	0.85076	1.58295	0.30709	1.09712	2.00000	1.15277	0.44157
0.42677	0.11081	0.86334	0.98624	0.85147	1.44859	0.30693	1.23047	2.00000	1.20434	0.45196
0.43639	0.10985	0.86428	0.98695	0.85300	1.32663	0.30677	1.37460	2.00000	1.25707	0.46235
0.44601	0.10898	0.86613	0.98754	0.85533	1.21632	0.30663	1.52985	2.00000	1.31094	0.47274
0.45564	0.10815	0.86887	0.98802	0.85846	1.11672	0.30649	1.69660	2.00000	1.36594	0.48312
0.46526	0.10824	0.86560	0.98839	0.85555	1.02709	0.29407	1.80000	2.00000	1.42209	0.49350
0.47489	0.10975	0.86171	0.98868	0.84227	0.94629	0.26681	1.80000	2.00000	1.47937	0.50388
0.48451	0.11169	0.85693	0.98888	0.82757	0.87343	0.24232	1.80000	2.00000	1.53778	0.51425
0.49413	0.11334	0.85276	0.98901	0.81174	0.80782	0.22163	1.80000	2.00000	1.59732	0.52462
0.50376	0.11552	0.84823	0.98908	0.79445	0.74853	0.20285	1.80000	2.00000	1.65798	0.53499
0.51338	0.11969	0.78435	0.98909	0.77578	0.69422	0.18615	1.80000	2.00000	1.71978	0.54535
0.52301	0.12325	0.78410	0.98902	0.75571	0.64436	0.17125	1.80000	2.00000	1.78270	0.55571
0.53263	0.12737	0.74243	0.98882	0.73420	0.60231	0.15791	1.80000	2.00000	1.84675	0.56607
0.54225	0.13210	0.71931	0.98876	0.71123	0.56227	0.14595	1.80000	2.00000	1.91193	0.57643
0.55188	0.13754	0.69471	0.98857	0.68677	0.52581	0.13518	1.80000	2.00000	1.97824	0.58678
0.56150	0.14379	0.66860	0.98833	0.65080	0.49255	0.12546	1.80000	2.00000	2.04568	0.59713
0.57113	0.15102	0.64095	0.98806	0.63330	0.46215	0.11658	1.80000	2.00000	2.11424	0.60748
0.58075	0.15941	0.61171	0.98776	0.60422	0.43433	0.10871	1.80000	2.00000	2.18393	0.61783
0.59037	0.16921	0.58087	0.98742	0.57357	0.40881	0.10147	1.80000	2.00000	2.25475	0.62817
0.60000	0.18076	0.54839	0.98706	0.54130	0.38536	0.09488	1.80000	2.00000	2.32670	0.63852

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WSG:JEF:mmj

THE ADVANCE RATIO IS 0.84400

RT/RR	SIGMA
0.3494720	2.2597461
0.3785555	1.6994997
0.4054131	1.3967762
0.4324800	1.2328453
0.4570527	1.1470328
0.4803691	1.1149607
0.5026341	1.1133928
0.5237354	1.1339526
0.5444040	1.1701269
0.5641304	1.2175961
0.5831898	1.2734556

May 3, 1979
WSG:JEF:mmj

THE ADVANCE RATIO IS 0.84400

R/RP	CP-NEW	EFF-ROT	EFF-STAT	EFF-TOT	CL-STAT	CL-ROT	S/C-ROT	S/C-STAT	SGMA	RT/R3
0.12842	2.69294	0.99997	0.99999	0.99998	2.61345	0.34241	0.24975	2.00000	0.12121	0.12174
0.13405	1.31292	0.99996	0.99996	0.99992	2.73407	0.33709	0.23710	2.00000	0.13214	0.13325
0.14767	0.85503	0.99989	0.99983	0.99977	2.84221	0.33614	0.22699	2.00000	0.14381	0.14457
0.15730	0.62731	0.99978	0.99974	0.99951	2.93466	0.33351	0.21875	2.00000	0.15623	0.15574
0.16542	0.49469	0.99959	0.99952	0.99911	3.01563	0.33116	0.21193	2.00000	0.16940	0.16681
0.17554	0.40647	0.99932	0.99919	0.99850	3.09685	0.32907	0.20620	2.00000	0.18333	0.17778
0.18617	0.34424	0.99893	0.99871	0.99764	3.14077	0.32719	0.20135	2.00000	0.19802	0.18868
0.19579	0.29836	0.99840	0.99805	0.99645	3.20553	0.32551	0.19720	2.00000	0.21347	0.19951
0.20542	0.26335	0.99769	0.99719	0.99488	3.25510	0.32400	0.19363	2.00000	0.22970	0.21028
0.21504	0.23574	0.99677	0.99604	0.99282	3.29929	0.32264	0.19053	2.00000	0.24671	0.22101
0.22465	0.21406	0.99560	0.99458	0.99020	3.33980	0.32142	0.18782	2.00000	0.26450	0.23171
0.23429	0.19633	0.99412	0.99273	0.98689	3.37425	0.32032	0.18544	2.00000	0.28308	0.24236
0.24391	0.18182	0.99229	0.99045	0.98281	3.40617	0.31933	0.18334	2.00000	0.30243	0.25299
0.25354	0.16985	0.99005	0.98765	0.97782	3.43502	0.31842	0.18147	2.00000	0.32256	0.26359
0.26316	0.15994	0.98734	0.98427	0.97180	3.46120	0.31760	0.17980	2.00000	0.34346	0.27416
0.27278	0.15122	0.98410	0.98360	0.96795	2.77559	0.31684	0.17830	1.59287	0.36513	0.28472
0.28241	0.14382	0.98026	0.98220	0.96379	2.13256	0.31615	0.17695	1.21426	0.38757	0.29526
0.29203	0.13765	0.97575	0.98221	0.95840	1.63389	0.31552	0.17572	0.92659	0.41078	0.30578
0.30165	0.13251	0.97050	0.98019	0.95127	1.24734	0.31494	0.17461	0.70092	0.43476	0.31628
0.31128	0.12854	0.96443	0.97634	0.94161	0.93139	0.31440	0.17361	0.52302	0.45952	0.32677
0.32090	0.12560	0.95737	0.97136	0.92768	0.74471	0.31391	0.17271	0.41836	0.48506	0.33725
0.33053	0.12225	0.94686	0.97593	0.92406	1.00623	0.31346	0.20925	0.58606	0.51139	0.34772
0.34015	0.11975	0.93589	0.97751	0.91581	1.26333	0.31304	0.24601	0.76855	0.53849	0.35818
0.34977	0.11774	0.92753	0.97780	0.90694	1.50739	0.31265	0.28728	0.96391	0.56637	0.36863
0.35940	0.11569	0.91893	0.97754	0.89833	1.72820	0.31229	0.33333	1.17002	0.59502	0.37907
0.36902	0.11482	0.91133	0.97707	0.89043	1.92007	0.31195	0.38458	1.38491	0.62444	0.38950
0.37865	0.11348	0.90461	0.97660	0.88344	2.07995	0.31164	0.44118	1.60705	0.65462	0.39993
0.38827	0.11242	0.89881	0.97622	0.87744	2.20774	0.31134	0.50345	1.83550	0.68556	0.41035
0.39789	0.11143	0.89391	0.97656	0.87295	2.22770	0.31107	0.57170	2.00000	0.71725	0.42076
0.40752	0.11042	0.88985	0.97815	0.87043	2.05766	0.31080	0.64617	2.00000	0.74970	0.43116
0.41714	0.10955	0.88659	0.97963	0.86853	1.89734	0.31056	0.72717	2.00000	0.78290	0.44157
0.42677	0.10879	0.88410	0.98091	0.86722	1.74784	0.31033	0.81493	2.00000	0.81685	0.45196
0.43639	0.10815	0.88232	0.98203	0.86647	1.60955	0.31011	0.90973	2.00000	0.85155	0.46235
0.44601	0.10761	0.88124	0.98301	0.86627	1.48272	0.30990	1.01178	2.00000	0.88699	0.47274
0.45564	0.10715	0.88081	0.98385	0.86658	1.36671	0.30970	1.12133	2.00000	0.92319	0.48312
0.46526	0.10676	0.88101	0.98456	0.86740	1.26104	0.30951	1.23858	2.00000	0.96009	0.49350
0.47489	0.10644	0.88180	0.98515	0.86871	1.16499	0.30933	1.36374	2.00000	0.99774	0.50388
0.48451	0.10619	0.88319	0.98554	0.87050	1.07779	0.30915	1.49703	2.00000	1.03612	0.51425
0.49413	0.10597	0.88514	0.98522	0.87277	0.99866	0.30899	1.63863	2.00000	1.07522	0.52462
0.50376	0.10580	0.88765	0.98531	0.87551	0.92684	0.30883	1.78876	2.00000	1.11505	0.53499
0.51338	0.10709	0.87587	0.98652	0.85703	0.85161	0.28528	1.80000	2.00000	1.15561	0.54535
0.52301	0.10871	0.86243	0.98666	0.83685	0.90231	0.26254	1.80000	2.00000	1.19689	0.55571
0.53263	0.11056	0.85720	0.98673	0.84582	0.74834	0.24218	1.80000	2.00000	1.23890	0.56607
0.54225	0.11264	0.84517	0.98673	0.83396	0.69715	0.22390	1.80000	2.00000	1.28163	0.57643
0.55188	0.11502	0.83232	0.98668	0.82123	0.65428	0.20744	1.80000	2.00000	1.32510	0.58678
0.56150	0.11765	0.81864	0.98658	0.80765	0.61325	0.19259	1.80000	2.00000	1.36928	0.59713
0.57113	0.12056	0.80411	0.98643	0.79320	0.57570	0.17915	1.80000	2.00000	1.41420	0.60748
0.58075	0.12383	0.78873	0.98623	0.77787	0.54128	0.16697	1.80000	2.00000	1.45984	0.61783
0.59037	0.12743	0.77247	0.98600	0.76165	0.50967	0.15589	1.80000	2.00000	1.50620	0.62817
0.60000	0.13141	0.75532	0.99572	0.74454	0.48059	0.14580	1.80000	2.00000	1.55330	0.63852

