https://ntrs.nasa.gov/search.jsp?R=19690026414 2020-03-23T20:35:29+00:00Z

NASA CR-72585
NREC Report No 1147-2

THE ANALYSIS OF GEOMETRY AND DESIGN-POINT PERFORMANCE OF AXIAL-FLOW TURBINES USING SPECIFIED MERIDIONAL VELOCITY GRADIENTS

PART II - DESIGN EXAMPLES

N69-33792 (ACCESSION NUMBER) 166 (PAGES) NASA-72585 (NASA CR OR TMX OR AD NUMBER) 1 (THRU) 28 (CODE) (CATEGORY) FACILITY FORM 602

by

F. K. Lenherr and A. F. Carter

SEP 1969
RECEIVED
NASA STI FACILITY
INPUT BRANCH

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS3-12419

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va. 22151

NORTHERN RESEARCH AND ENGINEERING CORPORATION

NASA CR-72585
NREC Report No. 1147-2

FINAL REPORT

THE ANALYSIS OF GEOMETRY AND DESIGN-POINT PERFORMANCE OF AXIAL-FLOW TURBINES USING SPECIFIED MERIDIONAL VELOCITY GRADIENTS

PART II - DESIGN EXAMPLES

by

F. K. Lenherr and A. F. Carter

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

August 20, 1969

CONTRACT NAS3-12419

Technical Management
NASA Lewis Research Center
Cleveland, Ohio
Fluid System Components Division
Arthur J. Glassman

NORTHERN RESEARCH AND ENGINEERING CORPORATION
219 Vassar Street
Cambridge, Massachusetts 02139

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

This report is the second part of a two-part report documenting the development and subsequent application of a computer program for the design of axial-flow turbines. The Part I report (NREC Report No. 1147-1) describes the computer program itself and the analysis procedure upon which it is based. This Part II report is concerned with the application of the computer program to the analysis of turbine design requirements.

The report presents the results of a general investigation of the effects of changes in the meridional velocity distributions specified at stator and rotor exits. These results are intended to provide future users of the program with some guidance in choosing suitable values of this new analysis variable. The report also presents the results of a specific investigation of the geometry and design-point performance of six multistage turbines which satisfy a selected design requirement. The six turbines consist of five-, four-, and three-stage versions of an lp spool at each of two maximum tip diameters. The performance predictions show a 6.0 per cent drop in total-to-total efficiency as the number of stages is reduced from five to three at the larger tip diameter, and a 4.1 per cent drop for the same reduction at the smaller tip diameter. For the two most highly loaded designs, the total-to-total efficiency of the smaller spool was 2.4 per cent higher than that of the original tip diameter design.

INTRODUCTION

Under Contract No. NAS3-9418 for NASA-Lewis Research Center, Northern Research and Engineering Corporation developed a computer program for the analysis of the geometry and design-point performance of axial-flow turbines. During the development of the program and its subsequent use for particular design specifications, it became clear that for some design requirements, the resultant solution of the design problem was extremely sensitive to two of the analysis variables which had to be selected by the program user. These two analysis variables were the radial variation of stator exit tangential velocity and the variation of power output function with streamline number. Flow conditions at stator exit are controlled by the first of these variables; the second is the major factor influencing the solution at rotor exit. While the choice of these variables for a stream-filament analysis of a turbine design-point requirement appeared logical and acceptable, experience with the computer program has shown that considerable skill and experience are required in order to obtain satisfactory design solutions.

A modified computer program, designated Program TD2, has been developed to overcome these deficiencies in the original program. This has been accomplished by deleting the specification of stator exit tangential velocity distributions and stage power output distributions, and substituting in their place options to specify distributions of meridional velocity at stator and/or rotor exits. In this manner, the variable which has in the past exhibited the greatest variation may be limited by the turbine designer in advance to a reasonable range of values. Thus, the computation of designs for which there is no acceptable solution in terms of blading angles has been largely eliminated.

A full description of the resulting revisions in the analysis and the detailed Fortran coding of the program has been presented in the Part I report (NREC Report No. 1147-1). This Part II report has two major objectives. First, it is intended to provide guidance to future users of the program in selecting suitable values of the new input analysis variables. At stator exit design stations, a range of

meridional velocity gradients corresponding approximately to constant section, free vortex, and solid body stator angle distributions are considered. At rotor exit design stations, the effects of these same gradients on the radial variation of work output, rotor exit angle, and velocity ratio are discussed. Second, the report illustrates the suggested use of the program for a design analysis and performance optimization of a multistage turbine. Six alternative versions of the turbine were established by employing a conservative number of stages and two lower numbers of stages at each of two maximum tip diameters. All six versions of the turbine maintain the same hub contour. Thus, the results provide a means of evaluating the likely tradeoff of efficiency with annulus height over a range of individual stage loadings.

Report Arrangement

The report is divided into three main sections. The first section presents the results of a general investigation of the effects of varying the distribution of meridional velocity specified at a stator or rotor exit. The second section contains the performance predictions for the six alternative versions of a multistage turbine. The annulus dimensions chosen for each design are presented first. Next, the effects on predicted efficiency of work split between the stages, specified meridional velocity gradients, and stage mean reactions are discussed. Finally, the predicted variation of optimum efficiency with maximum tip diameter and number of stages is presented. The last section of the report consists of tabulated velocity triangle data and the full computer output for each of the six final designs.

THE EFFECTS OF CHANGES IN MERIDIONAL VELOCITY GRADIENTS

Introduction

The increased design freedom of the rotational flow approach to turbine design, while overcoming the arbitrary restrictions of conventional free-vortex design procedure, necessarily leads to increased demands on the judgment of the designer. As a result of the wide range of designs specifiable with the previous version of the program, intractable cases often arose; for many of the possible choices of input variables there proved to be, in fact, no valid solution for the flow field at a design station. Thus, whenever a design was to be executed, it was necessary to devote considerable effort to merely achieving usable results.

The present revision of the set of input variables has resulted in a version of the program essentially free from this prospect of failure. Nevertheless, in exercising the new capability, some decisions must still be made as to the relative desirability of various nonconstant distributions of through-flow velocity.

In the absence of any directly relevant experimental data, the choice of meridional velocity distributions for a particular design requirement must be based on an analytical investigation of the aerodynamic and mechanical acceptability of a range of alternative designs. In this section, the results of such an investigation are presented with the intent of providing some guidance for future users of the program.

The total-pressure-loss assumptions employed in the calculations may exert considerable influence on the variation of flow conditions and performance with specified velocity gradient. These assumptions are accordingly reviewed in the first part of this section. Next, the variation of stator exit parameters for a range of meridional velocity gradients are discussed. The section concludes by considering the corresponding variations at stage exit design stations.

Total-Pressure-Loss Assumptions

The recommended values of the input constants defining the loss correlation given in Reference 1 have been used without exception in all

the calculations described in this report. For convenience, the resulting correlation is repeated here:

$$Y = \frac{|\tan\beta_{in} - \tan\beta_{ex}|}{0.6 + 0.8\cos\beta_{ex}} \cdot \left[0.055 + 0.15\left(\frac{V_{in}}{V_{ex}} - 0.6\right)\right] \quad \text{if} \quad \frac{V_{in}}{V_{ex}} \geq 0.6$$

$$Y = \frac{\tan\beta_{in} - \tan\beta_{ex}}{0.6 + 0.8\cos\beta_{ex}} \cdot \left[0.03 + 0.157255\left(\frac{V_{in}}{V_{ex}}\right)^{3.6}\right] \quad \text{if} \quad \frac{V_{in}}{V_{ex}} < 0.6$$

where the suffices *in* and *ex* denote inlet and exit conditions relative to a stator or a rotor section. Throughout the analysis no additional loss factors were specified. Hence, no attempt is made to account for penalties imposed by tip clearance or aspect ratio effects. Finally, it must be recognized that any loss correlation derived from over-all stage efficiency data will be subject to question when applied locally on a streamline basis. Nevertheless, experience with the current correlation has reinforced the belief that both the radial variations of loss at each design station and the over-all efficiency trends in a family of designs will be predicted with acceptable accuracy so long as extreme designs subject to separation or shock losses are avoided.

Stator Exit Flow Parameters

The primary analysis variable governing flow conditions at stator exit design stations is a specification of the radial gradient of meridional velocity as a function of radius, along with the tangential velocity at the mean streamline. The secondary option of specifying flow angle as a function of radius has been retained without modification exactly as in the prior version; thus, it does not require further description here.

For the initial investigation, it was decided to consider only linear distributions of meridional velocity. Thus, a single value of meridional velocity gradient was specified at an arbitrary radius within the annulus.

Results from three such runs have been compared in Figure 1. The actual gradients specified were 400, 0, and -400 fps per ft; annulus

dimensions and other design requirements correspond to the first stage of a four-stage version of the lp spool. (This design is discussed at greater length in the second section of this report.) Equal tangential velocities of 1035 fps were specified at the mean streamline for each of the three alternative meridional velocity gradients. In general, the stage may be considered typical except for the presence at stator inlet of a significant positive gradient of total pressure with radius, due to specification of constant work output for the preceding rotor of the hp spool.

The computed tangential and meridional velocity distributions, which have been normalized by their mean streamline values, behave in the familiar manner already reported in Reference 2. The specified 18 per cent change with respect to the constant distribution in hub and casing meridional velocity level produces an average of only a 3 per cent change in the corresponding tangential velocities. As a result, it is the meridional velocities which determine the variations of stator exit and rotor inlet blade angles; at both hub and casing, the angles are lowered where the meridional velocities are high. Consequently, the negative gradient yields the most constant distribution of rotor inlet angle with radius; the 21 deg rotor inlet twist required by the positive gradient is reduced to only 8 deg when the negative gradient is imposed.

The same trend is exhibited by the absolute stator angle distributions. However, the magnitude of the chosen negative gradient exceeds that required for a constant stator angle design. Furthermore, it would probably be necessary to specify more than a single value of meridional velocity gradient to obtain a strictly constant distribution. Were this required, however, the simplest alternative would, of course, be to specify the desired distribution directly, using the alternative stator exit input option.

The same set of parameters has been plotted in Figure 2 for the final stage of the four-stage lp spool. The primary difference here lies in the increased annulus height due to the 22 deg flare at the outer casing. Thus, the hub meridional velocities for the same positive and negative gradients differ in this instance by 57 per cent of the meanline value. Once again the corresponding tangential velocities exhibit little variation, differing by only 4 per cent at hub and tip between the two

extreme gradients. As can be seen from the similar shapes of the three tangential velocity distributions, the majority of even this small change is due to displacement of the mean streamline toward the hub as the meridional velocity gradient is decreased.

A final comment should be made regarding the crossing of the normalized tangential velocity distribution, observed in Figure 1, which does not appear in the results for the final stator. The reason for this point of difference lies primarily in the differing stator inlet conditions to the two rows. Because of the fixed inlet total pressure profile to the first stator assumed in the lp spool analysis, tip tangential velocity must increase as the tip meridional velocity decreases. The final stator, on the other hand, follows a rotor designed by the specified meridional velocity gradient technique; the stator inlet total pressures for the three designs therefore vary in a manner reflecting the stator inlet meridional velocity variation (set equal to that at stator exit). As a result no additional tilting of the tangential velocity distributions is required to satisfy radial equilibrium and each follows an approximately free-vortex variation.

Rotor Exit Flow Parameters

The effects of varying the specified gradient of meridional velocity at a rotor exit design station have been illustrated in Figures 3 and 4 for the two stages discussed earlier (first and last stages of a four-stage lp spool). Both stages were designed for approximately zero exit swirl; work output of the first stage is approximately 75 per cent of that of the final stage.

With regard to the rotor exit blading angles, it will be seen that a significant reduction in twist may be achieved by manipulation of the velocity gradient. In the case of the final rotor, for example, when the negative gradient is specified, hub and casing values of blade exit angle differ by 25 deg. This variation is reduced to less than 3 deg when a positive gradient of meridional velocity is substituted. The positive gradient achieves this reduction at a rotor exit design station

simply by eliminating the effect of the radially increasing blade speed on the rotor blading angles.

Although reduction of rotor exit twist is often a desirable objective, consideration of the remaining curves presented in Figures 3 and 4 show that it cannot be achieved, at least for these designs, without decidedly undesirable side effects. The low hub meridional velocities required by the positive gradient greatly reduce the absolute velocities at rotor hub exit. Hence, the row velocity ratio of the final stage is increased from 1.23 obtained with negative gradient to 1.75. At the same time, the magnitude of the rotor hub exit angle has been increased by more than 10 deg, from -49 deg to -60. The net result of these changes is, of course, to significantly increase the rotor hub total-pressure-loss coefficient.

The final parameter shown in Figures 3 and 4, the radial variation of total temperature drop normalized with respect to the mean streamline value, presents at first sight a relatively confusing picture. For the first-stage rotor, the positive gradient yields a hub total temperature drop 93.5 per cent of the meanline value, as opposed to 91 per cent for the negative gradient. In the case of the final stage, the situation is reversed with the positive gradient associated with the lowest total temperature drop, 85 per cent of the meanline value, as against 94.5 per cent for the negative.

This behavior may be explained qualitatively as the result of two opposing trends. When hub meridional velocities are locally high, the correlated value of loss coefficient will be low. Hence, the achievable work output will tend to be high. However, in a stage of near-zero exit tangential velocity, the requirement of radial equilibrium is for approximately constant static pressure across the annulus; hence, the high hub meridional velocity will require a locally high value of total pressure, reducing the available hub total pressure ratio across the stage. Hence, the achievable hub work output will tend to be low. It is therefore necessary to determine which of these two effects will predominate in a given case before any conclusion can be reached on the effect of velocity gradient on hub total temperature drop.

Considering now the first-stage rotor, it will be seen that the relatively small increase in velocity ratio with the positive gradient proved less important than the associated increase in total pressure ratio, and thus a 3.5 per cent greater hub work output was achieved. In the case of the final rotor, the much greater increase in hub velocity ratio predominated, and consequently it was necessary to unload the hub of the positive gradient design.

The complexitity of this situation is not at all unexpected; in fact, it forms the basis of the need for the present program revision, since with the prior version it was necessary to estimate a work output distribution a priori, by attempting to assess the relative importance of the two opposing trends described above. Figures 3 and 4 illustrate the difficulty associated with specifying a work distribution to obtain a design; relatively small changes of the stage total temperature drop distribution have accompanied considerable changes in the other design parameters. The major advantage of the present version of the computer program lies in the ability to control the most relevant variable, namely the meridional velocity, directly rather than indirectly through the intermediary of a power output distribution.

PERFORMANCE PREDICTIONS FOR A MULTISTAGE, TWIN-SPOOL TURBINE

Introduction

Design requirements for a multistage twin-spool turbine were specified by NASA for use in demonstrating the capabilities of the revised computer program. They are as follows:

Inlet Total Temperature	2410 deg R
Inlet Total Pressure	342.4 psia
Inlet Flow Angle	0 deg
Inlet Mass Flow	111.9 lbm/sec
Specific Gas Constant	53.35 ft lbf/lbm deg R
High Pressure Spool:	
Power Output	24,530 hp
Rotational Speed	10,800 rpm
Low Pressure Spool:	
Power Output	20,110 hp
Rotational Speed	4646 rpm

In addition, coolant flows to the first three hp rows of 1.9, 1.9, and 1.8 lbm/sec at 1400 deg R were specified, and a schedule of specific heat variation from 0.288 Btu/lbm deg R at hp inlet to 0.262 Btu/lbm deg R at lp exit was provided.

The geometry and performance of a total of six turbines satisfying the above design requirement were to be predicted. Three were to have a maximum tip diameter of 43.2 in at exit from the lp spool, while the remaining three were to have a reduced maximum tip diameter. Within each of these two groups, a number of stages consistent with conservative aerodynamics and two lower numbers of stages were to be considered. This section presents the results of this investigation.

Annulus Definition

Hub and tip diameters for the larger maximum tip diameter designs were established by NASA and may be summarized as follows:

	hp Inlet	hp Exit/ lp Inlet	lp Exit
Root Diameter, in	28.0	28.2	29.0
Casing Diameter, in	30.2	32.2	43.2

Based on the results of preliminary calculations, a design consisting of two hp stages and five lp stages was chosen to represent the most conservatively loaded turbine. Since it did not appear advisable to attempt a single-stage hp spool, the more highly loaded designs were obtained by two reductions in the number of lp stages. The three designs at the original tip diameter thus consist of identical hp configurations with either three-, four-, or five-stage versions of the lp spool.

To define the streamline angles of inclination at each calculation point throughout the machine, the axial spacings between the interrow design stations are required. For the conservative design, equal spacings of 1.5 in were assumed, thereby limiting the maximum streamline slope angle at the tip to 20 deg. The hub and tip diameters were assumed to vary linearly with axial distance between the values tabulated above. For the four- and three-stage lp spool designs, slightly larger design station spacings of 1.7 and 2.0 in, respectively, were chosen, reflecting the anticipated decrease in optimum pitch/chord ratio as blade deflection increases. The resulting tip flare angle of the most highly loaded design was therefore 25 deg, an acceptable value.

In generating annulus dimensions for the three reduced tip diameter lp spools, two approaches are available. First, the lp exit annulus could be maintained at its original value by sufficiently reducing the hub diameter. Alternatively, the hub contour could be held constant and the exit annulus area allowed to decrease. The first option was judged undesirable on two counts. First, hub loadings of the three- and four-stage lp spools are already high at the original hub diameter, so any additional reduction in wheel speed would lead to excessive performance deterioration. Second, the effects of reduced tip diameter at constant exit annulus area have already been adequately studied with the prior version of the program, and hence such an investigation would only duplicate prior efforts. It was therefore decided to adopt the second alternative of employing the identical hub line for all six turbines.

An lp spool exit tip diameter of 37.4 in was finally selected. This value was chosen so as to halve both the exit annulus area and the tip flare angle. Identical design station axial locations were employed for the corresponding original and reduced tip diameter versions of the lp spool. The six resulting annulus configurations have been shown schematically in Figures 5 and 6, accompanied by a summary of the performance parameters eventually obtained for each.

Optimization Procedure

With the design requirements and annulus dimensions preselected, only three analysis variables remain to be chosen by the designer. These are the following:

1. Work split between the stages
2. Row exit meridional velocity gradients
3. Stator exit meanline tangential velocities (and, hence, meanline reaction)

Each of these parameters was accordingly varied independently of the others, and optimum values derived for each of the six designs, using the criterion of predicted total-to-static efficiency. Final designs were then executed, based on a consideration of both the calculated optimum values and the requirements of good design practice.

Variation of Efficiency With Stage Work Split

Included with the design requirements originally furnished by NASA was a specification of the fractions of over-all spool work produced by each lp stage. These had been chosen to maintain equal meanling stage loadings, defined as $g_o J c_p \Delta T_o / u^2$ for the five stages. As a result the ratio of first-to-last stage work output was approximately 0.75.

To determine whether constant meanline stage loading in fact produced optimum spool performance, a series of four-stage, original tip diameter spool designs was investigated. The ratio of first-to-last stage work output was varied from 0.54 tó 1.44; work outputs of the intermediary stages were linearly interpolated between the values established

for the first and last stages. To permit a valid comparison between the various spools, meanline stage exit swirls throughout the machine were maintained at zero. Similarly, all row exit meridional velocity gradients were set equal to zero in the input data.

Results of these runs are presented in Figure 7. The optimum total-to-total efficiency of 86.87 per cent was obtained when the work output of the first stage was 13 per cent greater than that of the fourth. However, over the wide range of work output ratios from 0.95 to 1.40, less than a 0.1 per cent deterioration in total efficiency is indicated. At the constant stage loading point (work ratio = 0.75), the predicted performance decrement has begun to increase more rapidly and amounts to approximately 0.5 per cent. Hence, selection of the stage work split for an optimized design does not appear highly critical. However, results for the four-stage spool show that choice of slightly decreasing stage enthalpy drops is preferable to use of a constant stage loading design criterion. This approach was accordingly adopted for the four-stage spools.

The lower pair of curves in Figure 7 presents the results of a similar investigation on the three-stage lp spool at original tip diameter. Because of larger mean stage work output for this design, the achievable range of work output ratios was limited by the occurrence of sonic conditions at stator exit. Over the entire range investigated, however, the efficiency increases at a modest rate as the loading of the first stage is increased. Hence, in choosing an optimum work split for the three-stage spool, the designer must weigh a 0.3 per cent predicted efficiency improvement against the disadvantages of specifying high Mach number blading for the stator of the first lp stage. As a consequence, constant stage enthalpy drops (work ratio = 1.0) were specified for the three-stage spools.

Variation of Efficiency With Meridional Velocity Gradients

To investigate the influence of meridional velocity distribution on predicted spool efficiency, a series of ten alternative designs

based on the three-stage versions of the lp spool were analyzed. Four of these runs specified equal velocity gradients of 0, -200, -400, and -600 fps/ft at both stator and rotor exits. The remaining six designs applied the same gradients to stator or rotor exits only, while maintaining radially constant meridional velocity for the rotors or stators, respectively. The predicted variation of total-to-total and total-to-static efficiency is presented in Figure 8.

Optimum total-to-static efficiency of 80.65 per cent was predicted when a meridional velocity gradient of -200 fps/ft was imposed at rotor exits only. None of the other combinations of stator and/or rotor velocity gradients proved superior, on the basis of calculated static efficiency, to the datum constant-meridional-velocity design. A slight improvement in total efficiency could be achieved by the use of very large rotor exit meridional velocity variation; an optimum was found with the -600 fps/ft gradient. However, the large resulting spool exit gradient of absolute velocity led to a more than 0.2 per cent decrease in static efficiency. Since the rotor exit twist also increases (as shown in Figures 3 and 4) as the gradient becomes larger, the optimum static efficiency point (stator gradient = 0, rotor gradient = -200 fps/ft) was selected for the final designs.

Variation of Efficiency With Mean Stage Reaction

Previous investigations using the current loss correlation have shown that mean stage reaction, conventionally defined as the ratio of static-to-total temperature drop across the rotor at the mean streamline is a significant factor in the performance level predicted for a design. Hence, a series of designs ranging from impulse to full reaction were analyzed for the three-stage, original tip diameter spool. Calculated efficiencies and spool exit absolute flow angles have been plotted versus the average stage reaction of the three stages in Figure 9.

When stage reaction falls below about 0.4, spool efficiency drops rapidly because of the unfavorable decelerations experienced near the rotor hub sections. If, on the other hand, reactions above 0.6 are

specified, performance again deteriorates significantly due to the excessive deflections required in the stator rows and the elevated level of spool exit Mach number. Hence, optimum total and static efficiencies occurred at average stage meanline reactions of 0.56 and 0.36, respectively. On the basis of these results, a reaction of 0.41 was selected for the final design. This permitted the first two stages to operate near peak total efficiency while using a lower reaction for the third stage so as to limit the spool exit swirl angle. As can be seen from the symbols representing final design values, a net increase in static efficiency was achieved.

Similar investigations were undertaken for both the original and reduced tip diameter versions of the four- and five-stage lp spools. In all cases, the inlet tangential velocity to the rotors of the final stages was fixed so as to avoid undesirable levels of spool exit swirl. Results of these computations are presented in Figures 10 and 11, respectively. Optimum performance was in all cases predicted for the 50 per cent meanline reaction designs. The original tip diameter spools proved more sensitive to the choice of meanline reaction than those executed with the reduced annulus configuration. This occurs since the lower meridional velocity levels in the larger annulus result in greater stator row velocity ratio changes and hence greater increases in stator loss as the rotor inlet tangential velocity level is reduced to achieve high reaction designs.

Variation of Efficiency With Maximum Tip Diameter and Number of Stages

Full details of the thermodynamic and velocity triangle data calculated for the six final designs have been tabulated at hub, mean, and tip radii in Tables I through VII. The computer output from which these tables were constructed is reproduced in appendices to this report. Appendix I contains the output for the common hp spool used for all six lp designs. Appendices II and III present the output obtained for the original and reduced tip diameter lp spools, respectively.

Because of the manner in which the tip diameter reduction was effected, the primary point of contrast between the designs lies in the higher meridional velocity levels in the later stages of the reduced diameter spools. As a consequence, significant reductions in stator and rotor blading angles were achieved. This may be seen in the following tabulation of stage loading and flow factor, defined as the ratio of average meanline meridional velocity to average blade speed.

	Stage				
	1	2	3	4	5
Five-Stage Original:					
Stage Loading	1.5204	1.4072	1.3053	1.2131	1.1285
Flow Factor	0.7503	0.6014	0.5287	0.4936	0.4864
Five-Stage Reduced:					
Stage Loading	1.5619	1.4999	1.4411	1.3851	1.3316
Flow Factor	0.9022	0.8708	0.8726	0.9034	0.9735
Four-Stage Original:					
Stage Loading	1.9256	1.7358	1.5199	1.3314	
Flow Factor	0.7403	0.5904	0.5275	0.5103	
Four-Stage Reduced:					
Stage Loading	2.0534	1.8787	1.7172	1.5677	
Flow Factor	0.9197	0.9036	0.9286	1.0065	
Three-Stage Original:					
Stage Loading	2.4389	2.1479	1.8966		
Flow Factor	0.7102	0.5744	0.5625		
Three-Stage Reduced:					
Stage Loading	2.5497	2.3835	2.2288		
Flow Factor	0.9282	0.9438	1.0872		

Hence, in terms of the Smith correlation of achievable turbine efficiency (Ref 3) which is based on stage loading and flow factor, each stage of a reduced tip diameter design would be plotted at a slightly higher level of loading and at a higher value of stage flow factor than for the corresponding stage from a design using the original outside diameter. Thus, in conjunction with the range of stage loading levels achieved by varying the number of lp stages, a fairly wide range of points on the efficiency carpet has been covered.

The variation of lp spool total-to-total and total-to-static efficiency with number of stages and maximum tip diameter has been plotted for the final, optimized designs in Figure 12. Figure 13 shows the corresponding variations in spool exit absolute flow angle and Mach

number. Use of four rather than five stages at the original tip diameter led to a loss of 2 per cent in total efficiency. An additional four points were lost when three stages were employed.

The reduced tip diameter spools showed superior total-to-total efficiencies over the entire range investigated. However, the achievable improvement was relatively insignificant for the five-stage spools, amounting to only 0.5 per cent. As the number of stages is reduced, the advantage of the smaller spools became larger, reaching 2.5 per cent for the three-stage designs. Hence, depending on achievable diffuser performance, the reduced annulus height designs become increasingly attractive as stage loadings are increased.

Concluding Remarks

The predicted variations of total-to-total efficiency with stage loading can be considered reliable. The computed relation between the performance of the original and reduced annulus height designs is, however, more open to question. As was stated earlier, the predicted values are directly dependent on the loss correlation assumed in the analysis. Since the reduced designs would almost certainly have significantly higher relative rotor tip clearance and lower aspect ratio, some loss in efficiency beyond that predicted by the correlation would be anticipated. However, until such time as experimental data become available from stages designed using the current analysis procedure, the loss correlation recommended and used in the program can be considered satisfactory.

During the investigation of the effect on predicted performance of changes in the analysis variables, only relatively small changes in efficiency were predicted over a wide range of stage work splits and meridional velocity gradients. Whereas the actual performance of a blade row is undoubtedly affected by the over-all design of the row, a purely stream-filament analysis with loss assumptions derived ultimately from a meanline performance correlation cannot fully predict the actual performance differences of designs having the same annulus geometry and meanline reaction. Thus although specification of a meridional velocity gradient at a row exit will modify the radial distribution of local flow angle

and velocity ratio and hence lead to a redistribution of losses across the annulus, the mean values of angle and velocity ratio, and hence the over-all loss level of the row, will remain relatively constant. Similarly, variation of the work split between the stages will not significantly alter the average stage loading of the spool. Thus, the observed efficiency variation when these parameters are varied may be somewhat smaller than that which would be expected in practice. Choice of these analysis variables should accordingly include careful consideration of the over-all desirability of the resulting design rather than merely the predicted mass-averaged efficiency. Particularly in the area of selecting rotor exit meridional velocity gradients, experimental data derived from stage testing would be of considerable value to the designer.

CONCLUSIONS

1. Performance predictions for a series of multistage turbines having the same over-all design requirement have shown a 6.0 per cent drop in total-to-total efficiency for a reduction from five to three lp stages at a constant maximum tip diameter of 43.2 in, as against only a 4.1 per cent reduction over the same range when a tip diameter of 37.4 in is employed. Values of total-to-static efficiency were approximately 2.0 per cent lower than corresponding total-to-total values for the designs at the higher tip diameter; for the reduced diameter spools, the difference amounted to 6.0 per cent. Hence, the advantages of reduced annulus height become increasingly significant as the individual stage loadings are increased, amounting to 2.5 per cent in total-to-total efficiency for the most highly loaded spools.
2. In a study of the effects of changes in the specified gradients of meridional velocity, it was established that desired variations in blading geometry may be rapidly obtained in a manner fully consistent with chosen assumptions regarding the radial distribution of total pressure loss. Although the revised program no longer requires specification of interfilament mixing to obtain valid solutions in a multistage design analysis, it should be recognized that arbitrary omission of this effect may result in designs which employ greater radial variation of work than that required in the actual stage environment. Thus, an effort should be made to derive a realistic correlation of the intensity of interfilament mixing with the flow conditions at a design station.
3. An investigation of the effects of varying the stage work splits and row exit meridional velocity gradients, using the recommended form of the loss correlation, indicated relatively little variation in mass-averaged turbine efficiency over a wide range of values of these analysis variables. Predicted values of efficiency for a given design requirement depended primarily on the chosen annulus configuration and stage mean reactions. Hence, it would be desirable to review the form of the correlation using experimental data from stages designed

using the specified velocity gradient approach. Since the correlation is now applied on an iterative basis, it would be possible to include parameters related to the over-all flow field at a design station in assessing the performance levels of the individual stream filaments.

REFERENCES

1. Carter, A. F., Platt, M., and Lenherr, F. K., Analysis of Geometry and Design Point Performance of Axial Flow Turbines, Part I - Development of the Analysis Method and the Loss Coefficient Correlation (NASA CR-1181), National Aeronautics and Space Administration, Washington, D. C., September, 1968.

2. Carter, A. F. and Lenherr, F. K., Analysis of Geometry and Design Point Performance of Axial Flow Turbines, Part III - Design Analysis of Selected Examples (NASA CR-72385), National Aeronautics and Space Administration, February 29, 1968.

3. Smith, S. F., "A Simple Correlation of Turbine Efficiency", J. Royal Aero, Soc., vol. 69, July, 1965.

TABLES

TABLE I - VELOCITY TRIANGLE DATA FOR TWO-STAGE HP SPOOL

STAGE 1

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.025	14.706	15.350
Stage Exit	14.050	14.866	15.600
Angles (deg)			
Stator Exit	72.3	72.4	71.9
Rotor Relative Inlet	13.8	-2.0	-16.4
Rotor Relative Exit	-72.0	-71.1	-71.4
Stage Exit	3.3	5.4	6.7
Velocities (fps)			
Stator Exit	1494	1439	1390
Rotor Relative Inlet	450	437	455
Rotor Relative Exit	1367	1435	1494
Stage Exit	424	470	486
Blade Speed (fps)			
Rotor Inlet	1322	1386	1447
Rotor Exit	1324	1401	1470
Total Pressure (psia)			
Stator Exit	332.28	333.28	334.04
Rotor Relative Inlet	257.58	263.45	269.30
Rotor Relative Exit	251.30	257.74	263.60
Stage Exit	200.51	201.64	202.08
Total Temperature (deg R)			
Stator Exit	2393.1	2393.1	2393.1
Rotor Relative Inlet	2252.4	2262.9	2273.5
Rotor Relative Exit	2238.8	2249.5	2260.6
Stage Exit	2119.2	2119.2	2119.2
Velocity Ratio			
Stator	0.286	0.297	0.307
Rotor	0.329	0.305	0.305
Loss Coefficient			
Stator	0.124	0.120	0.116
Rotor	0.129	0.108	0.101

TABLE I - VELOCITY TRIANGLE DATA FOR TWO-STAGE HP SPOOL (CONTINUED)

STAGE 2

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.075	14.998	15.850
Stage Exit	14.100	15.202	16.100
Angles (deg)			
Stator Exit	70.6	69.8	69.1
Rotor Relative Inlet	15.1	-2.0	-17.6
Rotor Relative Exit	-69.6	-66.9	-65.5
Stage Exit	3.2	6.0	6.4
Velocities (fps)			
Stator Exit	1554	1488	1429
Rotor Relative Inlet	535	516	541
Rotor Relative Exit	1389	1493	1596
Stage Exit	485	595	685
Blade Speed (fps)			
Rotor Inlet	1327	1414	1494
Rotor Exit	1329	1433	1517
Total Pressure (psia)			
Stator Exit	194.71	196.45	197.39
Rotor Relative Inlet	143.49	148.73	153.89
Rotor Relative Exit	140.34	146.34	151.93
Stage Exit	108.23	108.86	110.69
Total Temperature (deg R)			
Stator Exit	2108.2	2108.2	2108.2
Rotor Relative Inlet	1957.4	1970.3	1984.4
Rotor Relative Exit	1961.0	1974.2	1988.9
Stage Exit	1838.0	1838.0	1838.0
Velocity Ratio			
Stator	0.273	0.316	0.340
Rotor	0.385	0.346	0.339
Loss Coefficient			
Stator	0.101	0.097	0.094
Rotor	0.118	0.084	0.067

TABLE II - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER)

STAGE 1

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.140	15.437	16.650
Stage Exit	14.180	15.698	17.200
Angles (deg)			
Stator Exit	60.2	59.7	59.5
Rotor Relative Inlet	31.3	24.3	15.3
Rotor Relative Exit	-55.7	-60.2	-64.3
Stage Exit	-13.5	-15.8	-16.7
Velocities (fps)			
Stator Exit	1015	988	950
Rotor Relative Inlet	591	552	521
Rotor Relative Exit	831	879	915
Stage Exit	481	459	434
Blade Speed (fps)			
Rotor Inlet	573	626	675
Rotor Exit	575	636	697
Total Pressure (psia)			
Stator Exit	107.07	108.46	108.99
Rotor Relative Inlet	95.98	97.37	98.50
Rotor Relative Exit	94.73	96.08	97.17
Stage Exit	87.84	87.60	87.31
Total Temperature (deg R)			
Stator Exit	1838.0	1838.0	1838.0
Rotor Relative Inlet	1788.5	1789.2	1792.2
Rotor Relative Exit	1789.8	1790.2	1793.0
Stage Exit	1756.2	1749.1	1745.5
Velocity Ratio			
Stator	0.478	0.603	0.721
Rotor	0.711	0.628	0.569
Loss Coefficient			
Stator	0.069	0.089	0.115
Rotor	0.142	0.130	0.126

TABLE II - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 2

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.220	16.073	17.750
Stage Exit	14.260	16.289	18.300
Angles (deg)			
Stator Exit	66.0	63.8	62.3
Rotor Relative Inlet	39.8	21.7	1.5
Rotor Relative Exit	-59.1	-64.4	-68.9
Stage Exit	-15.4	-17.9	-17.8
Velocities (fps)			
Stator Exit	1003	908	836
Rotor Relative Inlet	531	438	408
Rotor Relative Exit	808	869	916
Stage Exit	431	400	364
Blade Speed (fps)			
Rotor Inlet	577	652	720
Rotor Exit	578	660	742
Total Pressure (psia)			
Stator Exit	86.34	86.41	86.33
Rotor Relative Inlet	76.43	77.66	78.91
Rotor Relative Exit	75.30	76.74	77.89
Stage Exit	69.47	69.22	68.92
Total Temperature (deg R)			
Stator Exit	1756.2	1749.1	1745.5
Rotor Relative Inlet	1703.2	1702.8	1706.5
Rotor Relative Exit	1704.2	1703.7	1707.4
Stage Exit	1669.8	1659.8	1655.4
Velocity Ratio			
Stator	0.480	0.506	0.519
Rotor	0.657	0.503	0.445
Loss Coefficient			
Stator	0.111	0.106	0.102
Rotor	0.157	0.114	0.114

TABLE II - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 3

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.300	16.725	18.850
Stage Exit	14.340	16.877	19.400
Angles (deg)			
Stator Exit	68.1	65.3	63.4
Rotor Relative Inlet	41.8	15.3	-13.3
Rotor Relative Exit	-60.2	-66.5	-71.5
Stage Exit	-16.0	-19.1	-18.3
Velocities (fps)			
Stator Exit	976	857	774
Rotor Relative Inlet	489	377	373
Rotor Relative Exit	802	880	938
Stage Exit	415	376	329
Blade Speed (fps)			
Rotor Inlet	580	678	764
Rotor Exit	581	684	787
Total Pressure (psia)			
Stator Exit	68.22	68.32	68.24
Rotor Relative Inlet	60.11	61.49	62.88
Rotor Relative Exit	59.20	60.73	61.94
Stage Exit	54.33	54.09	53.79
Total Temperature (deg R)			
Stator Exit	1669.8	1659.8	1655.3
Rotor Relative Inlet	1617.2	1616.1	1621.4
Rotor Relative Exit	1617.8	1616.8	1622.4
Stage Exit	1582.7	1569.5	1564.9
Velocity Ratio			
Stator	0.441	0.467	0.470
Rotor	0.609	0.428	0.398
Loss Coefficient			
Stator	0.118	0.107	0.098
Rotor	0.149	0.105	0.115

