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RESEARCH MEMORANDUM

A METHOD FOR RAPID SELECTION OF DESIGN CHARACTERISTICS OF 1-, $1\frac{1}{2}$-, AND 2-STAGE TURBINES WITH OPTIMUM ANNULUS TAPER

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

February 18, 1958

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SUMMARY

A method is presented for the rapid selection of a turbine design within specified aerodynamic limits. Tables present detailed information on the over-all design parameters and velocity-diagram variables of each design. Charts prepared from the tables facilitate the evaluation of turbine diameter and exit radius ratio for a selected number of stages. The turbine annulus was tapered to yield maximum work output. Aerodynamic variables accepted as limiting in the turbine designs were: (1) turbine rotor exit axial Mach number, (2) blade-row entrance relative Mach number, and (3) zero relative velocity change across a blade row. Several examples demonstrate the use of the charts and tables.

INTRODUCTION

Some of the most important considerations in the initial phases of a turbine design are the number of turbine stages, the division of work between the stages, the aerodynamic limits to be imposed on the turbine, and the turbine diameter. A rapid, accurate method of estimating the turbine diameter for a selected number of stages and a given set of aerodynamic limits would accelerate this preliminary phase of the design and make it more definitive.

Reference 1 presents a method for rapid estimation of the aerodynamic characteristics of 1-stage and multistage turbines within specified aerodynamic limits. Reference 2 contains a similar method for 1-stage turbines with downstream stators (hereinafter called "$1\frac{1}{2}$-stage turbines"). In both analyses, annulus taper is an independent variable whose magnitude is left to the designer. Tapering the annulus is especially important at high blade speeds, because turbine work can thereby be increased as much as 85 percent. The selection of annulus taper for maximum turbine work (or, alternatively, minimum turbine diameter for a given work output) requires considerable effort, even with the assistance of references 1 and 2.

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The velocity-diagram analysis of the present report considers turbines having 1, $1\frac{1}{2}$, and 2 stages. The data of references 1 and 2 were extended in the following ways:

(1) The amount of annulus taper was selected to produce maximum work output. For simplicity, the inner wall of the tapered annulus was assumed to be conical, even though such a specification probably does not produce the greatest turbine work within the specified design limits; and the outer wall of the annulus was made cylindrical.

(2) For 2-stage turbines, deceleration in the second stator was avoided. (In ref. 1, exclusion of those turbines with deceleration in the second stator is left to the designer.)

(3) For those design problems in which turbine diameter is not specified and minimum turbine diameter is desired, charts were prepared to permit rapid determination of turbine diameter.

(4) The range of blade speed was extended to both higher and lower values.

(5) The tabulated results were expanded to present more information on the internal flow of each design.

The turbine aerodynamic variables accepted as limiting in the design were: (1) turbine rotor exit axial Mach number, (2) blade-row entrance relative Mach number, and (3) zero relative velocity change across a blade row. Both the turbine exit axial Mach number and the blade-row entrance relative Mach number were varied to yield turbines of conservative, moderate, and critical design.

DESCRIPTION OF TABLES AND CHARTS

The symbols used in this analysis are defined in appendix A. The derivations of the equations and the methods of analyzing the 1-, $1\frac{1}{2}$-, and 2-stage turbines are described in appendixes B, C, and D, respectively.

Assumptions

The following assumptions were made to simplify the analysis:

(1) There is no radial variation in stagnation state relative to the stator.

(2) Free-vortex flow conditions prevail at each axial station.

(3) Any effects of annulus wall curvature or radial components of velocity may be neglected.

(4) The losses occur as follows:

(a) In a 1-stage turbine, all losses occur in the rotor.

(b) In a $1\frac{1}{2}$-stage turbine, the losses corresponding to the polytropic efficiency all occur in the rotor; additional losses in the downstream stator are considered in the form of a stagnation-pressure loss coefficient $\bar{\omega}_m = 0.05$.

(c) In a 2-stage turbine, the entropy rise per stage is split, with one-third occurring in the stator and two-thirds in the rotor.

(5) The constant value for the ratio of specific heats γ_T is 4/3.

(6) The turbine polytropic efficiency $\eta_{p,T}$ is 0.85.

(7) The amount of exit whirl to be tolerated in turbines without downstream stators can be assigned as a percentage of the turbine work $\frac{-V_{\theta,o,m}^2}{2gJ\Delta H}$.

(8) In the $1\frac{1}{2}$-stage turbines, the downstream stator eliminates exit whirl.

(9) In the 2-stage turbines, the inner annulus wall is a single conical surface from the first-rotor inlet to the turbine exit.

The effects of assumptions (4) to (6) on the results of the analysis are described in the DISCUSSION.

Organization of Tables

Each of tables I, II, and III corresponds to a given number of stages and a particular combination of aerodynamic limits. Table IV summarizes and identifies these tables for easy reference. (In table identification, a Roman numeral corresponds to the number of stages; a letter, to the exit axial Mach number; and an Arabic numeral, to other limiting aerodynamic variables.)

Figure 1 shows the geometry of the turbines and the axial stations. Figure 2 presents typical velocity diagrams of the turbines. The tables were prepared with blade-speed parameter $\frac{U_t}{a_{a,cr,1}}$ as the independent variable and exit radius ratio $\left(\frac{r_h}{r_t}\right)_o$ as the parameter.

Construction of Charts

Charts were prepared from the tables to facilitate entry into the tables. Both the abscissa and the ordinate of the charts are dimensionless quantities that the designer can evaluate from the requirements of the turbine design. The abscissa and the ordinate were obtained from the table information in the following manner:

$$\frac{w\omega^2}{\pi\rho_{a,1}a^3_{a,cr,1}} = \hat{w}_1\left(\frac{U_t}{a_{a,cr,1}}\right)^2 \qquad (1)$$ 4575

and

$$\frac{-gJ\Delta H}{a^2_{a,cr,1}} = \left(\frac{-gJ\Delta H}{U_t^2}\right)\left(\frac{U_t}{a_{a,cr,1}}\right)^2 \qquad (2)$$

It can be seen that the abscissa of the charts $\frac{w\omega^2}{\pi\rho_{a,1}a^3_{a,cr,1}}$ has a close relation to the parameter e described in reference 3, differing only in that parameter e is expressed in terms of the compressor-inlet stagnation conditions and this parameter is expressed in terms of the turbine-inlet stagnation conditions. This parameter is useful because it relates the compressor and the turbine in a manner that is independent of actual diameter. The ordinate of the charts $\frac{-gJ\Delta H}{a^2_{a,cr,1}}$ is also expressed in terms of turbine-inlet stagnation conditions and is independent of turbine diameter.

The chart numbering system parallels that of the tables; that is, data in table I(a) are plotted in chart I(a), and so forth. Each part of charts I and II represents information corresponding to two parts of tables I and II so that both $\left(\frac{V'}{a}\right)_{2,h} \leq$ limit and $\left(\frac{V_2'}{V_3'}\right)_h \leq 1.0$ were satisfied; that is, chart I(a)1 contains data from both tables I(a)1 and I(a)3. (Neither table III nor chart III exceeds either the Mach number limit or the velocity-ratio limit.) Each chart consists of a grid of curves representing constant $\frac{U_t}{a_{a,cr,1}}$ and $\left(\frac{r_h}{r_t}\right)_o$. On charts I and II, where applicable, there is an additional curve representing those designs for which $\left(\frac{V'}{a}\right)_{2,h} =$ limit and $\left(\frac{V_2'}{V_3'}\right)_h = 1.0$ simultaneously. Along this curve, the slopes of some curves are discontinuous because the turbines change from Mach-number-limited to velocity-ratio-limited.

DISCUSSION

Annulus Taper

Figure 3 compares the attainable work parameter of high-output 1-stage turbines designed with optimum annulus taper and that attainable from turbines without taper. The maximum benefit from annulus taper is achieved at a combination of high blade speed and low radius ratio. For

4575 $\left(\frac{r_h}{r_t}\right)_3 = 0.5$ (fig. 3(a)), when $\left(\frac{V'}{a}\right)_{2,h} = 0.8$ and $\frac{U_t}{a_{a,cr,1}} = 1.0$, there is a maximum increase of 85 percent in turbine work; when $\left(\frac{V_2'}{V_3'}\right)_h = 1.0$ and $\frac{U_t}{a_{a,cr,1}} = 1.0$, there is a maximum increase of 102 percent in turbine work. In the latter case, $\left(\frac{V'}{a}\right)_{2,h} = 1.334$ (fig. 4 or table I(c)3), which exceeds the currently accepted limits; the 85-percent increase of the first example would be the more realistic of the two. Since both the preceding examples are extreme, a more typical example might be $\frac{U_t}{a_{a,cr,1}} = 0.7$ and $\left(\frac{r_h}{r_t}\right)_3 = 0.5$; in this case there is a 26-percent increase in turbine work when $\left(\frac{V'}{a}\right)_{2,h} = 0.8$ and $\left(\frac{V_2'}{V_3'}\right)_h < 1.0$.

Rotor Inlet Mach Number Limitation

Figure 3 also shows that, if rotor inlet Mach number can exceed normal limits, large amounts of work are available at high blade speeds from turbines limited by velocity ratio. Figure 4 shows the increases in rotor inlet Mach number associated with this increase in turbine work for high-output 1-stage turbines. In order to show the potential gain resulting from elimination of the limit on rotor inlet Mach number, the design information corresponding to the complete ranges of $\frac{U_t}{a_{a,cr,1}}$ and $\left(\frac{r_h}{r_t}\right)_o$ is tabulated for all 1- and $1\frac{1}{2}$-stage turbines limited by velocity ratio.

Inlet Radius Ratio

Figure 5 shows the variation of turbine work with inlet radius ratio for selected high-output 1-stage designs. Figure 6 shows this same variation for selected high-output 2-stage designs. In both figures an arrow indicates the inlet radius ratio that corresponds to the maximum turbine work and is the design value in the tables. It can be seen that, as the inlet radius ratio exceeds the value for maximum work, there can be a sudden decrease in turbine work. This is most critical at high blade speeds and high radius ratios.

A comparison of figures 5 and 6 shows that the gain in work from annulus taper is greater in a 2-stage turbine than in a 1-stage turbine. 4575
For example, when $\left(\frac{r_h}{r_t}\right)_o = 0.5$ and $\frac{U_t}{a_{a,cr,1}} = 0.6$, the increase in turbine work is 14 percent for the 1-stage turbine and 43 percent for the 2-stage turbine.

Ratio of Specific Heats γ_T

In an effort to determine the effect of changes in γ_T from the assumed value of 4/3, two 1-stage designs were re-evaluated for γ_T varying from 1.3 to 1.4. The results are shown in figure 7. For low blade speeds, there is no change in either inlet radius ratio or turbine work. At higher blade speeds, the effect is still quite small. The maximum error introduced by assuming $\gamma_T = 4/3$ over this range is 1.6 percent in turbine work and 0.6 in inlet radius ratio.

Polytropic Efficiency

In the same way, the effect of varying polytropic efficiency from the assigned value of 0.85 was investigated by varying $\eta_{p,T}$ from 0.75 to 0.90. The results are shown in figure 8. The effect of varying polytropic efficiency is greater at high blade speeds than at low blade speeds. The maximum variation in turbine work is 4.9 percent when $\frac{U_t}{a_{a,cr,1}} = 0.4$, and 10.3 percent when $\frac{U_t}{a_{a,cr,1}} = 0.8$. The maximum variation in inlet radius ratio is 2.5 percent when $\frac{U_t}{a_{a,cr,1}} = 0.4$, and 5.0 percent when $\frac{U_t}{a_{a,cr,1}} = 0.8$.

It should also be noted in figure 8 that, as the assigned value of turbine efficiency increases, the maximum turbine-work parameter decreases. This variation in turbine work is a direct result of the effect of turbine efficiency on turbine pressure ratio. Decreasing turbine efficiency raises both the pressure ratio $\frac{p_{in}}{p_o}$ and the ratio of densities $\frac{\rho_{a,in}}{\rho_{a,o}}$

across the turbine. This effect can be simply explained by considering a set of conditions different from those used in the analysis: For given values of turbine work, blade speed, and inlet and exit radius ratios, and for a given set of turbine exit conditions, the increased density ratio accompanying lower efficiency decreases the inlet axial Mach number and thereby increases the potential turbine work capacity within the specified design limits.

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Loss Assumptions

Assumption (4) in the DESCRIPTION OF TABLES AND CHARTS considers that, for 1- and $1\frac{1}{2}$-stage turbines, the losses in the first two blade rows are concentrated in the rotor, whereas for the 2-stage turbines the losses are divided between the stator and the rotor. In order to determine the effect of these differing assumptions on the final results, three 1-stage designs were computed with the loss distribution assumed for the 2-stage turbines; that is, one-third of the entropy rise occurs in the stator and two-thirds in the rotor. All three designs were high-output 1-stage turbines $\left(\left(\frac{V_z}{a}\right)_{3,m} = 0.7 \text{ and } \left(\frac{V'}{a}\right)_{2,h} = 0.8\right)$. The comparative results are shown in the following table:

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	All losses occur in rotor				One-third of losses occur in stator, two-thirds in rotor				Percent change			
		$\left(\frac{r_h}{r_t}\right)_2$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\hat{w}_1$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\hat{w}_1$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\hat{w}_1$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$
0.5	0.1	0.50	9.061	0.4191	0.5742	0.50	8.986	0.4192	0.5742	0	-0.8	0	0
.5	1.0	.840	5.405	.0530	.5495	.825	5.148	.0601	.5514	-1.8	-4.8	13.4	.4
.9	1.0	.96	2.210	.0050	.5334	.965	2.186	.0052	.5343	.5	-1.1	4.0	.2

The largest change occurs at a high blade speed and low radius ratio. Decreasing the blade speed or increasing the radius ratio causes the change in turbine work to approach 1 percent. In addition it should be noted that, of the two weight-flow parameters, the turbine-exit weight-flow parameter is much less sensitive to the loss assumptions and is consequently more reliable.

Second-Stage-Stator Velocity Limitations

In order to determine the effect of the velocity limits of the second-stage stator on design turbine work, these limits were decreased and a selected group of designs was recalculated. Figure 9 shows the comparative results. At high blade speeds the last three blade rows are all limited by Mach number. As the blade speed is decreased, the second rotor becomes limited by velocity ratio while the first rotor and second stator remain limited by Mach number. A further decrease in blade speed changes the second-stator limitation to velocity ratio, and finally at low blade speeds the last three blade rows all become limited by velocity ratio. The effect of decreasing the Mach number limit from 0.8 to 0.7 is a minor decrease in turbine work (5 percent at the maximum), but the effect of decreasing the velocity-ratio limit is a major decrease in turbine work (31 percent or more). As the blade-speed parameter was decreased to 0.2, it became impossible to compute a design for $\left(\frac{V_z}{a}\right)_{5,m} = 0.6$ and $\left(\frac{V_3}{V_4}\right)_t = 0.9$. The velocity level at the inlet to the second stator, dictated by the limit imposed, was insufficient to pass the necessary mass flow even in a straight annulus. It should be noted that at the low blade speeds, where the second stator is limited by velocity ratio, use of reference 1 will yield inappropriate results.

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Comparison of Work Available

Figure 10 compares the amount of work available in 1-, $1\frac{1}{2}$, and 2-stage turbines for selected design limitations. It is interesting to note that at extremely low blade speeds there is more work available in a $1\frac{1}{2}$-stage turbine than in a 2-stage turbine. The large work output of the $1\frac{1}{2}$-stage turbine results from the large tangential velocity at the inlet to the downstream stator. The inlet tangential velocity acceptable by this stator is independent of rotor blade speed and remains high even at low speeds.

USE OF TABLES

General

The charts facilitate entry into the tables when turbine blade speed and exit radius ratio are unknown and enable the designer to determine rapidly which of the many possible designs is most applicable to the given design problem.

The turbine design requirements will commonly consist of:

(1) Angular velocity ω, radians/sec

(2) Work per pound of gas $-\Delta H$, Btu/lb

(3) Weight flow w, lb/sec

(4) Turbine-inlet stagnation temperature T_1, °R

(5) Turbine-inlet stagnation pressure P_1, lb/sq ft

These turbine variables are not convertible to those in the tables without some selection of turbine diameter. However, they are readily expressed in terms of the chart variables, namely, $\frac{w\omega^2}{\pi\rho_{a,1}a_{a,cr,1}^3}$ and $\frac{-gJ\Delta H}{a_{a,cr,1}^2}$

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$$\rho_{a,1} = \frac{P_1}{RT_1} \tag{3}$$

and

$$a_{a,cr,1} = \sqrt{\frac{2\gamma_T}{\gamma_T + 1} gRT_1} \tag{B5}$$

With calculated values for these parameters, it is possible to enter any

CW-2 of the charts and determine $\frac{U_t}{a_{a,cr,1}}$ and $\left(\frac{r_h}{r_t}\right)_o$.

In order to help determine which of the designs is most applicable, the tip radius of the turbine may be calculated by

$$r_t = \frac{U_t}{a_{a,cr,1}} \frac{a_{a,cr,1}}{\omega} \tag{4}$$

and compared with a limiting or desired value. All designs with too large a diameter may then be discarded, and only those that are reasonable should be further investigated through use of the appropriate tables.

Interpolation in Tables

Any of the tables may be entered directly if a blade-speed parameter and exit radius ratio are known for any given set of turbine design limits. In general, linear interpolation in a given table would be adequate, and no more than one significant figure would be lost in the result. However, this is not always true, and the tabulated results should be scanned in the region of interest to determine the method of interpolation to be used. For example, the pressure ratios corresponding to a high blade-speed parameter are extremely nonlinear, and some other method of interpolation is advisable. The turbine characteristics do not vary linearly with rotor inlet Mach number; for many 1- and $1\frac{1}{2}$-stage turbines, two values of rotor inlet Mach number are provided by parts 1 and 2 of tables I and II and a third value can be obtained from part 3.

To illustrate the use of the tables, an example requiring direct interpolation is shown. A 1-stage turbine, with an exit axial Mach number $\left(\frac{V_z}{a}\right)_{3,m}$ of 0.6, a rotor inlet velocity limitation $\left(\frac{V'}{a}\right)_{2,h}$ of 0.6, an exit radius ratio $\left(\frac{r_h}{r_t}\right)_3$ of 0.63, and a blade-speed parameter $\frac{U_t}{a_{a,cr,1}}$ of 0.562 is investigated through use of the tables. Table I(b)1 is indicated. Linear interpolation is used to determine $\frac{-gJ\Delta H}{U_t^2}$, $\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$, $\left(\frac{r_h}{r_t}\right)_2$, $\frac{P_1}{P_3}$, $\left(\frac{V_2'}{V_3'}\right)_h$, and $\Delta\beta_{h,2-3}$. Interpolating with respect to $\frac{U_t}{a_{a,cr,1}}$ holding $\left(\frac{r_h}{r_t}\right)_3 = 0.6$ yields $\frac{-gJ\Delta H}{U_t^2} = 0.980$, and holding $\left(\frac{r_h}{r_t}\right)_3 = 0.7$ yields $\frac{-gJ\Delta H}{U_t^2} = 1.221$. Then, interpolating with respect to $\left(\frac{r_h}{r_t}\right)_3$ between the preceding two numbers yields the final $\frac{-gJ\Delta H}{U_t^2} = 1.052$. In a similar way $\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m} = 0.5246$, $\left(\frac{r_h}{r_t}\right)_2 = 0.663$, $\frac{P_1}{P_3} = 1.61$, $\left(\frac{V_2'}{V_3'}\right)_h = 0.780$, and $\Delta\beta_{h,2-3} = 77.7^\circ$. 4575

EXAMPLES OF USE OF CHARTS SUPPLEMENTED BY TABLES

Design Specifications and Preliminary Calculations

To illustrate the use of the charts and tables, a turbojet engine with high weight flow and high compressor pressure ratio is investigated. Four turbine designs are read from the charts: a high-output 1-stage turbine, a high-output $1\frac{1}{2}$-stage turbine, a conservative 2-stage turbine, and a moderate 2-stage turbine. The frontal area (in proportion to compressor frontal area) of each of these turbine designs is then evaluated and the most applicable ones are chosen. These are further evaluated through the use of the tables.

The turbine design requirements are specified by the following conditions:

Compressor pressure ratio, $\left(\frac{P_o}{P_{in}}\right)_C$	9.0
Compressor polytropic efficiency, $\eta_{p,C}$	0.88
Compressor equivalent weight flow, $\left(\frac{w\sqrt{\theta_{in}}}{\delta_{in}A_t}\right)_C$	35.0 (lb/sec)/sq ft
Compressor equivalent tip speed, $\left(\frac{U_t}{\sqrt{\theta_{in}}}\right)_C$	1000 ft/sec
Turbine-inlet temperature, T_1	2200° R
Compressor-inlet temperature, $T_{in,C}$	518.7° R
Compressor-inlet pressure, $P_{in,C}$	2116 lb/sq ft

The assigned quantities are:

Ratio of turbine to compressor weight flow, $(1+f)(1-b)$	1.0
Combustor pressure loss, $\left(\frac{P_o}{P_{in}}\right)_B$	0.95
Ratio of specific heats in compressor, γ_C	1.4
Ratio of specific heats in turbine, γ_T	4/3
Gas constant, R	53.4 ft-lb/(lb)(°R)

The dimensionless parameters $\frac{w\omega^2}{\pi\rho_{a,1}a_{a,cr,1}^3}$ and $\frac{-gJ\Delta H_{1-3}}{a_{a,cr,1}^2}$ are then calculated for use in entering the charts:

$$c_{p,C} = \left(\frac{\gamma_C}{\gamma_C - 1}\right)\left(\frac{R}{J}\right)$$

$$= \left(\frac{1.4}{0.4}\right)\left(\frac{53.4}{778.2}\right)$$

$$= 0.2402 \text{ Btu/(lb)(}^{\circ}\text{R)}$$

$$\Delta H_C = \left[\left(\frac{P_o}{P_{in}}\right)_C^{\frac{\gamma_C - 1}{\gamma_C \eta_{p,C}}} - 1.0\right] c_{p,C} T_{in,C}$$

$$= \left[(9.0)^{0.3247} - 1.0\right](0.2402)(518.7)$$

$$= 129.7 \text{ Btu/lb}$$

$$P_1 = P_{in,C}\left(\frac{P_o}{P_{in}}\right)_C\left(\frac{P_o}{P_{in}}\right)_B$$

$$= (2116)(9.0)(0.95)$$

$$= 18{,}092 \text{ lb/sq ft}$$

$$\rho_{a,1} = \frac{18{,}092}{(53.4)(2200)}$$

$$= 0.1540 \text{ lb/cu ft, from eq. (3)}$$

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$$a_{a,cr,1} = \sqrt{2\left(\frac{4}{7}\right)(32.17)(53.4)(2200)}$$

$$= 2078 \text{ ft/sec, from eq. (B5)}$$

$$\frac{w\omega^2}{\pi\rho_{a,1}a_{a,cr,1}^3} = \left(\frac{w\sqrt{\theta_{in}}}{\delta_{in}A_t}\right)_C(1 + f)(1 - b)\left(\frac{U_t}{\sqrt{\theta_{in}}}\right)_C^2 \frac{\delta_{in}\sqrt{\theta_{in}}}{\rho_{a,1}a_{a,cr,1}^3}$$

$$= (35.0)(1.0)(1000)^2\left(\frac{2116}{2116}\right)\sqrt{\frac{518.7}{518.7}}\left[\frac{1}{(0.1540)(2078)^3}\right]$$

$$= 0.0253$$

$$\frac{-gJ\Delta H_{1-3}}{a_{a,cr,1}^2} = \frac{(32.17)(778.2)(129.7)}{(2078)^2}$$

$$= 0.7520$$

Entry into Charts

All the following values are linearly interpolated from the charts.

Example 1. - Entry into chart I(c)1 for a 1-stage turbine with exit axial Mach number of 0.7 and rotor hub inlet Mach number limit of 0.8 yields

$$\left(\frac{U_t}{a_{a,cr,1}}\right)_T = 0.645 \quad \text{and} \quad \left(\frac{r_h}{r_t}\right)_{o,T} = 0.840$$

The location of the point on the chart indicates that the design is limited by Mach number.

Example 2. - Entry into chart II(c)1 for a $1\frac{1}{2}$-stage turbine with exit axial Mach number of 0.7 and rotor hub inlet Mach number limit of 0.8 yields

$$\left(\frac{U_t}{a_{a,cr,1}}\right)_T = 0.593 \quad \text{and} \quad \left(\frac{r_h}{r_t}\right)_{o,T} = 0.791$$

The entire range of this chart is limited by Mach number.

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Example 3. - Entry into chart III(a)1 for a 2-stage turbine with exit axial Mach number of 0.5 and rotor hub and second-stage stator hub Mach number limit of 0.6 yields

$$\left(\frac{U_t}{a_{a,cr,1}}\right)_T = 0.492 \quad \text{and} \quad \left(\frac{r_h}{r_t}\right)_{o,T} = 0.617$$

Example 4. - Entry into chart III(a)2 for a 2-stage turbine with exit axial Mach number of 0.5 and hub Mach number limit of 0.8 yields

$$\left(\frac{U_t}{a_{a,cr,1}}\right)_T = 0.459 \quad \text{and} \quad \left(\frac{r_h}{r_t}\right)_{o,T} = 0.533$$

Evaluation of Turbine Frontal Area

No limiting value for tip radius is specified in this problem, but the comparative compressor and turbine tip areas may be evaluated as follows:

$$\left(\frac{A_T}{A_C}\right)_t = \frac{\left(\frac{U_t}{a_{a,cr,1}}\right)_T^2 \left(a_{a,cr,1}\right)_T^2}{\left(\frac{U_t}{\sqrt{\theta_{in}}}\right)_C^2 \left(\frac{T_{in,C}}{518.7}\right)} \tag{5}$$

Example 1. -

$$\left(\frac{A_T}{A_C}\right)_t = \frac{(0.645)^2(2078)^2}{(1000)^2(1.0)}$$

$$= (4.318)(0.645)^2$$

$$= 1.796$$

Example 2. -

$$\left(\frac{A_T}{A_C}\right)_t = (4.318)(0.593)^2$$

$$= 1.518$$

Example 3. -

$$\left(\frac{A_T}{A_C}\right)_t = (4.318)(0.492)^2$$

$$= 1.045$$

Example 4. -

$$\left(\frac{A_T}{A_C}\right)_t = (4.318)(0.459)^2$$

$$= 0.910$$

It can be seen from the preceding results that, if the compressor is not the component which limits the engine frontal area, a conservative 2-stage turbine (example 3) will meet the requirements. However, if the turbine must be no larger than the compressor, increasing the turbine hub Mach number limit to 0.8 (example 4) will more than satisfy this requirement. Examples 3 and 4 are further investigated through the use of the tables.

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Entry into Tables

Table III yields the following results:

Example	$\left(\frac{r_h}{r_t}\right)_5$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-5}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{5,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\frac{\Delta H_{1-3}}{\Delta H_{3-5}}$	$\frac{p_1}{p_5}$	$\Delta\beta_{h,2-3}$, deg	$\alpha_{5,h}$, deg	$\left(\frac{V_2'}{V_3'}\right)_h$	$\left(\frac{V'}{a}\right)_{2,h}$	$\left(\frac{V_3}{V_4}\right)_t$	$\left(\frac{V}{a}\right)_{3,h}$	$\left(\frac{V_4'}{V_5'}\right)_h$	$\left(\frac{V'}{a}\right)_{4,h}$
3	0.617	0.492	3.107	0.4636	0.768	1.673	3.17	114.1	-19.0	0.698	0.600	0.811	0.600	0.862	0.600
4	.533	.459	3.599	.4634	.751	2.105	3.42	115.8	-20.9	.807	.800	*1.000	*.777	1.000	.678

All of the tabulated values were obtained by linear interpolation from the table except those values marked with a superscript (*). Example 4 is located in the table in a region very near the transition of the second stator from velocity-ratio-limited to Mach-number-limited, and linear interpolation would yield $\left(\frac{V_3}{V_4}\right)_t < 1.0$ and $\left(\frac{V}{a}\right)_{3,h} < 0.8$. Therefore, the surrounding points were plotted and cross-plotted, and the desired values were read from the cross plots. In each of the plots, enough points beyond the transition point were plotted to determine whether each point to be used in cross-plotting was limited by velocity ratio or by Mach number.