May 3, 1979
WSG:JEF:mmj

THE ADVANCE RATIO IS 1.12500

RT/RH	SIGMA
0.3484730	2.0330902
0.3785555	1.4360980
0.4064131	1.0966337
0.4324800	0.8929732
0.4570627	0.7624249
0.4803491	0.6656156
0.5026341	0.5943132
0.5239354	0.5351475
0.5444040	0.6315765
0.5641304	0.6393092
0.5831898	0.6554335

May 3, 1979
WSG:JEF:mmj

THE ADVANCE RATIO IS 1.12500

R/RB	CP-USA	EFF-ROT	EFF-STAT	EFF-TOT	CL-STAT	CL-ROT	S/C-ROT	S/C-STAT	SGMA	RT/RB
0.12842	2.69293	0.99999	0.99999	0.99999	2.17398	0.35337	0.30525	2.00000	0.09939	0.12174
0.13905	1.31289	0.99997	0.99997	0.99994	2.30149	0.35035	0.28773	2.00000	0.10600	0.13325
0.14757	0.85577	0.99992	0.99992	0.99985	2.41545	0.34753	0.27277	2.00000	0.11305	0.14457
0.15730	0.62321	0.99984	0.99983	0.99967	2.51771	0.34492	0.26045	2.00000	0.12053	0.15574
0.16592	0.49476	0.99972	0.99969	0.99940	2.60873	0.34251	0.25016	2.00000	0.12845	0.16681
0.17654	0.40525	0.99953	0.99947	0.99900	2.69074	0.34028	0.24145	2.00000	0.13681	0.17778
0.18617	0.34367	0.99927	0.99917	0.99844	2.76775	0.33822	0.23401	2.00000	0.14562	0.18868
0.19579	0.29800	0.99892	0.99876	0.99767	2.83565	0.33633	0.22759	2.00000	0.15489	0.19951
0.20542	0.26268	0.99845	0.99820	0.99666	2.89717	0.33458	0.22203	2.00000	0.16462	0.21028
0.21504	0.23534	0.99786	0.99749	0.99535	2.95299	0.33298	0.21717	2.00000	0.17481	0.22101
0.22466	0.21331	0.99710	0.99657	0.99368	3.00371	0.33151	0.21291	2.00000	0.18548	0.23171
0.23429	0.19540	0.99616	0.99543	0.99161	3.04990	0.33016	0.20914	2.00000	0.19662	0.24236
0.24391	0.18067	0.99501	0.99402	0.98906	3.09205	0.32891	0.20580	2.00000	0.20823	0.25299
0.25354	0.16845	0.99361	0.99230	0.98596	3.13062	0.32776	0.20281	2.00000	0.22030	0.26359
0.26316	0.15824	0.99193	0.99024	0.98226	3.16602	0.32670	0.20013	2.00000	0.23283	0.27416
0.27278	0.14968	0.98995	0.98779	0.97786	3.19858	0.32572	0.19771	2.00000	0.24581	0.28472
0.28241	0.14250	0.98761	0.98491	0.97271	3.22859	0.32481	0.19553	2.00000	0.25926	0.29526
0.29203	0.13621	0.98490	0.98339	0.96654	2.96205	0.32396	0.19354	1.75786	0.27315	0.30578
0.30165	0.13079	0.98175	0.98308	0.96514	2.98514	0.32318	0.19174	1.39253	0.28752	0.31628
0.31128	0.12565	0.97814	0.98240	0.96092	1.82435	0.32245	0.19009	1.10382	0.30235	0.32677
0.32090	0.12212	0.97402	0.98111	0.95562	1.45264	0.32178	0.18859	0.87314	0.31765	0.33725
0.33053	0.11905	0.96934	0.97886	0.94885	1.15008	0.32115	0.18722	0.68709	0.33342	0.34772
0.34015	0.11666	0.96407	0.97508	0.94005	0.90177	0.32056	0.18595	0.53573	0.34966	0.35818
0.34977	0.11504	0.95816	0.96979	0.92926	0.69643	0.32002	0.18479	0.41160	0.36636	0.36863
0.35940	0.11334	0.95132	0.96274	0.92253	0.75613	0.31951	0.20310	0.45823	0.33352	0.37907
0.36902	0.11116	0.94434	0.97286	0.91871	0.93027	0.31903	0.23386	0.58990	0.40114	0.38950
0.37865	0.10974	0.93759	0.97426	0.91356	1.08838	0.31858	0.26780	0.72694	0.41921	0.39993
0.38827	0.10853	0.93150	0.97485	0.90907	1.22052	0.31815	0.30509	0.86795	0.43772	0.41035
0.39789	0.10775	0.92584	0.97506	0.90275	1.34047	0.31775	0.34569	1.01175	0.45668	0.42076
0.40752	0.10705	0.92075	0.97514	0.89795	1.44571	0.31737	0.39037	1.15749	0.47607	0.43116
0.41714	0.10649	0.91622	0.97519	0.89349	1.52215	0.31702	0.43868	1.30470	0.49592	0.44157
0.42677	0.10604	0.91225	0.97530	0.88972	1.57974	0.31668	0.49096	1.45322	0.51619	0.45196
0.43639	0.10570	0.90883	0.97547	0.88653	1.62095	0.31635	0.54736	1.60322	0.53691	0.46235
0.44601	0.10546	0.90592	0.97572	0.88392	1.64862	0.31604	0.60802	1.75509	0.55806	0.47274
0.45564	0.10529	0.90350	0.97604	0.88185	1.66536	0.31575	0.67306	1.90941	0.57963	0.48312
0.46526	0.10516	0.90155	0.97679	0.89062	1.61953	0.31547	0.74261	2.00000	0.60163	0.49350
0.47489	0.10505	0.90004	0.97794	0.89018	1.50410	0.31520	0.81678	2.00000	0.62404	0.50388
0.48451	0.10503	0.89894	0.97895	0.88002	1.39775	0.31494	0.89568	2.00000	0.64688	0.51425
0.49413	0.10502	0.89824	0.97982	0.89011	1.30005	0.31469	0.97942	2.00000	0.67013	0.52462
0.50376	0.10523	0.89791	0.98056	0.89046	1.21044	0.31445	1.06813	2.00000	0.69379	0.53499
0.51338	0.10539	0.89795	0.98119	0.89106	1.12832	0.31422	1.16190	2.00000	0.71786	0.54535
0.52301	0.10562	0.89834	0.98170	0.89191	1.05311	0.31399	1.26083	2.00000	0.74236	0.55571
0.53263	0.10591	0.89907	0.98212	0.89299	0.98421	0.31378	1.36504	2.00000	0.76726	0.56607
0.54225	0.10624	0.90012	0.98245	0.89432	0.92107	0.31357	1.47461	2.00000	0.79258	0.57643
0.55188	0.10662	0.90149	0.98269	0.89593	0.86319	0.31337	1.58962	2.00000	0.81832	0.58678
0.56150	0.10704	0.90317	0.98285	0.89769	0.81007	0.31318	1.71017	2.00000	0.84446	0.59713
0.57113	0.10778	0.90274	0.98295	0.89734	0.76128	0.30690	1.80000	2.00000	0.87103	0.60748
0.58075	0.10936	0.89600	0.98293	0.89075	0.71641	0.28608	1.80000	2.00000	0.89301	0.61783
0.59037	0.11109	0.88885	0.98295	0.87369	0.67511	0.26724	1.80000	2.00000	0.92540	0.62817
0.60000	0.11296	0.88126	0.98287	0.86616	0.63704	0.25007	1.80000	2.00000	0.95321	0.63852

