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**DESIGN COMPARISON OF CESIUM AND POTASSIUM VAPOR
TURBINE-GENERATOR UNITS FOR SPACE POWER PLANTS**

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REACTOR DIVISION

DESIGN COMPARISON OF CESIUM AND POTASSIUM VAPOR
TURBINE-GENERATOR UNITS FOR SPACE POWER PLANTS

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FEBRUARY 1969

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FOREWORD

This report summarizes design studies of turbine generator units designed as part of an analytical comparison of cesium and potassium as working fluids for Rankine cycle space power plants. The work was conducted by the Oak Ridge National Laboratory for NASA under AEC Interagency Agreement 40-98-66, NASA Order W-12,353 under the technical management of A. P. Fraas of the Oak Ridge National Laboratory. Project management for NASA was performed by S. V. Manson of NASA Headquarters.

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DESIGN COMPARISON OF CESIUM AND POTASSIUM VAPOR TURBINE-GENERATOR UNITS FOR SPACE POWER PLANTS

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Abstract

The first phase of the study comparing cesium and potassium as working fluids for 300 kw electrical output power plants was concerned with a review of the literature and operating experience both with all sorts of small turbines and with rotating machinery in high temperature systems. From this review a basic set of design precepts was developed to provide a self-consistent set of bases for the study. The next phase of the work entailed a parametric study to determine the effects on turbine efficiency, size, and other key parameters of variations in the number of stages, the rpm, the turbine inlet and exhaust temperatures, and effects of various losses such as aerodynamic, seal leakage, moisture churning, and bleed-off for regenerative feed heating. On the basis of this work a two-stage and a three-stage cesium turbine and a five-stage and an eight-stage potassium turbine were chosen as reference designs for detailed analytical and layout studies. Layouts were prepared and then analyses were made of the major problems including creep stresses in the turbine rotors, temperature distribution and thermal stresses in the turbine rotors, the dynamics of the bearings and rotors, and moisture formation, deposition, and possible turbine bucket erosion. The results indicate that the two working fluids yield essentially the same overall thermal efficiency, but that cesium gives a lighter and simpler turbine-generator unit.

INTRODUCTION

A number of authorities have pointed out that the thermodynamic properties of cesium afford the turbine designer some degrees of freedom that are not available with potassium, and that these may make possible lighter, simpler, more reliable turbines. The problems involved have been examined by a number of organizations.¹⁻³ Some have concluded that there would be a major advantage to the use of cesium. The Oak Ridge National Laboratory was asked by NASA to undertake a comparative study of the two systems with the objective of highlighting the principal

differences that result from the use of one fluid or the other, and the principal advantages and disadvantages of each from the standpoint of the design and development of the individual components and the complete integrated systems (AEC Interagency Agreement 40-98-66, NASA Order W-12,353).

This report summarizes the analytical and layout work on which the reference designs for the turbine-generator units were based. In view of the fact that there are over twenty independent design parameters that affect the performance of a turbine-generator, it is difficult indeed to establish an "optimum" design. The matter is rendered even more difficult by the fact that both fabricability and reliability must be considered, and the influence of the design parameters on these considerations are subtle and difficult to evaluate. Thus this study has been less concerned with the development of an "optimum" design than with a critical comparison of the influence of the choice of working fluid on the design and performance of the turbine with due consideration for reliability and fabricability.

By a fortunate coincidence, this study has been carried out almost concurrently with a roughly similar study of steam turbine generator units⁴ carried out under the Terrestrial Low Power Reactor program of the AEC. The similarities and differences that have become apparent in the course of the design studies for the wide variety of conditions considered have helped greatly to place the many different problems in perspective.

SUMMARY

This study indicates that there is no difference between cesium and potassium in the aerodynamic performance obtainable from a well-proportioned turbine. The optimum operating speed for the 300 kw cesium turbines appears to be about 18,000 rpm as compared with 24,000 rpm for potassium (this stems from the higher molecular weight of the cesium). The greater density of the cesium vapor leads to the somewhat smaller turbine rotor diameters for cesium.

Thermodynamic cycle analyses indicate that there is no difference in the overall thermodynamic cycle efficiency for operation between a

given set of temperature limits using a simple Rankine cycle. If regenerative feed heating is employed, the thermodynamic calculations show a small advantage for cesium stemming from the greater specific heat of the liquid. The Mollier diagrams also indicate a somewhat higher moisture content for an isentropic expansion of potassium as compared to cesium between the same temperature limits. This leads to somewhat higher moisture churning losses for potassium than for cesium. The higher molecular weight of cesium also leads to lower sonic velocities and hence lower leakage losses through labyrinth seals. The combined effects of these factors lead to a loss of about one point in cycle efficiency if the number of stages is the same. The difference can be balanced by reducing the exit losses by using more stages in the potassium turbines.

An investigation of the turbine bucket erosion problem indicates that the threshold for erosion would be at a higher tip speed for cesium than for potassium, and the threshold for either would be higher than for steam. In the reference design turbines there should be no difficulty with erosion caused by droplets dribbling from the stator blades, but it will probably be necessary to provide for moisture removal between stages in both the cesium and potassium turbines to avoid erosion caused by large drops that would otherwise be torn from the relatively thick film of liquid that would move along the wall of the outer casing.

The higher molecular weight of cesium gives a greater temperature ratio per stage without excessive tip speeds so that close to a maximum efficiency is obtainable with a three-stage cesium turbine as compared to a seven- or eight-stage potassium turbine. If approximately one point in cycle efficiency is sacrificed to reduce the number of stages, it is possible to use either a two-stage cesium turbine or a five-stage potassium turbine and obtain the same efficiency. Thus for a given cycle efficiency the cesium turbines are substantially smaller and lighter than their potassium counterparts.

Using the parametric study as a basis, both a two-stage and a three-stage cesium turbine and both a five-stage and an eight-stage potassium turbine were chosen for reference design purposes. Both two-bearing and four-bearing layouts were investigated for the three-stage cesium and the

five-stage potassium turbines. The two-stage cesium turbine was designed as a two-bearing machine while the eight-stage potassium was made a four-bearing machine. Of these, the two-bearing, three-stage cesium turbine and the four-bearing, eight-stage potassium turbine-generator units (having weights of 810 lb and 1230 lb, respectively) were chosen for use in the overall system layout and integration studies.

A creep stress analysis of the rotors indicates that creep will not be a problem in the first stage rotors of the cesium turbines but it would be a serious problem in the original reference designs for the potassium turbines.

If this condition were alleviated by reducing the turbine inlet temperature, the loss in overall cycle efficiency would run about one point. However, it appears reasonable to hold the turbine inlet temperature at 2150°F and reduce the turbine wheel stresses sufficiently to avoid difficulties with the creep by reducing the first-stage rotor diameter about 22%. The resulting deviation from optimum aerodynamic proportions gives a loss of about 3% in the efficiency of the first stage and an overall loss in cycle efficiency of about two-tenths of a point.

A study of the bearing and rotor dynamics indicates that, for five of the six reference designs, the third critical speed can be placed well above the design speed and the damping in the bearings should be adequate to limit the amplitude of journal gyrations in the bearings to moderate values in passing through the first two critical speeds which are rigid body critical speeds. The sixth reference design, the five-stage potassium turbine in which three-stages would be overhung at one end of the generator shaft and two stages overhung at the other, gave rather large amplitudes of journal gyrations, and hence appeared to be an undesirable choice for a development program. In general, the orbit amplitudes were lower for cesium than for potassium.

BASIC DESIGN CONSIDERATIONS

A review of the literature and extensive discussions with many experts in the field served to delineate the basic design considerations

for the work on the turbine-generator units. These are summarized and some of the subtleties are discussed in this section to show the rationale behind the boundary conditions established first for the parametric studies and then for the layout and analytical design work.

Generator

The size and weight of the generator and much of the equipment in the electric power distribution system, particularly motors and transformers, falls off fairly rapidly with an increase in frequency up to 1000 to 2000 cps, whereas line losses associated with inductive effects increase fairly rapidly with frequency above about 2000 or 3000 cps. Thus for minimum weight of the electrical system, the generator frequency should be somewhere between 1000 and 3000 cps. There is very little equipment in the way of motors, transformers, switchgear, etc., that has been designed and built for frequencies above 400 cps, so that higher frequencies will require the development of much new equipment. The weight savings possible by going to 1200 cps as opposed to 400 cps have led NASA to favor the development of the 1200 cps equipment, hence this study was based on 1200 cps for the reference designs.

There seems to be general agreement that the most reliable type of generator for power outputs of more than about 100 kw is an inductor-alternator. Four or more poles must be used in this type of machine because the rotating magnetic couple associated with a two-pole machine would lead to severe vibration and bearing problems.

The choice of 1200 cps for the generator gives quite a range of possible speeds, that is, a four-pole machine would operate at 36,000 rpm, a six-pole machine would operate at 24,000 rpm, an eight-pole machine would operate at 18,000 rpm, a ten-pole machine would operate at 14,400 rpm, and a twelve-pole machine would operate at 12,000 rpm, thus providing considerable latitude in the choice of turbine rpm. This approach makes it possible to take advantage of the high speed potential of the potassium and cesium vapor turbines, although the advantage of the 1200 cps generator over a 400 cps is not as great for cesium as for potassium.

Possible reference designs for the generator were discussed with NASA personnel in connection with the investigation of the rotor and bearing dynamics problem. It was agreed that the SNAP-50 generator would be used as the reference design machine, and that both a four-bearing and a two-bearing configuration for the complete turbine-generator unit would be examined. (In a four-bearing machine, the turbine would be coupled to the generator with a quill shaft; in the two-bearing machine, the turbine would be overhung out-board of the bearing at one or both ends of the generator rotor.). In view of the difference between the 1200 cps generator output frequency specified by NASA for this study and the 3200 cps for which the SNAP-50 generator was designed, it seemed best to check with Westinghouse on the effects of the change in design frequency on the rotor proportions. The problems were discussed with Westinghouse in light of their recent work on the problem under AEC Contract,⁵ and the generator proportions defined in Table 1 were taken from Refs. 5 and 6.

Turbines

The number of stages, size, weight, and cost of a turbine for a cesium or potassium Rankine cycle can be reduced as the rotor tip speed is increased up to the range of 1000 ft/sec to 1500 ft/sec. At the higher speeds, compressibility losses, rotor stresses, and bucket erosion by moisture become progressively more likely to induce substantial losses. Thus the combination of roughly 1000 ft/sec tip speed required for good turbine design and the 12,000 to 24,000 shaft rpm dictated by generator design considerations leads to rotor diameters of approximately 10 in. if the blading design is compromised between that for maximum efficiency and that for maximum work per stage. (That is, the tip speed should be made somewhat less than about half the tangential velocity at the nozzle exit.)

Since efficiency is a less important consideration than reliability in space power plants than in central stations, it is possible to reduce the size and bearing loads, simplify the design, and reduce the cost of the turbine by reducing the number of stages through the use of a relatively high pressure ratio per stage with simple impulse turbine blading.

Design for Reliability

In view of the high importance of reliability, it seems in order to give particular attention to the bearings. The radial loads will depend mainly on the weight of the rotor per square inch of bearing area. Experience indicates that, to avoid scuffing during startup, it is desirable to keep the bearing loads to about 30 psi or less. As discussed in the previous section, high speeds will be required for good efficiency, light weight, and compactness, hence the bearings must be designed to avoid instability and whip. This implies the use of stepped pad, tilting pad, or similar bearings. The turbine should also be designed to keep the thrust loads low - if possible, negligible. Thus the aerodynamic design of the turbine should be such that the axial piston pressure loads on the rotor will be balanced, which implies that impulse blading should be used. Impulse blading will yield a somewhat lower efficiency than reaction blading, particularly for the last stage, but this loss in efficiency would be offset in large measure by greatly reduced frictional power losses in the thrust bearing. These commonly run 5% or more in a high speed reaction turbine of this type.

It may be desirable to reverse the flow or go to double flow in the last stage of the larger turbines so that the last stage will be at the end of the rotor adjacent to the first stage. This would permit balancing of small amounts of reaction in the longer blades of the last stages, and has the additional advantage that, if bearings are used at both ends of the rotor, neither bearing will be exposed to the high-temperature vapor entering the turbine.

The reversed flow arrangement introduces complications, and will reduce the turbine efficiency somewhat, but it has the advantage that, if a journal bearing is used at either end of the rotor, the structure joining the two bearings can be held at a uniform temperature so that good alignment can be maintained. Some designs, for example, the AiResearch SNAP-50 turbines, have included provisions for cooling the bearings so that they would be held at a substantially lower temperature than either the inlet or exhaust vapor. This approach has the disadvantages that thermal distortion seems more likely and either a good deal of heat will

be lost to the bearing coolant as a consequence of condensation of vapor on the bearing mount, or a very close clearance labyrinth seal must be employed to inhibit leakage of vapor into the cavity surrounding the bearing. Such a close clearance labyrinth seal would be likely to detract from the reliability of the machine.

Moisture Removal

It is advantageous to employ a regenerative feed heater in the system to improve the thermal efficiency of the cycle and thus reduce the size of both the reactor and the radiator — both of which represent major size, weight, and cost items. Feed heating also has the advantages that it should reduce thermal stresses at the boiler inlet, improve flow stability in the boiler, and provide a convenient means for bleeding off liquid and vapor between stages to keep down the moisture content and thus reduce the losses in turbine efficiency associated with liquid impingement on the rotor blades as well as possible turbine bucket erosion.

Moisture deposition on turbine rotor and stator blades leads to large momentum losses as liquid is thrown off the rotor blade tips or dribbles off the stator blades into the rotor and is accelerated to the rotor tip speed. These liquid churning losses commonly run from about 0.5% to 1.5 % (Ref. 7-10) in turbine efficiency for each 1% of moisture in the vapor stream. The most effective moisture removal devices in common use rarely take out more than 25% of the moisture.¹¹ However, there is reason to believe that the use of interstage bleeds, possibly coupled with porous stator blades, can be vented to a regenerative feed heater to make possible a substantial reduction in these losses.

Turbine bucket erosion is a function of many parameters, particularly turbine tip speed. Current practice indicates that, with proper design for moisture removal and with stellite inserts, it is possible to keep steam turbine bucket erosion within acceptable limits for tip speeds as high as 1850 ft/sec. Analyses in a companion report⁹ indicate that for cesium or potassium the threshold for erosion is higher than for water.

The thermodynamic analyses indicate that vapor can be bled off between stages to aid in the removal of moisture and at the same time used

in a regenerative feed heater to improve the cycle efficiency as much as 18%. This makes possible a corresponding decrease in the size and weight at the radiator as well as appreciable reductions in the size and weight of the reactor and shield assembly. Interstage bleed-off in this fashion also improves the proportions of the turbine in that it increases the height of the first stage blades (which tend to be too short) and reduces both the diameter and the blade height in the last stage. In view of these major advantages, it was decided that the reference design turbines and systems should include interstage bleeds and regenerative feed heating.

Heat losses as a consequence of conduction from one stator stage to the next should be reduced through the use of heat dams. These might be formed by gaps filled with vapor which — for either potassium or cesium — has a thermal conductivity of less than 0.01 Btu/hr·ft.°F.

Design Precepts

The design precepts and boundary conditions on which the turbine design work was based are summarized in Table 2. Many of these are implicit in the above discussion. In general, these stem from operating experience at ORNL coupled with an extensive survey covered in a companion report.¹² Others, while not mentioned above, are sufficiently straightforward that discussion seemed unnecessary. Still others required special treatment in the analyses, and it seemed best to combine the general discussions of these items with the detailed explanation of the way in which the calculations were handled in this report, hence these are discussed in later sections.

ANALYTICAL DESIGN PROCEDURE

There are so many variables involved in the design of a turbine and so many boundary conditions must be met that it is difficult to see how to arrive at a nearly optimum design, especially if allowances are made for losses associated with seal leakage, regenerative feed heating, and moisture churning by the rotor. After a number of false tries, a procedure

was worked out for carrying out the thermodynamic and aerodynamic calculations including these factors in a systematic fashion to yield the proportions and performance of a turbine that will meet the boundary conditions of Table 2 and yet give close to the maximum efficiency obtainable with any given number of stages. This procedure utilizes the analytical approach presented by Baljé in Refs. 15 and 16. The bases for it are summarized in Table 3. The symbols used are defined in the table of nomenclature at the end of this report. The symbols used by Baljé served as a point of departure in setting up this table, but a number of changes were made because other aspects of turbine design are treated elsewhere in the report, and an effort was made to employ a single set of symbols for the entire report insofar as this was possible.

Thermodynamic Analysis

The thermodynamic calculations were carried out using the thermodynamic data compiled by the Naval Research Laboratory.^{17,18} The NRL data for cesium were used to draw a larger scale chart with constant temperature lines at 25°F intervals instead of the 100°F intervals of the NRL chart to facilitate a more precise reading of the chart scales. This chart is included as Fig. 46.

Simple Idealized Cycles

A number of simple idealized cycle calculations were carried out partly to provide a basis for appraising the accuracy with which the Mollier diagrams might be read, partly to give some insight as to the possibility of accumulations of errors stemming from uncertainties in the physical properties used to construct the Mollier diagrams, and partly to provide a simple means of checking the calculations for the multi-stage turbines. These calculations are summarized in Table 4, and the results are plotted in Figs. 1 through 3. Note in Fig. 1 that the calculated points for cesium and potassium scatter indiscriminately about the curves for the two different turbine inlet temperatures considered so that, at

any given turbine inlet temperature, there is no appreciable difference in the thermal efficiency of the ideal Rankine cycle between cesium and potassium. This is not surprising, but it is interesting that there is apparently no accumulation of errors that would lead to an apparent difference for calculations made using the charts employed in the study. Note, too, that the scatter of the points relative to the mean curves amounts to less than 0.4 of a percentage point, a surprisingly small amount in view of the fact that each cycle efficiency represents the ratio of two differences in enthalpies read from the Mollier diagrams.

Figure 2 shows an interesting comparison of the calculated thermal efficiencies for the 2150°F turbine inlet temperature idealized Rankine cycles of Fig. 1, the ideal Carnot cycle, and a series of approximations to the actual cycle. In this instance, the line drawn through the points calculated for the ideal, simple, Rankine cycle was actually drawn as a line for cycles having a thermal efficiency 89% that of the ideal Carnot cycle efficiency. Note that this appears to be as good a mean line through the points from Table 4 as one could draw. Figure 3 shows a similar chart for a turbine inlet temperature of 2000°F. As a matter of interest, other lines have been drawn on the same charts to show the results of aerodynamic and thermodynamic calculations made in later sections. These curves show the effects on the overall thermal efficiency of allowances for regenerative feed heating and the principal aerodynamic, moisture churning, and seal-leakage losses.

Multi-Stage Calculations

A series of thermodynamic calculations was carried out for multi-stage turbines to provide the basis for the aerodynamic calculations. To facilitate the calculations, the temperature drop per stage was held constant throughout any given turbine except that the turbine inlet temperature to each stage was rounded off to the nearest 10°F and the slightly greater temperature drops stemming from this were introduced at the low temperature end. The pressure, specific volume, and liquid enthalpy data were taken from tables in the NRL reports.^{17,18} Points in the expansion were obtained from the Mollier diagrams by conventional techniques. The

reheating effects associated with the aerodynamic losses in each stage were approximated by assuming a stage efficiency of 0.75 for each stage. While the thermodynamic calculations could be iterated after obtaining a better value for the efficiency from the aerodynamic calculations, the constant pressure lines are so nearly parallel on the Mollier diagram that an approximation is usually good enough so that, for a parametric study such as this, the thermodynamic calculations need not be iterated. (A second iteration was made for the reference design turbines covered in a later section.) The turbine nozzle efficiency will be so close to 100% that the nozzle exit velocity may be taken as being the ideal value. Allowances for regenerative feed heating were made by assuming a regenerative feed heater having a thermal effectiveness of 80% with an inter-stage bleed-off between each pair of turbine stages supplying the requisite vapor to the corresponding stage of the feed heater. The vapor bleed-off requirements for this purpose were calculated and tabulated together with the resulting net vapor flow fraction into each stage. The calculations are tabulated in Tables 5 and 6. The circled number at the head of each column in Tables 5 and 6 was used as a symbol to indicate steps in the calculations in subsequent columns and in subsequent tables for the aerodynamic calculations.

Aerodynamic Calculations Using the Baljé Charts

A number of different techniques for carrying out the turbine aerodynamic design calculations were considered. Of these, the most suitable for the purposes of this study appeared to be one based on the use of the analyses and charts presented by Baljé in Ref. 15 and reproduced here as Figs. 4 and 5. These charts were developed by Baljé from a very clever analysis in which he reduced the many different turbine design parameters and basic relations to a few equations. Inasmuch as practical problems ordinarily are such that these equations cannot be solved explicitly, Baljé devised a set of charts to facilitate their solution. The charts make it possible to find the best combination of parameters for the case at hand, that is, the designer can choose the appropriate chart for the

type of turbine stage at hand and find the point on the chart that most nearly satisfies the conditions that he wishes to meet and, once he becomes familiar with the charts, can easily see the effects of changes in design conditions. It should be noted that the basic relations used by Baljé in his derivation are widely accepted as fundamentally sound, but that it is necessary in using them to employ such quantities as the aerodynamic characteristics of airfoils that are normally derived from tests. In preparing his charts, Baljé derived the necessary constants from a comprehensive set of test data obtained with representative turbines. Since these were not fully optimized, developments through the years should bring about some improvements. However, it is believed that the basic relations are valid so that any improvement will benefit one working fluid as much as another. Thus, for the purposes of this study, a valid comparison of cesium and potassium turbines can be made using the charts. If, for example, developments in aerodynamics should make possible a general increase in efficiency (which would in effect dilate the constant efficiency contour lines of the chart of Fig. 4*), this improvement in efficiency would apply equally well to cesium and potassium provided that, in both instances, the turbine designer made use of the available degrees of freedom to take advantage of the improvement. Care has been exercised in this study to do this, and nothing has come up to suggest that the degrees of freedom are not sufficient to permit achieving essentially the same aerodynamic efficiencies.

The charts from Ref. 15 presented in Figs. 4 and 5 depend on the fact that the 25 independent parameters indicated in Table 7 can be reduced to a few dimensionless parameters. The balance of the parameters have substantially smaller effects on turbine performance, and their effects can be taken into consideration by applying corrections to the proportions derived from Figs. 4 and 5. Some useful cross-plots of the data

*A recent report of Baljé presents a refinement of the analysis of Ref. 15 applicable to reaction turbines.¹⁶ This shows that higher efficiencies are possible through proper selection of the pitch-chord and blade height-chord ratios. These refinements were not included in the subject study because the new data are for reaction rather than impulse turbines.

in Figs. 4 and 5 for the maximum efficiency obtainable at any given value of N_s are presented in Fig. 6.

Effects of h/D

A detailed study of Baljé's derivation and its use as the basis for a computer program led to somewhat different values of the ratio of blade height to wheel diameter (h/D) for maximum efficiency than are given by either the h/D lines in Fig. 4 or Eq. (31) of Baljé's analysis. The matter was discussed with Baljé, and he pointed out that the turbine efficiency is insensitive to the h/D ratio over a wide range of h/D ratios. A computing machine program was developed to solve Baljé's equations on which the charts of Figs. 4 and 5 were based. A typical set of solutions gave the curves of Fig. 7 for the turbine efficiency as a function of h/D for constant values of D_s and N_s . Also plotted in Fig. 7 are curves for α_2 and β_2 , that is, the inlet nozzle angle and the blade rotor entrance angle. Note that the efficiency is surprisingly insensitive to h/D , particularly for intermediate stages where the efficiency based on the total pressure at the stage exit is more significant than the static efficiency. However, the large kinetic energy losses in efficiency in the last stage for small blade heights coupled with the diffuser losses to be expected with large amounts of channel divergence favor selection of the larger h/D ratios even in the intermediate stages.

Seal Leakage

Some fraction of the vapor stream tends to bypass each stage by flowing through the labyrinth seal between the stator and the rotor. With the impulse turbine design contemplated, the pressure differential across each of these labyrinth seals will be equal to the total pressure drop for the stage. In addition, leakage from the first-stage rotor (which will be at the static pressure of the first-stage discharge nozzle) back toward the adjacent bearing will represent a substantial loss. The effects of this loss can be reduced through the use of a series of intermediate bleed points to conduct a portion of the leakage to appropriate

points in the regenerative feed heater. Of course, it is necessary to make sure that the amount of vapor bled off for this purpose does not exceed the requirements of the feed heater, but this has been found not to be a problem for the turbine proportions under consideration in this study.

In estimating the magnitude of the seal leakage losses, the work of Egli was employed.¹³ While this was based on work with steam, it is also readily applicable to potassium and cesium vapor. Egli's relation for the leakage through a labyrinth of n lands is

$$G = A\alpha\Phi\gamma\sqrt{\frac{gp_0}{v_0}}$$

where

A = orifice area, ft^2

G = flow rate, lb/sec

g = acceleration of gravity, ft/sec^2

n = number of lands

p_n = downstream pressure, lb/ft^2 abs.

p_0 = upstream pressure, lb/ft^2 abs.

v_0 = upstream specific volume, ft^3/lb

α = orifice coefficient

Φ = labyrinth coefficient (a function of n and p_n/p_0)

γ = coefficient dependent on geometry

Egli determined the value of $\alpha\Phi$ experimentally with steam for a wide range of seal proportions and pressure ratios, and his experimental results checked closely with analytically derived values. The effects of both the number of lands in the seal and the ratio of the upstream and downstream pressures are summarized in Fig. 8.

A major factor influencing the magnitude of the seal leakage is the radial clearance between the shaft and the lands of the labyrinth seal. Dodge¹⁴ recommends a clearance of 0.0015 in. to 0.0025 in. for a 3.5-in. journal diameter, the value which preliminary layouts indicate will be appropriate. If an attempt is made to rationalize a clearance, it is evident that the diametral clearance in the bearings — about 0.003 in. — will

be a major factor. In addition, some allowance must be made for the accumulation of tolerances affecting the concentricity of the casing with respect to the shaft, ovality of the casing, and distortion of the rotor. Experience with high-temperature pumps at ORNL indicates that the combined effects of these factors will be such as to require approximately an additional 0.002 in. of radial clearance. If the minimum clearance is to be 0.002 in. after allowance for these factors, the nominal overall radial clearance becomes about 0.0055 in. This is somewhat higher than the allowance recommended by Dodge, but it seems in order in view of the much higher temperature at which the machine will operate, and consequently the greater opportunity for differential thermal expansion and thermal distortion.

Preliminary estimates of the seal leakage losses indicate that these will run of the order of 5% for the turbines under consideration even with 12 lands in each seal. As a consequence, it seemed best for the purposes of this study to assume that each seal would employ twelve lands with no steps in diameter between lands (steps would cut the leakage by a factor of 2), and that the seal between the first-stage rotor and the adjacent bearing would consist of three or four sets of twelve lands each with intermediate bleed-offs to the regenerative feed heater. (The number of bleed-offs in the seal would correspond to the number of extraction points for multi-stage feed heating.) To facilitate the calculation of the amount of flow bypassing each stage, Fig. 9 was prepared to define the leakage rate through the labyrinth seals as a function of the upstream pressure. For 0.010-in.-thick lands on 0.050 in. centers, the values of α and γ taken from Egli's paper (Ref. 13) for construction of Fig. 9 were both unity, and values for ϕ were taken from Fig. 8.

In calculating the aerodynamic performance of the turbine, the thermodynamic data of Tables 5 and 6 were used as a point of departure. Allowances for the flow bypass through the labyrinth seals was made on the basis of the chart of Fig. 9 with a correction to allow for the value of the leakage bled from intermediate stages in the seal between the first-stage rotor and the adjacent bearing. (In effect this would reduce the amount of interstage bleeding required for feed heating — for which allowances have already been made in Tables 5 and 6.) These calculations are summarized in Table 8.

It should be noted that the preceding paragraph implies a four-bearing machine, but the same reasoning also applies to a two-bearing machine with the turbine wheels overhung from the generator rotor with all of the stages at one end of the generator. This comes about because a seal is required between the first stage rotor and the end of the shaft to balance the piston pressure forces on the rotor shaft at the high pressure end of the turbine, as the pressure force would otherwise give an excessive axial thrust load. The region outboard of the seal should be vented to the low pressure end of the turbine so that the same pressure will act on both ends of the shaft. (For the cesium vapor turbine under consideration here, for example, without such a seal the axial thrust load arising from piston pressure forces would run around 2100 lb, a completely unacceptable thrust force.) If a two-bearing machine were employed with some stages at one end of the generator and some at the other, it would be possible to use two different journal diameters at the labyrinth seals and choose these to balance the piston forces at design conditions. Unfortunately, it is not possible to obtain a good balance throughout the load range, and large axial loads would occur under some conditions unless the seal arrangement used is similar to that postulated above.

The power losses associated with friction in labyrinth seals of the type used here are not large and were neglected in this study. The frictional losses in the type of seal required in the generator, however, are likely to be substantial if the pressure in the generator rotor cavity is to be kept to the low level desired to minimize windage losses. In view of the many uncertainties in the detail design of the generator, and since these losses are insensitive to turbine design parameters over the range of interest in this study, the shafts frictional losses in the bearings and seals were neglected.

Tip Clearance Losses

On the basis of steam and gas turbine experience, Baljé' chose to prepare his charts on the basis that the clearance between the tips of the blades and the casing would be responsible for a loss which happens to be roughly equal to twice the ratio of the tip clearance to the blade

height (Ref. 15, p. 89), and Baljé prepared the charts of Ref. 15 assuming a value of 0.02 for the ratio of tip clearance to blade height.

In attempting to rationalize a suitable tip clearance for this study, the approach employed in the previous section on labyrinth seal leakage appears in order except that a somewhat greater distortion must be anticipated at the greater diameter of the rotor tip, and this implies that a radial clearance of the order of at least 0.01 in. should be provided. In addition, some allowance must be made, particularly in the higher temperature stages, for growth of the rotor as a consequence of creep. Since this is difficult to specify, it seemed desirable to proceed with the aerodynamic calculations using an additional allowance of 0.01 in. for this factor with the intent that a correction could be superimposed on the calculations as a final step if such a correction appears to be in order. On this basis a tip clearance of 0.020 in. appears reasonable; this would be the same as that assumed in the construction of Baljé's charts provided that the blade height is 1 in. It can be seen intuitively that a flat assumption of the clearance of 0.020 in. throughout the turbine will probably give a value for the ratio of the tip clearance to the blade height that would be greater than 0.02 for the earlier stages and less than 0.02 for the latter stages. Thus the estimates of stage efficiency using Baljé's charts will probably be on the high side for the early stages and perhaps on the low side for the last stages where the long blades may permit a small reduction in the tip leakage loss.

Calculation Techniques

Both the computing machine program referred to in the discussion of the effects of h/D and a hand calculation technique were employed independently to investigate the effects of design conditions on the turbine proportions yielded by application of Baljé's approach to the optimization for maximum turbine efficiency within the framework of the design precepts presented in the previous section. The detailed procedures used are presented in the two following sections. Each approach was found to have its advantages and disadvantages; for example, the hand calculation procedure lent itself better to the investigation of the detailed effects

of the various types of loss, while the machine program required only about one-half a manhour per case as compared to about four manhours for the hand calculations. However, no good way was found for programming sub-routines for the computing machine to investigate the effects of such factors as bleed-off for regenerative feed heating and seal leakage, hence these effects had to be investigated by hand calculations only. As will be shown later, the results of the two independent approaches where both could be used provided a valuable check on each other.

Aerodynamic Calculation Procedure Using a Desk Calculator

Balje's analysis shows that the efficiency of a turbine stage is completely determined by the specific speed, N_s , and the specific diameter, D_s . Since $N_s = N V_3^{1/2} / H_{ad}^{3/4}$ and $D_s = D V_3^{1/2} / H_{ad}^{3/4}$, and since N , V_3 , and H_{ad} are defined for any particular stage and vapor weight flow rate by values given in Tables 5 and 6, the problem is reduced to one of determining the rotor diameter that will give as high an efficiency as possible. It happens that a simple way of determining this without attempting a complex interpolation is provided by cross plotting data from Balje's charts of Figs. 4 and 5 to give Fig. 6. Inasmuch as a major boundary condition is that the number of stages be minimized (i.e., the head per stage be a maximum), the minimum value of N_s for any given efficiency represents a point on the curve defining the desired relationships. Thus, points for both efficiency and D_s were plotted on Fig. 6 as a function of N_s for each of the constant efficiency curves of Balje's charts in Figs. 4 and 5 to define curves for the maximum stage efficiency obtainable. Note that two curves are given, one based on the total and one on the static pressure at the stage exit. The former curve can be used for all but the last stage, while the latter should be used for the last stage because the velocity energy in the stream leaving the last stage of a turbine is not recoverable. Curves for H_{ad} , D , and the tip speed U for 24,000 rpm and some typical values of V_3 were added on the same sheet to give an insight into the relations involved.

Table 9 presents the series of operating conditions for which parametric study calculations were made. These combinations of conditions were chosen to provide as much insight as possible into the effects of the design conditions on turbine proportions and cycle efficiency. The

calculations themselves are presented in Tables 10 and 11, and the steps in the calculational procedure are summarized in Table 12.

The turbine output, and hence the efficiency, is reduced by the loss of mass flow through the turbine buckets as a consequence of flow bypassing through the labyrinth seals as well as bleed-off for moisture removal and regenerative feed heating. These items can be estimated and the net flow fraction passing through each rotor stage determined. The loss associated with churning of the droplets impinging on the rotor blades can also be estimated assuming that it will run 1.25% per 1% of moisture. The work input to each stage of the turbine can then be calculated, and the values assumed to give the total work output of the turbine per pound of vapor entering the first stage. This value divided by the heat added in the boiler (from Table 5 or 6) gives the gross cycle efficiency.

The ideal work input to the feed pump is approximately 2 Btu/lb for potassium. If a free-turbine-driven feed pump is supplied with vapor bled from the inlet to the last stage of the main turbine, the overall efficiency for the turbine and pump unit would be about 25%. This would give a value of about 8 Btu/lb for the feed pump work, or about 1% of the heat input to the cycle. The value for cesium would be similar. (Bleed-off for the feed pump turbine would reduce the vapor flow through the last stage of the turbine by roughly 10%, but this effect was not included in the calculations of Tables 5 and 6.) The generator efficiency will run about 92%. Miscellaneous heat losses to radiation, etc., will run about 1%. Thus, the net thermal efficiency of the plant will run about 90% of the gross cycle efficiency. The net electrical power output is given by the product of the vapor flow rate, the boiler heat input per pound of vapor, the net thermal efficiency, and the ratio 3600/3413 for conversion of units.

Inspection of Tables 5 and 6 and further calculations showed that in virtually all cases the relative velocity of the vapor entering the turbine buckets was below sonic, and hence no Mach number correction was required except for the single stage cesium turbine.

Aerodynamic Calculations Using a Computer Program

In carrying out the calculations outlined in the previous section it became evident that appreciable errors might be introduced by interpolation between the lines of the complex networks of the Baljé charts. To avoid such errors a computing machine program was prepared to solve the equations on which Baljé based his charts,¹⁵ and thus a more accurate set of results could be obtained for turbines proportioned to minimize the aerodynamic losses. It proved very difficult to include the effects of seal leakage and regenerative feed heating in this program, however. In view of these difficulties and the good correlation obtained between the results obtained from the charts and those obtained from the computer program, the computing machine calculational work was limited to an investigation of the aerodynamic and moisture churning losses, but a wider range of combinations of rpm, number of stages, and turbine inlet and exhaust conditions was investigated. These included some single stage cesium turbines in which the relative Mach numbers entering the blades exceeded 1.1 so that additional hand corrections for compressibility losses were in order and were applied in obtaining the overall cycle efficiency (although they were not included in the "overall turbine efficiency" yielded by the machine program).

Machine Calculation Procedure. The velocity diagram calculations were based upon a pitch-line procedure similar to the aforementioned Baljé method.¹⁵ The following salient differences should be noted:

- a) The nozzle coefficient was assumed to be given by

$$\psi_n = 0.9488 + 0.0131 \epsilon_s - 0.0867/\epsilon_s$$

where

$$\epsilon_s = \alpha_1 + \alpha_2 \quad (\text{angles in radians})$$

- b) The rotor velocity coefficient was assumed as relation (27) in Ref. 15.

- c) Axial inlet and discharge were assumed for each stage and $\alpha_2 \geq 15^\circ$ whichever gave the maximum total-to-total efficiency.

- d) The moisture correction was assumed to be given by

$$\Delta\eta = 4(1 - q_2)(u/c_o)^{7/4}$$

where q_2 is the leaving nozzle quality (which is nearly equal to the quality q_3 leaving the stage).

- e) For the cesium turbines, an entering velocity of 300 ft/sec was assumed, while 500 ft/sec was assumed for the potassium turbine designs.

With the above assumptions, the calculations were performed by dividing the isentropic static enthalpy into equal stage increments, and the total stage efficiency maximized on α_2 . This gave all the pertinent variables directly for an assumed weight flow. The weight flow was then matched for the specific turbine output. Table 13 gives the pitch line velocity diagrams for cesium, while Table 14 shows the results of similar calculations for potassium. The detailed steps in the program were as follows:

1. The entering velocity was taken as axial - 300 ft/sec for cesium and 500 ft/sec for potassium.

2. The nozzle coefficient ψ_n :

$$\psi_n = .9488 + 0.0131 \epsilon_s - 0.0867/\epsilon_s$$

where

$$\epsilon_s = \alpha_1 + \alpha_2 \text{ (not stator deflection)(angles in radians)}$$

3. Rotor velocity coefficient ψ_R :

$$\psi_R = \left[1 - 0.228 \left(1 - \frac{2\beta_2}{\pi} \right)^3 \right] [1 - .06 c/h]$$

- 4.

$$c/h = 4 \left(\frac{a^*}{D} \right) \cos \beta_2 / (h/D)$$

with $a^*/D = 0.015$.

5. Use either $\alpha_2 \geq 15^\circ$ or $\alpha_3 \leq 90^\circ$ which ever gives the greater efficiency.

6. The change in efficiency due to moisture was calculated using the outlet quality since the quality entering the rotor will be quite close to this value. The equation used is:

$$\Delta\eta = 4(1 - Q_{out})(U/C_o)^{7/4} .$$

This fits Escher-Wyss data cited by Csanady, (Ref. 10, p. 347) presented here in Fig. 10. Note that the moisture churning losses are greater in reaction turbines, and increase as the degree of reaction increases.

7. The turbine rotor Reynolds number based on hydraulic diameter = 100,000. This affects only the disc power since the velocity coefficients do not change much above 100,000.

RESULTS OF PARAMETRIC CALCULATIONS

The objective of the parametric calculations was not so much to yield a highly optimized pair of reference designs for cesium and potassium turbines, but rather to show the sensitivity of the major geometric and performance parameters to variations in design conditions for nearly optimum combinations of design parameters.

Effects of the Number of Stages on Turbine Efficiency

A good insight into the effects of the number of stages on the size and efficiency of potassium and cesium turbines is given by Fig. 11. This set of calculations was carried out with the computing machine program with all the losses included by Baljé in Ref. 15, but with no provisions for regenerative feed heating or seal leakage. Note that the cycle efficiency increases very little with the number of stages beyond three stages for cesium or beyond five stages for potassium. This implies that these three-stage and five-stage units should be used for reference design purposes, since it is worthwhile to accept a small loss in efficiency to reduce the number of stages and thus ease the rotor dynamics problems and reduce the turbine size and weight.

Figure 12 shows the effects of the number of stages on the cycle efficiency and other parameters as determined by the hand calculations of Tables 10 and 11 which include allowances for both bypass leakage through labyrinth seals and regenerative feed heating. In this instance, the overall cycle efficiency has been plotted rather than the gross cycle efficiency because of the complex effects of regenerative feed heating. Note that again the three-stage cesium and five-stage potassium units appear to represent well-proportioned designs.

An examination of the data in Tables 5, 6, 10, and 11 discloses that the principal factor responsible for the increase in efficiency with the number of stages is the kinetic energy loss in the last stage; this becomes a progressively smaller fraction of the total head across the turbine as the number of stages is increased. It can also be seen from Fig. 12 that reducing the number of stages below three for cesium and five for potassium would lead to relative Mach numbers greater than 0.8 at the inlet to the turbine buckets, so that additional losses caused by compressibility effects might begin to become important.

Effects of Design RPM

Inspection of Table 5 together with Fig. 6 indicates that 24,000 rpm tends to give a rather high specific speed for cesium, and that there may be an advantage to employing a lower speed. Figures 13 and 14 show the effects of design rpm and number of stages on the turbine size, turbine bucket inlet Mach number, and the overall cycle thermal efficiency with allowances for aerodynamic, moisture, and seal-leakage losses as well as regenerative feed heating. These curves show that there is some advantage to the use of 18,000 rpm for the cesium turbine, and that 24,000 rpm is close to optimum for the potassium turbine. It should be noted, however, that reducing the cesium turbine speed from 24,000 rpm to 18,000 rpm will lead to an increase in generator weight (see Table 1).

Effects of Turbine Inlet and Outlet Temperatures

Results of the calculations of Tables 5, 6, 10, and 11 have been summarized and plotted in Figs. 15 and 16 to show the effects of the choice

of the turbine outlet temperature on the overall cycle efficiency with allowances for aerodynamic, moisture churning, and seal-leakage losses, together with regenerative feed heating. Note that, as one might expect, these points fall on curves that are consistent with the idealized cycle calculations cited earlier in the report. Note, too, that a comparison of Figs. 12 and 16 shows that the effects on the overall cycle efficiency of changing the number of stages would be much less than the effects of either the choice of turbine inlet and outlet temperatures for the sets of conditions considered here or the use of regenerative feed heating.

Some additional insight into the effects on major turbine design parameters of variations in condenser inlet temperature is given by Fig. 17 which was prepared for a series of five-stage cesium and potassium vapor turbines with regenerative feed heating and allowances for aerodynamic, moisture churning, and seal-leakage losses. Other than the increase in cycle efficiency, perhaps the most important effect of reducing the condenser temperature is the increase in diameter of the last stage that results from the rather rapid decrease in vapor density with a drop in temperature. This increase in diameter would be substantially greater were it not for the fact that the number of stages has been kept constant for the points of Fig. 17, and thus the head drop per stage has been increased as the condenser temperature was reduced. Note that keeping the number of stages constant has little effect on the turbine efficiency, however, for the range considered here. It is also evident that the amount of moisture in the vapor entering the last stage increases rapidly as the condenser temperature is reduced, hence moisture removal between the stages becomes progressively more advantageous as the design condenser temperature is reduced for a given turbine inlet temperature. Moisture removal between stages should be particularly helpful in improving the turbine efficiency at the lower condenser temperatures relative to the values given in Fig. 17.

Effects of Regenerative Feed Heating

The effects of regenerative feed heating on the overall thermal efficiency of the cesium and potassium vapor cycles are shown graphically

in Fig. 18 as a function of the number of stages in the turbine. Data are presented in Table 15 and Fig. 18 for three basic cycles, the ideal Rankine cycle, a Rankine cycle with a 75% turbine efficiency, and a set of Rankine cycles with a 75% turbine efficiency with regenerative feed heating using a feed heater having a heating effectiveness of 80%. In each instance, bleed-off for regenerative feed heating was assumed between each pair of adjacent turbine stages, that is, a two-stage turbine would have one bleed-off, a three-stage turbine would have two bleed-offs, etc. Note the dramatic improvement in cycle efficiency obtainable through the use of regenerative feed heating. The improvement runs as much as four points in cycle efficiency, or about 18.5%. This would permit a very substantial reduction in radiator size and weight, and appreciable reductions in the size and weight of the reactor and shield assembly. These savings much more than offset the extra weight and complication represented by the introduction of the feed heater.

Bleed-off for regenerative feed heating reduces the amount of work obtained per pound of vapor entering the first stage, and thus makes it necessary to increase the vapor flow to the first stage of the turbine by a small amount. At the same time, it greatly reduces the amount of vapor flowing through the latter stages. The combined effects of these two factors tend to reduce the amount of channel divergence between the first and last stage, an important factor from the standpoint of aerodynamic efficiency. Note, too, that the size and weight of the vapor ducts between the turbine and the condenser will be reduced with the regenerative feed heater. This is especially important if the ducts are fairly long, as they would be if a direct condensing radiator were employed. Note, too, that bleed-off for regenerative feed heating makes it possible to employ to advantage the vapor leaking past the labyrinth seal between the first stage and the adjacent bearing. This leakage represents a relatively small loss with regenerative feed heating, but a substantially larger one if it cannot be used to advantage in this fashion. (In large steam plants about one-third of the steam is bled off for regenerative feed heating, thus greatly easing the design of the last stages of the turbine.)