TABLE II - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 4

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.380	17.389	19.950
Stage Exit	14.420	17.467	20.500
Angles (deg)			
Stator Exit	68.8	65.4	63.0
Rotor Relative Inlet	41.9	6.1	-27.6
Rotor Relative Exit	-60.2	-67.5	-73.0
Stage Exit	-16.4	-19.6	-18.1
Velocities (fps)			
Stator Exit	959	818	727
Rotor Relative Inlet	466	348	386
Rotor Relative Exit	810	902	971
Stage Exit	419	372	314
Blade Speed (fps)			
Rotor Inlet	583	705	809
Rotor Exit	585	708	831
Total Pressure (psia)			
Stator Exit	53.30	53.41	53.32
Rotor Relative Inlet	46.74	48.18	49.66
Rotor Relative Exit	46.02	47.55	48.77
Stage Exit	41.95	41.71	41.42
Total Temperature (deg R)			
Stator Exit	1582.7	1569.5	1564.9
Rotor Relative Inlet	1530.3	1528.7	1536.7
Rotor Relative Exit	1530.5	1529.1	1537.7
Stage Exit	1494.4	1478.2	1474.0
Velocity Ratio			
Stator	0.432	0.460	0.453
Rotor	0.575	0.386	0.398
Loss Coefficient			
Stator	0.122	0.107	0.093
Rotor	0.137	0.097	0.118

TABLE II - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 5

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.460	18.073	21.050
Stage Exit	14.500	18.065	21.600
Angles (deg)			
Stator Exit	69.9	66.0	63.3
Rotor Relative Inlet	47.0	6.8	-30.8
Rotor Relative Exit	-55.4	-65.9	-72.7
Stage Exit	-2.9	-9.7	-7.1
Velocities (fps)			
Stator Exit	1026	850	745
Rotor Relative Inlet	516	354	403
Rotor Relative Exit	740	871	960
Stage Exit	421	366	304
Blade Speed (fps)			
Rotor Inlet	586	733	853
Rotor Exit	588	732	876
Total Pressure (psia)			
Stator Exit	40.97	41.12	41.03
Rotor Relative Inlet	35.04	36.48	37.94
Rotor Relative Exit	34.42	36.00	37.21
Stage Exit	31.90	31.63	31.37
Total Temperature (deg R)			
Stator Exit	1494.4	1478.2	1474.1
Rotor Relative Inlet	1435.1	1433.2	1444.5
Rotor Relative Exit	1434.8	1433.1	1445.2
Stage Exit	1406.5	1385.5	1382.0
Velocity Ratio			
Stator	0.408	0.438	0.422
Rotor	0.697	0.407	0.420
Loss Coefficient			
Stator	0.126	0.107	0.089
Rotor	0.166	0.092	0.116

TABLE III - VELOCITY TRIANGLE DATA FOR FOUR-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER)

STAGE 1

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.150	15.516	16.788
Stage Exit	14.200	15.844	17.475
Angles (deg)			
Stator Exit	65.2	64.5	64.1
Rotor Relative Inlet	45.7	39.2	31.3
Rotor Relative Exit	-60.4	-64.3	-68.0
Stage Exit	-27.4	-29.9	-31.5
Velocities (fps)			
Stator Exit	1201	1148	1088
Rotor Relative Inlet	722	645	578
Rotor Relative Exit	939	991	1027
Stage Exit	523	502	472
Blade Speed (fps)			
Rotor Inlet	574	629	681
Rotor Exit	576	642	709
Total Pressure (psia)			
Stator Exit	106.41	107.90	108.33
Rotor Relative Inlet	91.70	93.29	94.47
Rotor Relative Exit	89.19	90.91	92.22
Stage Exit	80.60	80.50	80.26
Total Temperature (deg R)			
Stator Exit	1838.0	1838.0	1838.0
Rotor Relative Inlet	1771.0	1772.5	1776.3
Rotor Relative Exit	1772.8	1773.7	1777.0
Stage Exit	1728.2	1720.1	1715.9
Velocity Ratio			
Stator	0.401	0.520	0.639
Rotor	0.768	0.651	0.563
Loss Coefficient			
Stator	0.081	0.095	0.125
Rotor	0.224	0.191	0.171

TABLE III - VELOCITY TRIANGLE DATA FOR FOUR-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 2

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.250	16.318	18.163
Stage Exit	14.300	16.585	18.850
Angles (deg)			
Stator Exit	68.9	66.9	65.7
Rotor Relative Inlet	49.3	33.6	14.1
Rotor Relative Exit	47.1	20.3	-11.5
Stage Exit	-30.3	-33.1	-33.6
Velocities (fps)			
Stator Exit	1124	1009	924
Rotor Relative Inlet	621	482	415
Rotor Relative Exit	929	995	1038
Stage Exit	490	456	408
Blade Speed (fps)			
Rotor Inlet	578	662	736
Rotor Exit	580	672	764
Total Pressure (psia)			
Stator Exit	78.44	78.77	78.81
Rotor Relative Inlet	67.46	68.81	70.09
Rotor Relative Exit	65.64	67.42	68.64
Stage Exit	58.77	58.65	58.35
Total Temperature (deg R)			
Stator Exit	1728.2	1720.1	1715.9
Rotor Relative Inlet	1663.7	1662.5	1665.9
Rotor Relative Exit	1665.1	1663.6	1666.9
Stage Exit	1618.9	1605.5	1599.3
Velocity Ratio			
Stator	0.466	0.498	0.511
Rotor	0.668	0.485	0.400
Loss Coefficient			
Stator	0.140	0.136	0.134
Rotor	0.211	0.143	0.139

TABLE III - VELOCITY TRIANGLE DATA FOR FOUR-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 3

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.350	17.139	19.538
Stage Exit	14.400	17.326	20.225
Angles (deg)			
Stator Exit	69.4	66.6	64.8
Rotor Relative Inlet	47.1	20.3	-11.5
Rotor Relative Exit	-63.6	-69.0	-73.6
Stage Exit	-31.9	-34.0	-33.6
Velocities (fps)			
Stator Exit	1043	905	811
Rotor Relative Inlet	539	390	373
Rotor Relative Exit	943	1017	1068
Stage Exit	494	444	379
Blade Speed (fps)			
Rotor Inlet	582	695	792
Rotor Exit	584	702	820
Total Pressure (psia)			
Stator Exit	57.22	57.52	57.51
Rotor Relative Inlet	49.44	50.87	52.27
Rotor Relative Exit	48.28	49.92	51.11
Stage Exit	42.71	42.55	42.23
Total Temperature (deg R)			
Stator Exit	1618.9	1605.5	1599.3
Rotor Relative Inlet	1559.6	1556.0	1560.9
Rotor Relative Exit	1560.5	1556.9	1562.1
Stage Exit	1512.0	1494.1	1487.2
Velocity Ratio			
Stator	0.470	0.504	0.503
Rotor	0.571	0.383	0.349
Loss Coefficient			
Stator	0.149	0.140	0.128
Rotor	0.165	0.118	0.130

TABLE III - VELOCITY TRIANGLE DATA FOR FOUR-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 4

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.450	17.994	20.913
Stage Exit	14.500	18.072	21.600
Angles (deg)			
Stator Exit	70.7	67.3	65.1
Rotor Relative Inlet	52.0	20.2	-17.8
Rotor Relative Exit	-57.2	-66.7	-73.0
Stage Exit	-11.5	-18.5	-16.7
Velocities (fps)			
Stator Exit	1122	938	825
Rotor Relative Inlet	601	393	386
Rotor Relative Exit	805	934	1015
Stage Exit	445	396	329
Blade Speed (fps)			
Rotor Inlet	586	730	848
Rotor Exit	588	733	876
Total Pressure (psia)			
Stator Exit	41.30	41.63	41.61
Rotor Relative Inlet	34.60	36.04	37.43
Rotor Relative Exit	33.74	35.44	36.63
Stage Exit	30.78	30.57	30.29
Total Temperature (deg R)			
Stator Exit	1512.0	1494.1	1487.2
Rotor Relative Inlet	1444.6	1439.6	1447.2
Rotor Relative Exit	1444.6	1440.0	1448.2
Stage Exit	1410.3	1385.4	1377.9
Velocity Ratio			
Stator	0.440	0.473	0.459
Rotor	0.747	0.421	0.381
Loss Coefficient			
Stator	0.154	0.137	0.119
Rotor	0.211	0.109	0.124

TABLE IV - VELOCITY TRIANGLE DATA FOR THREE-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER)

STAGE 1

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.167	15.648	17.017
Stage Exit	14.233	16.087	17.933
Angles (deg)			
Stator Exit	69.1	68.3	68.1
Rotor Relative Inlet	55.4	49.8	43.3
Rotor Relative Exit	-65.0	-68.5	-71.9
Stage Exit	-40.9	-43.4	-45.5
Velocities (fps)			
Stator Exit	1378	1297	1216
Rotor Relative Inlet	867	750	648
Rotor Relative Exit	1070	1122	1157
Stage Exit	599	573	533
Blade Speed (fps)			
Rotor Inlet	574	634	690
Rotor Exit	577	652	727
Total Pressure (psia)			
Stator Exit	105.47	107.12	107.49
Rotor Relative Inlet	87.53	89.33	90.57
Rotor Relative Exit	82.98	85.21	86.83
Stage Exit	72.69	72.80	72.64
Total Temperature (deg R)			
Stator Exit	1838.0	1838.0	1838.0
Rotor Relative Inlet	1754.5	1756.6	1761.1
Rotor Relative Exit	1757.3	1758.2	1761.7
Stage Exit	1699.4	1689.6	1684.0
Velocity Ratio			
Stator	0.346	0.462	0.583
Rotor	0.810	0.668	0.560
Loss Coefficient			
Stator	0.097	0.107	0.139
Rotor	0.331	0.271	0.234

TABLE IV - VELOCITY TRIANGLE DATA FOR THREE-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 2

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.300	16.734	18.850
Stage Exit	14.367	17.083	19.767
Angles (deg)			
Stator Exit	72.4	70.5	69.7
Rotor Relative Inlet	59.4	46.9	30.3
Rotor Relative Exit	-66.2	-70.8	-74.7
Stage Exit	-43.0	-46.4	-47.7
Velocities (fps)			
Stator Exit	1313	1160	1053
Rotor Relative Inlet	780	572	450
Rotor Relative Exit	1080	1160	1198
Stage Exit	596	558	489
Blade Speed (fps)			
Rotor Inlet	580	678	764
Rotor Exit	582	693	801
Total Pressure (psia)			
Stator Exit	69.25	70.05	70.33
Rotor Relative Inlet	56.94	58.53	59.93
Rotor Relative Exit	53.82	56.32	57.75
Stage Exit	46.37	46.54	46.27
Total Temperature (deg R)			
Stator Exit	1699.4	1689.6	1684.0
Rotor Relative Inlet	1617.3	1614.5	1617.2
Rotor Relative Exit	1619.3	1616.0	1618.2
Stage Exit	1558.5	1538.7	1528.7
Velocity Ratio			
Stator	0.456	0.494	0.506
Rotor	0.722	0.493	0.376
Loss Coefficient			
Stator	0.188	0.185	0.184
Rotor	0.315	0.194	0.181

TABLE IV - VELOCITY TRIANGLE DATA FOR THREE-STAGE LP SPOOL (ORIGINAL MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 3

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.433	17.891	20.683
Stage Exit	14.500	18.097	21.600
Angles (deg)			
Stator Exit	73.6	70.9	69.6
Rotor Relative Inlet	63.0	46.9	23.6
Rotor Relative Exit	-59.2	-68.0	-73.6
Stage Exit	-23.0	-32.3	-33.6
Velocities (fps)			
Stator Exit	1450	1221	1082
Rotor Relative Inlet	904	590	441
Rotor Relative Exit	917	1069	1144
Stage Exit	511	482	412
Blade Speed (fps)			
Rotor Inlet	585	725	839
Rotor Exit	588	734	876
Total Pressure (psia)			
Stator Exit	43.56	44.50	44.73
Rotor Relative Inlet	33.99	35.62	36.96
Rotor Relative Exit	32.02	34.33	35.73
Stage Exit	28.47	28.49	28.24
Total Temperature (deg R)			
Stator Exit	1558.4	1538.7	1528.7
Rotor Relative Inlet	1462.3	1453.3	1455.6
Rotor Relative Exit	1462.9	1454.0	1456.0
Stage Exit	1418.7	1384.7	1369.1
Velocity Ratio			
Stator	0.411	0.457	0.451
Rotor	0.985	0.552	0.386
Loss Coefficient			
Stator	0.191	0.181	0.168
Rotor	0.406	0.191	0.163

TABLE V - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER)

STAGE 1

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.140	15.295	16.360
Stage Exit	14.180	15.423	16.620
Angles (deg)			
Stator Exit	56.8	56.3	55.6
Rotor Relative Inlet	27.4	22.0	15.5
Rotor Relative Exit	-50.1	-53.9	-57.0
Stage Exit	-11.1	-13.4	-14.5
Velocities (fps)			
Stator Exit	1039	1023	998
Rotor Relative Inlet	642	614	591
Rotor Relative Exit	896	938	970
Stage Exit	586	569	551
Blade Speed (fps)			
Rotor Inlet	573	620	663
Rotor Exit	575	625	674
Total Pressure (psia)			
Stator Exit	107.19	108.66	109.45
Rotor Relative Inlet	96.29	97.60	98.66
Rotor Relative Exit	95.07	96.33	97.38
Stage Exit	88.14	87.92	87.67
Total Temperature (deg R)			
Stator Exit	1838.0	1838.0	1838.0
Rotor Relative Inlet	1789.5	1789.4	1791.0
Rotor Relative Exit	1790.0	1789.9	1791.4
Stage Exit	1756.3	1749.2	1744.7
Velocity Ratio			
Stator	0.487	0.579	0.634
Rotor	0.716	0.655	0.609
Loss Coefficient			
Stator	0.059	0.069	0.077
Rotor	0.112	0.105	0.099

TABLE V - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 2

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.220	15.614	16.880
Stage Exit	14.260	15.732	17.140
Angles (deg)			
Stator Exit	58.3	55.8	53.8
Rotor Relative Inlet	29.9	17.9	6.3
Rotor Relative Exit	-51.2	-54.9	-58.1
Stage Exit	-13.6	-14.9	-15.5
Velocities (fps)			
Stator Exit	1052	982	928
Rotor Relative Inlet	638	581	557
Rotor Relative Exit	922	960	993
Stage Exit	594	572	549
Blade Speed (fps)			
Rotor Inlet	577	633	684
Rotor Exit	578	638	695
Total Pressure (psia)			
Stator Exit	86.84	86.80	86.70
Rotor Relative Inlet	77.20	78.10	79.00
Rotor Relative Exit	76.09	77.13	78.07
Stage Exit	69.84	69.60	69.33
Total Temperature (deg R)			
Stator Exit	1756.4	1749.2	1744.7
Rotor Relative Inlet	1705.2	1703.4	1704.4
Rotor Relative Exit	1705.7	1703.9	1704.9
Stage Exit	1669.2	1660.2	1654.5
Velocity Ratio			
Stator	0.557	0.580	0.594
Rotor	0.693	0.606	0.561
Loss Coefficient			
Stator	0.087	0.085	0.082
Rotor	0.114	0.092	0.083

TABLE V - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 3

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.300	15.936	17.400
Stage Exit	14.340	16.044	17.660
Angles (deg)			
Stator Exit	57.3	54.4	51.9
Rotor Relative Inlet	27.6	13.2	-0.3
Rotor Relative Exit	-50.9	-55.0	-58.4
Stage Exit	-14.6	-15.9	-16.4
Velocities (fps)			
Stator Exit	1035	956	898
Rotor Relative Inlet	630	574	559
Rotor Relative Exit	952	994	1031
Stage Exit	621	595	568
Blade Speed (fps)			
Rotor Inlet	580	646	705
Rotor Exit	581	650	716
Total Pressure (psia)			
Stator Exit	68.77	68.71	68.59
Rotor Relative Inlet	61.03	61.92	62.82
Rotor Relative Exit	60.15	61.16	62.07
Stage Exit	54.71	54.47	54.21
Total Temperature (deg R)			
Stator Exit	1669.2	1660.2	1654.5
Rotor Relative Inlet	1619.5	1617.0	1618.1
Rotor Relative Exit	1619.9	1617.5	1618.7
Stage Exit	1581.1	1570.2	1563.6
Velocity Ratio			
Stator	0.574	0.598	0.612
Rotor	0.662	0.577	0.542
Loss Coefficient			
Stator	0.090	0.085	0.081
Rotor	0.102	0.081	0.075

TABLE V - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 4

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.380	16.260	17.920
Stage Exit	14.420	16.359	18.180
Angles (deg)			
Stator Exit	55.5	52.0	49.1
Rotor Relative Inlet	24.4	8.0	-6.5
Rotor Relative Exit	-49.7	-54.1	-57.8
Stage Exit	-15.2	-16.3	-16.8
Velocities (fps)			
Stator Exit	1028	943	881
Rotor Relative Inlet	639	588	586
Rotor Relative Exit	997	1041	1080
Stage Exit	668	638	607
Blade Speed (fps)			
Rotor Inlet	583	659	727
Rotor Exit	585	663	737
Total Pressure (psia)			
Stator Exit	53.82	53.76	53.63
Rotor Relative Inlet	47.68	48.55	49.43
Rotor Relative Exit	46.99	47.94	48.81
Stage Exit	42.29	42.05	41.80
Total Temperature (deg R)			
Stator Exit	1581.1	1570.2	1563.6
Rotor Relative Inlet	1532.9	1529.8	1531.3
Rotor Relative Exit	1533.3	1530.3	1531.9
Stage Exit	1492.1	1479.3	1471.7
Velocity Ratio			
Stator	0.604	0.632	0.645
Rotor	0.642	0.565	0.543
Loss Coefficient			
Stator	0.091	0.085	0.079
Rotor	0.090	0.071	0.068

TABLE V - VELOCITY TRIANGLE DATA FOR FIVE-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 5

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.460	16.591	18.440
Stage Exit	14.500	16.678	18.700
Angles (deg)			
Stator Exit	54.6	50.6	47.4
Rotor Relative Inlet	26.1	9.1	-5.8
Rotor Relative Exit	-44.5	-50.1	-54.6
Stage Exit	-8.9	-10.8	-11.7
Velocities (fps)			
Stator Exit	1103	1003	935
Rotor Relative Inlet	711	646	642
Rotor Relative Exit	997	1050	1096
Stage Exit	720	687	654
Blade Speed (fps)			
Rotor Inlet	586	673	748
Rotor Exit	588	676	758
Total Pressure (psia)			
Stator Exit	41.49	41.43	41.30
Rotor Relative Inlet	36.02	36.83	37.64
Rotor Relative Exit	35.46	36.34	37.15
Stage Exit	32.16	31.91	31.65
Total Temperature (deg R)			
Stator Exit	1492.1	1479.3	1471.7
Rotor Relative Inlet	1438.5	1434.9	1436.9
Rotor Relative Exit	1438.8	1435.3	1437.4
Stage Exit	1402.5	1387.3	1378.5
Velocity Ratio			
Stator	0.606	0.636	0.649
Rotor	0.713	0.616	0.585
Loss Coefficient			
Stator	0.088	0.082	0.076
Rotor	0.091	0.070	0.065

TABLE VI - VELOCITY TRIANGLE DATA FOR FOUR-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER)

STAGE 1

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.150	15.337	16.425
Stage Exit	14.200	15.501	16.750
Angles (deg)			
Stator Exit	61.3	60.5	59.7
Rotor Relative Inlet	40.1	34.6	28.5
Rotor Relative Exit	-54.7	-57.9	-60.5
Stage Exit	-23.7	-25.6	-26.7
Velocities (fps)			
Stator Exit	1213	1175	1136
Rotor Relative Inlet	761	705	659
Rotor Relative Exit	1022	1064	1096
Stage Exit	644	630	611
Blade Speed (fps)			
Rotor Inlet	574	622	666
Rotor Exit	576	628	679
Total Pressure (psia)			
Stator Exit	106.69	108.25	109.10
Rotor Relative Inlet	92.40	93.87	95.03
Rotor Relative Exit	90.15	91.72	92.99
Stage Exit	81.19	81.13	80.98
Total Temperature (deg R)			
Stator Exit	1838.0	1838.0	1838.0
Rotor Relative Inlet	1773.2	1773.8	1775.8
Rotor Relative Exit	1774.0	1774.4	1776.1
Stage Exit	1727.8	1720.4	1715.3
Velocity Ratio			
Stator	0.420	0.506	0.552
Rotor	0.745	0.663	0.601
Loss Coefficient			
Stator	0.067	0.073	0.077
Rotor	0.163	0.144	0.128

TABLE VI - VELOCITY TRIANGLE DATA FOR FOUR-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 2

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.250	15.737	17.075
Stage Exit	14.300	15.890	17.400
Angles (deg)			
Stator Exit	60.4	58.1	56.3
Rotor Relative Inlet	36.8	25.9	14.9
Rotor Relative Exit	-55.2	-58.2	-60.8
Stage Exit	-26.2	-26.9	-27.1
Velocities (fps)			
Stator Exit	1157	1078	1018
Rotor Relative Inlet	715	635	591
Rotor Relative Exit	1073	1108	1136
Stage Exit	683	657	628
Blade Speed (fps)			
Rotor Inlet	578	638	692
Rotor Exit	580	644	705
Total Pressure (psia)			
Stator Exit	79.41	79.57	79.60
Rotor Relative Inlet	68.88	69.82	70.72
Rotor Relative Exit	67.28	68.49	69.49
Stage Exit	59.58	59.44	59.22
Total Temperature (deg R)			
Stator Exit	1727.8	1720.4	1715.3
Rotor Relative Inlet	1667.0	1664.6	1664.9
Rotor Relative Exit	1667.7	1665.2	1665.4
Stage Exit	1616.8	1606.1	1598.9
Velocity Ratio			
Stator	0.556	0.584	0.600
Rotor	0.666	0.573	0.521
Loss Coefficient			
Stator	0.108	0.108	0.105
Rotor	0.134	0.105	0.093

TABLE VI - VELOCITY TRIANGLE DATA FOR FOUR-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 3

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.350	16.140	17.725
Stage Exit	14.400	16.284	18.050
Angles (deg)			
Stator Exit	57.3	54.4	51.9
Rotor Relative Inlet	29.8	15.5	2.0
Rotor Relative Exit	-54.1	-57.3	-60.1
Stage Exit	-26.6	-26.8	-26.6
Velocities (fps)			
Stator Exit	1092	1008	946
Rotor Relative Inlet	679	612	590
Rotor Relative Exit	1130	1163	1191
Stage Exit	741	706	671
Blade Speed (fps)			
Rotor Inlet	582	654	719
Rotor Exit	584	660	732
Total Pressure (psia)			
Stator Exit	58.23	58.32	58.28
Rotor Relative Inlet	50.93	51.82	52.69
Rotor Relative Exit	49.90	50.95	51.84
Stage Exit	43.47	43.29	43.07
Total Temperature (deg R)			
Stator Exit	1616.8	1606.1	1598.9
Rotor Relative Inlet	1562.6	1558.5	1558.4
Rotor Relative Exit	1563.3	1559.2	1559.1
Stage Exit	1508.6	1495.1	1486.4
Velocity Ratio			
Stator	0.626	0.652	0.664
Rotor	0.601	0.526	0.495
Loss Coefficient			
Stator	0.117	0.112	0.106
Rotor	0.101	0.081	0.076

TABLE VI - VELOCITY TRIANGLE DATA FOR FOUR-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 4

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.450	16.555	18.375
Stage Exit	14.500	16.681	18.700
Angles (deg)			
Stator Exit	56.4	52.8	49.9
Rotor Relative Inlet	31.6	16.3	2.1
Rotor Relative Exit	-46.7	-51.6	-55.6
Stage Exit	-14.6	-16.0	-16.6
Velocities (fps)			
Stator Exit	1189	1085	1012
Rotor Relative Inlet	773	686	659
Rotor Relative Exit	1070	1120	1161
Stage Exit	759	726	692
Blade Speed (fps)			
Rotor Inlet	586	671	745
Rotor Exit	588	676	758
Total Pressure (psia)			
Stator Exit	42.29	42.36	42.30
Rotor Relative Inlet	36.00	36.82	37.61
Rotor Relative Exit	35.25	36.20	37.02
Stage Exit	31.37	31.16	30.93
Total Temperature (deg R)			
Stator Exit	1508.6	1495.1	1486.4
Rotor Relative Inlet	1447.2	1442.1	1442.0
Rotor Relative Exit	1447.7	1442.6	1442.7
Stage Exit	1404.2	1387.2	1376.4
Velocity Ratio			
Stator	0.623	0.651	0.662
Rotor	0.722	0.612	0.567
Loss Coefficient			
Stator	0.112	0.105	0.098
Rotor	0.107	0.081	0.072

TABLE VII - VELOCITY TRIANGLE DATA FOR THREE-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER)

STAGE 1

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.167	15.407	16.533
Stage Exit	14.233	15.631	16.967
Angles (deg)			
Stator Exit	65.0	64.0	63.1
Rotor Relative Inlet	49.5	44.5	39.1
Rotor Relative Exit	-58.7	-61.4	-63.7
Stage Exit	-34.3	-35.9	-36.9
Velocities (fps)			
Stator Exit	1398	1338	1284
Rotor Relative Inlet	910	825	755
Rotor Relative Exit	1154	1196	1227
Stage Exit	726	710	688
Blade Speed (fps)			
Rotor Inlet	574	625	670
Rotor Exit	577	634	688
Total Pressure (psia)			
Stator Exit	105.98	107.34	108.63
Rotor Relative Inlet	88.31	89.95	91.21
Rotor Relative Exit	84.50	86.45	88.01
Stage Exit	73.78	73.92	73.90
Total Temperature (deg R)			
Stator Exit	1838.0	1838.0	1838.0
Rotor Relative Inlet	1756.3	1757.4	1759.6
Rotor Relative Exit	1757.5	1758.2	1759.9
Stage Exit	1698.2	1689.9	1683.8
Velocity Ratio			
Stator	0.370	0.446	0.483
Rotor	0.789	0.690	0.615
Loss Coefficient			
Stator	0.077	0.079	0.080
Rotor	0.231	0.196	0.170

TABLE VII - VELOCITY TRIANGLE DATA FOR THREE-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 2

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.300	15.946	17.400
Stage Exit	14.367	16.156	17.833
Angles (deg)			
Stator Exit	63.7	61.5	59.9
Rotor Relative Inlet	46.3	36.9	27.2
Rotor Relative Exit	-58.2	-60.8	-63.1
Stage Exit	-36.3	-36.7	-36.8
Velocities (fps)			
Stator Exit	1343	1242	1168
Rotor Relative Inlet	862	743	666
Rotor Relative Exit	1257	1290	1313
Stage Exit	822	787	749
Blade Speed (fps)			
Rotor Inlet	580	647	705
Rotor Exit	582	655	723
Total Pressure (psia)			
Stator Exit	71.16	71.62	71.86
Rotor Relative Inlet	59.08	60.14	61.09
Rotor Relative Exit	56.64	58.20	59.38
Stage Exit	47.97	48.01	47.88
Total Temperature (deg R)			
Stator Exit	1698.2	1689.9	1683.8
Rotor Relative Inlet	1620.2	1616.8	1616.0
Rotor Relative Exit	1621.3	1617.7	1616.6
Stage Exit	1553.6	1539.7	1529.7
Velocity Ratio			
Stator	0.541	0.572	0.589
Rotor	0.686	0.576	0.508
Loss Coefficient			
Stator	0.134	0.134	0.132
Rotor	0.177	0.132	0.113

TABLE VII - VELOCITY TRIANGLE DATA FOR THREE-STAGE LP SPOOL (REDUCED MAXIMUM TIP DIAMETER) (CONTINUED)

STAGE 3

	Hub	Mean	Casing
Station Radius (ins)			
Stator Exit	14.433	16.509	18.267
Stage Exit	14.500	16.688	18.700
Angles (deg)			
Stator Exit	62.1	59.2	57.0
Rotor Relative Inlet	47.0	36.3	25.7
Rotor Relative Exit	-48.8	-53.3	-56.8
Stage Exit	-21.5	-23.2	-23.8
Velocities (fps)			
Stator Exit	1529	1389	1293
Rotor Relative Inlet	1048	885	790
Rotor Relative Exit	1191	1245	1284
Stage Exit	843	813	778
Blade Speed (fps)			
Rotor Inlet	585	669	741
Rotor Exit	588	677	758
Total Pressure (psia)			
Stator Exit	45.82	46.23	46.38
Rotor Relative Inlet	36.06	37.00	37.80
Rotor Relative Exit	34.45	35.71	36.70
Stage Exit	29.83	29.76	29.59
Total Temperature (deg R)			
Stator Exit	1553.6	1539.7	1529.7
Rotor Relative Inlet	1460.9	1454.1	1451.4
Rotor Relative Exit	1461.6	1454.6	1451.7
Stage Exit	1407.6	1386.9	1372.2
Velocity Ratio			
Stator	0.537	0.567	0.579
Rotor	0.880	0.711	0.616
Loss Coefficient			
Stator	0.126	0.121	0.115
Rotor	0.191	0.138	0.111

FIGURES

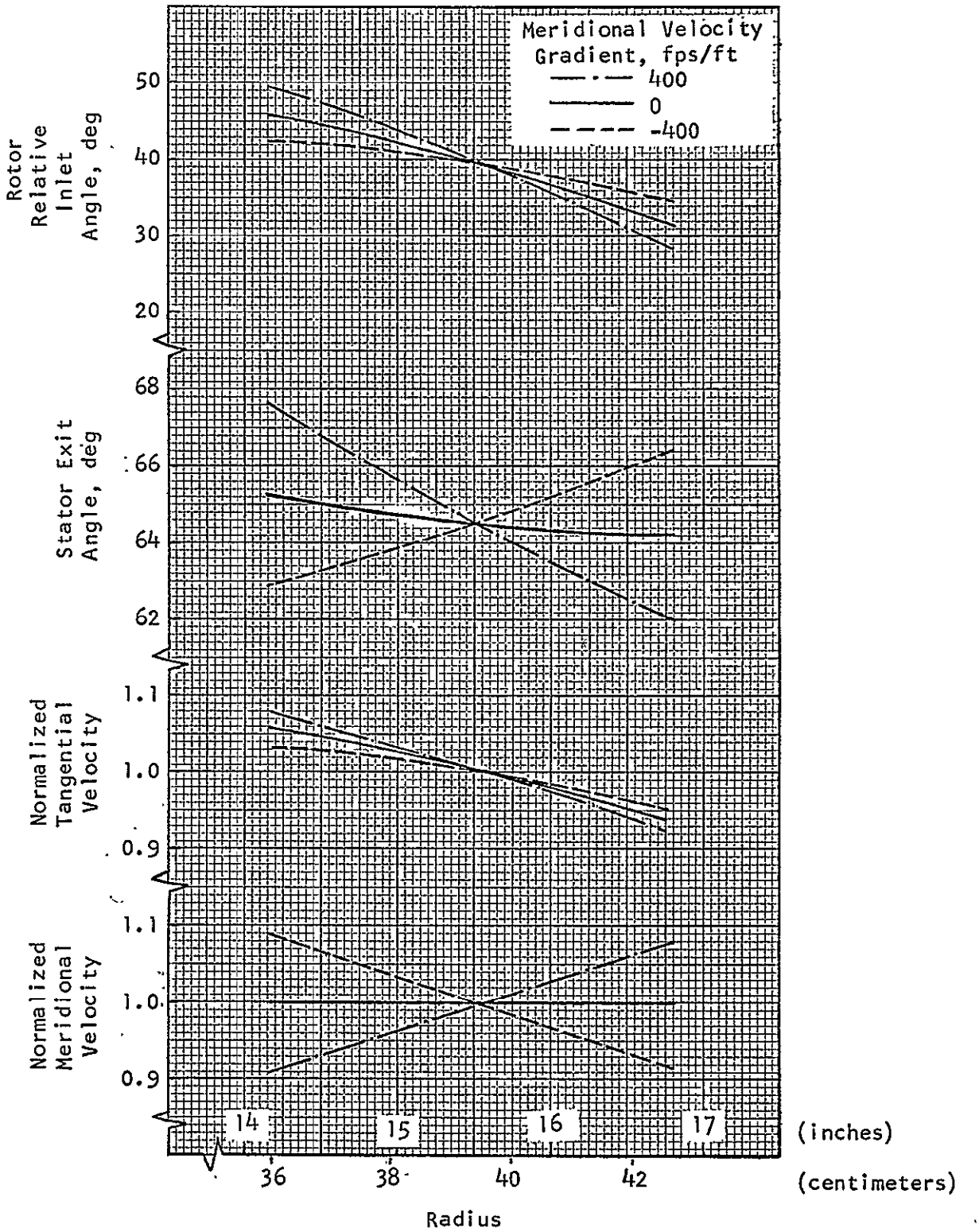

FIGURE 1 - EFFECT OF MERIDIONAL VELOCITY GRADIENT ON STATOR EXIT CONDITIONS (FIRST STAGE OF FOUR-STAGE LP SPOOL)

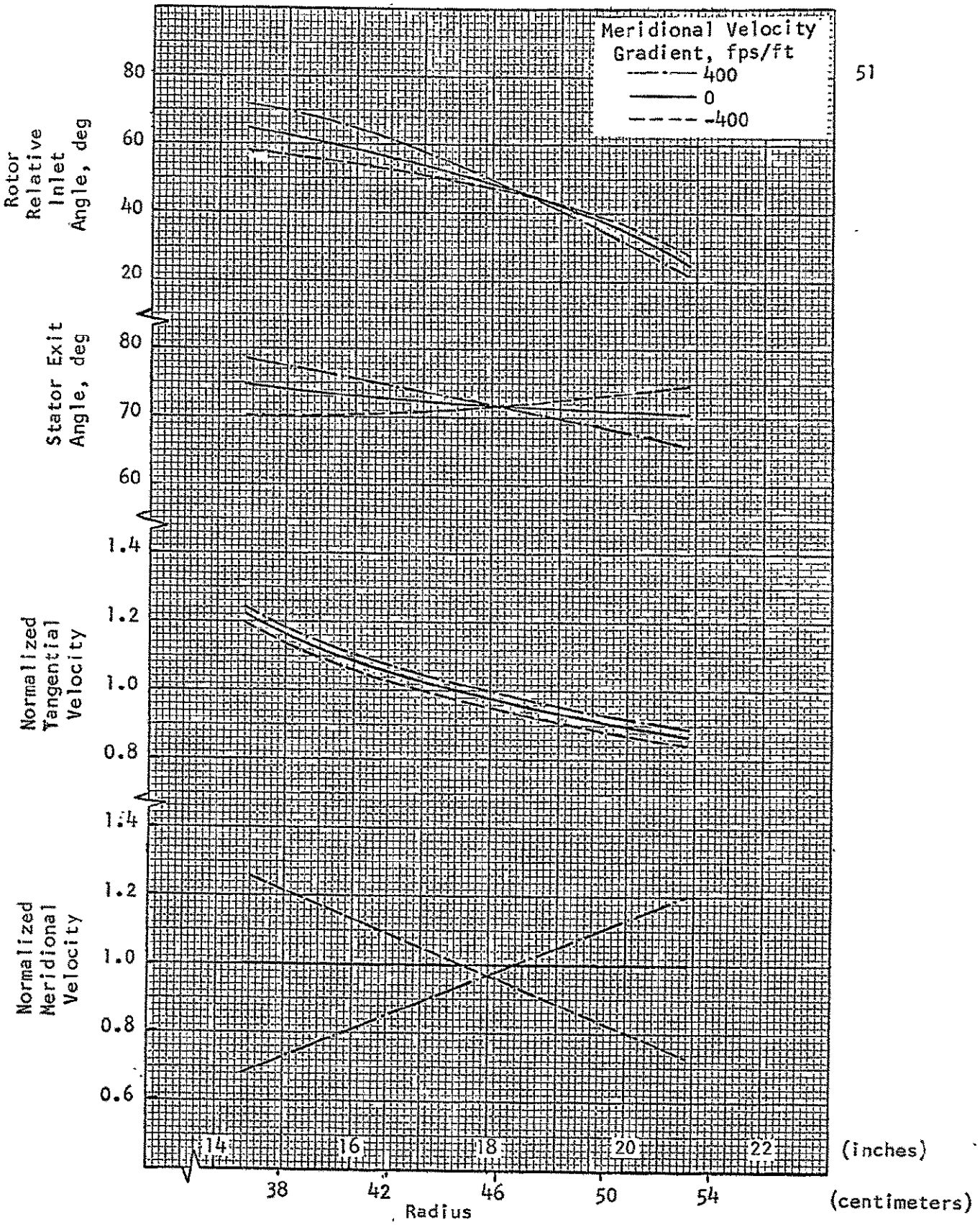

FIGURE 2 - EFFECT OF MERIDIONAL VELOCITY GRADIENT ON STATOR EXIT CONDITIONS (FINAL STAGE OF FOUR-STAGE LP SPOOL)