It can be seen from the foregoing results that examples 3 and 4 are almost alike in some respects. There is almost the same amount of turning in the first rotor (a glance will show this is the most critical blade row in this region of the table) and almost the same amount of exit whirl. There is less pressure drop across the turbine and less taper required in example 3. Therefore, if the additional 4.5 percent in frontal area could be tolerated, example 3 would provide the velocity parameters for the final design calculations. If the turbine frontal area is critical, specifying an exit axial Mach number of 0.5 with a limiting hub inlet relative Mach number of 0.7 would probably yield a turbine of sufficient capabilities and frontal area to satisfy the requirements.

CONCLUDING REMARKS

A method was devised for the rapid selection of 1-, $1\frac{1}{2}$-, and 2-stage turbine designs within specified aerodynamic limits. The turbine annulus was tapered to yield maximum work output. For given sets of turbine design limits, charts permit determination of attainable values of blade-speed parameter, exit radius ratio, and turbine diameter from turbine design data commonly specified in turbojet-engine design. For ranges of blade-speed parameter and exit radius ratio, detailed design information is tabulated.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, October 17, 1957

APPENDIX A

SYMBOLS

A	annular area, sq ft
A_t	tip frontal area, sq ft
a	sonic velocity, $\sqrt{\gamma gRt}$, ft/sec 4575
$a_{a,cr}$	critical velocity, $\sqrt{\frac{2\gamma}{\gamma+1} gRT}$, ft/sec
b	ratio of bleed air to compressor-inlet airflow
c_p	specific heat at constant pressure, Btu/(lb)(°R)
D	diffusion factor of downstream stator blades
e	parameter used in relating compressors and turbines, $\left(\frac{wU_t^2}{A_t\delta_{in}\sqrt{\theta_{in}}}\right)_C$, lb/sec^3
f	fuel-air ratio
g	acceleration due to gravity, 32.17 ft/sec^2
H	stagnation specific enthalpy, Btu/lb
J	mechanical equivalent of heat, 778.2 ft-lb/Btu
P	stagnation pressure, lb/sq ft
p	static pressure, lb/sq ft
R	gas constant, ft-lb/(lb)(°R)
r	radius, ft
S	entropy, Btu/(lb)(°R)
T	stagnation temperature, °R
t	static temperature, °R
U	blade velocity, ft/sec

[redacted]

V velocity of gas, ft/sec

w weight-flow rate of gas, lb/sec

$\hat{w}$ weight-flow parameter, $w/\rho_a a_{a,cr} A_t$

α flow angle of absolute velocity measured from axial direction (fig. 2), deg

4575 β flow angle of relative velocity measured from axial direction (fig. 2), deg

γ ratio of specific heats

δ ratio of stagnation pressure to NACA standard sea-level pressure, P/2116

η_p polytropic efficiency

θ ratio of stagnation temperature to NACA standard sea-level temperature, T/518.7

ρ gas density, lb/cu ft

σ solidity, ratio of blade chord to pitch

ω angular velocity, radians/sec

CW-3 $\bar{\omega}$ stagnation-pressure loss coefficient of downstream stator blades

Subscripts:

a stagnation condition

B combustor

C compressor

h hub radius

i ideal

in inlet

m mean radius

o exit

R rotor

S stator

T turbine

t tip radius

z axial component

θ tangential component 4575

Superscripts:

' relative to rotor

* stagnation state relative to stator, which would exist if only the axial component of velocity were considered

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CW-3 back

APPENDIX B

METHOD OF ANALYZING 1-STAGE TURBINES

The following conditions were assumed in the computations for the 1-stage turbines:

(1) Flow through the turbine is adiabatic.

(2) At any given axial station, both stagnation pressure P and stagnation temperature T are constant radially.

(3) Free-vortex flow conditions prevail at each axial station; that is,

$$\frac{\partial(rV_\theta)}{\partial r} = \frac{\partial V_z}{\partial r} = 0 \qquad \text{(B1)}$$

(4) Tip radius is constant from entrance to exit.

(5) Any effects of annulus wall curvature or radial components of velocity may be neglected.

(6) The turbine working fluid obeys the perfect-gas law; that is,

$$\frac{p}{\rho} = Rt \qquad \text{(B2)}$$

(7) At the mean radius, $\rho V_z A$ is constant from inlet to outlet.

(8) The entire loss in the turbine occurs across the rotor.

The following constants were assigned:

(1) Ratio of specific heats $\gamma_T = 4/3$

(2) Turbine polytropic efficiency $\eta_{p,T} = 0.85$

The following quantities were assigned and varied independently:

(1) Exit axial Mach number $\left(\frac{V_z}{a}\right)_{3,m}$

(2) Either rotor hub inlet Mach number $\left(\frac{V'}{a}\right)_{2,h}$ or rotor hub velocity ratio $\left(\frac{V_2'}{V_3'}\right)_h$

(3) Exit radius ratio $\left(\frac{r_h}{r_t}\right)_3$

(4) Blade-speed parameter $\frac{U_t}{a_{a,cr,1}}$

(5) Leaving loss $\frac{-V_{\theta,3,m}^2}{2gJ\Delta H_{1-3}}$ 4575

The general method of solution was as follows: Values for both inlet radius ratio $\left(\frac{r_h}{r_t}\right)_2$ and turbine-work parameter $\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$ were assumed. For each assumed value of inlet radius ratio the turbine-work parameter was varied until the computed rotor hub inlet velocity was equal to the assigned limit. This assigned limit was either in the form of Mach number $\left(\frac{V'}{a}\right)_{2,h}$, or velocity ratio $\left(\frac{V_2'}{V_3'}\right)_h$. The inlet radius ratio was repeatedly increased by some increment $\Delta\left(\frac{r_h}{r_t}\right)_2$, usually 0.005, until the value of turbine-work parameter began to decrease. The greatest value of turbine work obtained in this manner was taken to be the maximum turbine work that could be achieved by varying inlet radius ratio. See figures 1(a) and 2(a) for the axial stations and velocity diagrams, respectively.

Conservation of energy requires that

$$H_1 - H_3 = c_{p,T}(T_1 - T_3) = -\Delta H \tag{B3}$$

where

$$c_p = \frac{\gamma}{\gamma - 1}\frac{R}{J} \tag{B4}$$

Critical velocity is defined as

$$a_{a,cr} \equiv \sqrt{\frac{2\gamma}{\gamma + 1} gRT} \tag{B5}$$

Combination of equations (B3), (B4), and (B5) yields

$$\frac{T_3}{T_1} = 1 - 2\left(\frac{\gamma_T - 1}{\gamma_T + 1}\right)\left(\frac{-gJ\Delta H_{1-3}}{U_t^2}\right)\left(\frac{U_t}{a_{a,cr,1}}\right)^2 \tag{B6}$$

and

$$\left(\frac{V_\theta}{a_{a,cr}}\right)_{3,m} = -\sqrt{2\left(\frac{-V_{\theta,3,m}^2}{2gJ\Delta H_{1-3}}\right)\left(\frac{-gJ\Delta H}{U_t^2}\right)\left(\frac{U_t}{a_{a,cr,1}}\right)^2\left(\frac{T_1}{T_3}\right)} \tag{B7}$$

The definition of total state requires that

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$$\frac{t}{T} = 1 - \left(\frac{\gamma - 1}{\gamma + 1}\right)\left(\frac{V}{a_{a,cr}}\right)^2 \tag{B8}$$

As an aid in analysis, a temperature T^* was defined

$$T^* \equiv T - \frac{V_\theta^2}{2gJc_p} \tag{B9}$$

which is identical to the relation

$$T^* = t + \frac{V_z^2}{2gJc_p} \tag{B10}$$

This temperature T^* is herein called "axial stagnation temperature" because equation (B10) indicates that, if the static enthalpy is increased by the kinetic energy contained in the axial component of velocity, the temperature reached is T^*. Equations (B8), (B9), and (B10) may be combined to produce

$$\frac{T}{t} = \frac{\frac{T^*}{t}}{\frac{T^*}{T}} = \frac{1 + \left(\frac{\gamma - 1}{2}\right)\left(\frac{V_z}{a}\right)^2}{1 - \left(\frac{\gamma - 1}{\gamma + 1}\right)\left(\frac{V_\theta}{a_{a,cr}}\right)^2} \tag{B11}$$

where

$$a = \sqrt{\gamma gRt} \tag{B12}$$

Equations (B5) and (B12) may be combined to show that

$$\frac{V_z}{a_{a,cr}} = \frac{V_z}{a}\sqrt{\frac{\gamma + 1}{2}\,\frac{t}{T}} \tag{B13}$$

It is now possible to evaluate the complete velocity diagrams at the turbine exit in terms of the critical velocity $a_{a,cr,3}$.

[redacted]

From the isentropic relation

$$\frac{\rho}{\rho_a} = \left(\frac{t}{T}\right)^{\frac{1}{\gamma-1}} \tag{B14}$$

and equation (B8), the specific-mass-flow parameter can be expressed 4575

$$\frac{\rho V_z}{\rho_a a_{a,cr}} = \left\{1 - \frac{\gamma - 1}{\gamma + 1}\left[\left(\frac{V_\theta}{a_{a,cr}}\right)^2 + \left(\frac{V_z}{a_{a,cr}}\right)^2\right]\right\}^{\frac{1}{\gamma-1}} \frac{V_z}{a_{a,cr}} \tag{B15}$$

and can be evaluated at the turbine exit.

The definition of polytropic efficiency and assumption (8) result in

$$\frac{P_1}{P_3} = \left(\frac{T_1}{T_3}\right)^{\frac{\gamma_T}{\eta_{p,T}(\gamma_T-1)}} = \frac{P_2}{P_3} \tag{B16}$$

From assumption (7)

$$(\rho V_z A)_{2,m} = (\rho V_z A)_{3,m} \tag{B17}$$

where

$$A = \pi r_t^2\left[1 - \left(\frac{r_h}{r_t}\right)^2\right] \tag{B18}$$

Combination of equations (B2), (B5), (B17), and (B18) yields

$$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{2,m} = \left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m} \sqrt{\frac{T_2}{T_3}}\, \frac{P_3}{P_2}\left[\frac{1 - \left(\frac{r_h}{r_t}\right)_3^2}{1 - \left(\frac{r_h}{r_t}\right)_2^2}\right] \tag{B19}$$

Turbine work may also be expressed as

$$H_1 - H_3 = \omega\,\frac{r_2 V_{\theta,2} - r_3 V_{\theta,3}}{gJ} = -\Delta H \tag{B20}$$

Manipulating equation (B20) gives

$$\left(\frac{V_\theta}{a_{a,cr}}\right)_{2,t} = \left[\frac{-gJ\Delta H}{U_t^2} + \left(\frac{V_\theta}{U}\right)_{3,t}\right]\left(\frac{U_t}{a_{a,cr}}\right)_1 \tag{B21}$$

The complete velocity diagrams at the turbine rotor inlet can now be evaluated in terms of critical velocity $a_{a,cr,2}$.

4575 By use of equations (B5), (B8), and (B12), it is possible to write

$$\left(\frac{V'}{a}\right)_{2,h} = \left(\frac{V'}{a_{a,cr}}\right)_{2,h} \sqrt{\frac{2}{\gamma_T + 1}\left[\frac{1}{1 - \left(\frac{\gamma_T - 1}{\gamma_T + 1}\right)\left(\frac{V}{a_{a,cr}}\right)_{2,h}^2}\right]} \tag{B22}$$

From equation (B5) it is obvious that

$$\left(\frac{V_2'}{V_3'}\right)_h = \frac{\left(\frac{V'}{a_{a,cr}}\right)_{2,h}}{\left(\frac{V'}{a_{a,cr}}\right)_{3,h}\left(\frac{T_3}{T_1}\right)^{1/2}} \tag{B23}$$

The definition of inlet weight-flow parameter is

$$\hat{w}_1 \equiv \frac{w}{A_t(\rho_a a_{a,cr})_1} \tag{B24}$$

where

$$w = (\rho_1 V_{z,1} A_1)_m \tag{B25}$$

and

$$A_t = \pi r_t^2 \tag{B26}$$

The combination of equations (B18), (B24), (B25), and (B26) and the use of assumptions (4) and (8) yield

$$\hat{w}_1 = \left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{2,m}\left[1 - \left(\frac{r_h}{r_t}\right)_2^2\right] \tag{B27}$$

[redacted]

APPENDIX C

METHOD OF ANALYZING $1\frac{1}{2}$-STAGE TURBINES

The following conditions were assumed in the computations for the $1\frac{1}{2}$-stage turbines:

(1 to 7) Same as for 1-stage turbines (appendix B). 4575

(8) The entire loss in the first stage occurs in the rotor.

(9) The chord length of the downstream stator blades is constant radially.

(10) Annular area across the downstream stator is constant.

(11) The gas leaving the downstream stator has only axial velocity; that is, $V_{\theta,4} = 0$.

The following constants were assigned:

(1 and 2) Same as for 1-stage turbines (appendix B).

(3) Mean solidity of downstream stator blades $\sigma_{3,m} = 1.5$.

(4) Stagnation-pressure loss coefficient of downstream stator blades $\bar{\omega}_m = 0.05$.

(5) Hub diffusion factor of downstream stator blades $D_h = 0.4$.

The same quantities as for the 1-stage turbines were assigned and varied independently.

The general method of solution was as follows: A value for tangential Mach number at the inlet of the downstream stator $\left(\frac{V_\theta}{a}\right)_{3,m}$ was assumed. The specific-weight-flow parameter downstream of the stator was then computed from two independent relations. In one case $\bar{\omega}$ was used to determine the pressure ratio through the stator, and in the other D_h was used to determine the velocity leaving the stator. The value of $\left(\frac{V_\theta}{a}\right)_{3,m}$ was adjusted until the two methods of computing $\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m}$ gave identical results. Since these computations were independent of both inlet radius ratio and turbine work, this trial-and-error computation was solved, and then the method of solution outlined in appendix B was followed. The axial stations and velocity diagrams for $1\frac{1}{2}$-stage turbines are given in figures 1(b) and 2(b), respectively.

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From the definition of total state

$$\frac{t}{T} = \left[1 + \left(\frac{\gamma - 1}{2}\right)\left(\frac{V}{a}\right)^2\right]^{-1} \tag{C1}$$

Equations (B5), (B12), and (C1) may be combined to yield

$$\frac{a}{a_{a,cr}} = \left\{\frac{2}{\gamma + 1}\left[1 + \left(\frac{\gamma - 1}{2}\right)\left(\frac{V}{a}\right)^2\right]\right\}^{-1/2} \tag{C2}$$

CW-4

where

$$\left(\frac{V}{a}\right)^2 = \left(\frac{V_z}{a}\right)^2 + \left(\frac{V_\theta}{a}\right)^2 \tag{C3}$$

The specific-mass-flow parameter at the inlet to the downstream stator may be evaluated from equation (B15), where

$$\left(\frac{V_z}{a_{a,cr}}\right)_{3,m} = \left(\frac{V_z}{a}\right)_{3,m}\left(\frac{a}{a_{a,cr}}\right)_{3,m} \tag{C4}$$

and

$$\left(\frac{V_\theta}{a_{a,cr}}\right)_{3,m} = \left(\frac{V_\theta}{a}\right)_{3,m}\left(\frac{a}{a_{a,cr}}\right)_{3,m} \tag{C5}$$

A derivation similar to that used for equation (B19) incorporating assumption (10) yields

$$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m} = \frac{\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}}{\frac{P_4}{P_3}} \tag{C6}$$

where $\frac{P_4}{P_3}$ may be solved in equation (B5) of reference 4 as follows:

$$\frac{P_4}{P_3} = 1 - \bar{\omega}_m\left\{1 - \left[1 + \left(\frac{\gamma_T - 1}{2}\right)\left(\frac{V}{a}\right)^2_{3,m}\right]^{-\frac{\gamma_T}{\gamma_T - 1}}\right\} \tag{C7}$$

Incorporating assumption (11) into equation (13) of reference 4 yields

$$D = \left(1 - \frac{V_4}{V_3}\right) + \frac{|V_{\theta,3}|}{2\sigma V_3} \tag{C8}$$

The solution of equation (C8) for $\left(\frac{V}{a_{a,cr}}\right)_{4,h}$ is

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$$\left(\frac{V}{a_{a,cr}}\right)_{4,h} = \left(\frac{V}{a_{a,cr}}\right)_{3,h}\left[-D_h + 1 + \frac{\left|\left(\frac{V_\theta}{a_{a,cr}}\right)_{3,h}\right|}{2\sigma_h\left(\frac{V}{a_{a,cr}}\right)_{3,h}}\right] \tag{C9}$$

where from assumption (9)

$$\sigma_h = \sigma_m\left[\frac{1 + \left(\frac{r_h}{r_t}\right)_3}{2\left(\frac{r_h}{r_t}\right)_3}\right] \tag{C10}$$

By application of assumptions (3) and (11), equation (B15) may be written:

$$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m} = \left(\frac{V}{a_{a,cr}}\right)_{4,h}\left[1 - \left(\frac{\gamma_T - 1}{\gamma_T + 1}\right)\left(\frac{V}{a_{a,cr}}\right)_{4,h}^2\right]^{\frac{1}{\gamma_T - 1}} \tag{C11}$$

Equation (C6) yields the specific-weight-flow parameter from the pressure losses, and equation (C11) gives this parameter from the diffusion factor.

The use of equations (B1) through (B6) with (C4) and (C5) permits evaluation of the complete velocity diagrams at the turbine rotor exit in terms of the critical velocity $a_{a,cr,3}$.

Equations (B16) through (B27) specify the necessary information to complete the calculation.

APPENDIX D

METHOD OF ANALYZING 2-STAGE TURBINES

The following conditions were assumed in the computations for the 2-stage turbines:

(1 to 7) Same as for 1-stage turbines (appendix B).

(8) The inner annulus wall is a single conical surface from the first rotor inlet to the turbine exit.

(9) The axial lengths of the last three blade rows are equal.

(10) One-third of the over-all stage loss occurs in the stator blade row and two-thirds in the rotor blade row.

(11) The velocity ratio across the hub of each rotor blade row is never greater than 1.0.

The following constants were assigned:

(1) Ratio of specific heats $\gamma_T = 4/3$

(2) Turbine stage polytropic efficiency
$\eta_{p,T,1-3} = \eta_{p,T,3-5} = \eta_{p,T,1-5} = 0.85$

The following quantities were assigned and varied independently:

(1) Exit axial Mach number $\left(\frac{V_z}{a}\right)_{5,m}$

(2) Rotor hub inlet limiting Mach number $\left(\frac{V'}{a}\right)_{2,h}^{limit} = \left(\frac{V'}{a}\right)_{4,h}^{limit}$

(3) Second-stage stator hub inlet limiting Mach number $\left(\frac{V}{a}\right)_{3,h}^{limit}$

(4) Limiting velocity ratio across tip of second-stage stator
$\left(\frac{V_3}{V_4}\right)_t^{limit}$

(5) Exit radius ratio $\left(\frac{r_h}{r_t}\right)_5$

(6) Blade-speed parameter $\left(\frac{U_t}{a_{a,cr}}\right)_1$

(7) Leaving loss $\frac{-V_{\theta,5,m}^2}{2gJ\Delta H_{1-5}}$

[redacted]

The general method of solution was as follows: Values for inlet radius ratio $\left(\frac{r_h}{r_t}\right)_2$, turbine-work parameter $\frac{-gJ\Delta H_{1-5}}{U_{h,5}^2}$, and turbine second-stage work ratio $\frac{\Delta H_{3-5}}{\Delta H_{1-5}}$ were assumed. For each assumption of inlet radius ratio and work parameter, the second-stage work ratio was varied until the second-stage rotor hub inlet velocity satisfied the assigned limits. These assigned limits were: either the rotor hub velocity ratio $\left(\frac{V_4'}{V_5'}\right)_h = 1.0$ and the rotor hub inlet Mach number $\left(\frac{V'}{a}\right)_{4,h} \leq$ assigned value, or $\left(\frac{V_4'}{V_5'}\right)_h \leq 1.0$ and $\left(\frac{V'}{a}\right)_{4,h}$ = assigned value. 4575

A similar restriction was put on the velocity into the second-stage stator. The velocity ratio at the tip $\left(\frac{V_3}{V_4}\right)_t$ was assigned, and the hub inlet Mach number $\left(\frac{V}{a}\right)_{3,h}$ was evaluated. If this Mach number exceeded its assigned limit, then $\left(\frac{V}{a}\right)_{3,h}$ was set equal to its assigned limit and the tip velocity ratio $\left(\frac{V_3}{V_4}\right)_t$ was computed.

While the inlet radius ratio was held constant, the turbine-work parameter was varied (with the iteration just described being carried out for each trial value) until the first-stage rotor hub inlet velocity satisfied the assigned limits. These assigned limits were identical to those for the second-stage rotor; that is, either $\left(\frac{V_2'}{V_3'}\right)_h = 1.0$ and $\left(\frac{V'}{a}\right)_{2,h} \leq$ assigned value, or $\left(\frac{V_2'}{V_3'}\right)_h \leq 1.0$ and $\left(\frac{V'}{a}\right)_{2,h}$ = assigned value.

The inlet radius ratio was successively increased by an arbitrary increment, $\Delta\left(\frac{r_h}{r_t}\right)_2 = 0.005$, until the value of over-all turbine-work parameter began to decrease. The greatest value of turbine work obtained in this manner was taken to be the maximum turbine work that could be achieved by varying inlet radius ratio.

Figure 1(c) shows the assumed 2-stage turbine geometry and axial stations, and figure 2(c) shows the velocity diagrams.

Equations (B3) through (B15) permit evaluation of the velocity diagrams, in terms of the critical velocity, and the specific-mass-flow parameter at the turbine exit by rewriting the equations to apply to overall turbine conditions where necessary. For example, equation (B6) would become:

$$\frac{T_5}{T_1} = 1 - 2\left(\frac{\gamma_T - 1}{\gamma_T + 1}\right)\left(\frac{-gJ\Delta H_{1-5}}{U_t^2}\right)\left(\frac{U_t}{a_{a,cr,1}}\right)^2 \tag{D1}$$

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Equations (B3) to (B5) combine to become

$$\frac{T_3}{T_5} = 1 + \frac{2(\gamma_T - 1)}{\gamma_T + 1}\left(\frac{-gJ\Delta H_{1-5}}{U_t^2}\right)\left(\frac{\Delta H_{3-5}}{\Delta H_{1-5}}\right)\left(\frac{U_t}{a_{a,cr,1}}\right)^2\left(\frac{T_1}{T_5}\right) \tag{D2}$$

and thus all necessary temperature ratios are defined.

If the expansion across the second turbine stage were isentropic with the gases expanding from some inlet pressure P_3 to some ideal exit pressure $P_{5,i}$, this expansion could be expressed

$$\frac{P_3}{P_{5,i}} = \left(\frac{T_3}{T_5}\right)^{\frac{\gamma_T}{\gamma_T - 1}} \tag{D3}$$

However, from the definition of polytropic efficiency the actual expansion is expressed

$$\frac{P_3}{P_5} = \left(\frac{T_3}{T_5}\right)^{\frac{\gamma_T}{\eta_{p,T,3-5}(\gamma_T - 1)}} \tag{D4}$$

The losses ΔS that occur during the actual expansion may be expressed in terms of the ideal and actual pressures as

$$\Delta S_{3-5} = \frac{R}{J}\ln\left(\frac{P_5}{P_{5,i}}\right) \tag{D5}$$

From assumption (10)

$$\frac{1}{3}\Delta S_{3-5} = \frac{1}{3}\frac{R}{J}\ln\left(\frac{P_5}{P_{5,i}}\right) = \Delta S_{3-4} = \frac{R}{J}\ln\left(\frac{P_4}{P_3}\right) \tag{D6}$$

Solution of equation (D6) for stator pressure ratio yields

$$\frac{P_4}{P_3} = \left(\frac{P_5}{P_{5,i}}\right)^{1/3} \tag{D7}$$

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Equations (D2), (D4), (D7), and equations (B15) to (B21) permit evaluation of complete velocity diagrams at the second-stage rotor inlet in terms of the critical velocity $a_{a,cr,4}$, where

$$\frac{-gJ\Delta H_{3-5}}{U_t^2} = \frac{-gJ\Delta H_{1-5}}{U_t^2}\,\frac{\Delta H_{3-5}}{\Delta H_{1-5}} \tag{D8}$$

and evaluation of the specific-mass-flow parameter, where

$$\left(\frac{r_h}{r_t}\right)_4 = \frac{1}{3}\left(\frac{r_h}{r_t}\right)_2 + \frac{2}{3}\left(\frac{r_h}{r_t}\right)_5 \tag{D9}$$

from assumptions (8) and (9).

Equations (B22) and (B23) define the second-stage rotor hub inlet velocity in terms of the specified limits $\left(\frac{V'}{a}\right)_{4,h}$ and $\left(\frac{V_4'}{V_5'}\right)_h$.

A derivation similar to that for (B19) yields

$$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m} = \left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m}\left(\frac{P_4}{P_3}\right)\left[\frac{1 - \left(\frac{r_h}{r_t}\right)_4^2}{1 - \left(\frac{r_h}{r_t}\right)_3^2}\right] \tag{D10}$$

where

$$\left(\frac{r_h}{r_t}\right)_3 = \frac{2}{3}\left(\frac{r_h}{r_t}\right)_2 + \frac{1}{3}\left(\frac{r_h}{r_t}\right)_5 \tag{D11}$$

from assumptions (8) and (9).

From assumption (3) and the velocity diagrams

$$\left(\frac{V_\theta}{a_{a,cr}}\right)_{3,m}^2 = \left(\frac{r_t}{r_m}\right)_3^2\left[\left(\frac{V_3}{V_4}\right)_t^2\left(\frac{V}{a_{a,cr}}\right)_{4,t}^2 - \left(\frac{V_z}{a_{a,cr}}\right)_{3,m}^2\right] \tag{D12}$$

where

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$$\frac{r_t}{r_m} = \frac{2.0}{1.0 + \frac{r_h}{r_t}} \tag{D13}$$

and $\left(\frac{V_3}{V_4}\right)_t$ has been assigned. Substitution of (D12) in (B15) yields

$$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m} = \left(\frac{V_z}{a_{a,cr}}\right)_{3,m}\left(1 - \frac{\gamma_T - 1}{\gamma_T + 1}\left\{\left(\frac{V_z}{a_{a,cr}}\right)_{3,m}^2\left[1 - \left(\frac{r_t}{r_m}\right)_3^2\right] + \left(\frac{V_3}{V_4}\right)_t^2\left(\frac{r_t}{r_m}\right)_3^2\left(\frac{V}{a_{a,cr}}\right)_{4,t}^2\right\}\right)^{\frac{1}{\gamma_T - 1}} \tag{D14}$$

From equation (D14) $\left(\frac{V_z}{a_{a,cr}}\right)_{3,m}$ may be evaluated and then $\left(\frac{V_\theta}{a_{a,cr}}\right)_{3,m}$ may be evaluated from equation (D12).