May 3, 1979
WSG:JEF:mmj

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// READ DEVICE-SYSIN
// PRINT DEVICE-PRTR
*PROCESS MAP,LINK(R,LIB(JEFLIB)),SIZE(24)
    1          PROGRAM PSPPDP
    2          REAL LORB,MSFLO
    3          DIMENSION AA(60),A(60),AOAB(60),A2OAB(60),B(60),C(60),CP(60)
    4          DIMENSION CPP(60),CT(60),DLTAV(60),EL(60),FFF(60),FF(60),F(60)
    5          DIMENSION V(60),VBAR(60),VMOM(60),VENG(60),VVMOM(60),VVENG(60)
    6          DIMENSION FMASS(60),RR(60),R(60),RT(60),SC(60),SIGMA(60),VV(60)
    7          DIMENSION CPPP(60),RTRB(60),CLS(60),CLR(60),SOCR(60),SOCS(60)
    8          DIMENSION EROT(60),ESTAT(60),ETOT(60),SGMA(60)
    9          EQUIVALENCE (A(1),VVMOM(1)),(B(1),VVENG(1))
               C
               C     THE PRELIMINARY PUMPJET DESIGN COMPUTER PROGRAM SELECTS AN
               C     OPTIMUM FLOW AREA FROM THE REFERENCE VELOCITY PROFILE BASED ON
               C     A MINIMUM VALUE OF PROPULSIVE COEFFICIENT.  FROM THESE DATA THE
               C     PROGRAM ALSO PREDICTS THE CAVITATION PERFORMANCE AS A FUNCTION
               C     OF ADVANCE RATIO AND ROTOR TIP DIAMETER.
               C     ADDITIONALLY, THE PROGRAM COMPUTES THE SPACE TO CHORD RATIO,
               C     LIFT COEFFICIENT, STAGE EFFICIENCY, AND TOTAL PUMPJET
               C     EFFICIENCY AS A FUNCTION OF INGESTED MASS FLOW AND ADVANCE RATIO.
               C
   10          READ(4,100)N
   11          DO 1 I=1,N
   12        1 READ(4,101)R(I),V(I)
   13          READ(4,101)CDBB,CDS,V1OV2,ETAH
   14          READ(4,101)PHI,LORB,RH1,RH2
   15          CALL SPFIT(N,R,V,SC,EL,A,B,C)
               C
               C     N IS THE NUMBER OF DATA POINTS DEFINING THE THE REFERENCE VELOCITY
               C     PROFILE
               C     R(I) AND V(I) ARE THE DATA POINTS DEFINING THE REFERENCE VELOCITY
               C     PROFILE
               C     CDBB IS THE BARE BODY DRAG COEFFICIENT
               C     CDS IS THE SKIN FRICTION DRAG COEFFICIENT
               C     V1OV2 IS A VELOCITY RATIO WHICH REPRESENTS THE ACCELERATION OF THE
               C     FLUID FROM THE REFERENCE STATION TO THE ROTOR DISK PLANE
               C     ETAH IS THE HYDRAULIC EFFICIENCY
               C     PHI IS THE LOCAL BODY ANGLE AT THE REFERENCE STATION WITH RESPECT
               C     TO THE VEHICLE CENTERLINE
               C     LORB IS THE NONDIMENSIONAL SHROUD LENGTH
               C     RH1 IS THE NONDIMENSIONAL BODY RADIUS AT THE REFERENCE STATION
               C     RH2 IS THE NONDIMENSIONAL BODY RADIUS AT THE ROTOR HUB
               C
   16          DLTAR=(R(N)-R(1))/50.0
   17          RR(1)=R(1)
   18          DO 2 I=2,51
   19        2 RR(I)=RR(I-1)+DLTAR
   20          DO 3 I=1,51
   21          CALL SPGET(N,R,V,SC,EL,RR(I),VV(I),YP,DP)
```

```
      CT(I)=1.00*CDBB+4.0*CDS*LORB*SQRT(V1OV2*((RR(I))**2-RH1**2)+
     -RH2**2)
C
C     CT(I) IS THE REQUIRED THRUST COEFFICIENT
C
    3 F(I)=2.0*RR(I)/COS(PHI)
      AOAB(1)=0.0
      DO 4 I=2,51
    4 AOAB(I)=AOAB(I-1)+0.5*(F(I)+F(I-1))*(RR(I)-RR(I-1))
C
C     AOAB(I) IS THE FLOW AREA AT THE REFERENCE STATION AS A FUNCTION OF
C     R/RB
C
      DO 5 I=1,51
      F(I)=2.0*(VV(I)*RR(I)/COS(PHI))
      FF(I)=VV(I)*F(I)
    5 FFF(I)=VV(I)*FF(I)
      FMASS(1)=0.0
      VVMOM(1)=0.0
      VVENG(1)=0.0
      DO 6 I=2,51
      FMASS(I)=FMASS(I-1)+0.5*(F(I)+F(I-1))*(RR(I)-RR(I-1))
      VVMOM(I)=VVMOM(I-1)+0.5*(FF(I)+FF(I-1))*(RR(I)-RR(I-1))
      VVENG(I)=VVENG(I-1)+0.5*(FFF(I)+FFF(I-1))*(RR(I)-RR(I-1))
      VBAR(I)=FMASS(I)/AOAB(I)
      VMOM(I)=VVMOM(I)/FMASS(I)
      VENG(I)=SQRT(VVENG(I)/FMASS(I))
    6 DLTAV(I)=0.5*(CT(I)/(COS(PHI)*AOAB(I)*VMOM(I)))
C
C     FMASS(I) IS THE MASS FLOW RATE COEFFICIENT
C     VBAR(I) IS AN AVERAGE VELOCITY RATIO BASED ON MASS FLOW RATE
C     VMOM(I) IS AN AVERAGE VELOCITY RATIO BASED ON MOMENTUM
C     VENG(I) IS AN AVERAGE VELOCITY RATIO BASED ON ENERGY
C     DLTAV(I) IS THE NONDIMENSIONAL VELOCITY CHANGE BASED ON MOMENTUM
C
      READ(4,101)XXK
      WRITE(3,104)XXK
      WRITE(3,105)
C
C     XXK IS THE LOSS COEFFICIENT
C
      WRITE(3,102)RR(1),VV(1),AOAB(1),FMASS(1),CT(1)
      DO 7 I=2,51
      CP(I)=(2.0*DLTAV(I)*VENG(I)+DLTAV(I)**2+XXK*VENG(I)**2)
     -*AOAB(I)*VBAR(I)/ETAH
    7 WRITE(3,102)RR(I),VV(I),AOAB(I),FMASS(I),CT(I),VBAR(I),DLTAV(I),
     -CP(I),VMOM(I),VENG(I)
C
C     THE FOLLOWING STATEMENTS (THROUGH 12) LOCATE THE POINT OF
C     MINIMUM PROPULSIVE COEFFICIENT
C
```