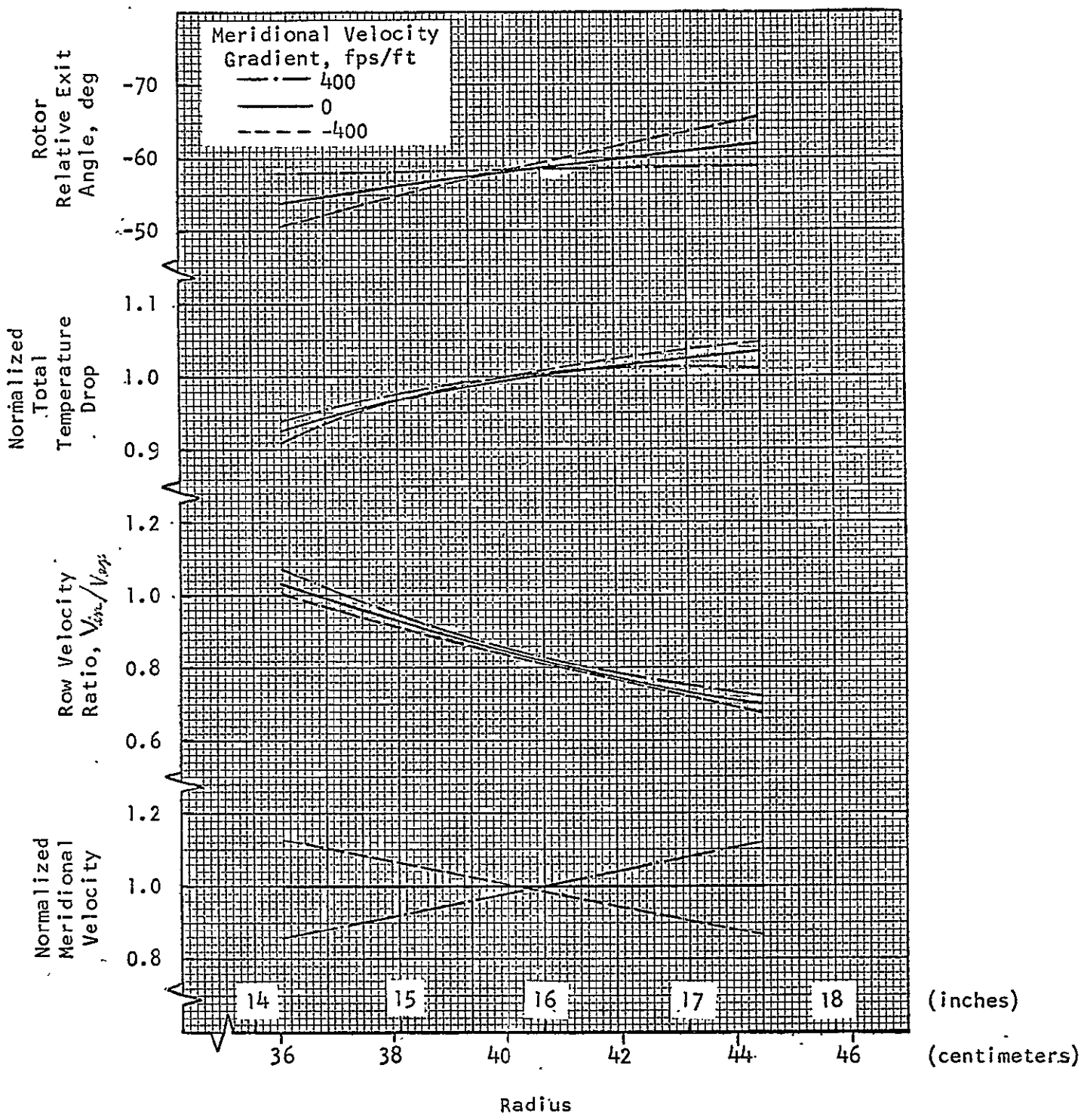

FIGURE 3 - EFFECT OF MERIDIONAL VELOCITY GRADIENT ON ROTOR EXIT CONDITIONS (FIRST STAGE OF FOUR-STAGE LP SPOOL)

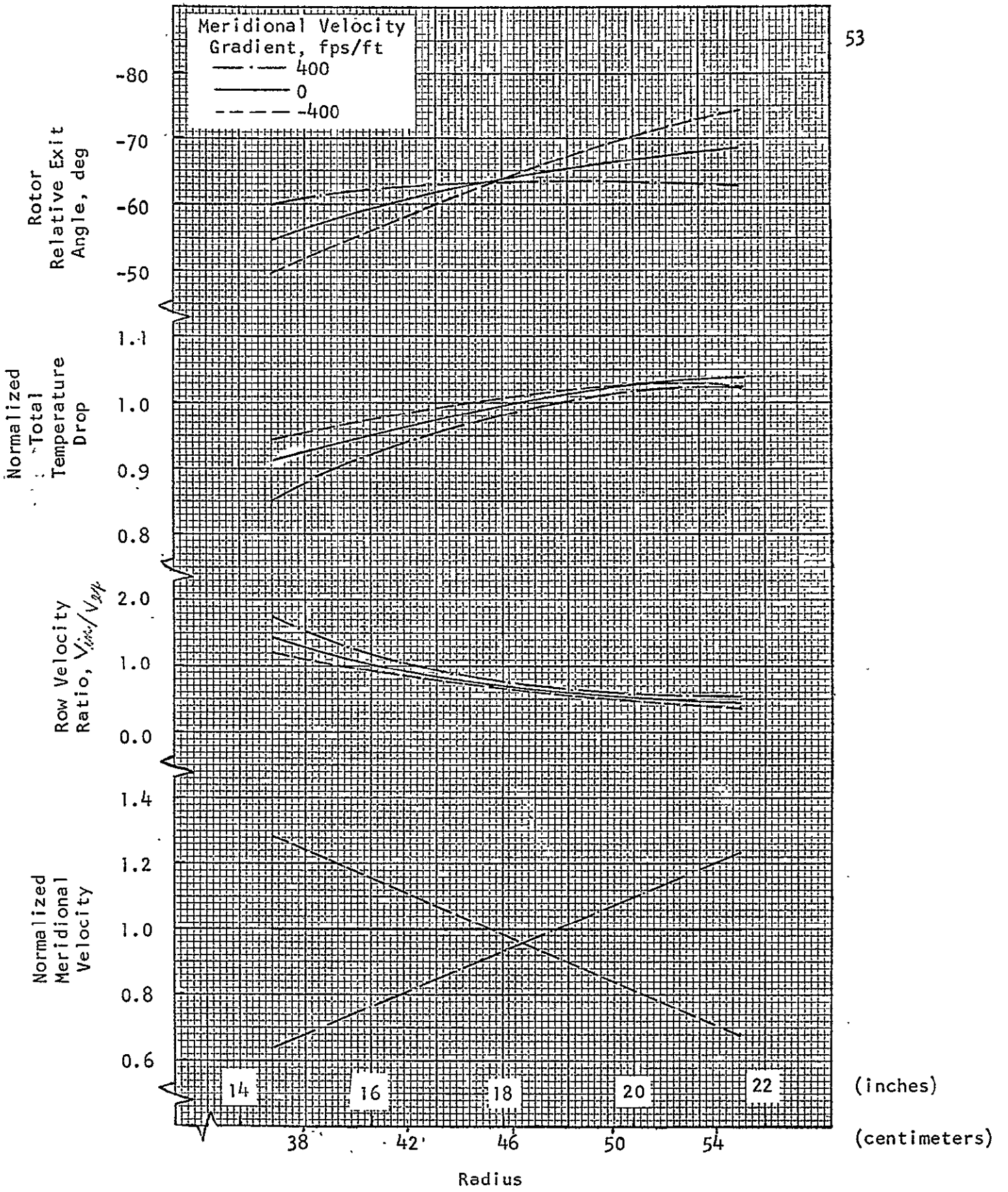

FIGURE 4 - EFFECT OF MERIDIONAL VELOCITY GRADIENT ON ROTOR EXIT CONDITIONS (FINAL STAGE OF FOUR-STAGE LP SPOOL)

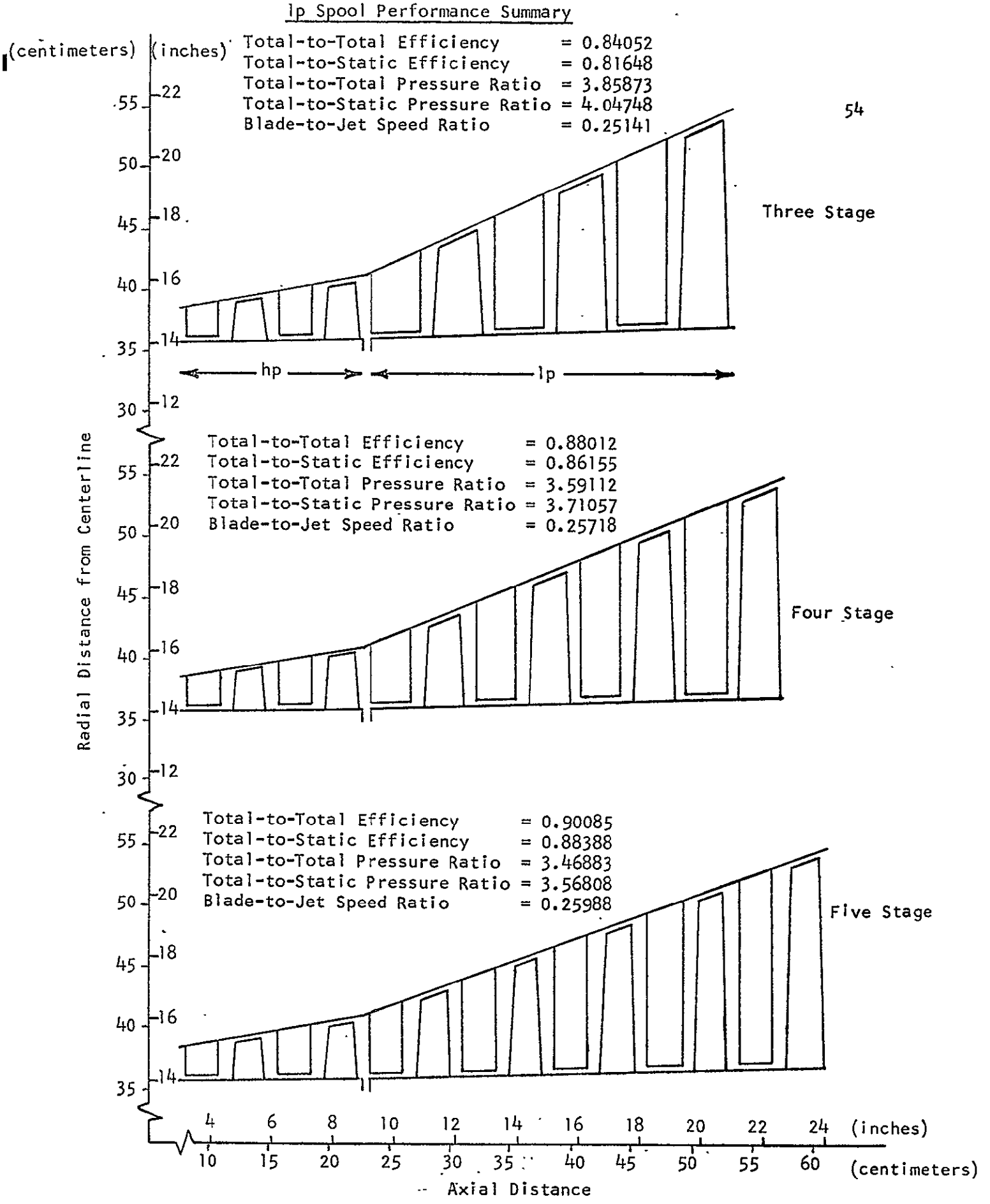

FIGURE 5 - SCHEMATIC SIDE VIEWS OF THE THREE ALTERNATIVE TURBINE DESIGNS AT THE ORIGINAL MAXIMUM TIP DIAMETER

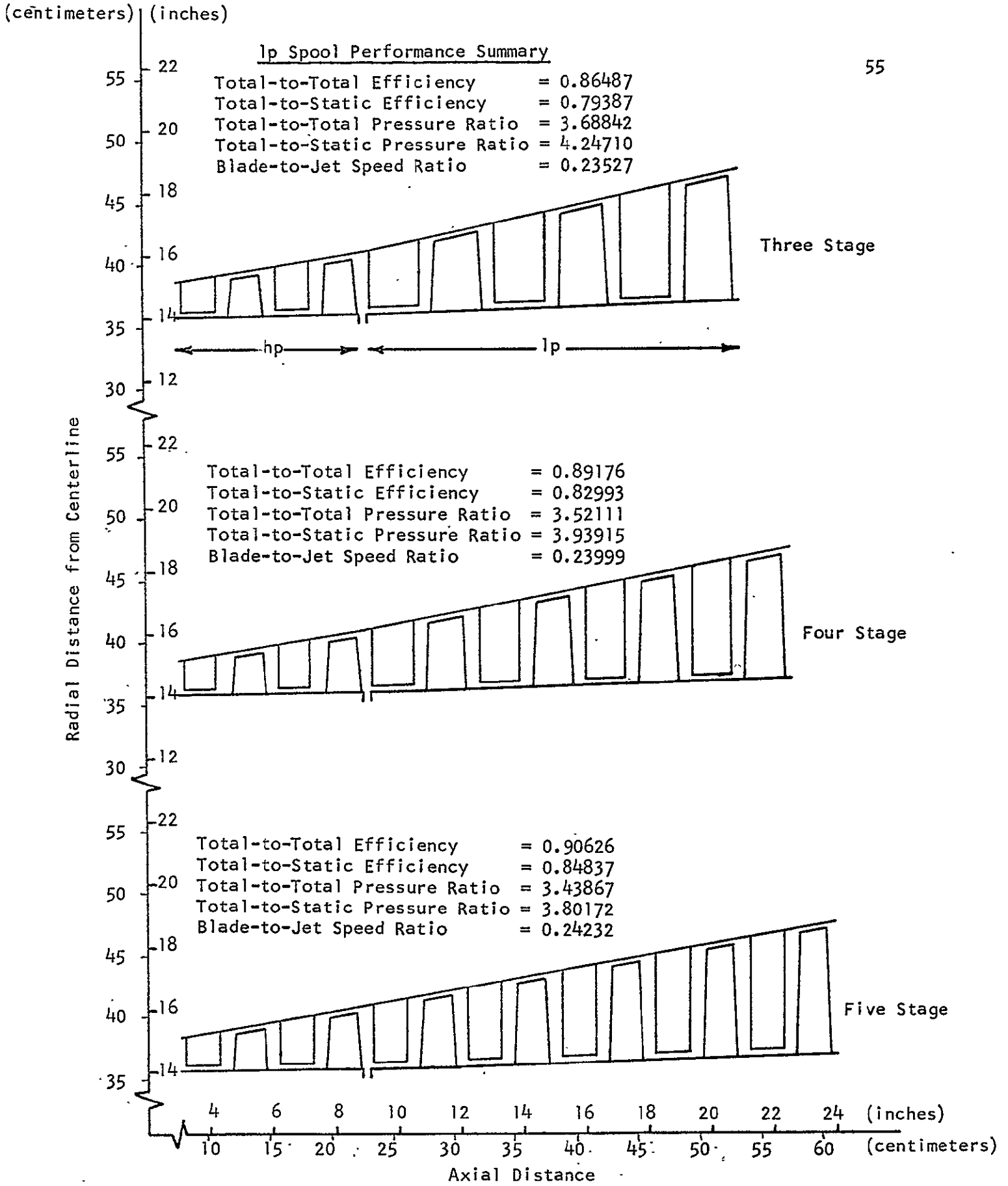

FIGURE 6 - SCHEMATIC SIDE VIEWS OF THE THREE ALTERNATIVE TURBINE DESIGNS AT THE REDUCED MAXIMUM TIP DIAMETER

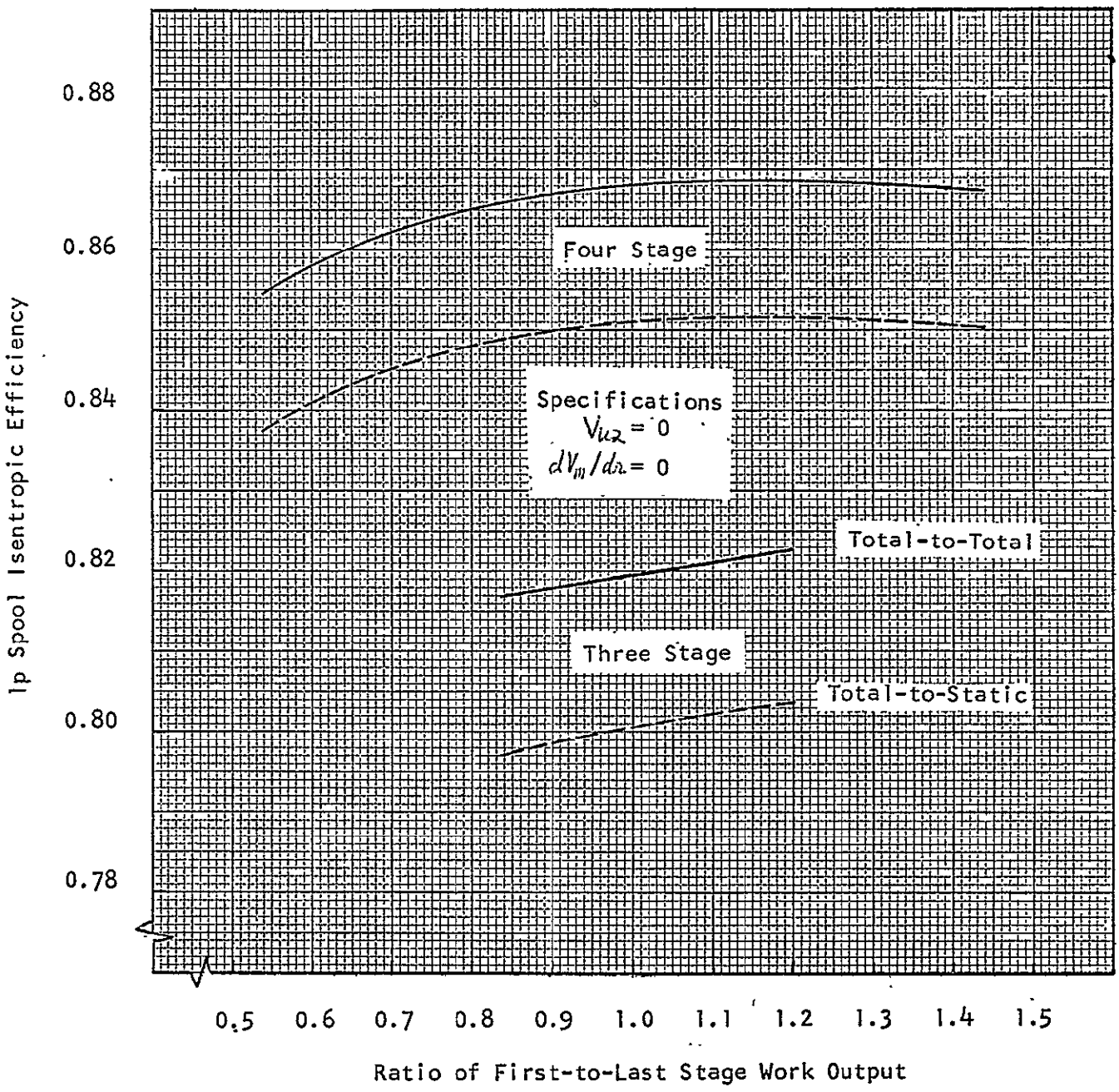

FIGURE 7 - VARIATION OF TOTAL-TO-TOTAL AND TOTAL-TO-STATIC ISENTROPIC EFFICIENCY WITH STAGE WORK SPLIT FOR THE THREE- AND FOUR-STAGE LP SPOOLS AT ORIGINAL MAXIMUM TIP DIAMETER

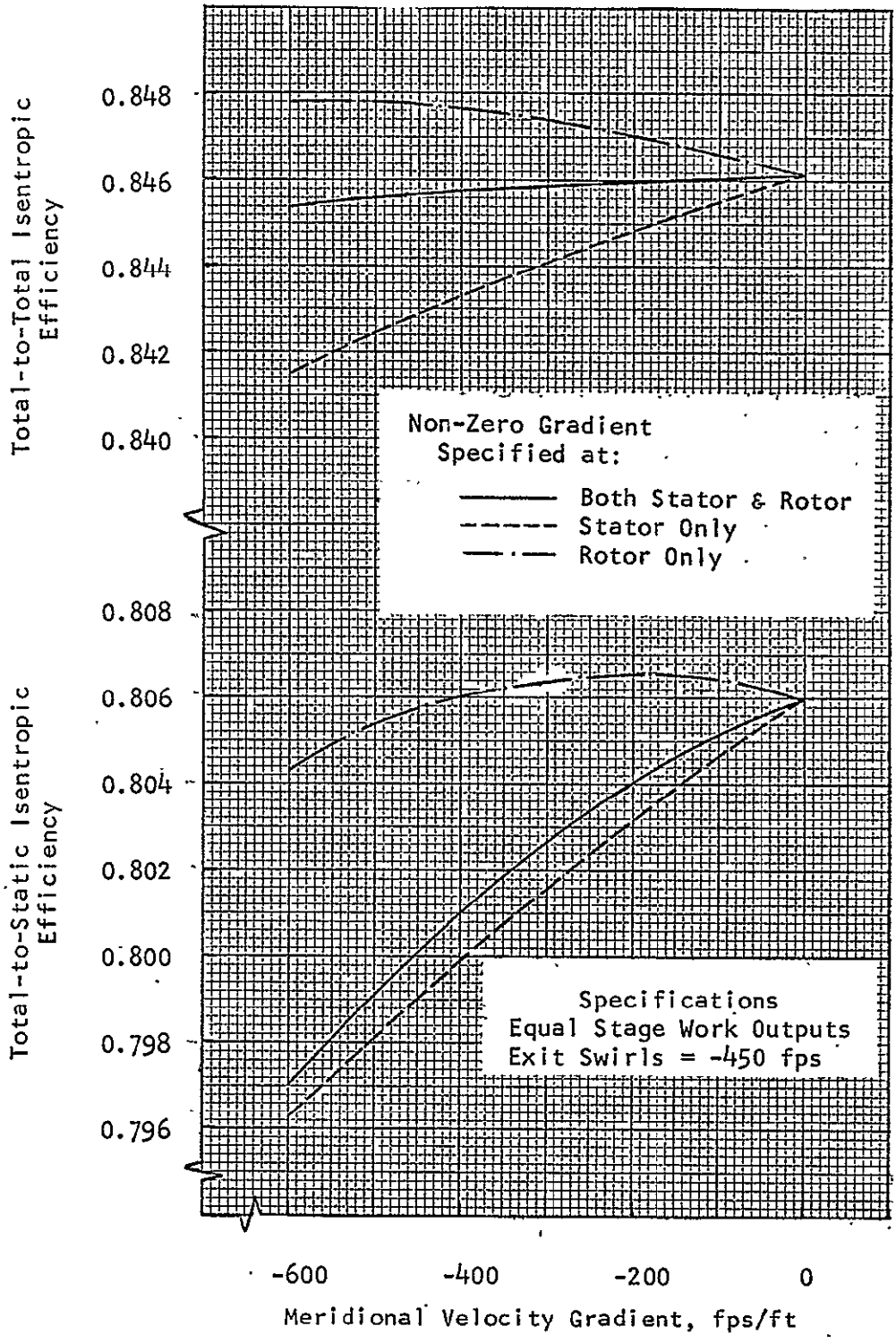

FIGURE 8 - VARIATION OF TOTAL-TO-TOTAL AND TOTAL-TO-STATIC ISENTROPIC EFFICIENCY WITH MERIDIONAL VELOCITY GRADIENT FOR THE THREE-STAGE LP SPOOL AT ORIGINAL MAXIMUM TIP DIAMETER

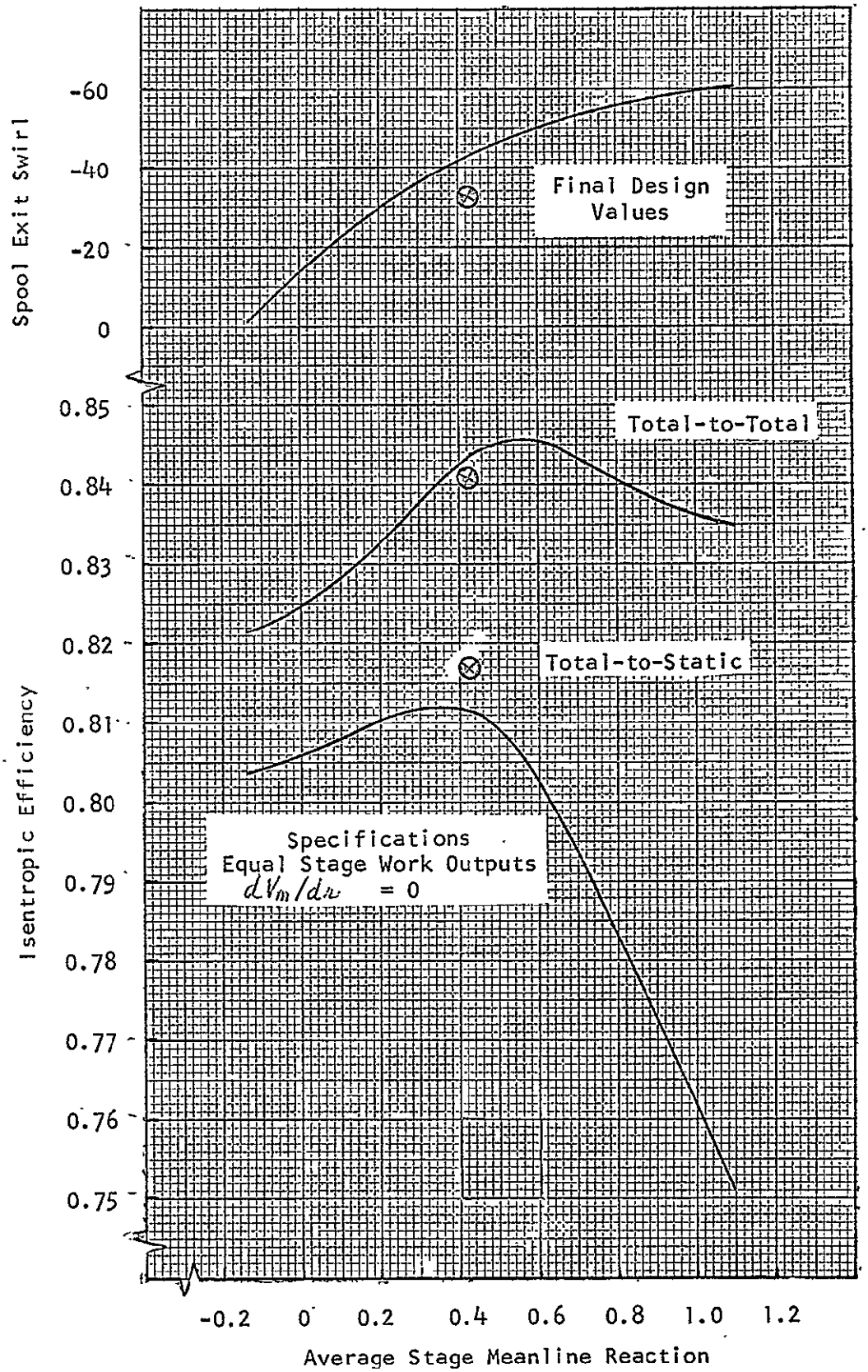

FIGURE 9 - VARIATION OF ISENTROPIC EFFICIENCY AND SPOOL EXIT SWIRL WITH AVERAGE STAGE MEANLINE REACTION FOR THE THREE-STAGE LP SPOOL AT ORIGINAL MAXIMUM TIP DIAMETER

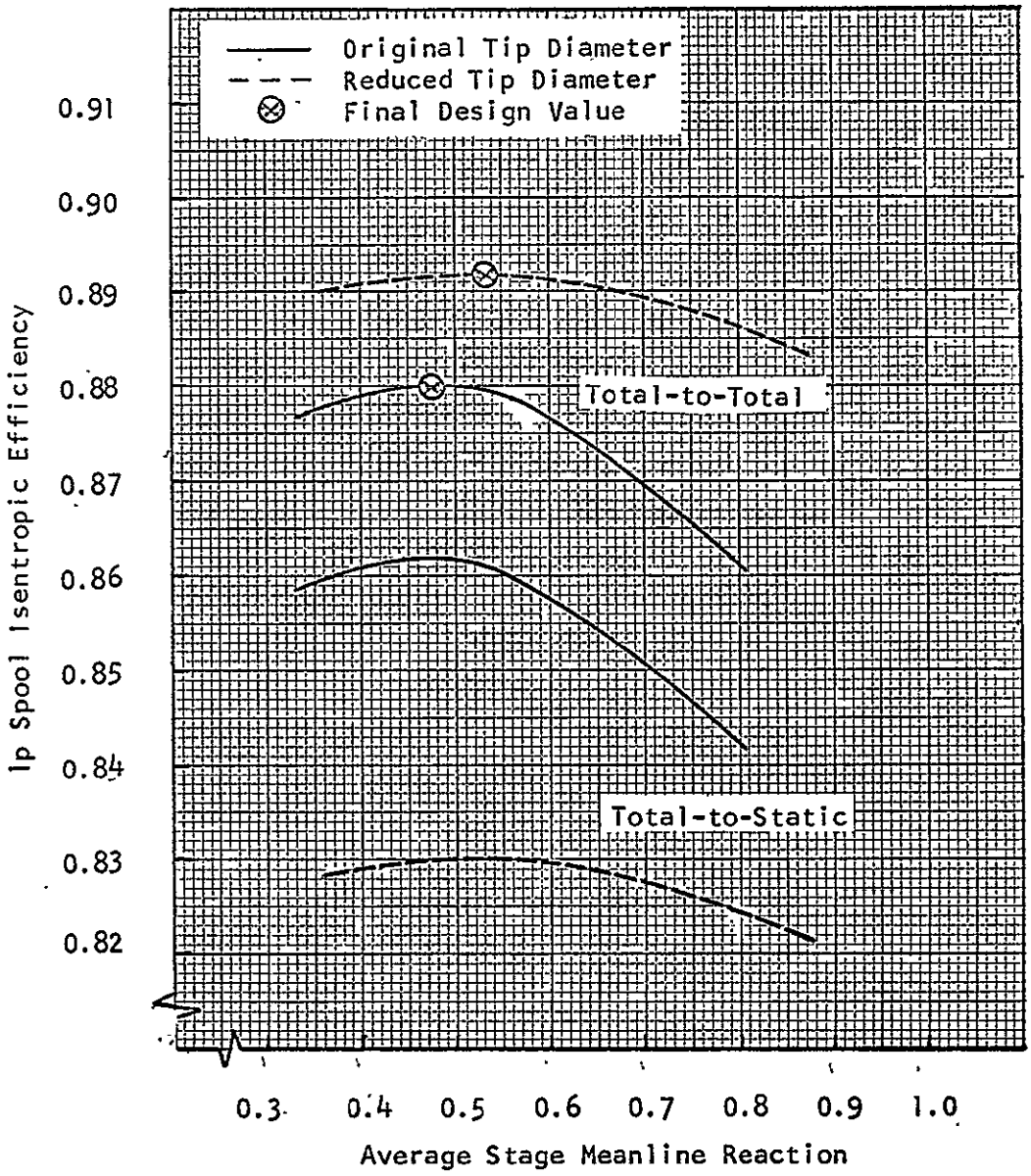

FIGURE 10 - VARIATION OF ISENTROPIC EFFICIENCY WITH AVERAGE STAGE MEANLINE REACTION FOR BOTH ORIGINAL AND REDUCED FOUR-STAGE LP SPOOLS (CONSTANT SPOOL EXIT SWIRL)

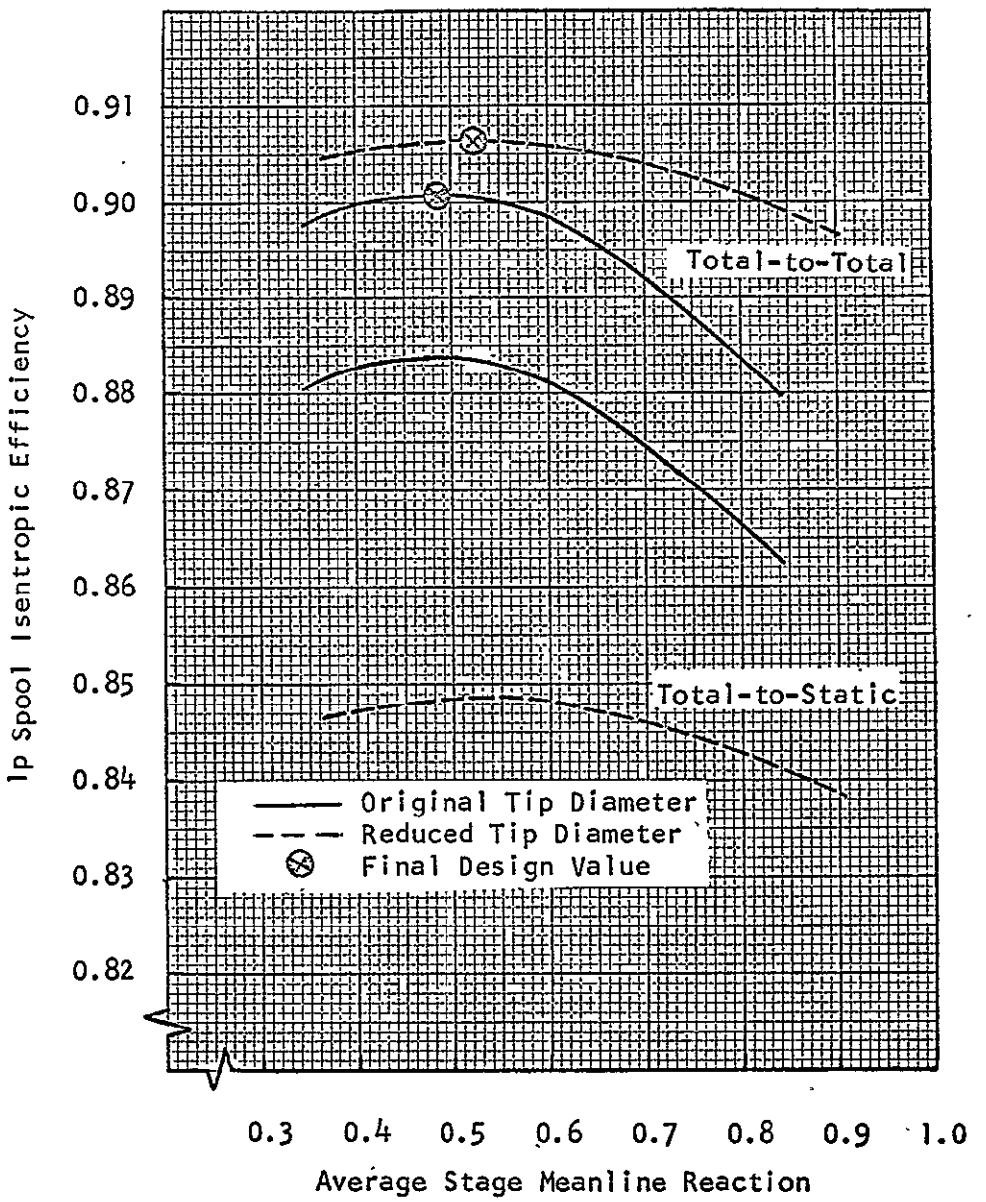

FIGURE 11 - VARIATION OF ISENTROPIC EFFICIENCY WITH AVERAGE STAGE MEANLINE REACTION FOR BOTH ORIGINAL AND REDUCED FIVE-STAGE LP SPOOLS (CONSTANT SPOOL EXIT SWIRL)