A derivation similar to (B22) yields

$$\left(\frac{V}{a}\right)_{3,h} = \left(\frac{V}{a_{a,cr}}\right)_{3,h}\sqrt{\frac{2}{\gamma_T + 1}\left[\frac{1}{1 - \left(\frac{\gamma_T - 1}{\gamma_T + 1}\right)\left(\frac{V}{a_{a,cr}}\right)_{3,h}^2}\right]} \tag{D15}$$

If the result of equation (D15) exceeds the assigned limit, $\left(\frac{V}{a}\right)_{3,h}$ is set equal to the limit, and from equation (C1)

$$\left(\frac{V}{a_{a,cr}}\right)_{3,h} = \left(\frac{V}{a}\right)_{3,h}\sqrt{\frac{\gamma_T + 1}{2}\left[\frac{1}{1 + \left(\frac{\gamma_T - 1}{2}\right)\left(\frac{V}{a}\right)_{3,h}^2}\right]} \tag{D16}$$

From assumption (3) and the velocity diagrams

$$\left(\frac{V_\theta}{a_{a,cr}}\right)_{3,m}^2 = \left(\frac{r_h}{r_m}\right)_3^2\left[\left(\frac{V}{a_{a,cr}}\right)_{3,h}^2 - \left(\frac{V_z}{a_{a,cr}}\right)_{3,m}^2\right] \tag{D17}$$

where

$$\frac{r_h}{r_m} = \frac{2\frac{r_h}{r_t}}{1 + \frac{r_h}{r_t}} \tag{D18}$$

Substitution of equation (D17) in (B15) yields

$$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m} = \left(\frac{V_z}{a_{a,cr}}\right)_{3,m}\left(1 - \frac{\gamma_T - 1}{\gamma_T + 1}\left\{\left(\frac{V_z}{a_{a,cr}}\right)^2_{3,m}\left[1 - \left(\frac{r_h}{r_m}\right)^2_3\right] + \left(\frac{r_h}{r_m}\right)^2_3\left(\frac{V}{a_{a,cr}}\right)^2_{3,h}\right\}\right)^{\frac{1}{\gamma_T - 1}} \tag{D19}$$

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Again $\left(\frac{V_z}{a_{a,cr}}\right)_{3,m}$ may be evaluated from equation (D19) and then $\left(\frac{V_\theta}{a_{a,cr}}\right)_{3,m}$ may be evaluated from equation (D17). Velocity diagrams and assumption (3) permit evaluation of $\left(\frac{V}{a_{a,cr}}\right)_{3,t}$ and then

$$\left(\frac{V_3}{V_4}\right)_t = \frac{\left(\frac{V}{a_{a,cr}}\right)_{3,t}}{\left(\frac{V}{a_{a,cr}}\right)_{4,t}} \tag{D20}$$

It is now possible to evaluate the complete velocity diagrams at the first rotor exit in terms of the critical velocity $a_{a,cr,3}$.

By repeating the procedure outlined for the second-stage rotor, the specific-mass-flow parameter, the velocity diagrams at the inlet to the first-stage rotor in terms of the critical velocity $a_{a,cr,2}$, and the first-stage rotor hub inlet velocity in terms of the specified limits $\left(\frac{V'}{a}\right)_{2,h}$ and $\left(\frac{V'_2}{V'_3}\right)_h$ may be evaluated.

A derivation similar to that for equation (B27) yields

$$\hat{w}_1 = \left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{2,m}\left(\frac{P_2}{P_1}\right)\left[1 - \left(\frac{r_h}{r_t}\right)^2_2\right] \tag{D21}$$

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TABLE I. - 1-STAGE TURBINES

(a) $\left(\frac{V_z}{a}\right)_{3,m} = 0.5$

1. $\left(\frac{V'}{a}\right)_{2,h} = 0.6;\ \left(\frac{V_2'}{V_3'}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{p_1}{p_3}$	$\hat{w}_1$	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$
0.5	0.50	0.850	0.4671	0.585	0.486	3.400	1.34	0.2692	0.995	68.8	-10.8
	.60	.852	.4666	.625	.484	3.407	1.54	.2380	.932	74.3	-13.1
	.70	.883	.4659	.670	.480	3.531	1.86	.2007	.868	80.0	-15.7
	.80	.938	.4648	.720	.473	3.753	2.42	.1580	.803	85.8	-18.9
	.90	1.015	.4631	.770	.454	4.059	3.52	.1127	.737	93.4	-22.6
	1.00	1.108	.4606	.825	.432	4.432	6.00	.0697	.672	101.3	-27.1
0.6	0.50	1.041	0.4668	0.655	0.465	2.891	1.44	0.2160	0.951	76.1	-10.7
	.60	1.024	.4662	.690	.462	2.844	1.69	.1869	.881	81.8	-12.9
	.70	1.038	.4654	.725	.452	2.884	2.09	.1539	.811	88.4	-15.4
	.80	1.077	.4642	.770	.448	2.992	2.81	.1181	.744	93.6	-18.3
	.90	1.135	.4623	.815	.436	3.152	4.19	.0822	.678	99.8	-21.7
	1.00	1.207	.4596	.860	.414	3.352	7.31	.0497	.615	107.3	-25.9
0.7	0.40	1.360	0.4671	0.700	0.435	2.775	1.35	0.1819	0.983	77.8	- 8.9
	.50	1.263	.4665	.725	.433	2.577	1.56	.1599	.905	84.4	-10.8
	.60	1.220	.4658	.755	.432	2.490	1.88	.1352	.829	90.2	-13.0
	.70	1.213	.4648	.785	.423	2.475	2.40	.1084	.755	96.4	-15.4
	.80	1.229	.4634	.820	.416	2.509	3.31	.0810	.687	101.9	-18.1
	.90	1.264	.4614	.855	.400	2.580	5.10	.0549	.622	108.2	-21.4
	1.00	1.311	.4584	.890	.374	2.676	9.10	.0325	.561	115.5	-25.2
0.8	0.40	1.642	0.4668	0.800	0.433	2.566	1.44	0.1211	0.945	81.5	- 9.1
	.50	1.523	.4662	.800	.392	2.380	1.72	.1034	.859	93.5	-11.1
	.60	1.447	.4653	.820	.384	2.260	2.13	.0851	.777	100.1	-13.2
	.70	1.409	.4641	.845	.380	2.202	2.81	.0663	.702	105.6	-15.6
	.80	1.398	.4626	.870	.369	2.184	4.01	.0481	.633	111.4	-18.3
	.90	1.404	.4603	.895	.349	2.193	6.35	.0318	.570	117.7	-21.4
	1.00	1.421	.4571	.920	.321	2.220	11.60	.0184	.512	124.7	-25.0
0.9	0.40	1.944	0.4666	0.900	0.432	2.400	1.55	0.0599	0.908	84.9	- 9.4
	.50	1.813	.4657	.900	.387	2.238	1.92	.0494	.813	97.6	-11.5
	.60	1.716	.4647	.900	.337	2.119	2.49	.0390	.727	109.3	-13.7
	.70	1.640	.4633	.910	.315	2.025	3.41	.0294	.650	116.6	-16.1
	.80	1.590	.4615	.925	.304	1.963	5.04	.0207	.582	122.1	-18.7
	.90	1.560	.4590	.940	.286	1.926	8.23	.0133	.522	127.8	-21.7
	1.00	1.541	.4554	.955	.263	1.903	15.37	.0075	.468	133.7	-25.2

2. $\left(\frac{V'}{a}\right)_{2,h} = 0.8;\ \left(\frac{V_2'}{V_3'}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{p_1}{p_3}$	$\hat{w}_1$	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$
0.5	0.90	1.271	0.4614	0.815	0.533	5.082	5.15	0.0800	0.925	102.9	-25.9
	1.00	1.338	.4581	.860	.492	5.353	9.65	.0453	.839	111.6	-30.6
0.6	0.80	1.340	0.4629	0.805	0.522	3.721	3.75	0.0909	0.941	102.8	-20.8
	.90	1.373	.4606	.845	.501	3.813	6.04	.0591	.854	109.3	-24.5
	1.00	1.420	.4571	.885	.467	3.945	11.58	.0328	.771	116.9	-28.9
0.7	0.70	1.488	0.4639	0.810	0.490	3.036	3.00	0.0886	0.961	104.6	-17.3
	.80	1.476	.4621	.845	.486	3.011	4.39	.0628	.870	109.6	-20.3
	.90	1.485	.4596	.875	.454	3.030	7.25	.0399	.785	116.8	-23.8
	1.00	1.508	.4559	.910	.431	3.078	14.20	.0217	.706	123.0	-27.9
0.8	0.60	1.747	0.4646	0.840	0.458	2.729	2.54	0.0727	0.994	106.0	-14.8
	.70	1.671	.4632	.860	.439	2.610	3.50	.0544	.894	112.6	-17.3
	.80	1.629	.4612	.885	.427	2.545	5.28	.0375	.804	118.1	-20.2
	.90	1.609	.4585	.910	.406	2.514	8.96	.0233	.721	123.9	-23.5
	1.00	1.604	.4544	.935	.378	2.506	17.89	.0124	.646	130.1	-27.5
0.9	0.60	2.011	0.4639	0.900	0.363	2.483	2.98	0.0333	0.930	117.3	-15.1
	.70	1.890	.4623	.915	.355	2.333	4.25	.0241	.830	122.9	-17.6
	.80	1.808	.4601	.930	.339	2.232	6.61	.0162	.740	128.4	-20.4
	.90	1.750	.4571	.945	.316	2.161	11.51	.0098	.661	134.0	-23.6
	1.00	1.709	.4527	.960	.287	2.110	23.41	.0051	.591	139.7	-27.4

TABLE I. - Continued. 1-STAGE TURBINES

(a) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.5$

3. $\left(\frac{V_2}{V_3'}\right)_h = 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{P_1}{P_3}$	ϕ_1	$\left(\frac{V'}{a}\right)_{2,h}$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$
0.5	0.20	0.800	0.4680	0.500	0.485	3.198	1.04	0.3378	0.517	34.2	-4.1
	.30	.794	.4678	.500	.468	3.177	1.10	.3217	.538	50.2	-6.2
	.40	.802	.4675	.535	.473	3.206	1.19	.2998	.566	60.3	-8.3
	.50	.858	.4671	.590	.491	3.431	1.35	.2686	.604	68.4	-10.9
	.60	.950	.4664	.645	.507	3.799	1.62	.2271	.652	77.7	-13.9
	.70	1.067	.4653	.705	.526	4.270	2.14	.1767	.712	86.7	-17.5
	.80	1.205	.4635	.765	.544	4.821	3.23	.1221	.788	96.1	-21.8
	.90	1.358	.4607	.820	.547	5.434	5.91	.0707	.887	107.3	-27.0
	1.00	1.523	.4557	.875	.543	6.091	14.70	.0309	1.021	119.0	-33.5
0.6	0.20	1.085	0.4680	0.600	0.484	3.014	1.06	0.2848	0.522	38.5	-4.3
	.30	1.078	.4677	.600	.464	2.996	1.14	.2660	.550	56.2	-6.4
	.40	1.074	.4673	.615	.454	2.983	1.27	.2421	.587	70.0	-8.6
	.50	1.114	.4667	.665	.479	3.093	1.48	.2108	.635	78.2	-11.1
	.60	1.190	.4659	.715	.504	3.306	1.85	.1722	.696	86.6	-14.0
	.70	1.292	.4646	.760	.518	3.588	2.56	.1286	.771	96.4	-17.4
	.80	1.410	.4625	.810	.542	3.916	4.07	.0845	.865	105.2	-21.5
	.90	1.541	.4591	.855	.548	4.280	7.97	.0460	.986	115.4	-26.6
	1.00	1.682	.4532	.900	.546	4.672	21.82	.0185	1.151	126.3	-32.8
0.7	0.20	1.406	0.4679	0.700	0.483	2.869	1.08	0.2230	0.529	42.4	-4.4
	.30	1.398	.4675	.700	.463	2.854	1.19	.2045	.564	61.6	-6.7
	.40	1.389	.4670	.700	.436	2.834	1.36	.1808	.612	78.9	-9.0
	.50	1.408	.4663	.735	.455	2.862	1.64	.1526	.672	88.5	-11.5
	.60	1.456	.4653	.775	.481	2.972	2.15	.1200	.747	97.0	-14.3
	.70	1.534	.4637	.815	.510	3.131	3.12	.0855	.840	105.2	-17.6
	.80	1.628	.4612	.850	.523	3.323	5.28	.0532	.956	114.6	-21.6
	.90	1.734	.4573	.890	.557	3.538	11.17	.0270	1.105	122.5	-26.5
	1.00	1.849	.4501	.925	.561	3.774	34.35	.0097	1.314	132.6	-32.9
0.8	0.20	1.759	0.4678	0.800	0.484	2.749	1.10	0.1547	0.536	46.2	-4.6
	.30	1.752	.4674	.800	.465	2.738	1.24	.1387	.580	66.6	-7.0
	.40	1.742	.4667	.800	.438	2.723	1.48	.1186	.639	84.6	-9.4
	.50	1.733	.4658	.810	.427	2.708	1.86	.0962	.714	98.1	-11.9
	.60	1.758	.4646	.840	.459	2.742	2.55	.0724	.806	106.2	-14.8
	.70	1.802	.4627	.865	.477	2.816	3.93	.0490	.919	115.1	-18.1
	.80	1.865	.4597	.895	.518	2.914	7.12	.0286	1.062	122.1	-22.1
	.90	1.940	.4549	.920	.535	3.032	16.53	.0134	1.250	130.8	-27.0
	1.00	2.025	.4460	.945	.539	3.164	58.34	.0042	1.521	140.1	-33.6
0.9	0.20	2.145	0.4677	0.900	0.486	2.649	1.12	0.0801	0.544	49.6	-4.8
	.30	2.139	.4672	.900	.469	2.640	1.30	.0700	.597	71.0	-7.3
	.40	2.130	.4664	.900	.445	2.629	1.62	.0576	.669	89.6	-9.8
	.50	2.119	.4652	.900	.415	2.616	2.16	.0443	.761	105.3	-12.6
	.60	2.107	.4636	.905	.398	2.601	3.16	.0315	.873	117.5	-15.5
	.70	2.112	.4613	.920	.420	2.607	5.20	.0201	1.012	125.4	-18.9
	.80	2.135	.4577	.935	.443	2.636	10.27	.0109	1.190	132.9	-23.0
	.90	2.170	.4518	.950	.462	2.679	26.65	.0046	1.431	140.4	-28.0
	1.00	2.215	.4405	.965	.470	2.734	111.52	.0012	1.792	148.5	-34.9

TABLE I. - Continued. 1-STAGE TURBINES

(b) $\left(\frac{V_x}{a}\right)_{3,m} = 0.6$

1. $\left(\frac{V'}{a}\right)_{2,h} = 0.6;\ \left(\frac{V'_2}{V'_3}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_x}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_x}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{P_1}{P_3}$	ϕ_1	$\left(\frac{V'_2}{V'_3}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$
0.5	0.10	0.800	0.5284	0.500	0.594	3.200	1.01	0.3926	0.993	14.6	-2.4
	.15	.798	.5283	.500	.587	3.190	1.02	.3878	.984	21.8	-3.7
	.20	.791	.5282	.500	.577	3.166	1.04	.3813	.973	28.8	-4.9
	.30	.776	.5278	.500	.551	3.105	1.10	.3637	.948	42.4	-7.3
	.40	.757	.5272	.500	.519	3.089	1.18	.3410	.903	55.2	-9.6
	.50	.747	.5264	.530	.507	2.989	1.29	.3135	.859	62.7	-12.0
	.60	.773	.5253	.575	.501	3.092	1.48	.2781	.810	69.1	-14.7
	.70	.830	.5237	.630	.494	3.318	1.79	.2337	.758	75.3	-17.9
	.80	.914	.5211	.690	.482	3.654	2.36	.1812	.702	82.4	-21.0
	.90	1.022	.5171	.755	.463	4.085	3.56	.1247	.645	90.5	-26.5
	1.00	1.148	.5107	.825	.443	4.593	6.49	.0719	.587	98.9	-32.0
0.6	0.10	1.064	0.5284	0.600	0.593	2.955	1.01	0.3339	0.991	16.1	-2.5
	.15	1.058	.5283	.600	.585	2.938	1.03	.3286	.980	24.1	-3.8
	.20	1.050	.5281	.600	.574	2.917	1.06	.3213	.965	31.8	-5.0
	.30	1.029	.5275	.600	.544	2.858	1.13	.3016	.926	46.8	-7.4
	.40	1.003	.5267	.600	.507	2.786	1.25	.2768	.878	60.7	-9.9
	.50	.977	.5257	.615	.480	2.713	1.41	.2483	.826	71.0	-12.3
	.60	.982	.5244	.655	.475	2.727	1.65	.2145	.771	77.4	-14.9
	.70	1.019	.5224	.700	.465	2.831	2.06	.1750	.715	83.9	-17.9
	.80	1.082	.5194	.750	.452	3.007	2.82	.1315	.658	90.9	-21.5
	.90	1.166	.5150	.805	.437	3.239	4.39	.0878	.601	98.0	-25.8
	1.00	1.264	.5079	.860	.418	3.510	8.23	.0494	.546	106.4	-30.9
0.7	0.10	1.348	0.5284	0.700	0.592	2.759	1.02	0.2652	0.989	17.5	-2.6
	.15	1.341	.5282	.700	.584	2.736	1.04	.2598	.975	26.1	-3.9
	.20	1.331	.5279	.700	.572	2.717	1.07	.2525	.957	34.5	-5.1
	.30	1.305	.5272	.700	.539	2.664	1.17	.2330	.909	50.7	-7.7
	.40	1.272	.5262	.700	.497	2.596	1.33	.2086	.852	65.7	-10.2
	.50	1.235	.5249	.700	.449	2.520	1.54	.1816	.792	79.4	-12.7
	.60	1.212	.5233	.730	.438	2.474	1.87	.1585	.732	86.6	-15.3
	.70	1.224	.5209	.770	.434	2.497	2.48	.1206	.672	92.3	-18.2
	.80	1.260	.5175	.810	.421	2.578	3.43	.0877	.614	98.9	-21.6
	.90	1.315	.5125	.850	.398	2.683	5.58	.0560	.558	106.7	-25.6
	1.00	1.380	.5048	.895	.379	2.817	10.60	.0312	.505	113.6	-30.4
0.8	0.10	1.653	0.5283	0.800	0.592	2.583	1.02	0.1865	0.986	18.8	-2.6
	.15	1.645	.5281	.800	.583	2.570	1.05	.1819	.969	28.0	-4.0
	.20	1.633	.5278	.800	.570	2.552	1.09	.1756	.947	37.0	-5.3
	.30	1.603	.5269	.800	.535	2.504	1.22	.1590	.891	54.8	-7.9
	.40	1.563	.5257	.800	.490	2.443	1.42	.1386	.825	70.1	-10.5
	.50	1.518	.5240	.800	.437	2.372	1.72	.1165	.757	84.7	-13.1
	.60	1.470	.5219	.805	.389	2.297	2.16	.0943	.692	96.8	-15.8
	.70	1.447	.5192	.835	.384	2.261	2.90	.0721	.630	102.6	-18.7
	.80	1.450	.5153	.865	.372	2.266	4.26	.0508	.571	108.8	-22.0
	.90	1.470	.5097	.895	.351	2.297	7.08	.0319	.517	115.7	-25.8
	1.00	1.500	.5013	.925	.323	2.344	13.93	.0171	.466	123.1	-30.3
0.9	0.10	1.978	0.5283	0.900	0.592	2.442	1.03	0.0980	0.983	20.0	-2.7
	.15	1.969	.5280	.900	.582	2.430	1.06	.0951	.963	29.7	-4.1
	.20	1.956	.5277	.900	.569	2.415	1.11	.0918	.937	39.3	-5.4
	.30	1.921	.5266	.900	.532	2.372	1.27	.0809	.872	57.4	-8.1
	.40	1.876	.5250	.900	.484	2.316	1.52	.0684	.798	74.2	-10.9
	.50	1.823	.5230	.900	.427	2.250	1.93	.0583	.723	89.5	-13.7
	.60	1.764	.5204	.900	.365	2.178	2.57	.0496	.653	103.4	-16.5
	.70	1.703	.5170	.905	.316	2.103	3.60	.0312	.588	114.2	-19.4
	.80	1.661	.5125	.925	.311	2.051	5.49	.0212	.531	119.2	-22.6
	.90	1.638	.5063	.940	.281	2.022	9.42	.0130	.478	126.7	-26.3
	1.00	1.625	.4971	.960	.272	2.006	18.86	.0068	.430	131.4	-30.5

TABLE I. - Continued. 1-STAGE TURBINES

(b) Continued. $\left(\frac{V_z}{a}\right)_{3,m} = 0.6$

2. $\left(\frac{V'}{a}\right)_{2,h} = 0.8$; $\left(\frac{V'_2}{V'_3}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{p_1}{p_3}$	$\hat{W}_1$	$\left(\frac{V'_2}{V'_3}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$
0.5	0.70	1.167	0.5213	0.695	0.572	4.666	2.31	0.1848	0.953	87.7	-21.5
	.80	1.223	.5179	.750	.559	4.893	3.29	.1340	.879	94.2	-25.6
	.90	1.303	.5127	.805	.530	5.212	5.41	.0850	.804	102.3	-30.5
	1.00	1.397	.5043	.865	.503	5.590	11.00	.0444	.728	110.2	-36.2
0.6	0.60	1.326	0.5227	0.705	0.556	3.685	1.99	0.1806	0.981	87.5	-17.5
	.70	1.331	.5201	.750	.550	3.697	2.64	.1399	.905	93.3	-20.8
	.80	1.366	.5163	.795	.532	3.794	3.87	.0987	.829	100.2	-24.6
	.90	1.422	.5106	.840	.498	3.950	6.54	.0610	.754	108.3	-29.2
	1.00	1.491	.5016	.890	.469	4.142	13.63	.0311	.681	116.0	-34.5
0.7	0.60	1.539	0.5216	0.765	0.516	3.141	2.25	0.1289	0.933	94.8	-17.4
	.70	1.515	.5186	.800	.504	3.091	3.07	.0971	.853	101.2	-20.6
	.80	1.521	.5144	.840	.494	3.105	4.64	.0666	.776	107.0	-24.8
	.90	1.549	.5081	.875	.456	3.162	8.08	.0401	.703	115.2	-28.5
	1.00	1.589	.4984	.915	.427	3.242	17.24	.0200	.633	122.3	-33.6
0.8	0.50	1.896	0.5227	0.805	0.476	2.963	1.98	0.1021	0.970	96.2	-14.8
	.60	1.782	.5203	.830	.468	2.785	2.59	.0799	.883	102.6	-17.6
	.70	1.721	.5169	.855	.451	2.689	3.66	.0584	.801	109.4	-20.7
	.80	1.692	.5121	.885	.440	2.644	5.71	.0389	.724	115.1	-24.2
	.90	1.685	.5052	.910	.398	2.633	10.24	.0227	.652	123.0	-28.3
	1.00	1.691	.4947	.940	.373	2.641	22.30	.0111	.586	129.4	-33.1
0.9	0.50	2.223	0.5216	0.900	0.464	2.745	2.26	0.0479	0.926	100.6	-15.3
	.60	2.075	.5185	.900	.390	2.561	3.09	.0359	.833	112.7	-18.1
	.70	1.962	.5146	.915	.371	2.422	4.53	.0253	.750	119.4	-21.2
	.80	1.886	.5093	.930	.342	2.329	7.32	.0163	.673	126.2	-24.6
	.90	1.836	.5017	.950	.333	2.266	13.50	.0093	.605	131.1	-28.5
	1.00	1.799	.4904	.965	.290	2.221	29.86	.0045	.542	138.3	-33.1

TABLE I. - Continued. 1-STAGE TURBINES

(b) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.6$

3. $\left(\frac{V_2'}{V_3'}\right)_h = 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{p_1}{p_3}$	θ_1	$\left(\frac{V'}{a}\right)_{2,h}$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$
0.5	0.10	0.968	0.5284	0.500	0.594	3.873	1.01	0.3918	0.605	17.6	-2.7
	.15	.965	.5283	.500	.587	3.859	1.03	.3860	.611	26.2	-4.0
	.20	.961	.5281	.500	.577	3.843	1.05	.3782	.619	34.7	-5.4
	.30	.950	.5276	.500	.551	3.800	1.12	.3567	.643	50.9	-8.0
	.40	.948	.5268	.530	.547	3.791	1.23	.3280	.675	61.9	-10.7
	.50	1.002	.5257	.585	.563	4.009	1.42	.2885	.718	70.3	-13.9
	.60	1.101	.5238	.645	.581	4.405	1.76	.2370	.776	79.3	-17.7
	.70	1.234	.5208	.705	.594	4.934	2.44	.1760	.850	89.5	-22.2
	.80	1.392	.5160	.770	.613	5.568	3.98	.1126	.949	99.4	-27.6
	.90	1.571	.5077	.830	.614	6.284	8.39	.0569	1.084	111.4	-34.1
	1.00	1.766	.4918	.890	.602	7.064	27.26	.0192	1.281	124.5	-42.3
0.6	0.10	1.283	0.5284	0.600	0.593	3.563	1.02	0.3330	0.606	19.4	-2.8
	.15	1.279	.5282	.600	.586	3.553	1.04	.3266	.614	28.9	-4.1
	.20	1.274	.5280	.600	.576	3.540	1.07	.3177	.625	38.2	-5.5
	.30	1.262	.5273	.600	.547	3.504	1.17	.2938	.655	55.9	-8.3
	.40	1.247	.5263	.610	.523	3.463	1.32	.2632	.696	70.5	-11.0
	.50	1.277	.5248	.660	.547	3.547	1.57	.2247	.750	78.8	-14.1
	.60	1.355	.5225	.710	.560	3.763	2.03	.1780	.819	87.8	-17.7
	.70	1.465	.5190	.760	.585	4.068	2.94	.1266	.909	97.4	-22.0
	.80	1.598	.5134	.810	.596	4.438	5.08	.0768	1.085	107.7	-27.1
	.90	1.749	.5038	.860	.599	4.858	11.49	.0364	1.184	118.7	-33.3
	1.00	1.916	.4851	.915	.625	5.321	41.67	.0111	1.416	129.2	-41.4
0.7	0.10	1.628	0.5283	0.700	0.594	3.323	1.02	0.2643	0.608	21.1	-2.8
	.15	1.624	.5281	.700	.586	3.315	1.05	.2578	.617	31.4	-4.2
	.20	1.620	.5276	.700	.576	3.306	1.09	.2489	.631	41.4	-5.7
	.30	1.606	.5269	.700	.547	3.277	1.22	.2251	.668	60.4	-8.5
	.40	1.588	.5256	.700	.510	3.242	1.43	.1953	.721	77.6	-11.4
	.50	1.588	.5238	.730	.517	3.240	1.76	.1611	.787	88.8	-14.5
	.60	1.637	.5211	.770	.539	3.340	2.38	.1284	.878	97.1	-18.0
	.70	1.718	.5169	.810	.560	3.506	3.65	.0829	.979	106.3	-22.8
	.80	1.822	.5103	.850	.576	3.717	6.73	.0474	1.120	115.8	-27.1
	.90	1.942	.4989	.890	.584	3.964	16.59	.0207	1.312	125.9	-33.3
	1.00	2.078	.4764	.930	.573	4.240	69.23	.0055	1.603	137.4	-41.5
0.8	0.10	2.002	0.5283	0.800	0.594	3.128	1.03	0.1857	0.609	22.6	-2.9
	.15	1.999	.5280	.800	.587	3.123	1.06	.1801	.621	33.7	-4.4
	.20	1.994	.5276	.800	.578	3.116	1.11	.1724	.638	44.4	-5.8
	.30	1.981	.5268	.800	.551	3.096	1.22	.1522	.684	64.4	-8.8
	.40	1.964	.5249	.800	.514	3.069	1.56	.1272	.748	82.4	-11.9
	.50	1.945	.5226	.805	.482	3.038	2.08	.1003	.830	97.3	-15.1
	.60	1.955	.5193	.835	.510	3.054	2.88	.0787	.932	105.9	-18.6
	.70	1.999	.5143	.865	.540	3.124	4.69	.0465	1.062	114.2	-22.7
	.80	2.066	.5064	.895	.572	3.229	9.33	.0248	1.233	122.6	-27.7
	.90	2.151	.4927	.920	.561	3.361	25.55	.0096	1.473	133.2	-33.9
	1.00	2.250	.4649	.950	.563	3.518	127.00	.0022	1.848	143.5	-42.4
0.9	0.10	2.405	0.5283	0.900	0.595	2.969	1.03	0.0975	0.611	24.1	-3.0
	.15	2.402	.5279	.900	.589	2.966	1.08	.0940	.626	35.8	-4.5
	.20	2.397	.5275	.900	.581	2.960	1.14	.0892	.645	47.1	-6.0
	.30	2.386	.5261	.900	.556	2.946	1.35	.0766	.701	68.0	-9.1
	.40	2.371	.5240	.900	.526	2.927	1.72	.0615	.778	86.6	-12.4
	.50	2.353	.5211	.900	.484	2.905	2.38	.0457	.878	103.9	-15.8
	.60	2.332	.5169	.900	.435	2.879	3.63	.0310	1.004	117.1	-19.5
	.70	2.327	.5109	.920	.478	2.872	6.39	.0185	1.163	124.1	-23.7
	.80	2.347	.5012	.935	.490	2.897	13.99	.0090	1.375	132.8	-28.7
	.90	2.383	.4844	.955	.550	2.942	43.56	.0032	1.678	139.6	-35.2
	1.00	2.435	.4486	.970	.527	3.007	270.54	.0006	2.189	150.1	-44.2

TABLE I. - Continued. 1-STAGE TURBINES

(c) $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$

1. $\left(\frac{V'}{a}\right)_{2,h} = 0.8$.