The disparity in cycle efficiency between the points for the five-stage cesium and potassium vapor turbines was investigated by examining

the data in Tables 5, 6, 10, and 11 for the 2150°F/1330°F condition. Note that there is essentially no difference in efficiency between these two turbines yielded by the thermodynamic calculations with no regenerative feed heating, but that the difference amounts to over one percentage point in cycle efficiency (i.e., over 4%) with regenerative feed heating. The points read from the Mollier diagram were rechecked using a magnifying glass, and some small errors in Tables 5 and 6 were found, but these were not nearly large enough to account for this difference. Closer inspection revealed that the amount of heat added to the liquid in the regenerative feed heater represented a substantially larger fraction of the heat of vaporization for cesium than for potassium (note that in both instances the turbines were five-stage units, and the extraction points were at the same temperature). To check this, data were taken from the NRL reports for thermodynamic properties of cesium and potassium (Refs. 17 and 18) and tabulated in Table 16 for cycles designed to operate between a saturated boiler outlet condition of 2150°F and a condenser temperature of 1400°F (these values were chosen to avoid uncertainties associated with interpolation or extrapolation of the NRL tables). Note that in Table 16 the ratio of the heat added to the liquid between the condenser temperature of 1400°F and the boiler temperature of 2150°F represents 28.1% of the heat vaporization for cesium and only 20.9% of the heat vaporization for potassium. Thus the benefits of regenerative feed heating are substantially greater for cesium than for potassium. It is not clear whether this improvement stems from inherent differences in the physical properties of the two fluids, or whether it is an artifact of the approximations used to correlate the experimental data for the physical properties. This matter is discussed by H. W. Hoffman in a companion report.¹⁹

Effects of Aerodynamic, Seal Leakage, and Moisture Losses

The data in Tables 5, 6, 10, and 11 were employed to separate and distinguish the various effects of the aerodynamic, seal leakage, and moisture losses. In analyzing these data, some small inaccuracies in

the calculations in Tables 5, 6, 10, and 11 were disclosed because the effects of the individual losses were found to be a bit irregular, and these small inaccuracies (mostly associated with difficulties in reading the Mollier diagram for potassium) were corrected. The additional calculations made to separate the various losses are shown in Table 17, and the results are summarized in Table 18.

A good insight into the relative importance of the aerodynamic, moisture, and seal losses is given by Fig. 15 which was prepared for cycles with no regenerative feed heating. The points for the aerodynamic losses were those obtained through the use of Balje's charts, reproduced here as Figs. 4 and 5. The effects of moisture assuming 1.25% loss in turbine efficiency per percent of moisture is about as great as the sum total of the aerodynamic losses. This points up sharply the possible gains associated with removal of the moisture in a manner that would minimize the amount of liquid churning, that is, transfer of momentum from the rotor to liquid droplets. Porous stator blades appear to offer a promising approach to the removal of the liquid in such a manner.

The effects of flow bypass through the labyrinth seals on the cycle efficiency are also shown in Figs. 15 and 16. Note that the use of regenerative feed heating makes it possible to use much of the leakage past the seal between the first-stage rotor and the adjacent bearing in the feed heater, and this makes the seal loss substantially lower than is the case for the simple nonregenerative cycles.

It is worth noting that both the seal and moisture losses are somewhat greater for potassium than for cesium. The seal losses are definitely higher for potassium because of its higher velocity through the clearance openings in the labyrinth seal. The moisture losses appear to be higher for potassium because an isentropic expansion from the dry saturated vapor condition between the same temperature limits gives about 10% more moisture for potassium than cesium according to the NRL Mollier diagrams of Refs. 17 and 18. This difference may be real or it may be simply an artifact of the approximations employed in the construction of the charts. The matter also is discussed in a companion report by H. W. Hoffman.¹⁹

Effects of Generator and Feed Pump Losses

The effects of losses in the electrical generator and the feed pump are shown in Fig. 16. The generator losses were the same for cesium and potassium. The feed pump losses were higher for cesium than for potassium, but the effect is so small that it is not apparent in Fig. 16. However, it does have a large effect on the size and weight of the feed pump and its auxiliaries if an electromagnetic pump is employed.²⁰

REFERENCE DESIGNS

Consultation with S. V. Manson, W. L. Stewart, A. J. Glassman, J. A. Heller, and J. P. Joyce of NASA led to the selection of a series of reference designs for detailed analysis. The curves shown in Figs. 12 and 13 span the range of interest. For one set of reference designs it seemed well to choose the number of turbine stages to give a turbine efficiency close to the peak obtainable, and this led to the choice of a three-stage cesium turbine and an eight-stage potassium turbine. In addition, it seemed well to consider a pair of turbines having the number of stages reduced to the point where the loss in turbine efficiency would run approximately one percentage point, and this led to the choice of a two-stage cesium turbine and a five-stage potassium turbine.

In selecting rotor and bearing configurations, two basic cases were considered: a) the turbine and generator rotors each straddle-mounted and connected by a quill shaft to give a four-bearing machine, and b) the turbine stages overhung from the end of the generator rotor to give a two-bearing machine. It was decided that it would be well to look at both two-bearing and four-bearing machines for the three-stage cesium turbine and the five-stage potassium turbine. In addition, a two-stage cesium turbine in a two-bearing machine and an eight-stage potassium turbine in a four-bearing machine appeared appropriate. Table 19 summarizes these six cases.

The moisture removal and erosion problems are rendered less severe for those cases in which the number of stages is small or the rotor is split as was contemplated in the five-stage potassium turbine in a

two-bearing machine (with the first three stages of the potassium turbine at one end of the generator and the other two stages at the other end). As a consequence, only four of the above six cases were considered for detailed analysis of the moisture removal problem.

Layout Studies

Layouts were prepared for each of the six cases in Table 19. Two drawings were prepared for each case; one drawing was intended to show the principal details of the turbine construction while the other was prepared to specify the key dimensions involved in the studies of the rotor and bearing dynamics. These drawings are presented in Figs. 19 through 30.

It is believed that the drawings showing the details of construction of the turbines make it possible to satisfy all of the boundary conditions summarized in Table 2. In the time available it was not possible to prepare the additional drawings required to show many minor details that were considered and for which allowances were made by allocating the space required, etc., but it is believed that these details would have little effect on the evaluation of the relative merits of cesium and potassium as working fluids.

Inasmuch as the layouts of Figs. 19 to 30 had to be prepared before making the final set of iterative calculations summarized in Tables 21 and 22 there are some disparities in blade height and stage diameter between these dimensions in the layouts and the corresponding values in Tables 21 and 22. These disparities are small, and simply mean that the blade height and stage diameter should be obtained from the tables rather than by scaling from the drawings.

Aerodynamic Considerations

The first step in preparing the layouts in Figs. 19 through 30 was to repeat the calculations of Tables 5, 6, 10, and 11 using — where available — the overall turbine efficiency implied by those tables rather than the value of 75% assumed in Tables 5 and 6. The results are tabulated in Tables 20 and 21. In making the thermodynamic calculations of Table 20, the amount of reheat to be expected from the adiabatic expansion

was found by taking the product of the aerodynamic efficiency and the efficiency associated with the moisture churning losses.

In employing the data of Tables 20 and 21 in preparing the layouts, some changes in rotor diameter and blade height were made to assure that the inlet nozzle angle would not be less than 15 deg, that the flow from the rotor into the subsequent stator would be within 15 deg of axial (to avoid divergence in the channel through the stator inlet vanes), and the diameter was stepped fairly uniformly from one stage to the next. An examination of Baljé's charts indicates that the procedure followed in the preparation of Table 21 is such that variations in diameter up to around 10% can be made in the vicinity of the diameter for maximum efficiency with little effect on the efficiency. With these modifications to the turbine proportions, the layouts of Figs. 19 through 30 were prepared together with the dimensional and performance data of Table 22. Note that splitting the five-stage potassium turbine so that three stages might be mounted at one end of the generator and two stages at the other to give a two-bearing machine cause increased aerodynamic losses between the third and fourth stages (for which no allowance was made in the data presented in Table 22).

The velocity diagrams for the various cases are presented in Figs. 31 through 34. Note that, in preparing these, the axial velocity was selected to yield a minimum stator exit angle of 15 deg, which in turn meant adjusting the blade height in accordance with the rotor diameter chosen from aerodynamic passage layout considerations.

It was difficult to decide how best to handle the increases in diameter from one stage to the next as implied by the calculations of Tables 10, 11, and 21. Rotor stress considerations (to be discussed in the next section) strongly favor keeping the first stage rotor diameter to a minimum. This stems from the fact that the small blade height in the first stage rotor makes the performance of that stage quite sensitive to the tip clearance. The first stage tip clearance, with allowances for distortion and creep over a 20,000- to 40,000-hr rotor life, would be likely to run on the order of 10% of the blade height, which would give a loss in efficiency in the first stage as a consequence of tip leakage of perhaps 15%. Note that, for a given set of conditions, this loss will increase rather rapidly with an increase in stage diameter - as will creep in the rotor. In view of the rather large losses associated with flow

bypass through the labyrinth seals at the hub and the need for pronounced thickening in the web of the rotor at the hub, it was found difficult to keep the centerline spacing between rotors to less than 1.25 in. As can be seen in Fig. 19, for example, this relatively wide spacing makes it possible to obtain a passage layout having a longitudinal section in which the radius of curvature of the S-shaped passage connecting the two rotor stages is large relative to the radial thickness of the passage, and hence the S-shaped passage should not give serious difficulty with flow separation, and the aerodynamic losses associated with distortion of the velocity distribution should not be too serious. Note, too, that the stator exit angle is only 15 deg, and that the stator pressure ratio in most cases is close to two or greater, so that the stator blading is quite different from that for a conventional reaction turbine. Another approach would be to employ essentially conical passage walls for the rotor casing, but this greatly complicates both the design and the fabrication of the rotor blades without yielding a clear-cut performance advantage. As a consequence, the flow through the rotors was kept axial and the stage diameters were stepped as shown in Figs. 19 through 30 as a compromise measure because no clearly better approach was evident.

Generalized diagrams for the rotor and stator blading in Figs. 19 through 30 are presented in Figs. 35 and 36, while Tables 22, 23, and 24 summarize the principal dimensions for the four cases to be examined in the moisture removal analyses. Note that the axial width of the turbine blades has been tapered in the radial direction so that the blade profile generated by a conventional end-milling procedure will yield the appropriate blade angle variation from root to tip. Similarly, the stator blade layouts were made to be elements of an elliptical cylinder with the leading edge defined by a slice through the cylinder at an angle chosen to give the proper variation in the inlet angle as required by radial variations in the direction of the rotor exit velocity vector from the previous stage.

The relatively large changes in diameter from one stage to another led to rather complex stator flow passages. For the moisture removal analysis it was necessary that analytical expressions be defined for these passages. In doing this, several approaches were tried, and it was found

that a simple way of handling the problem was to specify that the longitudinal projection of the pitch line would be in the form of a sine curve, with the stator blade length representing one-half cycle, as shown in Fig. 37. The dimensions given on the curves are in inches, and the symbols used are defined in the table of nomenclature given in this section. The inner and outer walls of the passage would be generated by a circle whose diameter would vary according to an appropriate schedule as discussed below. Figure 38 shows a diagram similar to that of Fig. 37 except that it is for the circumferential projection of the stator blades.

Nomenclature

A_s	Stator flow passage area normal to the local mean flow direction
d	Diameter of a circle tangent to both boundaries of passage in the circumferential projection
$\bar{D}$	Passage mean line diameter
D_p	Diameter of radial projection cylinder
h	Blade height
S	Wheel centerline spacing
L	Stator axial length
w	Blade width of turbine bucket in axial direction
y	Circumferential distance on radial projection cylinder
z	Distance in the axial direction (parallel to turbine centerline)
θ	Angle between flow direction and turbine centerline
φ	Nozzle exit angle

Subscripts

O	Inlet, $z = 0$
L	Exit, $z = L$
t	Throat

Added

D_O, D_L	Stator inlet and exit OD, respectively
A_t	A_s at $z = z_t$
a	Ellipse semi-minor axis

Stator Flow Passage Area

The stator passage flow area is defined as a function of axial distance, z , along the turbine centerline by

$$A_s = \pi d \bar{D} \cos \theta . \quad (1)$$

The various terms appearing in the equations presented here will be found defined in the Nomenclature in the previous section.

The direction of the flow in the developed radial projection is defined by

$$\cos \theta = \frac{1}{\sqrt{1 + \tan^2 \theta}} , \quad (2)$$

where $\tan \theta$ is the slope of the stator blade contour in the radial projection, that is,

$$\tan \theta = \frac{dy}{dz} = y' . \quad (3)$$

In the radial projection, the stator blade contour is a quarter-ellipse defined by

$$Az^2 + By^2 + Czy + Dz + Ey = 0 , \quad (4)$$

with

$$A = 1 + 3 \cos^2 \varphi ,$$

$$B = 1 + 3 \sin^2 \varphi ,$$

$$C = -3 \sin 2\varphi ,$$

$$D = -4 a \sin \varphi ,$$

$$E = -4 a \cos \varphi .$$

The semi-minor axis, a , of the ellipse is given by

$$a = \frac{L}{\cos \varphi + 2 \sin \varphi} . \quad (5)$$

The axial length, L , of the stator blade is found from

$$L = S - \frac{1}{2}(w_0 + w_L) - 0.35 . \quad (6)$$

The constant, 0.35, arises from an allowance of 0.10 in. at the stator inlet and 0.25 at the exit, the latter for droplet acceleration. Finally, the slope, y' , is determined from

$$y' = - \frac{2Az + Cy + D}{Cz + aBy + E} . \quad (7)$$

In order to minimize angular deviations resulting from the change in stator radius from inlet to exit, the projection cylinder diameter (i.e., the constant radius circular cylinder on which the radial view of the stator is projected) is taken to be the mean of the inlet and exit mean diameters. Thus,

$$D_p = \frac{1}{2}[(D_0 - h_0) + (D_L - h_L)] . \quad (8)$$

The diameter of the passage mean line in the circumferential projection is given by

$$\bar{D} = (D_0 - h_0) + [(D_L - h_L) - (D_0 - h_0)] \sin^2 \frac{\pi s}{2L} . \quad (9)$$

Specification of the flow area can now be completed by defining d , the diameter of the circle tangent to the passage boundaries in the circumferential projection, as a function of z . The supersonic case will be considered first.

With the throat area, A_t , and location, z_t , specified, we find d_t from Eq. (1), rewritten as

$$d_t = A_t / \pi \bar{D} \cos \theta , \quad (10)$$

where all quantities on the right hand side are evaluated at $z = z_t$. The stator throat is located by specifying that the arc length from exit to throat be equal to the separation distance between the same exit and throat areas in an equivalent circular cone of specified divergence angle. Because of the favorable pressure gradient, one can use a rather large angle, say 20 deg.

We now take a linear variation of d from inlet to throat and from throat to exit, that is,

$$d = \frac{d_t z + h_0(z_t - z)}{z_t}, \quad 0 \leq z \leq z_t, \quad (11)$$

and

$$d = \frac{d_t(L - z) + h_L(z - z_t)}{L - z_t}, \quad z_t < z \leq L. \quad (12)$$

The subsonic case is handled by ignoring Eq. (10) through (12) and simply specifying a single linear variation of d from inlet to exit, that is, we have

$$d = \frac{h_L z + h_0(L - z)}{L}, \quad 0 \leq z \leq L. \quad (13)$$

Stress and Creep in the Rotor

Creep-stress limitations present a major problem in the design of the rotors for the first one or two stages. Some indication of the severity of the problem is given by Fig. 39 which shows two curves, one for the stress in a typical turbine rotor as a function of tip speed, and the other for the stress that would give a creep rate of 0.5% per 10,000 hr. These curves show the importance of reducing both the rotor tip speed and the rotor temperature. This problem is vital, and will be treated later in detail.

One advantage of the impulse turbine is that the temperature drop in the nozzle ahead of the turbine leads to a lower static temperature for the vapor passing through the turbine wheel than the static temperature prevailing at the inlet to the stator for that stage. However, as the pressure ratio and temperature ratio across the stator are increased, it is necessary to increase the turbine wheel tip speed in order to make effective use of the higher velocity jet associated with the higher temperature and pressure ratio across the stage. The higher tip speed leads to increased stresses, and this may more than offset the increased allowable

stress in the turbine wheel as a result of its lower operating temperature. In an effort to determine the net effect, data were taken from Tables 10 and 11 for the first stage of 4-, 5-, 7-, and 9-stage potassium turbines, and 1-, 2-, 3-, and 5-stage cesium turbines. The first stage tip speed and temperature drop were entered in Table 25, and the stress corresponding to that tip speed was taken from Fig. 39. The static temperature corresponding to that stress was also taken from Fig. 39 to give the maximum allowable static temperature of the vapor passing through the turbine wheel, and hence the turbine wheel temperature. To this value was added the temperature drop in the stator to yield the vapor temperature entering the stage. The latter data were then plotted in Fig. 40. These data indicate that a nine-stage potassium vapor turbine could be operated with a turbine inlet temperature about 50°F above that for a five-stage potassium vapor turbine. Similarly, a three-stage cesium turbine could be operated at a temperature about 80°F above that for a two-stage turbine, while a single-stage cesium turbine could be run at a temperature about 150°F above that for a two-stage unit. However, the single-stage cesium vapor turbine would be likely to give other difficulties, as indicated in earlier discussions. Thus, it appears from Fig. 40 that, from the standpoint of creep in the turbine wheel, there is little gain in a turbine inlet temperature obtainable through an increase in the first stage pressure ratio.

An important point shown by Fig. 40 is that, if creep stresses in the first stage turbine wheel were the controlling consideration in the selection of the system operating temperature, cesium would permit an increase in the turbine inlet temperature of about 300°F relative to the corresponding value for potassium. However, it appears that creep stresses in the fuel elements, which will have to run hotter by 300°F or more, will be more likely to limit the vapor temperature entering the turbine than turbine wheel stresses, hence the advantage of cesium will be that it will provide a greater margin between the design stress and the creep limit or provide more latitude in the design of the turbine.

Rotor Balancing

The stacked disc casing and rotor configuration employed here has the disadvantage that final balancing of the rotor would have to be carried out with the rotor and casing assembled. At the outlet end, the rim of the last stage of the rotor would be readily accessible for removing material. At the inlet end it would be necessary to remove material at a relatively small radius, that is, at the outer perimeter of the hub just in-board of the bearing.

Rotor Masses and Moments of Inertia

To provide data for the rotor and bearing dynamics analyses, each rotor in the layouts of Figs. 19 through 30 was broken down into a large number of small, simple, geometric elements for which the weight and polar moment of inertia could be estimated. The values for the various small elements were then summed to provide weights and moments of inertia for each wheel in the turbine and each stub-shaft at either end of each turbine rotor. Similarly, the Westinghouse data summarized in Table 1 for the generator was employed to estimate the weight and moment of inertia of the generator rotors. In addition, a coupling weight was estimated for the four-bearing machines. Results of these calculations are summarized in Table 26.

Turbine Casing Design for Dimensional Control

A major problem in the layout of the casing for a high temperature turbine is the development of a detail design that will lend itself to fabrication and assembly, give good centering of the various parts to provide good bearing alignment and permit small running clearances, accommodate the necessary amounts of differential thermal expansion, minimize bypass leakage, and avoid heat losses associated with vapor condensation on surfaces at temperatures below that corresponding to the local saturation pressure. In the layouts of Figs. 19 through 30 considerable care has been taken to reduce the temperature gradients and thermal stresses

by making the interstage diaphragms conical and by adding membranes for thermal insulation. Care has been taken in designing these diaphragms and membranes so that they will accommodate whatever pressure differential might occur across them.

An important question associated with the layouts of Figs. 19 through 30 is the degree to which tolerances may tend to build up in the stack of casing or rotor elements and lead to sufficient eccentricity to cause a rub in the interstage labyrinth seals or at the rotor blade tips. In an effort to analyze this, Fig. 41 was prepared to show the basic geometric relations. The width of the conical surface forming the joint between adjacent sections of the casing is referred to as w , while the distance from the inner edge of the conical mating surface to the shaft center line measured along an element of a cone perpendicular to the mating surface was taken as R , and c_1 was taken as the distance from the apex of the aforementioned cone to the outer edge of the conical mating surface. The principal form of misalignment that might result from this structural geometry appears to be analogous to that to be expected from slipping one sphere inside another (where the conical surfaces are taken as approximations to a sphere). Such a slippage would cause the distance w_1 to be reduced to w_2 and, at the same time, the length c_1 would be reduced to the length c_2 of Fig. 41. The difference between c_1 and c_2 as compared to the difference between w_1 and w_2 then gives an indication of the amount of misalignment that might accrue from a given deviation from ideality in the fabrication of the surfaces. The relation between these two differences can be derived quite simply on the basis of relations that can be deduced from Fig. 41.

The results of the above derivation coupled with an inspection of the turbine layouts of Figs. 19 through 30 indicates that, if the concentricity error associated with a 45 deg conical joint between two casing sections is to be kept to 0.001 in., the conical surfaces should have the same slope within 0.001 in. This will require either that the parts be lapped together in a special fixture before final assembly or that the final surface finishing operation be carried out in the same machine with the same compound cross-slide setting to generate the conical surfaces of

the mating parts. Note, too, that the precision required for a given permissible build-up in eccentricity is a function of the number of stages because of tolerance accumulations.

To avoid difficulty with buckling or other damage to the thin membranes, the space between the membrane and the diaphragm would be vented to a lower stage pressure or the turbine discharge pressure, and spiral wires or embossed stand-off points would be provided on sufficiently close centers to support the membrane in such a way that the bending stresses induced in the membrane would be acceptable.

Size and Weight of Reference Design Units

The overall diameters and lengths of the six reference design turbine-generator units were scaled from Figs. 20, 22, 24, 26, 28, and 30 and summarized in Table 27. The weights of the rotors were taken from Table 26, and the weights of the casings including the outer shell (for hermetic sealing) were estimated and tabulated. Inasmuch as the weight of a turbine stage increases as the cube of the diameter, the larger diameter of the potassium turbines increased the turbine weight by roughly a factor of two over the corresponding cesium turbines. In addition, for a given turbine efficiency the greater number of stages for the potassium turbine evidently lead to an additional factor of two increase in weight for the potassium turbines.

In making the weight estimates there was no attempt to allow for weight reductions that might be effected by refining the details of the design. It is difficult to estimate to what extent wall thicknesses might be reduced by using ribs, milling out recesses, or the like short of a quite detailed analysis, but it appears that substantial savings would be possible. On the other hand, it is possible that some important items that would increase the weight substantially have been overlooked. In the balance it is believed that the values given in Table 27 represent overestimates of the weights, and the effect of this is probably to penalize the potassium turbines somewhat in comparing the potassium and cesium system weights.

ANALYSES OF SPECIAL PROBLEMS

Very early in the design study it became evident that four major problem areas were so deserving of special attention that each should be attacked by a group of specialists and their work covered in a separate report. The first of these - turbine bucket erosion - was so vital to the layout of the reference design turbines that an extensive survey of the literature was carried out concurrently with the parametric studies, and the results were summarized in a report.⁹ The other three major problem areas were creep in the first stage rotors, bearing and rotor dynamics and temperature distribution and thermal stresses. All of these have been discussed in general terms in previous sections, but detailed analyses could not be undertaken until detailed reference designs were available. In view of the great technical difficulty of the problems, the high order of technical competence required to cope with them, and the need for special computer programs, it was deemed best to seek assistance outside of ORNL. A subcontract was arranged with Mechanical Technology, Inc. to estimate the amount of creep to be expected in the first stage rotors of the reference design turbines, to design bearings suitable for each of the reference design turbines, and to investigate the bearing and rotor dynamics for each of the reference design turbines. Similarly, a contract was arranged with the Westinghouse Astronuclear Laboratory to make a detailed analysis of moisture formation, deposition, and possible turbine bucket erosion in the reference design turbines. Extensive experience with thermal stress problems at ORNL led to the conclusion that it would be just as well to handle these problems in the reference design turbines within the ORNL organization.

Detailed presentations of these specialized design studies and analyses are presented in companion reports.²¹⁻²³ A brief summary of the results is presented in the following sections together with a discussion of the modifications in the reference design that are shown to be in order by these studies.

Rotor Creep Stress Analysis

The rough preliminary rotor creep analysis presented earlier clearly showed the need for a more refined analysis, and this was arranged. ORNL supplied MTI with the data on the reference designs presented in the previous section together with what data could be found by ORNL metallurgists on creep and creep rupture in TZM, the molybdenum alloy chosen for the rotor. MTI correlated the latter data using a Larson-Miller plot to develop charts for the creep analysis work. These data were then applied to estimating the creep in the reference design rotors using a modification of a technique developed at the NASA-Lewis Laboratory for turbo-jet engines.²⁴ The results of the study are presented in Table 28 in which the upper portion represents the data developed at ORNL for the reference designs, the central portion gives the data on bearings and bearing and rotor dynamics developed at MTI, and the last portion summarizes the MTI rotor creep stress analyses. These results show that the cesium reference designs would yield a radial growth in the first stage less than 0.003 in. in 40,000 hr, and hence are acceptable from the creep standpoint. The potassium turbines, however, were found to have excessive creep stresses and growth so that some modification would be essential. One approach would be to reduce the turbine inlet temperature. Figure 42 shows the effects of turbine wheel operating temperature on the growth of the wheel for 40,000 hr of operation. These curves indicate that the turbine inlet temperature would have to be reduced by over 100°F to bring the growth rate within acceptable limits.

To avoid the loss of performance that a reduction in the turbine inlet temperature would entail it seemed in order to consider the possibility of reducing the stresses by reducing the diameter of the first stage rotor. Figure 5 shows that reducing the rotor diameter at a constant specific speed results in only a small loss in efficiency in the region in which the first stage potassium rotors fall, that is, at the extreme left end of the constant efficiency "contour lines" in Fig. 5. An examination of the curves in Fig. 39 indicates the reducing the diameter by about 22% would reduce the stress by about 40%, and this would have about the same effect on creep as reducing the turbine rotor temperature by 125°F. An examination of Figs. 15 and 16 indicates that reducing the turbine inlet temperature would result in a loss of about one point in overall cycle

efficiency, whereas Fig. 5 indicates that reducing the diameter of the first stage 22% would cause a loss of about 3 points in the efficiency of the first stage. This would amount to about half a point loss in the overall efficiency for the turbine, and only about two-tenths of a point in the overall cycle efficiency. Thus it appears that the better course would be to reduce the diameter of the first stage rotor in each of the potassium reference design turbines.

Bearing Rotor and Dynamics

Discussions with both MTI and the Aerospace Electrical Division of Westinghouse in the course of the preliminary design work disclosed that MTI was carrying out a set of bearing and seal design studies for a Westinghouse generator similar to that chosen for this study. As a consequence, a subcontract was arranged under which it was agreed that ORNL would supply MTI with turbine and generator layout drawings in which the bearing regions were left vague with the intent that MTI would specify the detailed proportions of these regions. Thus the first step in the MTI study was to develop a set of bearing layouts for the two-bearing and four-bearing machines, and these are shown in Figs. 43 and 44. The MTI studies showed that four tilting pads in each bearing gave the most promising arrangement, and this configuration was used in all cases because it avoids difficulties induced by shaft whip in turbulent film hydrodynamically lubricated bearings, and this greatly eases the problems of obtaining an acceptable bearing and rotor configuration for the reference design turbines. Further, it is inherently self-aligning, hence insensitive to distortion.

It may be noted that the basic layout for the four-bearing machines includes a thin-walled section in the shaft between the first stage rotor and the adjacent bearing, and that for the two-bearing machines has a thin-walled section between the last stage rotor and the adjacent bearing. This was done to provide a heat dam both to reduce the heat loss to the bearings and to reduce the thermal stresses in the hub region where the thermal gradient would be high. As will be discussed in the next section, the temperature distribution and thermal stress studies carried out at ORNL indicate that the heat dam regions would not be necessary if the rotor were segmented as in Figs. 19 to 30.

Frictional Horsepower

The power losses associated with fluid friction in the bearings not only reduce the net power output of the turbine-generator but also increase the heat load on the radiator. These losses were calculated by MTI and are summarized in Table 28 in the third from the last line of the table. The 2.0 in. diameter journals for the four-bearing machines gave about one-quarter of the frictional loss per bearing given by the 3.0 in. diameter bearings used in the two-bearing machines. As a consequence, the overall bearing frictional power losses in the turbine-generator units ran about half as much for the four-bearing machines as for the two-bearing machines.

Critical Speed Analyses

In attempting to summarize the results of the MTI analyses it was noted that the critical speeds for the alternators were close to those for the turbines. As a consequence, each critical speed value given in Table 28 for a four-bearing machine is a mean between that for the turbine and that for the generator.

It should be pointed out that the first two critical speeds in all the cases analyzed were rigid body criticals and the third critical speed is a flexural one. Analysis by MTI of the unbalance response of each of the damped rotor bearing systems showed that the amplitudes of the rotor when passing through the first two critical speeds were not excessive.

Turbine-Bucket Erosion Analysis

ORNL supplied the data on the four reference designs (presented in previous sections) to the Westinghouse Astronuclear Division for use in their computing machine programs for estimating the moisture formation in the course of the expansion of wet vapor in passing through a turbine, the extent to which the moisture will tend to deposit on rotor and stator blades, the behavior of the liquid dribbling off the stator blades, and the threshold for damage to the rotor blades.

The Westinghouse study (reported in Ref. 22) began by estimating the amount of moisture present in the vapor as a function of axial position

in the turbine. In all cases the droplet diameters were found to be less than 1 micron for both cesium and potassium. The amount of moisture that deposited in the various blade rows was then calculated and in no instance was it as much as 4% of the total moisture present in the vapor at that station. The initial diameter of the liquid droplets shed from the trailing edges of the stator was then calculated together with the extent to which these droplets would be accelerated and broken up into smaller droplets. From these calculations the velocity of the droplets relative to the rotor at the point at which they would strike the turbine buckets was calculated and in all instances was found to be less than 800 ft/sec. The droplet diameter at the point of interception was found to range from 1 to 5 microns for cesium, and from 8 to 26 microns for potassium for the last stages of the reference designs.

Following Pouchot's thesis that the threshold velocity for damage varies with the droplet diameter and the Vickers diamond point hardness of the blade material, the last portion of the analysis was concerned with the estimation of the threshold velocity for damage for each of the four reference designs considered using the range of diameter for the drops impacting on the last stage rotor as the basis for the estimates. The results are summarized in Table 29. Note that in all instances the threshold velocity for damage to TZM blades is at least three times the actual relative velocity between the droplet and the blade, and hence droplets dribbling off the stator and impinging on the rotor should not cause turbine bucket erosion in the reference designs.

In view of the large margin available between estimated operating conditions and the point at which turbine bucket erosion would become a problem, consideration was given in the Westinghouse report²² to the possibility that the provisions for moisture removal between stages shown in the reference designs might be eliminated. It was concluded that the inter-stage moisture removal provisions are necessary because otherwise the liquid film traveling along the wall of the outer casing would build up to the point where large droplets would be torn from wave crests and would impinge on turbine buckets where they would cause damage. Further, lash of such droplets back and forth between the rotor and the casing could cause substantial amounts of damage to the casing.

Four different values of VPN were used to bracket potential bucket materials. These were:

<u>VPN</u>	<u>Typical Material</u>
190	12% chrome steel
260	TZM
400	Stellite 6
500	Maraging steel

Thermal Stress Analyses

A substantial effort was made to determine the temperature distribution in the rotor and stator of the reference design turbines and from these temperature distributions to determine the thermal stresses. Segmentation of the rotor and stator to provide heat dams between stages, while an effective technique from the standpoint of reducing thermal stresses, greatly complicates the computational process. It was found necessary to develop a new computer program to allow for the discontinuities represented by the parting surfaces between stages. Such a program was developed to define the temperature distribution in the rotor, and a second program was adapted from an existing one to determine the thermal stresses in any given segment using the temperature distribution as input. The results of these analyses indicate that segmentation reduces the heat losses associated with axial heat flow, and appears to keep thermal stresses within acceptable limits in all of the reference designs. The details of these calculations are presented in Ref. 23.

An attempt was made to carry out a similar series of analyses for the casings. However, the complexities of the geometry are such that a workable program was not developed within the limits of the time and funds available.

The most severe thermal stresses in the rotors were found in the four-bearing machines and occurred in the hub between the bearing at the high-temperature end and the first stage rotor. These require careful attention in the design, but either the segmented rotor shown in the reference designs of Figs. 19 through 30 or the thin-walled shaft arrangement proposed by MTI²¹ (see Fig. 44) appear entirely adequate to keep the thermal

stresses well within acceptable limits. Another area that threatens to yield thermal stress difficulties lies in the casing between the turbine and the generator. The most severe thermal stresses in this region occur in the two-bearing machines as a consequence of the short distances over which the difference in temperature must be distributed. Crude order of magnitude calculations indicate that these problems can be handled, but time did not permit a definitive study.

An attempt was made to analyze the local thermal stresses in the turbine buckets associated with the stagnation temperature rise in the vapor at the leading edge of the blade. For example, if the blade leading edge were approximated as a cylinder with a radius of 0.010 in., the temperature spike would occur over a distance of about 0.005 in. The effect of this highly localized impact temperature rise in the vapor on the temperature distribution and hence the thermal stress in the rotor blade is difficult indeed to resolve. However, there is reason to believe that the liquid film on the blades that is so important in minimizing erosion by droplet impact will also serve to diminish the effect of the impact temperature spike as a consequence partly of heat transport by the flowing liquid film and partly by re-evaporation of the liquid. In short, the analysis indicated that the relationships are very complex and probably can be resolved only by a well-thought-out series of experiments. In any event, there appears to be very little difference between cesium and potassium if the same number of turbine stages is employed, but the effect becomes progressively more pronounced as the number of stages is reduced and the temperature drop per stage is increased.

NOMENCLATURE

A	Area, ft^2
a*	Cutter diameter, ft
C	Chord length, ft
C _O	Spouting velocity
c _p	Specific heat at constant pressure, $\text{Btu}/\text{lb}\cdot^\circ\text{F}$
D	Rotor diameter, ft
D _s	Specific diameter, ft
g	Gravitational constant, ft/sec^2
H	Head, ft
h	Blade height, ft, and enthalpy, Btu/lb
J	Rotor blade chord, in.
M	Mach number
N	Rotative speed, rpm
N _s	Specific speed
n	Number of stages or nth stage
P	Pressure, psia
r	Radius, in.
Re	Reynolds number
S	Entropy, $\text{Btu}/\text{lb}\cdot^\circ\text{F}$
s	Tip clearance, ft
T	Temperature, $^\circ\text{R}$
t	Blade pitch, ft
U	Peripheral speed, fps
V	Volume flow, ft^3/sec
v	Specific volume, ft^3/lb
W	Weight flow, lb/sec
w	Relative velocity, ft/sec
X	Vapor quality
α	Absolute angle, deg
β	Relative angle, deg
η	Efficiency
μ	Dynamic viscosity, $\text{lb}/\text{ft}\cdot\text{sec}$

Subscripts

ad	Adiabatic
c	Cycle, condenser
is	Isentropic
<i>l</i>	liquid
m	Mean
s	Specific, sound
sv	Saturated vapor
t	Turbine
1	Inlet of stage
2	Before turbine rotor
3	Outlet of stage

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Table 1. Effects of Design Speed and Frequency on the Size and Performance of a Series of Inductor Alternators for Space Power Plants^{6*}

Coolant temp., °F	800	800	800	800	800
Rating, kva	400	400	400	400	400
Power factor, lagging	0.85	0.85	0.85	0.85	0.85
Frequency, cps	2000	2000	2000	1200	1200
Voltage, L-N	500	500	500	500	500
Speed, rpm	15,000	20,000	24,000	24,000	18,000
Number of poles	16	12	10	6	8
Pole width, in.	1.64	2.01	2.30	3.95	3.21
Stack length, in.	3.54	3.29	2.92	3.39	3.78
Length between stacks, in.	2.49	2.44	2.60	2.37	2.22
Rotor OD, in.	12.51	11.51	11.03	11.55	12.38
Rotor core OD, in.	7.94	7.15	6.63	7.14	7.80
Rotor ID, in.	0.53	0.46	0.42	0.37	0.37
Polar mom. inertia, in.·lb·ft ²	6.897	4.519	3.340	4.632	6.840
Rotor weight, lb	192	150	124	155	195
Pole face losses, watts	3536	1476	2583	640	2402
Pole tip temperature, °F	950	950	950	950	950
Material of rotor	H-11	H-11	H-11	H-11	H-11
Frame OD, in.	21.69	20.05	18.93	19.61	20.75
Frame ID, in.	19.56	18.13	17.21	18.263	19.23
Stator OD, in.	15.78	15.03	14.64	16.40	16.26
Stator ID, in.	12.71	11.72	11.23	11.75	12.58
Total elec. weight, lb	528	430	363	440	500
Stator losses, watts	20,800	22,200	21,500	18,835	17,703
Windage losses, watts	172	235	229	366	258
Vapor density in rotor cavity, lb/ft ³	0.00033	0.00028	0.00025	0.00025	0.0003
Hot spot temp., °F	<1058	<1148	<1220	<1328	<1184
Vapor viscosity, lb/hr·ft	0.0396	0.0396	0.0396	0.0396	0.0396
Windage Loss $\sim \rho^{.86} \mu^{.14}$					

*Data Supplied by Aerospace Electrical Division, Westinghouse Electric Corporation, Lima, Ohio.

Table 2. Summary of Design Precepts for Potassium and Cesium
for 300 Kwe Nuclear Space Power Plants

1. Turbine Speed

- (a) The turbine should be directly coupled to a 1200 cps generator, hence its speed will be 14,400, 18,000, or 24,000 rpm.
- (b) The relative velocity of the vapor entering the turbine should not exceed a Mach number of unity to avoid compressibility losses.

2. Bearings and Rotor Dynamics

- (a) Condensed vapor feed through a Micropore filter will serve as the bearing lubricant.
- (b) Tilting pad (or similar) bearings should be used with radial loads kept to less than 50 psi.
- (c) The rotor length and weight should be kept low, that is, the turbine diameter and tip speed should be chosen to give a minimum number of stages consistent with good efficiency.
- (d) Loads on thrust bearings should be less than 5 psi. This requires the use of nearly pure impulse blading, split flow, or folded flow through the rotor.
- (e) Bearing instability and shaft whip must be avoided.
- (f) It is desirable to keep the first critical speed of the rotor above the operating range. Under any circumstances the third critical speed of the rotor should be well above the operating range, and, for such designs, damping in the bearings must be sufficient to permit transient operation through the first and second critical speeds if these are below the design speed.
- (g) The design should be such that the estimated temperature distribution will not lead to thermal distortion in the rotor or casing that would change the bearing film thickness more than 10^{-5} in. from one end of the bearing to the other as a consequence of misalignment, ovality, etc.
- (h) Axial leakage of lubricant from the bearings into the rotor blade region should be kept small to avoid moisture churning losses.
- (i) The bearing surfaces should be of tungsten carbide or other material compatible with the working fluid.

3. Seals

- (a) In small turbines the amount of flow bypassing the stator nozzles through a casing split on the horizontal center line is likely to represent a large loss, hence the casing should be assembled by stacking rotor and stator discs alternately. The

Table 2. (continued)

rotor discs can be joined by a central, hollow, through bolt, and the stator casings by a set of bolts around the outer perimeter.

- (b) The stator blades should be coupled to diaphragms with labyrinth seals fitted to the rotor hub to reduce leakage.
- (c) The labyrinth seals should be designed to keep bypass flow losses to 1% if practicable.^{13,14}
- (d) Labyrinth seals should have sufficient shaft clearances so that contact with the shaft can never occur. (High leakage is preferable to shaft whip induced by possible contact.) A minimum clearance of 0.001 in. per inch of rotor diameter appears reasonable (see Ref. 14).

4. Regenerative Feed Heating and Moisture Removal

- (a) Regenerative feed heating should be employed to improve the cycle efficiency and thus reduce the size, weight, and cost of the reactor and radiator. It also contributes to flow stability in the boiler and reduces thermal stresses in the boiler.
- (b) Interstage bleeds should be provided to remove moisture between stages to inhibit turbine bucket erosion and reduce churning losses.
- (c) Leakage outboard from the first stage wheel through the labyrinth seal toward the adjacent bearing should be adjusted to give up to 75% of the desired flow to the appropriate stage of the feed heater.
- (d) Vapor will be bled from the exit of each rotor except the last and from each stator except the first to give up to four bleed stages. For turbines with more than five stages, bleeds should be placed between alternate pairs of stages. The bleed flow from each stator casing will be combined with that from the corresponding point in the labyrinth seal on the shaft and fed to the appropriate stage in the feed heater.
- (e) Heat dams should be used to prevent appreciable condensation on parts such as nozzle diaphragms that are exposed to two vapor regions at substantially different pressures and temperatures.

5. Generator

- (a) The generator should be a liquid-cooled 1200 cps machine with liquid metal-lubricated bearings.
- (b) The generator should be designed so that it can be seal-welded into the same outer housing as the turbine to avoid the need for a zero-leakage shaft seal.

Table 2. (continued)

6. Thermal Stresses and Distortion

- (a) Thermal sleeves should be provided to minimize thermal stresses around penetrations.
- (b) Conical webs should be used where possible to minimize the effects of radial temperature differences.
- (c) Conical mating surfaces should be used where good alignment (and/or a seal) is required between coaxial stationary parts having different coefficients of expansion or operating at different temperatures.
- (d) Temperature differences within any given part should be less than 100°F unless the temperature distribution is such that 100 thermal strain cycles will not be likely to cause a failure.
- (e) The high-temperature vapor should enter the casing through two or more symmetrically placed penetrations.
- (f) Where practicable, the materials of construction should have a low coefficient of expansion.

7. Maintainability and Fabricability

- (a) The complete turbine rotor, stator, and bearing assembly should be removable from the power plant by cutting only a single seal weld and removing a few nuts or cap screws. No lines should enter the cover plate to interfere with its removal.
- (b) It should be possible to test the complete rotor, stator, and bearing assembly outside the turbine casing to check for balance, bearing leakage, and aerodynamic performance.
- (c) The materials of construction should be such that no galling or self-welding will occur between mating surfaces in bolted assemblies.
- (d) The rotor and stator should be fabricable by Eloxing to cut the cost of experimental units.
- (e) Small blades with a minimum blade height are desirable to cut the cost of Eloxing.
- (f) The discs constituting the rotor should be assembled with a sufficiently high bolt tension so that static friction will suffice to resist the output torque, or splines should be employed.