```
      DO 9 I=1,48
      CPP(I)=CP(I+3)
    9 AA(I)=AOAB(I+3)
      CALL SPFIT(48,AA,CPP,SC,EL,A,B,C)
      AINC=AOAB(51)/1000.0
      AAA=AOAB(4)
      CALL SPGET(48,AA,CPP,SC,EL,AAA,Y,YD,YDP)
      AQ=AAA
      YQ=Y
      DO 11 I=1,1000
      AAA=AAA+AINC
      CALL SPGET(48,AA,CPP,SC,EL,AAA,Y,YD,YDP)
      IF(Y-YQ)10,12,12
   10 AQ=AAA
      YQ=Y
   11 CONTINUE
   12 AMIN1=0.5*(AQ+AAA)
      READ(4,101)PRCNT
      AMIN2=(1.0+PRCNT)*AMIN1
C
C     AMIN1 IS THE FLOW AREA AT THE REFERENCE STATION CORRESPONDING TO
C     THE POINT OF MINIMUM PROPULSIVE COEFFICIENT
C     PRCNT IS THE AMOUNT BY WHICH THE DESIGNER INCREASES AMIN1 TO AMIN2
C     AMIN2 IS THE DESIGN VALUE OF THE FLOW AREA AT THE REFERENCE
C     STATION
C
      CALL SPGET(48,AA,CPP,SC,EL,AMIN1,Y1,YP,YDP)
      CALL SPGET(48,AA,CPP,SC,EL,AMIN2,Y2,YP,YDP)
      CALL SPFIT(51,AOAB,FMASS,SC,EL,A,B,C)
      CALL SPGET(51,AOAB,FMASS,SC,EL,AMIN1,Y3,YP,YDP)
      CALL SPGET(51,AOAB,FMASS,SC,EL,AMIN2,Y4,YP,YDP)
      WRITE(3,111)Y1,AMIN1,Y3
      P=100.0*PRCNT
      WRITE(3,112)P,AMIN2,Y2,Y4
      VENG(1)=0.0
      CALL SPFIT(51,AOAB,VENG,SC,EL,A,B,C)
      CALL SPGET(51,AOAB,VENG,SC,EL,AMIN2,Y5,YP,YDP)
      MSFLO=AMIN2*Y5
C
C     MSFLO IS A MASS FLOW RATE COEFFICIENT BASED ON VENG(I)
C     RT(I) IS THE NONDIMENSIONAL ROTOR TIP RADIUS
C     SIGMA(I) IS THE CAVITATION INDEX
C
      AINC2=AMIN2/10.0
      A2OAB(1)=AMIN2/2.0
      READ(4,101)CB,PHI2
C
C     CB IS AN ASSUMED VALUE OF THE MINIMUM PRESSURE COEFFICIENT OF THE
C     BLADE TIP SECTION
C     PH2 IS THE LOCAL FLOW ANGLE AT THE ROTOR HUB IN RADIANS
C
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```
      RT(1)=SQRT(A2OAB(1)*COS(PHI2)+RH2**2)
      DO 13 I=2,11
      A2OAB(I)=A2OAB(I-1)+AINC2
   13 RT(I)=SQRT(A2OAB(I)*COS(PHI2)+RH2**2)
      READ(4,100)NN
      DO 29 J=1,NN
      READ(4,101)ADRAT
      IF(J.NE.1) GO TO 15
      WRITE(3,106)ADRAT
      GO TO 17
   15 WRITE(3,114)ADRAT
   17 WRITE(3,107)
      DO 19 I=1,11
      SIGMA(I)=CB*(MSFLO**2/(A2OAB(I)**2)+((3.1416/ADRAT)**2)*RT(I)**2+
     -0.990+0.245*((ADRAT/3.1416)**2)/RT(I)**2)+MSFLO**2*(1.0/A2OAB(I)**
     -2-0.95/(AMIN2**2))+0.245*(ADRAT/3.1416)**2/RT(I)**2
   19 WRITE(3,108)RT(I),SIGMA(I)
C
      WRITE(3,114)ADRAT
      WRITE(3,115)
      DO 27 I=2,51
C
C     STATOR APPLICATION
C
      HBAR=2.*DLTAV(I)*VBAR(I)+DLTAV(I)**2+XXK*VBAR(I)**2
      RTRB(I)=SQRT(AOAB(I)*V1OV2*COS(PHI2)+RH2**2)
      UBARS=0.9*3.1416*RTRB(I)/ADRAT
      VTHVS=HBAR/(2.*UBARS)
      IF(VTHVS.LE.UBARS) GO TO 21
      VTHVS=UBARS
   21 CONTINUE
      WOVS=1.
      CLSA=1.4
      SOCS(I)=0.5*CLSA/VTHVS
      IF(SOCS(I).LT.2.) GO TO 23
      SOCS(I)=2.
   23 CONTINUE
      CLS(I)=2.*SOCS(I)*VTHVS/WOVS
      CDPS=0.012-.004*SOCS(I)
      CDSS=0.018*CLS(I)**2
      CDS=CDPS+CDSS
      ALP1S=0.
      CA1S=1.
      ALP2S=ATAN(VTHVS/VBAR(I))
      ALPMS=ATAN(0.5*(SIN(ALP2S)/COS(ALP2S)))
      CAMS=COS(ALPMS)
      PLOSS=CDS*CA1S**2/(SOCS(I)*CAMS**3)
      ESTAT(I)=1.-PLOSS*WOVS**2/HBAR
C
C     ROTOR APPLICATION
C
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      VTHVR=VTHVS
      UBARR=0.9*3.1416*RTRB(I)/ADRAT+VTHVR
      W1OV=SQRT(UBARR**2+VBAR(I)**2)
      SGMA(I)=CB*W1OV**2+VTHVR**2+XXK*VBAR(I)**2
      SOCR(I)=(SGMA(I)-VTHVR**2)/(2.*VTHVR*W1OV)
      IF(SOCR(I).LT.1.8) GO TO 25
      SOCR(I)=1.8
   25 CONTINUE
      CLR(I)=2.*VTHVR*SOCR(I)/W1OV
      CDPR=0.020-0.004*SOCR(I)
      CDSR=0.018*CLR(I)**2
      CDR=CDPR+CDSR
      ALP1R=ATAN(UBARR/VBAR(I))
      CA1R=COS(ALP1R)
      ALP2R=ATAN(UBARS/(1.25*VBAR(I)))
      TN1=SIN(ALP1R)/COS(ALP1R)
      TN2=SIN(ALP2R)/COS(ALP2R)
      ALPMR=ATAN((TN1+TN2)/2.)
      CAMR=COS(ALPMR)
      PLOSR=CDR*CA1R**2/(SOCR(I)*CAMR**3)
      EROT(I)=1.-PLOSR*W1OV**2/HBAR
      ETOT(I)=EROT(I)*ESTAT(I)
      CPPP(I)=CP(I)*ETAH/ETOT(I)
   27 WRITE(3,110)RR(I),CPPP(I),EROT(I),ESTAT(I),ETOT(I),CLS(I),CLR(I),
     -SOCR(I),SOCS(I),SGMA(I),RTRB(I)
   29 CONTINUE
C
C     HBAR IS THE NONDIMENSIONAL EXPRESSION FOR THE ENERGY
C     PLACED IN THE FLUID
C     UBARR IS THE PERIPHERAL RELATIVE VELOCITY COMPONENT
C     AT THE ROTOR INLET
C     UBARS IS THE ROTOR PERIPHERAL VELOCITY RATIO AT 0.9 RT/RB
C     RTRB(I) IS THE NONDIMENSIONAL ROTOR TIP RADIUS
C     VTHVR IS AN AVERAGE PERIPHERAL ABSOLUTE VELOCITY RATIO
C     AT THE ROTOR LEADING EDGE
C     W1OV IS AN AVERAGE RELATIVE VELOCITY RATIO AT THE
C     ROTOR LEADING EDGE
C     SOCR(I) IS THE BLADE SPACING TO CHORD RATIO FOR THE ROTOR
C     CLR(I) IS THE ROTOR LIFT COEFFICIENT
C     CDPR IS THE ROTOR PROFILE DRAG COEFFICIENT
C     CDSR IS THE ROTOR SECONDARY FLOW DRAG COEFFICIENT
C     CDR IS THE ROTOR DRAG COEFFICIENT
C     EROT(I) IS THE ROTOR HYDRAULIC EFFICIENCY
C     PLOSR IS THE PRESSURE LOSS THROUGH THE ROTOR
C     VTHVS IS AN AVERAGE PERIPHERAL ABSOLUTE VELOCITY RATIO
C     AT THE STATOR INLET
C     WOVS IS AN AVERAGE RELATIVE VELOCITY RATIO AT THE STATOR INLET
C     SOCS(I) IS THE BLADE SPACING TO CHORD RATIO FOR THE STATOR
C     CLS(I) IS THE STATOR LIFT COEFFICIENT
C     CDPS IS THE STATOR PROFILE DRAG COEFFICIENT
C     CDSS IS THE STATOR SECONDARY FLOW DRAG COEFFICIENT
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C     CDS IS THE STATOR DRAG COEFFICIENT
C     PLOSS IS THE PRESSURE LOSS THROUGH THE STATOR
C     ESTAT(I) IS THE STATOR HYDRAULIC EFFICIENCY