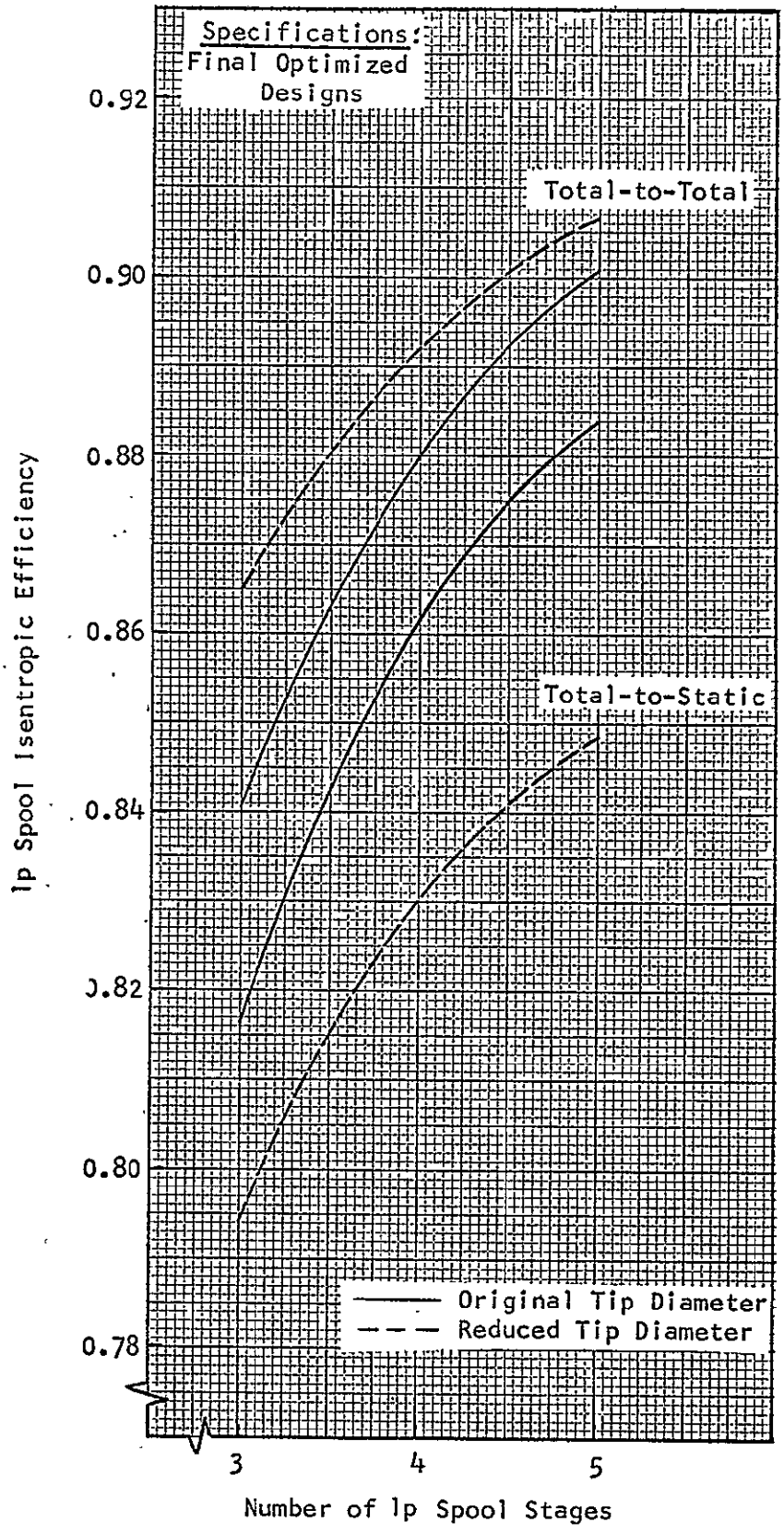

FIGURE 12 - VARIATION OF LP SPOOL TOTAL-TO-TOTAL AND TOTAL-TO-STATIC EFFICIENCY WITH NUMBER OF STAGES AND MAXIMUM TIP DIAMETER

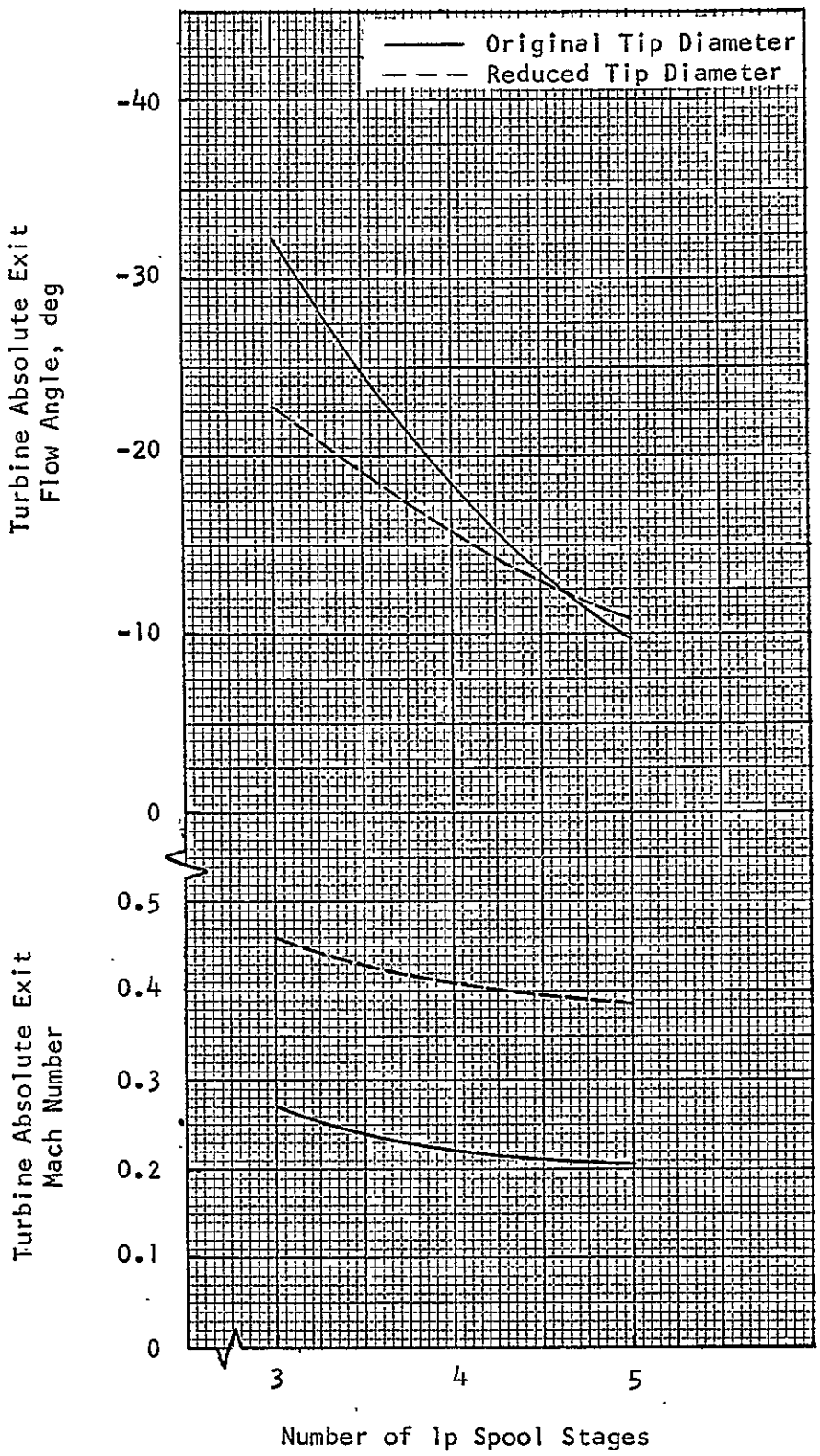

FIGURE 13 - VARIATION OF SPOOL EXIT CONDITIONS WITH NUMBER OF STAGES AND MAXIMUM TIP DIAMETER

APPENDICES

APPENDIX I

COMPUTER OUTPUT FOR THE HIGH-PRESSURE SPOOL

This appendix presents the computer output for the common hp spool employed by all six of the final turbine designs. A printout of the input data specified for the case appears on the first four pages, followed immediately by the results of the design analysis for the spool.

PROGRAM TD2 - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES

HP SPOOL OF NASA MULTISTAGE TWINSPOOL TURBINE

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 1
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.35000 LBF FT/LBM DEG R
INLET MASS FLOW = 111.90000 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
14.5000	2410.00	342.4000	0.000

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 10800.0 RPM
POWER OUTPUT = 24530.00 HP

** ANALYSIS VARIABLES **

NUMBER OF STAGES = 2

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	.49000
2	.51000

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	.28800
2	.28800
3	.28200
4	.28200
5	.27500

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	0.0000	13.9750	14.8500
2	1.5000	14.0000	15.1000
3	3.0000	14.0250	15.3500
4	4.5000	14.0500	15.6000
5	6.0000	14.0750	15.8500

6	7.5000	14.1000	16.1000
7	9.0000	14.1400	16.6500

* COOLANT SCHEDULE *

BLADE ROW NUMBER	FRACTION OF INLET MASS FLOW	TOTAL TEMPERATURE (DEG R)
1	.01698	1400.00
2	.01698	1400.00
3	.01609	1400.00
4	0.00000	1400.00

* BLADE-ROW EXIT CONDITIONS *

STATOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
14.6900	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1370.7000 FEET PER SEC

ROTOR 1

SOLUTION COMPUTED FOR RADIALLY CONSTANT WORK OUTPUT

STATOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
9000.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1395.6000 FEET PER SEC

ROTOR 2

SOLUTION COMPUTED FOR RADIALLY CONSTANT WORK OUTPUT

* BASIC INTERNAL LOSS CORRELATION *

$$Y = \frac{\text{TAN(INLET ANGLE)} + \text{TAN(EXIT ANGLE)}}{.60000000 + .80000000 * \text{COS(EXIT ANGLE)}} \text{ *TIMES* } \begin{cases} .03000000 + .15725500 * (\text{V RATIO})^{**} 3.60) & \text{IF (V RATIO) .LT. .60000000} \\ .05500000 + .15000000 *((\text{V RATIO}) - .600)) & \text{IF (V RATIO) .GE. .60000000} \end{cases}$$

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF 2.00000000

*** OUTPUT OF SPOOL DESIGN ANALYSIS ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.0000	0.00000	427.145	427.086	0.000	427.145	.18380	342.4000	2410.00	0.000
2	14.1415	13.98750	427.145	426.872	0.000	427.145	.18380	342.4000	2410.00	0.000
3	14.2817	27.97500	427.145	426.507	0.000	427.145	.18380	342.4000	2410.00	0.000
4	14.4207	41.96250	427.145	425.994	0.000	427.145	.18380	342.4000	2410.00	0.000
5	14.5585	55.95000	427.145	425.337	0.000	427.145	.18380	342.4000	2410.00	0.000
6	14.6953	69.93750	427.145	424.539	0.000	427.145	.18380	342.4000	2410.00	0.000
7	14.8311	83.92500	427.145	423.604	0.000	427.145	.18380	342.4000	2410.00	0.000
8	14.9660	97.91250	427.145	422.535	0.000	427.145	.18380	342.4000	2410.00	0.000
9	15.1000	111.90000	427.145	421.334	0.000	427.145	.18380	342.4000	2410.00	0.000

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	334.9123	2397.35	.955	0.00000
2	334.9123	2397.35	2.049	0.00000
3	334.9123	2397.35	3.134	0.00000
4	334.9123	2397.35	4.208	0.00000
5	334.9123	2397.35	5.274	0.00000
6	334.9123	2397.35	6.332	0.00000
7	334.9123	2397.35	7.383	0.00000
8	334.9123	2397.35	8.426	0.00000
9	334.9123	2397.35	9.462	0.00000

** STATOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	342.4000	2393.14
2	342.4000	2393.14

3	342.4000	2393.14
4	342.4000	2393.14
5	342.4000	2393.14
6	342.4000	2393.14
7	342.4000	2393.14
8	342.4000	2393.14
9	342.4000	2393.14

** STATOR EXIT = ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.0250	0.00000	437.094	437.034	1428.782	1494.146	.66539	332.2768	2393.14	72.992
2	14.1993	14.22472	437.094	436.808	1413.482	1479.521	.65843	332.5536	2393.14	72.827
3	14.3768	28.44944	437.094	436.424	1398.728	1465.433	.65174	332.8116	2393.14	72.671
4	14.5396	42.67416	437.094	435.888	1384.480	1451.839	.64530	333.0523	2393.14	72.524
5	14.7059	56.89887	437.094	435.207	1370.700	1438.704	.63909	333.2773	2393.14	72.385
6	14.8760	71.12359	437.094	434.387	1357.356	1425.997	.63309	333.4880	2393.14	72.254
7	15.0319	85.34831	437.094	433.434	1344.419	1413.688	.62729	333.6855	2393.14	72.131
8	15.1919	99.57302	437.094	432.353	1331.862	1401.751	.62167	333.8708	2393.14	72.015
9	15.3500	113.79774	437.094	431.147	1319.659	1390.162	.61622	334.0449	2393.14	71.907

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	250.8971	2238.33	.955	.00000	1321.825	449.991	.20039	257.5755	2252.37	13.752
2	252.5303	2241.35	2.074	.00000	1338.252	443.521	.19738	259.0495	2254.99	9.772
3	254.0918	2244.22	3.175	.00000	1354.411	439.335	.19539	260.5185	2257.61	5.798
4	255.5870	2246.97	4.259	.00000	1370.321	437.324	.19438	261.9840	2260.23	1.860
5	257.0208	2249.60	5.327	-.00000	1386.000	437.362	.19428	263.4473	2262.87	-2.013
6	258.3977	2252.13	6.380	-.00000	1401.463	439.314	.19504	264.9096	2265.51	-5.798
7	259.7217	2254.55	7.420	-.00000	1416.725	443.035	.19659	266.3721	2268.16	-9.471
8	260.9962	2256.88	8.447	-.00000	1431.801	448.374	.19885	267.8358	2270.82	-13.015
9	262.2246	2259.13	9.462	-.00000	1446.703	455.183	.20177	269.3017	2273.49	-16.418

** ROTOR 1 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)
1	332.2768	2376.83	257.1118	2236.06
2	332.5536	2376.83	258.5923	2238.68
3	332.8116	2376.83	260.0680	2241.30

4	333.0523	2376.83	261.5403	2243.92
5	333.2773	2376.83	263.0104	2246.56
6	333.4880	2376.83	264.4797	2249.20
7	333.6855	2376.83	265.9493	2251.85
8	333.8708	2376.83	267.4202	2254.51
9	334.0449	2376.83	268.8934	2257.18

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.0500	0.00000	423.323	423.264	24.443	424.028	.19401	200.5074	2119.19	3.305
2	14.2665	14.46105	439.374	439.066	30.502	440.431	.20156	200.9018	2119.19	3.974
3	14.4732	28.92239	451.405	450.667	35.610	452.808	.20726	201.2102	2119.19	4.518
4	14.6725	43.38386	460.486	459.148	40.000	462.222	.21160	201.4514	2119.19	4.979
5	14.8659	57.84537	467.519	465.418	43.858	469.571	.21499	201.6438	2119.19	5.383
6	15.0546	72.30690	473.005	469.994	47.304	475.365	.21766	201.7982	2119.19	5.747
7	15.2394	86.76844	477.231	473.167	50.426	479.888	.21975	201.9206	2119.19	6.083
8	15.4210	101.23000	480.359	475.107	53.288	483.305	.22133	202.0145	2119.19	6.400
9	15.6000	115.69158	482.474	475.910	55.939	485.706	.22243	202.0815	2119.19	6.704

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	195.5982	2106.46	.955	-.00000	1324.181	1366.938	.62541	251.3036	2238.78	-71.962
2	195.5988	2105.45	2.143	-.00000	1344.588	1385.596	.63410	253.0179	2241.42	-71.524
3	195.5997	2104.67	3.278	-.00000	1364.069	1403.057	.64221	254.6483	2244.08	-71.261
4	195.6007	2104.06	4.371	-.00000	1382.849	1419.619	.64988	256.2171	2246.78	-71.123
5	195.6020	2103.57	5.433	.00000	1401.079	1435.487	.65723	257.7438	2249.51	-71.072
6	195.6034	2103.19	6.469	.00000	1418.864	1450.831	.66431	259.2400	2252.25	-71.085
7	195.6050	2102.88	7.483	.00000	1436.283	1465.725	.67118	260.7122	2255.02	-71.149
8	195.6067	2102.65	8.480	.00000	1453.399	1480.221	.67786	262.1639	2257.82	-71.256
9	195.6086	2102.48	9.462	.00000	1470.265	1494.356	.68436	263.5974	2260.63	-71.402

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.28588	.32920	.12439	.12859	.98668	.91211	.94091	.88505
2	.28871	.32009	.12304	.12090	.98727	.91772	.94290	.88810
3	.29148	.31313	.12180	.11930	.98781	.92184	.94423	.89051
4	.29421	.30806	.12067	.11811	.98829	.92404	.94507	.89239

5	.29690	.30468	.11963	.10786	.90873	.92710	.94557	.89396
6	.29856	.30280	.11868	.10532	.90913	.92879	.94580	.89511
7	.30215	.30226	.11782	.10334	.90947	.93006	.94583	.89608
8	.30472	.30291	.11704	.10182	.90978	.93095	.94567	.89682
9	.30728	.30460	.11633	.10074	.91004	.93151	.94533	.89735

** MASS-AVERAGED QUANTITIES **

STATOR BLADE-ROW EFFICIENCY = .90861

ROTOR BLADE-ROW EFFICIENCY = .92539

STAGE WORK = 73.427 BTU PER LBM

STAGE TOTAL EFFICIENCY = .90592

STAGE STATIC EFFICIENCY = .86064

STAGE BLADE- TO JET-SPEED RATIO = .86894

** STATOR 2 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)
1	200.5074	2108.17
2	200.9018	2108.17
3	201.2102	2108.17
4	201.4514	2108.17
5	201.6438	2108.17
6	201.7982	2108.17
7	201.9206	2108.17
8	202.0145	2108.17
9	202.0815	2108.17

** STATOR EXIT - ROTOR INLET 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.0750	0.00000	516.176	516.105	1465.878	1554.103	.74147	194.7134	2108.17	70.604
2	14.3139	14.68732	516.176	515.830	1447.792	1537.055	.73264	195.2623	2108.17	70.390
3	14.5470	29.37463	516.176	515.363	1430.017	1520.324	.72399	195.7240	2108.17	70.181
4	14.7749	44.05195	516.176	514.717	1412.593	1503.947	.71554	196.1135	2108.17	69.979
5	14.9980	58.74927	516.176	513.903	1395.600	1487.998	.70734	196.4474	2108.17	69.785
6	15.2168	73.43658	516.176	512.932	1379.069	1472.504	.69939	196.7368	2108.17	69.598
7	15.4315	88.12390	516.176	511.811	1362.989	1457.456	.69169	196.9885	2108.17	69.419
8	15.6425	102.81121	516.176	510.549	1347.332	1442.824	.68422	197.2065	2108.17	69.247
9	15.8500	117.49853	516.176	509.153	1332.059	1428.573	.67697	197.3936	2108.17	69.082

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	137.4813	1937.13	.955	0.00000	1326.537	534.653	.25509	143.4878	1957.37	15.109
2	138.9646	1940.86	2.100	0.00000	1349.049	525.536	.25050	144.8160	1960.42	10.837
3	140.3657	1944.48	3.217	0.00000	1371.021	519.537	.24741	146.1289	1963.60	6.530
4	141.6916	1947.99	4.309	0.00000	1392.502	516.567	.24577	147.4314	1966.88	2.235
5	142.9483	1951.37	5.379	0.00000	1413.532	516.488	.24552	148.7271	1970.26	-1.998
6	144.1417	1954.62	6.427	0.00000	1434.148	519.107	.24656	150.0189	1973.70	-6.129
7	145.2768	1957.74	7.456	0.00000	1454.384	524.205	.24878	151.3092	1977.20	-10.125
8	146.3581	1960.74	8.468	0.00000	1474.268	531.555	.25208	152.6000	1980.75	-13.962
9	147.3896	1963.64	9.462	0.00000	1493.827	540.931	.25633	153.8932	1984.36	-17.626

** ROTOR 2 MIXED AND/OR COOLED QUANTITIES **

STREAMLINE NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)
1	194.7134	2108.17	143.4878	1957.37
2	195.2623	2108.17	144.8160	1960.42
3	195.7240	2108.17	146.1289	1963.60
4	196.1135	2108.17	147.4314	1966.88
5	196.4474	2108.17	148.7271	1970.26
6	196.7368	2108.17	150.0189	1973.70
7	196.9885	2108.17	151.3092	1977.20
8	197.2065	2108.17	152.6000	1980.75
9	197.3936	2108.17	153.8932	1984.36

** STAGE EXIT 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.00000	484.611	484.497	27.198	485.373	.23788	108.2258	1837.96	3.213
2	14.4048	14.88746	518.558	517.684	39.613	520.069	.25506	108.7913	1837.96	4.376
3	14.6865	29.37503	546.058	543.762	49.039	548.256	.26904	109.2293	1837.96	5.153
4	14.9511	44.06262	569.947	565.617	56.274	572.719	.28120	109.5756	1837.96	5.682
5	15.2020	58.75021	592.235	585.288	61.887	595.459	.29252	109.8619	1837.96	6.036
6	15.4410	73.43779	613.991	603.864	66.239	617.554	.30354	110.1073	1837.96	6.260
7	15.6697	88.12537	635.785	621.924	69.559	639.579	.31454	110.3232	1837.96	6.382
8	15.8891	102.81295	657.937	639.790	71.998	661.864	.32569	110.5164	1837.96	6.421
9	16.1000	117.50052	680.608	657.628	73.667	684.583	.33708	110.6912	1837.96	6.392

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	104.2412	1820.85	1.241	.00666	1328.893	1388.977	.68072	140.3369	1960.96	-69.585
2	104.2023	1818.32	3.327	.02397	1357.616	1416.345	.69462	141.9500	1964.00	-68.556
3	104.1181	1816.13	5.256	.03998	1384.172	1442.484	.70786	143.4670	1967.24	-67.840
4	103.9895	1814.14	7.067	.05501	1409.112	1467.995	.72078	144.9223	1970.64	-67.310
5	103.8171	1812.21	8.784	.06926	1432.750	1493.321	.73360	146.3440	1974.16	-66.880
6	103.6016	1810.27	10.421	.08284	1455.281	1518.691	.74647	147.7476	1977.76	-66.504
7	103.3430	1808.26	11.986	.09584	1476.836	1544.232	.75944	149.1423	1981.43	-66.158
8	103.0412	1806.15	13.488	.10830	1497.513	1570.023	.77258	150.5339	1985.16	-65.829
9	102.6959	1803.93	14.931	.12028	1517.389	1596.108	.78590	151.9257	1988.94	-65.510

** STAGE 2 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.27284	.38493	.10114	.11791	.92554	.92380	.95214	.90533
2	.28654	.37105	.10006	.10561	.92591	.93290	.95577	.90977
3	.29784	.36017	.09904	.09684	.92629	.93946	.95829	.91319
4	.30734	.35189	.09806	.09006	.92667	.94437	.96009	.91593
5	.31557	.34586	.09713	.08441	.92701	.94835	.96149	.91824
6	.32283	.34181	.09624	.07946	.92733	.95177	.96266	.92030
7	.32926	.33946	.09539	.07498	.92764	.95483	.96371	.92221
8	.33497	.33856	.09457	.07082	.92794	.95767	.96470	.92403
9	.33999	.33891	.09377	.06691	.92824	.96036	.96569	.92581

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .92696

ROTOR BLADE-ROW EFFICIENCY = .94643

STAGE WORK = 75.253 BTU PER LBM
STAGE TOTAL EFFICIENCY = .93167
STAGE STATIC EFFICIENCY = .85815
STAGE BLADE- TO JET-SPEED RATIO = .67296

*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

STAGE NUMBER	STATOR BLADE-ROW EFFICIENCY	ROTOR BLADE-ROW EFFICIENCY	STAGE WORK (BTU/LBM)	STAGE TOTAL EFFICIENCY	STAGE STATIC EFFICIENCY	STAGE BLADE- TO JET-SPEED RATIO
1	.90861	.92539	73.427	.90592	.86064	.66894
2	.92696	.94643	75.253	.93167	.85815	.67290

SPOOL WORK = 148.679 BTU PER LBM
SPOOL POWER = 24830.00 HP
SPOOL TOTAL- TO TOTAL-PRESSURE RATIO = 3.12030
SPOOL TOTAL- TO STATIC-PRESSURE RATIO = 3.30191
SPOOL TOTAL EFFICIENCY = .92574
SPOOL STATIC EFFICIENCY = .88771
SPOOL BLADE- TO JET-SPEED RATIO = .48041

APPENDIX II

COMPUTER OUTPUT FOR THE ORIGINAL TIP DIAMETER LOW-PRESSURE SPOOL

The three alternative versions of the low-pressure spool employing the original maximum tip diameter at spool exit are presented in this appendix. The computer output for the five-stage design begins on the following page; the four- and three-stage versions will be found on pages 93 and 107, respectively. In all cases, spool inlet distributions of total pressure, total temperature, and absolute flow angle were obtained directly from the computer output for the hp spool.

PROGRAM TD2 - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES

OPTIMIZED FIVE STAGE VERSION OF NASA LP SPOOL AT ORIGINAL TIP DIAMETER

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 1
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.35000 LBF FT/LBM DEG R
INLET MASS FLOW = 117.50000 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
14.1000	1837.96	108.2258	3.213
14.4048	1837.96	108.7913	4.376
14.6865	1837.96	109.2293	5.153
14.9511	1837.96	109.5756	5.682
15.2020	1837.96	109.8619	6.036
15.4410	1837.96	110.1073	6.260
15.6697	1837.96	110.3232	6.382
15.8891	1837.96	110.5169	6.421
16.1000	1837.96	110.6916	6.392

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 4646.0 RPM
POWER OUTPUT = 20110.00 HP

** ANALYSIS VARIABLES **

NUMBER OF STAGES = 5

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	.20000
2	.20000
3	.20000
4	.20000
5	.20000

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	.27500
2	.27500
3	.27300
4	.27300
5	.27100
6	.27100
7	.26800
8	.26800
9	.26500
10	.26500
11	.26200

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	7.5000	14.0750	15.8500
2	9.0000	14.1000	16.1000
3	10.5000	14.1400	16.6500
4	12.0000	14.1800	17.2000
5	13.5000	14.2200	17.7500
6	15.0000	14.2600	18.3000
7	16.5000	14.3000	18.8500
8	18.0000	14.3400	19.4000
9	19.5000	14.3800	19.9500
10	21.0000	14.4200	20.5000
11	22.5000	14.4600	21.0500
12	24.0000	14.5000	21.6000
13	25.5000	14.5400	22.1500

* BLADE-ROW EXIT CONDITIONS *

STATOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 849.0000 FEET PER SEC

ROTOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.5000	-200.00

STATOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 811.0000 FEET PER SEC

ROTOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	-200.00

STATOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 776.0000 FEET PER SEC

ROTOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.5000	-200.00

STATOR 4

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 741.0000 FEET PER SEC

ROTOR 4

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	-200.00

STATOR 5

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 774.0000 FEET PER SEC

ROTOR 5

RADIAL POSITION	MERIDIONAL VELOCITY GRADIENT

(IN)	(PER SEC)
17.5000	-200.00

* BASIC INTERNAL LOSS CORRELATION *.

$$Y = \frac{\text{TAN(INLET ANGLE)} + \text{TAN(EXIT ANGLE)}}{.60000000 * .80000000 * \cos(\text{EXIT ANGLE})} * \text{TIMES} * \begin{cases} .03000000 + .157^{2}5500 * (\text{V RATIO})^{**} 3.60 & \text{IF (V RATIO) .LT. .60000000} \\ .05500000 + .15000000 * ((\text{V RATIO}) - .600) & \text{IF (V RATIO) .GE. .60000000} \end{cases}$$

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF 2.00000000

*** OUTPUT OF SPOOL DESIGN ANALYSIS ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.00000	484.349	484.235	26.999	485.101	.23774	108.2191	1837.96	3.213
2	14.4049	14.68729	518.309	517.434	39.387	519.803	.25493	108.7843	1837.96	4.376
3	14.6868	29.37461	545.931	543.634	48.948	548.121	.26898	109.2246	1837.96	5.154
4	14.9514	44.06195	569.991	565.658	56.252	572.760	.28122	109.5742	1837.96	5.683
5	15.2022	58.74929	592.353	585.402	61.903	595.579	.29258	109.8621	1837.96	6.036
6	15.4412	73.43664	614.145	604.013	66.276	617.711	.30362	110.1084	1837.96	6.260
7	15.6698	88.12400	635.960	622.093	69.611	639.758	.31463	110.3248	1837.96	6.382
8	15.8892	102.81136	658.114	639.962	72.061	662.048	.32578	110.5182	1837.96	6.421
9	16.1000	117.49873	680.778	657.791	73.728	684.758	.33717	110.6929	1837.96	6.392

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	104.2392	1820.87	1.241	.00666
2	104.2002	1818.34	3.328	.02398
3	104.1160	1816.14	5.258	.04000
4	103.9874	1814.14	7.069	.05503
5	103.8150	1812.20	8.786	.06928
6	103.5994	1810.25	10.422	.08285
7	103.3406	1808.24	11.987	.09584
8	103.0388	1806.13	13.488	.10830
9	102.6935	1803.91	14.931	.12028

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1400	0.00000	504.662	504.482	880.302	1014.700	.50536	107.0680	1837.96	60.184
2	14.4755	14.68744	504.662	503.423	875.620	1010.640	.50325	107.5635	1837.96	60.104
3	14.8026	29.37489	504.662	501.477	868.388	1004.381	.50001	107.9441	1837.96	59.994

4	15.1227	44.06233	504.662	498.704	859.274	996.511	.49593	108.2328	1837.96	59.870
5	15.4366	58.74978	504.662	495.152	849.000	987.666	.49135	108.4550	1837.96	59.749
6	15.7455	73.43722	504.662	490.660	838.134	978.341	.48653	108.6316	1837.96	59.644
7	16.0502	88.12467	504.662	485.858	827.030	968.846	.48162	108.7763	1837.96	59.567
8	16.3515	102.81211	504.662	480.171	815.809	959.285	.47669	108.8956	1837.96	59.520
9	16.6500	117.49956	504.662	473.815	804.488	949.676	.47174	108.9924	1837.96	59.503

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	90.6377	1763.19	1.528	.00000	573.292	590.710	.29420	95.9769	1788.53	31.323
2	91.1809	1763.78	4.015	.00000	586.895	581.417	.28952	96.3792	1788.33	29.835
3	91.6943	1764.70	6.440	.00000	600.158	571.516	.28452	96.7390	1788.42	28.141
4	92.1787	1765.84	8.813	.00000	613.133	561.488	.27943	97.0670	1788.74	26.269
5	92.6357	1767.12	11.141	.00000	625.863	551.791	.27451	97.3734	1789.23	24.258
6	93.0673	1768.45	13.431	.00000	638.387	542.754	.26991	97.6661	1789.84	22.143
7	93.4754	1769.79	15.690	.00000	650.740	534.567	.26574	97.9501	1790.55	19.943
8	93.8621	1771.13	17.923	.00000	662.954	527.303	.26203	98.2287	1791.32	17.658
9	94.2294	1772.46	20.136	.00000	675.057	520.995	.25880	98.5037	1792.18	15.279

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1800	0.00000	467.817	467.651	-111.875	481.008	.24091	87.8431	1756.18	-13.454
2	14.5546	14.68673	461.407	460.340	-117.103	476.035	.23855	87.7879	1753.88	-14.272
3	14.9451	29.37346	455.066	452.368	-120.453	470.738	.23600	87.7283	1751.97	-14.910
4	15.3226	44.06019	448.775	443.766	-122.296	465.140	.23328	87.6649	1750.40	-15.407
5	15.6981	58.74692	442.516	434.559	-122.976	459.286	.23040	87.5984	1749.09	-15.801
6	16.0726	73.43366	436.274	424.765	-122.729	453.208	.22740	87.5292	1747.97	-16.116
7	16.4471	88.12039	430.032	414.397	-121.680	446.916	.22428	87.4577	1747.00	-16.364
8	16.8226	102.80712	423.774	403.463	-119.863	440.399	.22103	87.3838	1746.16	-16.546
9	17.2000	117.49384	417.484	391.966	-117.289	433.647	.21766	87.3074	1745.46	-16.659

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	84.3201	1739.25	1.528	0.00000	574.914	830.983	.41619	94.7265	1789.77	-55.748
2	84.5301	1737.30	3.897	-.00000	590.507	844.754	.42333	95.1064	1789.50	-58.954
3	84.5404	1735.76	6.242	-.00000	605.933	857.159	.42973	95.4555	1789.51	-58.087
4	84.5509	1734.58	8.568	-.00000	621.238	868.471	.43555	95.7790	1789.75	-59.176
5	84.5612	1733.66	10.882	-.00000	636.463	878.958	.44093	96.0831	1790.18	-60.221
6	84.5714	1732.95	13.190	-.00000	651.648	888.816	.44597	96.3725	1790.74	-61.254
7	84.5812	1732.39	15.497	-.00000	666.832	898.153	.45072	96.6496	1791.40	-62.276
8	84.5905	1731.98	17.811	-.00000	682.055	907.004	.45522	96.9148	1792.16	-63.292

8	.5994	1731.70	20.136	-.00000	697.357	915.391	.45947	97.1681	1793.00	-64.308

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.47807	.71086	.06946	.14166	.94092	.88262	.92097	.87492
2	.51433	.68827	.07385	.13899	.93737	.88606	.92304	.87568
3	.54573	.66676	.07841	.13605	.93395	.88989	.92528	.87677
4	.57477	.64653	.08335	.13311	.93016	.89362	.92737	.87750
5	.60302	.62778	.08895	.13041	.92590	.89701	.92917	.87768
6	.63139	.61065	.09499	.12817	.92123	.89990	.93064	.87735
7	.66033	.59518	.10133	.12651	.91631	.90217	.93167	.87650
8	.69015	.58137	.10808	.12572	.91112	.90371	.93218	.87508
9	.72104	.56915	.11533	.12585	.90560	.90443	.93211	.87298

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY =	.92491
ROTOR BLADE-ROW EFFICIENCY =	.89574
STAGE WORK =	24.194 BTU PER LBM
STAGE TOTAL EFFICIENCY =	.87621
STAGE STATIC EFFICIENCY =	.76113
STAGE BLADE- TO JET-SPEED RATIO =	.50002

** STATOR EXIT - ROTOR INLET 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2200	0.00000	407.631	407.486	916.437	1003.005	.51073	86.3446	1756.20	66.028
2	14.7074	14.68746	407.631	406.590	886.704	975.914	.49670	86.3814	1753.90	65.367
3	15.1769	29.37492	407.631	404.952	859.509	951.272	.48393	86.4028	1751.99	64.773
4	15.6315	44.06238	407.631	402.648	834.391	928.640	.47221	86.4116	1750.41	64.240
5	16.0734	58.74984	407.631	399.732	811.000	907.681	.46134	86.4099	1749.09	63.762
6	16.5047	73.43730	407.631	396.249	789.057	888.129	.45121	86.3995	1747.97	63.335
7	16.9269	88.12476	407.631	392.235	768.338	869.774	.44171	86.3816	1747.00	62.956
8	17.3416	102.81222	407.631	387.717	748.663	852.443	.43273	86.3572	1746.16	62.621
9	17.7500	117.49968	407.631	382.715	729.878	835.993	.42422	86.3269	1745.45	62.329

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	72.8123	1682.61	1.528	-.00000	576.535	530.750	.27026	76.4285	1703.21	39.833
2	73.5058	1684.23	4.097	-.00000	596.297	500.499	.25473	76.7425	1702.55	35.536
3	74.1172	1685.79	6.572	-.00000	615.334	475.168	.24173	77.0514	1702.31	31.089
4	74.6612	1687.33	8.968	-.00000	633.764	454.329	.23102	77.3574	1702.43	26.486
5	75.1490	1688.82	11.298	-.00000	651.681	437.680	.22245	77.6627	1702.84	21.731
6	75.5894	1690.27	13.571	-.00000	669.165	424.897	.21587	77.9687	1703.47	16.834
7	75.9894	1691.66	15.797	-.00000	686.284	415.808	.21116	78.2770	1704.30	11.816
8	76.3545	1693.00	17.983	-.00000	703.097	410.170	.20822	78.5888	1705.31	6.703
9	76.6894	1694.33	20.136	-.00000	719.658	407.759	.20691	78.9051	1706.49	1.530