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{P_1}{P_3}$	Φ_1	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$
0.5	0.10	2.265	0.5742	0.500	0.714	9.061	1.03	0.4191	1.121	33.4	-3.6
	.15	1.731	.5740	.500	.699	6.923	1.05	.4108	1.112	38.6	-4.7
	.20	1.467	.5738	.500	.681	5.867	1.08	.4008	1.101	44.0	-5.8
	.30	1.203	.5732	.500	.638	4.813	1.16	.3767	1.079	54.8	-7.9
	.40	1.075	.5724	.520	.614	4.302	1.27	.3473	1.035	62.9	-10.0
	.50	1.029	.5713	.560	.607	4.118	1.43	.3108	.992	68.9	-12.3
	.60	1.035	.5697	.610	.603	4.139	1.70	.2662	.943	74.5	-14.9
	.70	1.076	.5673	.660	.584	4.303	2.16	.2142	.889	81.5	-18.0
	.80	1.146	.5638	.730	.591	4.585	3.02	.1573	.832	85.9	-21.7
	.90	1.243	.5584	.785	.548	4.970	4.93	.1007	.769	95.8	-26.2
	1.00	1.351	.5495	.840	.483	5.405	9.93	.0530	.704	107.7	-31.6
0.6	0.10	2.697	0.5741	0.600	0.721	7.492	1.04	0.3557	1.119	33.1	-3.5
	.15	2.093	.5739	.600	.705	5.813	1.07	.3470	1.109	38.9	-4.6
	.20	1.797	.5736	.600	.686	4.990	1.10	.3365	1.095	44.9	-5.7
	.30	1.502	.5728	.600	.639	4.173	1.20	.3107	1.058	57.1	-7.8
	.40	1.347	.5718	.600	.584	3.741	1.35	.2802	1.013	69.0	-10.0
	.50	1.264	.5708	.640	.585	3.512	1.56	.2452	.963	74.5	-12.8
	.60	1.242	.5686	.680	.575	3.450	1.90	.2049	.907	80.9	-14.7
	.70	1.258	.5659	.730	.573	3.495	2.49	.1604	.849	86.3	-17.6
	.80	1.305	.5619	.780	.559	3.624	3.61	.1143	.788	92.9	-21.1
	.90	1.374	.5559	.830	.529	3.817	6.06	.0711	.726	101.0	-25.2
	1.00	1.457	.5463	.880	.485	4.048	12.60	.0363	.662	110.6	-30.3
0.7	0.10	3.187	0.5741	0.700	0.727	6.382	1.04	0.2820	1.117	32.9	-3.4
	.15	2.460	.5738	.700	.711	5.021	1.08	.2737	1.104	39.2	-4.5
	.20	2.136	.5734	.700	.691	4.360	1.12	.2636	1.087	45.8	-5.6
	.30	1.817	.5725	.700	.642	3.708	1.25	.2388	1.043	59.1	-7.9
	.40	1.646	.5712	.700	.582	3.360	1.45	.2097	.990	72.2	-10.1
	.50	1.599	.5695	.720	.556	3.180	1.78	.1786	.931	80.9	-12.4
	.60	1.473	.5673	.745	.528	3.006	2.17	.1450	.869	89.8	-14.8
	.70	1.459	.5642	.780	.509	2.977	2.93	.1101	.805	96.3	-17.6
	.80	1.475	.5597	.830	.519	3.010	4.39	.0751	.743	100.4	-20.9
	.90	1.513	.5531	.870	.491	3.088	7.60	.0460	.680	108.1	-24.8
	1.00	1.562	.5427	.900	.405	3.188	16.18	.0230	.617	120.6	-29.5
0.8	0.10	3.557	0.5740	0.800	0.733	5.559	1.05	0.1980	1.115	32.8	-3.4
	.15	2.834	.5737	.800	.717	4.428	1.09	.1912	1.100	39.6	-4.5
	.20	2.487	.5733	.800	.698	3.886	1.15	.1829	1.080	46.6	-5.7
	.30	2.146	.5721	.800	.646	3.353	1.31	.1623	1.027	61.0	-8.0
	.40	1.964	.5705	.800	.583	3.068	1.56	.1383	.965	75.2	-10.3
	.50	1.834	.5684	.800	.518	2.866	1.94	.1134	.897	88.6	-12.7
	.60	1.734	.5658	.820	.487	2.710	2.52	.0891	.829	96.6	-15.1
	.70	1.681	.5622	.840	.450	2.626	3.53	.0655	.761	105.8	-17.9
	.80	1.660	.5571	.870	.429	2.594	5.49	.0438	.696	112.0	-21.0
	.90	1.660	.5497	.900	.397	2.594	9.80	.0257	.633	119.5	-24.7
	1.00	1.673	.5385	.930	.354	2.614	21.31	.0126	.573	127.7	-29.2
0.9	0.10	3.991	0.5740	0.900	0.738	4.987	1.06	0.1040	1.113	32.7	-3.3
	.15	3.216	.5736	.900	.723	3.971	1.10	.0998	1.095	39.9	-4.5
	.20	2.847	.5731	.900	.704	3.514	1.17	.0948	1.071	47.4	-5.7
	.30	2.490	.5717	.900	.652	3.074	1.37	.0822	1.010	62.7	-8.1
	.40	2.298	.5697	.900	.586	2.837	1.69	.0679	.938	77.8	-10.6
	.50	2.159	.5671	.900	.510	2.665	2.20	.0533	.862	92.1	-13.1
	.60	2.041	.5638	.900	.428	2.520	3.03	.0398	.788	105.4	-15.7
	.70	1.939	.5596	.910	.384	2.394	4.44	.0281	.717	114.3	-18.4
	.80	1.866	.5538	.930	.376	2.307	7.15	.0181	.651	119.8	-21.5
	.90	1.821	.5457	.940	.305	2.248	13.12	.0104	.589	130.0	-25.0
	1.00	1.790	.5334	.960	.279	2.210	29.09	.0050	.532	136.3	-29.3

TABLE I. - Continued. 1-STAGE TURBINES

(c) Continued. $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$

2. $\left(\frac{V'}{a}\right)_{2,h} = 1.0;\ \left(\frac{V_2'}{V_3'}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{P_1}{P_3}$	$\hat{w}_1$	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$
0.5	0.80	1.373	0.5611	0.750	0.643	5.498	3.90	0.1248	0.985	95.3	-24.2
	.90	1.450	.5544	.810	.612	5.800	6.85	.0745	.908	103.1	-28.9
	1.00	1.542	.5434	.870	.564	6.169	15.39	.0354	.828	112.5	-34.6
0.6	0.80	1.520	0.5591	0.795	0.615	4.228	4.63	0.0910	0.936	100.7	-23.1
	.90	1.570	.5518	.845	.580	4.368	8.38	.0528	.858	108.5	-27.5
	1.00	1.635	.5400	.895	.530	4.541	19.33	.0245	.779	117.6	-32.9
0.7	.70	1.686	0.5621	0.800	0.595	3.440	3.55	0.0924	0.962	100.3	-19.2
	.80	1.680	.5568	.840	.574	3.429	5.63	.0606	.883	107.0	-22.7
	.90	1.699	.5488	.880	.538	3.468	10.50	.0342	.805	114.7	-26.9
	1.00	1.731	.5361	.920	.489	3.532	24.79	.0155	.728	123.2	-32.0
0.8	0.60	1.986	0.5642	0.825	0.547	3.104	2.93	0.0777	0.994	101.8	-16.4
	.70	1.902	.5600	.855	.536	2.972	4.29	.0548	.910	107.9	-19.3
	.80	1.857	.5540	.885	.514	2.901	7.04	.0349	.829	114.6	-22.7
	.90	1.837	.5452	.915	.479	2.870	13.54	.0191	.752	121.8	-26.6
	1.00	1.831	.5315	.940	.400	2.860	32.58	.0085	.677	131.6	-31.5
0.9	0.60	2.297	0.5621	0.900	0.476	2.836	3.55	0.0344	0.944	110.1	-16.9
	.70	2.155	.5573	.915	.445	2.661	5.42	.0234	.857	117.5	-19.7
	.80	2.058	.5505	.930	.401	2.540	9.22	.0144	.775	125.2	-23.0
	.90	1.989	.5409	.950	.378	2.456	18.22	.0077	.700	131.2	-26.8
	1.00	1.937	.5261	.965	.311	2.391	44.40	.0034	.629	139.7	-31.5

TABLE I. - Concluded. 1-STAGE TURBINES

(c) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$

3. $\left(\frac{V_2'}{V_3'}\right)_h = 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{3,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{P_1}{P_3}$	$\hat{w}_1$	$\left(\frac{V'}{a}\right)_{2,h}$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$
0.5	0.10	1.066	0.5743	0.500	0.691	4.264	1.01	0.4253	0.704	16.8	-2.4
	.15	1.060	.5742	.500	.681	4.240	1.03	.4185	.710	25.0	-3.7
	.20	1.053	.5739	.500	.668	4.211	1.06	.4091	.717	33.1	-4.9
	.30	1.032	.5733	.500	.632	4.128	1.13	.3841	.739	48.6	-7.3
	.40	1.012	.5725	.520	.612	4.047	1.25	.3519	.768	60.0	-9.7
	.50	1.043	.5712	.560	.607	4.171	1.44	.3094	.808	69.6	-12.4
	.60	1.123	.5692	.630	.640	4.493	1.78	.2548	.860	75.7	-15.6
	.70	1.241	.5660	.680	.628	4.966	2.46	.1902	.929	87.2	-19.5
	.80	1.392	.5608	.750	.648	5.567	3.98	.1224	1.080	96.2	-24.4
	.90	1.566	.5519	.820	.665	6.264	8.31	.0624	1.146	106.3	-30.3
	1.00	1.762	.5347	.880	.628	7.047	26.94	.0211	1.334	120.8	-38.1
0.6	0.10	1.386	0.5743	0.600	0.691	3.850	1.02	0.3615	0.706	18.2	-2.5
	.15	1.382	.5741	.600	.681	3.838	1.04	.3539	.713	27.2	-3.7
	.20	1.372	.5738	.600	.667	3.812	1.08	.3437	.722	35.9	-5.0
	.30	1.349	.5730	.600	.630	3.748	1.18	.3161	.750	52.6	-7.4
	.40	1.323	.5719	.600	.583	3.674	1.34	.2816	.788	68.2	-9.9
	.50	1.325	.5702	.640	.589	3.681	1.60	.2403	.837	77.0	-12.5
	.60	1.380	.5678	.700	.629	3.834	2.06	.1909	.900	83.1	-15.6
	.70	1.476	.5640	.750	.644	4.099	2.97	.1364	.983	92.3	-19.3
	.80	1.600	.5580	.800	.649	4.445	5.10	.0833	1.093	102.6	-23.9
	.90	1.747	.5476	.850	.639	4.853	11.45	.0397	1.244	114.4	-29.7
	1.00	1.912	.5275	.900	.597	5.311	41.22	.0182	1.470	126.1	-37.3
0.7	0.10	1.731	0.5743	0.700	0.692	3.532	1.02	0.2869	0.707	19.4	-2.5
	.15	1.725	.5740	.700	.682	3.521	1.05	.2794	.716	29.0	-3.8
	.20	1.716	.5736	.700	.668	3.503	1.10	.2692	.728	38.3	-5.1
	.30	1.694	.5726	.700	.632	3.458	1.23	.2422	.762	56.2	-7.6
	.40	1.667	.5711	.700	.584	3.402	1.48	.2068	.810	72.8	-10.2
	.50	1.644	.5691	.720	.569	3.355	1.80	.1717	.871	84.5	-12.9
	.60	1.670	.5661	.760	.591	3.407	2.43	.1308	.950	92.8	-15.9
	.70	1.735	.5616	.800	.608	3.541	3.70	.0889	1.051	101.7	-19.6
	.80	1.828	.5545	.840	.616	3.731	6.79	.0511	1.185	111.5	-24.0
	.90	1.943	.5423	.880	.609	3.965	16.61	.0284	1.371	122.4	-29.7
	1.00	2.077	.5179	.930	.660	4.238	69.03	.0060	1.650	131.7	-37.5
0.8	0.10	2.100	0.5742	0.800	0.693	3.281	1.03	0.2016	0.708	20.6	-2.6
	.15	2.092	.5739	.800	.684	3.268	1.07	.1952	.719	30.7	-3.9
	.20	2.084	.5735	.800	.672	3.257	1.12	.1866	.734	40.6	-5.2
	.30	2.065	.5722	.800	.636	3.226	1.29	.1638	.776	59.4	-7.8
	.40	2.039	.5703	.800	.593	3.187	1.58	.1361	.835	76.8	-10.5
	.50	2.010	.5677	.800	.538	3.140	2.07	.1066	.911	92.6	-13.4
	.60	1.995	.5641	.820	.532	3.117	2.95	.0773	1.008	103.1	-16.4
	.70	2.022	.5587	.850	.552	3.159	4.79	.0496	1.133	111.7	-20.1
	.80	2.077	.5502	.880	.565	3.246	9.47	.0266	1.298	120.7	-24.5
	.90	2.153	.5355	.910	.564	3.365	25.70	.0106	1.531	130.7	-30.2
	1.00	2.246	.5056	.940	.525	3.509	125.11	.0024	1.899	142.5	-38.3
0.9	0.10	2.487	0.5742	0.900	0.694	3.071	1.03	0.1059	0.710	21.7	-2.6
	.15	2.480	.5738	.900	.687	3.062	1.08	.1019	.723	32.3	-4.0
	.20	2.474	.5733	.900	.677	3.054	1.14	.0965	.740	42.6	-5.3
	.30	2.458	.5717	.900	.648	3.035	1.36	.0825	.791	62.2	-8.0
	.40	2.437	.5694	.900	.609	3.008	1.74	.0658	.862	80.2	-10.9
	.50	2.411	.5661	.900	.559	2.977	2.43	.0486	.956	96.5	-13.9
	.60	2.382	.5615	.900	.500	2.941	3.75	.0327	1.077	111.1	-17.2
	.70	2.359	.5549	.910	.483	2.912	6.60	.0195	1.231	121.6	-21.0
	.80	2.366	.5444	.930	.520	2.921	14.39	.0095	1.438	129.1	-25.6
	.90	2.394	.5260	.950	.562	2.955	44.66	.0034	1.737	137.0	-31.5
	1.00	2.439	.4872	.970	.607	3.011	274.68	.0006	2.240	146.0	-40.1

TABLE II. - $1\frac{1}{2}$-STAGE TURBINES

(a) $\left(\frac{V_z}{a}\right)_{3,m} = 0.5$

1. $\left(\frac{V'}{a}\right)_{2,h} = 0.6$; $\left(\frac{V_2'}{V_3'}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{P_1}{P_4}$	θ_1	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$	$\left(\frac{V}{a}\right)_{3,h}$
0.5	0.20	2.394	0.4530	0.535	0.467	9.578	1.15	0.2994	0.843	83.8	-39.7	0.6547
	.30	1.764		.570	.467	7.056	1.26	.2768	.806	86.3		
	.40	1.473		.610	.470	5.890	1.40	.2510	.771	88.2		
	.50	1.320		.645	.464	5.280	1.61	.2219	.737	91.2		
	.60	1.240		.685	.462	4.960	1.92	.1896	.706	93.7		
	.70	1.204		.725	.455	4.815	2.41	.1548	.675	96.7		
	.80	1.197		.770	.451	4.789	3.23	.1190	.647	99.2		
	.90	1.212		.810	.434	4.847	4.75	.0843	.619	103.7		
	1.00	1.240		.850	.409	4.960	7.91	.0535	.593	109.3		
0.6	0.20	2.845	0.4507	0.600	0.436	7.904	1.18	0.2485	0.847	88.2	-38.1	0.6386
	.30	2.086		.635	.439	5.795	1.31	.2265	.803	90.8		
	.40	1.789		.670	.441	4.803	1.49	.2080	.760	93.3		
	.50	1.536		.705	.441	4.266	1.74	.1752	.720	95.9		
	.60	1.426		.740	.439	3.961	2.13	.1466	.682	98.7		
	.70	1.365		.775	.432	3.793	2.74	.1170	.647	101.9		
	.80	1.337		.810	.422	3.715	3.78	.0878	.613	105.6		
	.90	1.330		.845	.406	3.696	5.71	.0607	.582	109.9		
	1.00	1.338		.880	.387	3.716	9.74	.0377	.551	114.7		
0.7	0.20	3.323	0.4488	0.700	0.435	6.782	1.21	0.1925	0.848	88.5	-36.7	0.6260
	.30	2.440		.705	.407	4.979	1.37	.1725	.795	95.9		
	.40	2.008		.735	.409	4.099	1.59	.1511	.746	98.8		
	.50	1.767		.765	.410	3.606	1.91	.1285	.700	101.6		
	.60	1.622		.790	.400	3.311	2.39	.1051	.657	105.7		
	.70	1.534		.820	.394	3.130	3.15	.0820	.617	108.9		
	.80	1.480		.850	.387	3.021	4.46	.0601	.580	112.4		
	.90	1.450		.880	.376	2.958	6.91	.0406	.545	116.1		
	1.00	1.433		.905	.346	2.925	12.05	.0247	.511	122.0		
0.8	0.20	3.811	0.4472	0.800	0.435	5.955	1.25	0.1321	0.846	88.9	-35.6	0.6160
	.30	2.825		.800	.398	4.415	1.44	.1160	.785	97.9		
	.40	2.321		.805	.368	3.627	1.71	.0994	.729	105.3		
	.50	2.023		.825	.363	3.162	2.11	.0826	.677	109.2		
	.60	1.837		.850	.365	2.870	2.71	.0660	.630	111.9		
	.70	1.714		.870	.354	2.678	3.67	.0503	.587	116.0		
	.80	1.630		.890	.338	2.547	5.34	.0360	.546	120.3		
	.90	1.572		.915	.337	2.456	8.49	.0238	.509	122.9		
	1.00	1.530		.935	.317	2.391	15.11	.0142	.474	127.6		
0.9	0.20	4.310	0.4459	0.900	0.436	5.321	1.28	0.0678	0.841	89.4	-34.6	0.6078
	.30	3.224		.900	.398	3.981	1.52	.0583	.773	99.0		
	.40	2.668		.900	.356	3.294	1.86	.0485	.711	108.2		
	.50	2.321		.900	.313	2.866	2.37	.0391	.654	116.7		
	.60	2.083		.910	.298	2.571	3.14	.0304	.603	121.5		
	.70	1.916		.925	.297	2.366	4.39	.0225	.557	124.5		
	.80	1.796		.935	.274	2.217	6.58	.0157	.514	129.6		
	.90	1.704		.950	.271	2.104	10.71	.0102	.476	132.3		
	1.00	1.632		.960	.241	2.015	19.41	.0060	.440	137.9		

TABLE II. - Continued. $1\frac{1}{2}$-STAGE TURBINES

(a) Continued. $\left(\frac{V_z}{a}\right)_{3,m} = 0.5$

2. $\left(\frac{V'}{a}\right)_{2,h} = 0.8$; $\left(\frac{V_2'}{V_3'}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{p_1}{p_4}$	$\hat{w}_1$	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$	$\left(\frac{V}{a}\right)_{3,h}$
0.5	0.50	1.657	0.4530	0.690	0.553	6.628	1.83	0.1981	0.961	98.1	-39.7	0.6547
	.60	1.534		.725	.545	6.135	2.26	.1635	.918	101.1		
	.70	1.465		.760	.531	5.858	2.97	.1282	.878	104.5		
	.80	1.431		.800	.523	5.724	4.21	.0940	.839	107.4		
	.90	1.421		.840	.510	5.683	6.59	.0629	.802	110.9		
	1.00	1.427		.875	.474	5.708	11.87	.0372	.766	116.6		
0.6	0.40	2.127	0.4507	0.705	0.524	5.908	1.63	0.1857	0.990	99.6	-38.1	0.6386
	.50	1.867		.735	.518	5.185	1.98	.1564	.937	102.9		
	.60	1.711		.770	.519	4.752	2.51	.1265	.887	105.3		
	.70	1.615		.800	.504	4.487	3.38	.0971	.840	109.2		
	.80	1.559		.835	.497	4.330	4.90	.0697	.795	112.2		
	.90	1.527		.865	.469	4.243	7.86	.0456	.751	117.2		
	1.00	1.512		.900	.454	4.201	14.47	.0264	.710	120.9		
0.7	0.40	2.406	0.4488	0.760	0.487	4.911	1.75	0.1388	0.971	104.3	-36.7	0.6260
	.50	2.094		.785	.480	4.273	2.16	.1146	.910	108.0		
	.60	1.900		.815	.482	3.877	2.81	.0908	.853	110.6		
	.70	1.774		.840	.466	3.621	3.87	.0682	.800	114.6		
	.80	1.691		.870	.463	3.450	5.76	.0478	.750	117.5		
	.90	1.635		.895	.437	3.338	9.47	.0307	.702	122.2		
	1.00	1.598		.920	.406	3.260	17.79	.0174	.657	127.4		
0.8	0.40	2.722	0.4472	0.820	0.436	4.253	1.89	0.0911	0.949	110.2	-35.6	0.6160
	.50	2.347		.840	.430	3.667	2.40	.0737	.880	114.0		
	.60	2.108		.860	.421	3.293	3.19	.0570	.817	117.8		
	.70	1.945		.885	.426	3.040	4.51	.0418	.759	120.2		
	.80	1.831		.905	.412	2.861	6.88	.0287	.706	124.1		
	.90	1.748		.925	.393	2.731	11.58	.0180	.656	128.1		
	1.00	1.684		.940	.343	2.631	22.14	.0101	.608	134.5		
0.9	0.40	3.091	0.4459	0.900	0.396	3.816	2.07	0.0442	0.925	115.0	-34.6	0.6078
	.50	2.645		.905	.363	3.266	2.71	.0347	.849	121.3		
	.60	2.349		.915	.344	2.900	3.71	.0262	.781	126.0		
	.70	2.141		.930	.344	2.643	5.40	.0187	.720	129.0		
	.80	1.988		.940	.316	2.454	8.47	.0125	.663	133.9		
	.90	1.870		.955	.314	2.309	14.58	.0077	.611	136.6		
	1.00	1.776		.965	.277	2.193	28.33	.0043	.564	141.8		

TABLE II. - Continued. $1\frac{1}{2}$-STAGE TURBINES

(a) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.5$

3. $\left(\frac{V_2}{V_3'}\right)_h = 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{P_1}{P_4}$	ϕ_1	$\left(\frac{V'}{a}\right)_{2,h}$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$	$\left(\frac{V}{a}\right)_{3,h}$
0.5	0.20	2.836	0.4530	0.575	0.525	11.345	1.18	0.2930	0.721	88.0	-39.7	0.6547
	.30	2.167		.615	.540	8.668	1.32	.2644	.757	91.7		
	.40	1.864		.655	.555	7.457	1.54	.2314	.796	95.3		
	.50	1.710		.695	.570	6.840	1.86	.1946	.837	98.9		
	.60	1.638		.730	.571	6.527	2.40	.1554	.881	103.6		
	.70	1.598		.770	.579	6.392	3.32	.1160	.929	107.7		
	.80	1.592		.810	.582	6.369	5.10	.0791	.981	112.0		
	.90	1.606		.850	.580	6.428	8.99	.0477	1.039	116.9		
	1.00	1.630		.890	.571	6.528	19.30	.0241	1.103	122.4		
0.6	0.20	3.283	0.4507	0.630	0.488	9.180	1.21	0.2432	0.717	91.8	-38.1	0.6386
	.30	2.502		.670	.510	6.949	1.38	.2159	.761	95.6		
	.40	2.143		.705	.526	5.951	1.64	.1851	.809	100.0		
	.50	1.953		.740	.542	5.424	2.05	.1518	.861	104.2		
	.60	1.848		.775	.557	5.134	2.72	.1177	.918	108.4		
	.70	1.793		.810	.571	4.979	3.93	.0847	.980	112.6		
	.80	1.768		.845	.583	4.910	6.34	.0553	1.050	117.0		
	.90	1.763		.875	.567	4.897	11.90	.0315	1.131	123.3		
	1.00	1.770		.910	.567	4.917	27.84	.0147	1.225	128.7		
0.7	0.20	3.798	0.4488	0.700	0.456	7.738	1.24	0.1881	0.716	95.4	-36.7	0.6260
	.30	2.880		.730	.474	5.878	1.45	.1639	.769	100.4		
	.40	2.454		.760	.493	5.007	1.77	.1374	.827	105.2		
	.50	2.220		.790	.514	4.531	2.28	.1096	.890	109.6		
	.60	2.083		.820	.536	4.251	3.14	.0822	.961	113.8		
	.70	2.000		.845	.540	4.082	4.74	.0569	1.041	119.2		
	.80	1.958		.875	.561	3.983	8.06	.0354	1.133	123.4		
	.90	1.985		.900	.553	3.928	16.19	.0190	1.241	129.5		
	1.00	1.911		.930	.573	3.899	41.47	.0082	1.372	134.2		
0.8	0.20	4.340	0.4478	0.800	0.461	6.781	1.28	0.1287	0.719	95.4	-35.6	0.6160
	.30	3.318		.800	.434	5.185	1.54	.1095	.780	105.7		
	.40	2.809		.820	.448	4.389	1.93	.0894	.849	111.3		
	.50	2.521		.845	.477	3.939	2.57	.0691	.925	115.5		
	.60	2.343		.865	.492	3.662	3.70	.0500	1.012	120.6		
	.70	2.227		.885	.506	3.480	5.86	.0331	1.112	125.5		
	.80	2.149		.905	.518	3.357	10.58	.0198	1.230	130.6		
	.90	2.094		.925	.525	3.272	22.88	.0098	1.373	135.8		
	1.00	2.055		.945	.524	3.211	64.95	.0039	1.555	141.6		
0.9	0.20	4.905	0.4459	0.900	0.468	6.056	1.33	0.0658	0.723	95.6	-34.6	0.6078
	.30	3.797		.900	.445	4.688	1.64	.0544	.794	106.5		
	.40	3.229		.900	.416	3.987	2.14	.0428	.874	116.3		
	.50	2.878		.905	.404	3.553	2.98	.0318	.966	123.6		
	.60	2.647		.920	.438	3.268	4.51	.0220	1.071	127.6		
	.70	2.487		.930	.444	3.071	7.57	.0139	1.195	133.0		
	.80	2.370		.940	.444	2.926	14.64	.0077	1.345	138.5		
	.90	2.282		.955	.488	2.817	34.59	.0036	1.538	142.1		
	1.00	2.209		.965	.472	2.728	110.53	.0013	1.784	148.3		