C     ETOT(I) IS THE TOTAL PUMPJET HYDRAULIC EFFICIENCY
C     CPPP(I) IS THE PROPULSIVE COEFFICIENT AS A FUNCTION
C     OF CALCULATED TOTAL EFF. VS ASSUMED TOTAL EFF.
C     SGMA(I) IS THE CAVITATION INDEX FOR A GIVEN MASS FLOW
C
  100 FORMAT(I5)
  101 FORMAT(5F10.5)
  102 FORMAT(' ',10(F8.5,4X))
  104 FORMAT('1','THE LOSS COEFFICIENT, K, IS',F10.5)
  105 FORMAT(' ',1X,'R/RB',8X,'V/VREF',6X,'A/AB',8X,'FMASS',7X,'CT'
     -,9X,'VBAR/VREF',3X,'DELV/VREF',4X,'CP',9X,'VMOM/VREF',2X,
     -'VENG/VREF')
  106 FORMAT('0','THE ADVANCE RATIO IS',F10.5)
  107 FORMAT(' ',' RT/RB',7X,'SIGMA')
  108 FORMAT(' ',2(F10.7,3X))
  110 FORMAT(' ',10(F8.5,3X),F8.5)
  111 FORMAT('1','THE MINIMUM VALUE OF CP IS ',F10.7,' THE CORRESPONDING
     - AREA RATIO IS',F10.7,//' AND THE MASS FLOW RATE COEFFICIENT IS',
     -F10.7)
  112 FORMAT('0','THE AREA RATIO IS INCREASED BY',F10.5,'PERCENT TO THE
     -DESIGN VALUE ',F10.7,//' CP AND FMASS ARE',F10.7,' AND ',F10.7,
     -' RESPECTIVELY')
  114 FORMAT('1','THE ADVANCE RATIO IS',F10.5)
  115 FORMAT(' ',1X,'R/RB',7X,'CP-NEW',5X,'EFF-ROT',3X,'EFF-STAT',4X,'EF
     -F-TOT',4X,'CL-STAT',4X,'CL-ROT',5X,'S/C-ROT',3X,'S/C-STAT',4X,'SGM
     -A',7X,'RT/RB')
C
      CALL EXIT
      END
```

VARIABLE ALLOCATION MAP

NAME	AT	HEX1	DEC1	HEX2	DEC2	NAME	AT	HEX1	DEC1	HEX2	DEC2
LORB	R	01AD	00429			MSFLO	R	0131	00433		
AA	R	0185	00437	02A4	00676	AOAB	R	02A5	00677	0394	00916
A2OAB	R	0395	00917	0484	01156	C	R	0485	01157	0574	01396
CP	R	0575	01397	0664	01636	CPP	R	0665	01637	0754	01876
CT	R	0755	01877	0844	02116	DLTAV	R	0845	02117	0934	02356
EL	R	0935	02357	0A24	02596	FFF	R	0A25	02597	0B14	02836
FF	R	0B15	02837	0C04	03076	F	R	0C05	03077	0CF4	03316
V	R	0CF5	03317	0DE4	03556	VBAR	R	0DE5	03557	0ED4	03796
VMOM	R	0ED5	03797	0FC4	04036	VENG	R	0FC5	04037	10B4	04276
FMASS	R	10B5	04277	11A4	04516	RR	R	11A5	04517	1294	04756
R	R	1295	04757	1384	04996	RT	R	1385	04997	1474	05236
SC	R	1475	05237	1564	05476	SIGMA	R	1565	05477	1654	05716
VV	R	1655	05717	1744	05956	CPPP	R	1745	05957	1834	06196
RTRB	R	1835	06197	1924	06436	CLS	R	1925	06437	1A14	06676

May 3, 1979
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THE LOSS COEFFICIENT, K, IS 0.08000

R/RB	V/VREF	A/AB	FMASS	CT	VBAR/VREF	DELV/VREF	CP	VMOM/VREF	VENG/VREF
0.11880	0.43000	0.00000	0.00000	0.10387					
0.12842	0.43613	0.00240	0.00104	0.10397	0.43319	50.43454	3.06011	0.43321	0.43322
0.13805	0.44229	0.00499	0.00218	0.10406	0.43637	24.11546	1.49183	0.43641	0.43643
0.14767	0.44849	0.00777	0.00342	0.10415	0.43963	15.39349	0.97232	0.43971	0.43975
0.15730	0.45476	0.01073	0.00475	0.10424	0.44297	11.06691	0.71478	0.44310	0.44316
0.16692	0.46116	0.01388	0.00620	0.10433	0.44639	8.49567	0.56189	0.44659	0.44668
0.17654	0.46774	0.01722	0.00775	0.10441	0.44991	6.80000	0.46120	0.45019	0.45032
0.18617	0.47458	0.02075	0.00941	0.10450	0.45354	5.60299	0.39026	0.45391	0.45409
0.19579	0.48175	0.02446	0.01118	0.10459	0.45729	4.71637	0.33785	0.45778	0.45802
0.20542	0.48930	0.02836	0.01308	0.10467	0.46118	4.03566	0.29773	0.46181	0.46212
0.21504	0.49723	0.03244	0.01509	0.10476	0.46523	3.49832	0.26619	0.46603	0.46642
0.22466	0.50545	0.03672	0.01724	0.10484	0.46945	3.06472	0.24086	0.47043	0.47092
0.23429	0.51391	0.04118	0.01951	0.10493	0.47381	2.70856	0.22018	0.47502	0.47562
0.24391	0.52251	0.04583	0.02192	0.10501	0.47833	2.41167	0.20306	0.47978	0.48050
0.25354	0.53119	0.05066	0.02447	0.10510	0.48296	2.16114	0.18873	0.48469	0.48555
0.26316	0.53993	0.05568	0.02716	0.10518	0.48772	1.94753	0.17663	0.48974	0.49074
0.27278	0.54878	0.06089	0.02999	0.10527	0.49257	1.76373	0.16633	0.49492	0.49608
0.28241	0.55781	0.06629	0.03298	0.10535	0.49752	1.60429	0.15751	0.50021	0.50154
0.29203	0.56709	0.07187	0.03612	0.10543	0.50257	1.46497	0.14992	0.50564	0.50714
0.30165	0.57667	0.07764	0.03942	0.10552	0.50772	1.34243	0.14335	0.51119	0.51288
0.31128	0.58659	0.08359	0.04288	0.10560	0.51300	1.23399	0.13765	0.51689	0.51879
0.32090	0.59675	0.08974	0.04652	0.10569	0.51839	1.13754	0.13269	0.52275	0.52486
0.33053	0.60707	0.09607	0.05033	0.10577	0.52390	1.05134	0.12838	0.52875	0.53110
0.34015	0.61744	0.10259	0.05432	0.10585	0.52952	0.97400	0.12462	0.53489	0.53749
0.34977	0.62776	0.10929	0.05850	0.10594	0.53523	0.90436	0.12135	0.54116	0.54402
0.35940	0.63796	0.11618	0.06286	0.10602	0.54103	0.84148	0.11851	0.54753	0.55066
0.36902	0.64804	0.12326	0.06741	0.10610	0.54689	0.78452	0.11605	0.55399	0.55739
0.37865	0.65803	0.13053	0.07216	0.10618	0.55280	0.73281	0.11392	0.56051	0.56418
0.38827	0.66796	0.13798	0.07710	0.10627	0.55875	0.68572	0.11209	0.56708	0.57104
0.39789	0.67784	0.14562	0.08224	0.10635	0.56475	0.64274	0.11054	0.57371	0.57794
0.40752	0.68770	0.15345	0.08758	0.10643	0.57077	0.60343	0.10922	0.58037	0.58489
0.41714	0.69752	0.16146	0.09314	0.10652	0.57682	0.56738	0.10812	0.58706	0.59187
0.42677	0.70724	0.16967	0.09890	0.10660	0.58289	0.53425	0.10721	0.59379	0.59887
0.43639	0.71681	0.17805	0.10487	0.10668	0.58898	0.50376	0.10649	0.60053	0.60589
0.44601	0.72619	0.18663	0.11106	0.10677	0.59507	0.47564	0.10593	0.60727	0.61291
0.45564	0.73532	0.19539	0.11746	0.10685	0.60116	0.44968	0.10551	0.61401	0.61992
0.46526	0.74421	0.20434	0.12408	0.10693	0.60723	0.42566	0.10523	0.62072	0.62690
0.47489	0.75290	0.21348	0.13092	0.10701	0.61328	0.40341	0.10508	0.62740	0.63384