8. Turbine Efficiency

The Reynolds number should be above 10^5

$$Re = \frac{12 W}{\mu r_m}$$

Table 2. (continued)

W = flow, lb/sec, μ viscosity, lb/sec·ft
 r_m = mean radius, ft

Table 3. Bases for the Thermodynamic and Aerodynamic Design
Procedures for a Series of Turbines Meeting the Design
Precepts of Table 2

-
1. Balje's analysis and charts¹⁵ provide a good basis for estimating the proportions and efficiency of turbine stages.
 2. The turbine efficiency is not very sensitive to the adiabatic head distribution between the stages for a given number of stages. The turbine efficiency will not be much less than optimum if the adiabatic head drop per stage is kept uniform. (It can be deduced from Figs. 4 and 5 that the ideal stage efficiency can be increased somewhat by progressively increasing the head per stage from the inlet to the outlet.)
 3. The erosion-limited tip speed may favor increasing the head drop across the last stage and reducing the rotor diameter.
 4. A larger than average head drop in the early stages will reduce the losses stemming from flow bypassing through the labyrinth seals.
 5. The maximum efficiency for a given adiabatic head for a particular stage is given by the maximum efficiency for a given specific speed. To facilitate interpolation, a curve defining this relation was obtained by cross-plotting the minimum specific speeds for each of the constant efficiency curves of Balje's charts in Figs. 4 and 5 to give the curves of Fig. 6 for full admission turbines. Curves for D_s , H_{ad} , D , and U for some typical values of N and V_3 were also plotted on the same sheet.
 6. To reduce the tip speed in the last stage it may be desirable to reduce D_s somewhat from the value for maximum efficiency implied by the extreme right-hand point of the constant efficiency curves of Balje's charts in Figs. 4 and 5.
 7. The velocity energy in the stream leaving any stage except the last stage will be available in the subsequent stage, hence the performance curves of Fig. 5 are applicable. The velocity energy in the stream leaving the last stage will be lost to the exhaust, hence the curves of Fig. 4 will apply for the last stage.
 8. The bypass flow through labyrinth seals can be estimated from Fig. 9.
 9. The loss associated with the leakage flow from the first-stage rotor cavity toward the adjacent bearing can be reduced by bleeding off vapor at intervals through the labyrinth seal at the pressures corresponding to those at the outlets of the various turbine stages. This vapor would be directed to the appropriate stage in the regenerative feed heater, thus reducing the interstage bleed requirements.
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Table 4. Summary of Thermodynamic Calculations for a Series of Ideal Rankine Cycles

T_o/T_c	Fluid	h_o	h_1	h_2	Δh_{is}	Δh_b	$\eta = \Delta h_{is} / \Delta h_b$
2150/1330	Cs	320	258	97.75	62	222.25	27.9
	K		981	341.4	249.5	889.1	28.1
2150/1200	Cs	320	245.7	91.9	74.3	228.1	32.55
	K	1230.5	932	321.9	298.6	908.6	32.85
2000/1200	Cs	316.9	251	91.9	65.9	225	29.3
	K	1222.5	964	321.9	258.5	900.6	28.7
2000/1330	Cs	316.9	263.6	97.75	53.3	219.15	24.3
	K	1222.5	1012.5	341.4	210	881.1	23.85
2000/1040	Cs	316.9	235.6	81	81.3	235.9	34.5
	K	1222.5	900	286.1	322.5	936.4	34.4
2150/1040	Cs	320	230	81	90	239	37.65
	K	1230.5	873	286.1	357.5	944.4	37.9
2150/1125	Cs	320	238.8	86	81.2	234	34.7
2150/1140	K	1230.5	912.2	304.8	318.3	925.7	34.4
2150/1250	Cs	320	250.5	93.7	69.5	226.3	30.7
2150/1240	K	1230.5	949	323.8	281.5	906.7	31.05
2000/1125	Cs	316.9	243.9	86	73	230.9	31.6
2000/1140	K	1222.5	938	203.8	284.5	917.7	31.0
2000/1250	Cs	316.9	265.1	93.7	60.8	223.2	27.25
2000/1240	K	1222.5	977	323.8	245.4	898.7	27.3

Table 5. Thermodynamic Calculations for Cesium Vapor Cycles with Bleed-Off for Regenerative Feed Heating

①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	⑮	⑯	⑰	⑱	⑲	⑳	㉑	㉒	㉓
Stage No.	Temperature (°F)	P (psia)	V _g (ft ³ /lb)	S _{ad} (entropy)	Vapor Quality		h _{is} (enthalpy)	h _{ad}	Δh _{is}	η	Δh _{ad}	H _{ad}	C _o	T _l	h _l (Btu/lb)	Δh _l (Btu/lb)	h _{vapor} (Btu/lb)	Vapor Bleed Fraction (%)	Flow Fraction into Stage	Turbine Δh		
					Isentropic %	Assumed η %		⑨ _{n-1} - ⑫	⑨ _{n-1} - ⑧ _n		⑩⑪	778 ⑩	√64.34 ⑬									
0	2150	314.6	.525	.3205	100	100	320	320		.75												
1	1740	114.5	1.3065	.3238	89	93	291.4	298.6	28.6		21.45	22,251	1196.5	1652	124.62		187.46		1.00		28.6	
2	1330	23.6	5.5691	.3286	79.1	83.1	264	272.6	<u>34.6</u> 63.2		<u>25.95</u> Σ 47.4	26,919	1316.0	1300	99.75	24.87	207.20	12.0	.88	47.4	<u>30.45</u> 59.05	6.6
0	2150	314.6	.525	.3205	100	100	320	320														
1	1880	172.2	.9001	.3225	93.5	96	302.0	306.5	18		13.5	14,004	949.2	1814	133.09		180.81		1.00		18.0	
2	1610	74.4	1.9375	.3250	87.2	89.8	285.2	290.5	<u>21.3</u>		15.975	16,571	1032.6	1548	116.79	16.3	193.66	8.42	.916		19.51	
3	1330	23.6	5.5691	.3285	78.3	83.0	266.2	272.3	<u>24.3</u> 63.6		<u>18.225</u> Σ 47.7	18,905	1079.0	1300	99.75	17.04	207.20	8.22	.834	47.7	<u>20.27</u> 57.78	6.6
0	2150	314.6	.525	.3205	100	100	320	320														
1	1990	229.3	.6923	.3215	97	98.4	310.0	312.5	10		7.5	7,780	707.5	1950	139.99		175.32		1.00		10.00	
2	1820	145.5	1.0498	.3230	93	94.6	300.1	303.2	12.4		9.3	9,647	787.8	1790	129.43	9.95	183.68	5.42	.946		11.72	
3	1660	88.4	1.6549	.3246	89.3	91.1	290.6	293.8	12.6		9.45	9,803	794.2	1628	119.81	9.63	191.25	5.04	.895		11.27	
4	1500	49.4	2.8250	.3263	85.7	87.4	280.3	283.7	13.5		10.125	10,503	822.0	1460	110.12	10.29	199.01	5.17	.844		11.39	
5	1330	23.6	5.5691	.3285	81.5	83	268.5	272.3	<u>15.2</u> 63.7		<u>11.4</u> Σ 47.775	11,826	872.3	1300	99.75	10.37	207.20	5.00	.794	47.7	<u>12.07</u> 56.47	6.6
0	2150	314.6	.525	.3205	100	100	320	320														
1	1830	149.7	1.0226	.3229	92	94.8	298.2	303.6	21.8		16.35	16,960	1044.6	1762	130.04		183.20		1.00		21.8	
2	1520	53.4	2.6291	.3260	84.5	87.5	278.7	284.9	24.9		18.675	19,372	1116.4	1450	111.34	19.31	198.03	9.75	.902		22.46	
3	1200	12.11	10.316	.3306	76.8	80.3	255.0	262.5	<u>29.9</u> 76.6		<u>22.425</u> 57.45	23,262	1223.4	1170	91.90	19.44	213.14	9.12	.811	57.5	<u>24.25</u> 68.51	5.6
0	2000	220.4	.731	.3237	100	100	316.88	316.88														
1	1780	129.4	1.1687	.3254	94.2	96.2	301.7	305.5	15.18		11.385	11,810	871.7	1726	127.02		185.44		1.00		15.18	
2	1550	59.9	2.3671	.3279	88.0	90.8	286.6	291.3	18.9		14.175	14,704	972.6	1508	113.16	13.25	196.57	6.74	.933		17.63	
3	1330	23.6	5.5691	.3380	82.8	85.3	271.3	276.3	<u>20.0</u> 54.08		<u>15.0</u> 40.56	15,560	1000.6	1300	99.75	14.02	207.20	6.77	.865	40.58	<u>17.3</u> 50.11	7.5
0	2000	220.4	.731	.3237	100	100	316.88	316.88														
1	1730	111.0	1.3443	.32595	92.4	95.1	297.8	302.6	19.08		14.31	14,844	977.3	1674	124.02		187.93		1.00		19.08	
2	1470	43.8	3.1557	.3287	86.2	88.8	280.8	286.2	21.8		16.35	16,960	1044.6	1410	108.29	16.33	200.46	8.15	.918		20.01	
3	1200	12.1	10.316	.3327	78.6	82	259.4	266.1	<u>26.8</u> 67.68		<u>20.1</u> 50.76	20,850	1158.2	1170	91.90	16.39	213.14	7.69	.842	50.78	<u>22.57</u> 61.66	6.0

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Table 7. Factors Affecting Turbine Efficiency

Volume flow rate
Density of working fluid
Viscosity of working fluid
Thermodynamic properties of working fluid
RPM
Rotor diameter
Blade height
Blade inlet angle
Blade exit angle
Blade chord
Blade pitch
Blade profile (airfoil shape)
Blade twist
Tip clearance
Sonic velocity
Inlet nozzle angle
Number of stages
Head per stage
Head distribution (between stages)
Diameter distribution
Degree of reaction
Fraction admission
Labyrinth seal diameter
Labyrinth seal clearance
Number of lands in labyrinth seals

Table 8. Leakage Flow Through 12-Land Labyrinth Seals
for 3.25-in.-diam Straight Journals with a Radial
Clearance of 0.0055 in. (Based on Ref. 13)

$$G = A \alpha \Phi \gamma \sqrt{\frac{g p_o}{v_o}} = 0.00039 \times 1.0 \times 0.24 \times 2.2 \times 5.67 \sqrt{\frac{p_o}{v_o}}$$

$$= 0.00117 \sqrt{\frac{p_o}{v_o}} \quad (\text{for } p_o \text{ in lb/ft}^2)$$

$$= 0.014 \sqrt{\frac{p_o}{v_o}} \quad (\text{for } p_o \text{ in psia})$$

Pressure ahead of seal, psia	250	100	30
Pressure ratio across seal	0.5	0.5	0.5
Inlet specific volume of potassium, ft ³ /lb	2.35	5.5	16.2
Potassium leakage flow rate, lb/sec	0.145	0.060	0.019
Potassium temperature, °F	2190	1865	1545
Cesium temperature, °F	2030	1705	1388
Cesium specific volume, ft ³ /lb	0.627	1.45	4.35
Cesium flow rate, lb/sec	0.28	0.116	0.0368

Table 9. Summary of Design Conditions for Parametric
Calculations of the Efficiency and Proportions
of Cesium and Potassium Turbines

Calculation Number	Fluid	Number of stages	T _{inlet}	T _{cond.}	RPM
1	Cesium	2	2150	1330	18,000
2	Cesium	3	2150	1330	18,000
3	Cesium	5	2150	1300	18,000
4	Cesium	3	2150	1200	18,000
5	Cesium	3	2000	1300	18,000
6	Cesium	3	2000	1200	18,000
7	Cesium	2	2150	1330	14,400
8	Cesium	3	2150	1330	14,400
9	Cesium	5	2150	1330	14,400
10	Cesium	2	2150	1330	24,000
11	Cesium	3	2150	1330	24,000
12	Cesium	5	2150	1330	24,000
13	Potassium	5	2150	1330	24,000
14	Potassium	7	2150	1330	24,000
15	Potassium	9	2150	1330	24,000
16	Potassium	5	2150	1200	24,000
17	Potassium	5	2000	1330	24,000
18	Potassium	5	2000	1200	24,000
19	Potassium	5	2150	1330	18,000
20	Potassium	5	2150	1330	24,000
21	Cesium	1	2150	1330	24,000
22	Cesium	3	2150	1330	18,000

Table 10. Aerodynamic Calculations for Cesium

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	
Flow, W (lb/sec)	N (rpm)	Stage No.	P _s (psia)	No. Lands in Seal	Seal Leakage (lb/sec)	V's (ft ³ /sec)	H _{ad} (ft-lb/lb)	N _s	η	D _s	H _{ad} ^{1/4}	V's ^{1/2}	Rotor Diam (ft)	Turbine Tip Speed (ft/sec)	Moisture Assumed η	Δh _{is}	Net In-Flow Fraction	Δh _{boiler}	Δh _{boiler} (No Bleed)	h/D	η Δh _{is}	Moisture Churning Loss	Fraction of Flow Through Stage	Net Stage Output	E (Net Stage Output)	η _c (%)	Power (kwe)	Rotor Diam (in.)	Blade Height (in.)	Weight Flow Correction	Corrected Rotor Diam	Corrected Blade Height	C ₁	B	M	
7.9 (2150°F-1330°F)	18,000	1	114.5 23.6	12	-0- .33	9.5985 30.8296	22,251 26,919	30.64 47.56	81.8 82.2	1.83 1.55	12.2134 12.8090	3.0981 5.5524	.464 .672	.467 676	.07 .169	28.6 34.6	1.00 .88	195.38	195.38 220.25	.0540 .0664	23.39 28.44	8.75 21.125	.9825 .8010	2097 1797	38.94	19.93 (17.94)	292.03	5.57 8.06	.301 .535	1.068374	5.95 8.61	.322 .572	259.38 328.37	747.50 682.55	.898	
		2	172.2 74.4		-0- .43	6.8264 11.9049	14,004 16,571	36.53 42.52	83.3 84.4	1.60 1.43	10.8783 11.3459	2.6127 3.4503	.384 .435	.384 424	.04 .102	18 21.3	1.00 .916	186.91	186.91 203.21	.0653 .0764	18.99 17.98	5.0 12.75	.9900 .8382	1410 1315	39.46	21.11 (19.00)	295.93	4.61 5.22	.301 .399	1.061311	4.89 5.40	.319 .423	227.74 275.09	583.73 634.06	.710	
		3	23.6		.20	29.6835	18,905	60.83	82.5	1.28	11.7258	5.4483	.595	595	.170	24.3	.834			.0873	20.05	21.25	.7732	1221				7.14	.623		7.58	.661				
		1	229.3 145.5		-0- .59	5.3815 6.8677	7780 9647	50.41 48.46	85.5 85.3	1.25 1.29	9.3917 9.9106	2.3198 2.6206	.309 .341	.309 340	.016 .054	10 12.4	1.00 .946	180.01	180.01 190.57	.0922 .0883	8.55 10.58	2.0 6.75	.9970 .8585	835 847	39.63	22.02	297.21	3.71 4.09	.342 .361	1.059023	3.93 4.33	.362 .382	202.25 221.05	420.77 471.22		
		2	74.4		.34	10.2007	9803	58.35	86.3	1.14	9.9504	3.1939	.366	365	.089	12.6	.895			.1046	10.87	11.125	.8320	804				4.39	.458		4.65	.485		461.00		
		3	88.4		.224	15.9960	10,503	69.39	86.9	1.04	10.1234	3.9995	.411	410	.126	13.5	.844			.1183	11.73	15.75	.7891	780				5.71	.583		5.22	.617		456.20		
		4	49.4		.128	28.5240	11,826	84.77	78.3	.93	10.4282	5.3408	.476	475	.170	15.2	.794			.1375	11.90	21.25	.7441	697				5.91	.785		6.05	.831		464.06	.610	
6.7 (2150°F-1200°F)		1	149.7 53.4		-0- .398	6.4950 13.0767	16,960 26,919	30.87 39.64	81.9 83.9	1.83 1.50	11.4119 11.7976	2.5485 3.6162	.409 .460	.417 469	.052 .125	21.8 24.9	1.00 .902	189.96	189.96 208.66	.0540 .0715	17.85 20.89	6.5 15.625	.9870 .8144	1648 1436	44.74	23.55	284.56	4.91 5.52	.265 .395	1.082306	5.31 5.97	.287 .488	223.51 273.50	643.48 671.59	.821	
		2	53.4		.152	43.9901	23,262	63.38	82.4	1.24	12.3499	6.6325	.666	679	.197	29.9	.811			.0913	24.64	24.625	.7484	1390				7.99	.730		8.65	.790		605.31		
9.0 (2000°F-1330°F)		1	129.4 59.9		-0- .320	10.1187 17.4060	11,810 14,704	50.54 56.24	85.5 86.1	1.25 1.17	10.4247 11.0118	3.1810 4.1720	.381 .443	.376 437	.038 .092	15.18 18.9	1.00 .933	189.86	189.86 203.72	.0922 .1009	12.98 16.27	4.75 11.50	.9905 .8760	1224 1262	35.53	18.71 (16.84)	303.56	4.57 5.32	.422 .536	1.047888	4.79 5.57	.442 .562	252.90 297.05	523.37 572.26	.691	
		2	59.9		.165	36.3039	15,560	77.85	80.2	1.02	11.1687	6.0253	.550	543	.147	20.0	.865			.1207	16.04	18.375	.8149	1067				6.60	.797		6.92	.835		524.70		
7.2 (2000°F-1200°F)		1	111.0 43.8		-0- .296	9.2045 17.7605	14,844 16,960	40.61 51.04	84.0 85.6	1.49 1.25	11.0379 11.4119	3.0339 4.2143	.410 .462	.417 470	.049 .112	19.08 21.8	1.00 .918	192.86	192.86 208.59	.0721 .0921	16.03 18.66	6.125 14.00	.9878 .8512	1486 1366	41.77	21.66 (19.49)	285.50	4.92 5.54	.355 .511	1.080523	5.32 5.99	.384 .552	240.51 293.04	582.24 607.94	.786	
		2	43.8		.124	50.3995	20,850	73.65	81.1	1.08	12.0165	7.0993	.638	650	.180	26.8	.842			.1112	21.73	22.50	.7869	1325				7.66	.851		8.28	.920		580.15		
7.9 (2150°F-1330°F)	24,000	1	114.5 23.6	12	-0- .33	9.5985 30.8296	22,251 26,919	40.81 63.41	84.1 82.4	1.48 1.24	12.2134 12.8090	3.0981 5.5524	.375 .538	500 718	.07 .169	28.6 34.6	1.00 .88	195.38	195.38 220.25	.0728 .0913	24.05 28.51	8.75 21.125	.9825 .8010	2156 1801	3957	20.25 (18.225)	296.76	4.50 6.46	.328 .589	1.059826	4.77 6.85	.348 .624	303.01 385.50	723.96 663.70	.88	
		2	172.2 74.4		-0- .43	6.8264 11.9049	14,004 16,571	48.71 56.70	85.3 86.1	1.30 1.16	10.8783 11.3459	2.6127 3.4503	.312 .353	.415 470	.04 .102	18 21.3	1.00 .916	186.91	186.91 203.21	.0872 .1021	15.35 18.34	5.0 12.75	.9900 .8382	1444 1341	3960	21.19 (19.071)	296.98	3.74 4.24	.326 .432	1.059433	3.96 4.49	.345 .458	265.80 313.06	562.92 601.83	.725	
		3	23.6		.20	29.6835	18,905	81.10	79.4	.98	11.7258	5.4483	.455	605	.170	24.3	.834			.1277	19.29	21.25	.7732	1175				5.46	.697		5.78	.738		558.31		
		1	229.3 145.5		-0- .59	5.3815 6.8677	7780 9647	67.21 64.61	87.4 86.7	1.05 1.08	9.3917 9.9106	2.3198 2.6206	.259 .286	.352 388	.016 .054	10 12.4	1.00 .946	180.01	180.01 190.57	.1169 .1125	8.74 10.75	2.0 6.75	.9960 .8585	853 861				3.11 3.43	.363 .386	1.080221	3.36 3.71	.392 .417	229.02 247.63	391.41 436.84		
		2	74.4		.34	10.2007	9803	77.80	87.2	.98	9.9504	3.1939	.315	427	.089	12.6	.895			.1281	10.99	11.125	.8320	812				3.78	.484		4.08	.523		474.44		
		3	88.4		.224	15.9960	10,503	92.52	87.4	.92	10.1234	3.9995	.363	493	.126	13.5	.844			.1389	11.80	15.75	.7891	784				4.36	.605		4.71	.654		404.48		
		4	49.4		.128	28.5240	11,826	113.03	56.0	.74	10.4282	5.3408	.379	516	.170	15.2	.794			.1884	8.51	21.25	.7441	499	3809	21.16 (19.04)	285.66	4.55	.857		4.92	.926		381.87	466.68	.613
7.9 (2150°F-1330°F)	14,400	1	114.5 23.6	12	-0- .33	9.5985 30.8296	22,251 26,919	24.49 38.05	79.9 80.4	2.20 1.79	12.2134 12.8090	3.0981 5.5524	.558 .776	.455 632	.07 .169	28.6 34.6	1.00 .88	195.38	195.38 220.25	.0414 .0543	22.85 27.82	8.75 21.125	.9825 .8010	2049 1758	38.07	1948 (17.53)	285.51	6.70 9.31	.277 .506	1.080504	7.24 10.06	.299 .547	229.06 293.43	754.96 713.96	.939	
		2	172.2 74.4	12	-0- .43	6.8264 11.9049	14,004 16,571	29.23 34.02	81.4 82.7	1.90 1.68	10.8783 11.3459	2.6127 3.4503	.456 .511	.368 412	.04 .102	18 21.3	1.00 .916	186.91	186.91 203.21	.0512 .0610	14.65 17.62	5.0 12.75	.9900 .8382	1378 1288				5.47 6.13	.280 .374	1.070024	5.85 6.56	.300 .400	201.09 236.97	594.68 638.63		
		3	23.6		.20	29.6835	18,905	48.66	82.2	1.52	11.7258	5.4483	.706	570	.170	24.3	.834			.0684	19.97	21.25	.7732	1216	38.82	20.76 (18.68)	291.13	8.47	.579		9.06	.620		260.97	543.69	.717
		1	229.3 145.5	12	-0- .59	5.3815 6.8677	7780 9647	40.32 38.77	84.0 83.7	1.49 1.53	9.3917 9.9106	2.3198 2.6206	.368 .405	.295 324	.016 .054	10 12.4	1.00 .946	180.01	180.01 190.57	.0722 .0696	8.40 6.75	2.0 6.75	.9960 .8585	819 831				4.42 4.86	.319 .338	1.061580	4.69 5.16	.339 .359	177.53 193.89	428.38 480.43		
		2	74.4		.34	10.2007	9803	46.68	85.0	1.33	9.9504	3.1939	.427	342	.089	12.6	.895			.0846	10.71	11.125	.8320	792				5.12	.433		5.44	.460		474.44		
		3	88.4		.224	15.9960	10,503	55.51	86.1	1.18	10.1234	3.9995	.466	373	.126	13.5	.844			.0997	11.62	15.75	.7891	773				5.59	.558		5.93	.592		479.35		
		4	49.4		.128	28.5240	11,826	67.82	81.9	1.17	10.4282	5.3408	.599	480	.170	15.2	.794			.0992	12.45	21.25	.7441	729	39.44	21.91 (19.72)	295.78	7.19	.713		7.63	.757		266.77	440.48	.580
9.0 (2150°F-1330°F)	24,000	1	214	0	-0-	34	48,236	43.0	81.5	1.67	14.8198	5.8310	.657	805	.13	62	1.00	220.25	220.25	.0597	50.53	16.25	.9675	4094	40.94	18.59	349.78	7.88	.471	.97572	7.69	.460	457.22	1022	1.35	
7.5 (2150°F-1330°F)	18,000	1	172.2 43.4	12	-0- .43	6.4808 11.2675	14,004 16,571	35.60 41.37	83.1 84.2	1.63 1.46	10.8783 11.3459	2.5457 3.3567	.381 .442	.390 442	.044 .104	18.0 21.3	1.00 .916	186.91	186.91 203.21	.0636 .0742	14.96 17.93	5.50 13.00	.9890 .8348	1398 1303				4.57 5.18	.291 .384		4.97 5.63	.317 .418	219.09 257.89	576.80 614.60		
		2	43.4		.20	28.1415	18,983	59.04	82.5	1.31	11.7379	5.3049	.592	606	.158	24.4	.834			.0845	20.13	19.75	.7744	1251	39.52	21.14	281.38	7.10	.600	1.08787	7.72	.653</				

Table 11. Aerodynamic Calculations for Potassium

25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	55	56	57	58	59	60	
Flow, W (lb/sec)	N (rpm)	Stage No.	P _s (psia)	No. Lands in Seal	Seal Leakage (lb/sec)	V's (ft ³ /sec)	H _{ad} (ft-lb/lb)	N _s	η	D _s	H _{ad} ^{1/4}	V _s ^{1/2}	Rotor Diam D (ft)	Turbine Tip Speed U (ft/sec)	Moisture Assumed (%)	Δh _{1s}	Net In-Flow Fraction	Δh _{boiler}	Δh _{boiler}	h/D	η Δh _{1s}	Moisture Churning Loss	Fraction of Flow Through Stage	Net Stage Output	Σ (Net Stage Output)	η _c (%)	Power (kwe)	Weight Flow Correction	Corrected Rotor Diameter (in.)	Corrected Blade Height (in.)	Axial Velocity (ft/sec)	Relative Velocity Entering Turbine (ft/sec)	Relative Mach No. Entering Turbine	
					Fig.	$\frac{1}{100} \left(\frac{V_s}{20} \right)^2$		$\sqrt{\frac{N_s}{20}}$	Fig.	Fig.	$\frac{1}{25} H_{ad}$	$\sqrt{\frac{V_s}{30}}$	$\frac{35}{30}$	$0.004363 \frac{U}{20}$	$1 - \frac{7}{100}$	$\frac{10}{10}$	$\frac{20}{20}$	$\frac{30}{30} - \frac{40}{10}$	$\frac{80}{80} - \frac{90}{10}$	Fig. 7	$\frac{30}{30}$	$1.25 \frac{40}{40}$	$\frac{80}{80} - \frac{90}{10}$	$\frac{30}{30}$	$\frac{40}{40}$	$\frac{50}{50}$	$0.9493 \frac{25}{25}$	$\sqrt{\frac{330}{50}}$	$\frac{12}{12}$	$\frac{30}{30}$	$\frac{40}{40}$	$\frac{50}{50} \times \left(\frac{144}{30} - \frac{144}{30} \right)$	$\frac{80}{80} - \frac{90}{10}$	$\frac{50}{50} \text{ (Fig. 45)}$
1.61 (2150°F to 1330°F)	24,000	1 2 3 4 5	148 87 48.6 24.7 10.4	12	-0- 0.178 0.111 0.068 0.038	6.0333 7.9956 13.0935 23.0116 47.2509	30,731 38,044 40,223 44,657 47,536	25.40 24.91 30.58 37.48 51.24	80.1 79.9 81.8 83.5 82.4	2.13 2.17 1.83 1.57 1.46	13.2402 13.9660 14.1618 14.5369 14.7658	2.4563 2.8276 3.6185 4.7970 6.8739	0.3952 0.4394 0.4676 0.5181 0.6797	599 666 709 786 1031	0.035 0.072 0.110 0.153 0.197	39.5 48.9 51.7 57.4 61.1	1.00 0.955 0.195 0.876 0.836	752.11	752.11 786.49 818.06 849.45 883.17	0.0434 0.0423 0.0540 0.0671 0.0724	31.64 39.07 42.29 47.93 50.35	4.375 9.00 13.75 19.125 24.625	0.99125 0.82725 0.82089 0.80026 0.77122	29.99 29.41 29.94 31.02 29.27	149.63	19.89	228.69	1.206698 (R)	5.72 6.36 6.77 7.51 9.85	0.249 0.269 0.366 0.503 0.713	244.96 269.91 308.98 361.13 401.17	822.91 915.72 923.00 942.15 781.92	.544	
1.61 (2150°F to 1330°F)	24,000	1 2 3 4 5 6 7	169 120.5 81.3 52.5 33.9 19.4 10.4	12	-0- 0.176 0.136 0.096 0.075 0.047 0.029	5.4083 6.1821 8.5230 13.1520 17.6804 27.8228 46.5548	21,395 25,207 30,031 29,253 44,58 34,854 34,388	31.55 29.83 30.71 38.91 44.58 49.63 64.85	82.1 81.6 81.8 83.7 84.7 85.4 82.2	1.80 1.87 1.83 1.60 1.38 1.28 1.22	12.0942 12.6003 13.1641 13.0780 13.1299 13.6635 13.6176	2.3256 2.4864 2.9194 3.6266 4.2048 5.2747 6.8231	0.3461 0.3690 0.4058 0.4437 0.4419 0.4941 0.6113	513 548 602 658 656 734 908	0.020 0.048 0.079 0.100 0.131 0.162 0.194	27.5 32.4 38.6 37.6 38.2 44.8 44.2	1.00 0.969 0.937 0.902 0.880 0.851 0.823	742.99	742.99 766.33 790.48 818.06 835.68 859.36 883.17	0.0553 0.0524 0.0549 0.0649 0.0803 0.0891 0.0934	22.58 26.44 31.57 31.47 32.36 38.26 36.33	2.50 6.00 9.875 12.50 16.375 20.25 24.25	0.99500 0.84806 0.83402 0.81982 0.80460 0.78734 0.76507	21.91 21.08 23.73 22.57 21.77 24.02 21.05	156.13	21.01	238.63	1.181298	4.90 5.23 5.75 6.28 6.26 7.01 8.67	0.272 0.274 0.311 0.409 0.503 0.624 0.809	232.63 246.51 272.83 296.57 330.60 378.06 396.38	678.15 743.47 808.39 743.20 762.14 808.79 658.41	.457	
1.61 (2150°F to 1330°F)	24,000	1 2 3 4 5 6 7 8 9	180 139.9 106.4 78.3 56.7 38.2 26.2 17.3 10.4	12	-0- 0.166 0.137 0.108 0.084 0.069 0.047 0.034 0.026	5.1000 5.5320 7.3522 8.8977 11.5623 15.9191 21.9961 30.7230 46.4160	16,727 20,150 20,228 22,951 20,539 25,363 25,052 22,951 27,930	36.85 33.38 38.37 38.39 47.57 47.65 56.53 71.34 75.68	83.3 82.5 83.6 85.2 85.2 86.1 87.1 80.7	1.60 1.72 1.55 1.55 1.31 1.31 1.16 1.02 1.04	11.3725 11.9143 11.9258 12.3084 11.9714 12.6197 12.5809 12.3084 12.9276	2.2583 2.3520 2.7115 2.9829 3.4003 3.9899 4.6900 5.5428 6.8129	0.3177 0.3395 0.3524 0.3756 0.3721 0.4142 0.4324 0.4593 0.5481	469 501 520 555 550 612 639 678 809	0.013 0.035 0.054 0.078 0.095 0.120 0.144 0.163 0.189	21.5 25.9 26.0 29.5 26.4 32.6 32.2 29.5 35.9	1.00 0.975 0.951 0.928 0.905 0.880 0.858 0.838 0.816	737.94	737.94 756.18 774.43 792.47 810.23 829.80 847.48 864.32 883.17	0.0653 0.0590 0.0682 0.0682 0.0864 0.0864 0.1022 0.1215 0.1175	17.91 21.37 21.74 24.66 22.49 27.28 27.72 25.69 28.97	1.625 4.375 6.75 9.75 11.875 15.0 18.0 20.375 23.625	0.99675 0.86336 0.85307 0.84282 0.83133 0.81074 0.79792 0.78273 0.76129	17.56 17.64 17.29 18.76 16.48 19.14 18.14 16.01 16.84	157.86	21.39	241.27	1.174818	4.48 4.78 4.97 5.30 5.25 5.84 6.10 6.47 7.73	0.298 0.282 0.338 0.361 0.453 0.504 0.623 0.787 0.908	223.86 234.85 252.88 268.73 286.52 318.75 347.14 369.91 403.51	588.22 656.56 644.13 685.02 632.00 701.58 677.85 605.63 618.94	.419	
1.37 (2150°F to 1200°F)	24,000	1 2 3 4 5	135.5 73.2 35.4 14.5 4.8	12	-0- 0.168 0.100 0.052 0.025	5.5186 7.7016 14.4788 30.8068 77.9067	39,289 44,813 45,435 52,593 57,494	20.20 21.62 29.35 38.36 57.05	78.0 78.6 81.4 83.6 82.6	2.59 2.45 1.90 1.55 1.34	14.0789 14.5496 14.5998 15.1437 15.4848	2.3492 2.7752 3.8051 5.5504 8.8265	0.4322 0.4673 0.4952 0.5678 0.7638	672 727 769 882 1188	0.046 0.090 0.132 0.181 0.232	50.5 57.6 58.4 67.6 73.9	1.00 0.950 0.904 0.858 0.815	758.21	758.21 796.44 833.72 871.27 908.60	0.0326 0.353 0.0512 0.0682 0.0819	39.39 45.27 47.54 56.51 61.04	5.75 11.25 16.50 22.625 29.00	0.98850 0.80600 0.80118 0.78122 0.74948	36.70 32.38 31.80 34.16 32.48	167.52	22.09	217.87	1.236299	6.42 6.94 7.34 8.42 11.34	0.208 0.245 0.376 0.575 0.928	242.03 266.07 313.34 387.01 456.91	931.37 986.58 964.18 994.70 819.45	.585	
1.90 (2000°F to 1330°F)	24,000	1 2 3 4 5	103.0 64.5 38.2 21.0 10.4	12	-0- 0.120 0.083 0.053 0.033	0.9953 13.3528 20.5495 31.9692 60.2507	25,285 31,587 35,088 37,966 38,278	37.84 37.01 42.44 49.89 68.07	83.5 83.4 84.4 85.4 81.9	1.56 1.58 1.43 1.27 1.15	12.6100 13.3314 13.6864 13.9588 13.9874	3.1615 3.6541 4.5332 5.6541 7.7621	0.3911 0.4331 0.4736 0.5144 0.6382	561 622 680 738 916	0.013 0.045 0.080 0.116 0.150	32.5 40.6 45.1 48.8 49.2	1.00 0.965 0.932 0.890 0.868	768.44	768.44 795.34 821.80 848.38 875.17	0.0677 0.0665 0.0764 0.0901 0.1019	27.14 33.86 38.06 41.68 40.29	1.625 5.625 10.00 14.50 18.75	0.99675 0.89099 0.86968 0.83630 0.81808	26.60 28.47 29.79 29.80 26.78	141.44	18.44	255.11	1.142506	5.36 5.94 6.49 7.05 8.75	0.363 0.395 0.496 0.635 0.891	288.57 319.26 361.97 410.99 450.60	740.01 831.15 858.31 872.72 740.18	.514	
1.55 (2000°F to 1200°F)	24,000	1 2 3 4 5	93.3 52.5 27.3 12.3 4.8	12	-0- 0.117 0.072 0.042 0.021	8.8558 13.6278 22.2730 42.8774 94.9550	31,509 38,200 42,245 47,925 48,547	30.20 32.42 38.44 48.52 71.51	81.6 82.3 83.6 85.2 81.3	1.85 1.75 1.55 1.29 1.06	13.3232 13.9803 14.3365 14.7959 14.8436	2.9759 3.4621 4.7194 6.5481 7.7444	0.4132 0.4621 0.5102 0.5709 0.6959	608 680 750 840 1023	0.020 0.057 0.098 0.142 0.183	40.5 49.1 54.3 61.6 62.4	1.00 0.955 0.921 0.883 0.846	774.48	774.48 810.06 837.51 869.23 900.60	0.0532 0.0576 0.0682 0.0883 0.1147	33.05 40.41 45.39 52.48 50.73	2.50 7.125 12.25 17.75 28.875	0.99500 0.86591 0.85198 0.82456 0.79375	32.06 32.50 33.94 35.59 31.06	165.15	21.32	243.01	1.170604	5.81 6.50 7.16 8.02 9.77	0.309 0.373 0.489 0.708 1.121	279.54 319.96 366.35 444.41 525.50	836.20 912.63 932.37 967.00 847.07	.606	
1.61 (2150°F to 1330°F)	18,000	1 2 3 4 5	148 87 48.6 24.7 10.4	12	-0- 0.178 0.111 0.068 0.038	6.0333 7.9956 13.0935 23.0116 47.2509	30,731 38,044 40,223 44,657 47,536	19.05 18.68 22.93 28.11 38.43	77.5 77.3 79.1 81.1 80.5	2.72 2.76 2.33 1.96 1.78	13.2402 13.9660 14.1618 14.5369 14.7658	2.4563 2.8276 3.6185 4.7970 6.8739	0.5046 0.5588 0.5985 0.6468 0.8286	583 646 687 747 957	0.035 0.072 0.110 0.153 0.197	39.5 48.9 51 																		

Table 12. Procedure for Turbine Aerodynamic
Design Hand Calculations

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1. Specify the number of stages, assume a 100% nozzle efficiency, and overall stage efficiencies. Allocate the pressure distribution and calculate the head drop per stage using a Mollier diagram. This procedure also specifies P_3 and V_3 for each stage. (Typical calculations are summarized in Table 5.)
 2. Neglecting heat losses to the surroundings, use a heat balance to calculate the ideal bleed flows to the regenerative feed heater assuming a heating effectiveness of 0.80 for each feed heater stage. (Typical calculations are summarized in Table 5.)
 3. Specify the rpm.
 4. Determine N_s for each point and enter in Table 10.
 5. Find the values for η and D_s from Fig. 6.
 6. Determine $H_{ad}^{1/4}$ and calculate $V_3^{1/2}$ and D .
 7. Calculate the tip speed, U . ($U = 2 \pi DN/60$).
 8. Values for h/d can be found in Fig. 9.
 9. Using the above calculated value for turbine efficiency and the isentropic enthalpy drop of Table 5 or 6, calculate the enthalpy drop per stage.
 10. Estimate the leakage through that seal from Fig. 9.
 11. Calculate the fraction of the flow passing through each stator by deducting the seal leakage, the moisture removed (assuming that 25% of the total moisture is removed), and the amounts bled off to the regenerative feed heater.
 12. Calculate the moisture churning loss assuming 1.25% loss in turbine efficiency per 1% moisture leaving the stage. (See Fig. 10).
 13. Calculate the net output of each stage in Btu per pound by multiplying the enthalpy drop per stage given by Step 9 by the fraction of the flow passing through the stage and the factor given by one minus the churning loss.
 14. Sum the net stage outputs to give the total net output of the turbine.
 15. Divide the total turbine net output per pound of vapor entering the turbine by the heat added in the boiler per pound of vapor generated to give the gross turbine cycle efficiency. The overall cycle efficiency will be 90% of this as a consequence of feed pump and generator losses.
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Table 13. Calculation of the Effects of Number of Stages and RPM on the Size and Performance of Cesium Turbines as Determined from a Computing Machine Program Including Aerodynamic and Moisture Churning Losses but with No Regenerative Feed Heating or Seal Leakage Losses. Note that the limitations of the computer printout equipment made it necessary to modify the symbols used. These can be defined as follows using the same format as in the printout reproduced on the following pages:

T1	Turbine inlet temperature, °R
NS	Specific speed
C1	Stator inlet velocity, ft/sec
A1	Stator inlet angle, deg
B2	Rotor inlet angle (relative), deg
UM	Mean peripheral velocity of blade, ft/sec
T3	Stage exit temperature, °R
HT1	Stage inlet enthalpy
DS	Specific diameter
C2	Tangential velocity leaving nozzle, ft/sec
A2	Inlet nozzle angle, deg
W2	Relative velocity into rotor, ft/sec
UT1P	Rotor tip speed, ft/sec
HT3	Stage exit enthalpy
S1	Stage inlet entropy
C0	Nozzle discharge velocity, ft/sec
C3	Stage exit velocity, ft/sec
A3	Stage exit angle, deg
W3	Stage exit relative velocity, ft/sec
DIA	Rotor diameter, in.
S3	Stage exit entropy
ETT	Aerodynamic efficiency based on total-to-total pressure
V1	Volume flow into stage, ft ³ /sec
H/D	Ratio of blade height to rotor diameter
M2	Mach number at nozzle exit
C/H	Ratio of blade chord to height
MR2	Relative Mach number at rotor inlet
H	Blade height, in.
V3	Vapor volume flow rate leaving stage, ft ³ /sec
ETS	Aerodynamic efficiency based on total-to-static pressures
Q1	Vapor quality at stage inlet
Q3	Vapor quality at stage exit

Table 13. (continued)

NUMBER OF STAGES= 2 RPM= 18000
INITIAL WEIGHT FLOW= 7.968

STAGE NO.-- 1

T1= 2610	HT1= 2.49228	S1= 2.4909	V1= .52288	J1= 1
VS= 29.4283	DS= 2.22438	CO= 1275.61	H/D= 4.12115	E-2
C1= 390	C2= 1130.58	C3= 258.904	M2= 1.32509	
A1= 90.	A2= 15	A3= 90	C/H= 1.3048	
B2= 26.3349	W2= 688.781	W3= 583.62	MR2= .773095	
UM= 523.054	UTIP= 545.033	DIA.= 6.93957	H= .28599	
T3= 2162	HT3= 2.32286	S3= 2.52468	V3= 1.34861	Q3= .924129
STAGE EFF.= .698893		ETT= .762658	ETS= .73124	

STAGE NO.-- 2

T1= 2162	HT1= 2.32286	S1= 2.52468	V1= 1.34861	J1= .924129
VS= 53.6445	DS= 1.29151	CO= 1297.64	H/D= 8.49018	E-2
C1= 258.904	C2= 1206.06	C3= 397.33	M2= 1.52761	
A1= 90.	A2= 21	A3= 90	C/H= .568957	
B2= 36.3809	W2= 728.671	W3= 669.864	MR2= .922946	
UM= 539.306	UTIP= 586.822	DIA.= 7.47164	H= .634356	
T3= 1790	HT3= 2.16557	S3= 2.56927	V3= 4.71749	Q3= .846779
STAGE EFF.= .663439		ETT= .795286	ETS= .720724	

TURBINE TOTAL ENTHALPY DROP= .326716 OVERALL CYCLE EFFICIENCY = .77897
OVERALL TURBINE EFFICIENCY= .699376

NEW WEIGHT FLOW= 7.96808

NUMBER OF STAGES= 3 RPM= 18000
INITIAL WEIGHT FLOW= 7.679

STAGE NO.-- 1

T1= 2610	HT1= 2.49228	S1= 2.4909	V1= .52288	Q1= 1
NS= 32.2116	DS= 2.05891	CO= 1055.84	H/D= 4.77364	E-2
C1= 390	C2= 977.197	C3= 217.419	M2= 1.05743	
A1= 90.	A2= 15.0313	A3= 90		
B2= 26.515	W2= 567.682	W3= 487.011	MR2= .614289	
UM= 435.79	UTIP= 457.062	DIA.= 5.8195	H= .277802	
T3= 2298	HT3= 2.37199	S3= 2.51051	V3= .950736	Q3= .948578
STAGE EFF.= .725169		ETT= .768886	ETS= .736283	

STAGE NO.-- 2

T1= 2298	HT1= 2.37199	S1= 2.51051	V1= .950736	Q1= .948578
NS= 46.3828	DS= 1.47269	CO= 1053.94	H/D= 7.01605	E-2
C1= 217.419	C2= 978.549	C3= 295.575	M2= 1.14696	
A1= 90.	A2= 19.5	A3= 90		
B2= 34.0018	W2= 584.111	W3= 528.549	MR2= .684639	
UM= 438.182	UTIP= 469.909	DIA.= 5.98306	H= .419775	
T3= 2032	HT3= 2.26128	S3= 2.53429	V3= 1.96066	Q3= .892134
STAGE EFF.= .696198		ETT= .789077	ETS= .727015	

STAGE NO.-- 3

T1= 2032	HT1= 2.26128	S1= 2.53429	V1= 1.96066	Q1= .892134
NS= 68.676	DS= 1.04424	CO= 1084.81	H/D= .122278	
C1= 295.575	C2= 1009.52	C3= 367.811	M2= 1.28315	
A1= 90.	A2= 22.875	A3= 90		
B2= 39.2606	W2= 620.088	W3= 581.197	MR2= .788162	
UM= 450.009	UTIP= 507.197	DIA.= 6.46546	H= .790584	
T3= 1790	HT3= 2.15328	S3= 2.56436	V3= 4.68721	Q3= .841331
STAGE EFF.= .667387		ETT= .803475	ETS= .711109	

TURBINE TOTAL ENTHALPY DROP= .339008 OVERALL CYCLE EFFICIENCY = .78715
OVERALL TURBINE EFFICIENCY= .720276

NEW WEIGHT FLOW= 7.67918

Table 13. (continued)

NUMBER OF STAGES= 4 RPM= 18000
INITIAL WEIGHT FLOW= 7.517

STAGE NO.-- 1
T1= 2610 HT1= 2.49228 S1= 2.4909 V1= .52288 Q1= 1
NS= 35.7899 DS= 1.87002 C0= 926.604 H/D= 5.29871 E-2
C1= 300 C2= 858.35 C3= 209.534 M2= .913289
A1= 90. A2= 16.25 A3= 90 C/H= .993964
B2= 28.6232 W2= 501.392 W3= 437.395 MR2= .533484
UM= 383.942 UTIP= 404.792 DIA.= 5.15396 H= .273094
T3= 2367 HT3= 2.39828 S3= 2.50471 V3= .810415 Q3= .961751
STAGE EFF.= .742617 ETT= .775357 ETS= .735709

STAGE NO.-- 2
T1= 2367 HT1= 2.39828 S1= 2.50471 V1= .810415 Q1= .961751
NS= 60.8954 DS= 1.4506 C0= 911.133 H/D= 7.18677 E-2
C1= 209.534 C2= 846.033 C3= 257.586 M2= .953414
A1= 90. A2= 19.625 A3= 90 C/H= .690433
B2= 34.2085 W2= 505.42 W3= 458.168 MR2= .569569
UM= 378.907 UTIP= 407.028 DIA.= 5.18244 H= .37245
T3= 2162 HT3= 2.31297 S3= 2.52015 V3= 1.339 Q3= .917483
STAGE EFF.= .718776 ETT= .789859 ETS= .72673

STAGE NO.-- 3
T1= 2162 HT1= 2.31297 S1= 2.52015 V1= 1.339 Q1= .917483
NS= 60.8954 DS= 1.15165 C0= 932.187 H/D= .100346
C1= 257.586 C2= 867.275 C3= 308.933 M2= 1.039
A1= 90. A2= 22.5 A3= 90 C/H= .466958
B2= 38.6519 W2= 531.376 W3= 494.619 MR2= .636593
UM= 386.277 UTIP= 426.716 DIA.= 5.43311 H= .54519
T3= 1970 HT3= 2.22958 S3= 2.53883 V3= 2.38881 Q3= .876197
STAGE EFF.= .693856 ETT= .799838 ETS= .711991