TABLE II. - Continued. $1\frac{1}{2}$-STAGE TURBINES

(b) $\left(\frac{V_z}{a}\right)_{3,m} = 0.6$

1. $\left(\frac{V'}{a}\right)_{2,h} = 0.8;\ \left(\frac{V_2'}{V_3'}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{P_1}{P_4}$	ϕ_1	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$	$\left(\frac{V}{a}\right)_{3,h}$
0.5	0.10	4.175	0.5064	0.500	0.529	16.700	1.07	0.3565	0.760	68.8	-38.6	0.7760
	.15	2.955		.500	.513	11.821	1.11	.3459	.746	73.1		
	.20	2.340		.500	.497	9.358	1.15	.3346	.733	77.2		
	.30	1.722		.525	.482	6.888	1.25	.3099	.706	81.8		
	.40	1.436		.570	.484	5.744	1.39	.2818	.681	83.7		
	.50	1.288		.610	.478	5.153	1.60	.2498	.656	86.6		
	.60	1.213		.655	.474	4.853	1.90	.2140	.638	89.2		
	.70	1.182		.700	.466	4.730	2.37	.1751	.610	92.3		
	.80	1.182		.750	.462	4.726	3.19	.1347	.588	94.9		
	.90	1.202		.795	.444	4.809	4.70	.0952	.568	99.5		
	1.00	1.237		.840	.419	4.948	7.88	.0599	.547	105.1		
0.6	0.10	4.935	0.5033	0.600	0.585	13.707	1.08	0.2994	0.773	68.6	-36.9	0.7556
	.15	3.520		.600	.508	9.777	1.13	.2887	.756	73.4		
	.20	2.804		.600	.490	7.790	1.18	.2772	.740	77.9		
	.30	2.075		.605	.457	5.763	1.31	.2524	.707	85.9		
	.40	1.718		.640	.454	4.772	1.49	.2254	.676	89.0		
	.50	1.525		.680	.454	4.237	1.74	.1957	.646	91.4		
	.60	1.418		.715	.444	3.939	2.13	.1638	.618	95.1		
	.70	1.361		.758	.438	3.780	2.74	.1307	.591	98.1		
	.80	1.336		.795	.429	3.711	3.79	.0979	.565	101.7		
	.90	1.333		.835	.416	3.702	5.75	.0674	.540	105.7		
	1.00	1.344		.875	.401	3.732	9.90	.0415	.516	110.1		
0.7	0.10	5.690	0.5008	0.700	0.523	11.612	1.09	0.2352	0.783	68.4	-35.4	0.7399
	.15	4.087		.700	.505	8.341	1.15	.2253	.763	73.6		
	.20	3.277		.700	.486	6.687	1.21	.2146	.743	78.6		
	.30	2.449		.700	.445	4.997	1.38	.1917	.705	88.1		
	.40	2.080		.715	.422	4.183	1.60	.1676	.668	94.3		
	.50	1.777		.745	.417	3.626	1.92	.1424	.633	97.8		
	.60	1.631		.775	.409	3.330	2.41	.1164	.600	101.5		
	.70	1.543		.810	.408	3.150	3.19	.0905	.569	104.2		
	.80	1.491		.840	.393	3.042	4.63	.0661	.539	108.6		
	.90	1.461		.870	.374	2.982	7.07	.0444	.510	113.4		
	1.00	1.447		.900	.351	2.953	12.47	.0267	.483	118.7		
0.8	0.10	6.444	0.4988	0.800	0.582	10.068	1.11	0.1638	0.790	68.2	-34.2	0.7275
	.15	4.661		.800	.503	7.282	1.17	.1559	.767	73.8		
	.20	3.758		.800	.483	5.872	1.25	.1473	.744	79.2		
	.30	2.835		.800	.440	4.430	1.45	.1288	.700	89.5		
	.40	2.353		.800	.395	3.676	1.73	.1098	.658	99.0		
	.50	2.052		.815	.375	3.206	2.14	.0910	.618	104.6		
	.60	1.861		.840	.373	2.908	2.76	.0725	.581	107.9		
	.70	1.736		.865	.369	2.712	3.76	.0549	.546	111.1		
	.80	1.651		.885	.348	2.580	5.50	.0391	.513	116.3		
	.90	1.598		.910	.340	2.488	8.81	.0256	.482	119.8		
	1.00	1.549		.930	.312	2.421	15.88	.0151	.452	125.6		
0.9	0.10	7.200	0.4971	0.900	0.522	8.889	1.12	0.0854	0.794	68.0	-33.1	0.7175
	.15	5.242		.900	.503	6.471	1.19	.0807	.768	74.0		
	.20	4.250		.900	.482	5.247	1.28	.0756	.743	79.8		
	.30	3.236		.900	.438	3.993	1.53	.0647	.693	90.7		
	.40	2.702		.900	.390	3.336	1.89	.0535	.645	100.9		
	.50	2.363		.900	.340	2.917	2.48	.0428	.601	110.5		
	.60	2.122		.905	.305	2.620	3.33	.0331	.560	117.6		
	.70	1.951		.920	.299	2.408	4.55	.0244	.522	121.2		
	.80	1.895		.938	.292	2.254	6.86	.0169	.486	124.7		
	.90	1.731		.948	.261	2.137	11.27	.0108	.453	130.7		
	1.00	1.686		.960	.252	2.045	20.69	.0063	.422	134.2		

TABLE II. - Continued. $1\frac{1}{2}$-STAGE TURBINES

(b) Continued. $\left(\frac{V_z}{a}\right)_{3,m} = 0.6$

2. $\left(\frac{V'}{a}\right)_{2,h} = 0.8;\ \left(\frac{V_2'}{V_3'}\right)_h \leq 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{p_1}{p_4}$	ψ_1	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$	$\left(\frac{V}{a}\right)_{3,h}$
0.5	0.10	5.572	0.5064	0.515	0.582	22.287	1.09	0.3505	0.992	83.6	-38.6	0.7760
	.15	3.875		.530	.578	15.502	1.14	.3372	.974	85.3		
	.20	3.037		.550	.580	12.147	1.20	.3232	.956	86.3		
	.30	2.220		.585	.575	8.880	1.34	.2928	.921	89.1		
	.40	1.836		.625	.575	7.344	1.53	.2593	.887	91.2		
	.50	1.628		.665	.573	6.514	1.81	.2229	.855	93.6		
	.60	1.512		.700	.556	6.046	2.24	.1842	.824	97.3		
	.70	1.448		.745	.555	5.794	2.94	.1445	.794	99.5		
	.80	1.421		.785	.536	5.683	4.17	.1058	.765	103.4		
	.90	1.416		.825	.510	5.666	6.57	.0705	.736	108.1		
	1.00	1.428		.870	.495	5.711	11.93	.0414	.710	112.0		
0.6	0.15	4.540	0.5033	0.600	0.549	12.612	1.16	0.2806	0.987	87.7	-36.9	0.7556
	.20	3.549		.615	.546	9.858	1.23	.2671	.965	89.4		
	.30	2.578		.645	.540	7.160	1.40	.2382	.922	92.9		
	.40	2.115		.680	.538	5.875	1.64	.2073	.881	95.7		
	.50	1.858		.715	.534	5.162	1.92	.1746	.842	98.6		
	.60	1.706		.750	.526	4.738	2.51	.1412	.804	101.8		
	.70	1.614		.785	.514	4.482	3.38	.1083	.767	105.3		
	.80	1.560		.825	.511	4.334	4.92	.0774	.733	108.0		
	.90	1.533		.860	.489	4.257	7.96	.0504	.699	112.4		
	1.00	1.521		.895	.464	4.224	14.81	.0289	.666	117.3		
0.7	0.15	5.226	0.5008	0.700	0.555	10.664	1.19	0.2183	0.995	86.8	-35.4	0.7399
	.20	4.102		.700	.531	8.372	1.27	.2059	.969	90.9		
	.30	2.969		.710	.497	6.060	1.47	.1804	.919	97.4		
	.40	2.417		.740	.496	4.934	1.76	.1540	.870	100.6		
	.50	2.104		.770	.493	4.293	2.18	.1270	.824	103.9		
	.60	1.910		.800	.487	3.898	2.84	.1004	.780	107.2		
	.70	1.785		.830	.477	3.643	3.92	.0752	.738	110.7		
	.80	1.703		.860	.464	3.476	5.87	.0585	.698	114.5		
	.90	1.649		.890	.447	3.365	9.73	.0334	.660	118.5		
	1.00	1.612		.915	.406	3.290	18.50	.0188	.622	124.7		
0.8	0.15	5.907	0.4988	0.800	0.563	9.229	1.22	0.1505	1.000	86.0	-34.2	0.7275
	.20	4.662		.800	.538	7.284	1.31	.1407	.970	90.6		
	.30	3.401		.800	.485	5.315	1.56	.1205	.912	99.4		
	.40	2.755		.810	.453	4.305	1.91	.1005	.856	105.7		
	.50	2.375		.830	.442	3.711	2.43	.0811	.803	109.9		
	.60	2.132		.855	.442	3.331	3.25	.0625	.754	112.9		
	.70	1.968		.878	.423	3.075	4.62	.0457	.707	117.4		
	.80	1.852		.900	.419	2.894	7.10	.0311	.663	120.5		
	.90	1.768		.920	.392	2.763	12.06	.0194	.621	125.4		
	1.00	1.703		.940	.362	2.662	23.36	.0107	.581	130.6		
0.9	0.20	5.225	0.4971	0.900	0.546	6.451	1.35	0.0719	0.968	90.2	-33.1	0.7175
	.30	3.845		.900	.492	4.747	1.65	.0601	.902	99.7		
	.40	3.135		.900	.434	3.871	2.10	.0486	.840	108.7		
	.50	2.698		.900	.374	3.383	2.77	.0380	.781	117.2		
	.60	2.388		.910	.351	2.948	3.82	.0285	.726	122.4		
	.70	2.174		.925	.344	2.684	5.60	.0208	.675	126.0		
	.80	2.017		.940	.336	2.491	8.84	.0134	.628	129.4		
	.90	1.890		.960	.375	2.334	15.80	.0083	.584	129.0		
	1.00	1.800		.965	.290	2.222	30.30	.0045	.542	138.4		

TABLE II. - Continued. $1\frac{1}{2}$-STAGE TURBINES

(b) Concluded. $\left(\frac{V_x}{a}\right)_{3,m} = 0.6$

3. $\left(\frac{V_2}{V_3'}\right)_h = 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_x}{\rho_a a_{a,cr}}\right)_{4,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_x}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{p_1}{p_4}$	$\hat{q}_1$	$\left(\frac{V'}{a}\right)_{2,h}$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$	$\left(\frac{V}{a}\right)_{3,h}$
0.5	0.10	5.615	0.5064	0.515	0.584	22.459	1.09	0.3503	0.807	84.0	-38.6	0.7760
	.15	3.970		.535	.590	15.681	1.14	.3363	.824	85.8		
	.20	3.162		.555	.596	12.646	1.20	.3218	.841	87.6		
	.30	2.382		.595	.608	9.529	1.36	.2874	.877	91.1		
	.40	2.024		.635	.619	8.095	1.60	.2492	.915	94.6		
	.50	1.836		.675	.627	7.345	1.96	.2076	.956	98.2		
	.60	1.736		.715	.631	6.942	2.66	.1640	.999	102.1		
	.70	1.686		.760	.645	6.744	3.60	.1208	1.046	105.3		
	.80	1.669		.800	.637	6.675	5.62	.0811	1.097	110.1		
	.90	1.673		.840	.618	6.692	10.15	.0478	1.153	115.6		
	1.00	1.691		.885	.613	6.763	22.60	.0234	1.214	120.5		
0.6	0.10	6.472	0.5033	0.600	0.569	17.976	1.11	0.2939	0.792	83.8	-36.9	0.7556
	.15	4.590		.600	.551	12.750	1.17	.2803	.812	88.2		
	.20	3.651		.620	.562	10.142	1.24	.2657	.832	90.0		
	.30	2.741		.655	.575	7.615	1.43	.2337	.876	94.2		
	.40	2.317		.690	.588	6.436	1.72	.1985	.923	98.3		
	.50	2.088		.725	.598	5.799	2.17	.1612	.974	102.5		
	.60	1.957		.760	.606	5.435	2.92	.1235	1.030	106.8		
	.70	1.882		.800	.628	5.228	4.27	.0878	1.091	110.8		
	.80	1.844		.835	.629	5.181	7.01	.0564	1.160	115.0		
	.90	1.828		.870	.621	5.078	13.48	.0314	1.239	120.5		
	1.00	1.827		.905	.601	5.074	32.64	.0143	1.332	126.8		
0.7	0.10	7.326	0.5008	0.700	0.573	14.951	1.12	0.2305	0.782	81.8	-35.4	0.7399
	.15	5.245		.700	.556	10.704	1.19	.2181	.804	86.9		
	.20	4.198		.700	.539	8.566	1.28	.2049	.828	91.9		
	.30	3.146		.720	.537	6.421	1.51	.1767	.880	98.1		
	.40	2.644		.750	.554	5.396	1.86	.1466	.936	102.6		
	.50	2.365		.780	.572	4.886	2.42	.1157	.999	106.9		
	.60	2.197		.810	.589	4.484	3.36	.0858	1.069	111.2		
	.70	2.093		.840	.605	4.271	5.18	.0586	1.148	115.6		
	.80	2.028		.865	.594	4.138	8.97	.0359	1.239	121.6		
	.90	1.988		.895	.599	4.057	18.43	.0189	1.347	126.7		
	1.00	1.964		.925	.597	4.008	48.85	.0079	1.478	132.5		
0.8	0.10	8.177	0.4988	0.800	0.577	12.776	1.13	0.1604	0.774	80.4	-34.2	0.7275
	.15	5.906		.800	.563	9.229	1.22	.1505	.800	86.0		
	.20	4.764		.800	.547	7.444	1.32	.1400	.827	91.4		
	.30	3.607		.800	.511	5.637	1.60	.1176	.887	101.5		
	.40	3.018		.810	.498	4.715	2.04	.0949	.955	108.9		
	.50	2.678		.835	.522	4.184	2.75	.0725	1.031	113.0		
	.60	2.464		.860	.552	3.850	4.01	.0518	1.117	116.9		
	.70	2.323		.880	.561	3.630	6.46	.0339	1.216	122.1		
	.80	2.226		.900	.565	3.478	11.86	.0197	1.334	127.5		
	.90	2.157		.920	.559	3.370	26.23	.0097	1.478	133.4		
	1.00	2.105		.945	.592	3.289	76.89	.0037	1.660	138.0		
0.9	0.10	9.030	0.4971	0.900	0.569	11.148	1.15	0.0835	0.769	79.2	-33.1	0.7175
	.15	6.577		.900	.571	8.119	1.24	.0777	.798	85.2		
	.20	5.342		.900	.558	6.596	1.36	.0715	.829	91.0		
	.30	4.092		.900	.527	5.052	1.71	.0584	.898	101.7		
	.40	3.450		.900	.491	4.259	2.27	.0453	.977	111.5		
	.50	3.050		.900	.449	3.765	3.22	.0331	1.048	120.4		
	.60	2.778		.910	.451	3.430	4.94	.0225	1.173	126.1		
	.70	2.589		.925	.479	3.197	8.43	.0140	1.297	130.2		
	.80	2.480		.940	.518	3.025	16.62	.0076	1.447	134.2		
	.90	2.342		.955	.563	2.898	40.02	.0035	1.637	138.1		
	1.00	2.257		.965	.538	2.787	132.52	.0012	1.895	144.9		

TABLE II. - Continued. $1\frac{1}{2}$-STAGE TURBINES

(c) $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$

1. $\left(\frac{V'}{a}\right)_{2,h} = 0.8;\ \left(\frac{V_2'}{V_3'}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{F_1}{F_4}$	θ_1	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{h,3}$	$\left(\frac{V}{a}\right)_{3,h}$
0.5	0.10	5.491	0.5461	0.500	0.620	21.963	1.09	0.3770	0.888	77.9	-37.2	0.8903
	.15	3.829		.500	.595	15.314	1.14	.3628	.869	81.7		
	.20	3.000		.520	.594	11.999	1.20	.3480	.858	82.9		
	.30	2.193		.560	.590	8.774	1.34	.3156	.829	85.4		
	.40	1.816		.600	.584	7.263	1.53	.2799	.803	88.1		
	.50	1.613		.645	.583	6.451	1.81	.2408	.779	90.2		
	.60	1.500		.685	.569	6.000	2.24	.1991	.754	93.6		
	.70	1.441		.730	.559	5.764	2.93	.1568	.731	96.5		
	.80	1.417		.775	.545	5.667	4.17	.1142	.709	100.0		
	.90	1.417		.820	.525	5.666	6.59	.0758	.687	104.1		
	1.00	1.431		.868	.501	5.725	12.07	.0441	.666	108.9		
0.6	0.10	6.418	0.5425	0.600	0.623	17.812	1.11	0.3159	0.899	76.4	-35.3	0.8657
	.15	4.501		.600	.597	12.504	1.17	.3018	.883	80.7		
	.20	3.538		.600	.570	9.827	1.23	.2871	.866	84.9		
	.30	2.571		.625	.551	7.142	1.40	.2561	.834	89.4		
	.40	2.110		.665	.553	5.862	1.64	.2229	.808	91.8		
	.50	1.855		.700	.543	5.153	1.98	.1878	.772	95.1		
	.60	1.704		.740	.540	4.735	2.52	.1518	.748	97.8		
	.70	1.615		.775	.521	4.486	3.40	.1168	.713	101.9		
	.80	1.564		.815	.510	4.345	4.96	.0828	.685	105.3		
	.90	1.538		.855	.497	4.273	8.06	.0536	.658	109.0		
	1.00	1.529		.890	.462	4.246	15.15	.0305	.631	114.9		
0.7	0.10	7.311	0.5397	0.700	0.628	14.920	1.12	0.2477	0.911	75.1	-33.8	0.8470
	.15	5.166		.700	.601	10.543	1.19	.2348	.892	79.8		
	.20	4.083		.700	.573	8.334	1.27	.2214	.873	84.4		
	.30	2.981		.700	.516	6.083	1.48	.1935	.834	93.1		
	.40	2.426		.730	.511	4.952	1.77	.1651	.797	96.6		
	.50	2.112		.760	.503	4.310	2.20	.1361	.760	100.1		
	.60	1.918		.790	.492	3.914	2.86	.1074	.725	103.9		
	.70	1.794		.825	.490	3.661	3.97	.0802	.691	106.7		
	.80	1.713		.855	.471	3.495	5.96	.0557	.658	111.1		
	.90	1.659		.885	.447	3.386	9.94	.0353	.626	115.8		
	1.00	1.623		.915	.422	3.312	19.08	.0197	.595	120.8		
0.8	0.10	8.198	0.5374	0.800	0.634	12.809	1.14	0.1782	0.920	74.0	-32.5	0.8327
	.15	5.829		.800	.607	9.108	1.22	.1620	.898	79.0		
	.20	4.633		.800	.579	7.238	1.31	.1513	.876	84.0		
	.30	3.413		.800	.519	5.333	1.57	.1293	.831	93.5		
	.40	2.779		.800	.458	4.343	1.93	.1074	.787	102.4		
	.50	2.395		.825	.456	3.741	2.46	.0864	.745	105.8		
	.60	2.149		.850	.451	3.358	3.30	.0665	.705	109.2		
	.70	1.984		.870	.427	3.100	4.70	.0484	.666	114.2		
	.80	1.868		.895	.417	2.918	7.27	.0328	.629	117.9		
	.90	1.782		.920	.408	2.785	12.43	.0203	.594	121.5		
	1.00	1.717		.940	.374	2.683	24.32	.0111	.559	127.1		
0.9	0.10	9.074	0.5356	0.900	0.640	11.202	1.15	0.0896	0.927	73.0	-31.4	0.8212
	.15	6.489		.900	.614	8.011	1.24	.0836	.901	78.3		
	.20	5.184		.900	.585	6.400	1.36	.0774	.876	83.6		
	.30	3.853		.900	.525	4.757	1.66	.0645	.825	93.8		
	.40	3.159		.900	.461	3.900	2.12	.0519	.776	103.4		
	.50	2.721		.900	.396	3.359	2.81	.0403	.726	112.5		
	.60	2.414		.910	.369	2.980	3.90	.0301	.683	118.0		
	.70	2.197		.925	.360	2.713	5.74	.0213	.640	121.8		
	.80	2.037		.940	.351	2.515	9.12	.0141	.600	125.6		
	.90	1.914		.950	.308	2.364	15.98	.0085	.561	131.8		
	1.00	1.815		.965	.298	2.241	31.77	.0046	.525	135.4		

TABLE II. - Continued. $1\frac{1}{2}$-STAGE TURBINES

(c) Continued. $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$

2. $\left(\frac{V'}{a}\right)_{2,h} = 1.0$; $\left(\frac{V_2'}{V_3'}\right)_h < 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{4,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{p_1}{p_4}$	$\hat{w}_1$	$\left(\frac{V_2'}{V_3'}\right)_h$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$	$\left(\frac{V}{a}\right)_{3,h}$
0.5	0.40	2.123	0.5461	0.620	0.667	8.490	1.64	0.2623	0.978	92.8	-37.2	0.8903
	.50	1.871		.660	.657	7.485	2.00	.2204	.947	95.7		
	.60	1.725		.705	.654	6.901	2.55	.1772	.917	97.9		
	.70	1.641		.745	.631	6.563	3.47	.1344	.888	101.7		
	.80	1.596		.790	.617	6.385	5.16	.0944	.860	104.9		
	.90	1.578		.835	.597	6.312	8.63	.0596	.833	108.7		
	1.00	1.577		.875	.550	6.307	17.01	.0325	.806	114.7		
0.6	0.40	2.422	0.5425	0.680	0.637	6.727	1.77	0.2085	0.976	95.7	-35.3	0.8657
	.50	2.114		.715	.626	5.872	2.20	.1715	.938	99.0		
	.60	1.927		.750	.610	5.353	2.88	.1349	.901	102.6		
	.70	1.810		.790	.604	5.028	4.02	.0999	.865	105.5		
	.80	1.738		.825	.576	4.826	6.15	.0684	.830	110.0		
	.90	1.693		.865	.562	4.704	10.56	.0422	.796	113.6		
	1.00	1.667		.900	.522	4.631	21.34	.0225	.762	119.2		
0.7	0.40	2.746	0.5397	0.740	0.591	5.603	1.91	0.1540	0.969	99.9	-33.8	0.8470
	.50	2.373		.770	.581	4.843	2.44	.1239	.924	103.5		
	.60	2.139		.800	.568	4.366	3.28	.0952	.880	107.2		
	.70	1.986		.830	.550	4.052	4.71	.0688	.837	111.2		
	.80	1.881		.865	.547	3.839	7.39	.0460	.797	114.2		
	.90	1.808		.895	.521	3.690	13.03	.0277	.757	118.7		
	1.00	1.755		.920	.463	3.581	26.89	.0145	.717	125.6		
0.8	0.40	3.109	0.5374	0.805	0.530	4.858	2.09	0.0998	0.957	105.3	-32.5	0.8327
	.50	2.660		.830	.526	4.156	2.74	.0784	.905	108.8		
	.60	2.371		.855	.520	3.705	3.79	.0587	.855	112.3		
	.70	2.174		.875	.491	3.396	5.61	.0413	.807	117.3		
	.80	2.032		.900	.478	3.175	9.05	.0270	.760	121.1		
	.90	1.926		.925	.467	3.010	16.35	.0159	.716	124.7		
	1.00	1.843		.945	.425	2.880	34.35	.0088	.673	130.4		
0.9	0.40	3.511	0.5356	0.900	0.531	4.334	2.32	0.0479	0.943	106.6	-31.4	0.8212
	.50	2.996		.900	.451	3.699	3.16	.0363	.884	115.5		
	.60	2.639		.910	.417	3.258	4.51	.0264	.827	121.0		
	.70	2.386		.925	.403	2.946	6.89	.0181	.774	125.1		
	.80	2.199		.940	.386	2.715	11.45	.0115	.724	129.2		
	.90	2.054		.955	.371	2.536	21.16	.0066	.676	133.1		
	1.00	1.936		.965	.318	2.390	45.00	.0034	.630	139.6		