0.48451	0.76145	0.22280	0.13798	0.10710	0.61930	0.38278	0.10504	0.63405	0.64073
0.49413	0.76989	0.23231	0.14527	0.10718	0.62530	0.36360	0.10510	0.64065	0.64757
0.50376	0.77827	0.24201	0.15277	0.10726	0.63126	0.34576	0.10526	0.64721	0.65437
0.51338	0.78661	0.25190	0.16051	0.10734	0.63720	0.32913	0.10551	0.65373	0.66111
0.52301	0.79492	0.26197	0.16847	0.10743	0.64310	0.31361	0.10585	0.66021	0.66781
0.53263	0.80319	0.27223	0.17667	0.10751	0.64898	0.29911	0.10627	0.66665	0.67447
0.54225	0.81141	0.28267	0.18510	0.10759	0.65483	0.28553	0.10677	0.67306	0.68109
0.55188	0.81959	0.29331	0.19378	0.10767	0.66066	0.27280	0.10734	0.67944	0.68767
0.56150	0.82773	0.30413	0.20269	0.10776	0.66646	0.26086	0.10798	0.68579	0.69421
0.57113	0.83583	0.31514	0.21184	0.10784	0.67223	0.24965	0.10868	0.69210	0.70072
0.58075	0.84390	0.32633	0.22125	0.10792	0.67799	0.23910	0.10945	0.69838	0.70719
0.59037	0.85195	0.33771	0.23090	0.10800	0.68371	0.22916	0.11029	0.70463	0.71363
0.60000	0.86000	0.34928	0.24080	0.10809	0.68942	0.21980	0.11118	0.71086	0.72005

May 3, 1979
WSG:JEF:mmj

THE MINIMUM VALUE OF CP IS 0.1050347 THE CORRESPONDING AREA RATIO IS 0.2220265

AND THE MASS FLOW RATE COEFFICIENT IS 0.1373917

THE AREA RATIO IS INCREASED BY 0.00000PERCENT TO THE DESIGN VALUE 0.2220265

CP AND FMASS ARE 0.1050347 AND 0.1373917 RESPECTIVELY

THE ADVANCE RATIO IS 0.67500

RT/RB	SIGMA
0.3484780	2.9489250
0.3785555	2.4214153
0.4064131	2.1573200
0.4324800	2.0341940
0.4570627	1.9933653
0.4803891	2.0038347
0.5026341	2.0479650
0.5239354	2.1151104
0.5444040	2.1985359
0.5641304	2.2938061
0.5831898	2.3979073

May 3, 1979
WSG:JEF:mmj

THE ADVANCE RATIO IS 0.67500

R/RB	CP-NEW	EFF-ROT	EFF-STAT	EFF-TOT	CL-STAT	CL-ROT	S/C-ROT	S/C-STAT	SGMA	RT/RB
0.12842	2.69303	0.99997	0.99998	0.99995	1.40000	0.31223	0.33922	1.37267	0.64343	0.12174
0.13805	1.31315	0.99983	0.99991	0.99974	1.40000	0.31060	0.33349	1.25416	0.75770	0.13325
0.14767	0.85628	0.99951	0.99974	0.99925	1.40000	0.30931	0.32906	1.15595	0.86019	0.14457
0.15730	0.63008	0.99888	0.99942	0.99830	1.40000	0.30827	0.32555	1.07299	1.01089	0.15574
0.16692	0.49610	0.99779	0.99889	0.99669	1.40000	0.30741	0.32271	1.00182	1.14981	0.16681
0.17654	0.40826	0.99604	0.99807	0.99412	1.40000	0.30669	0.32038	0.93999	1.29695	0.17778
0.18617	0.34681	0.99338	0.99684	0.99024	1.40000	0.30608	0.31844	0.88571	1.45231	0.18868
0.19579	0.30194	0.98949	0.99509	0.98464	1.40000	0.30557	0.31680	0.83763	1.61590	0.19951
0.20542	0.26923	0.98401	0.99267	0.97680	1.40000	0.30513	0.31541	0.79470	1.78774	0.21028
0.21504	0.24245	0.97649	0.98941	0.96615	1.40000	0.30475	0.31422	0.75612	1.96782	0.22101
0.22466	0.22264	0.96643	0.98510	0.95202	1.40000	0.30442	0.31320	0.72123	2.15614	0.23171
0.23429	0.20751	0.95324	0.97951	0.93371	1.40000	0.30413	0.31230	0.68952	2.35272	0.24236
0.24391	0.19527	0.93626	0.97241	0.91043	1.40000	0.30388	0.31152	0.66055	2.55754	0.25299
0.25354	0.18843	0.91476	0.96352	0.88139	1.40000	0.30365	0.31083	0.63399	2.77059	0.26359
0.26316	0.18377	0.88795	0.95252	0.84579	1.40000	0.30345	0.31022	0.60953	2.99189	0.27416
0.27278	0.18231	0.85493	0.93911	0.80288	1.40000	0.30327	0.30967	0.58694	3.22142	0.28472
0.29241	0.18432	0.81477	0.92293	0.75198	1.40000	0.30311	0.30918	0.56599	3.45918	0.29526
0.29203	0.19048	0.76545	0.90363	0.69259	1.40000	0.30296	0.30874	0.54652	3.70518	0.30578
0.30165	0.18508	0.74917	0.90978	0.68158	1.40000	0.30310	0.32491	0.58219	3.45967	0.31628
0.31128	0.16904	0.76702	0.93420	0.71656	1.40000	0.30351	0.36216	0.68200	2.87457	0.32677
0.32090	0.15754	0.78065	0.94945	0.74120	1.40000	0.30388	0.40497	0.79274	2.46291	0.33725
0.33053	0.14880	0.79133	0.95939	0.75920	1.40000	0.30421	0.45378	0.91489	2.17043	0.34772
0.34015	0.14190	0.79994	0.96613	0.77284	1.40000	0.30450	0.50907	1.04888	1.96164	0.35818
0.34977	0.13628	0.80707	0.97088	0.78357	1.40000	0.30475	0.57130	1.19508	1.81282	0.36863
0.35940	0.13162	0.81319	0.97436	0.79234	1.40000	0.30496	0.64090	1.35381	1.70777	0.37907
0.36902	0.12769	0.81860	0.97701	0.79978	1.40000	0.30512	0.71834	1.52532	1.63527	0.38950
0.37865	0.12432	0.82358	0.97909	0.80636	1.40000	0.30526	0.80404	1.70985	1.58740	0.39993
0.38827	0.12143	0.82829	0.98079	0.81238	1.40000	0.30536	0.89844	1.90759	1.55847	0.41035
0.39789	0.11883	0.83290	0.98279	0.81856	1.32157	0.30543	1.00197	2.00000	1.54437	0.42076
0.40752	0.11653	0.83752	0.98480	0.82479	1.19489	0.30548	1.11506	2.00000	1.54206	0.43116
0.41714	0.11452	0.84226	0.98640	0.83080	1.08463	0.30551	1.23813	2.00000	1.54928	0.44157
0.42677	0.11276	0.84720	0.98768	0.83676	0.98821	0.30552	1.37159	2.00000	1.56432	0.45196
0.43639	0.11119	0.85240	0.98872	0.84278	0.90353	0.30552	1.51581	2.00000	1.58588	0.46235
0.44601	0.10980	0.85792	0.98957	0.84897	0.82885	0.30551	1.67117	2.00000	1.61295	0.47274
0.45564	0.10901	0.86013	0.99027	0.85176	0.76273	0.29917	1.80000	2.00000	1.64474	0.48312
0.46526	0.11010	0.84889	0.99084	0.84111	0.70398	0.27264	1.80000	2.00000	1.68065	0.49350
0.47489	0.11151	0.83650	0.99131	0.82923	0.65160	0.24904	1.80000	2.00000	1.72016	0.50388
0.48451	0.11326	0.82296	0.99169	0.81612	0.60472	0.22800	1.80000	2.00000	1.76288	0.51425
0.49413	0.11535	0.80824	0.99201	0.80178	0.56264	0.20922	1.80000	2.00000	1.80850	0.52462
0.50376	0.11782	0.79231	0.99226	0.78618	0.52474	0.19239	1.80000	2.00000	1.85674	0.53499
0.51338	0.12069	0.77517	0.99246	0.76933	0.49051	0.17730	1.80000	2.00000	1.90740	0.54535