** STAGE EXIT 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2800	0.00000	415.381	415.234	-114.341	430.831	.22085	69.4713	1669.81	-15.396
2	14.7749	14.68638	406.800	405.858	-119.009	423.849	.21746	69.4145	1666.55	-16.342
3	15.2833	29.37277	398.326	395.965	-121.482	416.439	.21380	69.3539	1663.82	-17.056
4	15.7873	44.05915	389.927	385.581	-121.912	408.541	.20986	69.2888	1661.60	-17.546
5	16.2885	58.74553	381.573	374.725	-120.670	400.199	.20566	69.2197	1659.78	-17.850
6	16.7887	73.43192	373.235	363.411	-118.178	391.499	.20125	69.1477	1658.29	-18.014
7	17.2896	88.11830	364.888	351.647	-114.669	382.481	.19665	69.0735	1657.07	-18.061
8	17.7928	102.80468	356.501	339.435	-110.276	373.168	.19189	68.9974	1656.09	-17.998
9	18.3000	117.49107	348.048	326.774	-105.058	363.558	.18696	68.9197	1655.35	-17.823

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	67.2489	1656.13	1.528	0.00000	578.157	807.524	.41396	75.2987	1704.19	-59.052
2	67.2603	1653.31	3.899	.00000	599.032	825.264	.42341	75.7002	1703.50	-60.523
3	67.2720	1651.04	6.241	.00000	619.644	841.389	.43198	76.0744	1703.21	-61.886
4	67.2834	1649.30	8.562	.00000	640.078	855.963	.43969	76.4199	1703.29	-63.160
5	67.2944	1647.98	10.871	.00000	660.400	869.292	.44672	76.7413	1703.67	-64.370
6	67.3046	1646.99	13.175	.00000	680.682	881.750	.45326	77.0458	1704.29	-65.539
7	67.3141	1646.29	15.482	.00000	700.990	893.556	.45942	77.3376	1705.13	-66.678
8	67.3228	1645.83	17.800	.00000	721.391	904.856	.46530	77.6195	1706.16	-67.798
9	67.3306	1645.60	20.136	.00000	741.955	915.734	.47093	77.8928	1707.40	-68.904

** STAGE 2 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.47957	.65726	.11072	.15730	.91027	.87325	.92238	.85659
2	.48778	.60647	.10922	.13989	.91087	.88654	.92872	.86660
3	.49485	.56474	.10788	.12691	.91143	.89701	.93372	.87490
4	.50088	.53078	.10666	.11863	.91195	.90449	.93713	.88135
5	.50600	.50347	.10554	.11363	.91244	.90935	.93905	.88608
6	.51029	.48188	.10451	.11105	.91290	.91219	.93974	.88939
7	.51383	.46534	.10356	.11038	.91333	.91336	.93934	.89143
8	.51663	.45330	.10264	.11130	.91376	.91308	.93793	.89233
9	.51872	.44528	.10175	.11368	.91419	.91148	.93553	.89211

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .91236

ROTOR BLADE-ROW EFFICIENCY = .90355

STAGE WORK = 24.193 BTU PER LBM
STAGE TOTAL EFFICIENCY = .88206
STAGE STATIC EFFICIENCY = .79076
STAGE BLADE- TO JET-SPEED RATIO = .52949

** STATOR EXIT - ROTOR INLET 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3000	0.00000	364.109	363.979	905.763	976.208	.50919	68.2161	1669.82	68.107
2	14.9480	14.6H747	364.109	363.141	867.841	941.129	.49064	68.2668	1666.55	67.294
3	15.5646	29.3749	364.109	361.623	834.142	910.148	.47426	68.3009	1663.84	66.562
4	16.1554	44.06242	364.109	359.510	803.749	882.376	.45958	68.3167	1661.61	65.901
5	16.7248	58.74989	364.109	356.869	776.000	857.176	.44626	68.3194	1659.78	65.303
6	17.2764	73.43736	364.109	353.749	750.409	834.080	.43405	68.3118	1658.29	64.760
7	17.8129	88.12483	364.109	350.188	726.606	812.731	.42276	68.2957	1657.06	64.268
8	18.3367	102.81230	364.109	346.215	704.301	792.853	.41225	68.2727	1656.09	63.823
9	18.8500	117.49978	364.109	341.853	683.261	774.223	.40238	68.2438	1655.34	63.420

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	57.5607	1599.59	1.528	0.00000	579.779	488.713	.25491	60.1052	1617.19	41.848
2	58.2956	1601.28	4.178	-.00000	606.051	448.452	.23379	60.4576	1616.10	35.788
3	58.9194	1602.79	6.699	-.00000	631.049	416.920	.21725	60.8028	1615.60	29.319
4	59.4567	1604.23	9.116	-.00000	655.003	393.320	.20486	61.1465	1615.44	22.477

5	59.9250	1505.64	11.445	-.00000	678.090	377.043	.19630	61.4855	1616.11	15.342
6	60.3372	1607.02	13.700	-.00000	700.452	367.520	.19126	61.8280	1616.97	8.038
7	60.7030	1608.39	15.895	-.00000	722.205	364.135	.18941	62.1738	1618.16	.720
8	61.0300	1609.76	18.037	-.00000	743.444	366.207	.19041	62.5245	1619.65	-6.451
9	61.3240	1611.17	20.136	-.00000	764.254	373.008	.19386	62.8812	1621.42	-13.329

** STAGE EXIT 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3400	0.00000	398.536	398.394	-114.470	414.649	.21791	54.3348	1582.67	-16.031
2	14.9854	14.68763	387.779	386.881	-121.419	406.344	.21381	54.2832	1578.23	-17.424
3	15.6212	29.37525	377.182	374.947	-124.034	397.052	.20912	54.2242	1574.65	-18.304
4	16.2507	44.06288	366.690	362.611	-123.467	386.918	.20393	54.1590	1571.80	-18.803
5	16.8768	58.75050	356.256	349.880	-120.861	376.199	.19839	54.0898	1569.54	-19.057
6	17.5020	73.43813	345.835	336.758	-116.748	365.010	.19256	54.0180	1567.77	-19.121
7	18.1292	88.12576	335.382	323.243	-111.398	353.399	.18648	53.9442	1566.41	-19.015
8	18.7609	102.81338	324.854	309.327	-104.919	341.377	.18015	53.8688	1565.45	-18.736
9	19.4000	117.50101	314.202	294.997	-97.322	328.930	.17358	53.7921	1564.88	-18.258

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	52.6355	1569.86	1.528	.00000	581.401	801.914	.42142	59.2005	1617.78	-60.208
2	52.6476	1565.93	3.901	.00000	607.568	825.708	.43447	59.6464	1616.73	-62.045
3	52.6599	1562.90	6.239	.00000	633.367	846.104	.44563	60.0427	1616.25	-63.662
4	52.6718	1560.64	8.555	.00000	658.870	864.010	.45539	60.4001	1616.27	-65.132
5	52.6829	1558.99	10.857	.00000	684.251	880.411	.46428	60.7340	1616.75	-66.512
6	52.6931	1557.84	13.156	.00000	709.602	895.800	.47257	61.0519	1617.63	-67.828
7	52.7021	1557.11	15.463	.00000	735.030	910.451	.48042	61.3582	1618.88	-69.099
8	52.7100	1556.77	17.786	.00000	760.642	924.514	.48789	61.6549	1620.46	-70.335
9	52.7168	1556.82	20.136	.00000	786.553	938.061	.49503	61.9427	1622.39	-71.543

** STAGE 3 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.44133	.60943	.11776	.14944	.90513	.88292	.92803	.86116
2	.45030	.54311	.11484	.12683	.90656	.89905	.93553	.87404
3	.45755	.49275	.11221	.11437	.90791	.90923	.94005	.88332
4	.46300	.45523	.10970	.10778	.90929	.91495	.94215	.88970
5	.46688	.42826	.10724	.10490	.91071	.91782	.94258	.89402

6	.46938	.41027	.10484	.10463	.91216	.91846	.94158	.89657
7	.47061	.39995	.10246	.10040	.91364	.91723	.93923	.89749
8	.47066	.39611	.10010	.11000	.91516	.91429	.93554	.89662
9	.46958	.39764	.09772	.11540	.91673	.90969	.93040	.89450

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .91079

ROTOR BLADE-ROW EFFICIENCY = .91092

STAGE WORK = 24.194 BTU PER LBM
STAGE TOTAL EFFICIENCY = .88872
STAGE STATIC EFFICIENCY = .80592
STAGE BLADE- TO JET-SPEED RATIO = .55471

** STATOR EXIT - ROTOR INLET 4 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3800	0.00000	346.508	346.385	893.992	958.796	.51305	53.3046	1582.68	68.821
2	15.1968	14.68748	346.508	345.552	847.744	915.827	.48980	53.3632	1578.24	67.824
3	15.9643	29.37496	346.508	344.056	807.812	878.993	.46989	53.3963	1574.66	66.930
4	16.6924	44.06244	346.508	341.999	772.586	846.733	.45246	53.4105	1571.80	66.123
5	17.3886	58.74992	346.508	339.456	741.000	818.015	.43692	53.4105	1569.54	65.387
6	18.0584	73.43739	346.508	336.482	712.301	792.111	.42290	53.3996	1567.76	64.715
7	18.7063	88.12487	346.508	333.116	685.932	768.486	.41010	53.3803	1566.41	64.097
8	19.3358	102.81235	346.508	329.391	661.475	746.738	.39830	53.3543	1565.46	63.528
9	19.9500	117.49983	346.508	325.328	638.601	726.553	.38732	53.3226	1564.88	63.004

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	44.8380	1514.18	1.528	0.00000	583.022	465.586	.24913	46.7370	1530.33	41.916
2	45.5662	1515.74	4.256	-.00000	616.139	416.784	.22290	47.1064	1528.68	33.832
3	46.1611	1517.09	6.820	-.00000	647.255	381.698	.20416	47.4673	1527.96	25.017
4	46.6572	1518.38	9.253	-.00000	676.777	359.510	.19211	47.8248	1528.01	15.650
5	47.0778	1519.67	11.579	-.00000	705.002	348.373	.18608	48.1825	1528.72	6.053
6	47.4393	1521.01	13.817	-.00000	732.159	347.077	.18530	48.5431	1529.98	-3.377
7	47.7532	1522.41	15.981	-.00000	758.426	354.010	.18892	48.9085	1531.75	-12.278
8	48.0284	1523.91	18.084	-.00000	783.951	367.516	.19603	49.2804	1533.97	-20.396
9	48.2715	1525.55	20.136	-.00000	808.852	386.074	.20582	49.6600	1536.65	-27.624

** STAGE EXIT 4 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4200	0.00000	401.934	401.791	-118.254	418.969	.22623	41.9534	1494.36	-16.400
2	15.1980	14.68764	388.966	388.862	-126.042	408.878	.22116	41.9029	1488.68	-17.994
3	15.9620	29.37529	376.233	373.999	-128.322	397.515	.21529	41.8443	1484.24	-18.937
4	16.7169	44.06293	363.652	359.604	-126.799	385.125	.20877	41.7794	1480.81	-19.423
5	17.4670	58.75058	351.151	344.670	-123.004	372.071	.20182	41.7110	1478.19	-19.630
6	18.2163	73.43822	338.662	329.786	-117.521	358.473	.19453	41.6404	1476.24	-19.614
7	18.9689	88.12587	326.119	314.334	-110.581	344.357	.18691	41.5680	1474.90	-19.382
8	19.7287	102.81351	313.456	298.492	-102.206	329.698	.17895	41.4943	1474.16	-18.902
9	20.5000	117.50116	300.600	282.226	-92.308	314.454	.17064	41.4195	1474.02	-18.111

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	40.5360	1481.13	1.528	-.00000	584.644	809.702	.43722	46.0177	1530.54	-60.247
2	40.5486	1476.08	3.909	-.00000	616.189	837.975	.45326	46.4627	1529.00	-62.398
3	40.5614	1472.33	6.247	-.00000	647.164	861.933	.46682	46.8559	1528.32	-64.253
4	40.5735	1469.63	8.557	-.00000	677.769	882.934	.47863	47.2109	1528.38	-65.918
5	40.5846	1467.75	10.853	-.00000	708.180	902.315	.48945	47.5454	1529.11	-67.466
6	40.5944	1466.56	13.147	.00000	738.562	920.635	.49959	47.8665	1530.43	-68.932
7	40.6029	1465.97	15.450	.00000	769.073	938.161	.50920	48.1773	1532.30	-70.336
8	40.6101	1465.97	17.775	.00000	799.878	954.993	.51834	48.4784	1534.70	-71.691
9	40.6160	1466.57	20.136	.00000	831.152	971.153	.52700	48.7689	1537.65	-73.006

** STAGE & PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.43247	.57501	.12100	.13661	.90255	.89452	.93407	.86705
2	.44369	.49737	.11791	.11369	.90431	.91011	.94107	.88085
3	.45171	.44307	.11436	.10293	.90621	.91892	.94466	.89033
4	.45695	.40718	.11081	.09835	.90827	.92284	.94549	.89637
5	.45989	.38609	.10728	.09745	.91043	.92386	.94448	.89999
6	.46081	.37700	.10377	.09916	.91268	.92256	.94183	.90148
7	.45986	.37734	.10024	.10306	.91503	.91918	.93749	.90089
8	.45716	.38484	.09667	.10913	.91749	.91372	.93125	.89811
9	.45273	.39754	.09301	.11762	.92007	.90606	.92283	.89288

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .91071

ROTOR BLADE-ROW EFFICIENCY = .91644

STAGE WORK = 24.194 BTU PER LBM
STAGE TOTAL EFFICIENCY = .89349
STAGE STATIC EFFICIENCY = .81145
STAGE BLADE- TO JET-SPEED RATIO = .57701

** STATOR EXIT - ROTOR INLET 5 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4600	0.00000	352.015	351.890	963.375	1025.673	.56662	40.9739	1494.37	69.934
2	15.4599	14.68768	352.015	351.001	903.805	969.938	.53532	41.0506	1488.68	68.776
3	16.4598	29.37495	352.015	349.419	854.142	923.836	.50949	41.0939	1484.25	67.751
4	17.2516	44.06242	352.015	347.278	811.473	884.534	.48749	41.1137	1480.81	66.831
5	18.0730	58.74990	352.015	344.664	774.006	850.289	.46831	41.1170	1478.19	65.996
6	18.8578	73.43737	352.015	341.640	740.519	819.928	.45129	41.1081	1476.24	65.234
7	19.6120	88.12485	352.015	338.250	710.181	792.636	.43596	41.0901	1474.92	64.532
8	20.3414	102.81232	352.015	334.528	682.374	767.821	.42199	41.0649	1474.19	63.884
9	21.0500	117.49980	352.015	330.499	656.631	745.036	.40912	41.0338	1474.05	63.283

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	33.1893	1415.09	1.528	0.00000	586.266	515.874	.28499	35.0448	1435.14	46.981
2	33.9943	1417.78	4.351	0.00000	626.805	447.933	.24722	35.4173	1432.90	38.280
3	34.6268	1419.93	6.962	0.00000	664.297	399.945	.22057	35.7767	1431.98	28.516
4	35.1381	1421.85	9.411	0.00000	699.450	369.410	.20359	36.1307	1432.13	17.878
5	35.5612	1423.70	11.730	0.00000	732.753	354.423	.19520	36.4839	1433.17	6.824
6	35.9174	1425.58	13.945	0.00000	764.562	352.835	.19420	36.8397	1434.96	-4.026
7	36.2214	1427.57	16.076	0.00000	795.147	362.124	.19917	37.2002	1437.45	-14.101
8	36.4838	1429.76	18.135	0.00000	824.720	379.706	.20868	37.5672	1440.62	-23.050
9	36.7125	1432.21	20.136	0.00000	853.451	403.302	.22146	37.9420	1444.47	-30.775

** STAGE EXIT 5 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.5000	0.00000	420.092	419.942	-21.511	420.642	.23374	31.8997	1466.50	-2.932

2	15.4153	14.68782	404.837	403.886	-44.160	407.238	.22686	31.8328	1398.78	-6.240
3	16.3098	29.37564	389.929	387.596	-56.075	393.940	.21985	31.7680	1392.95	-8.232
4	17.1908	44.06345	375.246	371.046	-60.460	380.085	.21238	31.7016	1388.64	-9.255
5	18.0645	58.75127	360.683	354.212	-60.486	365.720	.20453	31.6344	1385.50	-9.690
6	18.9367	73.43909	346.146	337.062	-57.638	350.912	.19635	31.5669	1383.31	-9.704
7	19.8129	88.12691	331.544	319.559	-52.468	335.670	.18785	31.4995	1381.99	-9.324
8	20.6986	102.81473	316.781	301.661	-45.115	319.978	.17905	31.4325	1381.54	-8.506
9	21.6000	117.50255	301.758	283.314	-35.506	303.840	.16994	31.3663	1381.99	-7.143

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	30.7465	1393.02	1.528	.00000	587.888	740.164	.41130	34.4205	1434.78	-55.429
2	30.7474	1386.14	3.927	.00000	624.998	782.090	.43567	34.8911	1432.76	-58.886
3	30.7493	1381.12	6.271	.00000	661.264	816.467	.45565	35.3020	1431.93	-61.617
4	30.7516	1377.63	8.580	.00000	696.982	845.298	.47233	35.6631	1432.10	-63.901
5	30.7540	1375.31	10.870	.00000	732.407	871.075	.48715	35.9973	1433.14	-65.928
6	30.7562	1373.93	13.156	.00000	767.770	895.051	.50081	36.3166	1434.99	-67.787
7	30.7580	1373.40	15.452	.00000	803.293	917.741	.51360	36.6253	1437.60	-69.523
8	30.7594	1373.73	17.774	.00000	839.205	939.346	.52563	36.9240	1440.99	-71.164
9	30.7603	1374.95	20.136	.00000	875.750	959.920	.53690	37.2115	1445.19	-72.729

** STAGE 5 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.40848	.69697	.12573	.16647	.90191	.87594	.93241	.85460
2	.42155	.57274	.12065	.12345	.90414	.90332	.94325	.87505
3	.43029	.48985	.11594	.10268	.90653	.91934	.94960	.88931
4	.43540	.43702	.11137	.09433	.90910	.92645	.95165	.89813
5	.43758	.40688	.10693	.09209	.91175	.92851	.95089	.90323
6	.43720	.39421	.10256	.09359	.91450	.92725	.94799	.90546
7	.43445	.39458	.09821	.09800	.91737	.92318	.94292	.90496
8	.42939	.40422	.09381	.10521	.92039	.91638	.93542	.90160
9	.42207	.42014	.08932	.11557	.92356	.90670	.92502	.89499

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .91207

ROTOR BLADE-ROW EFFICIENCY = .91697

STAGE WORK = 24.194 BTU PER LBM
STAGE TOTAL EFFICIENCY = .89406
STAGE STATIC EFFICIENCY = .81419
STAGE BLADE- TO JET-SPEED RATIO = .59873

*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

STAGE NUMBER	STATOR BLADE-ROW EFFICIENCY	ROTOR BLADE-ROW EFFICIENCY	STAGE WORK (BTU/LBM)	STAGE TOTAL EFFICIENCY	STAGE STATIC EFFICIENCY	STAGE BLADE- TO JET-SPEED RATIO
1	.92491	.89574	24.194	.87621	.76113	.50002
2	.91236	.90355	24.193	.88206	.79076	.52949
3	.91079	.91092	24.194	.88872	.80592	.55471
4	.91071	.91644	24.194	.89349	.81145	.57701
5	.91207	.91697	24.194	.89406	.81419	.59873

SPOOL WORK = 120.968 BTU PER LBM
SPOOL POWER = 20110.12 HP
SPOOL TOTAL- TO TOTAL-PRESSURE RATIO = 3.46883
SPOOL TOTAL- TO STATIC-PRESSURE RATIO = 3.56808
SPOOL TOTAL EFFICIENCY = .90085
SPOOL STATIC EFFICIENCY = .88388
SPOOL BLADE- TO JET-SPEED RATIO = .25988

PROGRAM TD2 - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES

OPTIMIZED FOUR STAGE VERSION OF NASA LP SPOOL AT ORIGINAL TIP DIAMETER

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 1
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.35000 LBF FT/LBM DEG R
INLET MASS FLOW = 117.50000 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
14.1000	1837.96	108.2258	3.213
14.4048	1837.96	108.7913	4.376
14.6865	1837.96	109.2293	5.153
14.9511	1837.96	109.5756	5.682
15.2020	1837.96	109.8619	6.036
15.4410	1837.96	110.1073	6.260
15.6697	1837.96	110.3232	6.382
15.8891	1837.96	110.5169	6.421
16.1000	1837.96	110.6912	6.392

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 4646.0 RPM
POWER OUTPUT = 20110.00 HP

** ANALYSIS VARIABLES **

NUMBER OF STAGES = 4

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	.26500
2	.25500
3	.24500
4	.23500

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	.27500
2	.27500
3	.27200
4	.27200
5	.26900
6	.26900
7	.26600
8	.26600
9	.26200

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)

1	7.5000	14.0750	15.8500
2	9.0000	14.1000	16.1000
3	10.7000	14.1500	16.7875
4	12.4000	14.2000	17.4750
5	14.1000	14.2500	18.1625
6	15.8000	14.3000	18.8500
7	17.5000	14.3500	19.5375
8	19.2000	14.4000	20.2250
9	20.9000	14.4500	20.9125
10	22.6000	14.5000	21.6000
11	24.3000	14.5500	22.2875

* BLADE-ROW EXIT CONDITIONS *

STATOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1031.0000 FEET PER SEC

ROTOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.5000	-200.00

STATOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 924.0000 FEET PER SEC

ROTOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	-200.00

STATOR 3

MERIDIONAL

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 827.0000 FEET PER SEC

ROTOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.5000	-200.00

STATOR 4

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 862.0000 FEET PER SEC

ROTOR 4

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	-200.00

* BASIC INTERNAL LOSS CORRELATION *

$$Y = \frac{\text{TAN(INLET ANGLE)} + \text{TAN(EXIT ANGLE)}}{.60000000 * .80000000 * \text{COS(EXIT ANGLE)}} * \text{TIMES}$$

$$\begin{cases} .03000000 + .15725500 * (\text{V RATIO})^{**} 3.60) & \text{IF (V RATIO) .LT. .60000000} \\ .03500000 + .15000000 *((\text{V RATIO}) - .600)) & \text{IF (V RATIO) .GE. .60000000} \end{cases}$$

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF 2.00000000

*** OUTPUT OF SPOOL DESIGN ANALYSIS ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.00000	480.667	480.539	26.791	481.413	.23592	108.2191	1837.96	3.213
2	14.4068	14.68724	515.534	514.538	39.219	517.023	.25355	108.7874	1837.96	4.382
3	14.6898	29.37451	544.243	541.918	48.835	546.430	.26814	109.2289	1837.96	5.161
4	14.9551	44.06180	569.630	564.667	56.215	572.397	.28104	109.5787	1837.96	5.689
5	15.2060	58.74911	593.577	585.602	61.969	596.803	.29319	109.8662	1837.96	6.041
6	15.4446	73.43642	617.209	605.566	66.473	620.779	.30515	110.1118	1837.96	6.263
7	15.6725	88.12374	641.110	625.148	69.963	644.916	.31721	110.3272	1837.96	6.383
8	15.8907	102.81106	665.587	644.658	72.589	669.533	.32953	110.5195	1837.96	6.421
9	16.1000	117.49839	690.800	664.252	74.451	694.801	.34221	110.6928	1837.96	6.392

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	104.2986	1821.13	1.320	.00849
2	104.2513	1818.55	3.562	.02880
3	104.1511	1816.28	5.630	.04754
4	103.9986	1814.17	7.569	.06511
5	103.7945	1812.09	9.402	.08172
6	103.5392	1809.97	11.147	.09752
7	103.2326	1807.76	12.812	.11261
8	102.8744	1805.41	14.406	.12706
9	102.4639	1802.90	15.936	.14092

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1500	0.00000	503.997	503.779	1090.114	1200.986	.60329	106.4089	1837.96	65.197
2	14.5050	14.68737	503.997	502.496	1077.005	1189.097	.59696	106.9429	1837.96	64.988
3	14.8500	29.37474	503.997	500.152	1062.511	1175.986	.59000	107.3528	1837.96	64.792

4	15.1866	44.06212	503.997	496.626	1047.034	1162.021	.58259	107.6633	1837.96	64.615
5	15.5162	58.74949	503.997	492.581	1031.000	1147.595	.57496	107.8986	1837.96	64.463
6	15.8401	73.43686	503.997	487.467	1014.633	1132.913	.56721	108.0744	1837.96	64.339
7	16.1592	88.12423	503.997	481.521	997.992	1118.034	.55937	108.1993	1837.96	64.243
8	16.4747	102.81161	503.997	474.771	981.125	1103.005	.55147	108.2803	1837.96	64.177
9	16.7875	117.49898	503.997	467.235	964.179	1087.959	.54357	108.3275	1837.96	64.145

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	84.0927	1733.21	1.685	.00000	573.697	721.595	.36248	91.6971	1771.03	45.710
2	84.9190	1735.28	4.422	.00000	588.091	702.175	.35251	92.1688	1771.08	44.215
3	85.6891	1737.53	7.082	.00000	602.079	682.650	.34249	92.5825	1771.37	42.632
4	86.4082	1739.90	9.677	.00000	615.726	663.355	.33258	92.9523	1771.86	40.962
5	87.0812	1742.32	12.218	.00000	629.089	644.628	.32297	93.2907	1772.50	39.212
6	87.7124	1744.75	14.715	.00000	642.219	626.661	.31375	93.6062	1773.27	37.379
7	88.3057	1747.18	17.175	.00000	655.160	609.546	.30496	93.9044	1774.17	35.450
8	88.8647	1749.61	19.608	.00000	667.952	593.372	.29667	94.1897	1775.18	33.410
9	89.3924	1752.00	22.019	.00000	680.632	578.283	.28893	94.4674	1776.29	31.252

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2000	0.00000	464.716	464.515	-240.436	523.231	.26427	80.6021	1728.17	-27.366
2	14.6169	14.68773	457.768	456.495	-244.669	519.051	.26233	80.5945	1725.65	-28.190
3	15.0289	29.37547	450.900	447.699	-246.825	514.036	.25993	80.5740	1723.51	-28.869
4	15.4376	44.06320	444.089	438.166	-247.300	508.304	.25714	80.5423	1721.68	-29.440
5	15.8442	58.75094	437.313	427.926	-246.466	501.985	.25402	80.5012	1720.12	-29.940
6	16.2499	73.43867	430.551	417.001	-244.570	495.165	.25064	80.4522	1718.77	-30.392
7	16.6561	88.12641	423.781	405.405	-241.738	487.881	.24699	80.3960	1717.62	-30.807
8	17.0640	102.81414	416.982	393.144	-237.954	480.100	.24308	80.3325	1716.65	-31.186
9	17.4750	117.50188	410.133	380.217	-233.120	471.756	.23887	80.2610	1715.87	-31.513

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	76.9463	1708.07	1.685	0.00000	575.725	939.191	.47437	89.1888	1772.84	-60.354
2	76.9911	1705.87	4.273	.00000	592.627	954.262	.48229	89.6772	1772.73	-61.401
3	77.0353	1704.11	6.832	.00000	609.333	967.635	.48930	90.1226	1772.85	-62.394
4	77.0785	1702.71	9.369	.00000	625.902	979.641	.49558	90.5317	1773.18	-63.353
5	77.1204	1701.62	11.893	.00000	642.385	990.606	.50129	90.9122	1773.67	-64.292
6	77.1607	1700.77	14.413	.00000	658.836	1000.759	.50655	91.2696	1774.30	-65.223
7	77.1993	1700.14	16.935	.00000	675.306	1010.228	.51144	91.6067	1775.07	-66.151
8	77.2362	1699.73	19.467	.00000	691.844	1019.019	.51595	91.9239	1776.97	-67.080

77.2712	1699.53	22.019	.00000	708.506	1027.068	.52006	92.2150	1776.98	-88.012

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.40085	.76832	.08077	.22422	.93507	.83048	.88809	.83900
2	.43480	.73583	.08336	.21526	.93293	.83829	.89267	.84356
3	.46466	.70548	.08640	.20669	.93061	.84602	.89725	.84798
4	.49259	.67714	.09005	.19864	.92779	.85337	.90160	.85182
5	.52005	.65074	.09452	.19127	.92431	.86019	.90563	.85492
6	.54795	.62619	.10007	.18463	.92000	.86646	.90931	.85718
7	.57683	.60337	.10696	.17876	.91472	.87213	.91260	.85850
8	.60701	.58230	.11547	.17402	.90844	.87699	.91535	.85879
9	.63863	.56304	.12506	.17100	.90134	.88062	.91728	.85794

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY =	.92213	
ROTOR BLADE-ROW EFFICIENCY =	.85862	
STAGE WORK =	32.056	BTU PER LBM
STAGE TOTAL EFFICIENCY =	.85272	
STAGE STATIC EFFICIENCY =	.75354	
STAGE BLADE- TO JET-SPEED RATIO =	.43533	

** STATOR EXIT = ROTOR INLET 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2500	0.00000	404.481	404.305	1048.404	1123.724	.58003	78.4397	1728.18	68.911
2	14.7983	14.68734	404.481	403.215	1012.828	1090.608	.56245	78.5607	1725.66	68.292
3	15.3230	29.37468	404.481	401.237	980.664	1060.805	.54665	78.6523	1723.51	67.748
4	15.8283	44.06202	404.481	398.473	951.224	1033.649	.53228	78.7197	1721.69	67.271
5	16.3175	58.74936	404.481	394.999	924.000	1008.653	.51906	78.7674	1720.12	66.854
6	16.7934	73.43670	404.481	390.874	898.605	985.442	.50680	78.7987	1718.77	66.492
7	17.2583	88.12403	404.481	386.141	874.729	963.720	.49534	78.8158	1717.62	66.181
8	17.7141	102.81137	404.481	380.834	852.113	943.240	.48453	78.8203	1716.65	65.916
9	18.1625	117.49871	404.481	374.978	830.534	923.792	.47427	78.8131	1715.88	65.701

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	63.0270	1635.47	1.685	-.00000	577.752	620.579	.32033	67.4624	1663.74	49.336
2	63.9331	1638.33	4.534	-.00000	599.983	577.967	.29807	67.8154	1662.86	45.676
3	64.7243	1640.89	7.261	-.00000	621.256	541.091	.27883	68.1542	1662.39	41.852
4	65.4232	1643.24	9.888	-.00000	641.742	509.297	.26226	68.4835	1662.28	37.835
5	66.0484	1645.42	12.430	-.00000	661.577	482.152	.24812	68.8067	1662.49	33.599
6	66.6067	1647.47	14.903	-.00000	680.872	459.361	.23624	69.1267	1662.96	29.120
7	67.1140	1649.43	17.319	-.00000	699.719	440.719	.22652	69.4458	1663.69	24.381
8	67.5760	1651.33	19.688	-.00000	718.199	426.072	.21887	69.7660	1664.66	19.373
9	67.9949	1653.22	22.019	-.00000	736.386	415.295	.21321	70.0890	1665.88	14.095

** STAGE EXIT 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3000	0.00000	422.984	422.801	-247.174	489.908	.25510	58.7728	1618.85	-30.311
2	14.4817	14.68774	413.289	412.134	-250.973	483.524	.25207	58.7659	1614.63	-31.340
3	15.4546	29.37548	403.740	400.863	-251.749	475.798	.24828	58.7432	1611.04	-32.130
4	16.0215	44.06321	394.292	389.022	-249.594	466.651	.24369	58.7038	1608.03	-32.684
5	16.5849	58.75095	384.902	376.636	-245.078	456.304	.23842	58.6503	1605.52	-33.052
6	17.1471	73.43869	375.532	363.720	-238.909	445.087	.23266	58.5865	1603.43	-33.299
7	17.7105	88.12643	366.143	350.281	-231.466	433.171	.22650	58.5148	1601.71	-33.457
8	18.2773	102.81416	356.696	336.320	-222.959	420.645	.21999	58.4367	1600.33	-33.542
9	18.8500	117.50190	347.150	321.829	-213.470	407.533	.21315	58.3530	1599.29	-33.556

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	56.2751	1601.03	1.685	.00000	579.779	928.853	.48367	65.6388	1665.08	-62.920
2	56.3259	1597.28	4.284	.00000	603.363	949.051	.49476	66.1596	1664.15	-64.247
3	56.3751	1594.23	6.845	.00000	626.591	966.689	.50444	66.6307	1663.61	-65.469
4	56.4219	1591.86	9.378	.00000	649.576	981.821	.51272	67.0477	1663.43	-66.604
5	56.4657	1590.06	11.896	.00000	672.417	994.960	.51987	67.4186	1663.56	-67.682
6	56.5061	1588.72	14.409	.00000	695.211	1006.780	.52627	67.7570	1663.98	-68.725
7	56.5433	1587.78	16.926	.00000	718.052	1017.667	.53212	68.0708	1664.67	-69.751
8	56.5771	1587.20	19.459	.00000	741.034	1027.868	.53755	68.3652	1665.63	-70.767
9	56.6076	1586.96	22.019	.00000	764.254	1037.525	.54264	68.6429	1666.88	-71.780

** STAGE 2 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.46562	.66811	.14027	.21103	.89246	.84204	.89676	.82235
2	.47593	.60899	.13900	.18416	.89249	.86045	.90697	.83626
3	.48457	.55974	.13795	.16382	.89248	.87515	.91525	.84789
4	.49176	.51873	.13706	.15077	.89246	.88580	.92121	.85700
5	.49768	.48459	.13629	.14268	.89242	.89293	.92504	.86379
6	.50248	.45627	.13563	.13806	.89235	.89748	.92726	.86880
7	.50625	.43307	.13504	.13614	.89228	.90000	.92812	.87229
8	.50899	.41452	.13449	.13640	.89222	.90079	.92779	.87446
9	.51067	.40027	.13389	.13860	.89223	.90001	.92630	.87539

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .89238

ROTOR BLADE-ROW EFFICIENCY = .88545

STAGE WORK = 30.847 BTU PER LBM

STAGE TOTAL EFFICIENCY = .85868

STAGE STATIC EFFICIENCY = .77121

STAGE BLADE- TO JET-SPEED RATIO = .47072

** STATOR EXIT - ROTOR INLET 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3500	0.00000	366.593	366.435	976.354	1042.908	.55405	57.2231	1618.85	69.428
2	15.1040	14.68739	366.593	365.391	931.841	1001.359	.53162	57.3426	1614.63	68.589
3	15.8147	29.37479	366.593	363.518	892.996	965.315	.51220	57.4273	1611.05	67.850
4	16.4907	44.06218	366.593	360.939	858.374	933.379	.49502	57.4842	1608.03	67.194
5	17.1386	58.74958	366.593	357.743	827.900	904.610	.47954	57.5187	1605.52	66.608
6	17.7636	73.43697	366.593	353.993	798.209	878.367	.46542	57.5355	1603.43	66.083
7	18.3696	88.12435	366.593	349.740	771.512	854.179	.45240	57.5380	1601.71	65.614
8	18.9600	102.81176	366.593	345.018	746.531	831.685	.44028	57.5287	1600.34	65.195
9	19.5375	117.49915	366.593	339.854	722.956	810.590	.42890	57.5091	1599.30	64.822

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	46.8146	1538.10	1.685	-.00000	581.806	538.571	.28612	49.4394	1559.63	47.116
2	47.6480	1540.18	4.640	-.00000	612.377	486.259	.25815	49.8145	1557.74	41.163
3	48.3424	1541.87	7.426	-.00000	641.189	444.744	.23599	50.1742	1556.55	34.710
4	48.9320	1543.35	10.076	-.00000	668.597	412.802	.21893	50.5248	1556.00	27.735

5	47.4399	1544.77	12.616	-.00000	694.867	389.679	.20657	50.8708	1556.04	20.272
6	44.8827	1540.15	15.065	-.00000	720.205	374.800	.19860	51.2159	1556.58	12.427
7	56.2725	1547.55	17.441	.00000	744.775	367.567	.19468	51.5631	1557.58	4.372
8	50.6184	1548.99	19.755	.00000	768.712	367.264	.19442	51.9146	1559.00	-3.678
9	50.9276	1550.52	22.019	.00000	792.128	373.062	.19740	52.2723	1560.85	-11.505

** STAGE EXIT 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4000	0.00000	419.400	419.219	-261.223	494.099	.26586	42.7121	1511.96	-31.928
2	15.1488	14.68765	406.921	405.776	-262.658	484.329	.26105	42.6984	1506.07	-32.915
3	15.8830	29.37531	394.684	391.857	-259.344	472.266	.25489	42.6621	1501.23	-33.498
4	16.6074	44.06296	382.610	377.482	-252.731	458.544	.24774	42.6090	1497.30	-33.803
5	17.3264	58.75061	370.627	362.661	-244.199	443.844	.23997	42.5454	1494.10	-33.954
6	18.0438	73.43827	358.670	347.394	-234.334	428.436	.23176	42.4745	1491.54	-34.002
7	18.7635	88.12592	346.676	331.674	-223.404	412.424	.22317	42.3982	1489.55	-33.963
8	19.4892	102.81357	334.581	315.487	-211.471	395.809	.21422	42.3173	1488.09	-33.834
9	20.2250	117.50122	322.317	298.807	-198.483	378.528	.20486	42.2325	1487.17	-33.594