STAGE NO.-- 4
T1= 1970 HT1= 2.22958 S1= 2.53883 V1= 2.38881 Q1= .876197
NS= 81.562 DS= .909545 C0= 959.404 H/D= .16014
C1= 308.933 C2= 893.409 C3= 342.156 M2= 1.1376
A1= 90. A2= 23.875 A3= 90 C/H= .283868
B2= 40.7427 W2= 554.038 W3= 524.245 MR2= .705468
UM= 397.196 UTIP= 464.562 DIA.= 5.91498 H= .947227
T3= 1790 HT3= 2.14598 S3= 2.56187 V3= 4.67181 Q3= .83856
STAGE EFF.= .669683 ETT= .807666 ETS= .704941

TURBINE TOTAL ENTHALPY DROP= .346304 OVERALL CYCLE EFFICIENCY = .79318
OVERALL TURBINE EFFICIENCY= .731381

NEW WEIGHT FLOW= 7.51738

NUMBER OF STAGES= 5 RPM= 18000
INITIAL WEIGHT FLOW= 7.4075

STAGE NO.-- 1
T1= 2610 HT1= 2.49228 S1= 2.4909 V1= .52288 Q1= 1
NS= 39.2927 DS= 1.71519 C0= 839.569 H/D= 5.80322 E-2
C1= 300 C2= 778.422 C3= 207.16 M2= .82038
A1= 90. A2= 17.5 A3= 90 C/H= .88878
B2= 30.7247 W2= 458.15 W3= 405.465 MR2= .482845
UM= 348.554 UTIP= 369.328 DIA.= 4.70242 H= .272892
T3= 2410 HT3= 2.41463 S3= 2.50138 V3= .737346 Q3= .970127
STAGE EFF.= .75502 ETT= .780678 ETS= .733147

STAGE NO.-- 2
T1= 2410 HT1= 2.41463 S1= 2.50138 V1= .737346 Q1= .970127
NS= 49.3637 DS= 1.3885 C0= 821.001 H/D= 7.49398 E-2
C1= 207.16 C2= 762.8 C3= 243.751 M2= .840402
A1= 90. A2= 20.5 A3= 90 C/H= .651278
B2= 35.5662 W2= 459.281 W3= 419.071 MR2= .506006
UM= 340.894 UTIP= 367.307 DIA.= 4.67669 H= .35047
T3= 2241 HT3= 2.3445 S3= 2.5127 V3= 1.08824 Q3= .932983
STAGE EFF.= .734292 ETT= .791867 ETS= .722667

STAGE NO.-- 3
T1= 2241 HT1= 2.3445 S1= 2.5127 V1= 1.08824 Q1= .932983
NS= 59.9206 DS= 1.17256 C0= 832.439 H/D= 9.96843 E-2
C1= 243.751 C2= 774.148 C3= 267.693 M2= .895068
A1= 90. A2= 21.875 A3= 90 C/H= .475955
B2= 37.7438 W2= 471.196 W3= 437.311 MR2= .544795
UM= 345.808 UTIP= 381.764 DIA.= 4.86077 H= .484542
T3= 2083 HT3= 2.27573 S3= 2.52603 V3= 1.67142 Q3= .898804
STAGE EFF.= .71229 ETT= .799301 ETS= .716644

STAGE NO.-- 4
T1= 2083 HT1= 2.27573 S1= 2.52603 V1= 1.67142 Q1= .898804
NS= 74.2624 DS= .979363 C0= 847.138 H/D= .137987
C1= 267.693 C2= 788.607 C3= 294.642 M2= .957377
A1= 90. A2= 23.375 A3= 90 C/H= .33307
B2= 40.0051 W2= 486.699 W3= 458.331 MR2= .590858
UM= 351.079 UTIP= 402.158 DIA.= 5.12043 H= .706552
T3= 1933 HT3= 2.20797 S3= 2.54168 V3= 2.70569 Q3= .866581
STAGE EFF.= .691279 ETT= .805518 ETS= .708075

STAGE NO.-- 5
T1= 1933 HT1= 2.20797 S1= 2.54168 V1= 2.70569 Q1= .866581
NS= 94.4302 DS= .811549 C0= 865.176 H/D= .200787
C1= 294.642 C2= 806.255 C3= 324.83 M2= 1.028
A1= 90. A2= 25 A3= 90 C/H= .220918
B2= 42.3286 W2= 506.009 W3= 482.384 MR2= .645176
UM= 356.626 UTIP= 432.773 DIA.= 5.51023 H= 1.10638
T3= 1790 HT3= 2.14084 S3= 2.56 V3= 4.66029 Q3= .836489
STAGE EFF.= .671764 ETT= .810455 ETS= .696212

TURBINE TOTAL ENTHALPY DROP= .35144 OVERALL CYCLE EFFICIENCY = .79756
OVERALL TURBINE EFFICIENCY= .739422

NEW WEIGHT FLOW= 7.40753

Table 13. (continued)

NUMBER OF STAGES= 2 RPM= 18000
INITIAL WEIGHT FLOW= 6.868

STAGE NO.-- 1
 T1= 2610 HT1= 2.49228 S1= 2.4909 V1= .52288 Q1= 1
 NS= 26.7069 DS= 2.41634 CO= 1385.94 H/D= 3.52422 E-2
 C1= 300 C2= 1282.68 C3= 277.027 M2= 1.46924
 A1= 90. A2= 15 A3= 90 C/H= 1.5279
 B2= 26.1762 W2= 752.567 W3= 627.993 MR2= .862024
 UM= 563.59 UTIP= 583.789 DIA.= 7.43303 H= .261956
 T3= 2091 HT3= 2.29693 S3= 2.53332 V3= 1.65271 Q3= .911717
 STAGE EFF.= .681854 ETT= .754981 ETS= .724816

STAGE NO.-- 2
 T1= 2091 HT1= 2.29693 S1= 2.53332 V1= 1.65271 Q1= .911717
 NS= 57.8516 DS= 1.20589 CO= 1428.69 H/D= 9.33441 E-2
 C1= 277.027 C2= 1328.76 C3= 461.266 M2= 1.76159
 A1= 90. A2= 22 A3= 90 C/H= .507222
 B2= 37.8982 W2= 810.344 W3= 750.928 MR2= 1.07431
 UM= 592.563 UTIP= 650.134 DIA.= 8.27776 H= .77268
 T3= 1660 HT3= 2.11324 S3= 2.59381 V3= 8.49507 Q3= .823321
 STAGE EFF.= .6466 ETT= .798091 ETS= .7149

TURBINE TOTAL ENTHALPY DROP= .379044 OVERALL CYCLE EFFICIENCY = .77654
OVERALL TURBINE EFFICIENCY= .689329

NEW WEIGHT FLOW= 6.86806

NUMBER OF STAGES= 3 RPM= 18000
INITIAL WEIGHT FLOW= 6.593

STAGE NO.-- 1
 T1= 2610 HT1= 2.49228 S1= 2.4909 V1= .52288 Q1= 1
 NS= 28.0738 DS= 2.31568 CO= 1144.79 H/D= 3.81776 E-2
 C1= 300 C2= 1059.5 C3= 230.699 M2= 1.16132
 A1= 90. A2= 15 A3= 90 C/H= 1.4094
 B2= 26.2605 W2= 619.769 W3= 521.408 MR2= .679328
 UM= 467.597 UTIP= 485.775 DIA.= 6.18508 H= .236131
 T3= 2249 HT3= 2.35387 S3= 2.51517 V3= 1.07213 Q3= .939435
 STAGE EFF.= .708595 ETT= .759063 ETS= .728237

STAGE NO.-- 2
 T1= 2249 HT1= 2.35387 S1= 2.51517 V1= 1.07213 Q1= .939435
 NS= 43.8705 DS= 1.54952 CO= 1151.28 H/D= 6.55505 E-2
 C1= 230.699 C2= 1068.46 C3= 310.619 M2= 1.28815
 A1= 90. A2= 18.875 A3= 90 C/H= .767753
 B2= 32.9888 W2= 634.834 W3= 570.494 MR2= .765362
 UM= 478.522 UTIP= 510.834 DIA.= 6.50414 H= .42635
 T3= 1940 HT3= 2.22418 S3= 2.54675 V3= 2.66286 Q3= .875409
 STAGE EFF.= .679185 ETT= .786413 ETS= .729166

STAGE NO.-- 3
 T1= 1940 HT1= 2.22418 S1= 2.54675 V1= 2.66286 Q1= .875409
 NS= 73.7789 DS= .984192 CO= 1195.62 H/D= .136421
 C1= 310.619 C2= 1113.01 C3= 415.743 M2= 1.48114
 A1= 90. A2= 23.375 A3= 90 C/H= .336908
 B2= 40.0017 W2= 686.954 W3= 646.757 MR2= .91417
 UM= 495.436 UTIP= 566.674 DIA.= 7.21512 H= .984297
 T3= 1660 HT3= 2.09743 S3= 2.58802 V3= 8.43538 Q3= .817529
 STAGE EFF.= .649152 ETT= .805358 ETS= .707981

TURBINE TOTAL ENTHALPY DROP= .394852 OVERALL CYCLE EFFICIENCY = .78361
OVERALL TURBINE EFFICIENCY= .719066

NEW WEIGHT FLOW= 6.59311

RPM= 18000

T1= 2610	HT= 2.49228	S1= 2.4999	H1= .52288	Q1= 1
NS= 30.7913	DS= 2.14002	C0= 1092.7	V/D= 4.43884	E-2
A1= 300	C2= 927.998	C3= 204.817	M2= .996443	
A1= 99	A2= 15	A3= 90	C/H= 1.21072	
RM= 26.4018	W2= 540.146	W3= 469.639	M2= .579985	
U2= 412.57	UTIP= 131.269	DIA= 5.5	H= .24374	
T3= 2328	HT3= 2.38336	S3= 2.50816	V3= .886129	Q3= .954611
STAGE EFF.= .727507		ETT= .765885	ETS= .73393	

T1= 2328	HT = 2,38336	S1= 2.50816	V1= .8866129	Q1= .954611
N5= 42.9679	DS= 1.57571	C0= 985.727	H/D= 6.28922	E-2
A1= 204.817	C2= 914.9	G3= 267.299	M2= 1.05271	
C1= 90.	A2= 19.	A3= 90	C/H= .79867	
R2= 33.1576	W2= 544.593	D3= 488.713	MR2= .682623	
UM= 409.139	UTIP= 435.618	W1A= 5.54645	H= 3.48889	
T3= 2091	HT3= 2.285	S3= 2.52801	V3= 1.63399	Q3= .904311
STAGE EFF.=	.703219	ETT= .785372	ETS= .727621	

T1= 2091	DT= 2.285	S1= 2.52880	V1= 1.63939	Q1= .904311
N1= 59.0645	HS= 1.17559	C0= 1019.56	H/D= 9.35865	E=2
C1= 267.299	C2= 948.878	C3= 345.096	M2= 1.17419	
A1= 90.	A2= 23	A3= 90	C/H= .49586	
B2= 39.337	W2= 584.898	W3= 544.416	M/R2= .723738	
U0= 421.07	UTIP= 462.089	DIA= 5.88349	H= .550616	
T3= 1869	HT3= 2.18819	S3= 2.55273	V3= 3.42779	Q3= .856928
STAGE EFF.= .676963		ETT= .798725	ETS= .707829	

T1= 1869	HT1= 2.18819	S1= 2.55273	V1= 3.42779	Q1= .856928
NS= 86.6425	DS= .869005	Q= 1064.88	H/D= 1.76737	
C1= 345.096	C2= 991.797	C3= 384.567	M2= 1.32247	
A1= 90.	A2= 24.125	A3= 90	C/H= .255782	
B2= 41.1113	W2= 616.515	WS= 584.871	MR2= .822072	
UM= 440.664	UTP= 523.341	DIA= 6.66339	H= 1.17766	
T3= 1660	HT3= 2.08853	S3= 2.58499	V3= 8.40413	Q3= .814496
STAGE EFF= .650468		ETT= .808893	ETS= .703398	

NEW WEIGHT FLOW= 6.44767

RPM= 18000

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STAGE NO.-- 1
NS= 2610 HT= 2.49228 S= 2.4909 V1= .52288 Q1= 1
C1= 33.5418 DS= 1.96854 C0= 906.624 H/D= 5.03885 E-2
A1= 90 C2= 839.417 C3= 190.503 M2= .890739
A1= 90 A2= 15.25 A3= 90 C/H= 1.06168
Q2= 26.9242 W2= 487.604 S3= 420.71 MR2= .517415
UM= 375.109 UTIP= 394.458 DIA= 5.0224 H= .253071
T3= 2378 HT3= 2.40179 C3= 2.50404 V3= .791045 Q3= .964212
SJAEGE EFF.= .748886 ETT= .771629 ETS= .737384

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S1AGE N0.--	Z								
T1=	2378.	H1=	2.403179	S1=	2.50404	V1=	.791045	Q1=	.964212
A1=	190.218	D1=	1.53926	C0=	882.203	H/D=	6.66457	E-2	
S1=	190.503	G2=	818.744	C3=	2385.186	M=	.916719		
A1=	90.	A2=	15875	A3=	90	C/H=	.757337		
B2=	32.9972	W2=	486.353	W3=	437.359	MR2=	.544552		
UM=	366.815	UTIP=	391.932	DIA.=	4.99023	H=	.331579		
T3=	2183	HT3=	2.32109	S3=	2.51843	V3=	1.2658	Q3=	.922163
S1AGE EFF.=	.719765	ETT=	.786797	FTS=	.729444				

T1= 2183	DT= 2.32109	S1= 2.51843	V1= 1.2658	Q1= .922163
NS= 55.7369	HS= 1.24935	CO= 905.115	HVD= .089893	
A1= 238.186	C2= 841.38	C3= 281.251	M2= .99821	
C1= 90.	A2= 21.25	A3= 90	C/H= .534599	
B2= 36.7795	W2= 509.318	W3= 469.739	M/R2= .604252	
UM= 376.2738	UTIP= 411.398	DIA= 5.23807	H= .470866	
T3= 1999	HT3= 2.24107	S3= 2.53593	V3= 2.17198	Q3= .882688
STAGE EFF.= .69576		ETT= .796739	ETS= .719809	

T1 = 1999	HT = 2.24107	S1 = 2.53593	V1 = 2.17198	Q1 = .882688
NS = 73.3135	DS = .990081	C0 = 927.136	H/D = .135443	
C1 = 281.251	C2 = 863.006	C3 = 320.528	M2 = 1.08497	
A1 = 98.	A2 = 23.25	A3 = 90	C/H = .340225	
B2 = 39.237	W2 = 531.934	D3 = 500.488	M2 = .668746	
UM = 384.387	UTIP = 439.248	DIA = 5.59268	H = .757489	
T3 = 1826	HT3 = 2.16187	S3 = 2.55696	V3 = 4.03885	Q3 = .8462
STAGE EFF. = .673413		ETT = .805197	ETS = .708959	

T1= 1826	HT = 2.16187	S1= 2.55696	V1= 4.03885	Q1= .8462
NS= 100.41	DS= .781391	C0= 958.884	HVD= .225481	
A1= 320.528	C2= 893.436	C3= 356.835	M2= 1.19305	
C1= 90.	A2= 24.75	A3= 90	C/H= .19771	
B2= 42.0125	W2= 558.866	W3= 533.15	MR2= .746283	
UM= 396.132	UTIP= 491.069	DIA= 6.25248	H= 1.40891	
T3= 1660	HT3= 2.08167	S3= 2.58278	V3= 8.38135	Q3= .812285
STAGE EFF.= .651615		ETT= .811456	ETS= .699982	

NEW WEIGHT FLOW= 6.33996

Table 13. (continued)

NUMBER OF STAGES= 1 RPM= 18000
INITIAL WEIGHT FLOW= 8.166

STAGE NO.-- 1
 T1= 2460 HT1= 2.48032 S1= 2.51952 V1= .730224 Q1= 1
 NS= 43.9992 DS= 1.5457 C0= 1835.48 H/D= 6.58813 E-2
 C1= 300 C2= 1703.45 C3= 495.348 M2= 2.22103
 A1= 90. A2= 18.875 A3= 90 C/H= .76387
 B2= 32.9919 W2= 1012.03 W3= 909.692 MR2= 1.31953
 UM= 763.009 UTIP= 814.798 DIA.= 10.3743 H= .683474
 T3= 1660 HT3= 2.16149 S3= 2.61982 V3= 8.76347 Q3= .849366
 STAGE EFF.= .656884 EIT= .786556 ETS= .72927

TURBINE TOTAL ENTHALPY DROP= .31883 OVERALL CYCLE EFFICIENCY = .78656
OVERALL TURBINE EFFICIENCY= .656909

NEW WEIGHT FLOW= 8.16518

NUMBER OF STAGES= 2 RPM= 18000
INITIAL WEIGHT FLOW= 7.5365

STAGE NO.-- 1
 T1= 2460 HT1= 2.48032 S1= 2.51952 V1= .730224 Q1= 1
 NS= 33.9721 DS= 1.96279 C0= 1315.1 H/D= 5.07047 E-2
 C1= 330 C2= 1217.57 C3= 281.411 M2= 1.40629
 A1= 90. A2= 15.5 A3= 90 C/H= 1.05108
 B2= 27.3468 W2= 708.31 W3= 612.594 MR2= .818096
 UM= 544.134 UTIP= 572.382 DIA.= 7.28779 H= .369525
 T3= 2023 HT3= 2.3 S3= 2.55703 V3= 2.0821 Q3= .919166
 STAGE EFF.= .703198 EIT= .772216 ETS= .736857

STAGE NO.-- 2
 T1= 2023 HT1= 2.3 S1= 2.55703 V1= 2.0821 Q1= .919166
 NS= 66.936 DS= 1.06641 C0= 1344.49 H/D= .117393
 C1= 281.411 C2= 1251.08 C3= 452.771 M2= 1.64393
 A1= 90. A2= 22.75 A3= 90 C/H= .396815
 B2= 39.0687 W2= 767.637 W3= 718.397 MR2= 1.00868
 UM= 557.759 UTIP= 626.428 DIA.= 7.97593 H= .936321
 T3= 1660 HT3= 2.1349 S3= 2.60758 V3= 8.63719 Q3= .837112
 STAGE EFF.= .663035 EIT= .802753 ETS= .711715

TURBINE TOTAL ENTHALPY DROP= .345421 OVERALL CYCLE EFFICIENCY = .83711
OVERALL TURBINE EFFICIENCY= .702617

NEW WEIGHT FLOW= 7.53659

NUMBER OF STAGES= 3 RPM= 18000
INITIAL WEIGHT FLOW= 7.25

STAGE NO.-- 1
 T1= 2460 HT1= 2.48032 S1= 2.51952 V1= .730224 Q1= 1
 NS= 36.3855 DS= 1.84268 C0= 1087.65 H/D= 5.41019 E-2
 C1= 300 C2= 1007.63 C3= 248.379 M2= 1.11774
 A1= 90. A2= 16.375 A3= 90 C/H= .76387
 B2= 28.8443 W2= 588.836 W3= 514.848 MR2= .653185
 UM= 450.975 UTIP= 475.991 DIA.= 6.0605 H= .327885
 T3= 2156 HT3= 2.35317 S3= 2.54087 V3= 1.40456 Q3= .945765
 STAGE EFF.= .729845 EIT= .776323 ETS= .735839

STAGE NO.-- 2
 T1= 2156 HT1= 2.35317 S1= 2.54087 V1= 1.40456 Q1= .945765
 NS= 54.1911 DS= 1.27603 C0= 1095.21 H/D= 8.48045 E-2
 C1= 248.379 C2= 1018.26 C3= 343.89 M2= 1.2314
 A1= 90. A2= 21.5 A3= 90 C/H= .76387
 B2= 37.1217 W2= 618.373 W3= 569.815 MR2= .747808
 UM= 454.348 UTIP= 494.332 DIA.= 6.29403 H= .533762
 T3= 1896 HT3= 2.2361 S3= 2.56773 V3= 3.18099 Q3= .884821
 STAGE EFF.= .696878 EIT= .795675 ETS= .717228

STAGE NO.-- 3
 T1= 1896 HT1= 2.2361 S1= 2.56773 V1= 3.18099 Q1= .884821
 NS= 84.6911 DS= .879801 C0= 1132.25 H/D= .16805
 C1= 343.89 C2= 1054.8 C3= 415.161 M2= 1.39057
 A1= 90. A2= 24.5 A3= 90 C/H= .76387
 B2= 41.6136 W2= 658.656 W3= 625.145 MR2= .868326
 UM= 467.386 UTIP= 550.673 DIA.= 7.01139 H= 1.17826
 T3= 1660 HT3= 2.12134 S3= 2.60247 V3= 8.58444 Q3= .831993
 STAGE EFF.= .665581 EIT= .839445 ETS= .699752

TURBINE TOTAL ENTHALPY DROP= .358982 OVERALL CYCLE EFFICIENCY = .79348
OVERALL TURBINE EFFICIENCY= .722745

NEW WEIGHT FLOW= 7.25189

Table 13. (continued)

NUMBER OF STAGES= 4		RPM= 18000	
INITIAL WEIGHT FLOW= 7.0729			
STAGE NO.-- 1			
T1= 2460	HT1= 2.48032	S1= 2.51952	V1= .730224 Q1= 1
NS= 40.0518	DS= 1.6851	C0= 953.805	H/D= .0592
C1= 300	C2= 884.495	C3= 239.314	M2= .961784
A1= 90.	A2= 17.75	A3= 90	C/H= .867472
B2= 31.14	W2= 521.435	W3= 462.771	MR2= .567
UM= 396.09	UTIP= 420.183	DIA.= 5.34993	H= .316716
T3= 2223	HT3= 2.38131	S3= 2.53437	V3= 1.17645 Q3= .960165
STAGE EFF.= .747486	ETT= .781717	ETS= .732505	
STAGE NO.-- 2			
T1= 2223	HT1= 2.38131	S1= 2.53437	V1= 1.17645 Q1= .960165
NS= 53.6262	DS= 1.29187	C0= 947.376	H/D= 8.48514 E-2
C1= 239.314	C2= 880.516	C3= 290.076	M2= 1.02118
A1= 90.	A2= 21	A3= 90	C/H= .569297
B2= 36.3806	W2= 531.99	W3= 489.046	MR2= .616977
UM= 393.731	UTIP= 428.399	DIA.= 5.45455	H= .462826
T3= 2023	HT3= 2.29034	S3= 2.55187	V3= 2.06668 Q3= .912322
STAGE EFF.= .719828	ETT= .795273	ETS= .720715	
STAGE NO.-- 3			
T1= 2023	HT1= 2.29034	S1= 2.55187	V1= 2.06668 Q1= .912322
NS= 71.7384	DS= 1.00763	C0= 970.573	H/D= .130913
C1= 290.076	C2= 903.363	C3= 333.398	M2= 1.1172
A1= 90.	A2= 23.125	A3= 90	C/H= .352952
B2= 39.637	W2= 556.158	W3= 522.631	MR2= .687809
UM= 402.481	UTIP= 457.941	DIA.= 5.83068	H= .763312
T3= 1836	HT3= 2.20097	S3= 2.57351	V3= 3.97686 Q3= .868877
STAGE EFF.= .692249	ETT= .804643	ETS= .709698	
STAGE NO.-- 4			
T1= 1836	HT1= 2.20097	S1= 2.57351	V1= 3.97686 Q1= .868877
NS= 101.085	DS= .778018	C0= 997.103	H/D= .228211
C1= 333.398	C2= 929.047	C3= 371.112	M2= 1.22655
A1= 90.	A2= 24.75	A3= 90	C/H= .195339
B2= 42.0146	W2= 581.118	W3= 554.461	MR2= .767206
UM= 411.952	UTIP= 511.855	DIA.= 6.51714	H= 1.48728
T3= 1660	HT3= 2.11226	S3= 2.60024	V3= 8.56145 Q3= .829762
STAGE EFF.= .66658	ETT= .811559	ETS= .699137	
TURBINE TOTAL ENTHALPY DROP= .368063		OVERALL CYCLE EFFICIENCY = .79830	
OVERALL TURBINE EFFICIENCY= .733084			
NEW WEIGHT FLOW= 7.07298			
NUMBER OF STAGES= 5		RPM= 18000	
INITIAL WEIGHT FLOW= 6.9345			
STAGE NO.-- 1			
T1= 2460	HT1= 2.48032	S1= 2.51952	V1= .730224 Q1= 1
NS= 43.6768	DS= 1.55654	C0= 863.594	H/D= 6.54299 E-2
C1= 300	C2= 801.403	C3= 231.301	M2= .861016
A1= 90.	A2= 18.75	A3= 90	C/H= .770881
B2= 32.7917	W2= 475.644	W3= 427.08	MR2= .511025
UM= 359.026	UTIP= 383.223	DIA.= 4.87935	H= .319255
T3= 2265	HT3= 2.39861	S3= 2.53054	V3= 1.05917 Q3= .969226
STAGE EFF.= .759697	ETT= .786192	ETS= .729794	
STAGE NO.-- 2			
T1= 2265	HT1= 2.39861	S1= 2.53054	V1= 1.05917 Q1= .969226
NS= 55.1586	DS= 1.26003	C0= 854.593	H/D= 8.82747 E-2
C1= 231.301	C2= 794.416	C3= 265.384	M2= .89898
A1= 90.	A2= 21.25	A3= 90	C/H= .544458
B2= 36.7712	W2= 480.982	W3= 443.324	MR2= .544291
UM= 355.12	UTIP= 387.69	DIA.= 4.93622	H= .435743
T3= 2100	HT3= 2.3232	S3= 2.54346	V3= 1.63696 Q3= .929123
STAGE EFF.= .73538	ETT= .796353	ETS= .719558	
STAGE NO.-- 3			
T1= 2100	HT1= 2.3232	S1= 2.54346	V1= 1.63696 Q1= .929123
NS= 69.0042	DS= 1.04041	C0= 864.823	H/D= .1233
C1= 265.384	C2= 804.803	C3= 293.283	M2= .958977
A1= 90.	A2= 22.875	A3= 90	C/H= .376761
B2= 39.2633	W2= 494.314	W3= 463.404	MR2= .589008
UM= 358.79	UTIP= 405.262	DIA.= 5.15996	H= .636223
T3= 1946	HT3= 2.25003	S3= 2.55871	V3= 2.65501 Q3= .892496
STAGE EFF.= .711384	ETT= .803605	ETS= .711187	
STAGE NO.-- 4			
T1= 1946	HT1= 2.25003	S1= 2.55871	V1= 2.65501 Q1= .892496
NS= 84.1425	DS= .883898	C0= 934.066	H/D= .166148
C1= 293.283	C2= 870.171	C3= 342.428	M2= 1.09934
A1= 90.	A2= 24.5	A3= 90	C/H= .270002
B2= 41.6109	W2= 543.398	W3= 515.65	MR2= .68651
UM= 385.539	UTIP= 453.445	DIA.= 5.77344	H= .959244
T3= 1780	HT3= 2.1697	S3= 2.57951	V3= 4.9739 Q3= .854292
STAGE EFF.= .684432	ETT= .808313	ETS= .699679	
STAGE NO.-- 5			
T1= 1780	HT1= 2.1697	S1= 2.57951	V1= 4.9739 Q1= .854292
NS= 126.221	DS= .678614	C0= 853.775	H/D= .348309
C1= 342.428	C2= 795.695	C3= 324.094	M2= 1.05143
A1= 90.	A2= 25.125	A3= 90	C/H= .126845
B2= 42.5781	W2= 499.335	W3= 479.007	MR2= .65982
UM= 352.722	UTIP= 477.34	DIA.= 6.07767	H= 2.11691
T3= 1660	HT3= 2.1049	S3= 2.59887	V3= 8.54726 Q3= .828385
STAGE EFF.= .668427	ETT= .814566	ETS= .69719	
TURBINE TOTAL ENTHALPY DROP= .375425		OVERALL CYCLE EFFICIENCY = .80181	
OVERALL TURBINE EFFICIENCY= .740259			
NEW WEIGHT FLOW= 6.93428			

Table 13. (continued)

NUMBER OF STAGES= 1 RPM= 24000
INITIAL WEIGHT FLOW= 8.698

STAGE NO.-- 1
 T1= 2610 HT1= 2.49228 S1= 2.4909 V1= .52288 Q1= 1
 NS= 46.749 DS= 1.45814 C0= 1778.87 H/D= 6.96171 E-2
 C1= 300 C2= 1652.2 C3= 512.563 M2= 2.08352
 A1= 90. A2= 20 A3= 90 C/H= .708013
 B2= 34.765 W2= 991.008 W3= 898.897 MR2= 1.24972
 UM= 738.448 UTIP= 791.491 DIA.= 7.55818 H= .526179
 T3= 1790 HT3= 2.193 S3= 2.57549 V3= 4.75588 Q3= .853687
 STAGE EFF.= .663788 ETT= .789434 ETS= .723892

TURBINE TOTAL ENTHALPY DROP= .299288 OVERALL CYCLE EFFICIENCY = .78943
OVERALL TURBINE EFFICIENCY= .663813

NEW WEIGHT FLOW= 8.6983

NUMBER OF STAGES= 2 RPM= 24000
INITIAL WEIGHT FLOW= 7.9962

STAGE NO.-- 1
 T1= 2610 HT1= 2.49228 S1= 2.4909 V1= .52288 Q1= 1
 NS= 39.2396 DS= 1.71841 C0= 1275.61 H/D= .058272
 C1= 300 C2= 1182.6 C3= 312.363 M2= 1.32993
 A1= 90. A2= 17.375 A3= 90 C/H= .708013
 B2= 30.5262 W2= 695.278 W3= 614.967 MR2= .781892
 UM= 529.733 UTIP= 561.438 DIA.= 5.36134 H= .312416
 T3= 2162 HT3= 2.3229 S3= 2.5225 V3= 1.34399 Q3= .920931
 STAGE EFF.= .712655 ETT= .7806 ETS= .733793

STAGE NO.-- 2
 T1= 2162 HT1= 2.3229 S1= 2.5225 V1= 1.34399 Q1= .920931
 NS= 70.6807 DS= 1.0157 C0= 1307.36 H/D= .12609
 C1= 312.363 C2= 1217.13 C3= 456.348 M2= 1.54575
 A1= 90. A2= 23.5 A3= 90 C/H= .708013
 B2= 40.1531 W2= 752.644 W3= 707.701 MR2= .955857
 UM= 540.918 UTIP= 612.619 DIA.= 5.85008 H= .737635
 T3= 1790 HT3= 2.16668 S3= 2.56552 V3= 4.69434 Q3= .842615
 STAGE EFF.= .669884 ETT= .804257 ETS= .706263

TURBINE TOTAL ENTHALPY DROP= .325601 OVERALL CYCLE EFFICIENCY = .79243
OVERALL TURBINE EFFICIENCY= .708868

NEW WEIGHT FLOW= 7.99537

NUMBER OF STAGES= 3 RPM= 24000
INITIAL WEIGHT FLOW= 7.6645

STAGE NO.-- 1
 T1= 2610 HT1= 2.49228 S1= 2.4909 V1= .52288 Q1= 1
 NS= 42.8505 DS= 1.57935 C0= 1055.84 H/D= .062598
 C1= 300 C2= 979.974 C3= 286.241 M2= 1.06205
 A1= 90. A2= 19 A3= 90 C/H= .802452
 B2= 33.1545 W2= 583.376 W3= 523.386 MR2= .632238
 UM= 438.182 UTIP= 466.404 DIA.= 4.45383 H= .278801
 T3= 2298 HT3= 2.3737 S3= 2.50891 V3= .948182 Q3= .945994
 STAGE EFF.= .738877 ETT= .785232 ETS= .72752

STAGE NO.-- 2
 T1= 2298 HT1= 2.3737 S1= 2.50891 V1= .948182 Q1= .945994
 NS= 60.3786 DS= 1.15956 C0= 1068.98 H/D= 9.88634 E-2
 C1= 286.241 C2= 994.539 C3= 354.107 M2= 1.16801
 A1= 90. A2= 22.5 A3= 90 C/H= .474
 B2= 38.6459 W2= 609.431 W3= 567.019 MR2= .715729
 UM= 442.856 UTIP= 488.51 DIA.= 4.66493 H= .461191
 T3= 2032 HT3= 2.26234 S3= 2.5319 V3= 1.9537 Q3= .888944
 STAGE EFF.= .704521 ETT= .799552 ETS= .711816

STAGE NO.-- 3
 T1= 2032 HT1= 2.26234 S1= 2.5319 V1= 1.9537 Q1= .888944
 NS= 89.3836 DS= .849245 C0= 1100.51 H/D= .186012
 C1= 354.107 C2= 1025.06 C3= 399.897 M2= 1.30523
 A1= 90. A2= 24.25 A3= 90 C/H= .242349
 B2= 41.2942 W2= 637.967 W3= 605.971 MR2= .812338
 UM= 455.287 UTIP= 545.273 DIA.= 5.20697 H= .968559
 T3= 1790 HT3= 2.15263 S3= 2.56186 V3= 4.67179 Q3= .838557
 STAGE EFF.= .671669 ETT= .809482 ETS= .702597

TURBINE TOTAL ENTHALPY DROP= .339652 OVERALL CYCLE EFFICIENCY = 79809
OVERALL TURBINE EFFICIENCY= .727562

NEW WEIGHT FLOW= 7.6646

Table 13. (continued)

NUMBER OF STAGES= 4 RPM= 24000
INITIAL WEIGHT FLOW= 7.488

STAGE NO.-- 1

T1= 2610	HT1= 2.49228	S1= 2.4909	V1= .52288	Q1= 1
NS= 47.5817	DS= 1.4916	C0= 926.604	H/D= 7.25362	E-2
C1= 300	C2= 860.473	C3= 263.876	M2= .916564	
A1= 90.	A2= 19.75	A3= 90	C/H= .682462	
B2= 34.406	W2= 514.584	W3= 466.992	MR2= .548128	
UM= 385.297	UTIP= 414.166	DIA= 3.95499	H= .28688	
T3= 2367	HT3= 2.39964	S3= 2.5036	V3= .808852	Q3= .959867
STAGE EFF.= .755678		ETT= .790243	ETS= .726156	

STAGE NO.-- 2

T1= 2367	HT1= 2.39964	S1= 2.5036	V1= .808852	Q1= .959867
NS= 61.3643	DS= 1.1446	C0= 924.349	H/D= .101699	
C1= 263.876	C2= 859.983	C3= 306.458	M2= .970558	
A1= 90.	A2= 22.5	A3= 90	C/H= .460711	
B2= 38.6573	W2= 526.847	W3= 490.599	MR2= .594588	
UM= 383.109	UTIP= 423.774	DIA= 4.04674	H= .411549	
T3= 2162	HT3= 2.31369	S3= 2.5185	V3= 1.3355	Q3= .915065
STAGE EFF.= .727356		ETT= .800092	ETS= .712147	

STAGE NO.-- 3

T1= 2162	HT1= 2.31369	S1= 2.5185	V1= 1.3355	Q1= .915065
NS= 79.1942	DS= .930398	C0= 945.783	H/D= .15266	
C1= 306.458	C2= 880.653	C3= 335.158	M2= 1.05653	
A1= 90.	A2= 23.75	A3= 90	C/H= .298608	
B2= 40.557	W2= 545.489	W3= 515.465	MR2= .654427	
UM= 391.632	UTIP= 454.866	DIA= 4.34365	H= .663101	
T3= 1970	HT3= 2.22871	S3= 2.53706	V3= 2.38269	Q3= .873939
STAGE EFF.= .699244		ETT= .807025	ETS= .70568	

STAGE NO.-- 4

T1= 1970	HT1= 2.22871	S1= 2.53706	V1= 2.38269	Q1= .873939
NS= 107.104	DS= .749028	C0= 967.106	H/D= .252648	
C1= 335.158	C2= 901.171	C3= 362.256	M2= 1.14912	
A1= 90.	A2= 24.875	A3= 90	C/H= .17593	
B2= 42.2	W2= 564.323	W3= 539.294	MR2= .719591	
UM= 399.515	UTIP= 506.418	DIA= 4.83594	H= 1.22179	
T3= 1790	HT3= 2.14462	S3= 2.55988	V3= 4.65954	Q3= .836353
STAGE EFF.= .673074		ETT= .812412	ETS= .698424	

TURBINE TOTAL ENTHALPY DROP= .347662 OVERALL CYCLE EFFICIENCY = .80244
OVERALL TURBINE EFFICIENCY= .737677

NEW WEIGHT FLOW= 7.48801

NUMBER OF STAGES= 5 RPM= 24000
INITIAL WEIGHT FLOW= 7.363

STAGE NO.-- 1

T1= 2610	HT1= 2.49228	S1= 2.4909	V1= .52288	Q1= 1
NS= 52.1937	DS= 1.32342	C0= 839.569	H/D= 8.17382	E-2
C1= 30	C2= 780.185	C3= 253.426	M2= .822948	
A1= 90.	A2= 20.75	A3= 90		
B2= 35.9881	W2= 470.394	W3= 431.276	MR2= .496177	
UM= 348.964	UTIP= 378.531	DIA= 3.6147	H= .295459	
T3= 2410	HT3= 2.4159	S3= 2.50053	V3= .736246	Q3= .968653
STAGE EFF.= .76722		ETT= .794198	ETS= .721835	

STAGE NO.-- 2

T1= 2410	HT1= 2.4159	S1= 2.50053	V1= .736246	Q1= .968653
NS= 64.1106	DS= 1.10661	C0= 833.328	H/D= .110242	
C1= 253.426	C2= 775.235	C3= 275.287	M2= .854993	
A1= 90.	A2= 22.375	A3= 90		
B2= 38.5083	W2= 473.968	W3= 442.136	MR2= .522731	
UM= 345.981	UTIP= 385.898	DIA= 3.68505	H= .406246	
T3= 2241	HT3= 2.34453	S3= 2.51158	V3= 1.08624	Q3= .931245
STAGE EFF.= .742413		ETT= .801471	ETS= .714007	

STAGE NO.-- 3

T1= 2241	HT1= 2.34453	S1= 2.51158	V1= 1.08624	Q1= .931245
NS= 78.2797	DS= .939497	C0= 841.537	H/D= .150149	
C1= 275.287	C2= 783.522	C3= 296.481	M2= .907012	
A1= 90.	A2= 23.625	A3= 90		
B2= 40.3785	W2= 484.684	W3= 457.648	MR2= .561075	
UM= 348.631	UTIP= 403.969	DIA= 3.85762	H= .579216	
T3= 2083	HT3= 2.27528	S3= 2.5246	V3= 1.66777	Q3= .896824
STAGE EFF.= .718474		ETT= .806762	ETS= .706625	

STAGE NO.-- 4

T1= 2083	HT1= 2.27528	S1= 2.5246	V1= 1.66777	Q1= .896824
NS= 97.0944	DS= .796589	C0= 855.866	H/D= .21094	
C1= 296.481	C2= 797.58	C3= 321.55	M2= .969566	
A1= 90.	A2= 25	A3= 90		
B2= 42.3379	W2= 500.475	W3= 477.428	MR2= .608395	
UM= 352.909	UTIP= 432.08	DIA= 4.12606	H= .870351	
T3= 1933	HT3= 2.20725	S3= 2.53998	V3= 2.69912	Q3= .864468
STAGE EFF.= .695894		ETT= .810922	ETS= .69647	

STAGE NO.-- 5

T1= 1933	HT1= 2.20725	S1= 2.53998	V1= 2.69912	Q1= .864468
NS= 123.549	DS= .686651	C0= 873.809	H/D= .33205	
C1= 321.55	C2= 814.366	C3= 331.57	M2= 1.03947	
A1= 90.	A2= 25.125	A3= 90		
B2= 42.5727	W2= 511.104	W3= 490.107	MR2= .652382	
UM= 360.927	UTIP= 483.861	DIA= 4.62053	H= 1.53425	
T3= 1790	HT3= 2.13883	S3= 2.55849	V3= 4.65096	Q3= .83481
STAGE EFF.= .673676		ETT= .814297	ETS= .69705	

TURBINE TOTAL ENTHALPY DROP= .353458 OVERALL CYCLE EFFICIENCY = .80553
OVERALL TURBINE EFFICIENCY= .744747

NEW WEIGHT FLOW= 7.36523

Table 13. (continued)

NUMBER OF STAGES= 2 RPM= 24000
 INITIAL WEIGHT FLOW= 6.874

STAGE NO.-- 1
 T1= 2610 HT1= 2.49228 S1= 2.4909 V1= .52288 Q1= 1
 VS= 35.5553 DS= 1.87797 CO= 1385.94 H/D= 5.16781 E-2
 C1= 300 C2= 1284.08 C3= 318.187 M2= 1.47405
 A1= 90. A2= 16.5 A3= 90 C/H= 1.01531
 B2= 29.015 W2= 751.895 W3= 656.302 MR2= .863131
 UM= 573.675 UTIP= 604.041 DIA.= 5.76816 H= .298088
 T3= 2091 HT3= 2.29537 S3= 2.53075 V3= 1.64627 Q3= .908137
 STAGE EFF.= .696469 ETT= .774959 ETS= .734112

STAGE NO.-- 2
 T1= 2091 HT1= 2.29537 S1= 2.53075 V1= 1.64627 Q1= .908137
 VS= 76.468 DS= .952547 CO= 1434.76 H/D= .142551
 C1= 318.187 C2= 1336.18 C3= 513.343 M2= 1.77669
 A1= 90. A2= 24 A3= 90 C/H= .318212
 B2= 40.8852 W2= 830.306 W3= 784.274 MR2= 1.10404
 UM= 592.933 UTIP= 682.146 DIA.= 6.51401 H= .928577
 T3= 1660 HT3= 2.11359 S3= 2.58926 V3= 8.4482 Q3= .818773
 STAGE EFF.= .651812 ETT= .806222 ETS= .703015

TURBINE TOTAL ENTHALPY DROP= .378699 OVERALL CYCLE EFFICIENCY = .79059
 OVERALL TURBINE EFFICIENCY= .698722

NEW WEIGHT FLOW= 6.87432

NUMBER OF STAGES= 3 RPM= 24000
 INITIAL WEIGHT FLOW= 6.583

STAGE NO.-- 1
 T1= 2610 HT1= 2.49228 S1= 2.4909 V1= .52288 Q1= 1
 VS= 37.4518 DS= 1.79331 CO= 1144.79 H/D= 5.53976 E-2
 C1= 300 C2= 1060.85 C3= 268.435 M2= 1.16461
 A1= 90. A2= 16.75 A3= 90 C/H= .942889
 B2= 29.4758 W2= 621.335 W3= 545.537 MR2= .682107
 UM= 474.927 UTIP= 501.917 DIA.= 4.79295 H= .265513
 T3= 2249 HT3= 2.35303 S3= 2.5135 V3= 1.06918 Q3= .93682
 STAGE EFF.= .723644 ETT= .777839 ETS= .735071

STAGE NO.-- 2
 T1= 2249 HT1= 2.35303 S1= 2.5135 V1= 1.06918 Q1= .93682
 VS= 57.8097 DS= 1.2058 CO= 1157.99 H/D= 9.32262 E-2
 C1= 268.435 C2= 1076.99 C3= 373.851 M2= 1.3017
 A1= 90. A2= 22 A3= 90 C/H= .507867
 B2= 37.8977 W2= 656.811 W3= 608.627 MR2= .793852
 UM= 480.276 UTIP= 526.876 DIA.= 5.0313 H= .469049
 T3= 1940 HT3= 2.22467 S3= 2.54353 V3= 2.65071 Q3= .871397
 STAGE EFF.= .687801 ETT= .798066 ETS= .714864

STAGE NO.-- 3
 T1= 1940 HT1= 2.22467 S1= 2.54353 V1= 2.65071 Q1= .871397
 VS= 96.1979 DS= .801517 CO= 1211.19 H/D= .207493
 C1= 373.851 C2= 1128.7 C3= 454.944 M2= 1.50554
 A1= 90. A2= 25 A3= 90 C/H= .213757
 B2= 42.3349 W2= 708.295 W3= 675.529 MR2= .944771
 UM= 499.363 UTIP= 609.565 DIA.= 5.82092 H= 1.2078
 T3= 1660 HT3= 2.09684 S3= 2.58447 V3= 8.39875 Q3= .813974
 STAGE EFF.= .652917 ETT= .810769 ETS= .696378

TURBINE TOTAL ENTHALPY DROP= .395442 OVERALL CYCLE EFFICIENCY = .79556
 OVERALL TURBINE EFFICIENCY= .717975

NEW WEIGHT FLOW= 6.58326

Table 13. (continued)