0.52301	0.12400	0.75677	0.99262	0.75119	0.45951	0.16373	1.80000	2.00000	1.96030	0.55571
0.53263	0.12780	0.73710	0.99274	0.73175	0.43134	0.15149	1.80000	2.00000	2.01529	0.56607
0.54225	0.13215	0.71612	0.99283	0.71098	0.40569	0.14044	1.80000	2.00000	2.07224	0.57643
0.55188	0.13712	0.69380	0.99289	0.68887	0.38228	0.13044	1.80000	2.00000	2.13105	0.58678
0.56150	0.14280	0.67013	0.99292	0.66538	0.36085	0.12137	1.80000	2.00000	2.19164	0.59713
0.57113	0.14932	0.64506	0.99294	0.64050	0.34120	0.11313	1.80000	2.00000	2.25393	0.60748
0.58075	0.15682	0.61858	0.99293	0.61421	0.32315	0.10562	1.80000	2.00000	2.31786	0.61783
0.59037	0.16549	0.59065	0.99291	0.58647	0.30652	0.09878	1.80000	2.00000	2.38337	0.62817
0.60000	0.17558	0.56126	0.99287	0.55726	0.29118	0.09252	1.80000	2.00000	2.45041	0.63852

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THE ADVANCE RATIO IS 0.84400

RT/RB	SIGMA
0.3484780	2.7327461
0.3785555	2.1436138
0.4064131	1.8206558
0.4324800	1.6404524
0.4570627	1.5437746
0.4803891	1.4992752
0.5026341	1.4890871
0.5239354	1.5024080
0.5444040	1.5323944
0.5641304	1.5745325
0.5831898	1.6257486

May 3, 1979
WSG:JEF:mmj

THE ADVANCE RATIO IS 0.84400

R/RB	CP-NEW	EFF-ROT	EFF-STAT	EFF-TOT	CL-STAT	CL-ROT	S/C-ROT	S/C-STAT	SGMA	RT/RB
0.12842	2.69298	0.99998	0.99999	0.99997	1.40000	0.31760	0.35961	1.71634	0.43725	0.12174
0.13805	1.31302	0.99990	0.99994	0.99984	1.40000	0.31543	0.35109	1.56817	0.51072	0.13325
0.14767	0.85603	0.99972	0.99983	0.99955	1.40000	0.31367	0.34446	1.44537	0.58946	0.14457
0.15730	0.62964	0.99936	0.99963	0.99899	1.40000	0.31221	0.33918	1.34163	0.67346	0.15574
0.16692	0.49542	0.99875	0.99931	0.99806	1.40000	0.31101	0.33490	1.25264	0.76273	0.16681
0.17654	0.40725	0.99778	0.99881	0.99659	1.40000	0.30999	0.33136	1.17534	0.85728	0.17778
0.18617	0.34536	0.99631	0.99808	0.99440	1.40000	0.30912	0.32842	1.10747	0.95710	0.18868
0.19579	0.29993	0.99418	0.99706	0.99126	1.40000	0.30838	0.32593	1.04734	1.06220	0.19951
0.20542	0.26548	0.99119	0.99566	0.98689	1.40000	0.30774	0.32381	0.99367	1.17260	0.21028
0.21504	0.23878	0.98712	0.99381	0.98100	1.40000	0.30719	0.32199	0.94542	1.28830	0.22101
0.22466	0.21779	0.98168	0.99139	0.97323	1.40000	0.30670	0.32042	0.90180	1.40929	0.23171
0.23429	0.20116	0.97458	0.98830	0.96318	1.40000	0.30628	0.31905	0.86215	1.53559	0.24236
0.24391	0.18801	0.96547	0.98441	0.95041	1.40000	0.30590	0.31785	0.82594	1.66719	0.25299
0.25354	0.17773	0.95397	0.97958	0.93449	1.40000	0.30557	0.31679	0.79272	1.80407	0.26359
0.26316	0.16989	0.93965	0.97367	0.91491	1.40000	0.30527	0.31584	0.76214	1.94625	0.27416
0.27278	0.16424	0.92207	0.96652	0.89120	1.40000	0.30500	0.31500	0.73389	2.09372	0.28472
0.28241	0.16064	0.90071	0.95798	0.86286	1.40000	0.30476	0.31425	0.70770	2.24646	0.29526
0.29203	0.15905	0.87507	0.94785	0.82944	1.40000	0.30454	0.31357	0.68335	2.40450	0.30578
0.30165	0.15958	0.84457	0.93598	0.79050	1.40000	0.30434	0.31296	0.66065	2.56783	0.31628
0.31128	0.16244	0.80861	0.92216	0.74567	1.40000	0.30416	0.31240	0.63944	2.73646	0.32677
0.32090	0.16531	0.77468	0.91161	0.70636	1.40000	0.30409	0.31580	0.63400	2.81825	0.33725
0.33053	0.15334	0.79007	0.93247	0.73672	1.40000	0.30460	0.34789	0.73170	2.36985	0.34772
0.34015	0.14452	0.80208	0.94604	0.75880	1.40000	0.30508	0.38427	0.83886	2.04451	0.35818
0.34977	0.13773	0.81164	0.95529	0.77535	1.40000	0.30551	0.42524	0.95578	1.80634	0.36863
0.35940	0.13232	0.81942	0.96181	0.78813	1.40000	0.30590	0.47111	1.08272	1.63101	0.37907
0.36902	0.12792	0.82590	0.96658	0.79830	1.40000	0.30625	0.52214	1.21989	1.50174	0.38950
0.37865	0.12428	0.83143	0.97017	0.80663	1.40000	0.30655	0.57861	1.36748	1.40675	0.39993
0.38827	0.12123	0.83627	0.97297	0.81366	1.40000	0.30680	0.64082	1.52562	1.33769	0.41035
0.39789	0.11866	0.84061	0.97522	0.81978	1.40000	0.30701	0.70903	1.69446	1.28849	0.42076
0.40752	0.11646	0.84452	0.97708	0.82526	1.40000	0.30718	0.78351	1.87409	1.25477	0.43116
0.41714	0.11454	0.84841	0.97906	0.83064	1.35619	0.30731	0.86453	2.00000	1.23326	0.44157
0.42677	0.11283	0.85208	0.98137	0.83621	1.23563	0.30742	0.95235	2.00000	1.22153	0.45196
0.43639	0.11138	0.85571	0.98324	0.84137	1.12974	0.30750	1.04721	2.00000	1.21773	0.46235
0.44601	0.11015	0.85937	0.98476	0.84627	1.03637	0.30755	1.14935	2.00000	1.22046	0.47274
0.45564	0.10910	0.86310	0.98602	0.85103	0.95370	0.30759	1.25900	2.00000	1.22861	0.48312
0.46526	0.10822	0.86695	0.98706	0.85573	0.88024	0.30761	1.37635	2.00000	1.24134	0.49350
0.47489	0.10747	0.87095	0.98792	0.86043	0.81474	0.30761	1.50163	2.00000	1.25797	0.50388
0.48451	0.10683	0.87515	0.98864	0.86521	0.75612	0.30760	1.63504	2.00000	1.27796	0.51425
0.49413	0.10629	0.87956	0.98925	0.87010	0.70351	0.30758	1.77678	2.00000	1.30090	0.52462
0.50376	0.10714	0.87347	0.98975	0.86452	0.65612	0.28727	1.80000	2.00000	1.32642	0.53499
0.51338	0.10844	0.86471	0.99018	0.85622	0.61332	0.26535	1.80000	2.00000	1.35425	0.54535
0.52301	0.10996	0.85523	0.99053	0.84713	0.57455	0.24555	1.80000	2.00000	1.38415	0.55571
0.53263	0.11169	0.84502	0.99082	0.83727	0.53933	0.22764	1.80000	2.00000	1.41595	0.56607
0.54225	0.11366	0.83407	0.99106	0.82661	0.50726	0.21140	1.80000	2.00000	1.44947	0.57643
0.55188	0.11587	0.82237	0.99126	0.81518	0.47799	0.19667	1.80000	2.00000	1.48460	0.58678
0.56150	0.11834	0.80991	0.99142	0.80295	0.45120	0.18326	1.80000	2.00000	1.52121	0.59713