TABLE II. - Concluded. $1\frac{1}{2}$-STAGE TURBINES

(a) Concluded. $\left(\frac{V_x}{U}\right)_{3,m} = 0.7$

3. $\left(\frac{V'_2}{V'_3}\right)_h = 1.0$

$\left(\frac{r_h}{r_t}\right)_3$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-3}}{U_t^2}$	$\left(\frac{\rho V_x}{\rho_a a_{a,cr}}\right)_{4,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\left(\frac{V_x}{U}\right)_{2,m}$	$\frac{-gJ\Delta H_{1-3}}{U_{h,3}^2}$	$\frac{p_1}{p_4}$	θ_1	$\left(\frac{V'}{U}\right)_{2,h}$	$\Delta\beta_{h,2-3}$	$\alpha_{3,h}$	$\left(\frac{V}{U}\right)_{3,h}$
0.5	0.10	6.148	0.5461	0.500	0.653	24.894	1.10	0.3740	0.981	83.2	-37.2	0.8903
	.15	4.328		.520	.658	17.310	1.16	.3579	.937	84.9		
	.20	3.430		.540	.668	13.781	1.23	.3406	.954	86.6		
	.30	2.561		.580	.670	10.245	1.40	.3026	.990	90.0		
	.40	2.158		.620	.676	8.631	1.66	.2603	1.027	93.5		
	.50	1.943		.665	.691	7.771	2.05	.2150	1.067	96.3		
	.60	1.824		.705	.688	7.298	2.70	.1682	1.110	100.3		
	.70	1.761		.750	.698	7.043	3.85	.1225	1.155	103.7		
	.80	1.734		.790	.676	6.936	6.18	.0810	1.204	108.8		
	.90	1.731		.835	.664	6.928	11.29	.0468	1.258	113.6		
	1.00	1.742		.880	.640	6.966	25.94	.0223	1.316	119.3		
0.6	0.10	7.043	0.5425	0.600	0.658	19.564	1.12	0.3135	0.901	80.5	-35.3	0.8657
	.15	4.989		.600	.634	13.858	1.19	.2977	.920	85.2		
	.20	3.954		.605	.618	10.984	1.26	.2811	.941	89.0		
	.30	2.939		.640	.627	8.165	1.47	.2454	.983	93.1		
	.40	2.461		.680	.647	6.837	1.78	.2067	1.029	96.3		
	.50	2.200		.715	.653	6.110	2.27	.1664	1.079	100.4		
	.60	2.047		.750	.655	5.685	3.09	.1254	1.154	104.8		
	.70	1.957		.790	.670	5.436	4.29	.0888	1.195	108.4		
	.80	1.906		.825	.659	5.296	7.64	.0563	1.263	113.7		
	.90	1.882		.865	.662	5.226	14.98	.0308	1.339	118.3		
	1.00	1.872		.900	.622	5.201	37.31	.0136	1.429	125.4		
0.7	0.10	7.915	0.5397	0.700	0.663	16.154	1.13	0.2458	0.887	78.3	-33.8	0.8470
	.15	5.687		.700	.642	11.544	1.21	.2316	.909	83.5		
	.20	4.518		.700	.619	9.281	1.31	.2166	.933	88.4		
	.30	3.363		.710	.591	6.864	1.56	.1850	.983	96.2		
	.40	2.799		.740	.605	5.712	1.94	.1522	1.038	100.5		
	.50	2.482		.770	.618	5.066	2.55	.1191	1.100	104.8		
	.60	2.289		.800	.629	4.672	3.60	.0875	1.169	109.2		
	.70	2.167		.830	.637	4.423	5.57	.0592	1.247	115.8		
	.80	2.089		.860	.640	4.268	9.79	.0358	1.337	118.8		
	.90	2.038		.890	.632	4.159	20.48	.0185	1.443	124.5		
	1.00	2.005		.920	.611	4.092	55.71	.0076	1.573	131.1		
0.8	0.10	8.783	0.5374	0.800	0.670	13.723	1.15	0.1709	0.878	76.6	-32.5	0.8327
	.15	6.328		.800	.652	9.887	1.24	.1597	.903	82.1		
	.20	5.091		.800	.631	7.955	1.35	.1478	.929	87.4		
	.30	3.836		.800	.586	5.992	1.66	.1229	.968	97.5		
	.40	3.187		.805	.550	4.979	2.13	.0961	1.054	105.8		
	.50	2.803		.830	.575	4.380	2.91	.0743	1.128	109.9		
	.60	2.561		.850	.580	4.002	4.29	.0526	1.213	115.1		
	.70	2.399		.875	.606	3.748	6.98	.0340	1.312	119.2		
	.80	2.286		.895	.601	3.572	13.00	.0195	1.429	125.0		
	.90	2.205		.920	.626	3.445	29.26	.0094	1.572	129.6		
	1.00	2.143		.940	.593	3.349	87.89	.0035	1.757	136.9		
0.9	0.10	9.644	0.5356	0.900	0.677	11.906	1.16	0.0889	0.871	75.1	-31.4	0.8212
	.15	7.001		.900	.663	8.643	1.26	.0884	.899	80.9		
	.20	5.669		.900	.647	6.999	1.39	.0755	.929	86.5		
	.30	4.317		.900	.609	5.330	1.77	.0610	.996	97.1		
	.40	3.620		.900	.564	4.470	2.38	.0467	1.073	107.0		
	.50	3.185		.900	.513	3.932	3.43	.0338	1.163	116.1		
	.60	2.881		.910	.513	3.557	5.32	.0228	1.267	121.9		
	.70	2.669		.920	.506	3.295	9.19	.0140	1.391	127.2		
	.80	2.518		.935	.532	3.101	18.37	.0075	1.542	132.2		
	.90	2.391		.950	.563	2.952	45.12	.0034	1.734	136.9		
	1.00	2.292		.960	.516	2.830	151.87	.0011	1.996	144.4		

TABLE III. - 2-STAGE TURBINES

(a) $\left(\frac{V_z}{a}\right)_{5,m} = 0.5$

1. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \leq 0.6; \left(\frac{V_2}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4}{V_5'}\right)_h \leq 1.0$

$\left(\frac{r_h}{r_t}\right)_5$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-5}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{5,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\frac{\Delta H_{1-3}}{\Delta H_{3-5}}$	$\frac{-gJ\Delta H_{1-5}}{U_{h,5}^2}$	$\frac{P_1}{P_5}$	$\hat{w}_1$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\alpha_{2,h}$
0.5	0.20	3.052	0.4676	0.500	2.149	12.208	1.18	0.3020	0.445	47.5
	.30	2.688	.4669	.555	1.868	10.753	1.40	.2591	.426	53.1
	.40	2.585	.4660	.635	1.703	10.339	1.81	.2059	.416	57.9
	.50	2.526	.4646	.715	1.749	10.106	2.55	.1509	.406	62.3
	.60	2.594	.4622	.795	1.827	10.377	4.31	.0940	.385	67.3
	.70	2.725	.4581	.875	1.925	10.899	9.59	.0456	.358	71.8
	.80	2.821	.4509	.935	2.030	11.283	30.35	.0160	.305	76.7
0.6	0.20	4.004	0.4674	0.600	2.111	11.121	1.25	0.2456	0.434	50.1
	.30	3.417	.4666	.620	1.752	9.492	1.54	.2028	.382	58.7
	.40	3.137	.4654	.695	1.661	8.714	2.07	.1553	.375	62.6
	.50	3.009	.4637	.765	1.685	8.359	3.12	.1072	.357	67.0
	.60	3.023	.4608	.845	1.727	8.398	5.77	.0616	.348	70.5
	.70	3.091	.4558	.910	1.789	8.585	14.40	.0269	.312	74.9
	.80	3.103	.4470	.960	1.843	8.621	51.64	.0084	.277	78.3
0.7	0.20	4.959	0.4672	0.700	2.031	10.120	1.32	0.1864	0.424	52.4
	.30	4.252	.4661	.700	1.673	8.678	1.72	.1461	.344	63.2
	.40	3.750	.4648	.750	1.625	7.653	2.42	.1075	.318	68.0
	.50	3.523	.4627	.820	1.625	7.190	3.91	.0697	.312	71.0
	.60	3.457	.4592	.885	1.638	7.054	7.90	.0369	.294	74.3
	.70	3.440	.4531	.940	1.661	7.021	22.02	.0146	.268	77.5
	.80	3.365	.4425	.975	1.681	6.867	89.63	.0041	.225	80.8
0.8	0.20	5.964	0.4670	0.800	1.954	9.319	1.39	0.1249	0.416	54.4
	.30	5.112	.4657	.800	1.654	7.987	1.94	.0927	.326	65.9
	.40	4.436	.4640	.815	1.591	6.932	2.91	.0644	.262	72.8
	.50	4.070	.4615	.865	1.567	6.359	5.03	.0392	.242	76.0
	.60	3.890	.4573	.920	1.553	6.077	11.07	.0192	.231	78.2
	.70	3.771	.4501	.965	1.541	5.892	34.19	.0069	.229	79.6
	.80	3.609	.4371	.985	1.537	5.639	160.13	.0017	.162	83.5
0.9	0.20	7.037	0.4667	0.900	1.891	8.688	1.48	0.0623	0.407	56.3
	.30	5.986	.4652	.900	1.656	7.390	2.20	.0438	.310	68.1
	.40	5.210	.4631	.900	1.571	6.433	3.60	.0280	.218	76.5
	.50	4.670	.4600	.915	1.504	5.765	6.75	.0159	.162	81.0
	.60	4.329	.4551	.955	1.470	5.345	16.01	.0073	.163	82.0
	.70	4.086	.4466	.980	1.433	5.045	54.31	.0024	.145	83.6

2. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \leq 0.8; \left(\frac{V_2}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4}{V_5'}\right)_h \leq 1.0$

$\left(\frac{r_h}{r_t}\right)_5$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-5}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{5,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\frac{\Delta H_{1-3}}{\Delta H_{3-5}}$	$\frac{-gJ\Delta H_{1-5}}{U_{h,5}^2}$	$\frac{P_1}{P_5}$	$\hat{w}_1$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\alpha_{2,h}$
0.5	0.20	3.173	0.4675	0.500	2.249	12.692	1.19	0.3002	0.448	49.7
	.30	3.140	.4667	.515	2.236	12.558	1.49	.2457	.401	62.6
	.40	3.228	.4653	.660	2.179	12.913	2.12	.1783	.443	63.8
	.50	3.482	.4628	.780	2.136	13.927	3.84	.1043	.446	66.7
	.60	3.593	.4586	.875	2.039	14.372	8.77	.0494	.442	69.7
	.70	3.527	.4524	.930	2.131	14.107	24.61	.0194	.387	74.4
	.80	3.405	.4417	.965	2.215	13.621	98.14	.0055	.288	79.7
0.6	0.20	4.296	0.4673	0.600	2.297	11.934	1.27	0.2420	0.443	53.9
	.30	4.154	.4662	.630	2.238	11.540	1.70	.1855	.403	64.6
	.40	4.060	.4644	.730	2.108	11.277	2.63	.1254	.400	67.3
	.50	4.042	.4615	.835	1.935	11.228	4.97	.0705	.419	68.9
	.60	3.985	.4569	.905	1.903	11.068	11.96	.0318	.394	72.5
	.70	3.842	.4494	.950	1.959	10.672	37.82	.0112	.331	77.0
	.80	3.644	.4362	.980	1.999	10.122	175.04	.0028	.266	80.7
0.7	0.20	5.559	0.4670	0.700	2.333	11.345	1.36	0.1807	0.442	57.2
	.30	5.187	.4656	.700	2.159	10.586	1.96	.1301	.351	68.8
	.40	4.794	.4636	.800	1.962	9.785	3.20	.0835	.371	69.8
	.50	4.627	.4601	.875	1.775	9.443	5.61	.0434	.356	72.8
	.60	4.374	.4549	.930	1.785	8.927	16.65	.0188	.332	75.7
	.70	4.143	.4459	.965	1.806	8.455	59.28	.0059	.263	79.9
	.80	3.869	.4297	.985	1.821	7.895	324.98	.0012	.167	84.3
0.8	0.20	6.955	0.4667	0.800	2.363	10.867	1.48	0.1186	0.445	59.8
	.30	6.300	.4650	.800	2.103	9.843	2.30	.0796	.330	70.9
	.40	5.558	.4626	.850	1.821	8.684	3.97	.0485	.298	74.4
	.50	5.138	.4587	.910	1.692	8.029	8.60	.0241	.288	76.6
	.60	4.758	.4526	.955	1.676	7.434	23.64	.0096	.279	78.3
	.70	4.431	.4419	.980	1.666	6.924	95.40	.0027	.220	81.7
0.9	0.20	8.431	0.4664	0.900	2.370	10.408	1.61	0.0579	0.450	61.6
	.30	7.371	.4643	.900	2.014	9.100	2.69	.0365	.313	72.6
	.40	6.430	.4614	.905	1.697	7.938	-5.14	.0203	.205	79.7
	.50	5.677	.4571	.940	1.615	7.008	11.55	.0097	.183	81.7
	.60	5.140	.4500	.975	1.577	6.345	34.45	.0036	.197	81.9
	.70	4.708	.4372	.990	1.541	5.812	158.26	.0009	.151	84.4

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TABLE III. - 2-STAGE TURBINES

(a) $\left(\frac{V_z}{a}\right)_{5,m} = 0.5$

1. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \leq 0.6; \left(\frac{V'_2}{V'_3}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V'_4}{V'_5}\right)_h \leq 1.0$

$\Delta\beta_{h,2-3}$	$\Delta\alpha_{h,3-4}$	$\Delta\beta_{h,4-5}$	$\alpha_{5,h}$	$\left(\frac{V'_2}{V'_3}\right)_h$	$\left(\frac{V'}{a}\right)_{2,h}$	$\left(\frac{V_3}{V_4}\right)_t$	$\left(\frac{V}{a}\right)_{3,h}$	$\left(\frac{V'_4}{V'_5}\right)_h$	$\left(\frac{V'}{a}\right)_{4,h}$	$\frac{U_t}{a_{a,cr,1}}$	$\left(\frac{r_h}{r_t}\right)_5$
81.2	64.3	41.5	-8.1	0.953	0.600	1.000	0.575	1.000	0.527	0.20	0.5
90.2	77.8	56.6	-11.6	.862	.600	.983	.600	1.000	.559	.30	
95.9	86.9	71.1	-15.4	.801	.600	.932	.600	.994	.600	.40	
102.0	93.5	81.0	-19.4	.735	.600	.901	.600	.909	.600	.50	
111.2	104.2	93.1	-24.4	.661	.600	.846	.600	.814	.600	.60	
122.2	119.5	107.7	-30.6	.583	.600	.765	.600	.710	.600	.70	
136.8	139.5	124.9	-37.9	.513	.600	.670	.600	.604	.600	.80	
86.9	71.0	45.7	-8.3	0.902	0.600	1.000	0.595	1.000	0.535	0.20	0.6
101.1	87.5	63.9	-11.7	.833	.600	.921	.600	1.000	.574	.30	
105.9	94.2	75.9	-15.3	.768	.600	.867	.600	.956	.600	.40	
113.1	101.8	86.5	-19.3	.699	.600	.820	.600	.862	.600	.50	
120.0	112.1	98.7	-24.2	.626	.600	.755	.600	.761	.600	.60	
131.8	128.8	114.4	-30.3	.552	.600	.670	.600	.654	.600	.70	
143.2	148.5	131.9	-37.5	.490	.600	.587	.600	.550	.600	.80	
90.7	75.3	49.6	-8.5	0.876	0.600	0.980	0.600	1.000	0.543	0.20	0.7
110.4	95.9	70.6	-12.0	.802	.600	.854	.600	1.000	.592	.30	
118.0	103.4	81.6	-15.5	.734	.600	.797	.600	.916	.600	.40	
122.8	109.7	91.8	-19.4	.665	.600	.744	.600	.813	.600	.50	
130.4	120.9	104.7	-24.3	.594	.600	.673	.600	.707	.600	.60	
140.2	137.5	120.7	-30.5	.527	.600	.595	.600	.600	.600	.70	
151.5	156.6	138.6	-37.7	.472	.600	.524	.600	.500	.600	.80	
94.0	78.9	53.3	-8.7	0.858	0.600	0.949	0.600	1.000	0.552	0.20	0.8
115.5	100.1	74.5	-12.4	.774	.600	.807	.600	.981	.600	.30	
129.5	112.8	87.7	-15.9	.700	.600	.734	.600	.873	.600	.40	
135.8	120.3	98.4	-19.8	.632	.600	.672	.600	.763	.600	.50	
141.4	130.2	110.8	-24.7	.567	.600	.606	.600	.654	.600	.60	
147.4	145.3	126.8	-30.9	.506	.600	.536	.600	.549	.600	.70	
160.1	163.4	144.9	-38.4	.458	.600	.474	.600	.454	.600	.80	
97.3	82.4	56.7	-8.9	0.839	0.600	0.911	0.600	1.000	0.562	0.20	0.9
120.0	103.6	77.4	-12.7	.747	.600	.771	.600	.949	.600	.30	
138.5	120.8	93.2	-16.5	.667	.600	.684	.600	.828	.600	.40	
149.6	133.0	106.4	-20.5	.601	.600	.612	.600	.712	.600	.50	
152.4	139.8	117.3	-25.4	.542	.600	.551	.600	.604	.600	.60	
158.9	153.8	133.1	-31.6	.489	.600	.489	.600	.502	.600	.70	

2. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \leq 0.8; \left(\frac{V'_2}{V'_3}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V'_4}{V'_5}\right)_h \leq 1.0$

84.0	64.6	41.8	-8.3	1.000	0.633	1.000	0.575	1.000	0.528	0.20	0.5
109.4	88.1	60.6	-12.5	1.000	.766	1.000	.654	1.000	.563	.30	
109.7	94.0	74.3	-17.3	.923	.800	1.000	.691	1.000	.617	.40	
116.1	108.5	91.8	-23.4	.761	.800	1.000	.798	1.000	.699	.50	
123.8	123.2	109.7	-29.9	.689	.800	.869	.800	.983	.800	.60	
136.2	139.2	124.2	-36.7	.626	.800	.797	.800	.842	.800	.70	
151.2	156.5	139.5	-44.2	.572	.800	.723	.800	.706	.800	.80	
92.1	71.5	46.3	-8.6	1.000	0.672	1.000	0.597	1.000	0.536	0.20	0.6
113.9	93.6	65.8	-13.0	.962	.800	1.000	.691	1.000	.581	.30	
118.9	104.7	81.4	-17.7	.810	.800	1.000	.784	1.000	.647	.40	
121.7	114.4	97.9	-23.1	.734	.800	.891	.800	1.000	.742	.50	
131.2	128.9	113.8	-29.1	.666	.800	.788	.800	.922	.800	.60	
143.9	146.0	129.2	-35.9	.605	.800	.716	.800	.779	.800	.70	
155.3	162.6	145.0	-43.6	.556	.800	.650	.800	.646	.800	.80	
98.9	77.7	50.6	-9.0	1.000	0.715	1.000	0.621	1.000	0.545	0.20	0.7
124.0	104.9	73.2	-13.4	.869	.800	1.000	.758	1.000	.601	.30	
124.4	110.5	87.3	-17.9	.774	.800	.928	.800	1.000	.680	.40	
131.2	122.0	104.2	-23.2	.708	.800	.785	.800	1.000	.795	.50	
139.4	135.1	118.2	-28.9	.645	.800	.719	.800	.858	.800	.60	
152.0	152.5	134.3	-35.7	.588	.800	.651	.800	.716	.800	.70	
164.6	168.0	150.3	-43.7	.543	.800	.591	.800	.588	.800	.80	
104.5	83.2	54.7	-9.4	1.000	0.762	1.000	0.647	1.000	0.555	0.20	0.8
128.5	110.3	78.4	-13.9	.812	.800	.988	.800	1.000	.623	.30	
135.2	119.7	94.4	-18.2	.749	.800	.834	.800	1.000	.718	.40	
140.3	128.5	108.5	-23.2	.686	.800	.724	.800	.945	.800	.50	
146.5	141.0	122.5	-29.0	.626	.800	.662	.800	.795	.800	.60	
157.5	158.1	139.2	-35.9	.573	.800	.599	.800	.656	.800	.70	
108.9	88.0	58.5	-9.8	0.988	0.800	1.000	0.675	1.000	0.566	0.20	0.9
132.0	114.0	82.9	-14.3	.790	.800	.930	.800	1.000	.648	.30	
148.2	131.4	102.8	-18.8	.723	.800	.750	.800	1.000	.763	.40	
153.3	138.6	114.5	-23.6	.663	.800	.672	.800	.883	.800	.50	
155.8	147.7	127.1	-29.3	.608	.800	.614	.800	.735	.800	.60	
164.6	163.3	144.0	-36.5	.560	.800	.554	.800	.600	.800	.70	

TABLE III. - Continued. 2-STAGE TURBINES

(b) $\left(\frac{V_z}{a}\right)_{5,m} = 0.6$

1. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \le 0.6;\ \left(\frac{V_2'}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4'}{V_5'}\right)_h \le 1.0$

$\left(\frac{r_h}{r_t}\right)_5$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-5}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{5,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\frac{\Delta H_{1-3}}{\Delta H_{3-5}}$	$\frac{-gJ\Delta H_{1-5}}{U_{h,5}^2}$	$\frac{P_1}{P_5}$	$\hat{w}_1$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\alpha_{2,h}$
0.5	0.10	2.490	0.5282	0.500	1.664	9.958	1.03	0.3845	0.580	18.5
	.15	2.458	.5279	.500	1.643	9.832	1.08	.3703	.558	27.1
	.20	2.410	.5275	.500	1.619	9.640	1.14	.3518	.528	35.0
	.30	2.294	.5262	.500	1.560	9.175	1.33	.3056	.458	48.4
	.40	2.203	.5244	.550	1.544	8.813	1.65	.2517	.418	56.2
	.50	2.279	.5214	.650	1.589	9.117	2.31	.1852	.403	61.5
	.60	2.490	.5159	.765	1.668	9.961	4.02	.1115	.391	66.3
	.70	2.760	.5056	.870	1.778	11.038	9.95	.0486	.365	71.4
	.80	2.924	.4872	.940	1.880	11.696	36.60	.0146	.304	76.8
0.6	0.10	3.330	0.5282	0.600	1.708	9.251	1.05	0.3247	0.576	20.8
	.15	3.275	.5277	.600	1.680	9.097	1.11	.3088	.549	30.3
	.20	3.205	.5271	.600	1.651	8.904	1.19	.8883	.514	38.9
	.30	3.034	.5254	.600	1.582	8.427	1.47	.2389	.432	53.2
	.40	2.861	.5230	.630	1.535	7.947	1.93	.1856	.370	62.2
	.50	2.859	.5191	.725	1.555	7.942	2.93	.1271	.358	66.4
	.60	3.001	.5128	.825	1.598	8.337	5.68	.0694	.343	70.6
	.70	3.174	.4995	.910	1.660	8.817	15.88	.0270	.313	74.8
	.80	3.219	.4774	.960	1.719	8.941	65.35	.0073	.243	79.8
0.7	0.10	4.240	0.5281	0.700	1.734	8.652	1.06	0.2559	0.573	22.9
	.15	4.165	.5275	.700	1.707	8.499	1.14	.2400	.541	33.1
	.20	4.070	.5267	.700	1.674	8.306	1.25	.2199	.501	42.3
	.30	3.837	.5245	.700	1.595	7.831	1.63	.1728	.407	57.3
	.40	3.578	.5213	.710	1.520	7.302	2.32	.1254	.319	67.5
	.50	3.460	.5165	.795	1.516	7.060	3.80	.0798	.310	70.8
	.60	3.498	.5080	.880	1.525	7.140	8.16	.0397	.301	73.8
	.70	3.553	.4928	.945	1.544	7.251	25.48	.0139	.280	76.9
	.80	3.486	.4663	.975	1.570	7.114	118.39	.0033	.187	82.4
0.8	0.10	5.218	0.5280	0.800	1.756	8.153	1.07	0.1784	0.569	24.7
	.15	5.124	.5273	.800	1.728	8.007	1.17	.1649	.534	35.7
	.20	5.002	.5263	.800	1.691	7.815	1.32	.1479	.489	45.3
	.30	4.699	.5234	.800	1.603	7.342	1.83	.1096	.383	60.8
	.40	4.357	.5194	.800	1.508	6.808	2.84	.0735	.275	71.7
	.50	4.082	.5134	.855	1.471	6.379	5.07	.0434	.247	75.5
	.60	3.980	.5033	.920	1.451	6.218	11.91	.0198	.238	77.8
	.70	3.902	.4853	.965	1.439	6.097	41.22	.0063	.210	80.5
	.80	3.732	.4532	.985	1.434	5.831	280.65	.0013	.127	84.9
0.9	0.10	6.265	0.5278	0.900	1.775	7.735	1.09	0.0930	0.566	26.4
	.15	6.147	.5270	.900	1.744	7.589	1.21	.0845	.528	38.0
	.20	5.997	.5258	.900	1.705	7.404	1.40	.0741	.478	48.1
	.30	5.616	.5223	.900	1.607	6.933	2.08	.0515	.361	63.9
	.40	5.181	.5171	.900	1.501	6.397	3.57	.0315	.244	74.8
	.50	4.745	.5098	.900	1.403	5.859	7.01	.0170	.146	81.8
	.60	4.452	.4979	.955	1.375	5.496	17.84	.0072	.162	82.0
	.70	4.225	.4768	.985	1.335	5.217	67.61	.0021	.170	82.5

2. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \le 0.8;\ \left(\frac{V_2'}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4'}{V_5'}\right)_h \le 1.0$

$\left(\frac{r_h}{r_t}\right)_5$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-5}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{5,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\frac{\Delta H_{1-3}}{\Delta H_{3-5}}$	$\frac{-gJ\Delta H_{1-5}}{U_{h,5}^2}$	$\frac{P_1}{P_5}$	$\hat{w}_1$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\alpha_{2,h}$
0.5	0.10	3.848	0.5281	0.500	2.091	15.390	1.05	0.3781	0.579	28.2
	.15	3.818	.5276	.500	2.080	15.273	1.12	.3564	.554	39.8
	.20	3.790	.5268	.500	2.073	15.161	1.23	.3280	.521	49.5
	.30	3.549	.5248	.540	1.949	14.194	1.57	.2632	.466	59.2
	.40	3.559	.5214	.680	1.851	14.834	2.31	.1853	.493	60.6
	.50	3.589	.5159	.780	1.812	14.356	4.03	.1113	.474	64.9
	.60	3.614	.5069	.865	1.893	14.457	8.91	.0538	.441	69.6
	.70	3.624	.4914	.930	1.986	14.497	27.99	.0188	.376	74.8
	.80	3.517	.4648	.970	2.058	14.067	187.45	.0046	.284	79.9
0.6	0.10	5.076	0.5280	0.600	2.136	14.100	1.07	0.3178	0.578	30.9
	.15	5.052	.5273	.600	2.131	14.033	1.17	.2937	.551	43.2
	.20	5.017	.5263	.600	2.123	13.937	1.32	.2627	.516	53.1
	.30	4.522	.5237	.645	1.930	12.561	1.79	.1993	.455	61.1
	.40	4.256	.5196	.735	1.742	11.821	2.77	.1339	.436	65.1
	.50	4.113	.5133	.825	1.731	11.426	5.14	.0760	.423	68.6
	.60	4.052	.5025	.900	1.777	11.255	12.64	.0333	.389	72.6
	.70	3.960	.4839	.955	1.825	11.000	44.88	.0103	.348	76.6
	.80	3.759	.4515	.980	1.867	10.443	238.13	.0022	.212	82.6
0.7	0.10	6.434	0.5278	0.700	2.173	13.130	1.09	0.2490	0.578	33.4
	.15	6.407	.5269	.700	2.168	13.076	1.22	.2252	.552	46.0
	.20	6.269	.5257	.700	2.121	12.794	1.42	.1961	.510	55.3
	.30	5.470	.5225	.710	1.829	11.162	2.04	.1409	.394	66.0
	.40	4.993	.5177	.790	1.660	10.190	3.38	.0888	.374	69.5
	.50	4.653	.5103	.865	1.660	9.496	6.69	.0476	.358	72.6
	.60	4.477	.4976	.930	1.670	9.138	18.25	.0189	.334	75.6
	.70	4.275	.4754	.970	1.686	8.725	73.30	.0052	.273	79.6
	.80	3.990	.4352	.990	1.696	8.143	471.24	.0009	.184	83.7
0.8	0.10	7.903	0.5277	0.800	2.201	12.348	1.11	0.1726	0.580	35.5
	.15	7.879	.5265	.800	2.197	12.311	1.28	.1523	.556	48.3
	.20	7.554	.5250	.800	2.097	11.808	1.53	.1293	.501	56.9
	.30	6.526	.5211	.800	1.767	10.197	2.37	.0866	.358	69.1
	.40	5.728	.5155	.840	1.615	8.951	4.17	.0518	.296	74.5
	.50	5.207	.5069	.905	1.592	8.136	8.92	.0258	.290	76.4
	.60	4.889	.4920	.955	1.571	7.639	26.81	.0094	.271	78.6
	.70	4.569	.4657	.980	1.559	7.140	122.00	.0023	.187	83.0
0.9	0.10	9.478	0.5275	0.900	2.224	11.701	1.14	0.0893	0.584	37.3
	.15	9.459	.5261	.900	2.221	11.677	1.34	.0768	.564	50.1
	.20	8.922	.5243	.900	2.076	11.015	1.66	.0634	.491	58.5
	.30	7.645	.5195	.900	1.723	9.438	2.80	.0393	.337	71.1
	.40	6.569	.5128	.900	1.570	8.110	5.37	.0217	.208	79.5
	.50	5.792	.5029	.940	1.523	7.151	12.34	.0101	.189	81.4
	.60	5.289	.4857	.975	1.478	6.530	40.27	.0034	.186	82.4
	.70	4.851	.4543	.990	1.441	5.989	210.54	.0007	.122	85.5