NUMBER OF STAGES= 4		RPM= 24000	
INITIAL WEIGHT FLOW= 6.425			
STAGE NO.-- 1			
T1= 2610	HT1= 2.49228	S1= 2.4909	V1= .52288 Q1= 1
NS= 40.9353	DS= 1.65177	C0= 1002.7	H/D= 6.06875 E-2
C1= 300	C2= 930.004	C3= 255.825	M2= .999893
A1= 90.	A2= 18	A3= 90	
B2= 31.5563	W2= 549.142	W3= 488.832	MR2= .59041
UM= 416.548	UTIP= 442.538	DIA= 4.22592	H= .256461
T3= 2328	HT3= 2.38392	S3= 2.50682	V3= .88412 Q3= .952414
STAGE EFF.= .741962		ETT= .782879	ETS= .731919
STAGE NO.-- 2			
T1= 2328	HT1= 2.38392	S1= 2.50682	V1= .88412 Q1= .952414
NS= 56.1713	DS= 1.24029	C0= 996.555	H/D= 9.06928 E-2
C1= 255.825	C2= 926.46	C3= 311.707	M2= 1.06786
A1= 90.	A2= 21.375	A3= 90	
B2= 36.9686	W2= 561.439	W3= 518.322	MR2= .647185
UM= 414.124	UTIP= 453.179	DIA= 4.32754	H= .392477
T3= 2091	HT3= 2.28476	S3= 2.52598	V3= 1.6343 Q3= .901482
STAGE EFF.= .712271		ETT= .797028	ETS= .719051
STAGE NO.-- 3			
T1= 2091	HT1= 2.28476	S1= 2.52598	V1= 1.6343 Q1= .901482
NS= 77.2214	DS= .945619	C0= 1030.69	H/D= .145014
C1= 311.707	C2= 959.868	C3= 368.896	M2= 1.18983
A1= 90.	A2= 24	A3= 90	
B2= 40.8599	W2= 596.408	W3= 563.536	MR2= .73929
UM= 426.018	UTIP= 491.259	DIA= 4.69118	H= .680287
T3= 1869	HT3= 2.18658	S3= 2.55045	V3= 3.41708 Q3= .85424
STAGE EFF.= .682223		ETT= .806453	ETS= .703145
STAGE NO.-- 4			
T1= 1869	HT1= 2.18658	S1= 2.55045	V1= 3.41708 Q1= .85424
NS= 114.066	DS= .715683	C0= 1071.41	H/D= .279527
C1= 368.896	C2= 998.763	C3= 412.146	M2= 1.33426
A1= 90.	A2= 25.5	A3= 90	
B2= 43.0507	W2= 629.871	W3= 603.748	MR2= .841453
UM= 441.191	UTIP= 570.901	DIA= 5.4517	H= 1.5239
T3= 1660	HT3= 2.08722	S3= 2.58215	V3= 8.37479 Q3= .811649
STAGE EFF.= .653795		ETT= .813275	ETS= .692929
TURBINE TOTAL ENTHALPY DROP= .405065		OVERALL CYCLE EFFICIENCY = .79991	
OVERALL TURBINE EFFICIENCY= .727826			
NEW WEIGHT FLOW= 6.42687			
NUMBER OF STAGES= 5		RPM= 24000	
INITIAL WEIGHT FLOW= 6.306			
STAGE NO.-- 1			
T1= 2610	HT1= 2.49228	S1= 2.4909	V1= .52288 Q1= 1
NS= 44.5594	DS= 1.52811	C0= 906.824	H/D= 6.69477 E-2
C1= 300	C2= 841.667	C3= 246.69	M2= .894116
A1= 90.	A2= 19	A3= 90	
B2= 33.1973	W2= 500.471	W3= 450.554	MR2= .531658
UM= 377.023	UTIP= 403.039	DIA= 3.84873	H= .257664
T3= 2378	HT3= 2.40298	S3= 2.50293	V3= .789524 Q3= .962326
STAGE EFF.= .754733		ETT= .787173	ETS= .728919
STAGE NO.-- 2			
T1= 2378	HT1= 2.40298	S1= 2.50293	V1= .789524 Q1= .962326
NS= 57.4432	DS= 1.21204	C0= 895.244	H/D= 9.21979 E-2
C1= 246.69	C2= 832.626	C3= 288.92	M2= .933645
A1= 90.	A2= 22	A3= 90	
B2= 37.8928	W2= 507.837	W3= 470.41	MR2= .569451
UM= 371.232	UTIP= 406.842	DIA= 3.88505	H= .358194
T3= 2183	HT3= 2.32165	S3= 2.51678	V3= 1.26247 Q3= .919712
STAGE EFF.= .729021		ETT= .797838	ETS= .71474
STAGE NO.-- 3			
T1= 2183	HT1= 2.32165	S1= 2.51678	V1= 1.26247 Q1= .919712
NS= 72.3737	DS= .99976	C0= 918.71	H/D= .132427
C1= 288.92	C2= 855.162	C3= 317.457	M2= 1.01617
A1= 90.	A2= 23.25	A3= 90	
B2= 39.8169	W2= 527.175	W3= 495.766	MR2= .626428
UM= 380.796	UTIP= 433.895	DIA= 4.14339	H= .548695
T3= 1999	HT3= 2.24056	S3= 2.53398	V3= 2.16578 Q3= .880154
STAGE EFF.= .702229		ETT= .804873	ETS= .708769
STAGE NO.-- 4			
T1= 1999	HT1= 2.24056	S1= 2.53398	V1= 2.16578 Q1= .880154
NS= 95.7137	DS= .804223	C0= 937.6	H/D= .205645
C1= 317.457	C2= 873.747	C3= 352.137	M2= 1.10032
A1= 90.	A2= 25	A3= 90	
B2= 42.3332	W2= 548.319	W3= 522.89	MR2= .690503
UM= 386.544	UTIP= 471.084	DIA= 4.49852	H= .925097
T3= 1826	HT3= 2.161	S3= 2.55467	V3= 4.02642 Q3= .843589
STAGE EFF.= .677977		ETT= .810684	ETS= .696333
STAGE NO.-- 5			
T1= 1826	HT1= 2.161	S1= 2.55467	V1= 4.02642 Q1= .843589
NS= 131.34	DS= .664318	C0= 968.647	H/D= .384635
C1= 352.137	C2= 902.753	C3= 367.974	M2= 1.20714
A1= 90.	A2= 25.125	A3= 90	
B2= 42.5883	W2= 566.408	W3= 543.756	MR2= .757387
UM= 400.329	UTIP= 551.657	DIA= 5.26793	H= 2.02623
T3= 1660	HT3= 2.0795	S3= 2.58072	V3= 8.36006 Q3= .810219
STAGE EFF.= .653369		ETT= .815085	ETS= .697458
TURBINE TOTAL ENTHALPY DROP= .412789		OVERALL CYCLE EFFICIENCY = .80313	
OVERALL TURBINE EFFICIENCY= .734638			
NEW WEIGHT FLOW= 6.30661			

Table 13. (continued)

NUMBER OF STAGES= 1 RPM= 24000
INITIAL WEIGHT FLOW= 8.255

STAGE NO.-- 1

T1= 2460	HT1= 2.48032	S1= 2.51952	V1= .730224	Q1= 1
NS= 58.7992	DS= 1.1917	CO= 1835.48	H/D= 9.68835	E-2
C1= 300	C2= 1706.81	C3= 586.136	M2= 2.23291	
A1= 90.	A2= 21.75	A3= 90	C/H= .491	
B2= 37.5492	W2= 1037.78	W3= 961.755	MR2= 1.35767	
UM= 762.513	UTIP= 839.496	DIA.= 8.0166	H= .776676	
T3= 1660	HT3= 2.16791	S3= 2.6145	V3= 8.70853	Q3= .844035
STAGE EFF.= .664548		ETT= .798657	ETS= .717214	

TURBINE TOTAL ENTHALPY DROP= .312414 OVERALL CYCLE EFFICIENCY = .79566
OVERALL TURBINE EFFICIENCY= .66458

NEW WEIGHT FLOW= 8.33285

NUMBER OF STAGES= 2 RPM= 24000
INITIAL WEIGHT FLOW= 7.55

STAGE NO.-- 1

T1= 2460	HT1= 2.48032	S1= 2.51952	V1= .730224	Q1= 1
NS= 45.2506	DS= 1.50725	CO= 1315.1	H/D= 6.83586	E-2
C1= 300	C2= 1220.71	C3= 360.683	M2= 1.41269	
A1= 90.	A2= 19.125	A3= 90	C/H= .732725	
B2= 33.4043	W2= 726.439	W3= 655.127	MR2= .840601	
UM= 546.906	UTIP= 535.461	DIA.= 5.59074	H= .382175	
T3= 2023	HT3= 2.30256	S3= 2.55438	V3= 2.07419	Q3= .915656
STAGE EFF.= .715253		ETT= .78791	ETS= .726644	

STAGE NO.-- 2

T1= 2023	HT1= 2.30256	S1= 2.55438	V1= 2.07419	Q1= .915656
NS= 87.5456	DS= .362712	CO= 1361.02	H/D= .179981	
C1= 360.683	C2= 1267.61	C3= 491.656	M2= 1.66891	
A1= 90.	A2= 24.125	A3= 90	C/H= .251155	
B2= 41.1153	W2= 787.904	W3= 674.678	MR2= 1.03734	
UM= 563.294	UTIP= 670.957	DIA.= 6.40717	H= 1.15317	
T3= 1660	HT3= 2.13555	S3= 2.60453	V3= 8.60573	Q3= .83406
STAGE EFF.= .667336		ETT= .80909	ETS= .703508	

TURBINE TOTAL ENTHALPY DROP= .344777 OVERALL CYCLE EFFICIENCY = .7950
OVERALL TURBINE EFFICIENCY= .709542

NEW WEIGHT FLOW= 7.55068

NUMBER OF STAGES= 3 RPM= 24000
INITIAL WEIGHT FLOW= 7.24

STAGE NO.-- 1

T1= 2460	HT1= 2.48032	S1= 2.51952	V1= .730224	Q1= 1
NS= 48.4186	DS= 1.41717	CO= 1087.65	H/D= 7.43614	E-2
C1= 300	C2= 1010.12	C3= 312.203	M2= 1.12211	
A1= 90.	A2= 19.875	A3= 90		
B2= 34.6116	W2= 604.579	W3= 549.64	MR2= .671609	
UM= 452.369	UTIP= 487.141	DIA.= 4.65185	H= .345918	
T3= 2156	HT3= 2.35513	S3= 2.53921	V3= 1.40097	Q3= .943327
STAGE EFF.= .742189		ETT= .791019	ETS= .725845	

STAGE NO.-- 2

T1= 2156	HT1= 2.35513	S1= 2.53921	V1= 1.40097	Q1= .943327
NS= 70.643	DS= 1.01611	CO= 1110.17	H/D= .125972	
C1= 312.203	C2= 1033.55	C3= 387.509	M2= 1.25197	
A1= 90.	A2= 23.5	A3= 90		
B2= 40.1528	W2= 639.127	W3= 600.949	MR2= .774193	
UM= 459.326	UTIP= 500.154	DIA.= 4.9671	H= .625717	
T3= 1896	HT3= 2.23681	S3= 2.5655	V3= 3.17133	Q3= .882124
STAGE EFF.= .703604		ETT= .804243	ETS= .706255	

STAGE NO.-- 3

T1= 1896	HT1= 2.23681	S1= 2.5655	V1= 3.17133	Q1= .882124
NS= 110.841	DS= .728142	CO= 1144.77	H/D= .264764	
C1= 387.509	C2= 1067.15	C3= 440.126	M2= 1.40898	
A1= 90.	A2= 25.5	A3= 90		
B2= 43.043	W2= 673.095	W3= 644.827	MR2= .8887	
UM= 471.269	UTIP= 603.067	DIA.= 5.75886	H= 1.52474	
T3= 1660	HT3= 2.12078	S3= 2.60013	V3= 8.5603	Q3= .82965
STAGE EFF.= .66872		ETT= .812888	ETS= .69273	

TURBINE TOTAL ENTHALPY DROP= .359549 OVERALL CYCLE EFFICIENCY = .80272
OVERALL TURBINE EFFICIENCY= .728754

NEW WEIGHT FLOW= 7.24045

Table 13. (continued)

NUMBER OF STAGES= 4 RPM= 24000
 INITIAL WEIGHT FLOW= 7.045

STAGE NO.-- 1

T1= 2460	HT1= 2.48032	S1= 2.51952	V1= .730224	Q1= 1
NS= 53.2485	DS= 1.3006	C0= 953.805	H/D= 8.42198	E-2
C1= 300	C2= 886.416	C3= 290.1	M2= .96486	
A1= 90.	A2= 20.875	A3= 90	C/H= .574967	
B2= 36.1902	W2= 534.925	W3= 491.304	MR2= .582264	
UM= 396.515	UTIP= 431.161	DIA.= 4.11728	H= .346757	
T3= 2223	HT3= 2.38293	S3= 2.53322	V3= 1.17432	Q3= .958402
STAGE EFF.= .759182		ETT= .794994	ETS= .721451	

STAGE NO.-- 2

T1= 2223	HT1= 2.38293	S1= 2.53322	V1= 1.17432	Q1= .958402
NS= 69.7976	DS= 1.02557	C0= 960.692	H/D= .123351	
C1= 290.1	C2= 894.388	C3= 335.168	M2= 1.03866	
A1= 90.	A2= 23.5	A3= 90	C/H= .371819	
B2= 40.1459	W2= 553.15	W3= 519.851	MR2= .642375	
UM= 397.378	UTIP= 448.871	DIA.= 4.2864	H= .528731	
T3= 2023	HT3= 2.29134	S3= 2.5502	V3= 2.06169	Q3= .910107
STAGE EFF.= .727204		ETT= .803917	ETS= .706066	

STAGE NO.-- 3

T1= 2023	HT1= 2.29134	S1= 2.5502	V1= 2.06169	Q1= .910107
NS= 93.3965	DS= .817616	C0= 983.97	H/D= .196919	
C1= 335.168	C2= 916.959	C3= 369.33	M2= 1.13564	
A1= 90.	A2= 25	A3= 90	C/H= .225271	
B2= 42.3248	W2= 575.529	W3= 548.509	MR2= .712786	
UM= 405.536	UTIP= 490.447	DIA.= 4.68342	H= .922255	
T3= 1836	HT3= 2.20124	S3= 2.57152	V3= 3.96641	Q3= .866588
STAGE EFF.= .697132		ETT= .810264	ETS= .69611	

STAGE NO.-- 4

T1= 1836	HT1= 2.20124	S1= 2.57152	V1= 3.96641	Q1= .866588
NS= 132.09	DS= .662337	C0= 1008.57	H/D= .390828	
C1= 369.33	C2= 939.96	C3= 383.184	M2= 1.24234	
A1= 90.	A2= 25.125	A3= 90	C/H= .113024	
B2= 42.5899	W2= 589.735	W3= 566.214	MR2= .779448	
UM= 416.852	UTIP= 575.949	DIA.= 5.4999	H= 2.14952	
T3= 1660	HT3= 2.11082	S3= 2.59852	V3= 8.5437	Q3= .82804
STAGE EFF.= .668618		ETT= .815163	ETS= .697498	

TURBINE TOTAL ENTHALPY DROP= .369504 OVERALL CYCLE EFFICIENCY = .80608
 OVERALL TURBINE EFFICIENCY= .738035

NEW WEIGHT FLOW= 7.04539

Table 14. Calculation of the Effects of Number of Stages and RPM on the Size and Performance of Potassium Turbines as Determined from a Computing Machine Program Including Aerodynamic and Moisture Churning Losses but with No Regenerative Feed Heating or Seal Leakage Losses.

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NUMBER OF STAGES= 3          RPM= 18000
INITIAL WEIGHT FLOW= 1.966

STAGE NO.-- 1
T1= 2610      HT1= 9.61635    S1= 7.894      V1= 2.774      Q1= 1
NS= 14.8175   DS= 4.09137    CO= 2107.93   H/D= 1.42808 E-2
C1= 500       C2= 1950.88    C3= 354.967   M2= 1.13592
A1= 90.       A2= 15      A3= 90
B2= 24.5283   W2= 1216.27    W3= 855.057   MR2= .708184
UM= 777.899   UTIP= 789.086   DIA.= 10.047  H= .143478
T3= 2300      HT3= 9.18337    S3= 8.00219   V3= 5.59595   Q3= .959709
STAGE EFF.= .645469      ETT= .67363    ETS= .654527

STAGE NO.-- 2
T1= 2300      HT1= 9.18337    S1= 8.00219   V1= 5.59595   Q1= .959709
NS= 21.2811   DS= 2.92689    CO= 2118.43   H/D= .024871
C1= 354.967   C2= 1960.6     C3= 404.602   M2= 1.23428
A1= 90.       A2= 15      A3= 90
B2= 25.7152   W2= 1169.49    W3= 932.476   MR2= .736244
UM= 840.129   UTIP= 861.276   DIA.= 10.9661 H= .272738
T3= 2036      HT3= 8.74194    S3= 8.11537   V3= 13.0916   Q3= .904694
STAGE EFF.= .657006      ETT= .732561   ETS= .705839

STAGE NO.-- 3
T1= 2036      HT1= 8.74194    S1= 8.11537   V1= 13.0916   Q1= .904694
NS= 34.6123   DS= 1.92926    CO= 2168.57   H/D= 5.15487 E-2
C1= 404.602   C2= 2008.1     C3= 472.867   M2= 1.37524
A1= 90.       A2= 15.75     A3= 90
B2= 27.7755   W2= 1169.68    W3= 1014.71   MR2= .801047
UM= 897.802   UTIP= 945.203   DIA.= 12.0347 H= .620373
T3= 1790      HT3= 8.29215    S3= 8.2529    V3= 37.1489   Q3= .851259
STAGE EFF.= .646222      ETT= .773354   ETS= .736582

TURBINE TOTAL ENTHALPY DROP= 1.32419      OVERALL CYCLE EFFICIENCY = .72652
OVERALL TURBINE EFFICIENCY= .676021

NEW WEIGHT FLOW= 1.96595

NUMBER OF STAGES= 5          RPM= 18000
INITIAL WEIGHT FLOW= 1.8845

STAGE NO.-- 1
T1= 2610      HT1= 9.61635    S1= 7.8984     V1= 2.774      Q1= 1
NS= 16.8296   DS= 3.54598    CO= 1663.13   H/D= 1.79293 E-2
C1= 500       C2= 1539.22    C3= 298.077   M2= .87216
A1= 90.       A2= 15      A3= 90
B2= 25.1      W2= 939.133    W3= 702.68    MR2= .532134
UM= 636.328   UTIP= 647.838   DIA.= 8.24852 H= .14789
T3= 2412      HT3= 9.33116    S3= 7.95233   V3= 4.13314   Q3= .977581
STAGE EFF.= .685575      ETT= .702266   ETS= .679708

STAGE NO.-- 2
T1= 2412      HT1= 9.33116    S1= 7.95233   V1= 4.13314   Q1= .977581
NS= 21.6962   DS= 2.38007    CO= 1632.8    H/D= .025591
C1= 298.077   C2= 1511.15    C3= 313.241   M2= .896225
A1= 90.       A2= 15      A3= 90
B2= 25.7595   W2= 899.95     W3= 720.765   MR2= .533737
UM= 649.143   UTIP= 665.962   DIA.= 8.47929 H= .216993
T3= 2246      HT3= 9.05613    S3= 8.00753   V3= 6.5001    Q3= .94297
STAGE EFF.= .689319      ETT= .734726   ETS= .707685

STAGE NO.-- 3
T1= 2246      HT1= 9.05613    S1= 8.00753   V1= 6.5001    Q1= .94297
NS= 27.4919   DS= 2.35742    CO= 1652.48   H/D= 3.69125 E-2
C1= 313.241   C2= 1529.36    C3= 331.898   M2= .951659
A1= 90.       A2= 15      A3= 90
B2= 26.2258   W2= 895.719    W3= 751.048   MR2= .557369
UM= 673.739   UTIP= 699.048   DIA.= 8.90055 H= .328542
T3= 2087      HT3= 8.77878    S3= 8.06974   V3= 10.8186   Q3= .908365
STAGE EFF.= .681134      ETT= .757385   ETS= .726832

STAGE NO.-- 4
T1= 2087      HT1= 8.77878    S1= 8.06974   V1= 10.8186   Q1= .908365
NS= 36.0059   DS= 1.86047    CO= 1671.87   H/D= 5.35274 E-2
C1= 331.898   C2= 1548.72    C3= 378.317   M2= 1.01286
A1= 90.       A2= 16.25     A3= 90
B2= 28.6308   W2= 904.445    W3= 789.534   MR2= .591502
UM= 692.997   UTIP= 731.021   DIA.= 9.30765 H= .498214
T3= 1935      HT3= 8.50336    S3= 8.14036   V3= 19.2182   Q3= .874624
STAGE EFF.= .668323      ETT= .77571    ETS= .73599

STAGE NO.-- 5
T1= 1935      HT1= 8.50336    S1= 8.14036   V1= 19.2182   Q1= .874624
NS= 48.6934   DS= 1.40929    CO= 1696.85   H/D= 7.47001 E-2
C1= 378.317   C2= 1576.02    C3= 490.474   M2= 1.08557
A1= 90.       A2= 20      A3= 90
B2= 34.8053   W2= 944.359    W3= 859.292   MR2= .65048
UM= 705.567   UTIP= 760.055   DIA.= 9.67732 H= .722897
T3= 1790      HT3= 8.23473    S3= 8.21935   V3= 36.7474   Q3= .842051
STAGE EFF.= .65524      ETT= .791271   ETS= .725161

TURBINE TOTAL ENTHALPY DROP= 1.38162      OVERALL CYCLE EFFICIENCY = .75227
OVERALL TURBINE EFFICIENCY= .706288

NEW WEIGHT FLOW= 1.88424

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Table 14. (continued)

NUMBER OF STAGES= 7				RPM= 18000	
INITIAL WEIGHT FLOW= 1.843					
STAGE NO.-- 1					
T1= 2610	HT1= 9.61235	S1= 7.8984	V1= 2.774	Q1= 1	
NS= 19.6659	DS= 3.12475	C0= 1429.5	H/D= 2.21872	E-2	
C1= 500	C2= 1323.	C3= 267.778	M2= .741373		
A1= 90.	A2= 15	A3= 90			
B2= 25.5241	W2= 794.671	W3= 621.452	MR2= .445312		
UM= 560.805	UTIP= 573.382	DIA.= 7.30053	H= .161978		
T3= 2460	HT3= 9.39428	S3= 7.93325	V3= 3.66443	Q3= .985291	
STAGE EFF.= .711757		ETT= .723199	ETS= .697822		
STAGE NO.-- 2					
T1= 2460	HT1= 9.39428	S1= 7.93325	V1= 3.66443	Q1= .985291	
NS= 24.3237	DS= 2.61597	C0= 1373.35	H/D= 3.04319	E-2	
C1= 267.778	C2= 1271.03	C3= 269.889	M2= .735427		
A1= 90.	A2= 15	A3= 90			
B2= 26.0022	W2= 750.371	W3= 615.616	MR2= .434169		
UM= 553.306	UTIP= 570.392	DIA.= 7.26245	H= .22101		
T3= 2340	HT3= 9.19318	S3= 7.96772	V3= 4.9708	Q3= .959808	
STAGE EFF.= .713785		ETT= .74654	ETS= .717709		
STAGE NO.-- 3					
T1= 2340	HT1= 9.19318	S1= 7.96772	V1= 4.9708	Q1= .959808	
NS= 28.298	DS= 2.30001	C0= 1387.27	H/D= 3.86712	E-2	
C1= 269.889	C2= 1283.91	C3= 279.911	M2= .768264		
A1= 90.	A2= 15	A3= 90			
B2= 26.2734	W2= 750.697	W3= 632.342	MR2= .4492		
UM= 567.02	UTIP= 589.353	DIA.= 7.50387	H= .290184		
T3= 2223	HT3= 8.99101	S3= 8.00581	V3= 6.93448	Q3= .934286	
STAGE EFF.= .704766		ETT= .759687	ETS= .728759		
STAGE NO.-- 4					
T1= 2223	HT1= 8.99101	S1= 8.00581	V1= 6.93448	Q1= .934286	
NS= 33.4463	DS= 1.99167	C0= 1401.31	H/D= .050149		
C1= 279.911	C2= 1297.15	C3= 294.283	M2= .803652		
A1= 90.	A2= 15.25	A3= 90			
B2= 26.9206	W2= 753.586	W3= 649.981	MR2= .466887		
UM= 579.548	UTIP= 609.298	DIA.= 7.75782	H= .389047		
T3= 2109	HT3= 8.7887	S3= 8.04818	V3= 9.98448	Q3= .908997	
STAGE EFF.= .693613		ETT= .771253	ETS= .737239		
STAGE NO.-- 5					
T1= 2109	HT1= 8.7887	S1= 8.04818	V1= 9.98448	Q1= .908997	
NS= 40.51	DS= 1.65643	C0= 1405.34	H/D= 5.68664	E-2	
C1= 294.283	C2= 1304.37	C3= 378.951	M2= .83717		
A1= 90.	A2= 19	A3= 90			
B2= 33.088	W2= 777.867	W3= 694.142	MR2= .499252		
UM= 581.579	UTIP= 615.528	DIA.= 7.83714	H= .44567		
T3= 2000	HT3= 8.59427	S3= 8.09325	V3= 14.7739	Q3= .884177	
STAGE EFF.= .683293		ETT= .782217	ETS= .725341		
STAGE NO.-- 6					
T1= 2000	HT1= 8.59427	S1= 8.09325	V1= 14.7739	Q1= .884177	
NS= 48.3519	DS= 1.4188	C0= 1443.29	H/D= 7.41841	E-2	
C1= 378.951	C2= 1340.4	C3= 414.241	M2= .892227		
A1= 90.	A2= 19.875	A3= 90			
B2= 34.6103	W2= 802.287	W3= 729.306	MR2= .534038		
UM= 600.248	UTIP= 646.274	DIA.= 8.22861	H= .610432		
T3= 1893	HT3= 8.39512	S3= 8.14494	V3= 22.7986	Q3= .860184	
STAGE EFF.= .670503		ETT= .790959	ETS= .725803		
STAGE NO.-- 7					
T1= 1893	HT1= 8.39512	S1= 8.14494	V1= 22.7986	Q1= .860184	
NS= 60.1924	DS= 1.16714	C0= 1459.44	H/D= .100033		
C1= 414.241	C2= 1357.36	C3= 472.225	M2= .937889		
A1= 90.	A2= 22	A3= 90			
B2= 37.9274	W2= 827.242	W3= 768.265	MR2= .571596		
UM= 606.003	UTIP= 669.24	DIA.= 8.52102	H= .852383		
T3= 1790	HT3= 8.19971	S3= 8.20131	V3= 36.5315	Q3= .837101	
STAGE EFF.= .659503		ETT= .799456	ETS= .715757		
TURBINE TOTAL ENTHALPY DROP= 1.41264				OVERALL CYCLE EFFICIENCY = .76762	
OVERALL TURBINE EFFICIENCY= .722616					
NEW WEIGHT FLOW= 1.84286					

Table 14. (continued)

NUMBER OF STAGES= 9				RPM= 18000	
INITIAL WEIGHT FLOW= 1.814					
STAGE NO.-- 1					
T1= 2610	HT1= 9.61635	S1= 7.8984	V1= 2.774	Q1= 1	
NS= 22.1745	DS= 2.82798	C0= 1283.66	H/D= 2.64357	E-2	
C1= 500	C2= 1188.02	C3= 247.47	M2= .661177		
A1= 90.	A2= 15	A3= 90	C/H= 2.04327		
B2= 25.8084	W2= 706.267	W3= 568.418	MR2= .393062		
UM= 511.723	UTIP= 525.425	DIA.= 6.68991	H= .176853		
T3= 2488	HT3= 9.43644	S3= 7.92496	V3= 3.42744	Q3= .990766	
STAGE EFF.= .729723		ETT= .73711	ETS= .709715		
STAGE NO.-- 2					
T1= 2488	HT1= 9.43644	S1= 7.92496	V1= 3.42744	Q1= .990766	
NS= 27.0266	DS= 2.39197	C0= 1215.44	H/D= 3.59174	E-2	
C1= 247.47	C2= 1124.89	C3= 243.436	M2= .641854		
A1= 90.	A2= 15	A3= 90	C/H= 1.49891		
B2= 26.1968	W2= 659.504	W3= 551.436	MR2= .376309		
UM= 494.797	UTIP= 512.875	DIA.= 6.53013	H= .234545		
T3= 2393	HT3= 9.27532	S3= 7.9497	V3= 4.32214	Q3= .970197	
STAGE EFF.= .731247		ETT= .75598	ETS= .725655		
STAGE NO.-- 3					
T1= 2393	HT1= 9.27532	S1= 7.9497	V1= 4.32214	Q1= .970197	
NS= 30.3268	DS= 2.16798	C0= 1222.55	H/D= 4.32918	E-2	
C1= 243.436	C2= 1131.47	C3= 249.201	M2= .662619		
A1= 90.	A2= 15	A3= 90	C/H= 1.24162		
B2= 26.3798	W2= 659.084	W3= 560.858	MR2= .385979		
UM= 502.459	UTIP= 524.659	DIA.= 6.68016	H= .289196		
T3= 2300	HT3= 9.11451	S3= 7.97657	V3= 5.53812	Q3= .949744	
STAGE EFF.= .722416		ETT= .764826	ETS= .733047		
STAGE NO.-- 4					
T1= 2300	HT1= 9.11451	S1= 7.97657	V1= 5.53812	Q1= .949744	
NS= 34.4889	DS= 1.93256	C0= 1224.65	H/D= 5.05033	E-2	
C1= 249.201	C2= 1134.23	C3= 271.336	M2= .682052		
A1= 90.	A2= 16	A3= 90	C/H= 1.04728		
B2= 28.174	W2= 662.153	W3= 574.679	MR2= .398175		
UM= 506.595	UTIP= 532.787	DIA.= 6.78365	H= .342597		
T3= 2210	HT3= 8.9565	S3= 8.00534	V3= 7.1995	Q3= .929605	
STAGE EFF.= .713051		ETT= .773133	ETS= .735179		
STAGE NO.-- 5					
T1= 2210	HT1= 8.9565	S1= 8.00534	V1= 7.1995	Q1= .929605	
NS= 39.0932	DS= 1.72387	C0= 1237.03	H/D= 5.79025	E-2	
C1= 271.336	C2= 1146.83	C3= 302.799	M2= .707369		
A1= 90.	A2= 17.375	A3= 90	C/H= .892641		
B2= 33.5217	W2= 674.335	W3= 596.218	MR2= .415932		
UM= 513.606	UTIP= 544.146	DIA.= 6.92828	H= .401165		
T3= 2122	HT3= 8.79941	S3= 8.03664	V3= 9.53349	Q3= .909673	
STAGE EFF.= .702804		ETT= .780396	ETS= .733637		
STAGE NO.-- 6					
T1= 2122	HT1= 8.79941	S1= 8.03664	V1= 9.53349	Q1= .909673	
NS= 44.6762	DS= 1.51983	C0= 1251.06	H/D= 6.57705	E-2	
C1= 302.799	C2= 1161.57	C3= 349.768	M2= .737762		
A1= 90.	A2= 19.5	A3= 90	C/H= .756633		
B2= 33.9625	W2= 694.065	W3= 626.092	MR2= .440829		
UM= 519.287	UTIP= 554.473	DIA.= 7.05977	H= .464324		
T3= 2036	HT3= 8.64408	S3= 8.07046	V3= 12.8795	Q3= .890009	
STAGE EFF.= .692856		ETT= .787293	ETS= .725756		
STAGE NO.-- 7					
T1= 2036	HT1= 8.64408	S1= 8.07046	V1= 12.8795	Q1= .890009	
NS= 51.2965	DS= 1.34011	C0= 1270.42	H/D= 7.85462	E-2	
C1= 349.768	C2= 1180.76	C3= 387.834	M2= .771328		
A1= 90.	A2= 21	A3= 90	C/H= .615304		
B2= 36.3417	W2= 714.051	W3= 654.461	MR2= .466451		
UM= 527.171	UTIP= 570.04	DIA.= 7.25797	H= .570087		
T3= 1952	HT3= 8.48883	S3= 8.10743	V3= 17.7799	Q3= .870869	
STAGE EFF.= .682669		ETT= .793484	ETS= .719535		
STAGE NO.-- 8					
T1= 1952	HT1= 8.48883	S1= 8.10743	V1= 17.7799	Q1= .870869	
NS= 59.7456	DS= 1.17532	C0= 1287.9	H/D= 9.91769	E-2	
C1= 387.834	C2= 1197.71	C3= 414.092	M2= .805071		
A1= 90.	A2= 21.875	A3= 90	C/H= .478404		
B2= 37.7417	W2= 729.038	W3= 676.505	MR2= .490041		
UM= 534.969	UTIP= 590.3	DIA.= 7.51593	H= .745406		
T3= 1870	HT3= 8.33347	S3= 8.14792	V3= 25.1284	Q3= .852404	
STAGE EFF.= .672316		ETT= .799203	ETS= .716582		
STAGE NO.-- 9					
T1= 1870	HT1= 8.33347	S1= 8.14792	V1= 25.1284	Q1= .852404	
NS= 70.6425	DS= 1.01612	C0= 1303.4	H/D= .125971		
C1= 414.092	C2= 1213.45	C3= 454.958	M2= .839873		
A1= 90.	A2= 23.5	A3= 90	C/H= .36405		
B2= 40.1528	W2= 750.372	W3= 705.549	MR2= .51936		
UM= 539.276	UTIP= 610.689	DIA.= 7.77553	H= .97949		
T3= 1798	HT3= 8.17982	S3= 8.19159	V3= 36.4152	Q3= .834434	
STAGE EFF.= .662888		ETT= .804243	ETS= .706255		
TURBINE TOTAL ENTHALPY DROP= 1.43652					
OVERALL TURBINE EFFICIENCY= .732404					
OVERALL CYCLE EFFICIENCY = .77730					
NEW WEIGHT FLOW= 1.81222					

Table 14. (continued)

NUMBER OF STAGES= 3 RPM= 18000
 INITIAL WEIGHT FLOW= 1.697

STAGE NO.-- 1
 T1= 2610 HT1= 9.61635 S1= 7.8984 V1= 2.774 Q1= 1
 NS= 12.3964 DS= 4.48754 C0= 2286.02 H/D= 1.24343 E-2
 C1= 500 C2= 2115.71 C3= 366.817 M2= 1.24635
 A1= 90. A2= 15 A3= 90 C/H= 4.40454
 B2= 24.1059 W2= 1340.72 W3= 898.139 MR2= .789812
 UM= 819.816 UTIP= 830.073 DIA.= 10.5688 H= .131416
 T3= 2251 HT3= 9.12511 S3= 8.03009 V3= 6.46701 Q3= .95321
 STAGE EFF.= .621013 ETT= .652118 ETS= .635327

STAGE NO.-- 2
 T1= 2251 HT1= 9.12511 S1= 8.03009 V1= 6.46701 Q1= .95321
 NS= 20.7505 DS= 2.98903 C0= 2310.89 H/D= 2.39687 E-2
 C1= 366.817 C2= 2138.72 C3= 438.725 M2= 1.38315
 A1= 90. A2= 15 A3= 90 C/H= 2.25647
 B2= 25.6558 W2= 1278.49 W3= 1013.3 MR2= .826823
 UM= 913.401 UTIP= 935.549 DIA.= 11.9118 H= .28551
 T3= 1945 HT3= 8.61102 S3= 8.17701 V3= 18.718 Q3= .889653
 STAGE EFF.= .642687 ETT= .729657 ETS= .703358

STAGE NO.-- 3
 T1= 1945 HT1= 8.61102 S1= 8.17701 V1= 18.718 Q1= .889653
 NS= 39.2133 DS= 1.71939 C0= 2393.99 H/D= 5.82056 E-2
 C1= 438.725 C2= 2219.43 C3= 586.18 M2= 1.59334
 A1= 90. A2= 17.375 A3= 90 C/H= .887959
 B2= 30.5254 W2= 1304.88 W3= 1154.08 MR2= .936782
 UM= 994.132 UTIP= 1053.56 DIA.= 13.4144 H= .780791
 T3= 1660 HT3= 8.0815 S3= 8.36231 V3= 74.319 Q3= .827762
 STAGE EFF.= .632566 ETT= .780563 ETS= .733765

TURBINE TOTAL ENTHALPY DROP= 1.53484 OVERALL CYCLE EFFICIENCY = .72078
 OVERALL TURBINE EFFICIENCY= .665895

NEW WEIGHT FLOW= 1.69613

NUMBER OF STAGES= 5 RPM= 18000
 INITIAL WEIGHT FLOW= 1.6245

STAGE NO.-- 1
 T1= 2610 HT1= 9.61635 S1= 7.8984 V1= 2.774 Q1= 1
 NS= 14.4696 DS= 3.99284 C0= 1798.76 H/D= 1.48291 E-2
 C1= 500 C2= 1664.75 C3= 306.453 M2= .949803
 A1= 90. A2= 15 A3= 90 C/H= 3.6779
 B2= 24.6327 W2= 1033.75 W3= 735.253 MR2= .589795
 UM= 668.346 UTIP= 678.329 DIA.= 8.63675 H= .128075
 T3= 2381 HT3= 9.29412 S3= 7.96732 V3= 4.48395 Q3= .973432
 STAGE EFF.= .66011 ETT= .678902 ETS= .659197

STAGE NO.-- 2
 T1= 2381 HT1= 9.29412 S1= 7.96732 V1= 4.48395 Q1= .973432
 NS= 19.4804 DS= 3.14922 C0= 1772.85 H/D= 2.18909 E-2
 C1= 306.453 C2= 1640.76 C3= 331.276 M2= .987897
 A1= 90. A2= 15 A3= 90 C/H= 2.47386
 B2= 25.5001 W2= 986.407 W3= 769.498 MR2= .593911
 UM= 694.541 UTIP= 709.908 DIA.= 9.03883 H= .197868
 T3= 2188 HT3= 8.97805 S3= 8.03827 V3= 7.78107 Q3= .933831
 STAGE EFF.= .670671 ETT= .722018 ETS= .696807

STAGE NO.-- 3
 T1= 2188 HT1= 8.97805 S1= 8.03827 V1= 7.78107 Q1= .933831
 NS= 26.0999 DS= 2.46409 C0= 1803.13 H/D= 3.39797 E-2
 C1= 331.276 C2= 1668.79 C3= 358.994 M2= 1.06392
 A1= 90. A2= 15 A3= 90 C/H= 1.58522
 B2= 26.1353 W2= 980.526 W3= 814.981 MR2= .625121
 UM= 731.657 UTIP= 756.925 DIA.= 9.63747 H= .327479
 T3= 2004 HT3= 8.65517 S3= 8.11925 V3= 14.6957 Q3= .893957
 STAGE EFF.= .665498 ETT= .753003 ETS= .723155

STAGE NO.-- 4
 T1= 2004 HT1= 8.65517 S1= 8.11925 V1= 14.6957 Q1= .893957
 NS= 36.7452 DS= 1.82099 C0= 1837.66 H/D= 5.31673 E-2
 C1= 358.994 C2= 1703.22 C3= 436.831 M2= 1.15359
 A1= 90. A2= 17 A3= 90 C/H= .97877
 B2= 29.8525 W2= 1000.41 W3= 877.573 MR2= .677575
 UM= 761.134 UTIP= 802.61 DIA.= 10.2191 H= .543324
 T3= 1828 HT3= 8.33191 S3= 8.21324 V3= 30.834 Q3= .855074
 STAGE EFF.= .652923 ETT= .776888 ETS= .73299

STAGE NO.-- 5
 T1= 1828 HT1= 8.33191 S1= 8.21324 V1= 30.834 Q1= .855074
 NS= 54.6337 DS= 1.26754 C0= 1883.57 H/D= 8.60144 E-2
 C1= 436.831 C2= 1751.23 C3= 591.733 M2= 1.26547
 A1= 90. A2= 21.5 A3= 90 C/H= .556151
 B2= 37.1285 W2= 1063.33 W3= 980.332 MR2= .768375
 UM= 781.608 UTIP= 851.402 DIA.= 10.8404 H= .932429
 T3= 1660 HT3= 8.01423 S3= 8.32118 V3= 73.4002 Q3= .817525
 STAGE EFF.= .639396 ETT= .79599 ETS= .717431

TURBINE TOTAL ENTHALPY DROP= 1.60211 OVERALL CYCLE EFFICIENCY = .74536
 OVERALL TURBINE EFFICIENCY= .695386

NEW WEIGHT FLOW= 1.62492

Table 14. (continued)

NUMBER OF STAGES= 7 RPM= 18000
INITIAL WEIGHT FLOW= 1.585

STAGE NO.-- 1

T1= 2610	HT1= 9.61635	S1= 7.8984	V1= 2.774	Q1= 1
NS= 16.756	DS= 3.55842	C0= 1543.54	H/D= 1.78265	E-2
C1= 500	C2= 1428.55	C3= 276.271	M2= .804313	
A1= 90.	A2= 15	A3= 90	C/H= 3.04825	
B2= 25.0872	W2= 872.02	W3= 651.578	MR2= .490973	
UM= 590.113	UTIP= 600.725	DIA.= 7.64866	H= .136349	
T3= 2436	HT3= 9.3695	S3= 7.9457	V3= 3.89419	Q3= .982725
STAGE EFF.= .688786		ETT= .70163	ETS= .679154	

STAGE NO.-- 2

T1= 2436	HT1= 9.3695	S1= 7.9457	V1= 3.89419	Q1= .982725
NS= 21.3026	DS= 2.92442	C0= 1485.63	H/D= .024908	
C1= 276.271	C2= 1374.94	C3= 283.808	M2= .803706	
A1= 90.	A2= 15	A3= 90	C/H= 2.17025	
B2= 25.7176	W2= 820.077	W3= 654.032	MR2= .479366	
UM= 589.249	UTIP= 604.104	DIA.= 7.69168	H= .191584	
T3= 2297	HT3= 9.13954	S3= 7.98943	V3= 5.61193	Q3= .953722
STAGE EFF.= .69598		ETT= .732675	ETS= .705937	

STAGE NO.-- 3

T1= 2297	HT1= 9.13954	S1= 7.98943	V1= 5.61193	Q1= .953722
NS= 25.5972	DS= 2.50517	C0= 1504.54	H/D= 3.29535	E-2
C1= 283.808	C2= 1392.45	C3= 298.513	M2= .846802	
A1= 90.	A2= 15	A3= 90	C/H= 1.63508	
B2= 26.0998	W2= 819.192	W3= 678.534	MR2= .498182	
UM= 609.346	UTIP= 629.745	DIA.= 8.01816	H= .264226	
T3= 2162	HT3= 8.90669	S3= 8.03801	V3= 8.41628	Q3= .924447
STAGE EFF.= .689141		ETT= .75128	ETS= .721706	

STAGE NO.-- 4

T1= 2162	HT1= 8.90669	S1= 8.03801	V1= 8.41628	Q1= .924447
NS= 31.3234	DS= 2.10861	C0= 1530.39	H/D= .045574	
C1= 298.513	C2= 1416.41	C3= 314.	M2= .897795	
A1= 90.	A2= 15.0313	A3= 90	C/H= 1.17845	
B2= 26.4768	W2= 823.934	W3= 704.293	MR2= .522254	
UM= 630.429	UTIP= 659.78	DIA.= 8.40058	H= .382848	
T3= 2030	HT3= 8.67023	S3= 8.09325	V3= 13.2638	Q3= .895236
STAGE EFF.= .678283		ETT= .767045	ETS= .734755	

STAGE NO.-- 5

T1= 2030	HT1= 8.67023	S1= 8.09325	V1= 13.2638	Q1= .895236
NS= 39.7115	DS= 1.69484	C0= 1545.35	H/D= 5.76259	E-2
C1= 314.	C2= 1433.3	C3= 393.1	M2= .948252	
A1= 90.	A2= 18	A3= 90	C/H= .887572	
B2= 31.5206	W2= 847.188	W3= 751.903	MR2= .560486	
UM= 640.967	UTIP= 678.894	DIA.= 8.64394	H= .498115	
T3= 1903	HT3= 8.43878	S3= 8.154	V3= 21.9498	Q3= .86665
STAGE EFF.= .666903		ETT= .781249	ETS= .730696	

STAGE NO.-- 6

T1= 1903	HT1= 8.43878	S1= 8.154	V1= 21.9498	Q1= .86665
NS= 50.6811	DS= 1.35964	C0= 1587.4	H/D= 7.88384	E-2
C1= 393.1	C2= 1474.75	C3= 469.182	M2= 1.02044	
A1= 90.	A2= 20.375	A3= 90	C/H= .620319	
B2= 35.4044	W2= 886.263	W3= 809.949	MR2= .613243	
UM= 660.099	UTIP= 713.984	DIA.= 9.09073	H= .716698	
T3= 1779	HT3= 8.205	S3= 8.22345	V3= 38.7502	Q3= .838906
STAGE EFF.= .65423		ETT= .792986	ETS= .723711	