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	40.7386	1493.63	1.685	.00000	583.833	943.407	.50762	48.2775	1560.45	-63.615
2	40.7936	1488.46	4.298	.00000	614.191	966.669	.52104	48.7751	1558.61	-65.167
3	40.8453	1484.49	6.862	.00000	643.959	985.764	.53204	49.2019	1557.44	-66.549
4	40.8923	1481.51	9.391	.00000	673.332	1001.989	.54134	49.5750	1556.89	-67.823
5	40.9345	1479.31	11.900	.00000	702.482	1016.646	.54967	49.9158	1556.91	-69.039
6	40.9720	1477.76	14.405	.00000	731.569	1030.348	.55737	50.2367	1557.47	-70.219
7	41.0052	1476.78	16.917	.00000	760.746	1043.425	.56463	50.5377	1558.52	-71.375
8	41.0343	1476.33	19.450	.00000	790.168	1056.043	.57154	50.8276	1560.06	-72.517
9	41.0595	1476.42	22.019	-.00000	820.002	1068.270	.57814	51.1053	1562.10	-73.649

** STAGE 3 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.46975	.57088	.14883	.16474	.88552	.87560	.91424	.84054
2	.48287	.50303	.14676	.14026	.88583	.89226	.92367	.85541
3	.49289	.45117	.14477	.12717	.88627	.90255	.92936	.86601
4	.49996	.41199	.14256	.12042	.88704	.90826	.93217	.87342
5	.50442	.38330	.14007	.11762	.88816	.91116	.93311	.87844

6	.50672	.36376	.13737	.11761	.88948	.91180	.93246	.88199
7	.50712	.35227	.13450	.11981	.89102	.91057	.93033	.88360
8	.50577	.34777	.13147	.12404	.89274	.90759	.92672	.88351
9	.50276	.34922	.12828	.13035	.89462	.90282	.92151	.88162

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .88882

ROTOR BLADE-ROW EFFICIENCY = .90417

STAGE WORK = 29.637 BTU PER LBM
STAGE TOTAL EFFICIENCY = .87295
STAGE STATIC EFFICIENCY = .78358
STAGE BLADE- TO JET-SPEED RATIO = .50665

** STATOR EXIT - ROTOR INLET * **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4500	0.00000	370.215	370.055	1059.047	1121.891	.61966	41.3005	1511.95	70.739
2	15.4326	14.68738	370.215	368.529	997.349	1063.844	.58685	41.4438	1506.05	69.700
3	16.3397	29.37475	370.215	366.937	945.753	1015.632	.55972	41.5375	1501.23	68.795
4	17.1693	44.06213	370.215	364.245	901.245	974.321	.53653	41.5957	1497.30	67.994
5	17.9938	58.74951	370.215	360.964	862.000	938.138	.51625	41.6286	1494.10	67.278
6	18.7623	73.43688	370.215	357.173	826.795	905.897	.49817	41.6425	1491.55	66.636
7	19.5015	88.12426	370.215	352.926	794.753	876.751	.48182	41.6418	1489.56	66.055
8	20.2158	102.81163	370.215	348.262	765.233	850.083	.46684	41.6291	1488.11	65.529
9	20.9125	117.49901	370.215	343.211	737.736	825.417	.45295	41.6065	1487.19	65.051

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	32.1520	1417.45	1.685	-.00000	585.861	600.803	.33185	34.6035	1444.55	51.973
2	33.0830	1421.08	4.776	-.00000	625.698	524.579	.28937	34.9885	1441.74	45.210
3	33.8216	1423.79	7.631	-.00000	662.475	466.161	.25690	35.3502	1440.10	37.668
4	34.4247	1426.02	10.304	-.00000	696.921	422.856	.23286	35.6992	1439.45	29.290
5	34.9280	1428.03	12.835	-.00000	729.561	393.198	.21637	36.0425	1439.63	20.151
6	35.3553	1429.93	15.253	-.00000	760.699	376.069	.20681	36.3848	1440.55	10.484
7	35.7228	1431.85	17.579	-.00000	790.670	370.238	.20347	36.7294	1442.14	.663
8	36.0426	1433.86	19.830	-.00000	819.671	374.196	.20550	37.0788	1444.37	-8.884
9	36.3233	1436.04	22.019	-.00000	847.876	386.251	.21196	37.4349	1447.24	-17.792

** STAGE EXIT * **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.5000	0.00000	435.580	435.392	-88.735	444.526	.24682	30.7760	1410.25	-11.519
2	15.4194	14.68796	420.256	419.063	-110.330	434.497	.24194	30.7349	1401.66	-14.750
3	16.3163	29.37591	405.309	402.385	-121.785	423.210	.23618	30.6881	1394.80	-16.839
4	17.1982	44.06386	390.610	385.452	-124.982	410.118	.22925	30.6322	1389.45	-17.970
5	18.0717	58.75182	374.051	367.950	-122.786	395.589	.22138	30.5694	1385.35	-18.454
6	18.9429	73.43977	361.531	350.158	-117.417	380.120	.21290	30.5027	1382.22	-18.538
7	19.8175	88.12772	346.955	331.947	-109.727	363.893	.20391	30.4335	1379.95	-18.292
8	20.7011	102.81567	332.228	313.280	-100.031	346.961	.19446	30.3628	1378.52	-17.708
9	21.6000	117.50363	317.247	294.106	-88.349	329.319	.18455	30.2910	1377.92	-16.720

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	29.5387	1395.19	1.685	.00000	587.888	804.704	.44681	33.7359	1444.55	-57.240
2	29.5464	1387.27	4.318	.00000	625.165	847.094	.47169	34.2518	1441.97	-60.327
3	29.5560	1381.19	6.886	.00000	661.527	881.959	.49219	34.7062	1440.44	-62.811
4	29.5661	1376.63	9.412	.00000	697.282	910.326	.50885	35.0956	1439.80	-64.890
5	29.5757	1373.42	11.914	.00000	732.700	934.490	.52297	35.4392	1439.98	-66.727
6	29.5842	1371.21	14.409	.00000	768.022	956.403	.53567	35.7582	1440.93	-68.423
7	29.5916	1369.86	16.914	.00000	803.479	976.895	.54741	36.0612	1442.60	-70.024
8	29.5976	1369.34	19.445	.00000	839.304	996.357	.55842	36.3518	1445.01	-71.556
9	29.6024	1369.65	22.019	.00000	875.750	1014.955	.56878	36.6309	1448.17	-73.035

** STAGE 4 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.44042	.74661	.15415	.21115	.88545	.84870	.91465	.82439
2	.45526	.61927	.14988	.16055	.88648	.87997	.92795	.84699
3	.46500	.52855	.14564	.12907	.88798	.90175	.93778	.86468
4	.47003	.46451	.14126	.11459	.88989	.91389	.94303	.87695
5	.47311	.42076	.13683	.10863	.89205	.91921	.94459	.88481
6	.47294	.39321	.13237	.10762	.89443	.92055	.94380	.88966
7	.47040	.37899	.12785	.11003	.89698	.91888	.94093	.89191
8	.46561	.37856	.12326	.11537	.89972	.91453	.93597	.89163
9	.45859	.38056	.11856	.12367	.90265	.90751	.92867	.88864

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY	=	.89270
ROTOR BLADE-ROW EFFICIENCY	=	.90586
STAGE WORK	=	28.428 BTU PER LBM
STAGE TOTAL EFFICIENCY	=	.87537
STAGE STATIC EFFICIENCY	=	.79984
STAGE BLADE- TO JET-SPEED RATIO	=	.54636

*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

STAGE NUMBER	STATOR BLADE-ROW EFFICIENCY	ROTOR BLADE-ROW EFFICIENCY	STAGE WORK (BTU/LBM)	STAGE TOTAL EFFICIENCY	STAGE STATIC EFFICIENCY	STAGE BLADE- TO JET-SPEED RATIO
1	.92213	.85862	32.056	.85272	.75354	.43533
2	.89238	.88545	30.847	.85868	.77121	.47072
3	.88882	.90417	29.637	.87295	.78358	.50665
4	.89270	.90586	28.428	.87537	.79984	.54638

SPOOL WORK =	120.968	BTU PER LBM
SPOOL POWER =	20110.12	HP
SPOOL TOTAL- TO TOTAL-PRESSURE RATIO =	3.59112	
SPOOL TOTAL- TO STATIC-PRESSURE RATIO =	3.71057	
SPOOL TOTAL EFFICIENCY =	.88012	
SPOOL STATIC EFFICIENCY =	.86155	
SPOOL BLADE- TO JET-SPEED RATIO =	.25718	

PROGRAM TD2 - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES

OPTIMIZED THREE STAGE VERSION OF NASA LP SPOOL AT ORIGINAL TIP DIAMETER

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 1
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.35000 LBF FT/LBM DEG R
INLET MASS FLOW = 117.50000 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
14.1000	1837.96	108.2258	3.213
14.4048	1837.96	108.7913	4.376
14.6865	1837.96	109.2293	5.153
14.9911	1837.96	109.5756	5.682
15.2020	1837.96	109.8619	6.036
15.4410	1837.96	110.1073	6.260
15.6697	1837.96	110.3236	6.382
15.8891	1837.96	110.5164	6.421
16.1000	1837.96	110.6916	6.392

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 4646.0 RPM
POWER OUTPUT = 20110.00 HP

** ANALYSIS VARIABLES **

NUMBER OF STAGES = 3

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	.33333
2	.33333
3	.33333

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	.27500
2	.27500
3	.27100
4	.27100
5	.26700
6	.26700
7	.26200

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	7.5000	14.0750	15.8500
2	9.0000	14.1000	16.1000
3	11.0000	14.1667	17.0167

4	13.0000	14.2334	17.9334
5	15.0000	14.3000	18.8500
6	17.0000	14.3667	19.7667
7	19.0000	14.4334	20.6834
8	21.0000	14.5000	21.6000
9	23.0000	14.5667	22.5167

* BLADE-ROW EXIT CONDITIONS *

STATOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1200.0000 FEET PER SEC

ROTOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.0000	-200.00

STATOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1090.0000 FEET PER SEC

ROTOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	-200.00

STATOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1150.0000 FEET PER SEC

ROTOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	-200.00

* BASIC INTERNAL LOSS CORRELATION *

$$Y = \frac{\text{TAN(INLET ANGLE)} + \text{TAN(EXIT ANGLE)}}{.60000000 + .80000000 * \text{COS(EXIT ANGLE)}} * \text{TIMES} \begin{cases} .03000000 + .15725500 * (\text{V RATIO})^{**} 3.60) & \text{IF (V RATIO) .LT. .60000000} \\ .05500000 + .15000000 * ((\text{V RATIO}) - .600)) & \text{IF (V RATIO) .GE. .60000000} \end{cases}$$

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF 2.00000000

*** OUTPUT OF SPOOL DESIGN ANALYSIS ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.00000	475.863	475.714	-26.526	476.601	.23354	108.2190	1837.96	3.213
2	14.4093	14.68715	511.974	510.792	39.004	513.458	.25178	108.7916	1837.96	4.391
3	14.6938	29.37435	542.179	539.048	48.692	544.361	.26711	109.2346	1837.96	5.170
4	14.9598	44.06157	569.390	563.458	56.174	572.154	.28092	109.5845	1837.96	5.697
5	15.2108	58.74881	595.516	585.964	62.066	598.741	.29416	109.8715	1837.96	6.046
6	15.4490	73.43606	621.679	607.703	66.741	625.251	.30738	110.1161	1837.96	6.266
7	15.6759	88.12332	648.448	629.246	70.434	652.262	.32088	110.3303	1837.96	6.384
8	15.8926	102.81059	676.118	650.883	73.290	680.079	.33482	110.5211	1837.96	6.421
9	16.1000	117.49787	704.840	672.754	75.403	708.862	.34927	110.6928	1837.96	6.392

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	104.3754	1821.46	1.433	.01111
2	104.3167	1818.81	3.895	.03554
3	104.1942	1816.44	6.160	.05802
4	104.0087	1814.19	8.278	.07903
5	103.7608	1811.93	10.276	.09886
6	103.4504	1809.57	12.172	.11767
7	103.0771	1807.06	13.978	.13559
8	102.6399	1804.37	15.703	.15271
9	102.1375	1801.47	17.354	.16909

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1667	0.00000	492.137	491.863	1287.582	1378.429	.69916	105.4701	1837.96	69.093
2	14.5540	14.68716	492.137	490.266	1265.997	1358.284	.68813	106.0645	1837.96	68.831
3	14.9285	29.37433	492.137	487.369	1244.084	1337.887	.67700	106.5194	1837.96	68.607

4	13.2926	44.06149	492.137	483.285	1222.018	1317.394	.66586	106.8624	1837.96	68.422
5	15.6482	58.74865	492.137	478.099	1200.000	1296.996	.65481	107.1168	1837.96	68.277
6	15.9970	73.43582	492.137	471.877	1178.088	1276.743	.64388	107.3045	1837.96	68.172
7	16.3404	88.12298	492.137	464.664	1156.178	1256.561	.63302	107.4273	1837.96	68.105
8	16.6799	102.81014	492.137	456.493	1134.117	1236.293	.62215	107.4892	1837.96	68.075
9	17.0167	117.49731	492.137	447.381	1111.716	1215.776	.61117	107.4912	1837.96	68.079

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	77.1218	1699.97	1.910	0.00000	574.374	866.524	.43951	87.5341	1754.50	55.408
2	78.2917	1703.98	4.997	0.00000	590.078	836.098	.42358	88.0760	1754.74	54.045
3	79.3693	1707.97	7.982	0.00000	605.263	806.406	.40806	88.5452	1755.20	52.659
4	80.3664	1711.92	10.884	0.00000	620.024	777.558	.39301	88.9589	1755.83	51.242
5	81.2928	1715.80	13.718	0.00000	634.441	749.704	.37850	89.3321	1756.61	49.790
6	82.1568	1719.58	16.497	0.00000	648.581	722.888	.36456	89.6747	1757.53	48.293
7	82.9654	1723.29	19.235	0.00000	662.506	697.072	.35116	89.9927	1758.58	46.734
8	83.7245	1726.96	21.940	0.00000	676.270	672.177	.33826	90.2901	1759.78	45.085
9	84.4388	1730.62	24.624	0.00000	689.925	648.154	.32583	90.5700	1761.13	43.314

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2334	0.00000	452.632	452.381	-392.424	599.060	.30555	72.6870	1699.38	-40.940
2	14.7041	14.68850	444.788	443.829	-394.151	594.299	.30335	72.7506	1696.41	-41.646
3	15.1686	29.37700	437.046	433.157	-393.697	588.223	.30043	72.7889	1693.81	-42.268
4	15.6289	44.06550	429.374	422.217	-391.459	581.035	.29691	72.8051	1691.55	-42.835
5	16.0870	58.75399	421.739	410.448	-387.828	572.952	.29289	72.8031	1689.56	-43.377
6	16.5447	73.44249	414.111	397.874	-383.056	564.110	.28846	72.7856	1687.81	-43.913
7	17.0037	88.13099	406.461	384.511	-377.267	554.564	.28364	72.7541	1686.27	-44.455
8	17.4659	102.81949	398.757	370.361	-370.349	544.211	.27839	72.7077	1684.98	-44.999
9	17.9334	117.50799	390.966	355.414	-361.970	532.800	.27256	72.6437	1683.97	-45.524

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	68.3173	1672.93	1.909	-.00002	577.079	1069.959	.54572	82.9831	1757.29	-64.986
2	68.4374	1670.38	4.798	-.00002	596.161	1085.612	.55413	83.6198	1757.23	-65.888
3	68.5529	1668.32	7.650	-.00002	614.994	1099.303	.56147	84.1979	1757.37	-66.760
4	68.6635	1666.67	10.476	-.00002	633.659	1111.408	.56793	84.7255	1757.70	-67.615
5	68.7690	1665.37	13.288	-.00002	652.232	1122.313	.57372	85.2126	1758.20	-68.464
6	68.8694	1664.36	16.098	-.00002	670.786	1132.286	.57900	85.6665	1758.84	-69.316
7	68.9650	1663.61	18.916	-.00002	689.397	1141.482	.58383	86.0911	1759.63	-70.177
8	69.0556	1663.15	21.753	-.00002	708.138	1149.844	.58819	86.4832	1760.59	-71.047

9	69.1415	1653.05	24.623	-.00002	727.091	1157.112	.59193	86.8324	1761.72	-71.926

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.34576	.80987	.09673	.3311R	.92698	.77631	.84481	.79271
2	.37802	.77016	.09792	.31391	.92572	.78806	.85257	.80129
3	.40688	.73356	.09988	.29824	.92405	.79923	.86001	.80920
4	.43431	.69962	.10270	.28401	.92173	.80969	.86702	.81622
5	.46164	.66800	.10658	.2711R	.91864	.81942	.87354	.82226
6	.48972	.63843	.11179	.25962	.91461	.82848	.87959	.82728
7	.51909	.61067	.11862	.24923	.90944	.83685	.88516	.83121
8	.55010	.58458	.12744	.24024	.90292	.84431	.89008	.83382
9	.58305	.56015	.13876	.23394	.89482	.85035	.89401	.83473

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .91600

ROTOR BLADE-ROW EFFICIENCY = .81742

STAGE WORK = 40.322 BTU PER LBM
STAGE TOTAL EFFICIENCY = .81952
STAGE STATIC EFFICIENCY = .72539
STAGE BLADE- TO JET-SPEED RATIO = .38536

** STATOR EXIT - ROTOR INLET 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3000	0.00000	397.484	397.264	1251.022	1312.650	.69058	69.2520	1699.38	72.383
2	14.9562	14.68664	397.484	395.858	1203.557	1267.495	.66564	69.5287	1696.40	71.794
3	15.5759	29.37329	397.484	393.343	1161.722	1227.840	.64385	69.7467	1693.82	71.295
4	16.1667	44.05993	397.484	389.877	1124.178	1192.380	.62446	69.9185	1691.55	70.873
5	16.7342	58.74657	397.484	385.575	1090.000	1160.213	.60692	70.0536	1689.56	70.519
6	17.2830	73.43321	397.484	380.519	1058.510	1130.680	.59087	70.1585	1687.81	70.227
7	17.8166	88.11985	397.484	374.768	1029.188	1103.278	.57602	70.2377	1686.29	69.991
8	18.3381	102.80650	397.484	368.365	1001.612	1077.599	.56211	70.2939	1685.00	69.808
9	18.8500	117.49314	397.484	361.340	975.420	1053.299	.54895	70.3286	1683.99	69.673

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	50.9469	1572.40	1.909	.00002	579.779	780.103	.41041	56.9369	1617.25	59.382
2	52.2362	1578.01	5.185	.00002	606.384	717.362	.37673	57.3772	1615.94	56.460
3	53.3411	1582.72	8.278	.00002	631.511	662.660	.34748	57.7839	1615.08	53.430
4	54.3032	1586.78	11.228	.00002	655.462	614.564	.32185	58.1669	1614.61	50.246
5	55.1519	1590.37	14.061	.00002	678.472	572.145	.29930	58.5335	1614.49	46.865
6	55.9086	1593.60	16.800	.00002	700.721	534.796	.27948	58.8890	1614.68	43.237
7	56.5892	1596.58	19.464	.00002	722.354	502.135	.26216	59.2376	1615.17	39.308
8	57.2062	1599.43	22.068	.00002	743.499	473.937	.24722	59.5824	1615.98	35.019
9	57.7691	1602.23	24.623	.00002	764.256	450.094	.23458	59.9263	1617.16	30.302

** STAGE EXIT 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3667	0.00000	435.414	435.172	-406.265	595.514	.31660	46.3720	1558.48	-43.032
2	15.0629	14.68846	423.811	422.361	-410.581	590.079	.31428	46.4668	1552.45	-44.194
3	15.7448	29.37692	412.446	408.720	-411.018	582.278	.31060	46.5291	1547.14	-45.161
4	16.4169	44.06537	401.244	394.481	-407.153	571.638	.30529	46.5534	1542.56	-45.906
5	17.0833	58.75382	390.137	379.614	-399.291	558.247	.29841	46.5412	1538.69	-46.447
6	17.7478	73.44226	379.062	364.135	-388.569	542.839	.29036	46.5012	1535.42	-46.859
7	18.4140	88.13071	367.958	348.048	-375.819	525.959	.28146	46.4408	1532.67	-47.197
8	19.0857	102.81916	356.764	331.343	-361.459	507.871	.27186	46.3642	1530.42	-47.489
9	19.7667	117.50760	345.414	314.001	-345.643	488.651	.26160	46.2741	1528.69	-47.746

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	43.3731	1531.96	1.910	0.00000	582.483	1080.374	.57437	53.8222	1619.26	-66.245
2	43.5039	1526.41	4.838	0.00000	610.708	1105.734	.58892	54.5684	1617.86	-67.535
3	43.6286	1521.78	7.707	0.00000	638.356	1127.518	.60144	55.2440	1616.87	-68.720
4	43.7460	1518.12	10.534	0.00000	665.607	1145.342	.61168	55.8298	1616.24	-69.810
5	43.8550	1515.38	13.337	0.00000	692.626	1159.522	.61981	56.3239	1615.95	-70.830
6	43.9551	1513.38	16.132	0.00000	719.567	1171.176	.62645	56.7480	1615.98	-71.809
7	44.0464	1511.98	18.935	0.00000	746.579	1181.173	.63209	57.1206	1616.34	-72.772
8	44.1292	1511.13	21.760	0.00000	773.810	1190.007	.63700	57.4525	1617.05	-73.729
9	44.2039	1510.83	24.624	0.00000	801.421	1197.942	.64131	57.7495	1618.17	-74.691

** STAGE 2 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.45637	.72207	.18761	.31491	.86901	.79102	.85329	.76601
2	.46888	.64877	.18628	.27018	.86815	.81659	.86935	.78595
3	.47907	.58772	.18541	.23398	.86727	.83845	.88343	.80343
4	.48729	.53658	.18484	.20914	.86639	.85532	.89451	.81771
5	.49383	.49343	.18451	.19367	.86551	.86701	.90222	.82857
6	.49891	.45663	.18437	.18449	.86462	.87473	.90730	.83670
7	.50265	.42512	.18437	.17988	.86371	.87948	.91032	.84265
8	.50502	.39826	.18441	.17884	.86284	.88184	.91161	.84679
9	.50584	.37572	.18432	.18097	.86213	.88209	.91136	.84936

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .86551

ROTOR BLADE-ROW EFFICIENCY = .85625

STAGE WORK = 40.323 BTU PER LBM
STAGE TOTAL EFFICIENCY = .82114
STAGE STATIC EFFICIENCY = .73191
STAGE BLADE- TO JET-SPEED RATIO = .41203

** STATOR EXIT - ROTOR INLET 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4334	0.00000	410.137	409.910	1390.476	1449.702	.80587	43.5580	1558.43	73.575
2	15.4060	14.68633	410.137	408.288	1313.694	1376.229	.76245	43.9069	1552.38	72.735
3	16.2927	29.37266	410.137	405.455	1250.693	1316.224	.72745	44.1662	1547.12	72.038
4	17.1162	44.05899	410.137	401.676	1197.027	1265.340	.69803	44.3592	1542.56	71.450
5	17.8913	58.74532	410.137	397.117	1150.000	1220.947	.67251	44.5000	1538.69	70.949
6	18.6287	73.43165	410.137	391.889	1107.929	1181.405	.64985	44.6002	1535.42	70.521
7	19.3360	88.11797	410.137	386.069	1069.698	1145.629	.62941	44.6686	1532.68	70.155
8	20.0193	102.80430	410.137	379.708	1034.506	1112.841	.61069	44.7113	1530.45	69.845
9	20.6834	117.49063	410.137	372.843	1001.734	1082.443	.59334	44.7321	1528.71	69.585

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	29.7895	1401.23	1.909	-.00002	585.188	903.716	.50236	33.9943	1462.32	63.023
2	30.2471	1410.72	5.443	-.00002	624.621	801.894	.44426	34.4657	1456.82	59.353
3	31.4154	1417.54	8.666	-.00002	660.572	718.649	.39718	34.8832	1456.16	55.508
4	32.3817	1422.80	11.659	-.00002	693.958	649.069	.35806	35.2655	1454.32	51.394

5	33.1996	1427.19	14.476	-.00002	725.385	590.348	.32517	35.6241	1453.26	46.917
6	33.4035	1431.03	17.156	-.00002	755.281	540.900	.29753	35.9677	1452.91	41.983
7	34.5181	1434.52	19.726	-.00002	783.959	499.859	.27462	36.3027	1453.20	38.506
8	35.0007	1437.82	22.210	-.00002	811.664	466.767	.25615	36.6338	1454.11	30.408
9	35.5440	1441.07	24.623	-.00002	838.587	441.395	.24195	36.9644	1455.64	23.633

** STAGE EXIT 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.5000	0.00000	470.590	470.328	-199.637	511.185	.28347	28.4744	1418.71	-22.999
2	15.4320	14.68729	455.056	453.399	-225.773	507.985	.28272	28.5001	1408.34	-26.471
3	16.3369	29.37458	439.975	435.919	-241.979	502.127	.28033	28.5120	1399.29	-29.035
4	17.2228	44.06187	425.210	417.927	-250.588	493.557	.27627	28.5077	1391.40	-30.947
5	18.0967	58.74916	410.644	399.439	-252.926	482.286	.27054	28.4862	1384.70	-32.342
6	18.9653	73.43645	396.169	380.450	-249.044	467.946	.26292	28.4448	1379.24	-33.209
7	19.8345	88.12373	381.681	360.941	-240.185	450.965	.25367	28.3866	1374.91	-33.641
8	20.7106	102.81102	367.079	340.881	-228.001	432.125	.24326	28.3172	1371.54	-33.777
9	21.6000	117.49830	352.256	320.225	-213.129	411.714	.23187	28.2395	1369.06	-33.646

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	26.9766	1398.79	1.909	.00002	587.888	917.415	.50874	32.0194	1462.94	-59.153
2	27.0086	1388.67	4.890	.00002	625.674	965.422	.53731	32.6821	1459.72	-61.965
3	27.0442	1380.07	7.785	.00002	662.363	1005.689	.56146	33.2883	1457.16	-64.265
4	27.0810	1372.83	10.619	.00002	698.280	1039.786	.58202	33.8391	1455.24	-66.229
5	27.1173	1366.97	13.415	.00002	733.714	1068.685	.59948	34.3331	1454.02	-67.960
6	27.1516	1362.55	16.194	.00002	768.927	1092.346	.61375	34.7569	1453.50	-69.508
7	27.1829	1359.41	18.975	.00002	804.170	1111.916	.62546	35.1187	1453.65	-70.934
8	27.2105	1357.30	21.778	.00002	839.691	1129.032	.63558	35.4395	1454.47	-72.293
9	27.2345	1356.14	24.623	.00002	875.756	1144.440	.64453	35.7281	1455.98	-73.612

** STAGE 3 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.41078	.98507	.19053	.40619	.87555	.74865	.85933	.75498
2	.42876	.83062	.18741	.32730	.87424	.78728	.87559	.77965
3	.44239	.71458	.18524	.26898	.87304	.82044	.89103	.80149
4	.45177	.62423	.18312	.22392	.87231	.84839	.90501	.82093
5	.45722	.55241	.18062	.19095	.87218	.87060	.91659	.83761

6	.45949	.49517	.17777	.17277	.87250	.88548	.92436	.85038
7	.45910	.44955	.17468	.16386	.87316	.89383	.92848	.85933
8	.45637	.41342	.17139	.16115	.87411	.89781	.92997	.86549
9	.45143	.38569	.16794	.16312	.87529	.89824	.92919	.86916

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY =	.87337
ROTOR BLADE-ROW EFFICIENCY =	.85341
STAGE WORK =	40.323 BTU PER LBM
STAGE TOTAL EFFICIENCY =	.82827
STAGE STATIC EFFICIENCY =	.75942
STAGE BLADE- TO JET-SPEED RATIO =	.44586

*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

STAGE NUMBER	STATOR BLADE-ROW EFFICIENCY	ROTOR BLADE-ROW EFFICIENCY	STAGE WORK (BTU/LBM)	STAGE TOTAL EFFICIENCY	STAGE STATIC EFFICIENCY	STAGE BLADE- TO JET-SPEED RATIO
1	.91600	.91742	40.327	.81952	.72539	.38536
2	.86551	.85625	40.323	.82114	.73191	.41203
3	.87337	.85341	40.323	.82827	.75942	.44586

SPOOL WORK = 120.968 BTU PER LBM
SPOOL POWER = 20110.07 HP
SPOOL TOTAL- TO TOTAL-PRESSURE RATIO = 3.85873
SPOOL TOTAL- TO STATIC-PRESSURE RATIO = 4.04748
SPOOL TOTAL EFFICIENCY = .84052
SPOOL STATIC EFFICIENCY = .81648
SPOOL BLADE- TO JET-SPEED RATIO = .25141

APPENDIX III

COMPUTER OUTPUT FOR THE REDUCED TIP DIAMETER LOW-PRESSURE SPOOL

The three alternative versions of the low-pressure spool employing the reduced maximum tip diameter at spool exit are presented in this appendix. The computer output for the five-stage design begins on the following page; the four- and three-stage versions will be found on pages 136 and 150, respectively. In all cases, spool inlet distributions of total pressure, total temperature, and absolute flow angle were obtained directly from the computer output for the hp spool.

** PROGRAM TUZ - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES **

OPTIMIZED FIVE STAGE VERSION OF NASA LP SPOOL AT REDUCED TIP DIAMETER

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 1
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.35000 LBF FT/LBM DEG R
INLET MASS FLOW = 117.50000 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
14.1000	1837.96	108.2258	3.213
14.4040	1837.96	108.7913	4.376
14.6865	1837.96	109.2293	5.153
14.9511	1837.96	109.5756	5.682
15.2020	1837.96	109.8619	6.036
15.4410	1837.96	110.1073	6.260
15.6697	1837.96	110.3232	6.382
15.8891	1837.96	110.5164	6.421
16.1000	1837.96	110.6912	6.392

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 4646.0 RPM
POWER OUTPUT = 20110.00 HP

** ANALYSIS VARIABLES **

NUMBER OF STAGES = 5

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	.20000
2	.20000
3	.20000
4	.20000
5	.20000

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	.27500
2	.27500
3	.27300
4	.27300
5	.27100
6	.27100
7	.26800
8	.26800
9	.26500
10	.26500
11	.26200

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	7.5000	14.0750	15.8400
2	9.0000	14.1000	16.1000
3	10.5000	14.1400	16.3600
4	12.0000	14.1900	16.6200
5	13.5000	14.2400	16.8800
6	15.0000	14.2900	17.1400
7	16.5000	14.3000	17.4000
8	18.0000	14.3400	17.6600
9	19.5000	14.3900	17.9200
10	21.0000	14.4200	18.1800
11	22.5000	14.4600	18.4400
12	24.0000	14.5000	18.7000
13	25.5000	14.5400	18.9600

* BLADE-ROW EXIT CONDITIONS *

STATOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 849.0000 FEET PER SEC

ROTOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.5000	-200.00

STATOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 811.0000 FEET PER SEC

ROTOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	-200.00

STATOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 776.0000 FEET PER SEC

ROTOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.5000	-200.00

STATOR 4

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 741.0000 FEET PER SEC

ROTOR 4

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	-200.00

STATOR 5

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 774.0000 FEET PER SEC

ROTOR 5

RADIAL POSITION	MERIDIONAL VELOCITY GRADIENT

(IN)	(PER SEC)
17.5000	-200.00

* BASIC INTERNAL LOSS CORRELATION *

$$Y = \frac{\tan(\text{INLET ANGLE}) + \tan(\text{EXIT ANGLE})}{.60000000 + .80000000 * \cos(\text{EXIT ANGLE})} * \text{TIMES} * \begin{cases} .03000000 + .1572500 * (\text{V RATIO})^{**} 3.60) & \text{IF (V RATIO) .LT. .60000000} \\ .05500000 + .15000000 * ((\text{V RATIO}) - .600)) & \text{IF (V RATIO) .GE. .60000000} \end{cases}$$

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF 2.00000000

*** OUTPUT OF SPOOL-DESIGN ANALYSIS ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.00000	504.774	504.655	28.149	505.558	.24787	108.2194	1837.96	3.213
2	14.3947	14.68746	535.173	534.660	40.394	536.695	.26330	108.7672	1837.96	4.343
3	14.6696	29.37493	557.771	556.615	49.717	559.982	.27487	109.2000	1837.96	5.113
4	14.9302	44.06240	575.163	573.140	56.626	577.944	.28380	109.5480	1837.96	5.646
5	15.1796	58.74987	589.162	586.063	61.695	592.383	.29099	109.8376	1837.96	6.009
6	15.4201	73.43735	600.936	596.568	65.294	604.473	.29702	110.0876	1837.96	6.244
7	15.6530	88.12482	611.156	605.336	67.673	614.891	.30221	110.3095	1837.96	6.376
8	15.8794	102.81230	620.215	612.771	69.001	624.041	.30678	110.5100	1837.96	6.421
9	16.1000	117.49977	628.346	619.114	69.397	632.167	.31084	110.6930	1837.96	6.392

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	103.9019	1819.40	1.241	.00666
2	103.8863	1817.04	2.507	.00568
3	103.8734	1815.19	3.688	.00476
4	103.8630	1813.70	4.808	.00390
5	103.8552	1812.48	5.879	.00307
6	103.8498	1811.43	6.913	.00226
7	103.8467	1810.50	7.913	.00149
8	103.8458	1809.68	8.886	.00073
9	103.8469	1808.94	9.834	-.00000

** STATOR EXIT = ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1400	0.00000	569.858	569.656	868.934	1039.127	.51806	107.1945	1837.96	56.752
2	14.4389	14.68850	569.858	569.251	866.705	1037.264	.51709	107.6864	1837.96	56.703
3	14.7306	29.37700	569.858	568.646	862.184	1033.489	.51513	108.0808	1837.96	56.599

4	15.0157	44.06549	569.858	567.856	856.045	1028.373	.51246	108.3988	1837.96	56.442
5	15.2948	58.75399	569.858	566.892	849.000	1022.516	.50942	108.6638	1837.96	56.268
6	15.5684	73.44249	569.858	565.764	841.524	1016.317	.50620	108.8920	1837.96	56.087
7	15.8369	88.13099	569.858	564.482	833.908	1010.020	.50293	109.0944	1837.96	55.905
8	16.1006	102.81949	569.858	563.053	826.323	1003.767	.49969	109.2778	1837.96	55.730
9	16.3600	117.50798	569.858	561.486	818.835	997.611	.49650	109.4457	1837.96	55.561

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	89.9951	1759.54	1.528	.00000	573.292	641.983	.32006	96.2945	1789.47	27.429
2	90.4659	1759.83	2.646	.00000	585.411	635.503	.31681	96.6670	1789.15	26.296
3	90.9148	1760.39	3.737	.00000	597.237	628.439	.31324	97.0034	1789.07	24.982
4	91.3415	1761.15	4.804	.00000	608.797	621.184	.30955	97.3123	1789.18	23.529
5	91.7469	1762.03	5.848	.00000	620.113	614.107	.30595	97.6021	1789.42	21.987
6	92.1318	1762.95	6.872	.00000	631.205	607.431	.30254	97.8786	1789.74	20.392
7	92.4978	1763.88	7.876	.00000	642.090	601.276	.29940	98.1454	1790.13	18.768
8	92.8461	1764.79	8.863	.00000	652.784	595.696	.29655	98.4050	1790.56	17.130
9	93.1781	1765.69	9.836	.00000	663.300	590.702	.29398	98.6588	1791.02	15.483

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1800	0.00000	574.493	574.289	-113.072	585.515	.29393	88.1391	1756.34	-11.138
2	14.4964	14.68731	569.220	568.632	-119.717	581.673	.29216	88.0878	1754.13	-11.889
3	14.8088	29.37463	564.013	562.857	-124.781	577.651	.29027	88.0334	1752.25	-12.500
4	15.1176	44.06194	558.866	556.971	-128.582	573.467	.28827	87.9763	1750.64	-13.000
5	15.4232	58.74926	553.772	550.977	-131.421	569.153	.28619	87.9171	1749.23	-13.416
6	15.7260	73.43657	548.727	544.878	-133.509	564.735	.28404	87.8563	1747.97	-13.768
7	16.0262	88.12389	543.723	538.677	-134.987	560.229	.28184	87.7944	1746.81	-14.068
8	16.3241	102.81120	538.758	532.378	-135.950	555.646	.27959	87.7314	1745.74	-14.325
9	16.6200	117.49851	533.826	525.983	-136.460	550.992	.27730	87.6675	1744.73	-14.544