0.57113	0.12107	0.79668	0.99154	0.78994	0.42663	0.17105	1.80000	2.00000	1.55922	0.60748
0.58075	0.12410	0.78267	0.99163	0.77612	0.40406	0.15990	1.80000	2.00000	1.59854	0.61783
0.59037	0.12745	0.76787	0.99170	0.76150	0.38327	0.14971	1.80000	2.00000	1.63912	0.62817
0.60000	0.13115	0.75227	0.99175	0.74606	0.36409	0.14038	1.80000	2.00000	1.68089	0.63852

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THE ADVANCE RATIO IS 1.12500

RT/RB	SIGMA
0.3484780	2.6591120
0.3785555	2.0078077
0.4064131	1.6286163
0.4324800	1.3960419
0.4570627	1.2496357
0.4803891	1.1573019
0.5026341	1.1006804
0.5239354	1.0686359
0.5444040	1.0540876
0.5641304	1.0523520
0.5831898	1.0602245

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THE ADVANCE RATIO IS 1.12500

R/RB	CP-NEW	EFF-ROT	EFF-STAT	EFF-TOT	CL-STAT	CL-ROT	S/C-ROT	S/C-STAT	SGMA	RT/RB
0.12842	2.69294	0.99999	0.99999	0.99998	1.22389	0.32671	0.40028	2.00000	0.27727	0.12174
0.13305	1.31293	0.99995	0.99996	0.99991	1.33954	0.32384	0.38651	2.00000	0.31908	0.13325
0.14767	0.85585	0.99985	0.99990	0.99975	1.40000	0.32144	0.37568	1.92659	0.36387	0.14457
0.15730	0.62936	0.99967	0.99978	0.99945	1.40000	0.31940	0.36699	1.78831	0.41164	0.15574
0.16692	0.49498	0.99936	0.99959	0.99895	1.40000	0.31767	0.35988	1.66970	0.46239	0.16681
0.17654	0.40659	0.99888	0.99930	0.99819	1.40000	0.31618	0.35399	1.56665	0.51613	0.17778
0.18617	0.34444	0.99817	0.99890	0.99706	1.40000	0.31489	0.34904	1.47619	0.57286	0.18868
0.19579	0.29865	0.99714	0.99833	0.99548	1.40000	0.31377	0.34485	1.39605	0.63258	0.19951
0.20542	0.26377	0.99571	0.99758	0.99330	1.40000	0.31279	0.34127	1.32450	0.69531	0.21028
0.21504	0.23652	0.99378	0.99659	0.99039	1.40000	0.31194	0.33818	1.26019	0.76105	0.22101
0.22466	0.21484	0.99122	0.99531	0.98658	1.40000	0.31118	0.33551	1.20205	0.82981	0.23171
0.23429	0.19737	0.98790	0.99371	0.98169	1.40000	0.31051	0.33317	1.14919	0.90158	0.24236
0.24391	0.18317	0.98367	0.99172	0.97552	1.40000	0.30992	0.33111	1.10092	0.97636	0.25299
0.25354	0.17160	0.97835	0.98928	0.96786	1.40000	0.30938	0.32930	1.05665	1.05414	0.26359
0.26316	0.16217	0.97176	0.98633	0.95848	1.40000	0.30890	0.32768	1.01589	1.13493	0.27416
0.27278	0.15454	0.96370	0.98280	0.94713	1.40000	0.30847	0.32623	0.97823	1.21872	0.28472
0.28241	0.14847	0.95395	0.97863	0.93357	1.40000	0.30808	0.32493	0.94332	1.30550	0.29526
0.29203	0.14378	0.94228	0.97374	0.91753	1.40000	0.30773	0.32376	0.91086	1.39529	0.30578
0.30165	0.14035	0.92844	0.96805	0.89878	1.40000	0.30740	0.32270	0.88061	1.48808	0.31628
0.31128	0.13811	0.91216	0.96150	0.87705	1.40000	0.30711	0.32174	0.85233	1.58389	0.32677
0.32090	0.13703	0.89319	0.95400	0.85211	1.40000	0.30684	0.32087	0.82585	1.68270	0.33725
0.33053	0.13714	0.87124	0.94549	0.82375	1.40000	0.30659	0.32007	0.80099	1.78453	0.34772
0.34015	0.13851	0.84602	0.93587	0.79177	1.40000	0.30637	0.31934	0.77760	1.88937	0.35818
0.34977	0.14125	0.81723	0.92509	0.75602	1.40000	0.30616	0.31868	0.75556	1.99721	0.36863
0.35940	0.13753	0.81447	0.93103	0.75829	1.40000	0.30653	0.33675	0.81228	1.84156	0.37907
0.36902	0.13149	0.82434	0.94217	0.77667	1.40000	0.30716	0.36696	0.91519	1.61092	0.38950
0.37865	0.12675	0.83239	0.95021	0.79094	1.40000	0.30775	0.40045	1.02591	1.43593	0.39993
0.38827	0.12295	0.83906	0.95619	0.80230	1.40000	0.30829	0.43737	1.14455	1.30242	0.41035
0.39789	0.11986	0.84470	0.96076	0.81155	1.40000	0.30878	0.47788	1.27122	1.20024	0.42076
0.40752	0.11732	0.84954	0.96435	0.81925	1.40000	0.30922	0.52213	1.40598	1.12202	0.43116
0.41714	0.11521	0.85378	0.96724	0.82581	1.40000	0.30960	0.57026	1.54891	1.06235	0.44157
0.42677	0.11347	0.85756	0.96964	0.83152	1.40000	0.30994	0.62242	1.70004	1.01723	0.45196
0.43639	0.11202	0.86099	0.97166	0.83659	1.40000	0.31023	0.67875	1.85938	0.98364	0.46235
0.44601	0.11079	0.86416	0.97362	0.84136	1.38141	0.31047	0.73937	2.00000	0.95930	0.47274
0.45564	0.10968	0.86714	0.97628	0.84657	1.27122	0.31067	0.80441	2.00000	0.94246	0.48312
0.46526	0.10879	0.86999	0.97847	0.85126	1.17330	0.31084	0.87399	2.00000	0.93177	0.49350
0.47489	0.10808	0.87276	0.98029	0.85556	1.08599	0.31098	0.94820	2.00000	0.92616	0.50388
0.48451	0.10753	0.87549	0.98182	0.85957	1.00787	0.31108	1.02718	2.00000	0.92480	0.51425
0.49413	0.10712	0.87820	0.98311	0.86337	0.93773	0.31116	1.11102	2.00000	0.92703	0.52462
0.50376	0.10683	0.88094	0.98421	0.86702	0.87457	0.31122	1.19983	2.00000	0.93232	0.53499
0.51338	0.10665	0.88371	0.98514	0.87058	0.81752	0.31125	1.29372	2.00000	0.94024	0.54535
0.52301	0.10657	0.88655	0.98594	0.87408	0.76584	0.31127	1.39278	2.00000	0.95045	0.55571
0.53263	0.10656	0.88948	0.98662	0.87757	0.71890	0.31127	1.49713	2.00000	0.96267	0.56607
0.54225	0.10664	0.89250	0.98720	0.88107	0.67615	0.31126	1.60684	2.00000	0.97666	0.57643
0.55188	0.10678	0.89563	0.98770	0.88462	0.63713	0.31124	1.72201	2.00000	0.99224	0.58678
0.56150	0.10734	0.89584	0.98813	0.88520	0.60142	0.30400	1.80000	2.00000	1.00924	0.59713
0.57113	0.10870	0.89011	0.98850	0.87987	0.56867	0.28446	1.80000	2.00000	1.02754	0.60748
0.58075	0.11020	0.88398	0.98881	0.87409	0.53858	0.26655	1.80000	2.00000	1.04702	0.61783
0.59037	0.11183	0.87745	0.98907	0.86786	0.51087	0.25011	1.80000	2.00000	1.06758	0.62817
0.60000	0.11361	0.87052	0.98930	0.86120	0.48531	0.23499	1.80000	2.00000	1.08916	0.63852

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