STAGE NO.-- 7

T1= 1779	HT1= 8.205	S1= 8.22345	V1= 38.7502	Q1= .838906
NS= 67.5	DS= 1.05947	C0= 1619.24	H/D= .119126	
C1= 469.182	C2= 1506.74	C3= 545.498	M2= 1.09227	
A1= 90.	A2= 22.75	A3= 90	C/H= .391015	
B2= 39.0737	W2= 924.407	W3= 865.43	MR2= .670124	
UM= 671.868	UTIP= 755.848	DIA.= 9.62375	H= 1.14644	
T3= 1660	HT3= 7.97308	S3= 8.30131	V3= 72.9564	Q3= .812581
STAGE EFF.= .642176		ETT= .802991	ETS= .711858	

TURBINE TOTAL ENTHALPY DROP= 1.64327 OVERALL CYCLE EFFICIENCY = .76141
OVERALL TURBINE EFFICIENCY= .710729

NEW WEIGHT FLOW= 1.58422

RPM= 18000

T1= 2610	HT1= 9.61635	S1= 7.8984	V1= 2.774	Q1= 1
NS= 18.836	DS= 3.23728	C0= 1381.53	H/D= 2.08812	E-2
C1= 500	C2= 1278.61	C3= 255.854	M2= .714487	
A1= 90.	A2= 15	A3= 90	CH= 2.59536	
B2= 25.4129	W2= 771.143	W3= 596.198	MR2= .430916	
UM= 538.512	UTIP= 549.871	DIA= 7.00118	H= .146193	
T3= 2469	HT3= 9.4134	S3= 7.93301	V3= 3.58598	Q3= .988097
STAGE EFF.= .708575		ETT= .717731	ETS= .693115	

T1 = 2.469	HT1 = 9.41.34	S1 = 7.9.3301	V1 = 3.58958	Q1 = .988097
NS = 23.3458	DS = 2.70823	C0 = 1312.66	H/D = 2.85732	E - 2
C1 = 255.854	C2 = 1214.86	C3 = 255.853	M2 = .698893	
A1 = 0	A2 = 15	A3 = 90	C/H = 1.88865	
B2 = 25.9189	W2 = 719.353	D3 = 585.343	MR2 = .413834	
UM = 526.469	UTIP = 541.72	WIA = 6.89739	H = 1.9708	
T3 = 2359	HT3 = 9.2295	S3 = 7.96242	V3 = 4.7299	Q3 = .964768
STAGE EFF. = .714006		ETT = 7.42493	ETS = .714285	

T1= 2359	HT1= 9.2295	S1= 7.96424	V1= 4.7299	Q1= .964768
N8= 26.6963	DS= 2.41716	O0= 1326.77	H/D= 3.52199	E-2
C1= 255.853	C2= 1227.92	C3= 265.184	M2= .728382	
A1= 90.	A2= 15	A3= 90	C/H= 1.52888	
B2= 26.1755	W2= 720.454	D3= 601.156	MR2= .427362	
UM= 539.508	UT1P= 558.331	W1A= 7.11526	H= .250593	
T3= 2251	HT3= 9.04402	S3= 7.9985	V3= 6.38654	Q3= .941301
STAGE EFF.= .706329		ETT= 7.754947	ETS= .724788	

T1= 2251	HT1= 9.04402	S1= 7.9985	V1= 6.38654	Q1= .941301
NS= 31.2105	DS= 2.11512	CO= 1330.71	H/D= 4.53029	E-2
C1= 265.184	A2= 1231.6	C3= 272.899	M= .75372	
A1= 90.	C2= 15.0313	A3= 90	C/H= 1.18556	
B2= 26.4717	W2= 716.557	W3= 612.214	MR2= .438522	
UM= 548.031	UTIP= 573.391	DIA= 7.30064	H= .33074	
T3= 2147	HT3= 8.86016	S3= 8.03562	V3= 8.00722	Q3= .918239
STAGE EFF.= .69755		ETT= .768002	ETS= .734553	

T1 = 21.47	HT1 = 8.6016	S1 = 8.03562	V1 = 8.50722	Q1 = .918239
NS = 36.5483	DS = 1.83443	C0 = 1346.38	H/D = 5.41339	E-2
C1 = 272.899	C2 = 1247.43	C3 = 310.063	M2 = .788548	
A1 = 90.	A2 = 16.5	A3 = 90	C/H = .968927	
B2 = 29.0499	W2 = 729.634	W3 = 638.55	MR2 = .461175	
UM = 558.221	UT1P = 589.205	DIA = 7.50199	H = .406112	
T3 = 2045	HT3 = 8.67695	S3 = 8.07646	V3 = 12.509	Q3 = .895285
STAGE EFF. = .686857		ETT = .776586	ETS = .7354	

T1= 2045	HT1= 8.67695	S1= 8.07646	V1= 12.509	Q1= -.895285
NS= 43.1641	DS= 1.56965	C0= 1369.44	H/D= 6.33859	E-2
C1= 310.063	A2= 1271.04	C3= 371.504	M2= .830601	
A1= 90.	C2= 129	A3= 90	C/H= .792403	
B2= 33.1627	W2= 756.484	W3= 679.142	MR2= .494347	
UM= 568.528	JT1P= 605.619	DIA= 7.71097	H= .488767	
T3= 1945	HT3= 8.49442	S3= 8.12141	V3= 18.3594	Q3= -.872588
STAGE EFF.= .676174		ETT= .785603	ETS= .727788	

T1 = 19.45	HT1 = 8.49442	S1 = 8.12141	V1 = 18.3594	Q1 = .872588
NS = 51.835	DS = 1.32857	C0 = 1392.51	HD = 7.99844	E-2
C1 = 371.504	C2 = 1294.23	C3 = 425.411	M2 = .875075	
A1 = 90	A2 = 21	A3 = 90	C/H = .604167	
B2 = 36.3511	W2 = 782.494	W3 = 717.711	MR2 = .529072	
UM = 578.048	UT1P = 625.941	DIA = 7.96973	H = .637454	
T3 = 1848	HT3 = 8.31256	S3 = 8.17082	V3 = 27.8368	Q3 = .850698
STAGE EFF. = .665708		ETT = .793917	ETS = .719821	

TS = 1848	DT1 = 8.31256	S1 = 8.17082	V1 = 27.8368	Q1 = .850698
N1 = 63.0637	HS1 = 1.12228	C0 = 1422.84	H/D = .107574	
C1 = 425.411	C2 = 1323.54	C3 = 466.931	M2 = .926994	
A1 = 90.	A2 = 22.25	A3 = 90	C/H = .437599	
B2 = 38.3187	W2 = 808.272	W3 = 753.071	MR2 = .566105	
UM = 590.844	UTIP = 657.307	DIA = 8.36908	H = .900298	
T3 = 1753	HT3 = 8.12884	S3 = 8.22614	V3 = 43.9553	Q3 = .829573
STAGE EFF. = .654524		ETT = .800961	ETS = .714702	

T1= 1753	HT1= 8.12884	S1= 8.22614	V1= 43.9553	Q1= .829573
NS= 78.7916	DS= .933885	C0= 1450.19	H/D= 1.51306	
C1= 466.931	C2= 1350.33	C3= 513.819	M2= .981073	
A1= 90.	A2= 23.75	A3= 90	C/H= .301291	
B2= 40.5547	W2= 836.453	W3= 790.279	MR2= .60772	
UM= 600.447	UTIP= 696.513	DIA= 8.86827	H= 1.34182	
T3= 1660	HT3= 7.94489	S3= 8.28747	V3= 72.6472	Q3= .809136
STAGE EFF.= .64375		ETT= .806912	ETS= .705616	

OVERALL CYCLE EFFICIENCY = .77177

NEW WEIGHT FLOW= 1.5575

Table 14. (continued)

NUMBER OF STAGES= 3 RPM= 18000
INITIAL WEIGHT FLOW= 1.869

STAGE NO.-- 1
T1= 2460 HT1= 9.50645 S1= 7.96755 V1= 3.7187 Q1= 1
NS= 16.2441 DS= 3.64736 CO= 2178.05 H/D= 1.71228 E-2
C1= 500 C2= 2015.77 C3= 386.023 M2= 1.21225
A1= 90. A2= 15 A3= 90 C/H= 3.17591
B2= 24.9952 W2= 1234.72 W3= 913.574 MR2= .742535
UM= 828.014 UTIP= 842.311 DIA.= 10.7246 H= .183636
T3= 2158 HT3= 9.03783 S3= 8.0993 V3= 8.72036 Q3= .944764
STAGE EFF.= .656389 ETT= .697056 ETS= .67516

STAGE NO.-- 2
T1= 2158 HT1= 9.03783 S1= 8.0993 V1= 8.72036 Q1= .944764
NS= 26.2821 DS= 2.44955 CO= 2176.11 H/D= .034356
C1= 386.023 C2= 2013.98 C3= 433.778 M2= 1.31696
A1= 90. A2= 15 A3= 90 C/H= 1.56769
B2= 26.1478 W2= 1182.82 W3= 984.317 MR2= .773456
UM= 883.586 UTIP= 914.444 DIA.= 11.6431 H= .40001
T3= 1900 HT3= 8.57142 S3= 8.2257 V3= 22.7668 Q3= .886818
STAGE EFF.= .660104 ETT= .753608 ETS= .723663

STAGE NO.-- 3
T1= 1900 HT1= 8.57142 S1= 8.2257 V1= 22.7668 Q1= .886818
NS= 45.9995 DS= 1.4842 CO= 2226.24 H/D= 6.95429 E-2
C1= 433.778 C2= 2066.82 C3= 619.751 M2= 1.48008
A1= 90. A2= 19.375 A3= 90 C/H= .716925
B2= 33.8033 W2= 1232.45 W3= 1113.97 MR2= .882577
UM= 925.663 UTIP= 992.081 DIA.= 12.6316 H= .878436
T3= 1660 HT3= 8.11408 S3= 8.37815 V3= 74.6727 Q3= .831703
STAGE EFF.= .643752 ETT= .788689 ETS= .727567

TURBINE TOTAL ENTHALPY DROP= 1.39237 OVERALL CYCLE EFFICIENCY = .74645
OVERALL TURBINE EFFICIENCY= .671358

NEW WEIGHT FLOW= 1.8697

NUMBER OF STAGES= 5 RPM= 18000
INITIAL WEIGHT FLOW= 1.796

STAGE NO.-- 1
T1= 2460 HT1= 9.50645 S1= 7.96755 V1= 3.7187 Q1= 1
NS= 19.2365 DS= 3.18198 CO= 1716.49 H/D= 2.15052 E-2
C1= 500 C2= 1588.6 C3= 319.685 M2= .926824
A1= 90. A2= 15 A3= 90 C/H= 2.5189
B2= 25.4677 W2= 956.18 W3= 743.448 MR2= .557855
UM= 671.209 UTIP= 685.795 DIA.= 8.73181 H= .18778
T3= 2267 HT3= 9.19988 S3= 8.04732 V3= 6.22899 Q3= .965465
STAGE EFF.= .693719 ETT= .720431 ETS= .695441

STAGE NO.-- 2
T1= 2267 HT1= 9.19988 S1= 8.04732 V1= 6.22899 Q1= .965465
NS= 25.6728 DS= 2.4989 CO= 1676.98 H/D= 3.31067 E-2
C1= 319.685 C2= 1552.04 C3= 332.901 M2= .951338
A1= 90. A2= 15 A3= 90 C/H= 1.62744
B2= 26.1052 W2= 912.904 W3= 756.556 MR2= .559573
UM= 679.381 UTIP= 702.232 DIA.= 8.94109 H= .29601
T3= 2105 HT3= 8.90919 S3= 8.10863 V3= 10.346 Q3= .928273
STAGE EFF.= .692521 ETT= .751544 ETS= .721928

STAGE NO.-- 3
T1= 2105 HT1= 8.90919 S1= 8.10863 V1= 10.346 Q1= .928273
NS= 33.6304 DS= 1.98237 CO= 1696.17 H/D= 5.06115 E-2
C1= 332.901 C2= 1570.09 C3= 356.441 M2= 1.01287
A1= 90. A2= 15.25 A3= 90 C/H= 1.05697
B2= 26.9276 W2= 911.934 W3= 787.076 MR2= .588292
UM= 701.744 UTIP= 738.105 DIA.= 9.39785 H= .475639
T3= 1950 HT3= 8.61883 S3= 8.17885 V3= 18.3704 Q3= .892131
STAGE EFF.= .679504 ETT= .77159 ETS= .737517

STAGE NO.-- 4
T1= 1950 HT1= 8.61883 S1= 8.17885 V1= 18.3704 Q1= .892131
NS= 45.6166 DS= 1.49587 CO= 1721.89 H/D= .068928
C1= 356.441 C2= 1598.45 C3= 475.791 M2= 1.08799
A1= 90. A2= 19.25 A3= 90 C/H= .725
B2= 33.6042 W2= 952.19 W3= 859.677 MR2= .648114
UM= 716.015 UTIP= 766.923 DIA.= 9.76477 H= .673066
T3= 1801 HT3= 8.33581 S3= 8.25797 V3= 35.3594 Q3= .856992
STAGE EFF.= .665119 ETT= .788294 ETS= .728106

STAGE NO.-- 5
T1= 1801 HT1= 8.33581 S1= 8.25797 V1= 35.3594 Q1= .856992
NS= 63.9012 DS= 1.10948 CO= 1759.26 H/D= .109614
C1= 475.791 C2= 1636.62 C3= 581.075 M2= 1.17757
A1= 90. A2= 22.375 A3= 90 C/H= .428345
B2= 38.5062 W2= 1000.65 W3= 933.303 MR2= .719983
UM= 730.352 UTIP= 814.118 DIA.= 10.3657 H= 1.13622
T3= 1660 HT3= 8.05714 S3= 8.34819 V3= 74.0036 Q3= .824249
STAGE EFF.= .650429 ETT= .801372 ETS= .713946

TURBINE TOTAL ENTHALPY DROP= 1.44931 OVERALL CYCLE EFFICIENCY = .76665
OVERALL TURBINE EFFICIENCY= .696391

NEW WEIGHT FLOW= 1.79624

Table 14. (continued)

NUMBER OF STAGES= 7 RPM= 18000
INITIAL WEIGHT FLOW= 1.758

STAGE NO.-- 1
T1= 2460 HT1= 9.50645 S1= 7.96755 V1= 3.7187 Q1= 1
NS= 22.3479 DS= 2.80957 C0= 1475.11 H/D= 2.67461 E-2
C1= 500 C2= 1365.21 C3= 284.866 M2= .786211
A1= 90. A2= 15 A3= 90 C/H= 2.01927
B2= 25.8256 W2= 811.099 W3= 653.908 MR2= .467104
UM= 588.602 UTIP= 604.549 DIA.= 7.69735 H= .205874
T3= 2314 HT3= 9.27275 S3= 8.02886 V3= 5.45103 Q3= .975027
STAGE EFF.= .717936 EIT= .737947 ETS= .710427

STAGE NO.-- 2
T1= 2314 HT1= 9.27275 S1= 8.02886 V1= 5.45103 Q1= .975027
NS= 28.3199 DS= 2.29849 C0= 1410.98 H/D= 3.87197 E-2
C1= 284.866 C2= 1305.86 C3= 284.73 M2= .778775
A1= 90. A2= 15 A3= 90 C/H= 1.3895
B2= 26.2747 W2= 763.497 W3= 643.202 MR2= .455326
UM= 576.751 UTIP= 599.496 DIA.= 7.63302 H= .295549
T3= 2197. HT3= 9.0603 S3= 8.06723 V3= 7.66091 Q3= .947573
STAGE EFF.= .715926 EIT= .759747 ETS= .728809

STAGE NO.-- 3
T1= 2197 HT1= 9.0603 S1= 8.06723 V1= 7.66091 Q1= .947573
NS= 33.5537 DS= 1.98624 C0= 1428.78 H/D= 5.04185 E-2
C1= 284.73 C2= 1322.57 C3= 300.167 M2= .817922
A1= 90. A2= 15.25 A3= 90 C/H= 1.06104
B2= 26.9247 W2= 768.248 W3= 662.883 MR2= .47511
UM= 591.03 UTIP= 621.536 DIA.= 7.91363 H= .398993
T3= 2082 HT3= 8.84702 S3= 8.11042 V3= 11.1662 Q3= .920276
STAGE EFF.= .703409 EIT= .77145 ETS= .737402

STAGE NO.-- 4
T1= 2082 HT1= 8.84702 S1= 8.11042 V1= 11.1662 Q1= .920276
NS= 40.7441 DS= 1.65958 C0= 1439.33 H/D= 6.05772 E-2
C1= 300.167 C2= 1334.86 C3= 364.396 M2= .856716
A1= 90. A2= 17.875 A3= 90 C/H= .845816
B2= 31.3556 W2= 787.398 W3= 700.291 MR2= .505355
UM= 598.019 UTIP= 635.262 DIA.= 8.0884 H= .489973
T3= 1971 HT3= 8.6388 S3= 8.15762 V3= 16.8322 Q3= .893631
STAGE EFF.= .691145 EIT= .782629 ETS= .732466

STAGE NO.-- 5
T1= 1971 HT1= 8.6388 S1= 8.15762 V1= 16.8322 Q1= .893631
NS= 50.0589 DS= 1.37486 C0= 1454.23 H/D= 7.75608 E-2
C1= 364.396 C2= 1350.91 C3= 426.695 M2= .900107
A1= 90. A2= 20.25 A3= 90 C/H= .632082
B2= 35.2063 W2= 811.02 W3= 740.117 MR2= .540381
UM= 604.741 UTIP= 653.283 DIA.= 8.31786 H= .64514
T3= 1865 HT3= 8.43488 S3= 8.2093 V3= 26.2055 Q3= .868311
STAGE EFF.= .67903 EIT= .792465 ETS= .724239

STAGE NO.-- 6
T1= 1865 HT1= 8.43488 S1= 8.2093 V1= 26.2055 Q1= .868311
NS= 61.4838 DS= 1.14282 C0= 1496.2 H/D= 1.02045
C1= 426.695 C2= 1392.02 C3= 496.1 M2= .964747
A1= 90. A2= 22.5 A3= 90 C/H= .459139
B2= 38.6587 W2= 852.758 W3= 794.166 MR2= .591011
UM= 620.153 UTIP= 686.211 DIA.= 8.73711 H= .891578
T3= 1760 HT3= 8.22865 S3= 8.26803 V3= 43.0549 Q3= .843518
STAGE EFF.= .666137 EIT= .800155 ETS= .712186

STAGE NO.-- 7
T1= 1760 HT1= 8.22865 S1= 8.26803 V1= 43.0549 Q1= .843518
NS= 78.8656 DS= .933241 C0= 1515.86 H/D= .151554
C1= 496.1 C2= 1411.47 C3= 537.103 M2= 1.018
A1= 90. A2= 23.75 A3= 90 C/H= .300795
B2= 40.5551 W2= 874.321 W3= 826.083 MR2= .630586
UM= 627.647 UTIP= 728.234 DIA.= 9.27216 H= 1.40524
T3= 1660 HT3= 8.02461 S3= 8.3332 V3= 73.6688 Q3= .820518
STAGE EFF.= .653497 EIT= .806933 ETS= .705627

TURBINE TOTAL ENTHALPY DROP= 1.48183 OVERALL CYCLE EFFICIENCY = .77876
OVERALL TURBINE EFFICIENCY= .709415

NEW WEIGHT FLOW= 1.75681

Table 14. (continued)

NUMBER OF STAGES= 9				RPM= 18000	
INITIAL WEIGHT FLOW= 1.73					
STAGE NO.-- 1					
T1= 2460	HT1= 9.50645	S1= 7.96755	V1= 3.7187	Q1= 1	
NS= 25.1805	DS= 2.54033	CO= 1322.1	H/D= .032116		
C1= 500	C2= 1223.6	C3= 261.531	M2= .699505		
A1= 90.	A2= 15	A3= 90	C/H= 1.67816		
B2= 26.0691	W2= 720.647	W3= 595.122	MR2= .411976		
UM= 534.579	UTIP= 552.014	DIA.= 7.02846	H= .225726		
T3= 2341	HT3= 9.31491	S3= 8.01905	V3= 5.06324	Q3= .980609	
STAGE EFF.= .733888		ETT= .74979	ETS= .720451		
STAGE NO.-- 2					
T1= 2341	HT1= 9.31491	S1= 8.01905	V1= 5.06324	Q1= .980609	
NS= 31.15	DS= 2.11863	CO= 1251.01	H/D= 4.51577	E-2	
C1= 261.531	C2= 1157.84	C3= 256.487	M2= .680347		
A1= 90.	A2= 15.0313	A3= 90	C/H= 1.1894		
B2= 26.469	W2= 673.705	W3= 575.453	MR2= .395871		
UM= 515.136	UTIP= 538.896	DIA.= 6.86143	H= .309847		
T3= 2248	HT3= 9.1445	S3= 8.04688	V3= 6.56454	Q3= .958455	
STAGE EFF.= .731495		ETT= .76667	ETS= .734443		
STAGE NO.-- 3					
T1= 2248	HT1= 9.1445	S1= 8.04688	V1= 6.56454	Q1= .958455	
NS= 35.7731	DS= 1.87077	CO= 1250.47	H/D= 5.29454	E-2	
C1= 256.487	C2= 1158.36	C3= 282.755	M2= .699869		
A1= 90.	A2= 16.25	A3= 90	C/H= .994754		
B2= 28.6226	W2= 676.651	W3= 590.253	MR2= .408826		
UM= 518.123	UTIP= 546.236	DIA.= 6.95488	H= .368229		
T3= 2158	HT3= 8.97824	S3= 8.07666	V3= 8.64641	Q3= .936727	
STAGE EFF.= .721172		ETT= .775329	ETS= .735687		
STAGE NO.-- 4					
T1= 2158	HT1= 8.97824	S1= 8.07666	V1= 8.64641	Q1= .936727	
NS= 40.8303	DS= 1.65537	CO= 1263.51	H/D= 6.04217	E-2	
C1= 282.755	C2= 1171.91	C3= 322.287	M2= .728448		
A1= 90.	A2= 18	A3= 90	C/H= .846205		
B2= 31.5534	W2= 692.037	W3= 615.882	MR2= .430165		
UM= 524.827	UTIP= 557.426	DIA.= 7.09737	H= .428835		
T3= 2070	HT3= 8.81358	S3= 8.10915	V3= 11.62	Q3= .915349	
STAGE EFF.= .709973		ETT= .782744	ETS= .731817		
STAGE NO.-- 5					
T1= 2070	HT1= 8.81358	S1= 8.10915	V1= 11.62	Q1= .915349	
NS= 46.917	DS= 1.45376	CO= 1280.23	H/D= 7.00496	E-2	
C1= 322.287	C2= 1189.06	C3= 368.989	M2= .760811		
A1= 90.	A2= 20	A3= 90	C/H= .703611		
B2= 34.7686	W2= 713.147	W3= 647.048	MR2= .456301		
UM= 531.53	UTIP= 569.953	DIA.= 7.25687	H= .508341		
T3= 1984	HT3= 8.65037	S3= 8.14459	V3= 15.9596	Q3= .894459	
STAGE EFF.= .698944		ETT= .789601	ETS= .724007		
STAGE NO.-- 6					
T1= 1984	HT1= 8.65037	S1= 8.14459	V1= 15.9596	Q1= .894459	
NS= 54.4201	DS= 1.27162	CO= 1299.26	H/D= 8.54295	E-2	
C1= 368.989	C2= 1207.98	C3= 408.069	M2= .795955		
A1= 90.	A2= 21.5	A3= 90	C/H= .559983		
B2= 37.1252	W2= 733.522	W3= 676.103	MR2= .483329		
UM= 539.073	UTIP= 586.872	DIA.= 7.47229	H= .638353		
T3= 1900	HT3= 8.48772	S3= 8.18342	V3= 22.4445	Q3= .87425	
STAGE EFF.= .687948		ETT= .795839	ETS= .717334		
STAGE NO.-- 7					
T1= 1900	HT1= 8.48772	S1= 8.18342	V1= 22.4445	Q1= .87425	
NS= 63.9581	DS= 1.1087	CO= 1318.32	H/D= 1.09784		
C1= 408.069	C2= 1226.42	C3= 435.452	M2= .83265		
A1= 90.	A2= 22.375	A3= 90	C/H= .427675		
B2= 38.5068	W2= 749.839	W3= 699.4	MR2= .509088		
UM= 547.307	UTIP= 610.181	DIA.= 7.76906	H= .85292		
T3= 1818	HT3= 8.32491	S3= 8.2262	V3= 32.3859	Q3= .854824	
STAGE EFF.= .676711		ETT= .801399	ETS= .713963		
STAGE NO.-- 8					
T1= 1818	HT1= 8.32491	S1= 8.2262	V1= 32.3859	Q1= .854824	
NS= 76.5015	DS= .952236	CO= 1334.28	H/D= 1.4266		
C1= 435.452	C2= 1242.61	C3= 477.401	M2= .869928		
A1= 90.	A2= 24	A3= 90	C/H= .317967		
B2= 40.8854	W2= 772.154	W3= 729.358	MR2= .540573		
UM= 551.413	UTIP= 634.444	DIA.= 8.07798	H= 1.1524		
T3= 1738	HT3= 8.16414	S3= 8.27248	V3= 48.0384	Q3= .836015	
STAGE EFF.= .666511		ETT= .806233	ETS= .703021		
STAGE NO.-- 9					
T1= 1738	HT1= 8.16414	S1= 8.27248	V1= 48.0384	Q1= .836015	
NS= 92.4729	DS= .828613	CO= 1354.69	H/D= 1.96793		
C1= 477.401	C2= 1261.91	C3= 495.309	M2= .911492		
A1= 90.	A2= 24.375	A3= 90	C/H= .228429		
B2= 41.4771	W2= 786.327	W3= 747.838	MR2= .567971		
UM= 560.301	UTIP= 677.539	DIA.= 8.6267	H= 1.69767		
T3= 1660	HT3= 8.00234	S3= 8.32383	V3= 73.4594	Q3= .818185	
STAGE EFF.= .654959		ETT= .810094	ETS= .701798		
TURBINE TOTAL ENTHALPY DROP= 1.5041				OVERALL CYCLE EFFICIENCY = .78641	
OVERALL TURBINE EFFICIENCY= .717772					
NEW WEIGHT FLOW= 1.7308					

Table 14. (continued)

NUMBER OF STAGES= 3 RPM= 24000
INITIAL WEIGHT FLOW= 1.9325

STAGE NO.-- 1

T1= 2610	HT1= 9.61635	S1= 7.894	V1= 2.774	Q1= 1
NS= 18.4891	DS= 3.28677	C0= 2107.93	H/D= .02035	
C1= 500	C2= 1950.88	C3= 388.382	M2= 1.13872	
A1= 90.	A2= 15	A3= 90		
B2= 25.3634	W2= 1178.74	W3= 906.677	MR2= .688025	
UM= 819.285	UTIP= 836.123	DIA.= 7.98438	H= .162482	
T3= 2300	HT3= 9.16202	S3= 7.99123	V3= 5.57121	Q3= .955445
STAGE EFF.= .681199		ETT= .715296	ETS= .691013	

STAGE NO.-- 2

T1= 2300	HT1= 9.16202	S1= 7.99123	V1= 5.57121	Q1= .955445
NS= 28.0159	DS= 2.31976	C0= 2119.89	H/D= 3.80508	E-2
C1= 388.382	C2= 1961.95	C3= 427.065	M2= 1.23929	
A1= 90.	A2= 15	A3= 90		
B2= 26.2571	W2= 1147.81	W3= 965.33	MR2= .725023	
UM= 865.73	UTIP= 899.271	DIA.= 8.5874	H= .326757	
T3= 2036	HT3= 8.70999	S3= 8.09825	V3= 13.0107	Q3= .899096
STAGE EFF.= .674695		ETT= .7589	ETS= .7281	

STAGE NO.-- 3

T1= 2036	HT1= 8.70999	S1= 8.09825	V1= 13.0107	Q1= .899096
NS= 45.6346	DS= 1.49538	C0= 2166.63	H/D= 6.89748	E-2
C1= 427.065	C2= 2011.3	C3= 598.702	M2= 1.38325	
A1= 90.	A2= 19.25	A3= 90		
B2= 33.6046	W2= 1198.11	W3= 1081.74	MR2= .823992	
UM= 900.966	UTIP= 965.069	DIA.= 9.21572	H= .635653	
T3= 1790	HT3= 8.26909	S3= 8.22831	V3= 36.8546	Q3= .844511
STAGE EFF.= .654383		ETT= .788313	ETS= .728119	

TURBINE TOTAL ENTHALPY DROP= 1.34726 OVERALL CYCLE EFFICIENCY = .75417
OVERALL TURBINE EFFICIENCY= .695233

NEW WEIGHT FLOW= 1.9323

NUMBER OF STAGES= 5 RPM= 24000
INITIAL WEIGHT FLOW= 1.8575

STAGE NO.-- 1

T1= 2610	HT1= 9.61635	S1= 7.8984	V1= 2.774	Q1= 1
NS= 22.2508	DS= 2.81986	C0= 1663.13	H/D= 2.65719	E-2
C1= 500	C2= 1539.22	C3= 320.87	M2= .873364	
A1= 90.	A2= 15	A3= 90	C/H= 2.03266	
B2= 25.816	W2= 914.801	W3= 736.808	MR2= .519063	
UM= 663.276	UTIP= 681.128	DIA.= 6.50429	H= .172832	
T3= 2412	HT3= 9.31939	S3= 7.94654	V3= 4.123	Q3= .975167
STAGE EFF.= .717599		ETT= .73748	ETS= .71003	

STAGE NO.-- 2

T1= 2412	HT1= 9.31939	S1= 7.94654	V1= 4.123	Q1= .975167
NS= 28.6024	DS= 2.2791	C0= 1635.22	H/D= .039347	
C1= 320.87	C2= 1513.39	C3= 330.486	M2= .89943	
A1= 90.	A2= 15	A3= 90	C/H= 1.36716	
B2= 26.2906	W2= 884.339	W3= 746.142	MR2= .525574	
UM= 668.965	UTIP= 695.782	DIA.= 6.64422	H= .26143	
T3= 2246	HT3= 9.03652	S3= 7.99803	V3= 6.47559	Q3= .9394
STAGE EFF.= .70979		ETT= .760515	ETS= .729451	

STAGE NO.-- 3

T1= 2246	HT1= 9.03652	S1= 7.99803	V1= 6.47559	Q1= .9394
NS= 36.2925	DS= 1.84669	C0= 1652.89	H/D= 5.38688	E-2
C1= 330.486	C2= 1531.28	C3= 377.354	M2= .955313	
A1= 90.	A2= 16.375	A3= 90	C/H= .97566	
B2= 28.8411	W2= 894.937	W3= 782.267	MR2= .55832	
UM= 685.238	UTIP= 723.081	DIA.= 6.90491	H= .371959	
T3= 2087	HT3= 8.75725	S3= 8.05702	V3= 10.7674	Q3= .904061
STAGE EFF.= .69398		ETT= .776175	ETS= .735721	

STAGE NO.-- 4

T1= 2087	HT1= 8.75725	S1= 8.05702	V1= 10.7674	Q1= .904061
NS= 47.2763	DS= 1.44815	C0= 1677.79	H/D= 7.21192	E-2
C1= 377.354	C2= 1557.91	C3= 474.401	M2= 1.02198	
A1= 90.	A2= 19.625	A3= 90	C/H= .688008	
B2= 34.2105	W2= 930.647	W3= 843.775	MR2= .610502	
UM= 697.789	UTIP= 749.763	DIA.= 7.1597	H= .516352	
T3= 1935	HT3= 8.48454	S3= 8.12406	V3= 19.1091	Q3= .869655
STAGE EFF.= .677649		ETT= .78995	ETS= .726794	

STAGE NO.-- 5

T1= 1935	HT1= 8.48454	S1= 8.12406	V1= 19.1091	Q1= .869655
NS= 63.173	DS= 1.11958	C0= 1716.4	H/D= .107442	
C1= 474.401	C2= 1596.75	C3= 566.602	M2= 1.1033	
A1= 90.	A2= 22.375	A3= 90	C/H= .437048	
B2= 38.4987	W2= 976.434	W3= 910.207	MR2= .674687	
UM= 712.352	UTIP= 792.381	DIA.= 7.56668	H= .812979	
T3= 1790	HT3= 8.21486	S3= 8.20126	V3= 36.5309	Q3= .837089
STAGE EFF.= .661175		ETT= .801019	ETS= .71373	

TURBINE TOTAL ENTHALPY DROP= 1.40148 OVERALL CYCLE EFFICIENCY = .77303
OVERALL TURBINE EFFICIENCY= .721053

NEW WEIGHT FLOW= 1.85753

Table 14. (continued)

NUMBER OF STAGES= 7				RPM= 24000	
INITIAL WEIGHT FLOW= 1.818					
STAGE NO.-- 1					
T1= 2610	HT1= 9.61635	S1= 7.8984	V1= 2.774	Q1= 1	
NS= 25.9954	DS= 2.47252	CO= 1430.79	H/D= 3.37649	E-2	
C1= 500	C2= 1324.19	C3= 284.663	M2= .742438		
A1= 90.	A2= 15	A3= 90			
B2= 26.1281	W2= 778.249	W3= 646.399	MR2= .436344		
UM= 580.347	UTIP= 600.261	DIA.= 5.73207	H= .193543		
T3= 2460	HT3= 9.39034	S3= 7.93106	V3= 3.66096	Q3= .98435	
STAGE EFF.= .739746		ETT= .752651	ETS= .722859		
STAGE NO.-- 2					
T1= 2460	HT1= 9.39034	S1= 7.93106	V1= 3.66096	Q1= .98435	
NS= 32.0835	DS= 2.06591	CO= 1376.13	H/D= 4.74215	E-2	
C1= 284.663	C2= 1273.63	C3= 283.229	M2= .737696		
A1= 90.	A2= 15.0313	A3= 90			
B2= 26.5096	W2= 740.028	W3= 634.544	MR2= .428629		
UM= 567.833	UTIP= 595.364	DIA.= 5.6853	H= .269606		
T3= 2340	HT3= 9.1838	S3= 7.96322	V3= 4.96156	Q3= .958015	
STAGE EFF.= .732952		ETT= .768629	ETS= .73607		
STAGE NO.-- 3					
T1= 2340	HT1= 9.1838	S1= 7.96322	V1= 4.96156	Q1= .958015	
NS= 37.3651	DS= 1.79776	CO= 1388.7	H/D= 5.54309	E-2	
C1= 283.229	C2= 1286.88	C3= 325.642	M2= .771186		
A1= 90.	A2= 16.75	A3= 90			
B2= 29.4763	W2= 753.708	W3= 661.787	MR2= .451675		
UM= 576.127	UTIP= 608.889	DIA.= 5.81446	H= .322301		
T3= 2223	HT3= 8.9801	S3= 7.99897	V3= 6.91576	Q3= .931753	
STAGE EFF.= .719315		ETT= .777859	ETS= .735087		
STAGE NO.-- 4					
T1= 2223	HT1= 8.9801	S1= 7.99897	V1= 6.91576	Q1= .931753	
NS= 43.8354	DS= 1.55057	CO= 1409.38	H/D= 6.54605	E-2	
C1= 325.642	C2= 1308.	C3= 380.232	M2= .811917		
A1= 90.	A2= 18.875	A3= 90			
B2= 32.9879	W2= 777.176	W3= 698.36	MR2= .482418		
UM= 585.78	UTIP= 625.279	DIA.= 5.97097	H= .390863		
T3= 2109	HT3= 8.77825	S3= 8.03895	V3= 9.94975	Q3= .905827	
STAGE EFF.= .70533		ETT= .786374	ETS= .729138		
STAGE NO.-- 5					
T1= 2109	HT1= 8.77825	S1= 8.03895	V1= 9.94975	Q1= .905827	
NS= 52.5231	DS= 1.31657	CO= 1423.55	H/D= 8.26367	E-2	
C1= 380.232	C2= 1322.86	C3= 429.882	M2= .850732		
A1= 90.	A2= 20.75	A3= 90			
B2= 35.9936	W2= 797.481	W3= 731.469	MR2= .512861		
UM= 591.823	UTIP= 642.533	DIA.= 6.13574	H= .507037		
T3= 2000	HT3= 8.58025	S3= 8.08303	V3= 14.7195	Q3= .88092	
STAGE EFF.= .691923		ETT= .794449	ETS= .722003		
STAGE NO.-- 6					
T1= 2000	HT1= 8.58025	S1= 8.08303	V1= 14.7195	Q1= .88092	
NS= 63.124	DS= 1.12143	CO= 1455.07	H/D= .107754		
C1= 429.882	C2= 1353.52	C3= 477.531	M2= .902953		
A1= 90.	A2= 22.25	A3= 90			
B2= 38.3193	W2= 826.57	W3= 770.155	MR2= .551415		
UM= 604.242	UTIP= 672.33	DIA.= 6.42027	H= .691808		
T3= 1893	HT3= 8.38127	S3= 8.13299	V3= 22.705	Q3= .85665	
STAGE EFF.= .677813		ETT= .80099	ETS= .71472		
STAGE NO.-- 7					
T1= 1893	HT1= 8.38127	S1= 8.13299	V1= 22.705	Q1= .85665	
NS= 78.2116	DS= .940099	CO= 1475.97	H/D= .14992		
C1= 477.531	C2= 1374.22	C3= 519.982	M2= .951646		
A1= 90.	A2= 23.625	A3= 90			
B2= 40.3781	W2= 850.093	W3= 802.652	MR2= .58869		
UM= 611.453	UTIP= 708.358	DIA.= 6.76431	H= 1.01411		
T3= 1790	HT3= 8.1843	S3= 8.18858	V3= 36.3792	Q3= .83361	
STAGE EFF.= .664366		ETT= .806742	ETS= .706614		
TURBINE TOTAL ENTHALPY DROP= 1.43205				OVERALL CYCLE EFFICIENCY = .78396	
OVERALL TURBINE EFFICIENCY= .733807					
NEW WEIGHT FLOW= 1.81788					

Table 14. (continued)

NUMBER OF STAGES=				RPM= 24000	
INITIAL WEIGHT FLOW= 1.792					
STAGE NO.-- 1					
T1= 2610	HT1= 9.61635	S1= 7.8934	V1= 2.774	Q1= 1	
NS= 29.3702	DS= 2.22814	C0= 1283.66	H/D= 4.10738	E-2	
C1= 500	C2= 1188.02	C3= 260.463	M2= .661585		
A1= 90.	A2= 15	A3= 90			
B2= 26.3319	W2= 693.199	W3= 587.194	MR2= .386028		
UM= 526.271	UTIP= 548.312	DIA.= 5.23599	H= .215088		
T3= 2488	HT3= 9.43127	S3= 7.92247	V3= 3.42371	Q3= .989679	
STAGE EFF.= .75384		ETT= .762512	ETS= .731118		
STAGE NO.-- 2					
T1= 2488	HT1= 9.43127	S1= 7.92247	V1= 3.42371	Q1= .989679	
NS= 35.692	DS= 1.87183	C0= 1217.53	H/D= .052013		
C1= 260.463	C2= 1128.05	C3= 279.646	M2= .64431		
A1= 90.	A2= 16.5	A3= 90			
B2= 29.0199	W2= 660.427	W3= 576.453	MR2= .377217		
UM= 504.084	UTIP= 530.943	DIA.= 5.07013	H= .263713		
T3= 2393	HT3= 9.26803	S3= 7.94543	V3= 4.31434	Q3= .968435	
STAGE EFF.= .748209		ETT= .77519	ETS= .734295		
STAGE NO.-- 3					
T1= 2393	HT1= 9.26803	S1= 7.94543	V1= 4.31434	Q1= .968435	
NS= 39.814	DS= 1.69114	C0= 1229.23	H/D= 5.78794	E-2	
C1= 279.646	C2= 1140.11	C3= 312.769	M2= .668583		
A1= 90.	A2= 18	A3= 90			
B2= 31.5237	W2= 673.827	W3= 598.196	MR2= .395147		
UM= 509.921	UTIP= 540.229	DIA.= 5.15881	H= .298589		
T3= 2300	HT3= 9.10635	S3= 7.9706	V3= 5.52466	Q3= .947424	
STAGE EFF.= .736297		ETT= .781391	ETS= .730803		
STAGE NO.-- 4					
T1= 2300	HT1= 9.10635	S1= 7.9706	V1= 5.52466	Q1= .947424	
NS= 44.916	DS= 1.51299	C0= 1237.75	H/D= 6.63794	E-2	
C1= 312.769	C2= 1149.21	C3= 346.205	M2= .692173		
A1= 90.	A2= 19.5	A3= 90			
B2= 33.9683	W2= 686.578	W3= 619.622	MR2= .413527		
UM= 513.886	UTIP= 549.036	DIA.= 5.24291	H= .348021		
T3= 2210	HT3= 8.94732	S3= 7.99793	V3= 7.17851	Q3= .926885	
STAGE EFF.= .724753		ETT= .787555	ETS= .725941		
STAGE NO.-- 5					
T1= 2210	HT1= 8.94732	S1= 7.99793	V1= 7.17851	Q1= .926885	
NS= 50.6826	DS= 1.35961	C0= 1253.9	H/D= 7.88424	E-2	
C1= 346.205	C2= 1164.91	C3= 370.612	M2= .719797		
A1= 90.	A2= 20.375	A3= 90			
B2= 35.4044	W2= 700.066	W3= 639.707	MR2= .432569		
UM= 521.419	UTIP= 563.985	DIA.= 5.38566	H= .424618		
T3= 2122	HT3= 8.78843	S3= 8.02812	V3= 9.50262	Q3= .90672	
STAGE EFF.= .712641		ETT= .792987	ETS= .723712		
STAGE NO.-- 6					
T1= 2122	HT1= 8.78843	S1= 8.02812	V1= 9.50262	Q1= .90672	
NS= 57.9702	DS= 1.20663	C0= 1267.32	H/D= 9.49409	E-2	
C1= 370.612	C2= 1178.38	C3= 401.963	M2= .749836		
A1= 90.	A2= 21.625	A3= 90			
B2= 37.3572	W2= 715.69	W3= 662.449	MR2= .455413		
UM= 526.563	UTIP= 578.624	DIA.= 5.52545	H= .524591		
T3= 2036	HT3= 8.6311	S3= 8.06109	V3= 12.8353	Q3= .886945	
STAGE EFF.= .700924		ETT= .798162	ETS= .717867		
STAGE NO.-- 7					
T1= 2036	HT1= 8.6311	S1= 8.06109	V1= 12.8353	Q1= .886945	
NS= 66.7987	DS= 1.06812	C0= 1283.8	H/D= .116973		
C1= 401.963	C2= 1194.6	C3= 432.293	M2= .781888		
A1= 90.	A2= 22.75	A3= 90			
B2= 39.0675	W2= 733.004	W3= 685.923	MR2= .479764		
UM= 532.556	UTIP= 597.88	DIA.= 5.70933	H= .667839		
T3= 1952	HT3= 8.4746	S3= 8.09724	V3= 17.7158	Q3= .867725	
STAGE EFF.= .689244		ETT= .802695	ETS= .71168		
STAGE NO.-- 8					
T1= 1952	HT1= 8.4746	S1= 8.09724	V1= 17.7158	Q1= .867725	
NS= 77.9343	DS= .942564	C0= 1299.91	H/D= .148993		
C1= 432.293	C2= 1210.29	C3= 457.9	M2= .815169		
A1= 90.	A2= 23.625	A3= 90			
B2= 40.3764	W2= 748.714	W3= 706.844	MR2= .504282		
UM= 538.481	UTIP= 623.277	DIA.= 5.95186	H= .886784		
T3= 1870	HT3= 8.31876	S3= 8.13688	V3= 25.0338	Q3= .849192	
STAGE EFF.= .677633		ETT= .806662	ETS= .706568		
STAGE NO.-- 9					
T1= 1870	HT1= 8.31876	S1= 8.13688	V1= 25.0338	Q1= .849192	
NS= 92.1248	DS= .830739	C0= 1315.82	H/D= .195489		
C1= 457.9	C2= 1225.71	C3= 481.052	M2= .850028		
A1= 90.	A2= 24.375	A3= 90			
B2= 41.4757	W2= 763.788	W3= 726.333	MR2= .529686		
UM= 544.197	UTIP= 657.306	DIA.= 6.2768	H= 1.22705		
T3= 1790	HT3= 8.16351	S3= 8.18035	V3= 36.2807	Q3= .831351	
STAGE EFF.= .66614		ETT= .810028	ETS= .701762		
TURBINE TOTAL ENTHALPY DROP= 1.45284					
OVERALL TURBINE EFFICIENCY= .742158					
OVERALL CYCLE EFFICIENCY = .79080					
NEW WEIGHT FLOW= 1.79187					