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	83.2333	1731.25	1.528	0.00000	574.914	896.307	.44994	95.0663	1790.03	-50.147
2	83.2817	1729.38	2.605	0.00000	587.742	908.025	.45607	95.4173	1789.69	-51.209
3	83.2506	1727.84	3.668	0.00000	600.408	918.700	.46164	95.7426	1789.58	-52.183
4	83.2599	1726.58	4.719	0.00000	612.929	928.531	.46675	96.0464	1789.65	-53.089
5	83.2694	1725.54	5.760	0.00000	625.320	937.721	.47151	96.3342	1789.86	-53.942
6	83.2790	1724.64	6.790	0.00000	637.594	946.415	.47601	96.6097	1790.16	-54.754
7	83.2886	1723.85	7.812	0.00000	649.765	954.710	.48029	96.8756	1790.53	-55.533
8	83.2982	1723.15	8.826	0.00000	661.844	962.671	.48440	97.1334	1790.94	-56.284

83.3076	1722.52	9.834	0.00000	673.841	970.339	.48834	97.3843	1791.40	-57.012

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.48652	.71625	.05907	.11178	.94952	.90907	.92913	.88710
2	.51741	.69987	.06218	.11047	.94696	.91057	.93040	.88744
3	.54184	.68405	.06489	.10876	.94499	.91261	.93197	.88854
4	.56200	.66900	.06725	.10686	.94321	.91477	.93353	.88980
5	.57934	.65489	.06939	.10494	.94155	.91686	.93498	.89104
6	.59477	.64182	.07141	.10313	.93994	.91880	.93629	.89218
7	.60879	.62980	.07335	.10149	.93839	.92058	.93746	.89320
8	.62170	.61880	.07514	.10006	.93692	.92214	.93846	.89412
9	.63368	.60876	.07682	.09884	.93552	.92350	.93930	.89492

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY =	.94181	
ROTOR BLADE-ROW EFFICIENCY =	.91658	
STAGE WORK =	24.194	BTU PER LBM
STAGE TOTAL EFFICIENCY =	.89090	
STAGE STATIC EFFICIENCY =	.72046	
STAGE BLADE- TO JET-SPEED RATIO =	.47986	

** STATOR EXIT - ROTOR INLET 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2200	0.00000	553.538	553.341	894.710	1052.098	.53689	86.8416	1756.36	58.265
2	14.5833	14.68746	553.538	552.940	871.600	1032.516	.52677	86.8401	1754.15	57.609
3	14.9360	29.37492	553.538	552.344	850.087	1014.422	.51741	86.8326	1752.26	56.986
4	15.2791	44.06238	553.538	551.568	829.949	997.606	.50871	86.8199	1750.65	56.393
5	15.6137	58.74984	553.538	550.626	811.000	981.899	.50057	86.8027	1749.23	55.826
6	15.9404	73.43730	553.538	549.529	793.091	967.160	.49293	86.7817	1747.97	55.282
7	16.2599	88.12476	553.538	548.288	776.099	953.275	.48574	86.7574	1746.81	54.760
8	16.5730	102.81222	553.538	546.911	759.919	940.150	.47895	86.7303	1745.73	54.258
9	16.8800	117.49968	553.538	545.405	744.464	927.702	.47251	86.7006	1744.72	53.773

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	71.9619	1675.39	1.528	-.00000	576.535	638.466	.32581	77.1991	1705.21	29.899
2	72.4558	1676.16	2.662	-.00000	591.265	620.477	.31656	77.4264	1704.33	26.885
3	72.9031	1676.99	3.763	-.00000	605.564	605.141	.30866	77.6519	1703.77	23.879
4	73.3100	1677.84	4.835	-.00000	619.477	592.201	.30198	77.8764	1703.50	20.886
5	73.6820	1678.71	5.879	-.00000	633.040	581.441	.29642	78.1003	1703.44	17.911
6	74.0234	1679.54	6.900	-.00000	646.286	572.674	.29187	78.3243	1703.53	14.957
7	74.3377	1680.33	7.897	-.00000	659.249	565.738	.28827	78.5487	1703.74	12.031
8	74.6281	1681.07	8.875	-.00000	671.935	560.487	.28553	78.7740	1704.05	9.139
9	74.8971	1681.76	9.834	-.00000	684.382	556.789	.28359	79.0005	1704.44	6.286

** STAGE EXIT 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2600	0.00000	577.815	577.609	-139.703	594.463	.30594	69.8446	1669.17	-13.597
2	14.6360	14.68735	571.548	570.954	-142.249	588.984	.30333	69.7842	1666.43	-13.998
3	15.0063	29.37471	565.376	564.210	-144.107	583.652	.30065	69.7226	1664.05	-14.328
4	15.3716	44.06206	559.288	557.380	-145.365	577.870	.29792	69.6600	1661.98	-14.617
5	15.7324	58.74941	553.275	550.468	-146.100	572.240	.29514	69.5965	1660.16	-14.864
6	16.0892	73.43676	547.328	543.475	-146.353	566.558	.29231	69.5321	1658.53	-15.072
7	16.4424	88.12412	541.440	536.403	-146.149	560.818	.28944	69.4670	1657.06	-15.241
8	16.7926	102.81147	535.605	529.254	-145.539	555.026	.28653	69.4012	1655.72	-15.376
9	17.1400	117.49882	529.815	522.031	-144.584	549.189	.28358	69.3349	1654.49	-15.481

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	65.6354	1643.13	1.528	0.00000	578.157	921.516	.47426	76.0860	1705.71	-51.179
2	65.6475	1640.87	2.612	.00000	593.402	931.584	.47977	76.3583	1704.82	-52.184
3	65.6594	1638.96	3.680	.00000	608.416	941.244	.48502	76.6220	1704.25	-53.139
4	65.6712	1637.37	4.733	.00000	623.226	950.544	.49005	76.8780	1703.96	-54.050
5	65.6827	1636.03	5.774	.00000	637.854	959.529	.49489	77.1273	1703.88	-54.925
6	65.6939	1634.88	6.803	.00000	652.320	968.218	.49955	77.3703	1703.96	-55.766
7	65.7048	1633.88	7.822	.00000	666.642	976.620	.50403	77.6073	1704.17	-56.577
8	65.7153	1633.02	8.832	.00000	680.839	984.770	.50838	77.8388	1704.48	-57.362
9	65.7254	1632.27	9.834	.00000	694.924	992.712	.51259	78.0660	1704.89	-58.125

** STAGE 2 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.55652	.69284	.08719	.11375	.92858	.90908	.92929	.87167
2	.56335	.66605	.08673	.10687	.92862	.91458	.93257	.87703
3	.56944	.64292	.08620	.10107	.92876	.91931	.93551	.88193
4	.57484	.62301	.08559	.09620	.92898	.92349	.93805	.88634
5	.57965	.60597	.08494	.09216	.92926	.92703	.94015	.89025
6	.58391	.59147	.08423	.08889	.92959	.92991	.94181	.89362
7	.58769	.57928	.08350	.08641	.92997	.93215	.94299	.89647
8	.59102	.56915	.08273	.08461	.93038	.93380	.94372	.89880
9	.59393	.56088	.08192	.08338	.93084	.93492	.94405	.90067

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .92941

ROTOR BLADE-ROW EFFICIENCY = .92528

STAGE WORK = 24.193 BTU PER LBM
STAGE TOTAL EFFICIENCY = .88803
STAGE STATIC EFFICIENCY = .71758
STAGE BLADE- TO JET-SPEED RATIO = .48855

** STATOR EXIT - ROTOR INLET 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3000	0.00000	558.710	558.512	871.307	1035.052	.54147	68.7693	1669.19	57.340
2	14.7293	14.68746	558.710	558.100	844.615	1012.685	.52967	68.7626	1666.45	56.544
3	15.1440	29.37491	558.710	557.489	820.039	992.280	.51889	68.7499	1664.06	55.791
4	15.5456	44.06237	558.710	556.698	797.254	973.535	.50899	68.7321	1661.99	55.075
5	15.9355	58.74983	558.710	555.741	776.000	956.208	.49983	68.7101	1660.16	54.391
6	16.3150	73.43729	558.710	554.633	756.064	940.101	.49131	68.6845	1658.53	53.737
7	16.6850	88.12474	558.710	553.384	737.273	925.055	.48336	68.6558	1657.06	53.109
8	17.0464	102.81220	558.710	552.004	719.479	910.938	.47590	68.6245	1655.71	52.504
9	17.4000	117.49966	558.710	550.502	702.567	897.640	.46887	68.5908	1654.49	51.919

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	56.7826	1590.24	1.528	0.00000	579.779	638.195	.32968	61.8270	1619.50	27.563
2	57.2373	1590.87	2.678	0.00000	597.186	611.047	.31960	61.2515	1618.39	23.918
3	57.6417	1591.50	3.789	0.00000	613.997	595.492	.31140	61.4746	1617.64	20.284
4	58.0039	1592.14	4.865	0.00000	630.280	583.127	.30487	61.6972	1617.20	16.698

5	58.3302	1592.78	5.910	0.00000	646.090	573.615	.29984	61.9199	1617.03	13.157
6	58.6295	1593.40	6.927	0.00000	661.476	566.660	.29615	62.1431	1617.06	9.678
7	58.8941	1593.99	7.918	0.00000	676.478	562.008	.29366	62.3675	1617.27	6.269
8	59.1393	1594.56	8.886	0.00000	691.131	559.429	.29226	62.5932	1617.62	2.940
9	59.3639	1595.11	9.834	0.00000	705.465	558.718	.29184	62.8208	1618.11	-.302

** STAGE EXIT 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3400	0.00000	601.165	600.451	-157.078	621.347	.32837	54.7074	1581.13	-14.648
2	14.7770	14.08728	593.882	593.261	-159.490	614.925	.32526	54.6495	1577.84	-15.047
3	15.2061	29.37457	586.730	585.511	-161.057	608.434	.32206	54.5900	1574.96	-15.380
4	15.6282	44.06185	579.695	577.703	-161.882	601.873	.31879	54.5291	1572.44	-15.654
5	16.0442	58.74913	572.761	569.838	-162.046	595.243	.31544	54.4669	1570.23	-15.874
6	16.4547	73.43641	565.919	561.916	-161.647	588.552	.31203	54.4036	1568.28	-16.049
7	16.8605	88.12370	559.156	553.938	-160.803	581.819	.30858	54.3396	1566.54	-16.188
8	17.2621	102.81098	552.463	545.903	-159.602	575.055	.30509	54.2751	1564.98	-16.297
9	17.6600	117.49826	545.831	537.812	-158.098	568.266	.30156	54.2103	1563.58	-16.382

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	50.9180	1552.36	1.528	.00000	581.401	952.234	.50323	60.1455	1619.93	-50.862
2	50.9324	1549.66	2.621	.00000	599.117	963.421	.50959	60.4122	1618.83	-51.973
3	50.9465	1547.37	3.694	.00000	616.514	974.099	.51562	60.6695	1618.08	-53.020
4	50.9602	1545.45	4.750	.00000	633.629	984.319	.52135	60.9180	1617.65	-54.013
5	50.9736	1543.83	5.791	-.00000	650.495	994.122	.52682	61.1583	1617.47	-54.958
6	50.9862	1542.47	6.818	-.00000	667.141	1003.570	.53206	61.3916	1617.52	-55.863
7	50.9984	1541.31	7.833	-.00000	683.593	1012.749	.53713	61.6198	1617.74	-56.734
8	51.0101	1540.34	8.838	-.00000	699.876	1021.721	.54206	61.8440	1618.13	-57.578
9	51.0212	1539.51	9.834	-.00000	716.007	1030.529	.54688	62.0654	1618.65	-58.397

** STAGE 3 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.57433	.66181	.08970	.10184	.92686	.92126	.93316	.87560
2	.58161	.63425	.08863	.09476	.92731	.92656	.93671	.88185
3	.58799	.61133	.08756	.08902	.92780	.93124	.93973	.88734
4	.59358	.59242	.08649	.08444	.92833	.93499	.94216	.89208
5	.59845	.57701	.08539	.08103	.92891	.93788	.94396	.89605

6	.60246	.56464	.08427	.07858	.92954	.93997	.94515	.89929
7	.60625	.55493	.08310	.07680	.93023	.94140	.94580	.90190
8	.60929	.54754	.08189	.07582	.93098	.94227	.94598	.90395
9	.61181	.54217	.08064	.07527	.93177	.94264	.94571	.90547

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .92905

ROTOR BLADE-ROW EFFICIENCY = .93580

STAGE WORK = 24.194 BTU PER LBM
STAGE TOTAL EFFICIENCY = .89412
STAGE STATIC EFFICIENCY = .70975
STAGE BLADE- TO JET-SPEED RATIO = .49553

** STATOR EXIT - ROTOR INLET 4 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3800	0.00000	582.490	582.283	846.937	1027.909	.55218	53.8238	1581.14	55.491
2	14.8769	14.68745	582.490	581.847	816.848	1003.263	.53886	53.8145	1577.85	54.537
3	15.3544	29.37490	582.490	581.200	789.459	981.091	.52689	53.7994	1574.97	53.639
4	15.8148	44.06236	582.490	580.367	764.299	960.962	.51601	53.7794	1572.44	52.789
5	16.2601	58.74981	582.490	579.364	741.000	942.537	.50605	53.7551	1570.23	51.979
6	16.6919	73.43726	582.490	578.208	719.274	925.554	.49686	53.7271	1568.28	51.205
7	17.1118	88.12471	582.490	576.910	698.892	909.805	.48834	53.6961	1566.53	50.462
8	17.5208	102.81217	582.490	575.482	679.672	895.125	.48039	53.6624	1564.97	49.745
9	17.9200	117.49962	582.490	573.932	661.462	881.378	.47295	53.6265	1563.57	49.053

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	44.0817	1502.40	1.528	0.00000	583.022	639.489	.34353	47.6813	1532.88	24.382
2	44.4853	1502.84	2.694	.00000	603.171	620.446	.33325	47.8979	1531.53	20.165
3	44.8381	1503.24	3.814	.00000	622.528	605.938	.32541	48.1136	1530.60	16.025
4	45.1489	1503.63	4.894	.00000	641.193	595.357	.31969	48.3292	1530.04	11.976
5	45.4249	1504.03	5.939	.00000	659.248	588.199	.31580	48.5454	1529.81	8.032
6	45.6714	1504.44	6.952	.00000	676.758	584.040	.31353	48.7627	1529.86	4.205
7	45.8929	1504.85	7.937	.00000	693.781	582.513	.31267	48.9817	1530.14	.508
8	46.0927	1505.26	8.897	.00000	710.364	583.298	.31304	49.2026	1530.62	-3.053
9	46.2737	1505.68	9.834	.00000	726.548	586.115	.31451	49.4260	1531.28	-6.470

** STAGE EXIT 4 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4200	0.00000	644.625	644.396	-175.292	668.033	.36352	42.2898	1492.05	-15.218
2	14.9197	14.68727	636.297	635.626	-177.390	660.561	.35984	42.2335	1488.19	-15.593
3	15.4086	29.37454	628.148	626.830	-178.518	653.023	.35606	42.1753	1484.81	-15.897
4	15.8881	44.06181	620.156	618.007	-178.813	645.420	.35218	42.1155	1481.85	-16.137
5	16.3594	58.74908	612.302	609.154	-178.447	637.775	.34823	42.0544	1479.28	-16.328
6	16.8234	73.43635	604.569	600.270	-177.588	630.112	.34422	41.9924	1477.02	-16.481
7	17.2810	88.12362	596.942	591.352	-176.355	622.448	.34019	41.9300	1475.03	-16.606
8	17.7329	102.81089	589.409	582.399	-174.828	614.791	.33612	41.8673	1473.28	-16.709
9	18.1800	117.49815	581.958	573.408	-173.057	607.144	.33204	41.8044	1471.74	-16.794

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	38.7226	1458.42	1.528	-.00000	584.644	996.516	.54227	46.9858	1533.26	-49.703
2	38.7390	1455.31	2.631	-.00000	604.903	1008.393	.54932	47.2382	1531.94	-50.906
3	38.7549	1452.67	3.711	-.00000	624.727	1019.693	.55598	47.4808	1531.03	-52.033
4	38.7701	1450.46	4.771	-.00000	644.169	1030.482	.56229	47.7144	1530.49	-53.096
5	38.7847	1448.62	5.812	.00000	663.275	1040.870	.56832	47.9406	1530.27	-54.107
6	38.7985	1447.10	6.837	.00000	682.087	1050.973	.57414	48.1616	1530.34	-55.075
7	38.8116	1445.84	7.848	.00000	700.639	1060.876	.57980	48.3790	1530.65	-56.008
8	38.8241	1444.80	8.846	.00000	718.964	1070.638	.58535	48.5941	1531.18	-56.912
9	38.8359	1443.96	9.834	.00000	737.090	1080.298	.59080	48.8075	1531.91	-57.788

** STAGE 4 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.60448	.64172	.09070	.08950	.92651	.93202	.93656	.87915
2	.61293	.61528	.08950	.08289	.92699	.93698	.94017	.88574
3	.62016	.59424	.08822	.07777	.92758	.94095	.94303	.89137
4	.62632	.57775	.08687	.07405	.92829	.94395	.94513	.89605
5	.63153	.56510	.08545	.07144	.92908	.94609	.94650	.89986
6	.63589	.55571	.08398	.06969	.92996	.94752	.94726	.90292
7	.63950	.54909	.08248	.06862	.93089	.94833	.94746	.90529
8	.64243	.54481	.08095	.06810	.93187	.94862	.94715	.90703
9	.64475	.54255	.07940	.06806	.93289	.94843	.94637	.90820

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .92929

ROTOR BLADE-ROW EFFICIENCY = .94408

STAGE WORK = 24.194 BTU PER LBM
STAGE TOTAL EFFICIENCY = .89774
STAGE STATIC EFFICIENCY = .69084
STAGE BLADE- TO JET-SPEED RATIO = .49847

** STATOR EXIT - ROTOR INLET 5 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4600	0.00000	638.429	638.202	899.365	1102.927	.61249	41.4929	1492.06	54.640
2	15.0283	14.68743	638.429	637.713	863.130	1073.585	.59599	41.4850	1488.19	53.542
3	15.5706	29.37485	638.429	636.991	830.606	1047.615	.58141	41.4705	1484.81	52.515
4	16.0905	44.06228	638.429	636.066	801.075	1024.360	.56837	41.4505	1481.86	51.550
5	16.5910	58.74971	638.429	634.961	774.000	1003.328	.55658	41.4259	1479.28	50.636
6	17.0744	73.43713	638.429	633.692	748.973	984.150	.54582	41.3976	1477.02	49.766
7	17.5427	88.12456	638.429	632.276	725.675	966.538	.53594	41.3662	1475.03	48.935
8	17.9974	102.81199	638.429	630.725	703.852	950.263	.52680	41.3323	1473.28	48.136
9	18.4400	117.49941	638.429	629.049	683.298	935.140	.51830	41.2962	1471.74	47.367

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	32.4736	1400.38	1.528	0.00000	586.266	711.071	.39488	36.0244	1438.49	26.132
2	32.4804	1401.33	2.714	-.00000	609.308	687.035	.38140	36.2258	1436.90	21.704
3	33.2297	1402.10	3.845	-.00000	631.295	668.817	.37119	36.4258	1435.81	17.375
4	33.5328	1402.78	4.930	-.00000	652.375	655.517	.36372	36.6254	1435.16	13.158
5	33.7984	1403.41	5.975	-.00000	672.666	646.421	.35859	36.8253	1434.90	9.067
6	34.0328	1404.03	6.984	-.00000	692.265	640.942	.35547	37.0263	1434.98	5.114
7	34.2411	1404.63	7.961	-.00000	711.250	638.592	.35409	37.2289	1435.36	1.307
8	34.4273	1405.23	8.910	-.00000	729.687	638.951	.35422	37.4335	1435.99	-2.346
9	34.5944	1405.84	9.834	-.00000	747.631	641.662	.35584	37.6404	1436.86	-5.839

** STAGE EXIT 5 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.5000	0.00000	711.121	710.868	-110.851	719.709	.40431	32.1588	1402.48	-8.863

2	15.0642	14.68734	701.718	700.972	-117.197	711.438	.40021	32.0959	1397.87	-9.492
3	15.6141	29.37467	692.553	691.086	-121.913	703.202	.39603	32.0327	1393.85	-10.004
4	16.1515	44.06201	683.596	681.205	-125.343	694.992	.39179	31.9694	1390.33	-10.426
5	16.6781	58.74934	674.819	671.323	-127.789	686.812	.38749	31.9060	1387.26	-10.778
6	17.1951	73.43668	666.202	661.436	-129.458	678.664	.38316	31.8426	1384.58	-11.074
7	17.7038	88.12402	657.725	651.540	-130.496	670.545	.37878	31.7794	1382.25	-11.326
8	18.2051	102.8113	649.369	641.630	-131.016	662.454	.37438	31.7164	1380.22	-11.541
9	18.7000	117.4987	641.121	631.702	-131.104	654.389	.36995	31.6537	1378.47	-11.725

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	28.8341	1363.00	1.528	.00000	587.888	996.960	.56006	35.4557	1438.76	-44.507
2	28.8403	1359.29	2.643	.00000	610.761	1011.104	.56878	35.6877	1437.22	-46.082
3	28.8466	1356.15	3.731	.00000	633.056	1024.504	.57698	35.9110	1436.16	-47.530
4	28.8530	1353.51	4.796	.00000	654.847	1037.304	.58476	36.1270	1435.53	-48.875
5	28.8594	1351.30	5.835	-.00000	676.197	1049.654	.59221	36.3376	1435.29	-50.138
6	28.8657	1349.48	6.857	-.00000	697.159	1061.659	.59939	36.5442	1435.39	-51.334
7	28.8719	1347.98	7.863	-.00000	717.782	1073.395	.60635	36.7477	1435.80	-52.473
8	28.8778	1346.77	8.855	-.00000	738.108	1084.922	.61314	36.9491	1436.49	-53.563
9	28.8836	1345.82	9.834	-.00000	758.173	1096.289	.61978	37.1489	1437.44	-54.612

** STAGE 5 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.60569	.71324	.08834	.09062	.93024	.93265	.93578	.87291
2	.61529	.67949	.08698	.08324	.93070	.93801	.93970	.88051
3	.62334	.65282	.08552	.07756	.93131	.94232	.94284	.88700
4	.63007	.63194	.08398	.07322	.93206	.94573	.94528	.89252
5	.63566	.61584	.08239	.06998	.93290	.94833	.94706	.89716
6	.64026	.60372	.08077	.06765	.93382	.95020	.94821	.90097
7	.64400	.59493	.07914	.06610	.93480	.95138	.94874	.90398
8	.64697	.58894	.07749	.06522	.93581	.95195	.94868	.90623
9	.64925	.58530	.07584	.06491	.93686	.95195	.94805	.90779

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .93312

ROTOR BLADE-ROW EFFICIENCY = .94628

STAGE WORK = 24.194 BTU PER LBM

STAGE TOTAL EFFICIENCY = .89484

STAGE STATIC EFFICIENCY = .86479

STAGE BLADE- TO JET-SPEED RATIO = .49849

*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

STAGE NUMBER	STATOR BLADE-ROW EFFICIENCY	ROTOR BLADE-ROW EFFICIENCY	STAGE WORK (BTU/LBM)	STAGE TOTAL EFFICIENCY	STAGE STATIC EFFICIENCY	STAGE BLADE- TO JET-SPEED RATIO
1	.94181	.91658	24.194	.89090	.72046	.47986
2	.92941	.92528	24.193	.88883	.71758	.48855
3	.92905	.93580	24.194	.89412	.70975	.49553
4	.92929	.94408	24.194	.89774	.69084	.49847
5	.93312	.94628	24.194	.89484	.66479	.49849

SPOOL WORK = 120.968 BTU PER LBM
SPOOL POWER = 20110.04 HP
SPOOL TOTAL- TO TOTAL-PRESSURE RATIO = 3.43867
SPOOL TOTAL- TO STATIC-PRESSURE RATIO = 3.80172
SPOOL TOTAL EFFICIENCY = .90626
SPOOL STATIC EFFICIENCY = .84837
SPOOL BLADE- TO JET-SPEED RATIO = .24232

PROGRAM TD2 - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES

OPTIMIZED FOUR STAGE VERSION OF NASA LP SPOOL AT REDUCED TIP DIAMETER

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 1
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.35000 LBF FT/LBM DEG R
INLET MASS FLOW = 117.50000 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
14.1000	1837.96	108.2258	3.213
14.4048	1837.96	108.7913	4.376
14.6865	1837.96	109.2293	5.153
14.9511	1837.96	109.5756	5.682
15.2020	1837.96	109.8619	6.036
15.4418	1837.96	110.1073	6.260
15.6697	1837.96	110.3232	6.382
15.8891	1837.96	110.5164	6.421
16.1000	1837.96	110.6912	6.392

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 4646.0 RPM
POWER OUTPUT = 20110.00 HP

** ANALYSIS VARIABLES **

-NUMBER OF STAGES = 4

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	.26900
2	.25500
3	.24500
4	.23500

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	.27500
2	.27500
3	.27200
4	.27200
5	.26900
6	.26900
7	.26600
8	.26600
9	.26200

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)

1	7.5000	14.0750	15.7750
2	9.0000	14.1000	16.1000
3	10.7000	14.1500	16.4250
4	12.4000	14.2000	16.7500
5	14.1000	14.2500	17.0750
6	15.8000	14.3000	17.4000
7	17.5000	14.3500	17.7250
8	19.2000	14.4000	18.0500
9	20.9000	14.4500	18.3750
10	22.6000	14.5000	18.7000
11	24.3000	14.5500	19.0250

* BLADE-ROW EXIT CONDITIONS *

STATOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1021.0000 FEET PER SEC

ROTOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.5000	-200.00

STATOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 914.0000 FEET PER SEC

ROTOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	-200.00

STATOR 3

MERIDIONAL

RADIAL POSITION (IN)	VELOCITY GRADIENT (PER SEC)
16.5000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 817.0000 FEET PER SEC

ROTOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.5000	-200.00

STATOR 4

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 662.0000 FEET PER SEC

ROTOR 4

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	-200.00

* BASIC INTERNAL LOSS CORRELATION *

$$\omega = \frac{\tan(\text{INLET ANGLE}) + \tan(\text{EXIT ANGLE})}{.60000000 + .80000000 * \cos(\text{EXIT ANGLE})} * \text{TIMES} * \begin{cases} .03000000 + .15.25500 * (\text{V RATIO})^{**} 3.60) & \text{IF (V RATIO) .LT. .60000000} \\ .05500000 + .15000000 * ((\text{V RATIO}) - .600)) & \text{IF (V RATIO) .GE. .60000000} \end{cases}$$

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF 2.00000000

*** OUTPUT OF SPOOL DESIGN ANALYSIS ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.00000	569.073	568.938	28.399	569.864	.25000	108.2195	1837.96	3.213
2	14.3926	14.68748	539.114	538.464	40.619	540.642	.26526	108.7637	1837.96	4.336
3	14.6866	29.37496	561.175	559.662	49.903	563.389	.27656	109.1949	1837.96	5.104
4	14.9256	44.06244	577.814	575.122	56.741	580.594	.28512	109.5424	1837.96	5.638
5	15.1747	58.74992	590.826	586.665	61.696	594.038	.29182	109.8321	1837.96	6.003
6	15.4154	73.43740	601.379	595.479	65.137	604.896	.29723	110.0839	1837.96	6.241
7	15.6492	88.12488	610.152	602.260	67.314	613.854	.30169	110.3060	1837.96	6.374
8	15.8771	102.81237	617.550	607.427	68.399	621.326	.30542	110.5081	1837.96	6.421
9	16.1000	117.49985	623.815	611.235	68.515	627.566	.30854	110.6930	1837.96	6.392

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	103.8292	1819.68	1.320	.00849
2	103.8122	1816.73	2.813	.00491
3	103.8046	1814.91	4.208	.00156
4	103.8064	1813.48	5.533	-.00161
5	103.8173	1812.33	6.804	-.00466
6	103.8368	1811.39	8.032	-.00761
7	103.8646	1810.60	9.225	-.01047
8	103.9005	1809.92	10.388	-.01326
9	103.9439	1809.36	11.526	-.01599

** STATOR EXIT = ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1500	0.00000	581.611	581.359	1064.010	1212.595	.60948	106.6929	1837.96	61.348
2	14.4584	14.68745	581.611	580.854	1054.645	1204.387	.60510	107.2066	1837.96	61.156
3	14.7585	29.37491	581.611	580.101	1044.051	1195.120	.60016	107.6223	1837.96	60.942

4	15.0513	44.06236	581.611	579.120	1032.669	1185.191	.59488	107.9612	1837.96	60.716
5	15.3373	58.74981	581.611	577.925	1021.900	1175.037	.58949	108.2465	1837.96	60.488
6	15.6172	73.43726	581.611	576.531	1009.369	1164.945	.58414	108.4946	1837.96	60.266
7	15.8915	88.12472	581.611	574.949	997.956	1155.070	.57891	108.7158	1837.96	60.053
8	16.1606	102.81217	581.611	573.191	986.840	1145.480	.57384	108.9163	1837.96	59.850
9	16.4250	117.49962	581.611	571.265	976.041	1136.189	.56894	109.0996	1837.96	59.660

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	83.9207	1731.18	1.685	.00000	573.697	760.708	.38235	92.3956	1773.20	40.144
2	84.6066	1732.62	2.923	.00000	586.199	746.801	.37520	92.8233	1773.12	38.885
3	85.2526	1734.23	4.129	.00000	598.369	732.737	.36797	93.2651	1773.22	37.534
4	85.8611	1735.95	5.305	.00000	610.238	718.832	.36080	93.5516	1773.48	36.108
5	86.4347	1737.69	6.454	.00000	621.835	705.410	.35389	93.8736	1773.83	34.632
6	86.9763	1739.41	7.578	.00000	633.183	692.667	.34733	94.1784	1774.25	33.124
7	87.4885	1741.07	8.680	.00000	644.303	680.692	.34116	94.4706	1774.72	31.596
8	87.9738	1742.67	9.761	.00000	655.215	669.512	.33540	94.7531	1775.22	30.052
9	88.4346	1744.21	10.823	.00000	665.935	659.118	.33005	95.0277	1775.76	28.495

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2000	0.00000	590.002	589.747	-258.339	644.082	.32634	81.1935	1727.81	-23.656
2	14.5316	14.68692	584.475	583.740	-263.554	641.149	.32504	81.1923	1725.57	-24.299
3	14.8587	29.37385	579.024	577.581	-267.195	637.700	.32345	81.1810	1723.62	-24.826
4	15.1817	44.06077	573.640	571.277	-269.572	633.824	.32161	81.1611	1721.90	-25.262
5	15.5011	58.74769	568.317	564.833	-270.996	629.621	.31959	81.1344	1720.37	-25.631
6	15.8173	73.43462	563.048	558.256	-271.684	625.168	.31742	81.1024	1718.96	-25.951
7	16.1306	88.12154	557.826	551.549	-271.780	620.511	.31514	81.0659	1717.65	-26.232
8	16.4414	102.80846	552.646	544.717	-271.379	615.681	.31276	81.0257	1716.41	-26.483
9	16.7500	117.49538	547.502	537.763	-270.541	610.697	.31029	80.9820	1715.25	-26.706

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	75.6617	1697.36	1.685	0.00000	575.725	1021.648	.51764	90.1499	1771.99	-54.737
2	75.7020	1695.39	2.873	0.00000	589.170	1033.804	.52411	90.5877	1773.86	-55.606
3	75.7435	1693.76	4.045	0.00000	602.431	1044.757	.52991	90.9915	1773.90	-56.409
4	75.7839	1692.41	5.203	0.00000	615.527	1054.734	.53519	91.3670	1774.09	-57.160
5	75.8236	1691.26	6.347	0.00000	628.477	1063.971	.54006	91.7205	1774.38	-57.873
6	75.8625	1690.26	7.480	0.00000	641.295	1072.639	.54462	92.0571	1774.74	-58.556
7	75.9004	1689.38	8.603	0.00000	653.999	1080.849	.54893	92.3800	1775.15	-59.215
8	75.9373	1688.58	9.717	0.00000	666.600	1088.679	.55304	92.6912	1775.60	-59.854

75.9730	1687.87	10.823	0.00000	679.112	1096.175	.55696	92.9921	1776.09	-80.478

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.42047	.74459	.06665	.16305	.94579	.87670	.90564	.86238
2	.44889	.72238	.06846	.15811	.94427	.88085	.90859	.86532
3	.47141	.70135	.07006	.15311	.94308	.88522	.91170	.86864
4	.48987	.68153	.07145	.14819	.94200	.88955	.91475	.87197
5	.50555	.66300	.07270	.14356	.94099	.89368	.91766	.87517
6	.51925	.64576	.07387	.13913	.94000	.89757	.92039	.87819
7	.53144	.62977	.07500	.13511	.93902	.90119	.92294	.88101
8	.54242	.61498	.07611	.13147	.93806	.90454	.92529	.88362
9	.55234	.60129	.07721	.12817	.93709	.90761	.92745	.88601

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .94111

ROTOR BLADE-ROW EFFICIENCY = .89309

STAGE WORK = 32.056 BTU PER LBM
STAGE TOTAL EFFICIENCY = .87485
STAGE STATIC EFFICIENCY = .72093
STAGE BLADE- TO JET-SPEED RATIO = .4186

** STATOR EXIT - ROTOR INLET 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2500	0.00000	572.102	571.855	1006.161	1157.437	.59854	79.4083	1727.83	60.388
2	14.6394	14.68736	572.102	571.347	980.573	1135.264	.58680	79.4661	1725.59	59.772
3	15.0161	29.37468	572.102	570.593	956.858	1114.844	.57600	79.5112	1723.63	59.192
4	15.3814	44.06202	572.102	569.615	934.740	1095.919	.56598	79.5451	1721.91	58.643
5	15.7367	58.74936	572.102	568.431	914.000	1078.284	.55666	79.5698	1720.37	58.122
6	16.0829	73.43670	572.102	567.058	894.463	1061.774	.54794	79.5867	1718.96	57.627
7	16.4209	88.12404	572.102	565.509	875.983	1046.253	.53975	79.5969	1717.64	57.155
8	16.7514	102.81138	572.102	563.794	858.434	1031.605	.53203	79.6013	1716.41	56.704
9	17.0750	117.49872	572.102	561.925	841.710	1017.731	.52473	79.6004	1715.25	56.273

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	62.9328	1629.47	1.685	-.00000	577.757	714.727	.36960	68.8791	1666.98	36.839
2	63.5339	1630.96	2.944	-.00000	593.539	690.721	.35702	69.1226	1665.99	34.114
3	64.0770	1632.38	4.163	-.00000	608.811	669.655	.34598	69.3601	1665.30	31.382
4	64.5705	1633.73	5.345	-.00000	623.625	651.224	.33632	69.5929	1664.87	28.643
5	65.0212	1635.00	6.494	-.00000	638.030	635.185	.32791	69.8221	1664.62	25.896
6	65.4346	1636.18	7.614	-.00000	652.066	621.335	.32065	70.0489	1664.53	23.145
7	65.8152	1637.27	8.707	-.00000	665.768	609.500	.31443	70.2739	1664.55	20.391
8	66.1670	1638.27	9.776	-.00000	679.167	599.531	.30920	70.4979	1664.66	17.639
9	66.4931	1639.20	10.823	-.00000	692.289	591.293	.30486	70.7213	1664.87	14.891

** STAGE EXIT 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3000	0.00000	613.132	612.867	-301.071	683.063	.35779	59.5824	1616.83	-26.163
2	14.7075	14.68610	606.340	605.571	-300.698	676.807	.35480	59.5548	1613.67	-26.407
3	15.1079	29.37219	599.668	598.158	-299.652	670.367	.35166	59.5213	1610.87	-26.609
4	15.5019	44.05829	593.101	590.634	-297.982	663.748	.34839	59.4824	1608.37	-26.771
5	15.8903	58.74438	586.627	583.003	-295.694	656.938	.34499	59.4382	1606.13	-26.894
6	16.2737	73.43048	580.236	575.268	-292.859	649.951	.34147	59.3891	1604.10	-26.979
7	16.6528	88.11657	573.918	567.434	-289.576	642.834	.33786	59.3362	1602.24	-27.036
8	17.0281	102.80266	567.664	559.503	-285.964	635.624	.33418	59.2803	1600.51	-27.072
9	17.4000	117.48875	561.465	551.478	-282.077	628.340	.33044	59.2218	1598.92	-27.089