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TABLE III. - Continued. 2-STAGE TURBINES

(b) $\left(\frac{V_x}{a}\right)_{5,m} = 0.6$

1. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \leq 0.6; \left(\frac{V_2'}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4'}{V_5'}\right)_h \leq 1.0$

$\Delta\beta_{h,2-3}$	$\Delta\alpha_{h,3-4}$	$\Delta\beta_{h,4-5}$	$\alpha_{5,h}$	$\left(\frac{V_2'}{V_3'}\right)_h$	$\left(\frac{V'}{a}\right)_{2,h}$	$\left(\frac{V_3}{V_4}\right)_t$	$\left(\frac{V}{a}\right)_{3,h}$	$\left(\frac{V_4'}{V_5'}\right)_h$	$\left(\frac{V'}{a}\right)_{4,h}$	$\frac{U_t}{a_{a,cr,1}}$	$\left(\frac{r_h}{r_t}\right)_5$
28.4	22.5	17.0	- 4.3	0.985	0.600	0.994	0.600	0.989	0.600	0.10	0.5
42.1	33.5	25.4	- 6.4	.967	.600	.986	.600	.975	.600	.15	
55.0	44.1	33.6	- 8.5	.943	.600	.976	.600	.957	.600	.20	
78.5	64.1	49.3	-12.6	.888	.600	.947	.600	.910	.600	.30	
91.2	75.7	61.3	-16.6	.829	.600	.927	.600	.853	.600	.40	
98.5	84.2	72.7	-21.5	.761	.600	.908	.600	.784	.600	.50	
107.4	96.7	87.2	-27.7	.678	.600	.861	.600	.701	.600	.60	
120.5	116.9	105.9	-35.4	.587	.600	.771	.600	.606	.600	.70	
137.6	141.7	126.8	-44.0	.510	.600	.665	.600	.511	.600	.80	
32.0	25.2	18.7	- 4.4	0.979	0.600	0.990	0.600	0.986	0.600	0.10	0.6
47.1	37.4	27.9	- 6.6	.955	.600	.978	.600	.969	.600	.15	
61.5	49.2	36.8	- 8.8	.926	.600	.961	.600	.947	.600	.20	
87.2	71.3	54.0	-13.0	.856	.600	.918	.600	.890	.600	.30	
103.9	86.6	68.1	-17.1	.787	.600	.869	.600	.823	.600	.40	
110.4	94.8	79.6	-21.9	.715	.600	.831	.600	.747	.600	.50	
119.2	108.0	94.5	-28.0	.635	.600	.764	.600	.659	.600	.60	
131.6	128.6	113.7	-35.5	.552	.600	.670	.600	.565	.600	.70	
147.9	152.0	134.3	-43.9	.488	.600	.582	.600	.474	.600	.80	
35.1	27.6	20.2	- 4.6	0.973	0.600	0.985	0.600	0.983	0.600	0.10	0.7
51.7	40.9	30.1	- 6.8	.943	.600	.967	.600	.963	.600	.15	
67.3	53.8	39.8	- 9.1	.906	.600	.942	.600	.936	.600	.20	
95.0	77.7	58.4	-13.4	.825	.600	.877	.600	.869	.600	.30	
115.9	97.3	74.9	-17.7	.746	.600	.804	.600	.792	.600	.40	
121.5	105.0	86.2	-22.5	.674	.600	.753	.600	.708	.600	.50	
128.7	117.9	101.3	-28.6	.598	.600	.679	.600	.617	.600	.60	
139.2	138.3	120.8	-36.0	.526	.600	.593	.600	.524	.600	.70	
156.4	160.3	141.3	-44.3	.471	.600	.520	.600	.437	.600	.80	
38.0	29.7	21.6	- 4.7	0.967	0.600	0.979	0.600	0.980	0.600	0.10	0.8
55.8	44.1	32.2	- 7.0	.931	.600	.954	.600	.956	.600	.15	
72.6	58.0	42.5	- 9.4	.887	.600	.921	.600	.924	.600	.20	
102.0	83.7	62.4	-13.9	.793	.600	.837	.600	.846	.600	.30	
125.9	106.5	81.0	-18.5	.708	.600	.745	.600	.758	.600	.40	
134.0	116.5	93.6	-23.3	.637	.600	.679	.600	.669	.600	.50	
140.3	128.7	108.4	-29.3	.568	.600	.608	.600	.576	.600	.60	
150.2	147.9	127.9	-36.6	.505	.600	.533	.600	.485	.600	.70	
164.4	166.8	147.7	-45.1	.457	.600	.472	.600	.403	.600	.80	
40.6	31.8	22.9	- 4.8	0.960	0.600	0.972	0.600	0.976	0.600	0.10	0.9
59.7	47.1	34.1	- 7.3	.917	.600	.939	.600	.948	.600	.15	
77.5	61.9	45.1	- 9.7	.867	.600	.897	.600	.912	.600	.20	
108.5	89.3	66.2	-14.5	.763	.600	.798	.600	.822	.600	.30	
133.2	113.4	86.0	-19.3	.673	.600	.698	.600	.724	.600	.40	
151.8	134.1	104.6	-24.3	.602	.600	.610	.600	.629	.600	.50	
152.6	140.0	116.0	-30.2	.542	.600	.551	.600	.536	.600	.60	
156.8	155.4	134.3	-37.5	.488	.600	.487	.600	.449	.600	.70	

2. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \leq 0.8; \left(\frac{V_2'}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4'}{V_5'}\right)_h \leq 1.0$

$\Delta\beta_{h,2-3}$	$\Delta\alpha_{h,3-4}$	$\Delta\beta_{h,4-5}$	$\alpha_{5,h}$	$\left(\frac{V_2'}{V_3'}\right)_h$	$\left(\frac{V'}{a}\right)_{2,h}$	$\left(\frac{V_3}{V_4}\right)_t$	$\left(\frac{V}{a}\right)_{3,h}$	$\left(\frac{V_4'}{V_5'}\right)_h$	$\left(\frac{V'}{a}\right)_{4,h}$	$\frac{U_t}{a_{a,cr,1}}$	$\left(\frac{r_h}{r_t}\right)_5$
46.0	34.6	22.6	- 5.4	1.000	0.639	1.000	0.623	1.000	0.609	0.10	0.5
66.2	50.7	33.7	- 8.1	1.000	.684	1.000	.650	1.000	.620	.15	
84.1	65.7	44.5	-10.7	1.000	.746	1.000	.688	1.000	.637	.20	
102.9	85.7	62.5	-15.8	.926	.800	1.000	.758	1.000	.681	.30	
103.5	93.2	77.1	-21.5	.831	.800	.996	.800	1.000	.748	.40	
111.7	105.3	92.8	-27.7	.765	.800	.928	.800	.952	.800	.50	
122.7	120.3	107.8	-34.6	.694	.800	.873	.800	.833	.800	.60	
137.5	140.1	125.2	-42.4	.625	.800	.795	.800	.709	.800	.70	
152.6	159.6	142.4	-50.6	.570	.800	.720	.800	.593	.800	.80	
50.5	37.8	24.5	- 5.5	1.000	0.649	1.000	0.628	1.000	0.611	0.10	0.6
72.2	55.4	36.5	- 8.3	1.000	.708	1.000	.662	1.000	.625	.15	
91.0	71.5	48.2	-11.1	1.000	.785	1.000	.709	1.000	.645	.20	
107.0	90.8	66.5	-16.1	.864	.800	1.000	.800	1.000	.698	.30	
113.3	101.1	82.6	-21.3	.804	.800	.912	.800	1.000	.775	.40	
120.2	111.6	96.6	-27.2	.738	.800	.854	.800	.914	.800	.50	
131.0	127.6	112.4	-34.0	.668	.800	.789	.800	.790	.800	.60	
143.6	147.6	130.5	-41.8	.604	.800	.715	.800	.667	.800	.70	
160.4	165.9	147.9	-50.2	.555	.800	.648	.800	.554	.800	.80	
54.6	40.9	26.3	- 5.6	1.000	0.661	1.000	0.634	1.000	0.613	0.10	0.7
77.4	59.6	39.2	- 8.5	1.000	.732	1.000	.676	1.000	.630	.15	
95.7	76.4	51.6	-11.3	.972	.800	1.000	.732	1.000	.654	.20	
117.2	99.8	72.8	-16.3	.840	.800	.937	.800	1.000	.717	.30	
123.3	109.0	88.0	-21.5	.778	.800	.834	.800	.991	.800	.40	
129.9	118.8	100.9	-27.1	.712	.800	.785	.800	.870	.800	.50	
139.2	134.8	117.3	-33.9	.645	.800	.719	.800	.744	.800	.60	
152.0	154.8	135.9	-41.8	.586	.800	.650	.800	.622	.800	.70	
164.2	170.9	153.1	-50.6	.541	.800	.590	.800	.513	.800	.80	
58.2	43.7	28.0	- 5.8	1.000	0.673	1.000	0.641	1.000	0.616	0.10	0.8
81.8	63.4	41.7	- 8.8	1.000	.759	1.000	.690	1.000	.636	.15	
99.3	80.6	54.6	-11.6	.928	.800	1.000	.757	1.000	.664	.20	
123.7	105.8	77.7	-16.7	.817	.800	.882	.800	1.000	.740	.30	
134.9	118.1	93.2	-21.8	.751	.800	.778	.800	.951	.800	.40	
139.5	126.4	105.6	-27.4	.688	.800	.726	.800	.824	.800	.50	
147.4	141.9	122.2	-34.2	.625	.800	.661	.800	.697	.800	.60	
160.9	161.1	141.3	-42.2	.572	.800	.596	.800	.578	.800	.70	
61.5	46.3	29.6	- 6.0	1.000	0.687	1.000	0.648	1.000	0.618	0.10	0.9
85.6	66.8	44.1	- 9.1	1.000	.787	1.000	.706	1.000	.642	.15	
102.7	84.3	57.5	-12.0	.887	.800	1.000	.783	1.000	.675	.20	
128.2	109.7	81.5	-17.3	.794	.800	.834	.800	1.000	.765	.30	
147.5	129.4	100.1	-22.4	.724	.800	.731	.800	.907	.800	.40	
152.3	137.1	118.0	-28.0	.664	.800	.674	.800	.777	.800	.50	
157.2	149.4	127.5	-34.7	.608	.800	.612	.800	.651	.800	.60	
167.5	166.4	146.4	-43.0	.559	.800	.553	.800	.536	.800	.70	

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TABLE III. - Concluded. 2-STAGE TURBINES

(c) $\left(\frac{V_z}{a}\right)_{5,m} = 0.7$

$\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \le 0.8; \left(\frac{V_2'}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4'}{V_5'}\right)_h \le 1.0$

$\left(\frac{r_h}{r_t}\right)_5$	$\frac{U_t}{a_{a,cr,1}}$	$\frac{-gJ\Delta H_{1-5}}{U_t^2}$	$\left(\frac{\rho V_z}{\rho_a a_{a,cr}}\right)_{5,m}$	$\left(\frac{r_h}{r_t}\right)_2$	$\frac{\Delta H_{1-3}}{\Delta H_{3-5}}$	$\frac{-gJ\Delta H_{1-5}}{U_{h,5}^2}$	$\frac{p_1}{p_5}$	$\hat{w}_1$	$\left(\frac{V_z}{a}\right)_{2,m}$	$\alpha_{2,h}$
0.5	0.10	4.199	0.5740	0.500	2.118	16.796	1.06	0.4092	0.670	27.2
	.15	4.161	.5733	.500	2.110	16.644	1.14	.3837	.636	38.7
	.20	3.972	.5725	.500	2.016	15.889	1.24	.3532	.585	46.7
	.30	3.486	.5705	.540	1.787	13.942	1.56	.2883	.515	55.2
	.40	3.316	.5673	.635	1.738	13.264	2.17	.2131	.493	59.9
	.50	3.313	.5621	.735	1.794	13.252	3.56	.1354	.467	64.7
	.60	3.449	.5526	.845	1.870	13.797	7.86	.0656	.456	68.5
	.70	3.558	.5355	.925	1.968	14.231	25.63	.0221	.405	73.4
	.80	3.498	.5062	.970	2.048	13.993	121.95	.0052	.318	78.6
0.6	0.10	5.457	0.5738	0.600	2.163	15.157	1.08	0.3437	0.670	29.4
	.15	5.400	.5730	.600	2.147	15.000	1.18	.3161	.634	41.4
	.20	5.069	.5720	.600	2.009	14.081	1.32	.2848	.571	49.0
	.30	4.387	.5693	.610	1.726	12.186	1.76	.2203	.458	60.5
	.40	3.999	.5655	.695	1.701	11.108	2.59	.1548	.433	64.8
	.50	3.890	.5591	.790	1.727	10.805	4.63	.0910	.412	68.8
	.60	3.929	.5476	.885	1.769	10.914	11.43	.0397	.395	72.2
	.70	3.918	.5271	.950	1.820	10.883	42.18	.0119	.350	76.2
	.80	3.751	.4913	.980	1.863	10.418	232.42	.0024	.235	81.8
0.7	0.10	6.801	0.5736	0.700	2.194	13.880	1.10	0.2694	0.672	31.3
	.15	6.620	.5727	.700	2.135	13.510	1.23	.2432	.629	42.8
	.20	6.169	.5714	.700	1.974	12.590	1.41	.2143	.560	51.0
	.30	5.371	.5680	.700	1.699	10.962	2.01	.1550	.420	64.1
	.40	4.735	.5634	.755	1.663	9.6[illegible]4	3.15	.1030	.366	69.7
	.50	4.479	.5557	.840	1.663	9.141	6.14	.0560	.348	72.8
	.60	4.390	.5420	.920	1.670	8.959	16.89	.0221	.336	75.4
	.70	4.248	.5176	.965	1.686	8.670	70.14	.0059	.263	79.9
	.80	3.985	.4735	.990	1.694	8.132	463.14	.0010	.202	83.0
0.8	0.10	8.233	0.5735	0.800	2.218	12.864	1.12	0.1868	0.675	32.9
	.15	7.915	.5723	.800	2.124	12.367	1.28	.1654	.625	44.2
	.20	7.331	.5708	.800	1.944	11.454	1.51	.1422	.551	52.8
	.30	6.358	.5666	.800	1.710	9.934	2.32	.0963	.398	66.5
	.40	5.537	.5609	.820	1.626	8.652	3.95	.0592	.297	74.3
	.50	5.081	.5519	.890	1.601	7.939	8.35	.0298	.285	76.5
	.60	4.829	.5357	.950	1.574	7.546	25.31	.0107	.277	78.3
	.70	4.555	.5067	.980	1.558	7.118	118.95	.0025	.207	82.2
0.9	0.10	9.745	0.5733	0.900	2.236	12.031	1.14	0.0967	0.680	34.2
	.15	9.282	.5719	.900	2.115	11.459	1.34	.0839	.621	45.5
	.20	8.553	.5701	.900	1.920	10.559	1.62	.0703	.542	54.5
	.30	7.389	.5651	.900	1.718	9.122	2.70	.0443	.377	68.7
	.40	6.432	.5579	.900	1.598	7.940	5.15	.0245	.234	78.2
	.50	5.715	.5472	.930	1.530	7.056	11.81	.0114	.182	81.7
	.60	5.252	.5286	.970	1.482	6.485	38.74	.0038	.173	82.9
	.70	4.844	.4941	.990	1.442	5.980	207.50	.0008	.134	85.0

[redacted]

TABLE III. - Concluded. 2-STAGE TURBINES

(c) $\left(\frac{V_z}{a}\right)_{5,m} = 0.7$

$\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \leq 0.8;\ \left(\frac{V_2'}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4'}{V_5'}\right)_h \leq 1.0$

$\Delta\beta_{h,2-3}$	$\Delta\alpha_{h,3-4}$	$\Delta\beta_{h,4-5}$	$\alpha_{5,h}$	$\left(\frac{V_2'}{V_3'}\right)_h$	$\left(\frac{V'}{a}\right)_{2,h}$	$\left(\frac{V_3}{V_4}\right)_t$	$\left(\frac{V}{a}\right)_{3,h}$	$\left(\frac{V_4'}{V_5'}\right)_h$	$\left(\frac{V'}{a}\right)_{4,h}$	$\frac{U_t}{a_{a,cr,1}}$	$\left(\frac{r_h}{r_t}\right)_5$
44.1	32.9	21.2	- 4.9	1.000	0.737	1.000	0.722	1.000	0.708	0.10	0.5
64.0	48.5	31.7	- 7.3	1.000	.782	1.000	.748	1.000	.719	.15	
79.4	62.9	41.6	- 9.6	.957	.800	1.000	.784	1.000	.733	.20	
94.1	79.0	57.5	-13.6	.896	.800	.970	.800	1.000	.771	.30	
100.7	87.4	70.0	-18.1	.844	.800	.949	.800	.970	.800	.40	
109.1	97.7	82.6	-23.3	.781	.800	.930	.800	.892	.800	.50	
118.3	112.7	98.5	-29.9	.706	.800	.883	.800	.795	.800	.60	
133.2	135.1	118.1	-37.8	.630	.800	.803	.800	.686	.800	.70	
149.2	157.3	137.6	-46.3	.571	.800	.723	.800	.580	.800	.80	
47.7	35.5	22.7	- 4.9	1.000	0.747	1.000	0.727	1.000	0.710	0.10	0.6
68.7	52.2	33.9	- 7.4	.997	.800	1.000	.759	1.000	.723	.15	
83.9	67.2	44.4	- 9.7	.926	.800	.998	.800	1.000	.740	.20	
104.9	88.1	63.1	-13.8	.871	.800	.918	.800	1.000	.786	.30	
111.4	95.6	74.5	-18.0	.815	.800	.891	.800	.945	.800	.40	
118.9	105.7	87.4	-23.1	.750	.800	.858	.800	.859	.800	.50	
128.3	121.7	104.1	-29.6	.676	.800	.797	.800	.757	.800	.60	
141.7	144.1	124.3	-37.4	.607	.800	.719	.800	.647	.800	.70	
158.3	164.5	143.8	-46.0	.555	.800	.649	.800	.544	.800	.80	
50.8	37.8	24.0	- 5.0	1.000	0.757	1.000	0.732	1.000	0.712	0.10	0.7
71.7	55.3	35.7	- 7.5	.974	.800	1.000	.771	1.000	.727	.15	
87.1	70.1	46.8	- 9.8	.912	.800	.980	.800	1.000	.747	.20	
112.2	94.2	67.3	-14.1	.847	.800	.873	.800	.996	.800	.30	
122.5	104.4	79.6	-18.2	.786	.800	.833	.800	.916	.800	.40	
129.1	114.1	92.5	-23.3	.720	.800	.789	.800	.822	.800	.50	
137.4	130.2	109.8	-29.8	.650	.800	.725	.800	.716	.800	.60	
152.0	152.4	130.6	-37.5	.588	.800	.651	.800	.606	.800	.70	
162.6	170.0	149.6	-46.5	.541	.800	.591	.800	.505	.800	.80	
53.6	39.8	25.2	- 5.1	1.000	0.768	1.000	0.737	1.000	0.714	0.10	0.8
74.4	58.1	37.5	- 7.6	.950	.800	1.000	.783	1.000	.732	.15	
90.2	72.8	49.1	- 9.9	.897	.800	.959	.800	1.000	.756	.20	
117.0	97.6	69.9	-14.4	.824	.800	.845	.800	.974	.800	.30	
133.5	113.9	85.3	-18.7	.757	.800	.781	.800	.884	.800	.40	
138.6	122.5	97.9	-23.7	.693	.800	.731	.800	.783	.800	.50	
145.7	138.1	115.4	-30.2	.628	.800	.665	.800	.674	.800	.60	
158.8	159.2	136.5	-38.0	.572	.800	.598	.800	.565	.800	.70	
56.0	41.7	26.4	- 5.3	1.000	0.779	1.000	0.743	1.000	0.716	0.10	0.9
76.9	60.6	39.1	- 7.8	.926	.800	1.000	.795	1.000	.737	.15	
93.2	75.4	51.2	-10.1	.882	.800	.935	.800	1.000	.765	.20	
121.5	101.0	72.3	-14.8	.801	.800	.821	.800	.951	.800	.30	
143.3	123.0	91.2	-19.4	.728	.800	.740	.800	.848	.800	.40	
152.5	135.1	105.6	-24.4	.666	.800	.676	.800	.742	.800	.50	
157.7	147.5	121.8	-30.8	.609	.800	.614	.800	.632	.800	.60	
166.3	165.0	142.3	-38.9	.559	.800	.553	.800	.526	.800	.70	

TABLE IV. - SUMMARY OF TURBINE DESIGN CONDITIONS

1-Stage turbines					$1\frac{1}{2}$-Stage turbines			
$\left(\frac{V_z}{a}\right)_{3,m}$	$\left(\frac{V'}{a}\right)_{2,h}$	$\left(\frac{V_2'}{V_3'}\right)_h$	$\frac{-V_{\theta,o,m}^2}{2gJ\Delta H}$	Table	$\left(\frac{V_z}{a}\right)_{3,m}$	$\left(\frac{V'}{a}\right)_{2,h}$	$\left(\frac{V_2'}{V_3'}\right)_h$	Table
0.5	0.6 .8 ---	<1.0 <1.0 1.0	0.01	I(a)1 I(a)2 I(a)3	0.5	0.6 .8 ---	<1.0 <1.0 1.0	II(a)1 II(a)2 II(a)3
0.6	0.6 .8 ---	<1.0 <1.0 1.0	0.02	I(b)1 I(b)2 I(b)3	0.6	0.6 .8 ---	<1.0 ≤1.0 1.0	II(b)1 II(b)2 II(b)3
0.7	0.8 1.0 ---	---- <1.0 1.0	0.02	I(c)1 I(c)2 I(c)3	0.7	0.8 1.0 ---	<1.0 <1.0 1.0	II(c)1 II(c)2 II(c)3

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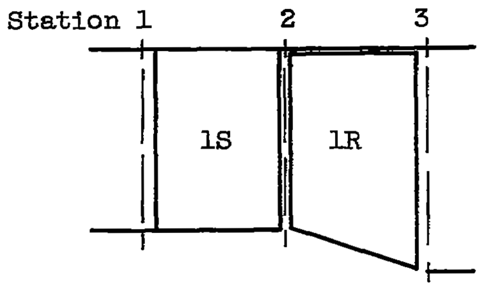
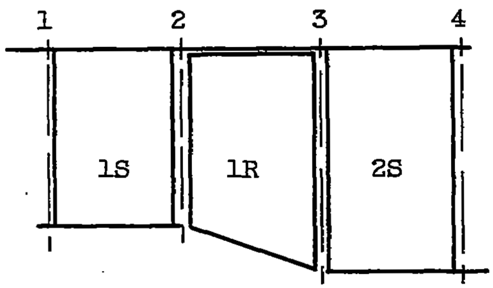
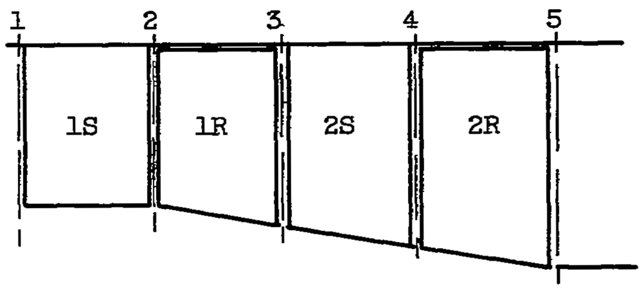
2-Stage turbines				
$\left(\frac{V_z}{a}\right)_{5,m}$	$\left(\frac{V'}{a}\right)_{2,h}$ $\left(\frac{V}{a}\right)_{3,h}$ $\left(\frac{V'}{a}\right)_{4,h}$	$\left(\frac{V_2'}{V_3'}\right)_h$ $\left(\frac{V_3}{V_4}\right)_t$ $\left(\frac{V_4'}{V_5'}\right)_h$	$\frac{-V_{\theta,o,m}^2}{2gJ\Delta H}$	Table
0.5	≤0.6 ≤.8	≤1.0 ≤1.0	0.01	III(a)1 III(a)2
0.6	≤0.6 ≤.8	≤1.0 ≤1.0	0.02	III(b)1 III(b)2
0.7	≤0.8	≤1.0	0.02	III(c)



(a) 1-Stage turbines.



(b) $1\frac{1}{2}$-Stage turbines.



(c) 2-Stage turbines.

Figure 1. - Annulus geometry and axial stations of turbines.

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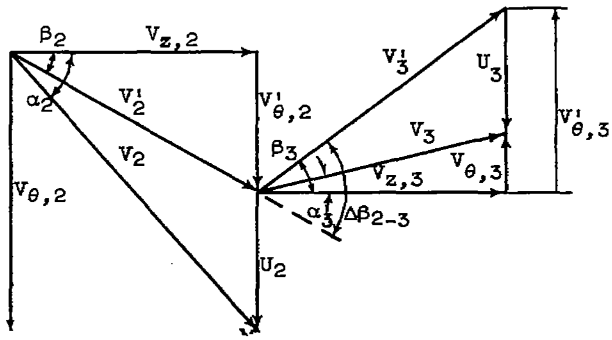
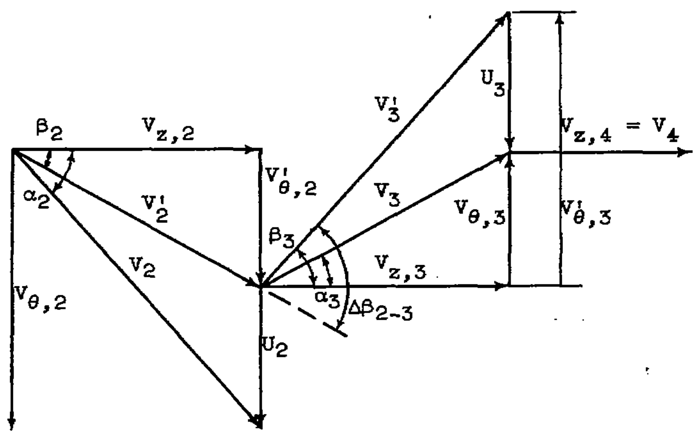
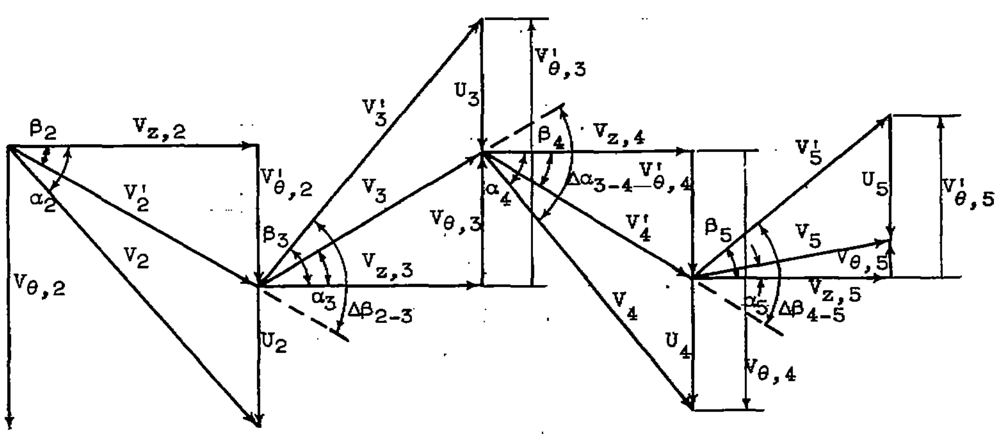


(a) 1-Stage turbines.