Table 14. (continued)

NUMBER OF STAGES= 3 RPM= 24000
INITIAL WEIGHT FLOW= 1.671

STAGE NO.-- 1
 T1= 2610 HT1= 9.61635 S1= 7.8984 V1= 2.774 Q1= 1
 NS= 16.3553 DS= 3.62767 C0= 2286.02 H/D= 1.72741 E-2
 C1= 500 C2= 2115.71 C3= 406.045 M2= 1.25024
 A1= 90. A2= 15 A3= 90 C/H= 3.14758
 B2= 25.0156 W2= 1294.94 W3= 960.229 MR2= .765219
 UM= 870.155 UTIP= 885.314 DIA.= 8.45412 H= .146037
 T3= 2251 HT3= 9.09769 S3= 8.01581 V3= 6.43065 Q3= .947829
 STAGE EFF.= .659579 ETT= .698072 ETS= .676048

STAGE NO.-- 2
 T1= 2251 HT1= 9.09769 S1= 8.01581 V1= 6.43065 Q1= .947829
 NS= 27.3429 DS= 2.36837 C0= 2311.36 H/D= 3.65922 E-2
 C1= 406.045 C2= 2139.16 C3= 463.82 M2= 1.38904
 A1= 90. A2= 15 A3= 90 C/H= 1.47102
 B2= 26.2167 W2= 1253.27 W3= 1049.92 MR2= .813801
 UM= 941.922 UTIP= 976.994 DIA.= 9.3296 H= .341391
 T3= 1945 HT3= 8.57221 S3= 8.15524 V3= 18.5776 Q3= .882972
 STAGE EFF.= .659643 ETT= .756941 ETS= .72646

STAGE NO.-- 3
 T1= 1945 HT1= 8.57221 S1= 8.15524 V1= 18.5776 Q1= .882972
 NS= 51.7487 DS= 1.3304 C0= 2390.37 H/D= .079753
 C1= 463.82 C2= 2221.68 C3= 730.178 M2= 1.6031
 A1= 90. A2= 21 A3= 90 C/H= .605931
 B2= 36.3496 W2= 1343.28 W3= 1231.92 MR2= .969271
 UM= 992.218 UTIP= 1074.18 DIA.= 10.2577 H= .818081
 T3= 1660 HT3= 8.0577 S3= 8.33023 V3= 73.6024 Q3= .819778
 STAGE EFF.= .639105 ETT= .793849 ETS= .719775

TURBINE TOTAL ENTHALPY DROP= 1.55865 OVERALL CYCLE EFFICIENCY = .74962
OVERALL TURBINE EFFICIENCY= .684975

NEW WEIGHT FLOW= 1.67023

NUMBER OF STAGES= 5 RPM= 24000
INITIAL WEIGHT FLOW= 1.59

STAGE NO.-- 1
 T1= 2610 HT1= 9.61635 S1= 7.8984 V1= 2.774 Q1= 1
 NS= 19.0558 DS= 3.2067 C0= 1798.76 H/D= 2.12222 E-2
 C1= 500 C2= 1664.75 C3= 334.165 M2= .951533
 A1= 90. A2= 15 A3= 90 C/H= 2.55301
 B2= 25.4433 W2= 1002.91 W3= 777.821 MR2= .573241
 UM= 702.384 UTIP= 717.445 DIA.= 6.85109 H= .145396
 T3= 2381 HT3= 9.27838 S3= 7.95955 V3= 4.46941 Q3= .970255
 STAGE EFF.= .696277 ETT= .719227 ETS= .694405

STAGE NO.-- 2
 T1= 2381 HT1= 9.27838 S1= 7.95955 V1= 4.46941 Q1= .970255
 NS= 25.5838 DS= 2.50628 C0= 1775.13 H/D= 3.29264 E-2
 C1= 334.165 C2= 1642.88 C3= 352.166 M2= .991853
 A1= 90. A2= 15 A3= 90 C/H= 1.63644
 B2= 26.0988 W2= 966.555 W3= 800.518 MR2= .583537
 UM= 718.898 UTIP= 742.944 DIA.= 7.09459 H= .233599
 T3= 2188 HT3= 8.95241 S3= 8.02554 V3= 7.74279 Q3= .929222
 STAGE EFF.= .693026 ETT= .751233 ETS= .721666

STAGE NO.-- 3
 T1= 2188 HT1= 8.95241 S1= 8.02554 V1= 7.74279 Q1= .929222
 NS= 34.3329 DS= 1.94005 C0= 1802.91 H/D= 5.01213 E-2
 C1= 352.166 C2= 1669.8 C3= 399.245 M2= 1.06797
 A1= 90. A2= 16 A3= 90 C/H= 1.05532
 B2= 28.168 W2= 975.004 W3= 845.746 MR2= .623592
 UM= 745.588 UTIP= 783.839 DIA.= 7.48511 H= .375163
 T3= 2004 HT3= 8.6268 S3= 8.10272 V3= 14.6089 Q3= .888672
 STAGE EFF.= .677884 ETT= .772853 ETS= .734954

STAGE NO.-- 4
 T1= 2004 HT1= 8.6268 S1= 8.10272 V1= 14.6089 Q1= .888672
 NS= 48.1772 DS= 1.42309 C0= 1840.87 H/D= 7.37211 E-2
 C1= 399.245 C2= 1709.64 C3= 528.209 M2= 1.16221
 A1= 90. A2= 19.875 A3= 90 C/H= .669877
 B2= 34.6068 W2= 1023.39 W3= 930.037 MR2= .695693
 UM= 765.491 UTIP= 823.81 DIA.= 7.8668 H= .579949
 T3= 1828 HT3= 8.30744 S3= 8.19236 V3= 30.6217 Q3= .849181
 STAGE EFF.= .660897 ETT= .7908 ETS= .725693

STAGE NO.-- 5
 T1= 1828 HT1= 8.30744 S1= 8.19236 V1= 30.6217 Q1= .849181
 NS= 70.8348 DS= 1.014 C0= 1900.91 H/D= .126571
 C1= 528.209 C2= 1769.71 C3= 663.592 M2= 1.28355
 A1= 90. A2= 23.5 A3= 90 C/H= .362317
 B2= 40.1543 W2= 1094.32 W3= 1029.07 MR2= .793695
 UM= 786.533 UTIP= 891.202 DIA.= 8.51035 H= 1.07716
 T3= 1660 HT3= 7.99011 S3= 8.2982 V3= 72.8871 Q3= .811809
 STAGE EFF.= .643627 ETT= .804315 ETS= .706297

TURBINE TOTAL ENTHALPY DROP= 1.62623 OVERALL CYCLE EFFICIENCY = .76769
OVERALL TURBINE EFFICIENCY= .710175

NEW WEIGHT FLOW= 1.60082

Table 14. (continued)

NUMBER OF STAGES= 7 RPM= 24000
INITIAL WEIGHT FLOW= 1.563

STAGE NO.-- 1

T1= 2610	HT1= 9.61635	S1= 7.8984	V1= 2.774	Q1= 1
NS= 22.1587	DS= 2.82967	CO= 1543.69	H/D= 2.64075	E-2
C1= 500	C2= 1428.68	C3= 297.553	M2= .805368	
A1= 90.	A2= 15	A3= 90	C/H= 2.04548	
B2= 25.8068	W2= 849.381	W3= 683.491	MR2= .478809	
UM= 615.328	UTIP= 631.786	DIA.= 6.0331	H= .15932	
T3= 2436	HT3= 9.3591	S3= 7.94065	V3= 3.88579	Q3= .980589
STAGE EFF.= .721507		ETT= .737033	ETS= .70965	

STAGE NO.-- 2

T1= 2436	HT1= 9.3591	S1= 7.94065	V1= 3.88579	Q1= .980589
NS= 28.0852	DS= 2.31487	CO= 1488.21	H/D= 3.82027	E-2
C1= 297.553	C2= 1377.34	C3= 299.925	M2= .806599	
A1= 90.	A2= 15	A3= 90	C/H= 1.40846	
B2= 26.2612	W2= 805.671	W3= 677.85	MR2= .471819	
UM= 607.891	UTIP= 631.538	DIA.= 6.03074	H= .230391	
T3= 2297	HT3= 9.12211	S3= 7.98121	V3= 5.59323	Q3= .95053
STAGE EFF.= .717796		ETT= .759095	ETS= .728264	

STAGE NO.-- 3

T1= 2297	HT1= 9.12211	S1= 7.98121	V1= 5.59323	Q1= .95053
NS= 33.7964	DS= 1.97278	CO= 1505.3	H/D= 5.06448	E-2
C1= 299.925	C2= 1393.53	C3= 319.212	M2= .849388	
A1= 90.	A2= 15.375	A3= 90	C/H= 1.0543	
B2= 27.1372	W2= 810.03	W3= 699.836	MR2= .493732	
UM= 622.798	UTIP= 655.091	DIA.= 6.25565	H= .316816	
T3= 2162	HT3= 8.88535	S3= 8.02722	V3= 8.38143	Q3= .920606
STAGE EFF.= .704114		ETT= .771896	ETS= .737184	

STAGE NO.-- 4

T1= 2162	HT1= 8.88535	S1= 8.02722	V1= 8.38143	Q1= .920606
NS= 41.3192	DS= 1.63381	CO= 1531.58	H/D= 6.01947	E-2
C1= 319.212	C2= 1421.03	C3= 402.455	M2= .903241	
A1= 90.	A2= 18.5	A3= 90	C/H= .842121	
B2= 32.3437	W2= 842.807	W3= 752.254	MR2= .535708	
UM= 635.55	UTIP= 674.875	DIA.= 6.44458	H= .387929	
T3= 2030	HT3= 8.65138	S3= 8.07912	V3= 13.1957	Q3= .890632
STAGE EFF.= .689507		ETT= .783365	ETS= .729274	

STAGE NO.-- 5

T1= 2030	HT1= 8.65138	S1= 8.07912	V1= 13.1957	Q1= .890632
NS= 51.5961	DS= 1.33366	CO= 1562.02	H/D= 7.93448	E-2
C1= 402.455	C2= 1451.78	C3= 477.047	M2= .963353	
A1= 90.	A2= 21	A3= 90	C/H= .609069	
B2= 36.347	W2= 877.839	W3= 804.905	MR2= .582503	
UM= 648.309	UTIP= 701.582	DIA.= 6.59961	H= .53158	
T3= 1903	HT3= 8.4193	S3= 8.1378	V3= 21.8277	Q3= .861825
STAGE EFF.= .675107		ETT= .793726	ETS= .719695	

STAGE NO.-- 6

T1= 1903	HT1= 8.4193	S1= 8.1378	V1= 21.8277	Q1= .861825
NS= 65.7357	DS= 1.07929	CO= 1606.23	H/D= .112827	
C1= 477.047	C2= 1494.88	C3= 546.627	M2= 1.03758	
A1= 90.	A2= 23	A3= 90	C/H= .410868	
B2= 39.4106	W2= 920.016	W3= 860.999	MR2= .638574	
UM= 665.225	UTIP= 743.834	DIA.= 7.10309	H= .801419	
T3= 1779	HT3= 8.18527	S3= 8.20549	V3= 38.5245	Q3= .834017
STAGE EFF.= .660271		ETT= .802227	ETS= .709317	

STAGE NO.-- 7

T1= 1779	HT1= 8.18527	S1= 8.20549	V1= 38.5245	Q1= .834017
NS= 87.5038	DS= .863	CO= 1639.16	H/D= .179831	
C1= 546.627	C2= 1526.66	C3= 592.125	M2= 1.10997	
A1= 90.	A2= 24.125	A3= 90	C/H= .251366	
B2= 41.1151	W2= 948.927	W3= 900.468	MR2= .689926	
UM= 678.407	UTIP= 807.961	DIA.= 7.71545	H= 1.38747	
T3= 1660	HT3= 7.95108	S3= 8.28309	V3= 72.5495	Q3= .808048
STAGE EFF.= .645109		ETT= .809081	ETS= .703503	

TURBINE TOTAL ENTHALPY DROP= 1.66526 OVERALL CYCLE EFFICIENCY = .77949
OVERALL TURBINE EFFICIENCY= .722668

NEW WEIGHT FLOW= 1.5633

Table 14. (continued)

NUMBER OF STAGES= 9				RPM= 24000	
INITIAL WEIGHT FLOW= 1.54					
STAGE NO.-- 1					
T1= 2610	HT1= 9.61635	S1= 7.8984	V1= 2.774	Q1= 1	
NS= 24.95	DS= 2.56023	C0= 1381.53	H/D= 3.16579	E-2	
C1= 500	C2= 1278.61	C3= 272.82	M2= .71511		
A1= 90.	A2= 15	A3= 90	C/H= 1.7027		
B2= 26.0516	W2= 753.51	W3= 621.197	MR2= .42143		
UM= 558.085	UTIP= 576.023	DIA.= 5.50061	H= .174138		
T3= 2469	HT3= 9.40602	S3= 7.92946	V3= 3.58405	Q3= .986563	
STAGE EFF.= .73794		ETT= .748941	ETS= .719735		
STAGE NO.-- 2					
T1= 2469	HT1= 9.40602	S1= 7.92946	V1= 3.58405	Q1= .986563	
NS= 30.8237	DS= 2.13776	C0= 1315.11	H/D= .04438		
C1= 272.82	C2= 1217.16	C3= 269.247	M2= .701157		
A1= 90.	A2= 15.0313	A3= 90	C/H= 1.2104		
B2= 26.454	W2= 708.595	W3= 604.396	MR2= .408193		
UM= 541.115	UTIP= 565.636	DIA.= 5.40142	H= .239715		
T3= 2359	HT3= 9.21698	S3= 7.95847	V3= 4.71856	Q3= .96244	
STAGE EFF.= .734192		ETT= .76595	ETS= .733845		
STAGE NO.-- 3					
T1= 2359	HT1= 9.21698	S1= 7.95847	V1= 4.71856	Q1= .96244	
NS= 35.288	DS= 1.89521	C0= 1327.9	H/D= 5.24839	E-2	
C1= 269.247	C2= 1229.87	C3= 294.998	M2= .730802		
A1= 90.	A2= 16	A3= 90	C/H= 1.00748		
B2= 28.2034	W2= 717.297	W3= 624.195	MR2= .426226		
UM= 550.09	UTIP= 579.672	DIA.= 5.53545	H= .290522		
T3= 2251	HT3= 9.02898	S3= 7.99066	V3= 6.36658	Q3= .938347	
STAGE EFF.= .721765		ETT= .774516	ETS= .736292		
STAGE NO.-- 4					
T1= 2251	HT1= 9.02898	S1= 7.99066	V1= 6.36658	Q1= .938347	
NS= 41.0935	DS= 1.64142	C0= 1335.01	H/D= 5.96338	E-2	
C1= 294.998	C2= 1238.66	C3= 350.619	M2= .759651		
A1= 90.	A2= 18.5	A3= 90	C/H= .850101		
B2= 32.3373	W2= 734.771	W3= 655.481	MR2= .450625		
UM= 553.83	UTIP= 587.77	DIA.= 5.61279	H= .334712		
T3= 2147	HT3= 8.84595	S3= 8.0255	V3= 8.7731	Q3= .914672	
STAGE EFF.= .709881		ETT= .783073	ETS= .72906		
STAGE NO.-- 5					
T1= 2147	HT1= 8.84595	S1= 8.0255	V1= 8.7731	Q1= .914672	
NS= 47.5249	DS= 1.4406	C0= 1361.82	H/D= 7.23865	E-2	
C1= 350.619	C2= 1264.63	C3= 387.781	M2= .801194		
A1= 90.	A2= 19.75	A3= 90	C/H= .683883		
B2= 34.4048	W2= 756.304	W3= 686.293	MR2= .479148		
UM= 566.241	UTIP= 608.578	DIA.= 5.81149	H= .420673		
T3= 2045	HT3= 8.66147	S3= 8.06477	V3= 12.4554	Q3= .891438	
STAGE EFF.= .696697		ETT= .79019	ETS= .726119		
STAGE NO.-- 6					
T1= 2045	HT1= 8.66147	S1= 8.06477	V1= 12.4554	Q1= .891438	
NS= 56.0457	DS= 1.24256	C0= 1386.39	H/D= 9.03399	E-2	
C1= 387.781	C2= 1288.88	C3= 433.585	M2= .844307		
A1= 90.	A2= 21.375	A3= 90	C/H= .530651		
B2= 36.9668	W2= 781.166	W3= 721.014	MR2= .511172		
UM= 576.082	UTIP= 630.194	DIA.= 6.01791	H= .543657		
T3= 1945	HT3= 8.47718	S3= 8.10855	V3= 18.2765	Q3= .868642	
STAGE EFF.= .683951		ETT= .796947	ETS= .718999		
STAGE NO.-- 7					
T1= 1945	HT1= 8.47718	S1= 8.10855	V1= 18.2765	Q1= .868642	
NS= 67.462	DS= 1.05993	C0= 1407.49	H/D= .119009		
C1= 433.585	C2= 1309.7	C3= 474.151	M2= .887728		
A1= 90.	A2= 22.75	A3= 90	C/H= .391402		
B2= 39.0734	W2= 803.525	W3= 752.242	MR2= .544638		
UM= 583.998	UTIP= 656.921	DIA.= 6.27313	H= .746559		
T3= 1848	HT3= 8.29394	S3= 8.15706	V3= 27.708	Q3= .846758	
STAGE EFF.= .671489		ETT= .802975	ETS= .711849		
STAGE NO.-- 8					
T1= 1848	HT1= 8.29394	S1= 8.15706	V1= 27.708	Q1= .846758	
NS= 82.3217	DS= .903479	C0= 1435.24	H/D= .162758		
C1= 474.151	C2= 1336.51	C3= 512.004	M2= .938433		
A1= 90.	A2= 23.875	A3= 90	C/H= .279286		
B2= 40.7467	W2= 828.757	W3= 784.419	MR2= .581912		
UM= 594.281	UTIP= 696.765	DIA.= 6.65361	H= 1.08293		
T3= 1753	HT3= 8.10991	S3= 8.21143	V3= 43.7474	Q3= .825646	
STAGE EFF.= .6588		ETT= .80786	ETS= .705051		
STAGE NO.-- 9					
T1= 1753	HT1= 8.10991	S1= 8.21143	V1= 43.7474	Q1= .825646	
NS= 102.912	DS= .769145	C0= 1462.32	H/D= .235704		
C1= 512.004	C2= 1362.51	C3= 544.474	M2= .992336		
A1= 90.	A2= 24.75	A3= 90	C/H= .189112		
B2= 42.02	W2= 852.16	W3= 813.387	MR2= .62064		
UM= 604.277	UTIP= 755.52	DIA.= 7.21468	H= 1.70053		
T3= 1660	HT3= 7.92501	S3= 8.27245	V3= 72.3119	Q3= .805401	
STAGE EFF.= .646045		ETT= .811828	ETS= .699281		
TURBINE TOTAL ENTHALPY DROP= 1.69134				OVERALL CYCLE EFFICIENCY = .78692	
OVERALL TURBINE EFFICIENCY= .731464					
NEW WEIGHT FLOW= 1.5392					

Table 14. (continued)

NUMBER OF STAGES= 3		RPM= 24000	
INITIAL WEIGHT FLOW= 1.851			
STAGE NO.-- 1			
T1= 2460	HT1= 9.50645	S1= 7.96755	V1= 3.7187 Q1= 1
NS= 21.5112	DS= 2.90074	C0= 2178.05	H/D= 2.52686 E-2
C1= 500	C2= 2015.77	C3= 417.029	M2= 1.21491
A1= 90.	A2= 15	A3= 90	C/H= 2.13886
B2= 25.74	W2= 1201.32	W3= 960.249	MR2= .724037
UM= 864.971	UTIP= 887.096	DIA.= 8.47114	H= .214054
T3= 2158	HT3= 9.01867	S3= 8.08863	V3= 8.68551 Q3= .940976
STAGE EFF.= .686867		ETT= .733772	ETS= .706872
STAGE NO.-- 2			
T1= 2158	HT1= 9.01867	S1= 8.08863	V1= 8.68551 Q1= .940976
NS= 34.7397	DS= 1.92324	C0= 2177.76	H/D= 5.18677 E-2
C1= 417.029	C2= 2016.61	C3= 475.071	M2= 1.32251
A1= 90.	A2= 15.75	A3= 90	C/H= 1.02346
B2= 27.7801	W2= 1174.45	W3= 1019.29	MR2= .770216
UM= 901.812	UTIP= 949.726	DIA.= 9.06921	H= .470399
T3= 1900	HT3= 8.54655	S3= 8.20954	V3= 22.6437 Q3= .882015
STAGE EFF.= .67269		ETT= .773574	ETS= .736761
STAGE NO.-- 3			
T1= 1900	HT1= 8.54655	S1= 8.20954	V1= 22.6437 Q1= .882015
NS= 60.7023	DS= 1.15459	C0= 2229.06	H/D= 9.97908 E-2
C1= 475.071	C2= 2073.84	C3= 738.603	M2= 1.49073
A1= 90.	A2= 22.5	A3= 90	C/H= .469569
B2= 38.6497	W2= 1270.7	W3= 1182.6	MR2= .913411
UM= 923.592	UTIP= 1019.73	DIA.= 9.73769	H= .971732
T3= 1660	HT3= 8.09943	S3= 8.35421	V3= 74.1361 Q3= .825747
STAGE EFF.= .650584		ETT= .799732	ETS= .711926
TURBINE TOTAL ENTHALPY DROP= 1.40701		OVERALL CYCLE EFFICIENCY = .76903	
OVERALL TURBINE EFFICIENCY= .686727			
NEW WEIGHT FLOW= 1.85023			
NUMBER OF STAGES= 5		RPM= 24000	
INITIAL WEIGHT FLOW= 1.778			
STAGE NO.-- 1			
T1= 2460	HT1= 9.50645	S1= 7.96755	V1= 3.7187 Q1= 1
NS= 25.4921	DS= 2.51394	C0= 1716.49	H/D= 3.27411 E-2
C1= 500	C2= 1588.6	C3= 340.307	M2= .927938
A1= 90.	A2= 15	A3= 90	C/H= 1.6458
B2= 26.0921	W2= 934.846	W3= 773.753	MR2= .546064
UM= 694.901	UTIP= 718.012	DIA.= 6.8565	H= .22449
T3= 2267	HT3= 9.18946	S3= 8.04179	V3= 6.21547 Q3= .96336
STAGE EFF.= .720796		ETT= .75091	ETS= .721394
STAGE NO.-- 2			
T1= 2267	HT1= 9.18946	S1= 8.04179	V1= 6.21547 Q1= .96336
NS= 33.9318	DS= 1.96607	C0= 1679.32	H/D= 5.09852 E-2
C1= 340.307	C2= 1554.63	C3= 356.285	M2= .954623
A1= 90.	A2= 15.375	A3= 90	C/H= 1.04722
B2= 27.1423	W2= 903.518	W3= 780.976	MR2= .554806
UM= 694.975	UTIP= 731.258	DIA.= 6.98299	H= .35603
T3= 2105	HT3= 8.89305	S3= 8.09978	V3= 10.3123 Q3= .925237
STAGE EFF.= .708283		ETT= .77214	ETS= .737384
STAGE NO.-- 3			
T1= 2105	HT1= 8.89305	S1= 8.09978	V1= 10.3123 Q1= .925237
NS= 44.429	DS= 1.53188	C0= 1698.32	H/D= .066611
C1= 356.285	C2= 1576.29	C3= 461.89	M2= 1.01938
A1= 90.	A2= 19	A3= 90	C/H= .753767
B2= 33.1942	W2= 937.369	W3= 843.666	MR2= .60619
UM= 706.003	UTIP= 754.468	DIA.= 7.20464	H= .479908
T3= 1950	HT3= 8.60641	S3= 8.16561	V3= 18.2865 Q3= .888051
STAGE EFF.= .690658		ETT= .787032	ETS= .728817
STAGE NO.-- 4			
T1= 1950	HT1= 8.60641	S1= 8.16561	V1= 18.2865 Q1= .888051
NS= 59.2666	DS= 1.18295	C0= 1743.13	H/D= 9.77939 E-2
C1= 461.89	C2= 1621.07	C3= 560.217	M2= 1.1063
A1= 90.	A2= 21.875	A3= 90	C/H= .485208
B2= 37.7359	W2= 986.86	W3= 915.35	MR2= .673487
UM= 723.9	UTIP= 797.694	DIA.= 7.61742	H= .744937
T3= 1801	HT3= 8.32174	S3= 8.24261	V3= 35.1842 Q3= .852743
STAGE EFF.= .672386		ETT= .798932	ETS= .716411
STAGE NO.-- 5			
T1= 1801	HT1= 8.32174	S1= 8.24261	V1= 35.1842 Q1= .852743
NS= 83.0796	DS= .892006	C0= 1780.04	H/D= .162491
C1= 560.217	C2= 1658.27	C3= 652.31	M2= 1.19638
A1= 90.	A2= 24.5	A3= 90	C/H= .276101
B2= 41.6056	W2= 1035.65	W3= 982.394	MR2= .747186
UM= 734.572	UTIP= 861.036	DIA.= 8.22228	H= 1.33605
T3= 1660	HT3= 8.04253	S3= 8.33117	V3= 73.6234 Q3= .820012
STAGE EFF.= .655077		ETT= .808049	ETS= .699535
TURBINE TOTAL ENTHALPY DROP= 1.46392		OVERALL CYCLE EFFICIENCY = .78341	
OVERALL TURBINE EFFICIENCY= .708054			
NEW WEIGHT FLOW= 1.77831			

Table 14. (continued)

NUMBER OF STAGES= 7 RPM= 24000
INITIAL WEIGHT FLOW= 1.739

STAGE NO.-- 1

T1= 2460	HT1= 9.50645	S1= 7.96755	V1= 3.7187	Q1= 1
NS= 29.6156	DS= 2.21236	C0= 1475.11	H/D= 4.16408	E-2
C1= 500	C2= 1365.21	C3= 299.673	M2= .786805	
A1= 90.	A2= 15	A3= 90	C/H= 1.29124	
B2= 26.3446	W2= 796.23	W3= 675.287	MR2= .458887	
UM= 605.157	UTIP= 630.856	DIA.= 6.02423	H= .250854	
T3= 2314	HT3= 9.26624	S3= 8.02546	V3= 5.44361	Q3= .973695
STAGE EFF.= .740996		ETT= .763123	ETS= .731629	

STAGE NO.-- 2

T1= 2314	HT1= 9.26624	S1= 8.02546	V1= 5.44361	Q1= .973695
NS= 37.427	DS= 1.79523	C0= 1413.14	H/D= 5.55865	E-2
C1= 299.673	C2= 1309.52	C3= 331.431	M2= .781925	
A1= 90.	A2= 16.75	A3= 90	C/H= .939662	
B2= 29.4783	W2= 766.924	W3= 673.51	MR2= .457936	
UM= 586.321	UTIP= 619.758	DIA.= 5.91825	H= .328975	
T3= 2197	HT3= 9.05185	S3= 8.06135	V3= 7.64365	Q3= .945431
STAGE EFF.= .731134		ETT= .777953	ETS= .73516	

STAGE NO.-- 3

T1= 2197	HT1= 9.05185	S1= 8.06135	V1= 7.64365	Q1= .945431
NS= 44.0329	DS= 1.54471	C0= 1437.3	H/D= .065968	
C1= 331.431	C2= 1333.91	C3= 387.916	M2= .826316	
A1= 90.	A2= 18.875	A3= 90	C/H= .76286	
B2= 32.9927	W2= 792.469	W3= 712.381	MR2= .49091	
UM= 597.507	UTIP= 638.118	DIA.= 6.09357	H= .401981	
T3= 2082	HT3= 8.8389	S3= 8.10201	V3= 11.1319	Q3= .917439
STAGE EFF.= .715517		ETT= .786594	ETS= .729297	

STAGE NO.-- 4

T1= 2082	HT1= 8.8389	S1= 8.10201	V1= 11.1319	Q1= .917439
NS= 52.8982	DS= 1.30768	C0= 1458.09	H/D= 8.32586	E-2
C1= 387.916	C2= 1355.08	C3= 443.289	M2= .871343	
A1= 90.	A2= 20.875	A3= 90	C/H= .581647	
B2= 36.1846	W2= 817.857	W3= 750.84	MR2= .5259	
UM= 606.022	UTIP= 658.351	DIA.= 6.28679	H= .523429	
T3= 1971	HT3= 8.62888	S3= 8.14756	V3= 16.773	Q3= .890487
STAGE EFF.= .700491		ETT= .794735	ETS= .72128	

STAGE NO.-- 5

T1= 1971	HT1= 8.62888	S1= 8.14756	V1= 16.773	Q1= .890487
NS= 64.95	DS= 1.08955	C0= 1473.65	H/D= .110481	
C1= 443.289	C2= 1371.49	C3= 501.228	M2= .915709	
A1= 90.	A2= 23	A3= 90	C/H= .419636	
B2= 39.4031	W2= 844.213	W3= 789.618	MR2= .56366	
UM= 610.14	UTIP= 680.692	DIA.= 6.50012	H= .718143	
T3= 1865	HT3= 8.42405	S3= 8.19773	V3= 26.1044	Q3= .864957
STAGE EFF.= .686429		ETT= .801866	ETS= .709101	

STAGE NO.-- 6

T1= 1865	HT1= 8.42405	S1= 8.19773	V1= 26.1044	Q1= .864957
NS= 79.7325	DS= .91467	C0= 1516.56	H/D= .149199	
C1= 501.228	C2= 1413.28	C3= 566.653	M2= .981636	
A1= 90.	A2= 25	A3= 90	C/H= .297621	
B2= 42.2616	W2= 888.123	W3= 842.584	MR2= .616872	
UM= 623.584	UTIP= 721.922	DIA.= 6.89384	H= 1.02856	
T3= 1760	HT3= 8.21742	S3= 8.25504	V3= 42.877	Q3= .84003
STAGE EFF.= .671988		ETT= .807089	ETS= .694413	

STAGE NO.-- 7

T1= 1760	HT1= 8.21742	S1= 8.25504	V1= 42.877	Q1= .84003
NS= 102.171	DS= .772702	C0= 1537.68	H/D= .232644	
C1= 566.653	C2= 1432.72	C3= 572.443	M2= 1.03541	
A1= 90.	A2= 24.75	A3= 90	C/H= .191607	
B2= 42.0178	W2= 896.112	W3= 855.205	MR2= .647605	
UM= 635.366	UTIP= 792.378	DIA.= 7.56665	H= 1.76034	
T3= 1660	HT3= 8.00976	S3= 8.32058	V3= 73.3869	Q3= .817378
STAGE EFF.= .656163		ETT= .81172	ETS= .699223	

TURBINE TOTAL ENTHALPY DROP= 1.49669 OVERALL CYCLE EFFICIENCY = .79187
OVERALL TURBINE EFFICIENCY= .718622

NEW WEIGHT FLOW= 1.73937

Table 14. (continued)

NUMBER OF STAGES= 9			RPM= 24000		
INITIAL WEIGHT FLOW= 1.714					
STAGE NO.-- 1					
T1= 2460	HT1= 9.50645	S1= 7.96755	V1= 3.7187	Q1= 1	
NS= 33.4024	DS= 1.9939	C0= 1322.1	H/D= 5.00389	E-2	
C1= 500	C2= 1223.83	C3= 277.604	M2= .700005		
A1= 90.	A2= 15.25	A3= 90	C/H= 1.06915		
B2= 26.9189	W2= 711.032	W3= 613.181	MR2= .406696		
UM= 546.744	UTIP= 574.746	DIA.= 5.48842	H= .274635		
T3= 2341	HT3= 9.31074	S3= 8.01669	V3= 5.05841	Q3= .979669	
STAGE EFF.= .753829		ETT= .771172	ETS= .737173		
STAGE NO.-- 2					
T1= 2341	HT1= 9.31074	S1= 8.01669	V1= 5.05841	Q1= .979669	
NS= 41.1615	DS= 1.63912	C0= 1253.91	H/D= 5.98025	E-2	
C1= 277.604	C2= 1163.41	C3= 329.371	M2= .684284		
A1= 90.	A2= 18.5	A3= 90	C/H= .847686		
B2= 32.3392	W2= 690.096	W3= 615.724	MR2= .405896		
UM= 520.227	UTIP= 552.201	DIA.= 5.27313	H= .315346		
T3= 2248	HT3= 9.14105	S3= 8.04239	V3= 6.55301	Q3= .956766	
STAGE EFF.= .746071		ETT= .783161	ETS= .729125		
STAGE NO.-- 3					
T1= 2248	HT1= 9.14105	S1= 8.04239	V1= 6.55301	Q1= .956766	
NS= 46.5317	DS= 1.46874	C0= 1266.4	H/D= 7.05496	E-2	
C1= 329.371	C2= 1175.82	C3= 355.252	M2= .71128		
A1= 90.	A2= 19.5	A3= 90	C/H= .705025		
B2= 34.005	W2= 701.804	W3= 635.21	MR2= .424538		
UM= 526.586	UTIP= 564.932	DIA.= 5.3947	H= .380594		
T3= 2158	HT3= 8.97277	S3= 8.0708	V3= 8.62725	Q3= .934646	
STAGE EFF.= .732938		ETT= .789224	ETS= .727119		
STAGE NO.-- 4					
T1= 2158	HT1= 8.97277	S1= 8.0708	V1= 8.62725	Q1= .934646	
NS= 53.0515	DS= 1.30457	C0= 1280.39	H/D= 8.36786	E-2	
C1= 355.252	C2= 1189.93	C3= 389.337	M2= .74069		
A1= 90.	A2= 20.875	A3= 90	C/H= .578709		
B2= 36.1871	W2= 718.139	W3= 659.418	MR2= .447018		
UM= 532.216	UTIP= 578.411	DIA.= 5.52342	H= .462191		
T3= 2070	HT3= 8.80633	S3= 8.10207	V3= 11.59	Q3= .912979	
STAGE EFF.= .719948		ETT= .794849	ETS= .721355		
STAGE NO.-- 5					
T1= 2070	HT1= 8.80633	S1= 8.10207	V1= 11.59	Q1= .912979	
NS= 60.9587	DS= 1.15069	C0= 1297.22	H/D= .100528		
C1= 389.337	C2= 1206.89	C3= 429.931	M2= .773417		
A1= 90.	A2= 22.5	A3= 90	C/H= .466106		
B2= 38.6527	W2= 739.443	W3= 688.331	MR2= .473862		
UM= 537.552	UTIP= 593.933	DIA.= 5.67164	H= .570159		
T3= 1984	HT3= 8.6417	S3= 8.13641	V3= 15.9137	Q3= .891879	
STAGE EFF.= .707311		ETT= .799873	ETS= .712012		
STAGE NO.-- 6					
T1= 1984	HT1= 8.6417	S1= 8.13641	V1= 15.9137	Q1= .891879	
NS= 70.7266	DS= 1.01519	C0= 1316.19	H/D= .126233		
C1= 429.931	C2= 1225.35	C3= 459.442	M2= .808728		
A1= 90.	A2= 23.5	A3= 90	C/H= .36329		
B2= 40.1534	W2= 757.719	W3= 712.492	MR2= .500094		
UM= 544.577	UTIP= 616.848	DIA.= 5.89046	H= .74357		
T3= 1900	HT3= 8.47751	S3= 8.1744	V3= 22.3758	Q3= .871569	
STAGE EFF.= .69462		ETT= .804274	ETS= .706273		
STAGE NO.-- 7					
T1= 1900	HT1= 8.47751	S1= 8.1744	V1= 22.3758	Q1= .871569	
NS= 83.3158	DS= .890184	C0= 1333.33	H/D= .163301		
C1= 459.442	C2= 1242.12	C3= 488.653	M2= .844789		
A1= 90.	A2= 24.5	A3= 90	C/H= .274727		
B2= 41.6068	W2= 775.735	W3= 735.905	MR2= .527591		
UM= 550.253	UTIP= 645.469	DIA.= 6.16377	H= 1.00655		
T3= 1818	HT3= 8.31435	S3= 8.21618	V3= 32.2797	Q3= .852019	
STAGE EFF.= .682329		ETT= .808109	ETS= .699567		
STAGE NO.-- 8					
T1= 1818	HT1= 8.31435	S1= 8.21618	V1= 32.2797	Q1= .852019	
NS= 99.5332	DS= .786936	C0= 1350.67	H/D= .222723		
C1= 488.653	C2= 1258.38	C3= 499.93	M2= .882411		
A1= 90.	A2= 24.625	A3= 90	C/H= .200697		
B2= 41.8409	W2= 786.039	W3= 749.446	MR2= .551191		
UM= 558.34	UTIP= 690.539	DIA.= 6.59416	H= 1.46867		
T3= 1738	HT3= 8.1506	S3= 8.26272	V3= 47.8905	Q3= .833439	
STAGE EFF.= .669329		ETT= .811315	ETS= .700166		
STAGE NO.-- 9					
T1= 1738	HT1= 8.1506	S1= 8.26272	V1= 47.8905	Q1= .833439	
NS= 121.684	DS= .692511	C0= 1360.99	H/D= .321439		
C1= 499.93	C2= 1268.41	C3= 516.291	M2= .917682		
A1= 90.	A2= 25.125	A3= 90	C/H= .137469		
B2= 42.5688	W2= 796.123	W3= 763.206	MR2= .575989		
UM= 562.078	UTIP= 748.593	DIA.= 7.14854	H= 2.29782		
T3= 1660	HT3= 7.98867	S3= 8.3136	V3= 73.231	Q3= .815641	
STAGE EFF.= .657206		ETT= .814106	ETS= .696951		
TURBINE TOTAL ENTHALPY DROP= 1.51777			OVERALL CYCLE EFFICIENCY = .79734		
OVERALL TURBINE EFFICIENCY= .725438					
NEW WEIGHT FLOW= 1.71521					

Table 15. Effects of Number of Stages of Regenerative Feed Heating
with a Turbine Inlet Temperature of 2150°F
and a Condenser Temperature of 1330°F

Fluid	Number of Turbine Stages	Number of Stages of Regenerative Feed Heating	Turbine Efficiency $\eta_t \sim \%$	Useful Enthalpy Drop in Turbine $\Sigma \eta_t \Delta h_{is}$	Enthalpy Rise in Boiler Δh_{boiler}	Cycle Efficiency η_c
Cs	1	0	100	62	220.25	28.15
		0	75	46.5	220.25	20.9
	2	0	75	47.4	220.25	21.5
		1	75	47.4	195.4	24.25
	3	0	75	47.7	220.25	21.65
		2		47.7	187	25.5
	5	0	75	47.8	220.25	21.7
		4		47.8	180	26.55
	1	0	100	249.5	883.2	28.3
		0	75	187	883.2	20.4
K	5	0	75	191.2	883.2	21.65
		4	75	191.2	752.1	25.4
	7	0	75	193.2	883.2	21.9
		6	75	193.2	743	26.0
	9	0	75	194.6	883.2	22.1
		8	75	194.6	738	26.4

Table 16. Effects of Ratio of h_l to h_{sv}

Fluid	Temperature (°F) T	Enthalpy of Liquid (-Btu/lb) h_l	Heat of Vaporization (-Btu/lb) Δh_v	Enthalpy Rise in Liquid from Condenser to Boiler (~Btu/lb) Δh_l	Ratio of Liquid Enthalpy Rise to Heat of Vaporization $\Delta h_l/h_v$
Cs	1400	103.81			
	2150	150.58	166.29	46.77	.281
K	1400	360.73			
	2150	510.18	714.7	149.45	.209

Table 17. Calculations Showing the Individual Effects of Aerodynamic (Balje), Interstage Bleed, Seal, and Moisture Churning Losses as Well as Regenerative Feed Heating

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
Conditions	No Interstage Bleed				No Seal, Bleed or Moisture Losses			No Seal or Bleed Losses				Balje Losses and Regenerative Feed Heating. No Seal or Moisture Losses			Balje + Moisture + Seal Losses No Regenerative Feed Heating			
	Fraction of Flow Through Stage	Net Stage Output	Turbine Output	η_c	Net Stage Output	Turbine Output	η_c	Net Stage Output	Turbine Output	η_c	Enthalpy Rise in Boiler	Net Stage Output	Turbine Output	η_c	In Flow Fraction	Net Stage Output	Turbine Output	η_c
	$\frac{(30) - (40)}{(40) - 1}$	$\frac{(47) - (40)}{(40) - 1} \times 100$	$\frac{(b)}{(40)}$	$\frac{(c)}{(44)}$ last stage	$\frac{(46) - (47)}{(47) - 1} \times 100$	$\frac{(e)}{(46) \text{ or } (47)}$	$\frac{(f)}{(44)}$ last stage	$\frac{(47) - (40)}{(40) - 1} \times 100$	$\frac{(i)}{(40)}$	$\frac{(1)}{(44)}$ last stage	$\frac{(44)}{(44)}$ last stage	$\frac{(30) - (40)}{(40) - 1} \times 100$	$\frac{(1)}{(40)}$	$\frac{(44) - (40)}{(40) - 1}$		$\frac{(46) - (47)}{(47) - 1} \times 100$	$\frac{(p)}{(40)}$	$\frac{(q)}{(40)}$
2150/1330 (5-Stage K) 24,000 rpm	.99125 .87144 .90356 .91951 .92715	29.99 30.98 32.96 35.64 35.19	164.76	18.66	31.64 39.07 42.29 47.93 50.35	211.28	23.92	30.26 35.55 36.48 38.76 37.95	179.00	20.27	883.17	31.64 37.3 38.65 41.95 42.00	191.54	25.45	.9912 .9217 .935 .939 .938	29.9 32.8 34.1 36.4 35.5	168.7	19.1
2150/1200 (5-Stage K) 24,000 rpm	.98850 .85487 .89401 .91679 .92375	36.70 34.35 35.49 40.09 40.03	186.66	20.54	39.39 45.27 47.54 56.51 61.04	249.75	27.49	37.12 40.18 39.70 43.72 43.34	204.06	22.46	908.60	39.4 43.0 43.0 48.5 49.8	223.7	29.7	.9885 .896 .919 .930 .930	36.7 36.0 36.4 40.6 40.3	190.0	20.9
2000/1300 (5-Stage K) 24,000 rpm	.99675 .92559 .93632 .94311 .94513	26.61 29.58 32.07 33.61 30.94	152.81	17.46	27.14 33.86 38.06 41.68 40.29	181.03	20.69	36.70 31.96 34.25 35.64 32.74	171.29	19.57	875.17							
2000/1200 (5-Stage K)	.99500 .91027 .92905 .93740 .94070	32.06 34.16 37.00 40.46 36.81	180.49	20.04	33.05 40.41 45.39 52.48 50.73	222.06	24.66	32.22 37.53 39.83 43.16 39.13	191.87	21.30	900.60							
2150/1330 (3-Stage Cs) 18,000 rpm	.99000 .92007 .93218	14.10 14.43 14.72	43.25	19.64	14.99 17.98 20.05	53.02	24.07	14.24 15.69 15.79	45.72	20.76	220.25	14.99 16.50 16.67	48.07	25.7				
2150/1200 (3-Stage Cs) 18,000 rpm	.98700 .90935 .92806	16.47 16.03 17.24	49.74	21.81	17.85 20.89 24.64	63.38	27.79	16.69 17.63 18.57	52.89	23.19	228.10	17.85 18.85 20.00	56.7	29.8				
2000/1330 (3-Stage Cs) 18,000 rpm	.99050 .94144 .94492	12.25 13.56 12.37	38.18	17.58	12.98 16.27 16.04	45.29	20.86	12.36 14.40 13.09	39.85	18.35	217.13							
2000/1200 (3-Stage Cs) 18,000 rpm	.98775 .93089 .93778	14.86 14.94 15.79	45.55	20.25	16.03 18.66 21.73	56.42	25.08	15.05 16.05 16.84	47.94	21.31	224.98							

Table 18. Summary of Calculations of Individual Effects of Aerodynamic (Baljé'), Seal Leakage and Moisture Losses and of Regenerative Feed Heating

Fluid	Number of Stages	T_o/T_c	Aerodynamic Losses (Baljé')	Regenerative Feed Heating	Seal Losses	Moisture Churning Losses	Enthalpy Drop in Turbine (Btu/lb) Δh_{ad}	Enthalpy Rise in Boiler (Btu/lb) Δh_b	Turbine Efficiency (%) η_t
Cs	3	2150/1330	No	No	No	No	62	220.25	27.9
			Yes	No	No	No	53.02	220.25	23.85
			Yes	Yes	No	No	48.07	186.91	25.7
			Yes	No	No	Yes	45.72	220.25	20.6
			Yes	Yes	Yes	Yes	39.46	186.91	21.11
			Yes	No	Yes	Yes	43.25	220.35	19.64
K	5	2150/1330	No	No	No	No	249.5	883.2	28.3
			Yes	No	No	No	207.5	883.2	23.55
			Yes	Yes	No	No	191.5	752	25.45
			Yes	No	No	Yes	179	883.2	20.3
			Yes	Yes	Yes	Yes	149.6	752	19.9
			Yes	No	Yes	Yes	168.7	883.2	19.12
Cs	3	2150/1200	No	No	No	No	74.3	228.1	32.55
			Yes	No	No	No	63.38	228.1	27.8
			Yes	Yes	No	No	56.7	190	29.85
			Yes	No	No	Yes	52.89	228.1	23.2
			Yes	Yes	Yes	Yes	44.74	190	23.55
			Yes	No	Yes	Yes	49.74	228.1	21.81
K	5	2150/1200	No	No	No	No	298.6	908.6	32.85
			Yes	No	No	No	249.75	908.6	27.5
			Yes	Yes	No	No	223.7	758.2	29.5
			Yes	No	No	Yes	204.1	908.6	22.46
			Yes	Yes	Yes	Yes	167.5	758.2	22.1
			Yes	No	Yes	Yes	190.0	908.6	20.9

Table 19. Reference Design Cases Chosen for Detailed Rotor and Bearing Dynamics Studies

Case No.	Figure No.	Fluid	Number of Turbine Stages	Number of Bearings	RPM	Moisture Deposition Analysis
1	20	Cs	3	4	18,000	Yes
2	22	Cs	2	2	18,000	Yes
3	24	Cs	3	2	18,000	No
4	26	K	5	4	24,000	Yes
5	28	K	8	4	24,000	Yes
6	30	K	3+2 ^a	2	24,000	No

^aThree stages at one end of the generator and two stages at the other end.