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	54.7286	1582.19	1.685	.00000	579.779	1073.233	.56216	67.2836	1667.70	-55.171
2	54.7800	1579.67	2.886	.00000	596.301	1082.707	.56758	67.6093	1666.70	-55.976
3	54.8289	1577.51	4.066	.00000	612.532	1091.641	.57265	67.9192	1665.98	-56.745
4	54.8755	1575.66	5.228	.00000	628.507	1100.069	.57741	68.2136	1665.51	-57.483
5	54.9198	1574.09	6.373	.00000	644.255	1107.989	.58186	68.4924	1665.23	-58.191
6	54.9619	1572.74	7.503	.00000	659.802	1115.448	.58603	68.7567	1665.11	-58.874
7	55.0017	1571.56	8.620	.00000	675.172	1122.551	.58998	69.0095	1665.11	-59.537
8	55.0393	1570.52	9.727	.00000	690.387	1129.381	.59377	69.2529	1665.21	-60.185
9	55.0749	1569.61	10.823	.00000	705.465	1135.995	.59742	69.4886	1665.42	-60.820

** STAGE 2 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.55647	.66596	.10833	.13425	.91527	.89914	.91498	.85162
2	.56476	.63796	.10832	.12506	.91483	.90596	.92001	.85853
3	.57201	.61344	.10817	.11719	.91452	.91204	.92453	.86487
4	.57835	.59199	.10790	.11050	.91435	.91734	.92849	.87059
5	.58391	.57328	.10754	.10516	.91427	.92176	.93178	.87560
6	.58880	.55703	.10710	.10100	.91427	.92532	.93440	.87990
7	.59308	.54296	.10660	.09776	.91434	.92815	.93645	.88359
8	.59682	.53085	.10603	.09529	.91448	.93038	.93801	.88674
9	.60006	.52051	.10541	.09345	.91466	.93208	.93915	.88942

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .91450

ROTOR BLADE-ROW EFFICIENCY = .91957

STAGE WORK = 30.847 BTU PER LBM

STAGE TOTAL EFFICIENCY = .87380

STAGE STATIC EFFICIENCY = .70386

STAGE BLADE- TO JET-SPEED RATIO = .43227

** STATOR EXIT - ROTOR INLET 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3500	0.00000	589.792	589.537	918.977	1091.959	.58197	58.2334	1616.83	57.319
2	14.8225	14.68733	589.792	589.003	890.171	1067.829	.56897	58.2688	1613.68	56.508
3	15.2771	29.37466	589.792	588.212	863.850	1045.988	.55722	58.2935	1610.88	55.748
4	15.7156	44.06200	589.792	587.192	839.576	1026.032	.54649	58.3088	1608.37	55.031
5	16.1401	58.74933	589.792	585.964	817.000	1007.643	.53660	58.3157	1606.13	54.351
6	16.5521	73.43666	589.792	584.547	795.852	990.573	.52743	58.3150	1604.09	53.703
7	16.9528	88.12399	589.792	582.955	775.926	974.636	.51886	58.3079	1602.23	53.082
8	17.3435	102.81133	589.792	581.203	757.061	959.685	.51083	58.2952	1600.51	52.486
9	17.7250	117.49868	589.792	579.301	739.122	945.598	.50327	58.2777	1598.91	51.912

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	46.6901	1528.31	1.685	-.00000	581.806	679.366	.36207	50.9339	1562.58	29.766
2	47.1643	1529.03	2.964	-.00000	600.967	656.882	.35001	51.1617	1561.06	26.151
3	47.5834	1529.65	4.195	-.00000	619.393	638.446	.34012	51.3852	1559.91	22.567
4	47.9569	1530.22	5.382	-.00000	637.173	623.555	.33212	51.6056	1559.08	19.019

5	48.2919	1530.75	6.532	-.00000	654.383	611.800	.32580	51.8239	1558.54	15.510
6	48.5940	1531.25	7.647	-.00000	671.087	602.844	.32098	52.0411	1558.23	12.048
7	48.8679	1531.71	8.732	-.00000	687.335	596.408	.31751	52.2579	1558.11	8.641
8	49.1173	1532.13	9.790	-.00000	703.174	592.249	.31525	52.4751	1558.17	5.297
9	49.3453	1532.53	10.823	-.00000	718.642	590.147	.31409	52.6933	1558.39	2.025

** STAGE EXIT 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4000	0.00000	662.420	662.134	-331.594	740.781	.40214	43.4670	1508.58	-26.602
2	14.8858	14.68720	654.323	653.485	-328.690	732.240	.39791	43.4332	1504.60	-26.701
3	15.3609	29.37440	646.405	644.758	-325.019	723.517	.39352	43.3923	1501.07	-26.752
4	15.8267	44.06160	638.642	635.957	-320.785	714.680	.38901	43.3456	1497.93	-26.767
5	16.2842	58.74879	631.018	627.083	-316.197	705.807	.38442	43.2948	1495.13	-26.759
6	16.7344	73.43599	623.514	618.138	-311.379	696.941	.37980	43.2408	1492.61	-26.736
7	17.1783	88.12318	616.116	609.123	-306.415	688.105	.37516	43.1845	1490.34	-26.704
8	17.6166	102.81038	608.811	600.039	-301.359	679.314	.37051	43.1265	1488.26	-26.667
9	18.0500	117.49757	601.587	590.886	-296.243	670.572	.36587	43.0670	1486.38	-26.627

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	39.0393	1467.39	1.685	.00000	583.833	1129.960	.61341	49.9037	1563.25	-54.122
2	39.0955	1464.35	2.901	.00000	603.531	1138.936	.61892	50.1906	1561.74	-54.970
3	39.1478	1461.77	4.091	.00000	622.794	1147.253	.62399	50.4580	1560.59	-55.774
4	39.1964	1459.58	5.257	.00000	641.677	1155.075	.62872	50.7097	1559.75	-56.545
5	39.2417	1457.73	6.402	.00000	660.225	1162.576	.63320	50.9497	1559.20	-57.290
6	39.2839	1456.15	7.529	.00000	678.480	1169.868	.63752	51.1809	1558.90	-58.016
7	39.3232	1454.79	8.641	.00000	696.476	1177.025	.64172	51.4055	1558.80	-58.727
8	39.3599	1453.62	9.738	.00000	714.247	1184.105	.64584	51.6253	1558.89	-59.425
9	39.3942	1452.62	10.823	.00000	731.819	1191.142	.64990	51.8412	1559.14	-60.112

** STAGE 3 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.62554	.60123	.11687	.10091	.90870	.92500	.92711	.86228
2	.63382	.57675	.11582	.09357	.90891	.93046	.93180	.86976
3	.64089	.55650	.11464	.08812	.90927	.93473	.93546	.87667
4	.64691	.53984	.11337	.08405	.90977	.93802	.93825	.88139
5	.65196	.52624	.11198	.08109	.91038	.94055	.94035	.88491

6	.65614	.51531	.11050	.07881	.91112	.94244	.94187	.89975
7	.65956	.50671	.10895	.07724	.91194	.94379	.94288	.89297
8	.66232	.50017	.10735	.07621	.91283	.94467	.94343	.89563
9	.66449	.49545	.10571	.07564	.91378	.94513	.94356	.89778

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .91068

ROTOR BLADE-ROW EFFICIENCY = .93872

STAGE WORK = 29.637 BTU PER LBM

STAGE TOTAL EFFICIENCY = .88393

STAGE STATIC EFFICIENCY = .68308

STAGE BLADE- TO JET-SPEED RATIO = .44519

** STATOR EXIT - ROTOR INLET 4 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4500	0.00000	658.446	658.162	990.375	1189.283	.66040	42.2945	1508.59	56.394
2	15.0124	14.68723	658.446	657.547	953.310	1158.599	.64304	42.3272	1504.61	55.404
3	15.5482	29.37446	658.446	656.643	920.019	1131.365	.62766	42.3469	1501.08	54.484
4	16.0613	44.06169	658.446	655.485	889.762	1106.900	.61388	42.3560	1497.93	53.621
5	16.5547	58.74892	658.446	654.102	862.000	1084.710	.60139	42.3565	1495.13	52.808
6	17.0310	73.43615	658.446	652.519	836.321	1064.417	.58998	42.3498	1492.61	52.038
7	17.4920	88.12338	658.446	650.753	812.400	1045.727	.57948	42.3372	1490.33	51.304
8	17.9396	102.81061	658.446	648.820	789.982	1028.408	.56976	42.3198	1488.26	50.603
9	18.3750	117.49784	658.446	646.734	768.855	1012.269	.56070	42.2981	1486.38	49.931

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	31.8636	1402.40	1.685	-.00000	585.861	772.776	.42912	36.0016	1447.23	31.575
2	32.3442	1403.82	2.994	-.00000	608.661	743.192	.41248	36.2118	1445.29	27.661
3	32.7597	1404.98	4.241	-.00000	630.385	719.333	.39907	36.4165	1443.82	23.801
4	33.1227	1405.95	5.436	-.00000	651.188	700.335	.38840	36.6176	1442.77	20.000
5	33.4428	1406.79	6.585	-.00000	671.195	685.535	.38008	36.8165	1442.08	16.262
6	33.7271	1407.55	7.694	-.00000	690.504	674.399	.37380	37.0143	1441.69	12.597
7	33.9814	1408.23	8.767	-.00000	709.197	666.485	.36933	37.2118	1441.58	9.012
8	34.2101	1408.86	9.809	-.00000	727.342	661.419	.36644	37.4099	1441.76	5.514
9	34.4168	1409.44	10.823	-.00000	744.996	658.878	.36496	37.6090	1442.04	2.113

** STAGE EXIT 4 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.5000	0.00000	734.209	733.891	-191.110	758.673	.42661	31.3721	1404.22	-14.596
2	15.0656	14.68726	724.781	723.843	-195.288	750.630	.42273	31.3236	1399.17	-15.099
3	15.6164	29.37451	715.602	713.758	-197.845	742.448	.41867	31.2720	1394.69	-15.493
4	16.1543	44.06177	706.637	703.634	-199.135	734.160	.41446	31.2181	1390.72	-15.802
5	16.6809	58.74903	697.861	693.671	-199.473	725.809	.41015	31.1622	1387.18	-16.048
6	17.1976	73.43629	689.249	683.267	-199.059	717.418	.40574	31.1050	1384.03	-16.243
7	17.7057	88.12354	680.781	673.020	-198.024	708.997	.40126	31.0465	1381.21	-16.396
8	18.2061	102.81080	672.440	662.730	-196.487	700.558	.39673	30.9872	1378.68	-16.514
9	18.7000	117.49806	664.209	652.394	-194.552	692.115	.39215	30.9272	1376.41	-16.605

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	27.7883	1360.35	1.685	.00000	587.888	1070.467	.60194	35.2488	1447.70	-46.708
2	27.8053	1359.22	2.915	.00000	610.821	1084.029	.61049	35.5038	1445.79	-48.078
3	27.8220	1352.68	4.114	.00000	633.152	1096.650	.61841	35.7451	1444.35	-49.340
4	27.8380	1349.64	5.284	.00000	654.959	1108.518	.62580	35.9748	1443.30	-50.517
5	27.8533	1347.03	6.430	-.00000	676.309	1119.823	.63280	36.1957	1442.62	-51.627
6	27.8679	1344.80	7.554	-.00000	697.259	1130.686	.63947	36.4094	1442.25	-52.682
7	27.8818	1342.89	8.660	-.00000	717.858	1141.185	.64586	36.6170	1442.16	-53.690
8	27.8950	1341.27	9.748	-.00000	738.149	1151.399	.65204	36.8197	1442.32	-54.660
9	27.9074	1339.90	10.823	-.00000	758.173	1161.403	.65804	37.0188	1442.71	-55.598

** STAGE 4 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.62288	.72191	.11238	.10694	.91512	.92346	.92676	.85203
2	.63200	.68558	.11077	.09793	.91550	.92992	.93180	.86110
3	.63951	.65594	.10902	.09076	.91608	.93531	.93605	.86908
4	.64566	.63178	.10717	.08506	.91684	.93975	.93957	.87604
5	.65069	.61218	.10527	.08056	.91770	.94335	.94241	.88208
6	.65476	.59645	.10334	.07708	.91864	.94616	.94459	.88724
7	.65802	.58403	.10141	.07456	.91964	.94822	.94611	.89156
8	.66055	.57445	.09949	.07284	.92069	.94959	.94702	.89508
9	.66244	.56731	.09757	.07178	.92177	.95036	.94736	.89788

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY =	.91794	
ROTOR BLADE-ROW EFFICIENCY =	.94115	
STAGE WORK =	28.427	BTU PER LBM
STAGE TOTAL EFFICIENCY =	.87964	
STAGE STATIC EFFICIENCY =	.86529	
STAGE BLADE- TO JET-SPEED RATIO =	.45956	

*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

STAGE NUMBER	STATOR BLADE-ROW EFFICIENCY	ROTOR BLADE-ROW EFFICIENCY	STAGE WORK (BTU/LBM)	STAGE TOTAL EFFICIENCY	STAGE STATIC EFFICIENCY	STAGE BLADE- TO JET-SPEED RATIO
1	.94111	.89309	32.056	.87485	.72093	.41861
2	.91450	.91957	30.847	.87380	.70386	.43227
3	.91068	.93872	29.637	.88393	.68308	.44519
4	.91794	.94115	28.427	.87964	.66529	.45956

SPOOL WORK = 120.958 BTU PER LBM
SPOOL POWER = 20110.04 HP
SPOOL TOTAL- TO TOTAL-PRESSURE RATIO = 3.52111
SPOOL TOTAL- TO STATIC-PRESSURE RATIO = 3.93915
SPOOL TOTAL EFFICIENCY = .89176
SPOOL STATIC EFFICIENCY = .82993
SPOOL BLADE- TO JET-SPEED RATIO = .23999

PROGRAM TD2 - AERODYNAMIC CALCULATIONS FOR THE DESIGN OF AXIAL TURBINES

OPTIMIZED THREE STAGE VERSION OF NASA LP SPOOL AT REDUCED TIP DIAMETER

*** GENERAL INPUT DATA ***

NUMBER OF SPOOLS = 1
NUMBER OF SETS OF ANALYSIS VARIABLES = 1
NUMBER OF STREAMLINES = 9

GAS CONSTANT = 53.35000 LBF FT/LBM DEG R
INLET MASS FLOW = 117.50000 LBM/SEC

* TABULAR INLET SPECIFICATIONS *

RADIAL COORDINATE (IN)	TOTAL TEMPERATURE (DEG R)	TOTAL PRESSURE (PSI)	ABSOLUTE FLOW ANGLE (DEG)
14.1000	1837.96	108.2258	3.213
14.4048	1837.96	108.7913	4.376
14.6865	1837.96	109.2293	5.153
14.9511	1837.96	109.5756	5.682
15.2020	1837.96	109.8619	6.036
15.4410	1837.96	110.1073	6.260
15.6697	1837.96	110.3232	6.382
15.8891	1837.96	110.5164	6.421
16.1000	1837.96	110.6916	6.392

*** SPOOL INPUT DATA ***

** DESIGN REQUIREMENTS **

ROTATIVE SPEED = 4646.0 RPM
POWER OUTPUT = 20110.00 HP

** ANALYSIS VARIABLES **

NUMBER OF STAGES = 3

* POWER-OUTPUT SPLIT *

STAGE NUMBER	FRACTION OF SPOOL POWER OUTPUT
1	.33333
2	.33333
3	.33333

* SPECIFIC-HEAT SPECIFICATION *

DESIGN STATION NUMBER	SPECIFIC HEAT (BTU/LBM DEG R)
1	.27500
2	.27500
3	.27100
4	.27100
5	.26700
6	.26700
7	.26200

* ANNULUS SPECIFICATION *

STATION NUMBER	AXIAL POSITION (IN)	HUB RADIUS (IN)	CASING RADIUS (IN)
1	7.5000	14.0750	15.6667
2	9.0000	14.1000	16.1000
3	11.0000	14.1667	16.5333

4	13.0000	14.2334	16.9667
5	15.0000	14.3000	17.4000
6	17.0000	14.3667	17.8333
7	19.0000	14.4334	18.2667
8	21.0000	14.5000	18.7000
9	23.0000	14.5667	19.1333

* BLADE-ROW EXIT CONDITIONS *

STATOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1200.0000 FEET PER SEC

ROTOR 1

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
15.0000	-200.00

STATOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1090.0000 FEET PER SEC

ROTOR 2

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
16.0000	-200.00

STATOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	0.00

WHIRL VELOCITY AT THE MEAN STREAMLINE = 1190.0000 FEET PER SEC

ROTOR 3

RADIAL POSITION (IN)	MERIDIONAL VELOCITY GRADIENT (PER SEC)
17.0000	-200.00

* BASIC INTERNAL LOSS CORRELATION *

$$Y = \frac{\text{TAN(INLET ANGLE)} + \text{TAN(EXIT ANGLE)}}{.60000000 + .80000000 * \text{COS(EXIT ANGLE)}} * \text{TIMES} \begin{cases} .03000000 + .15755500 * (\text{V RATIO})^{3.60} & \text{IF (V RATIO) .LT. .60000000} \\ .05500000 + .15000000 * ((\text{V RATIO}) - .600)) & \text{IF (V RATIO) .GE. .60000000} \end{cases}$$

THE PRESSURE-LOSS COEFFICIENT COMPUTED IN THIS MANNER MAY NOT EXCEED A LIMIT OF 2.00000000

*** OUTPUT OF SPOOL DESIGN ANALYSIS ***

** STATOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1000	0.00000	516.977	516.816	28.833	517.781	.25392	108.2196	1837.96	3.213
2	14.3888	14.68749	546.305	545.414	41.028	547.844	.26884	108.7574	1837.96	4.323
3	14.6595	29.37498	567.373	565.214	50.242	569.593	.27965	109.1855	1837.96	5.088
4	14.9174	44.06247	582.662	578.749	56.951	585.439	.28753	109.5322	1837.96	5.623
5	15.1658	58.74997	593.931	587.817	61.703	597.127	.29335	109.8224	1837.96	5.992
6	15.4068	73.43746	602.346	593.618	64.864	605.828	.29769	110.0745	1837.96	6.234
7	15.6422	88.12495	608.597	596.871	66.683	612.240	.30089	110.2998	1837.96	6.372
8	15.8729	102.81245	613.106	598.019	67.339	616.793	.30316	110.5065	1837.96	6.421
9	16.1000	117.49994	616.128	597.343	66.959	619.756	.30464	110.6931	1837.96	6.392

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)
1	103.6942	1818.49	1.433	.01111
2	103.6758	1816.16	3.274	.00317
3	103.6787	1814.40	5.000	-.00427
4	103.7026	1813.07	6.644	-.01136
5	103.7466	1812.07	8.228	-.01819
6	103.8100	1811.31	9.765	-.02482
7	103.8917	1810.74	11.266	-.03129
8	103.9910	1810.33	12.737	-.03763
9	104.1071	1810.07	14.185	-.04387

** STATOR EXIT - ROTOR INLET 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.1667	0.00000	591.241	590.913	1266.420	1397.636	.70971	105.9770	1837.96	64.986
2	14.4905	14.68738	591.241	590.248	1249.915	1382.698	.70150	106.5245	1837.96	64.722
3	14.8045	29.37476	591.241	589.261	1233.167	1367.577	.69321	106.9728	1837.96	64.459

4	14.1099	44.06214	591.241	587.980	1216.424	1352.499	.68497	107.3436	1837.96	64.202
5	14.4074	58.74952	591.241	586.425	1200.000	1337.747	.67693	107.6600	1837.96	63.956
6	14.6978	73.43691	591.241	584.618	1184.094	1323.497	.66918	107.9385	1837.96	63.723
7	14.9819	88.12429	591.241	582.575	1168.808	1309.832	.66176	108.1896	1837.96	63.507
8	15.2603	102.81167	591.241	580.309	1154.137	1296.765	.65469	108.4199	1837.96	63.306
9	15.5333	117.49905	591.241	577.833	1140.085	1284.274	.64794	108.6331	1837.96	63.123

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	76.7869	1696.10	1.910	0.00000	574.374	910.214	.46220	88.3103	1756.27	49.507
2	77.7356	1699.12	3.321	.00000	587.502	887.895	.45047	88.7871	1756.37	48.297
3	78.6208	1702.14	4.690	.00001	600.235	866.124	.43983	89.2110	1756.62	47.246
4	79.4486	1705.12	6.021	.00001	612.614	845.676	.42799	89.5945	1756.98	45.761
5	80.2243	1708.00	7.318	.00001	624.676	824.963	.41745	89.9494	1757.42	44.453
6	80.9533	1710.75	8.584	.00002	636.453	805.901	.40747	90.2843	1757.92	43.130
7	81.6400	1713.37	9.822	.00002	647.972	787.926	.39808	90.6044	1758.45	41.797
8	82.2886	1715.84	11.035	.00002	659.256	771.022	.38926	90.9133	1759.01	40.457
9	82.9026	1718.18	12.226	.00002	670.326	755.142	.38098	91.2129	1759.59	39.110

** STAGE EXIT 1 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.2334	0.00000	600.143	599.810	-408.802	726.148	.37188	73.7778	1698.18	-34.276
2	14.5905	14.68766	594.192	593.232	-412.050	723.083	.37054	73.8383	1695.77	-34.783
3	14.9420	29.37533	588.333	586.452	-413.794	719.279	.36879	73.8812	1693.62	-35.206
4	15.2886	44.06299	582.556	579.479	-414.328	714.870	.36669	73.9090	1691.68	-35.565
5	15.6309	58.75065	576.851	572.323	-413.950	710.008	.36434	73.9247	1689.91	-35.877
6	15.9694	73.43832	571.209	564.992	-412.873	704.880	.36179	73.9306	1688.25	-36.158
7	16.3046	88.12598	565.623	557.492	-411.238	699.318	.35908	73.9283	1686.68	-36.415
8	16.6369	102.81365	560.085	549.830	-409.140	693.406	.35625	73.9188	1685.19	-36.654
9	16.9667	117.50131	554.588	542.011	-406.638	687.692	.35330	73.9027	1683.77	-36.879

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	67.3269	1659.32	1.909	-.00002	577.079	1154.186	.59109	84.5006	1757.49	-58.684
2	67.4258	1657.24	3.256	-.00002	591.555	1166.313	.59768	85.0444	1757.48	-59.413
3	67.5223	1655.49	4.583	-.00002	605.807	1177.168	.60356	85.5464	1757.61	-60.093
4	67.6159	1654.02	5.892	-.00002	619.861	1186.979	.60885	86.0127	1757.85	-60.737
5	67.7065	1652.76	7.184	-.00002	633.739	1195.997	.61372	86.4508	1758.17	-61.353
6	67.7941	1651.64	8.461	-.00002	647.464	1204.406	.61828	86.8665	1758.54	-61.949
7	67.8786	1650.64	9.726	-.00002	661.054	1212.327	.62250	87.2638	1758.95	-62.530
8	67.9601	1649.74	10.981	-.00002	674.526	1219.847	.62653	87.6453	1759.40	-63.098

68.0386	1648.92	12.226	-.00002	687.898	1227.017	.63037	88.0126	1759.87	-83.655

** STAGE 1 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.37047	.78863	.07653	.23081	.94139	.83982	.87479	.82912
2	.39621	.76128	.07723	.22128	.94062	.84661	.87981	.83482
3	.41650	.73577	.07786	.21222	.94002	.85330	.88479	.84054
4	.43286	.71196	.07838	.20368	.93947	.85973	.88960	.84606
5	.44637	.68977	.07882	.19573	.93897	.86582	.89416	.85133
6	.45775	.66913	.07920	.18840	.93849	.87154	.89846	.85630
7	.46742	.64993	.07955	.18169	.93803	.87690	.90250	.86099
8	.47564	.63206	.07986	.17556	.93760	.88190	.90628	.86539
9	.48257	.61543	.08014	.16998	.93719	.88655	.90981	.86952

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .93906

ROTOR BLADE-ROW EFFICIENCY = .86488

STAGE WORK = 40.322 BTU PER LBM
STAGE TOTAL EFFICIENCY = .85071
STAGE STATIC EFFICIENCY = .70389
STAGE BLADE- TO JET-SPEED RATIO = .37115

** STATOR EXIT - ROTOR INLET 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3000	0.00000	595.647	595.316	1203.155	1342.527	.70788	71.1599	1698.19	63.674
2	14.7352	14.68682	595.647	594.625	1171.192	1313.958	.69211	71.3069	1695.78	63.083
3	15.1531	29.37364	595.647	593.603	1141.965	1287.975	.67782	71.4310	1693.63	62.534
4	15.5561	44.06046	595.647	592.287	1115.016	1264.143	.66474	71.5354	1691.69	62.023
5	15.9459	58.74728	595.647	590.705	1090.000	1242.133	.65269	71.6235	1689.91	61.545
6	16.3240	73.43410	595.647	588.881	1066.641	1221.687	.64153	71.6978	1688.25	61.097
7	16.6917	88.12092	595.647	586.836	1044.716	1202.591	.63113	71.7602	1686.68	60.676
8	17.0501	102.80774	595.647	584.584	1024.038	1184.673	.62140	71.8123	1685.19	60.280
9	17.4000	117.49455	595.647	582.141	1004.452	1167.783	.61225	71.8551	1683.78	59.905

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	51.5733	1565.37	1.909	.00002	579.779	862.203	.45462	59.0848	1620.15	46.319
2	52.3897	1568.55	3.357	.00002	597.423	827.047	.43564	59.3670	1618.96	43.977
3	53.1221	1571.38	4.748	.00002	614.368	795.709	.41875	59.6357	1618.04	41.631
4	53.7839	1573.92	6.088	.00001	630.706	767.692	.40368	59.8936	1617.35	39.273
5	54.3856	1576.20	7.386	.00001	646.510	742.616	.39021	60.1430	1616.84	36.899
6	54.9358	1578.26	8.644	.00001	661.840	720.180	.37818	60.3856	1616.48	34.505
7	55.4412	1580.10	9.867	.00001	676.748	700.139	.36744	60.6229	1616.23	32.089
8	55.9074	1581.76	11.050	.00000	691.278	682.294	.35789	60.8560	1616.07	29.650
9	56.3392	1583.27	12.224	.00000	705.465	666.474	.34942	61.0859	1616.00	27.185

** STAGE EXIT 2 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.3667	0.00000	662.619	662.251	-485.754	821.597	.44097	47.9696	1553.59	-36.260
2	14.6282	14.68622	654.927	653.852	-482.524	813.485	.43705	48.0001	1549.62	-36.426
3	15.2795	29.37244	647.405	645.296	-478.542	805.069	.43290	48.0165	1546.01	-36.560
4	15.7218	44.05866	640.034	636.594	-473.890	796.376	.42855	48.0201	1542.71	-36.665
5	16.1563	58.74488	632.793	627.754	-468.556	787.383	.42398	48.0116	1539.70	-36.738
6	16.5838	73.43109	625.667	618.783	-462.549	778.082	.41921	47.9916	1536.92	-36.779
7	17.0053	88.11730	618.642	609.685	-456.015	768.549	.41428	47.9620	1534.35	-36.795
8	17.4216	102.80351	611.704	600.465	-449.111	758.869	.40924	47.9248	1531.95	-36.794
9	17.8333	117.48972	604.843	591.126	-441.924	749.087	.40412	47.8812	1529.70	-36.782

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	42.1781	1503.10	1.910	0.00000	582.483	1257.058	.67469	56.6386	1621.30	-58.203
2	42.2996	1500.12	3.283	.00000	601.196	1266.245	.68029	57.0713	1620.05	-58.896
3	42.4136	1497.53	4.626	.00001	619.493	1274.682	.68542	57.4751	1619.06	-59.558
4	42.5206	1495.28	5.943	.00001	637.426	1282.445	.69011	57.8519	1618.29	-60.195
5	42.6211	1493.33	7.235	.00001	655.039	1289.533	.69438	58.2019	1617.71	-60.808
6	42.7153	1491.64	8.508	.00001	672.374	1295.959	.69823	58.5253	1617.26	-61.400
7	42.8038	1490.17	9.762	.00002	689.464	1301.860	.70176	58.8262	1616.94	-61.976
8	42.8868	1488.86	11.000	.00002	706.341	1307.383	.70504	59.1092	1616.73	-62.540
9	42.9646	1487.73	12.226	.00002	723.033	1312.615	.70813	59.3771	1616.60	-63.096

** STAGE 2 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.54088	.68589	.13363	.17678	.90316	.87863	.89045	.81942
2	.55031	.65315	.13378	.16297	.90227	.88783	.89828	.82914
3	.55846	.62424	.13380	.15109	.90154	.89609	.90536	.83803
4	.56550	.59862	.13370	.14079	.90097	.90342	.91167	.84611
5	.57160	.57588	.13350	.13231	.90052	.90973	.91712	.85329
6	.57691	.55571	.13322	.12562	.90017	.91494	.92165	.85953
7	.58151	.53780	.13287	.12032	.89991	.91922	.92538	.86493
8	.58548	.52188	.13246	.11614	.89972	.92274	.92844	.86964
9	.58889	.50775	.13198	.11287	.89961	.92560	.93094	.87374

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .90081

ROTOR BLADE-ROW EFFICIENCY = .90701

STAGE WORK = 40.322 BTU PER LBM

STAGE TOTAL EFFICIENCY = .85090

STAGE STATIC EFFICIENCY = .67721

STAGE BLADE- TO JET-SPEED RATIO = .37628

** STATOR EXIT - ROTOR INLET 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.4334	0.00000	715.464	715.067	1351.494	1529.191	.85698	45.8215	1553.59	62.117
2	14.9945	14.68621	715.464	714.191	1304.022	1487.401	.83192	45.9593	1549.62	61.291
3	15.5243	29.37242	715.464	712.908	1262.004	1450.705	.81009	46.0709	1546.01	60.538
4	16.0279	44.05863	715.464	711.279	1224.281	1418.010	.79077	46.1606	1542.71	59.844
5	16.5094	58.74484	715.464	709.350	1190.000	1388.520	.77345	46.2316	1539.70	59.201
6	16.9717	73.43105	715.464	707.156	1158.524	1361.641	.75773	46.2863	1536.92	58.600
7	17.4174	88.11726	715.464	704.725	1129.382	1336.934	.74334	46.3271	1534.35	58.036
8	17.8485	102.80347	715.464	702.079	1102.219	1314.069	.73007	46.3562	1531.95	57.504
9	18.2667	117.48969	715.464	699.239	1076.750	1292.780	.71775	46.3756	1529.70	57.000

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	29.7777	1378.68	1.909	-.00002	585.188	1048.386	.58753	36.0593	1460.89	46.981
2	29.6054	1384.14	3.419	-.00002	607.937	998.210	.55831	36.3141	1458.67	44.264
3	30.3251	1388.59	4.845	-.00002	629.416	955.016	.53329	36.5526	1456.81	41.584
4	30.9586	1392.31	6.200	-.00002	649.836	917.538	.51168	36.7787	1455.28	38.925

5	31.5218	1395.49	7.496	-.00002	669.358	884.850	.49289	36.9948	1454.05	36.278
6	32.0265	1398.24	8.749	-.00002	688.101	856.263	.47649	37.2030	1453.08	33.633
7	32.4821	1400.66	9.940	-.00002	706.179	831.262	.46218	37.4051	1452.34	30.986
8	32.8958	1402.79	11.100	-.00002	723.651	809.446	.44971	37.6027	1451.80	28.334
9	33.2733	1404.69	12.226	-.00002	740.605	790.495	.43888	37.7970	1451.43	25.675

** STAGE EXIT 3 **

STREAMLINE NUMBER	RADIAL POSITION (IN)	MASS-FLOW FUNCTION (LBM/SEC)	MERIDIONAL VELOCITY (FPS)	AXIAL VELOCITY (FPS)	WHIRL VELOCITY (FPS)	ABSOLUTE VELOCITY (FPS)	ABSOLUTE MACH NUMBER	ABSOLUTE TOTAL PRESSURE (PSI)	ABSOLUTE TOTAL TEMPERATURE (DEG R)	ABSOLUTE FLOW ANGLE (DEG)
1	14.5000	0.00000	784.430	783.995	-308.573	842.940	.47521	29.8333	1407.60	-21.484
2	15.0693	14.68619	774.942	773.651	-314.189	836.211	.47230	29.8277	1401.68	-22.103
3	15.6224	29.37238	765.724	763.186	-317.332	828.874	.46893	29.8125	1396.30	-22.577
4	16.1614	44.05857	756.740	752.619	-318.549	821.054	.46518	29.7888	1391.39	-22.941
5	16.6881	58.74476	747.962	741.928	-318.338	812.888	.46116	29.7585	1386.89	-23.223
6	17.2040	73.43095	739.363	731.146	-317.037	804.467	.45691	29.7226	1382.76	-23.442
7	17.7106	88.11714	730.920	720.268	-314.872	795.857	.45248	29.6822	1378.96	-23.613
8	18.2089	102.80333	722.615	709.295	-312.038	787.109	.44792	29.6380	1375.45	-23.746
9	18.7000	117.48952	714.430	698.232	-308.648	778.251	.44325	29.5907	1372.19	-23.847

STREAMLINE NUMBER	STATIC PRESSURE (PSI)	STATIC TEMPERATURE (DEG R)	STREAMLINE SLOPE ANGLE (DEG)	STREAMLINE CURVATURE (PER IN)	BLADE VELOCITY (FPS)	RELATIVE VELOCITY (FPS)	RELATIVE MACH NUMBER	RELATIVE TOTAL PRESSURE (PSI)	RELATIVE TOTAL TEMPERATURE (DEG R)	RELATIVE FLOW ANGLE (DEG)
1	25.6791	1353.44	1.909	.00002	587.868	1191.206	.67154	34.4492	1461.60	-48.829
2	25.7205	1348.38	3.307	.00002	610.970	1206.836	.68163	34.8010	1459.40	-50.096
3	25.7605	1343.93	4.665	.00002	633.394	1220.744	.69062	35.1251	1457.52	-51.245
4	25.7988	1340.00	5.989	.00002	655.247	1233.262	.69873	35.4254	1455.93	-52.301
5	25.8354	1336.52	7.283	.00001	676.602	1244.730	.70614	35.7064	1454.62	-53.280
6	25.8700	1333.43	8.550	.00001	697.520	1255.378	.71301	35.9715	1453.58	-54.221
7	25.9028	1330.68	9.794	.00001	718.058	1265.381	.71943	36.2234	1452.73	-55.112
8	25.9338	1328.22	11.018	.00000	738.261	1274.873	.72550	36.4644	1452.11	-55.966
9	25.9630	1326.02	12.224	-.00000	758.173	1283.945	.73127	36.6959	1451.68	-56.795

** STAGE 3 PERFORMANCE **

STREAMLINE NUMBER	STATOR REACTION	ROTOR REACTION	STATOR PRESSURE LOSS COEFFICIENT	ROTOR PRESSURE LOSS COEFFICIENT	STATOR BLADE ROW EFFICIENCY	ROTOR BLADE ROW EFFICIENCY	ROTOR ISENTROPIC EFFICIENCY	STAGE ISENTROPIC EFFICIENCY
1	.53728	.88010	.12604	.19074	.91560	.87391	.89266	.81126
2	.54692	.82713	.12480	.17367	.91509	.88473	.90058	.82285
3	.55495	.78232	.12357	.15957	.91475	.89425	.90766	.83325
4	.56162	.74399	.12233	.14779	.91457	.90261	.91401	.84262
5	.56707	.71088	.12101	.13786	.91456	.91000	.91969	.85119

6	.57143	.68208	.11960	.12942	.91471	.91653	.92476	.85886
7	.57486	.65693	.11811	.12224	.91501	.92227	.92925	.86589
8	.57750	.63492	.11656	.11614	.91541	.92729	.93320	.87226
9	.57944	.61568	.11496	.11097	.91590	.93165	.93664	.87800

* MASS-AVERAGED QUANTITIES *

STATOR BLADE-ROW EFFICIENCY = .91498

ROTOR BLADE-ROW EFFICIENCY = .90756

STAGE WORK = 40.322 BTU PER LBM
STAGE TOTAL EFFICIENCY = .84891
STAGE STATIC EFFICIENCY = .66738
STAGE BLADE- TO JET-SPEED RATIO = .38593

*** SPOOL PERFORMANCE SUMMARY (MASS-AVERAGED QUANTITIES) ***

STAGE NUMBER	STATOR BLADE-ROW EFFICIENCY	ROTOR BLADE-ROW EFFICIENCY	STAGE WORK (BTU/LBM)	STAGE TOTAL EFFICIENCY	STAGE STATIC EFFICIENCY	STAGE BLADE- TO JET-SPEED RATIO
1	.93906	.86488	40.322	.85071	.70389	.37115
2	.90081	.90701	40.322	.85090	.67721	.37628
3	.91498	.90756	40.322	.84891	.66738	.38593

SPOOL WORK = 120.967 BTU PER LBM
SPOOL POWER = 20110.00 HP
SPOOL TOTAL- TO TOTAL-PRESSURE RATIO = 3.68842
SPOOL TOTAL- TO STATIC-PRESSURE RATIO = 4.24710
SPOOL TOTAL EFFICIENCY = .86487
SPOOL STATIC EFFICIENCY = .79387
SPOOL BLADE- TO JET-SPEED RATIO = .23527