Table 20. Thermodynamic Calculations for Reference Designs

	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭	⑮	⑯	⑰	⑱	⑲	⑳	㉑	㉒
	Stage No.	Temperature (°F)	P (psia)	V _s (ft ³ /lb)	S _{ad} (entropy)	Vapor Quality Isentropic Assumed		h _{is} (enthalpy)	h _{ad}	Δh _{is}	η _t	Δh _{ad}	H _{ad}	C _o	T _ℓ	h _ℓ	Δh _ℓ	h _{vapor}	Vapor Bleed Fraction (%)	Flow Fraction into Stage	Turbine Δh (Btu/lb)	⑫ ⑳
						(%)	(%)		⑨ _{n-1} -⑫ _n	⑨ _{n-1} -⑧ _n	(%)	⑩⑪	778 ⑩	√64.44 ⑬		(Btu/lb)	(Btu/lb)	(Btu/lb)				
Cesium	0	2150	314.6	0.525	0.3205	100	100	320	320													
	1	1740	114.5	1.3065	0.3238	89	93	291.4	298.6	28.6	0.75	21.45	22,251	1196.5	1652	124.62		187.46		1.00		21.45
	2	1330	23.6	5.5691	0.3286	79.1	83.1	264	272.6	34.6 63.2		25.95 47.4	26,919	1316.0	1300	99.75	24.87	207.20	12.0	0.88	47.4	22.84 44.286
Cesium	0	2150	314.6	0.525	0.3205	100	100	320														
	1	1880	172.2	0.9001	0.3222	93.5	99.6	302	305.8	18.0	0.791	14.238	14,004	947.9	1814	133.09		180.81		1.00		14.238
	2	1610	74.4	1.9375	0.3248	86.7	89.6	284.5	290.1	21.3	0.736	15.677	16,571	1033.0	1548	116.79	16.3	193.66	8.42	0.916		14.360
	3	1330	23.6	5.5691	0.3296	80.2	84.2	265.7	274.2	24.4 63.7	0.650 0.726	15.86 45.775	18,983	1105.7	1300	99.75	17.04	207.20	8.22	0.834	45.76	13.227 41.825
Potassium	0	2150	214.3	2.77	1.0149	100	100	1230.5	1230.5							510.57						
	1	1990	148.0	3.82	1.0190	96.7	98.1	1192.0	1201.0	38.5	0.766	29.491	29,953	1388.9	1948	478.39	32.18	738.38	4.35	1.00		29.491
	2	1820	87.0	6.20	1.0255	92.6	94.3	1150.0	1163.9	51.0	0.727	37.077	39,678	1598.5	1780	444.01	34.38	763.44	4.50	0.955		35.408
	3	1660	48.6	10.56	1.0325	88.8	90.6	1110.0	1125.8	53.9	0.706	38.053	41,934	1643.3	1620	412.44	31.57	787.45	4.01	0.915		34.818
	4	1500	24.7	19.74	1.0410	85.2	87.3	1072.5	1089.8	53.3	0.675	35.978	41,467	1634.2	1460	381.05	31.39	812.35	3.86	0.876		31.517
	5	1330	10.4	43.74	1.0545	80.9	83.7	1025.0	1049.6	64.8 261.5	0.621 0.699	40.241 180.84	50,414	1801.8	1300	347.33	33.72	383.81	4.02	0.836	180.9	33.641 164.875
Potassium	0	2150	14.58	214.3	2.77	1.0149	100	100	1230.5	1230.5						510.57						
	1	2510	2050	11.93	175.3	3.28	1.017	1207.5	1213.25	23.0	0.75	17.25	17,894	1073.5	2025	489.46	21.11	729.78	2.89	1.00		17.25
	2	2410	1950	8.95	131.5	4.26	1.020	1185.5	1192.44	27.75		20.8125	21,590	1179.2	1925	469.36	20.10	744.37	2.70	0.971		20.21
	3	2310	1850	6.54	96.1	5.66	1.0235	1162.0	1169.61	30.44		22.83	23,682	1235.0	1825	449.58	18.78	758.97	2.61	0.944		21.55
	4	2210	1750	4.64	68.2	7.75	1.0272	1138.5	1146.28	31.11		23.3325	24,204	1248.5	1725	429.90	19.68	773.87	2.54	0.918		21.42
	5	2110	1650	3.18	46.7	10.96	1.0215	1113.2	1121.47	33.08		24.81	25,736	1287.4	1624	410.21	19.69	789.14	2.50	0.893		22.16
	6	2010	1550	2.10	30.8	16.07	1.0335	1088.0	1096.37	33.47		25.1025	26,040	1295.0	1522	390.44	19.77	804.70	2.46	0.868		21.79
	7	1900	1440	1.26	18.5	25.76	1.0405	1057.5	1067.22	38.87		29.1525	30,241	1395.5	1412	370.63	19.81	820.33	2.51	0.843		24.58
	8	1790	1330	0.71	10.4	43.74	1.0465	1024.2	1034.96	43.02		32.265	33,470	1468.2	1300	347.33	23.30	838.81	2.78	0.819	195.54	26.42 175.38

Table 21. Aerodynamic Calculations for Reference Designs

(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)	(45)	(46)	(47)	(48)	(49)	(50)	(51)	(52)	(53)	(54)	(55)	(56)	(57)
Flow, W	N	Stage No.	P ₃	No. Lands in Seal	Seal Leakage	V's	H _{ad}	N _s	η	D _s	H _{ad} ^{1/4}	V's ^{1/2}	Rotor Diam	Turbine Tip Speed	Moisture Assumed, η	Δh _{is}	Net In-Flow Fraction	Δh _{boiler}	Δh _{boiler} (No Bleed)	h/D	η Δh _{is}	Moisture Churning Loss	Fraction of Flow Through Stage	Net Stage Output	Σ (Net Stage Output)	η _c	Power	Rotor Diam	Blade Height	Weight Flow Correction	Corrected Rotor Diam	Corrected Blade Height
(lb/sec)	(rpm)		(psia)		(lb/sec)	(ft ³ /sec)	(ft-lb/lb)		(%)				(ft)	(ft/sec)												(%)	(kwe)	(in.)	(in.)			
$\frac{W}{V's \cdot \frac{1}{100}}$						$\frac{V's}{100}$	$\frac{H_{ad}}{V's \cdot \frac{1}{100}}$						$\frac{D_s}{V's \cdot \frac{1}{100}}$	$\frac{V's}{0.0523598}$	$\frac{1}{1 - \frac{1}{100}}$		$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$	$\frac{1}{100}$
Cesium	7.9	18,000	1 2	114.5 23.6	12 0.33	9.5985 30.8296	22,251 26,919	30.61 47.56	81.8 82.2	1.83 1.55	12.2134 12.8090	3.0981 5.5524	0.563 0.663	467 676	0.07 0.169	28.6 24.6	1.00 0.88	195.38	195.38 220.25	0.0540 0.0664	23.39 28.44	8.75 21.125	0.9825 0.8010	20.97 17.97	38.94	19.93 (17.94)	292.03	6.753 7.951	0.180 0.461	1.06837	7.215 8.495	0.193 0.493
	6.6	18,000	1 2 3	172.2 74.4 23.6	12 0.43 0.20	5.6793 9.8115 25.0291	14,004 16,571 18,983	33.32 38.60 55.68	82.5 83.7 82.6	1.72 1.54 1.38	10.8783 11.3459 11.7379	2.3831 3.1323 5.0029	0.424 0.473 0.530	413 467 646	0.044 0.104 0.158	18.0 21.3 24.4	1.00 0.916 0.834	186.91	186.91 203.21 220.25	0.0590 0.0689 0.0784	14.85 17.83 20.15	5.500 13.000 19.750	0.9890 0.8270 0.7708	13.88 12.83 12.47	39.18	20.96	245.48	5.085 5.682 6.359	0.216 0.308 0.702	1.16470	5.923 6.618 7.406	0.251 0.359 0.818
Potassium	1.6	24,000	1 2 3 4 5	148.0 87.0 48.6 24.7 10.4	12 0.178 0.111 0.068 0.038	5.9958 7.9397 13.0349 23.1272 47.8070	29,953 39,678 41,934 41,467 50,414	25.81 24.05 29.57 39.72 49.32	80.2 79.7 81.5 83.9 82.3	2.10 2.24 1.89 1.50 1.51	13.1556 14.1136 14.3101 14.2701 14.9843	2.4486 2.8177 3.6104 4.8091 6.9143	0.444 0.505 0.533 0.558 0.620	581 664 709 752 1036	0.019 0.057 0.094 0.127 0.163	38.5 51.0 53.9 53.3 64.8	1.00 0.955 0.915 0.876 0.836	752.11	752.11 786.49 818.06 849.45 883.17	0.0443 0.0403 0.0516 0.0715 0.0690	30.88 40.65 43.93 44.72 53.33	2.375 7.125 11.750 15.875 20.375	0.9952 0.8301 0.8241 0.8057 0.7782	30.00 31.34 31.95 30.31 33.05	156.65	20.83	237.94	5.323 6.065 6.391 6.694 7.437	0.147 0.146 0.224 0.401 0.692	1.18301	6.297 7.175 7.561 7.919 8.798	0.174 0.173 0.266 0.465 0.819
	2.16	24,000	1 2 3 4 5 6 7 8	175.3 131.5 96.1 68.2 46.7 30.8 18.5 10.4	12 0.158 0.121 0.096 0.072 0.055 0.037 0.023	7.0281 8.4427 10.3280 13.6124 18.4128 25.7800 39.1874 62.7747	17,894 21,590 23,682 24,204 25,736 26,040 30,241 33,470	41.12 39.15 40.40 45.63 50.68 59.45 65.51 76.84	84.3 83.6 84.0 84.9 85.5 86.4 86.6 80.4	1.46 1.55 1.47 1.35 1.25 1.13 1.07 1.04	11.5658 12.1217 12.4052 12.4730 12.6659 12.7031 13.1871 13.5258	2.6511 2.9056 3.2137 3.6895 4.2910 5.0774 6.2600 7.9230	0.423 0.459 0.485 0.501 0.529 0.557 0.620 0.642	420 467 479 502 532 568 638 766	0.008 0.029 0.052 0.073 0.099 0.122 0.150 0.180	23.0 27.75 30.44 31.11 33.08 33.47 38.87 43.02	1.00 0.971 0.944 0.918 0.893 0.868 0.843 0.819	74.104	741.04 761.14 780.92 800.60 820.29 840.06 859.87 883.17	0.0743 0.0681 0.0736 0.0829 0.0922 0.1058 0.1139 0.1173	19.39 23.20 25.57 26.41 28.28 28.92 33.74 34.59	1.00 3.62 6.50 9.12 12.38 15.25 18.75 22.50	0.9980 0.8908 0.8757 0.8568 0.8376 0.8161 0.7943 0.7715	19.16 19.92 20.94 20.56 20.75 20.00 21.77 20.68	16.378	22.10	335.83	5.076 5.503 5.818 6.014 6.353 6.684 7.442 7.699	0.238 0.227 0.264 0.337 0.422 0.572 0.736 1.150	5.076 5.503 5.818 6.014 6.353 6.684 7.442 7.699	0.238 0.227 0.264 0.337 0.422 0.572 0.736 1.150	

Table 22-a. Rotor and Stator Geometry and Velocity Diagram Data for Reference Designs

(70)	(71)	(72)	(73)	(74)	(75)	(76)	(77a)	(77b)	(78)	(79a)	(79b)	(80)	(81)	(82)	(83)	(84)	(85)	(86)	(87)		
Nozzle Pressure Ratio	Vapor Weight Flow Rate	Vapor Volume Flow Rate	Rotor OD	Rotor Diameter at Blade Root	Rotor Blade Height	Rotor Blade Width (Axial Pitchline Component)	Stator Flow Passage Area					Stator Inlet		Stator Exit		Stator Exit Velocity			Inlet Nozzle Angle α_1		
							Inlet		Throat	Exit		OD	ID	OD	ID	Absolute C_o	Axial Component	Tangential Component			
							Axial (ft ²)	Normal to Flow (ft ²)	Normal to Flow (ft ²)	Normal to Flow (ft ²)	Axial (ft ²)										
(P ₁ /P ₂)	(lb/sec)	(ft ³ /sec)	(in.)	(in.)		(in.)	(ft ²)	(ft ²)	(ft ²)	(ft ²)	(ft ²)	(in.)	(in.)	(in.)	(in.)	(ft/sec)	(ft/sec)	(ft/sec)	(deg)		
$\frac{(3)^{1/2}-1}{(3)}$	$\frac{(333)^{1/2}-1}{(23)}$	$\frac{(71)^{1/2}-1}{0.75(1-(71)^{1/2})}$				$\frac{(74)}{(73)} - \frac{1}{2}$					$\frac{(85)}{(72)}$				$\sqrt{\frac{(83)^2-144}{(82)^2}} - \frac{(72)}{0.786}$		$\frac{(84)}{0.259}$	$\frac{(86)}{0.966}$	$\frac{(87)}{\sin^{-1}}$		
C _s	2.75	7.39	9.148	7.215	6.83	0.193	0.0295	0.0285	0.00682	0.00764	0.0295			7.215	6.83	7.215	6.83	1196.5	310	1156	15
	4.85	6.03	29.325	8.495	7.51	9.493	0.0295	0.0285	0.0148	0.0223	0.0860					8.495	7.51	1316.0	341	1271	15
C _s	1.83	8.79	7.651	5.923	5.42	0.251	0.0311	0.0300	-	0.00805	0.0311			5.92	5.42	5.92	5.42	949.7	246	917	15
	2.31	7.35	13.130	6.618	5.90	0.359	0.0311	0.0300	0.0123	0.0127	0.0490	5.92	5.42	6.61	5.90	6.61	5.90	1033.0	268	998	15
	3.15	6.85	33.628	7.406	5.77	0.818	0.0490	0.0473	0.0254	0.0304	0.1176	6.61	5.90	7.406	5.77	7.406	5.77	1105.7	286	1068	15
K	1.45	2.21	8.322	6.297	5.95	0.174	0.0232	0.0224	-	0.00600	0.0232					6.297	5.95	1389.0	359	1340	15
	1.70	1.84	10.920	7.175	6.83	0.173	0.0232	0.0224	-	0.00683	0.0264	6.297	5.95	7.175	6.83	7.175	6.83	1598.5	414	1542	15
	1.79	1.83	17.962	7.561	7.03	0.266	0.0264	0.0255	-	0.0109	0.0423	7.175	6.83	7.561	7.03	7.561	7.03	1643.0	425	1587	15
	1.97	1.79	31.969	7.919	6.99	0.465	0.0423	0.0409	-	0.0196	0.0756	7.561	7.03	7.919	6.99	7.919	6.99	1634.0	423	1578	15
	2.38	1.73	66.420	8.798	7.16	0.819	0.0756	0.0730	0.0350	0.0369	0.1425	7.919	6.99	8.798	7.16	8.798	7.16	1801.0	466	1739	15
K	1.22	2.14	6.977	5.076	4.60	0.238	0.0251	0.0242	-	0.00650	0.0251					5.076	4.60	1073.5	278	1037	15
	1.33	1.91	7.960	5.503	5.05	0.227	0.0251	0.0242	-	0.00676	0.0261	5.076	4.60	5.503	5.05	5.503	5.05	1179.2	305	1139	15
	1.37	1.88	10.226	5.818	5.29	0.264	0.0261	0.0252	-	0.00828	0.0320	5.503	5.05	5.818	5.29	5.818	5.29	1235.0	320	1193	15
	1.41	1.84	13.479	6.014	5.34	0.337	0.0320	0.0309	-	0.0108	0.0417	5.818	5.29	6.014	5.34	6.014	5.34	1248.5	323	1206	15
	1.46	1.79	18.162	6.353	5.51	0.422	0.0417	0.0403	-	0.0141	0.0545	6.014	5.34	6.353	5.51	6.353	5.51	1287.4	333	1244	15
	1.52	1.75	25.549	6.684	5.54	0.572	0.0545	0.0526	-	0.0197	0.0763	6.353	5.51	6.684	5.54	6.684	5.54	1295.0	335	1251	15
	1.66	1.70	38.865	7.442	5.97	0.736	0.0763	0.0737	-	0.0279	0.1077	6.684	5.54	7.442	5.97	7.442	5.97	1395.5	361	1348	15
	1.77	1.65	62.428	7.699	5.40	1.150	0.1077	0.1040	-	0.0425	0.1643	7.442	5.97	7.699	5.40	7.699	5.40	1468.2	380	1418	15

Table 22-b. Rotor and Stator Geometry and Velocity Diagram Data for Reference Designs

(88)	(89)	(90)	(91)	(92)	(93)	(95)	(96)	(97)	(98)	(99)	(100)	(101)	(102)	(103)	(104)	(105)	(106)
Rotor Tip						Pitch Line						Rotor Blade Root					
Blade Velocity (ft/sec)	Vapor Inlet Relative Tangential Velocity (ft/sec)	Rotor Blade Inlet Angle (deg)	Total Relative Inlet Velocity (ft/sec)	Absolute Tangential Velocity Leaving Rotor (ft/sec)	Absolute Exit Angle α_3 (deg)	Blade Velocity (ft/sec)	Vapor Inlet Relative Tangential Velocity (ft/sec)	Rotor Blade Inlet Angle (deg)	Total Relative Inlet Velocity (ft/sec)	Absolute Tangential Velocity Leaving Rotor (ft/sec)	Absolute Exit Angle α_3 (deg)	Blade Velocity (ft/sec)	Vapor Inlet Relative Tangential Velocity (ft/sec)	Rotor Blade Inlet Angle (deg)	Total Relative Inlet Velocity (ft/sec)	Absolute Tangential Velocity Leaving Rotor (ft/sec)	Absolute Exit Angle α_3 (deg)
$C_s = \frac{300\pi}{12}$ $K = \frac{400\pi}{12}$	88 86	85 89 Tan^{-1}	85 89 $z +$	88 89 $-$	85 92 Tan^{-1}	$C_s = \frac{300\pi}{12}$ $K = \frac{400\pi}{12}$	95 86	85 96 Tan^{-1}	85 96 $z +$	95 96 $-$	85 99 Tan^{-1}	$C_s = \frac{300\pi}{12}$ $K = \frac{400\pi}{12}$	101 86	85 102 Tan^{-1}	85 102 $z +$	101 102 $-$	85 103 Tan^{-1}
568.6 677.8	587.4 593.2	27.8 29.9	664.2 684.2	18.7 -84.6	86.5 103.1	552.9 633.8	603.1 637.2	27.2 28.2	678.1 722.7	50.2 3.4	80.8 89.4	536.4 589.8	619.6 681.2	26.6 26.6	692.8 761.8	83.2 91.3	75.0 75.0
467.3 424.6 596.9	449.7 473.4 471.1	28.7 29.5 31.3	512.6 544.0 551.1	-17.6 -51.3 -125.8	94.9 100.2 114.0	446.1 494.0 524.6	470.9 504.0 543.4	27.6 28.0 27.8	531.3 570.8 614.0	24.8 10.0 18.7	84.2 87.9 86.2	425.7 463.4 453.2	491.3 534.6 614.8	26.6 26.6 25.0	549.5 598.0 678.1	65.6 71.2 161.6	75.1 75.1 60.5
658.7 752.9 796.9 837.8 942.5	681.3 789.1 790.1 740.2 796.5	27.8 27.7 28.3 29.7 30.3	770.1 891.1 897.1 852.6 922.8	22.6 36.1 -6.8 -97.5 -146.0	86.4 85.0 90.1 102.0 107.6	640.9 734.1 766.5 785.4 846.1	699.1 807.9 820.4 792.6 892.9	27.2 27.1 27.4 28.1 31.5	785.9 907.8 924.0 898.4 1007.2	58.2 73.8 53.9 7.2 46.7	80.8 79.9 82.8 89.0 84.3	622.0 715.2 736.2 732.0 749.8	718.0 826.8 850.8 846.0 989.2	26.6 26.6 26.5 26.6 25.2	802.7 924.6 951.1 945.9 1093.5	95.9 111.5 114.6 114.0 239.4	75.0 74.9 74.9 74.9 62.8
532.0 577.0 611.6 634.6 672.3 710.0 795.9 837.8	505.0 562.0 581.4 571.4 571.7 541.0 552.1 580.2	28.8 28.5 28.8 29.4 30.2 31.8 33.2 33.2	576.5 639.4 663.7 656.4 661.6 636.3 659.7 693.6	-27.0 -15.0 -30.1 -63.2 -100.6 -169.0 -243.7 -257.6	95.5 92.2 95.6 101.9 106.2 116.2 123.0 124.9	506.8 552.9 582.2 596.9 625.2 645.1 710.0 701.6	530.2 586.1 610.8 609.1 618.8 605.9 638.0 716.4	27.7 27.5 27.6 27.9 28.3 28.9 29.5 28.0	598.6 660.7 689.5 689.4 702.7 692.4 733.1 810.9	23.3 33.2 28.5 12.2 -6.4 -39.1 -72.0 14.8	85.2 83.8 84.9 87.8 91.9 96.3 101.7 87.8	481.7 528.8 554.0 559.2 577.0 580.1 625.2 565.5	555.3 610.2 639.0 646.8 667.0 670.8 722.8 852.5	26.6 26.6 26.6 26.5 26.5 26.5 26.5 24.0	621.0 682.1 714.7 723.0 745.5 749.8 808.0 933.4	73.6 81.3 85.1 87.6 90.0 90.7 97.6 287.0	75.2 75.1 75.1 74.8 74.9 74.8 74.9 52.9

Table 23. Data for Details of Turbine Buckets
(See Fig. 35 for definition of symbols)

Fluid	Stage No.	a* (in.)	J (in.)	$\beta_{a_{tip}}$ (deg)	$\beta_{a_{root}}$ (deg)	r (in.)	J' (in.)	Number of Blades	Root Area of Blade (in. ²)
Cesium	1	0.072	0.250	27.8	26.6	0.140	0.248	153	0.0107
	2	0.086	0.300	29.9	26.6	0.167	0.293	141	0.0144
Cesium	1	0.060	0.250	28.7	26.6	0.140	0.247	122	0.0107
	2	0.067	0.250	29.5	26.6	0.140	0.243	132	0.0107
	3	0.076	0.360	31.3	25.0	0.200	0.343	91	0.0271
Potassium	1	0.063	0.250	27.8	26.6	0.140	0.248	134	0.0107
	2	0.072	0.250	27.7	26.5	0.140	0.248	153	0.0107
	3	0.076	0.250	28.3	26.4	0.140	0.247	158	0.0107
	4	0.080	0.360	29.7	26.6	0.201	0.291	110	0.0271
	5	0.090	0.360	30.3	25.2	0.200	0.346	113	0.0271
Potassium	1	0.051	0.250	28.8	26.6	0.140	0.247	103	0.0107
	2	0.055	0.250	28.5	26.6	0.140	0.247	113	0.0107
	3	0.058	0.250	28.8	26.6	0.140	0.247	119	0.0107
	4	0.061	0.250	29.4	26.5	0.140	0.243	120	0.0107
	5	0.064	0.360	30.2	26.5	0.201	0.259	87	0.0271
	6	0.067	0.360	31.8	26.5	0.201	0.343	87	0.0271
	7	0.076	0.360	33.2	26.5	0.201	0.339	94	0.0271
	8	0.080	0.500	33.2	24.0	0.274	0.460	62	0.0600

Table 24. Stator Blade Dimensional Data

Turbine	Stator No.	Rotor Spacing S (in.)	Stator OD		Stator Blade Height		Blade Width		Blade Length (in.)	Number of Blades per Stage	Z_t^a (in.)
			D_o (in.)	D_L (in.)	h_o (in.)	h_L (in.)	w_o (in.)	w_L (in.)			
2-Stage Cs	1	1.42 ^b	7.215	7.215	0.193	0.193	0.25	0.25	0.82	40	0.76
	2	1.42	7.215	8.495	0.193	0.493	0.25	0.30	0.80	40	0.77
3-Stage Cs	1	1.25 ^b	5.923	5.923	0.251	0.251	0.25	0.25	0.65	36	
	2	1.25	5.923	6.618	0.251	0.359	0.25	0.25	0.65	36	0.64
	3	1.30	6.618	7.406	0.359	0.818	0.25	0.36	0.65	36	0.62
5-Stage K	1	1.25 ^b	6.297	6.297	0.179 ⁴	0.174	0.25	0.25	0.65	36	
	2	1.25	6.297	7.175	0.174	0.173	0.25	0.25	0.65	36	
	3	1.25	7.175	7.561	0.173	0.266	0.25	0.25	0.65	40	
	4	1.35	7.561	7.919	0.266	0.465	0.25	0.36	0.70	40	
	5	1.60	7.919	8.798	0.465	0.819	0.36	0.36	0.80	48	0.88
8-Stage K	1	1.25 ^b	5.076	5.076	0.238	0.238	0.25	0.25	0.65	30	
	2	1.25	5.076	5.503	0.238	0.227	0.25	0.25	0.65	30	
	3	1.25	5.503	5.818	0.227	0.264	0.25	0.25	0.65	30	
	4	1.25	5.818	6.014	0.264	0.337	0.25	0.25	0.65	36	
	5	1.30	6.014	6.353	0.337	0.422	0.25	0.36	0.65	36	
	6	1.30	6.353	6.684	0.422	0.572	0.36	0.36	0.59	36	
	7	1.50	6.684	7.442	0.572	0.736	0.36	0.36	0.79	40	
	8	1.50	7.442	7.699	0.736	1.150	0.36	0.50	0.72	40	

^a Z_t is given only for the definitely supersonic cases (See also Table 22a, columns 70 and 78).

^bDummy; used to define L for stator No. 1.

Table 25. Effects of the First Stage Temperature Drop on
the Maximum Turbine Inlet Temperature Permitted
by Creep in the First Stage Rotor

Fluid	First Stage Temperature Drop (°F)	First Stage Rotor Tip Speed From Balje's Charts (ft/sec)	Stress for 1% Creep in 20,000 hr (psi)	Turbine Wheel Temperature (°F)	Stator Inlet Temperature (°F)
Potassium	205	664	10,500	2010	2215
	160	599	8,500	2035	2195
	115	513	6,180	2110	2225
	90	469	5,150	2160	2250
Cesium	820	805	17,300	1900	2720
	410	467	5,100	2160	2570
	270	384	3,500	2220	2490
	160	309	2,250	2350	2510

Table 26. Data for the Weights and Moments of Inertia of Rotor Elements for the Reference Designs of Table 19

Note: The dias of the stub shafts on the generator rotor and the turbine wheel hubs were taken as 3.0 in. The turbine stub shaft diameter was taken as 3.0 in. except at the bearings where the diameter was 2.4 in.

Case No.	Stage No. (or Section)	Turbine Rotor		Generator Rotor		Coupling Weight (lb)
		Weight (lb)	Inertia (in·lb _f ·sec ²)	Weight (lb)	Inertia (in·lb _f ·sec ²)	
1 (Cs - 4 br)	Stub	10.72	0.029	13.0	0.0379	5.42
	1	5.557	0.03700			
	2	6.353	0.05096	195	6.840	
	3	7.9638	0.08740			
	Stub	2.26	0.00658	11.1	0.0322	
2 (Cs - 2 br)	Stub	3.25	0.000947	10.4	0.0306	
	1	8.641	0.07773	195	6.840	
	2	9.639	0.1415			
	Stub	3.64	0.0106	11.1	0.0322	
3 (Cs - 2 br)	Stub	3.9	0.01136	10.4	0.0306	
	1	5.557	0.03700			
	2	6.405	0.05111	195	6.840	
	3	7.8336	0.08702			
	Stub	3.51	0.0122	10.88	0.0317	
4 (K - 4 br)	Stub	7.08	0.01785	12.1	0.03525	6.5
	1	6.5999	0.04800			
	2	7.4152	0.07358			
	3	7.8981	0.08527	155	4.632	
	4	9.8523	0.12801			
	5	11.8653	0.17588			
	Stub	5.7	0.01138	10.9	0.0318	
5 (K - 4 br)	Stub	9.45	0.0273	13.0	0.0379	6.5
	1	4.7092	0.023311			
	2	5.1874	0.029835			
	3	5.6172	0.035201			
	4	5.5732	0.037092			
	5	7.1983	0.057775	155	4.632	
	6	7.5224	0.065011			
	7	8.7677	0.092883			
	8	9.8498	0.12663			
	Stub	6.12	0.01214	11.1	0.0322	
6 (K - 2 br)	Stub	9.45	0.0243	10.4	0.0306	
	1	6.2094	0.04686			
	2	7.4152	0.07358			
	3	7.7679	0.08489	155	4.632	
	Stub	3.64	0.0106			
	Stub	3.38	0.00985			
	4	10.4511	0.12975			
	5	11.6050	0.17513			
	Stub	3.64	0.0106	10.4	0.0306	

Table 27. Summary of Size and Weight Data for Reference
Design Turbine-Generator Units

Working fluid	Cs	Cs	Cs	K	K	K
Number of stages	3	2	3	5	8	3+2
Number of bearings	4	2	2	4	4	2
RPM	18,000	18,000	18,000	24,000	24,000	24,000
Turbine diameter, in.	16	16	16	20	20	20
Turbine length, in.	12	6	7	20	25	13
Turbine weight, lb	190	100	120	540	680	350
Generator diam, in.	23	23	23	21	21	19
Generator length, in.	20	20	20	19	19	19
Generator weight, lb	690	690	690	550	550	550
Total weight of turbine-generator unit, lb	880	790	810	1090	1230	900

Table 28. Summary of Data from Turbine Rotor and Bearing Dynamics and Creep Studies at MTI for ORNL²¹

Case Number	1	2	3	4	5	6
Working fluid	Cs	Cs	Cs	K	K	K
Number of stages in turbine	3	2	3	5	8	3/2 ^a
Number of bearings	4	2	2	4	4	2
Average temperature of 1st stage rotor	1740	1740	1880	1990	2050	1990
Rotor rpm	18,000	18,000	18,000	24,000	24,000	24,000
O.D. of 1st stage rotor, in.	5.923	7.215	5.923	6.297	5.076	6.297
Tip speed of 1st stage rotor, ft/sec	413	467	413	581	420	581
Bearings:						
Journal diameter, in.	2	3	3	2	2	3
Journal length, in.	1.5	2.25	2.25	1.5	1.5	2.25
Journal temperature, °F	1330	830	830	1330	1330	830
Diametral clearance, in.	0.0030	0.0045	0.0045	0.0030	0.0030	0.0045
Approximate critical speeds:						
1st, rpm	7,000	5,500	5,500	6,500	6,500	5,800
2nd, rpm	14,000			15,000	15,000	8,300
3rd, rpm	>30,000	>30,000	>30,000	>40,000	>40,000	27,000
Maximum journal orbit amplitude: ^b						
1st critical speed, mils	0.01	0.005	0.006	0.01	0.01	0.01
2nd critical speed, mils	0.024			0.036	0.036	0.015
Design speed, mils	0.032	0.015	0.019	0.055	0.055	0.075
Friction horsepower, hp	4.0	8	8	4.4	4.4	12.6
Average tangential stress, psi	9,100	10,900	9,100	14,200	12,700	14,200
Rim growth (circumferential), in.	<<0.0027	<<0.003	<0.0027	0.0891	Fracture	0.0891

^aThree stages overhung at one end of generator and two at other.

^bMaximum amplitude occurred in generator rather than in turbine bearings in four-bearing machines.

Table 29. Estimated Threshold of Damaging Impact Velocity
for the Reference Turbine Systems*

Turbine Stage	Primary Drop Diam (μ)	Threshold Velocities (fps) for Various Values of VPN			
		190	260	400	500
2Cs - 2	1.	> 3000	> 3000	> 3000	> 3000
	5.	2876	> 3000	> 3000	> 3000
3Cs - 3	1.	> 3000	> 3000	> 3000	> 3000
	5.	> 3000	> 3000	> 3000	> 3000
5K - 5	8.	> 3000	> 3000	> 3000	> 3000
	20.	2083	2850	> 3000	> 3000
8K - 8	10.	> 3000	> 3000	> 3000	> 3000
	30.	1822	2493	> 3000	> 3000

*This table was excerpted from Ref. 22.

Fig. 1. Effects of Condenser Temperature on the Efficiency of a Series of Ideal Rankine Cycles.

Fig. 2. Effects of Condenser Temperature on a Series of Cycles With a Turbine Inlet Temperature of 2150°F. (a) Ideal Carnot, (b) Ideal simple Rankine cycle, (c) Simple Rankine cycle with allowances for the aerodynamic losses included in Baljé's charts.

Fig. 3. Effects of Condenser Temperature on a Series of Cycles With a Turbine Inlet Temperature of 2000°F. (a) Ideal Carnot, (b) Ideal simple Rankine cycle, (c) Simple Rankine cycle with allowances for the aerodynamic losses included in Balje's charts.

$N_s D_s$ -diagrams for single-stage, full-admission, axial-impulse turbines

Fig. 4. $N_s D_s$ -Diagrams for Single-Stage, Full-Admission, Axial-Impulse Turbines. (From Baljé, Ref. 15)

N_D -diagram for single-disk turbines showing total efficiency

Fig. 5. N_D -Diagrams for Single-Disk Turbines Showing Total Efficiency. (From S_{SS} Báljé, Ref. 15)

Fig. 6. Maximum Efficiency and the Corresponding D_s for any given N_s with Full Admission. Curves for D , U and H_{ad} for typical values of V_3 are also shown for $N = 12,000$ rpm.

Fig. 7. Effects of h/D on Turbine Efficiency as Calculated from Eq. (31) of Ref. 12 for $N_s = 70$, and $D_s = 1.107$.

ORNL DWG. 68-9398

Fig. 8. Leakage Function ϕ for (a) Labyrinths With Four and More Throttlings, and (b) Labyrinths With One to Four Throttlings. (From Egli, Ref. 13)

Fig. 9. Leakage Through 12-Land Labyrinth Seals on Straight Journals for 3.0 in. Journal Diameter and a Radial Clearance of 0.0055 in.

Fig. 10. Effect of Steam Wetness on the Efficiency of the Affected Turbine Stages. The parameter C_0/U is proportional to E_n/N^2D^2 , with $C_0 = 2E_n$. Abscissa is wetness fraction ($1 - q$); ordinate drop in efficiency, $\Delta\eta$ (Csanady, Ref. 10)

Fig. 11a. Effects of Number of Stages and RPM on the Size and Performance of Cesium and Potassium Turbines as Determined from a Computing Machine Program Including Aerodynamic & Moisture Churning Losses but with No Regenerative Feed Heating or Seal Leakage Losses. Turbine inlet temperature 2150°F, turbine outlet temperature 1330°F.

Fig. 11b. Effects of Number of Stages and RPM on the Size and Performance of Cesium and Potassium Turbines as Determined from a Computing Machine Program Including Aerodynamic & Moisture Churning Losses but with No Regenerative Feed Heating of Seal Leakage Losses. Turbine inlet temperature 2150°F, turbine outlet temperature 1200°F.

Fig. 11c. Effects of Number of Stages and RPM on the Size and Performance of Cesium and Potassium Turbines as Determined from a Computing Machine Program Including Aerodynamic & Moisture Churning Losses but with No Regenerative Feed Heating or Seal Leakage Losses. Turbine inlet temperature 2000°F, Turbine outlet temperature 1200°F.

Fig. 12. Effects of Number of Stages on the Overall Thermal Efficiency, Size, and Inlet Mach Number of a Series of Cesium and Potassium Turbines Designed for 24,000 rpm With Allowances for Aerodynamic, Moisture, and Seal Leakage Losses With Regenerative Feed Heating. ($T_{in} = 2150^{\circ}\text{F}$, $T_{out} = 1330^{\circ}\text{F}$)

Fig. 13. Effects of Number of Stages and Design RPM on the Overall Cycle Efficiency, Size, and Rotor Blade Inlet Mach Number for a Series of Cesium Vapor Turbines With Allowances for Aerodynamic, Moisture, and Seal Leakage Losses With Regenerative Feed Heating. ($T_{in} = 2150^{\circ}\text{F}$, $T_{out} = 1330^{\circ}\text{F}$)

Fig. 14. Effects of Number of Stages and Design RPM on the Overall Cycle Efficiency, Size, and Rotor Blade Inlet Mach Number for a Series of Potassium Vapor Turbines With Allowances for Aerodynamic, Moisture, and Seal Leakage Losses With Regenerative Feed Heating. ($T_{in} = 2150^{\circ}\text{F}$, $T_{out} = 1330^{\circ}\text{F}$)

Fig. 15. Effects of Aerodynamic, Moisture, and Seal Losses on Cesium and Potassium Rankine Cycles With No Regenerative Feed Heating, a Turbine Inlet Temperature of 2150°F, a Turbine Outlet Temperature of 1330°F, and 25°F of Superheat.

Fig. 16. Effects of Aerodynamic, Moisture, and Seal Losses on Cesium and Potassium Rankine Cycles With Regenerative Feed Heating, a Turbine Inlet Temperature of 2150°F, a Turbine Outlet Temperature of 1330°F, and 25°F of Superheat.

Fig. 17. Effects of Condenser Temperature on a Series of 5-Stage Turbines Supplied With Vapor at 2150°F With Allowances for Regenerative Feed Heating and Aerodynamic, Moisture Churning, and Seal Leakage Losses.

Fig. 18. Effects of Regenerative Feed Heating on the Thermodynamic Cycle Efficiency Assuming a Turbine Efficiency of 75%, Bleed-off Between Each Set of Adjacent Stages, and a Heating Effectiveness of 0.80 for the Regenerative Feed Heater. ($T_{in} = 2150^{\circ}\text{F}$, $T_{out} = 1330^{\circ}\text{F}$)

ORNL DWG. 68-2577

Fig. 19. Reference Design Layout for the Three-Stage, Four-Bearing Cesium Vapor Turbine.

Fig. 20. Rotor Proportions for the Three-Stage, Four-Bearing, Cesium Vapor Turbine Reference Design of Fig. 19.

2-STAGE CESIUM VAPOR TURBINE

J.J.T.

7/14/67

C-113-9

Fig. 21. Reference Design Layout for the Two-Stage, Two-Bearing Cesium Vapor Turbine.

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Fig. 22. Rotor Proportions for the Two-Stage, Two-Bearing, Cesium Vapor Turbine Reference Design of Fig. 21.

3-STAGE CESIUM VAPOR TURBINE
(2 BEARING TURBINE-GENERATOR)

J.J.T. 7/6/67

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Fig. 23. Reference Design Layout for the Three-Stage, Two-Bearing, Cesium Vapor Turbine.

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Fig. 24. Rotor Proportions for the Three-Stage, Two-Bearing, Cesium Vapor Turbine Reference Design of Fig. 23.

5-STAGE POTASSIUM VAPOR TURBINE

Fig. 25. Reference Design Layout for the Five-Stage, Four-Bearing Potassium Vapor Turbine.

LAYOUT & DIMENSIONS OF ROTATING COMPONENTS
OF 5-STAGE POTASSIUM VAPOR TURBINE
(4 BEARING TURBINE-GENERATOR)

J.I.T.

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Fig. 26. Rotor Proportions for the Five-Stage, Four-Bearing Potassium Vapor Turbine Reference Design of Fig. 25.

Fig. 27. Reference Design Layout for the Eight-Stage, Four-Bearing Potassium Vapor Turbine.

Fig. 28. Rotor Proportions for the Eight-Stage, Four-Bearing Potassium Vapor Turbine Reference Design of Fig. 27.

Fig. 29. Reference Design Layout for the Five-Stage, Two-Bearing Potassium Vapor Turbine.

Fig. 30. Rotor Proportions for the Five-Stage, Two-Bearing Potassium Vapor Turbine Reference Design of Fig. 29.

Fig. 31. Velocity Diagrams for the Three-Stage Rotor for the Cesium Turbine of Table 22 and Fig. 19.

Fig. 32. Velocity Diagrams for the Two-Stage Rotor for the Cesium Turbine of Table 22 and Fig. 21.

Fig. 33. Velocity Diagrams for the Five-Stage Rotor for the Potassium Turbine of Table 22 and Fig. 25.

Fig. 34a. Velocity Diagrams of Stages 1, 2, 3, and 4 for the Eight-Stage Rotor for the Potassium Turbine of Table 22 and Fig. 27.

Fig. 34b. Velocity Diagrams of Stages 5, 6, and 7 for the Eight-Stage Rotor for the Potassium Turbine of Table 22 and Fig. 27.

Fig. 34c. Velocity Diagram of Stage 8 for the Eight-Stage Rotor for the Potassium Turbine of Table 22 and Fig. 27.

ORNL DWG. 68-12608

Fig. 35. Typical Row of Rotor Blades.

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Fig. 36. Typical Row of Stator Blades.

ORNL DWG. 68-12610

Fig. 37. Circumferential Projection of Stator Passage Onto a Radial Plane Through the Turbine Centerline.

Fig. 38. Radial Projection of Stator Passage Onto a Constant Radius Circular Cylinder Concentric With the Turbine Centerline.

Fig. 39. Preliminary Estimates of the Stress in a Typical Turbine Rotor as a Function of Tip Speed and of the Effects of Temperature on the Stress in TZM Alloy for a Creep Rate of 0.5% per 10,000 hr.

Fig. 40. Effects of First Stage Temperature Drop (or pressure ratio) on the Turbine Inlet Temperature Permitted by Creep Limitations in the First Stage Rotor.

From the Pythagorean Theorem:

$$R^2 + w_1^2 = c_1^2$$

$$R^2 + w_2^2 = c_2^2$$

Subtracting:

$$w_1^2 - w_2^2 = c_1^2 - c_2^2$$

$$(w_1 - w_2)(w_1 + w_2) = (c_1 - c_2)(c_1 + c_2)$$

For small differences:

$$w_1 + w_2 = 2 w_1 ; c_1 + c_2 = 2 c_1$$

Substituting:

$$(w_1 - w_2) 2 w_1 = (c_1 - c_2) 2 c_1$$

$$\therefore c_1 - c_2 = (w_1 - w_2) \frac{w_1}{c_1}$$

Fig. 41. Geometry of Conical Centering Surfaces.

ORNL DWG. 68-9401

Fig. 42. Effects of Turbine Wheel Operating Temperature on the Growth of the Wheel for 40,000 hr of Operation as Estimated by MTI. (Curve excerpted from Ref. 21)

ORNL DWG. 68-9399

Fig. 43. Bearing Layout Evolved by MTI for the Two-Bearing Turbine-Generator Reference Design Units. (Drawing excerpted from Ref. 21)

ORNL DWG. 68-9397

Fig. 44. Bearing Layout Evolved by MTI for the Four-Bearing Turbine-Generator Reference Design Units. (Drawing excerpted from Ref. 21)

Fig. 45. Sonic Velocities in Cesium and Potassium Vapor as Functions of Temperature (based on equilibrium conditions). (Data from Ref. 19)

Fig. 46. Mollier Diagram for Cesium. (Data from Ref. 19)

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