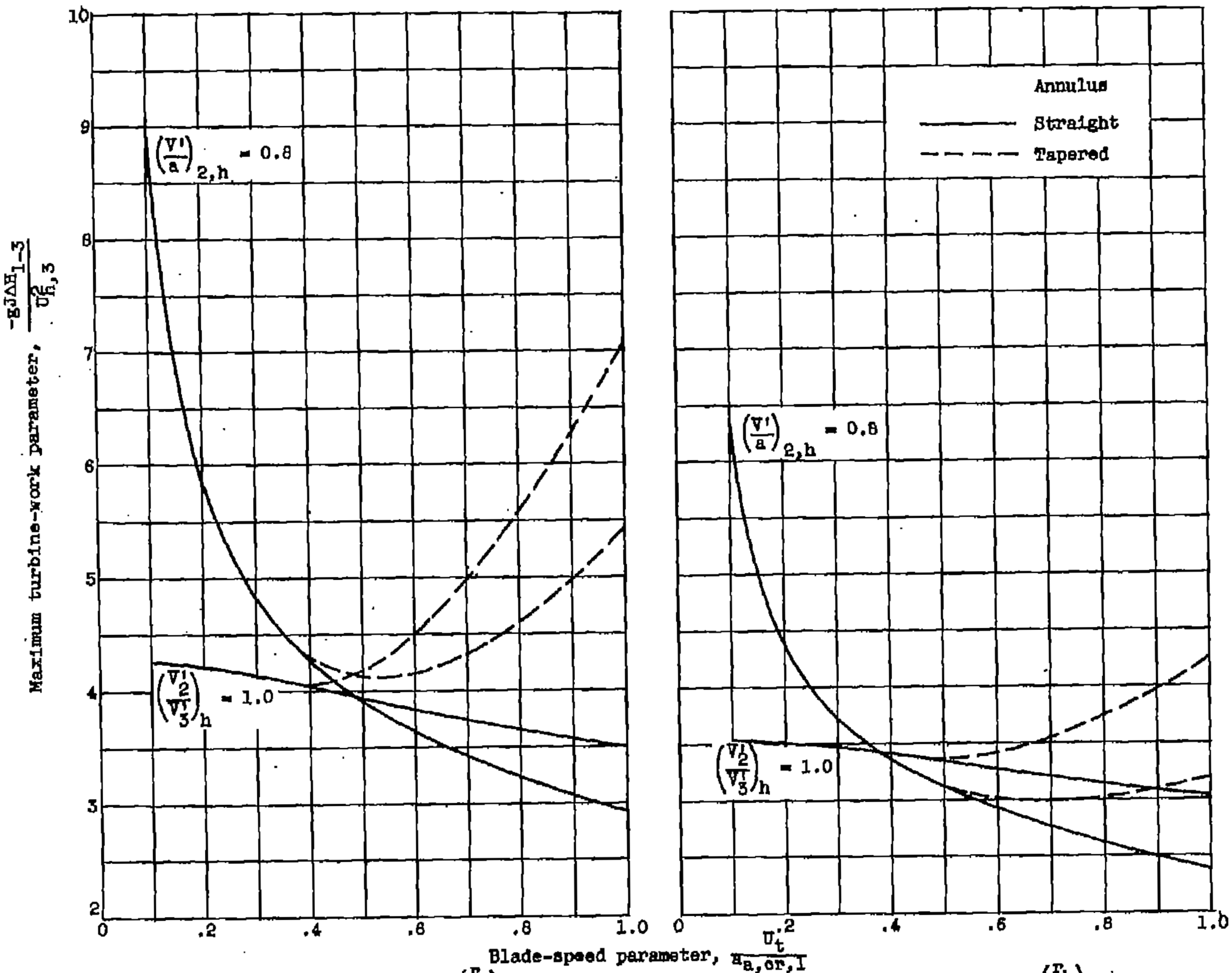


(b) $1\frac{1}{2}$-Stage turbines.



(c) 2-Stage turbines.

Figure 2. - Typical velocity diagrams for turbines.



(a) Turbine-exit radius ratio $\left(\frac{r_h}{r_t}\right)_3$ = 0.5. (b) Turbine-exit radius ratio $\left(\frac{r_h}{r_t}\right)_3$ = 0.7.

Figure 3. - Effect of annulus taper on work output of 1-stage turbines. $\left(\frac{V_x}{a}\right)_{3,m}$ = 0.7.

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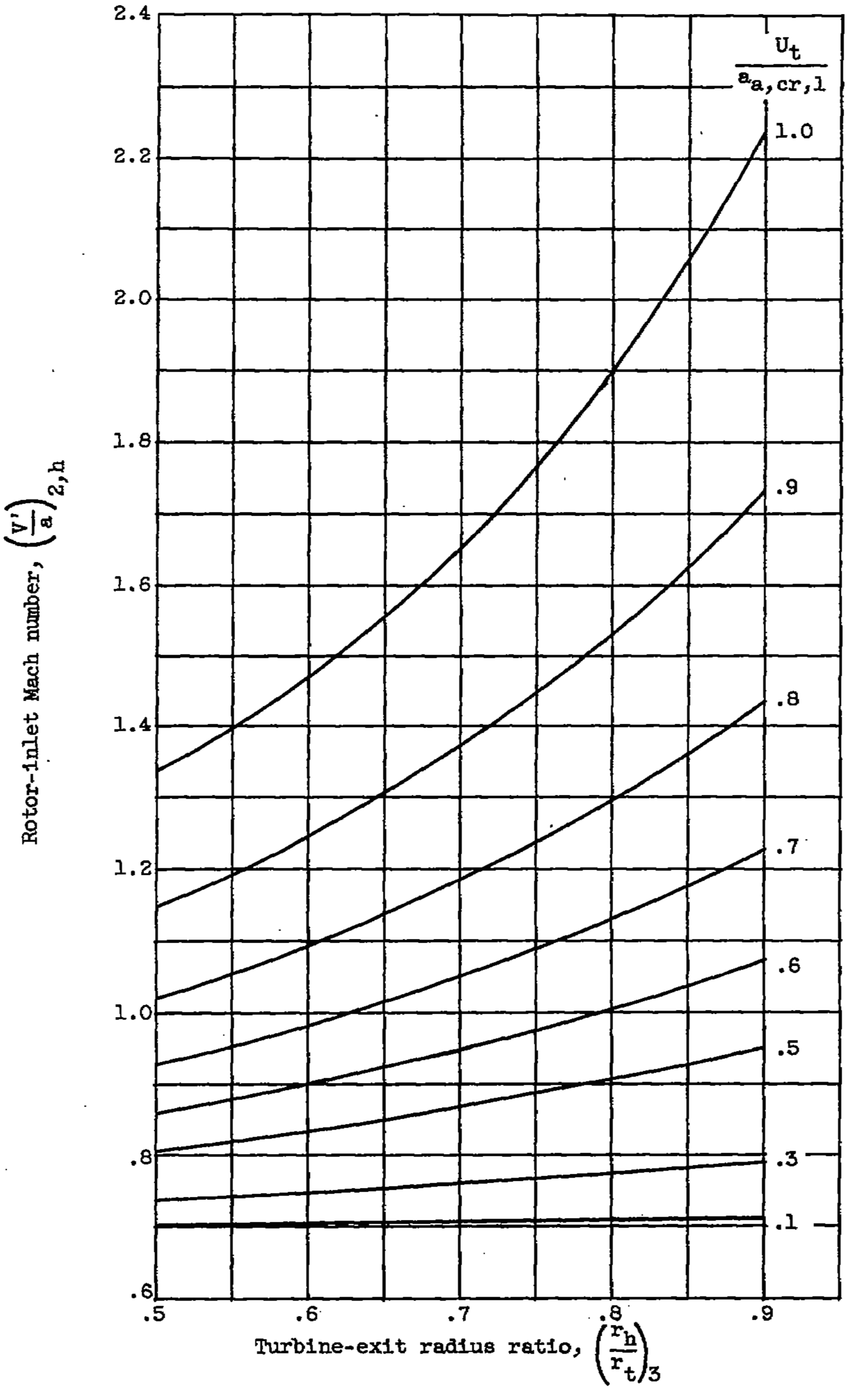
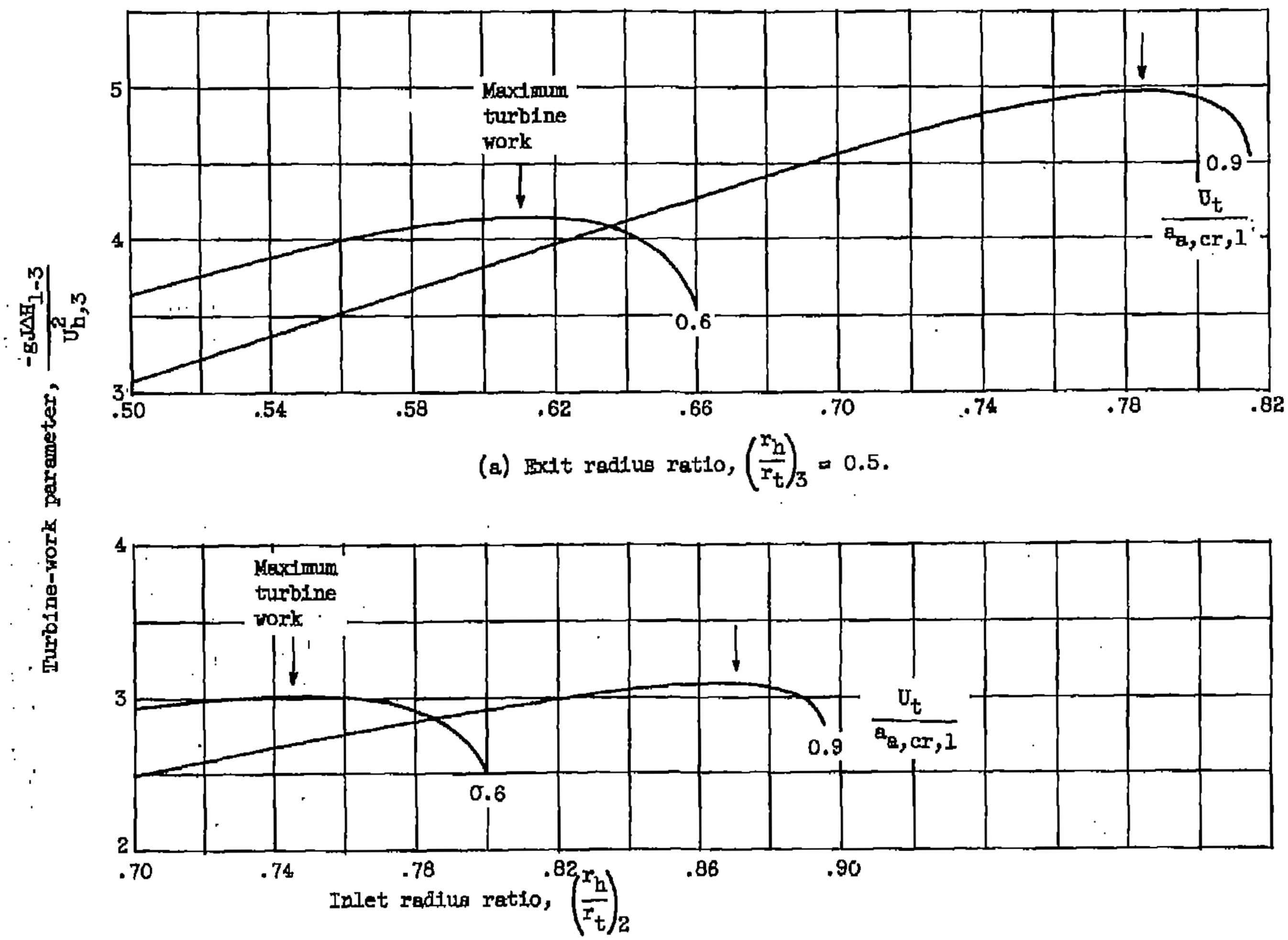


Figure 4. - Rotor-inlet Mach numbers for high-output 1-stage turbines with optimum taper limited by velocity ratio. $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$; $\left(\frac{V_2'}{V_3'}\right)_h = 1.0$.



(a) Exit radius ratio, $\left(\frac{r_h}{r_t}\right)_3 = 0.5$.

(b) Exit radius ratio, $\left(\frac{r_h}{r_t}\right)_3 = 0.7$.

Figure 5. - Variation of turbine work with inlet radius ratio in high-output 1-stage turbines. $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$; $\left(\frac{V'}{a}\right)_{2,h} = 0.8$.

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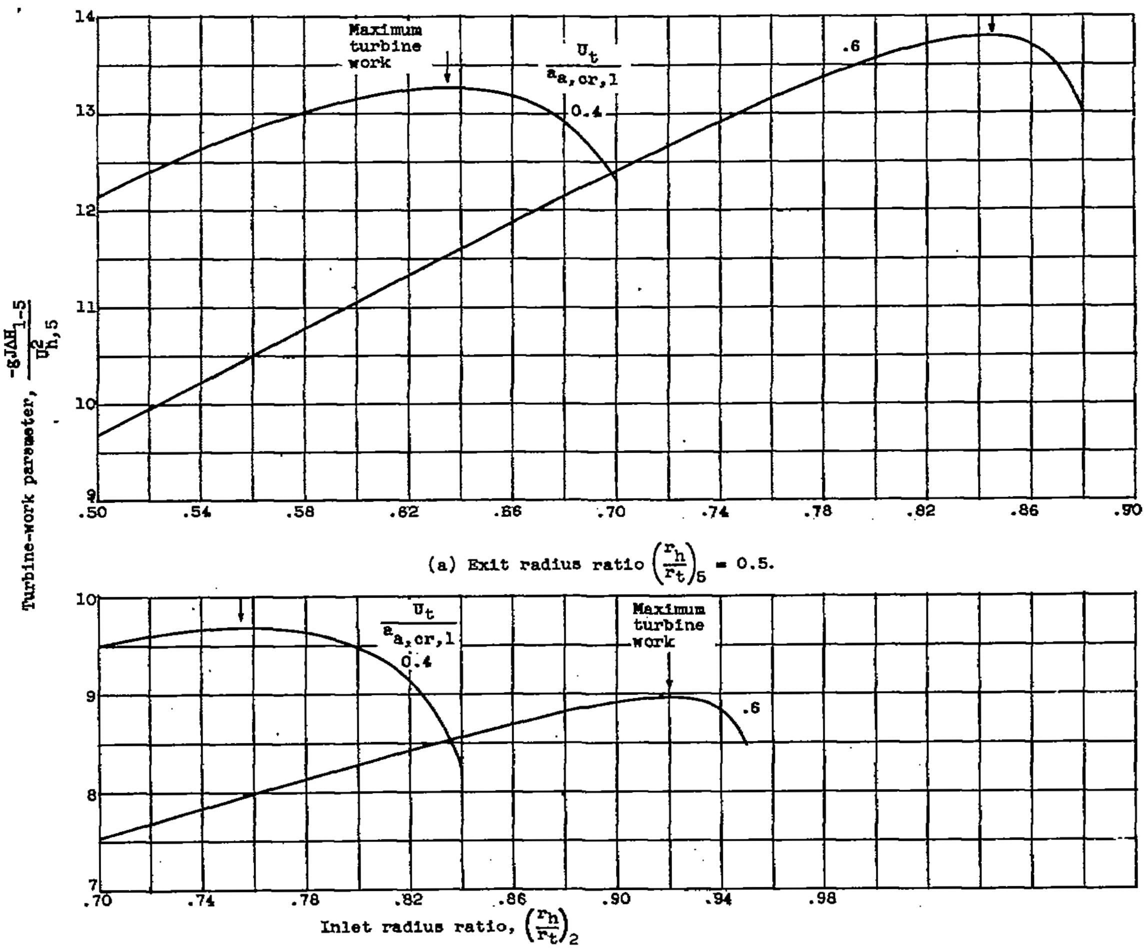

(b) Exit radius ratio $\left(\frac{r_h}{r_t}\right)_5 = 0.7$.

Figure 6. - Variation of turbine work with inlet radius ratio in high-output 2-stage turbines. $\left(\frac{V_z}{a}\right)_{5,m} = 0.7$; $\left(\frac{V'}{a}\right)_{2,h}$, $\left(\frac{V}{a}\right)_{3,h}$, $\left(\frac{V'}{a}\right)_{4,h} \leq 0.8$; $\left(\frac{V_2'}{V_3'}\right)_h$, $\left(\frac{V_3}{V_4}\right)_t$, $\left(\frac{V_4'}{V_5'}\right)_h \leq 1.0$.

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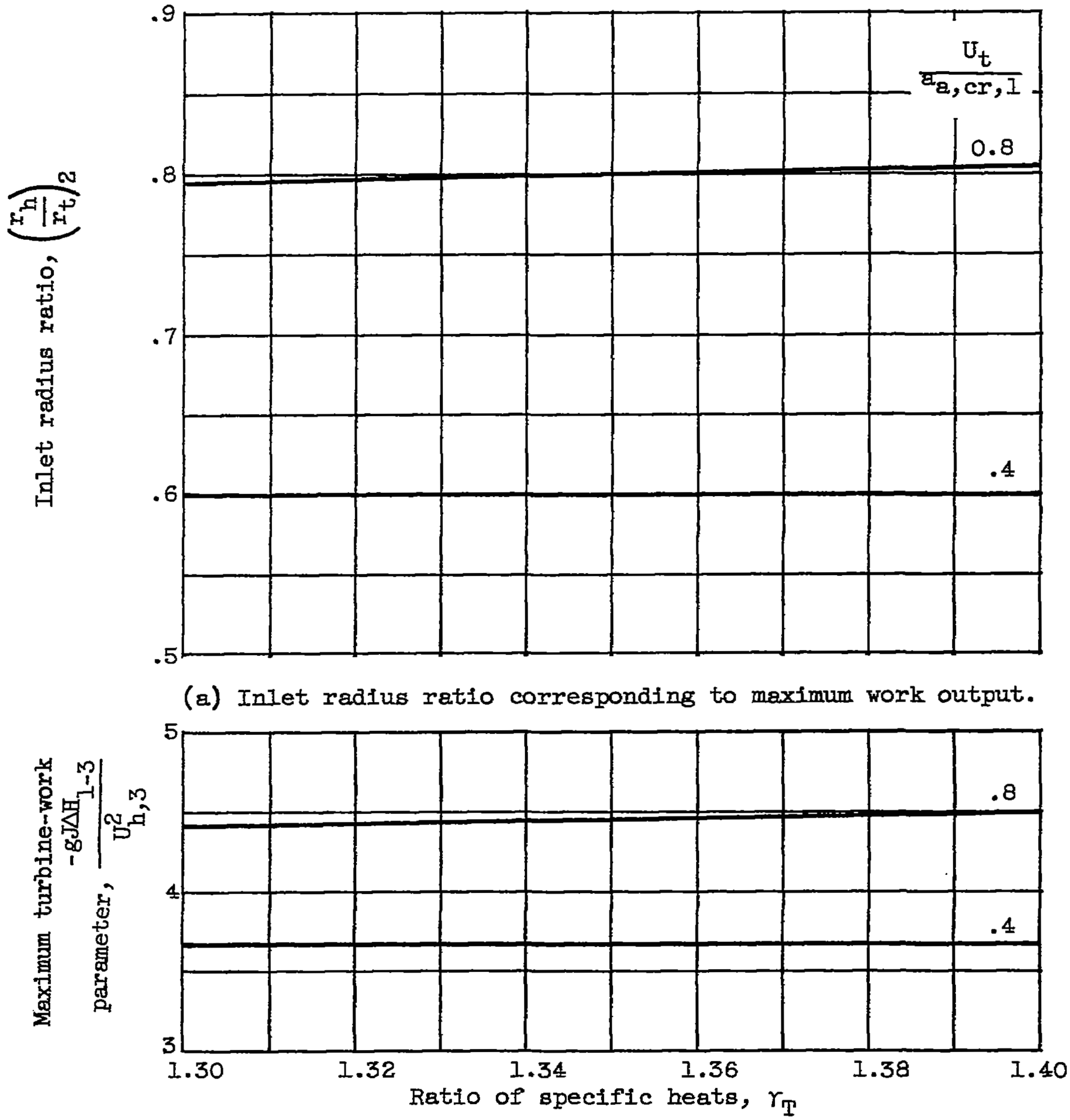
CW-9



(a) Inlet radius ratio corresponding to maximum work output.

(b) Maximum turbine work output.

Figure 7. - Effect of variation in ratio of specific heats on inlet radius ratio and maximum work of 1-stage turbines. $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$; $\left(\frac{V_2'}{V_3'}\right)_h = 1.0$; $\left(\frac{r_h}{r_t}\right)_3 = 0.6$.

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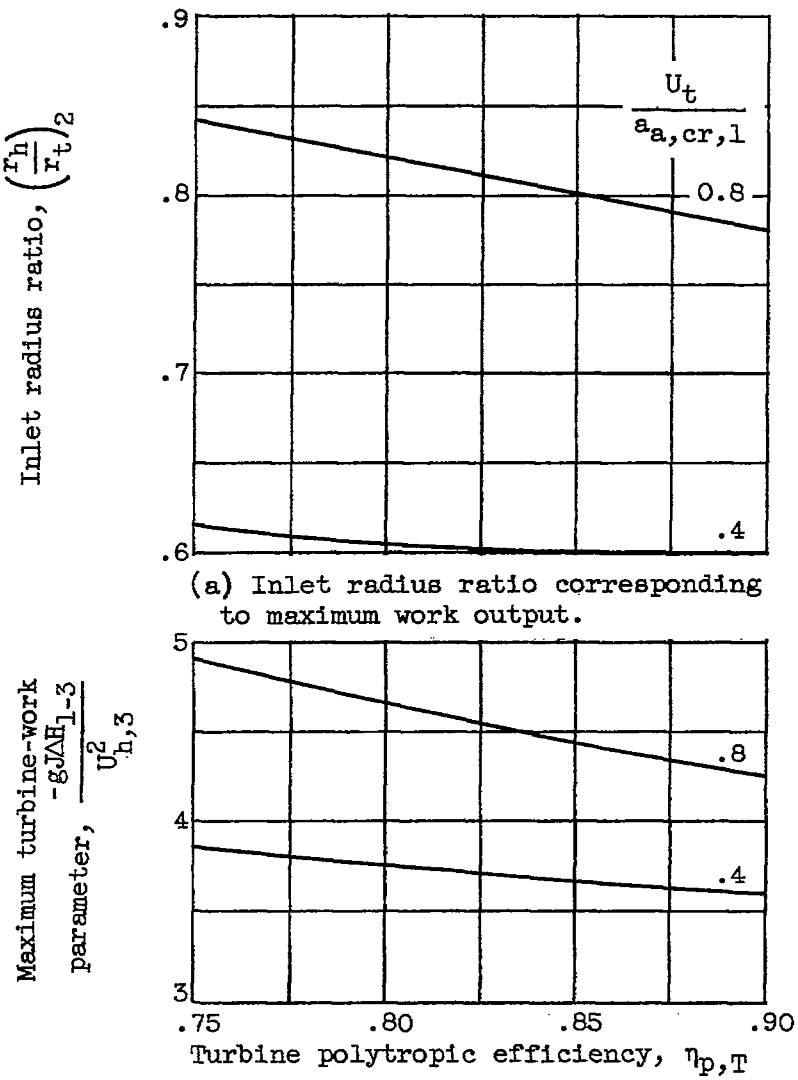

(a) Inlet radius ratio corresponding to maximum work output.

(b) Maximum turbine work output.

Figure 8. - Effect of variation in turbine polytropic efficiency on inlet radius ratio and maximum work of 1-stage turbines. $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$; $\left(\frac{V_2'}{V_3'}\right)_h = 1.0$; $\left(\frac{r_h}{r_t}\right)_3 = 0.6$.

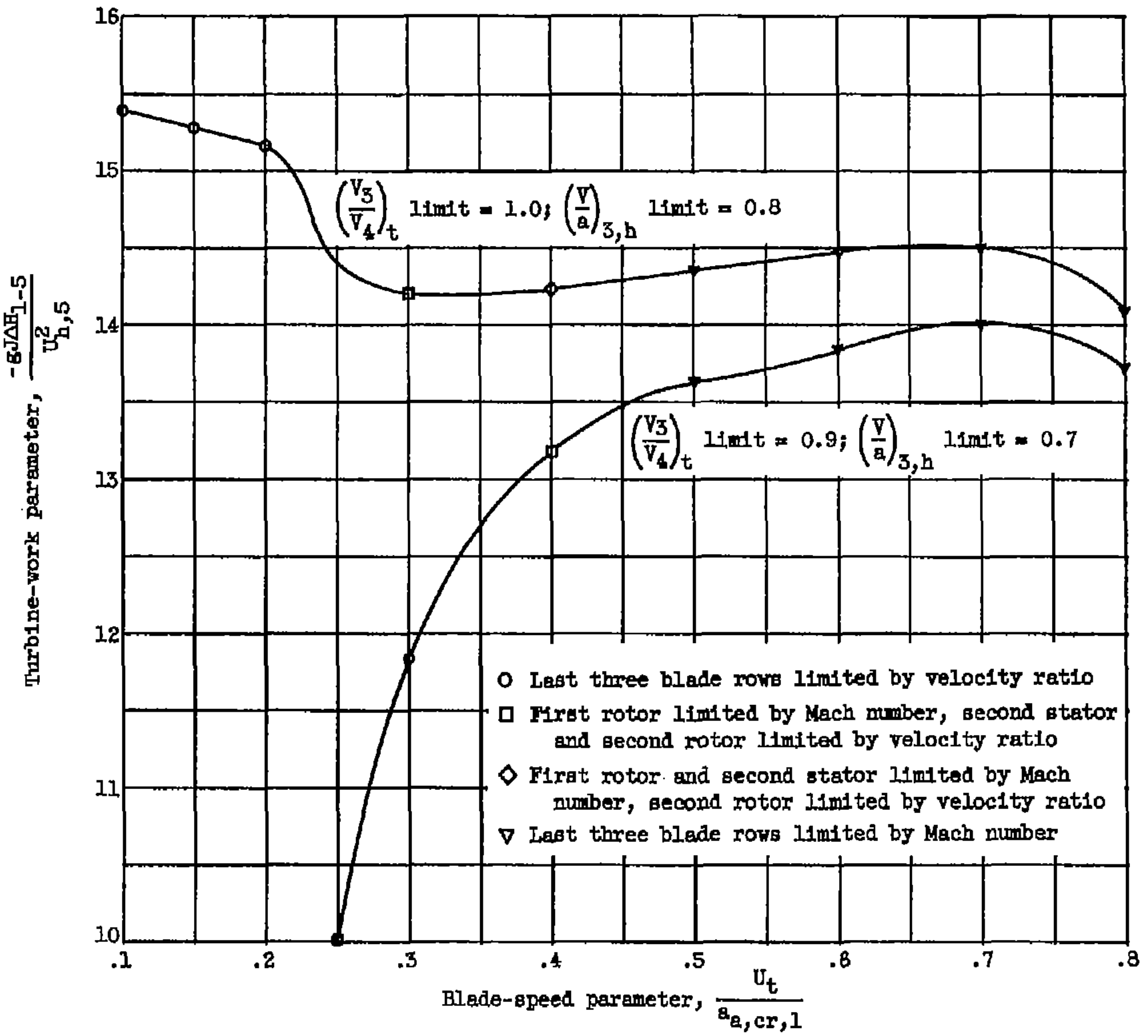

Figure 9. - Effect of second-stage stator-velocity limitation on design work of 2-stage turbine. $\left(\frac{V_z}{a}\right)_{5,m} = 0.6$; $\left(\frac{r_h}{r_t}\right)_5 = 0.5$; $\left(\frac{V'}{a}\right)_{2,h}$ limit = $\left(\frac{V'}{a}\right)_{4,h}$ limit = 0.8.

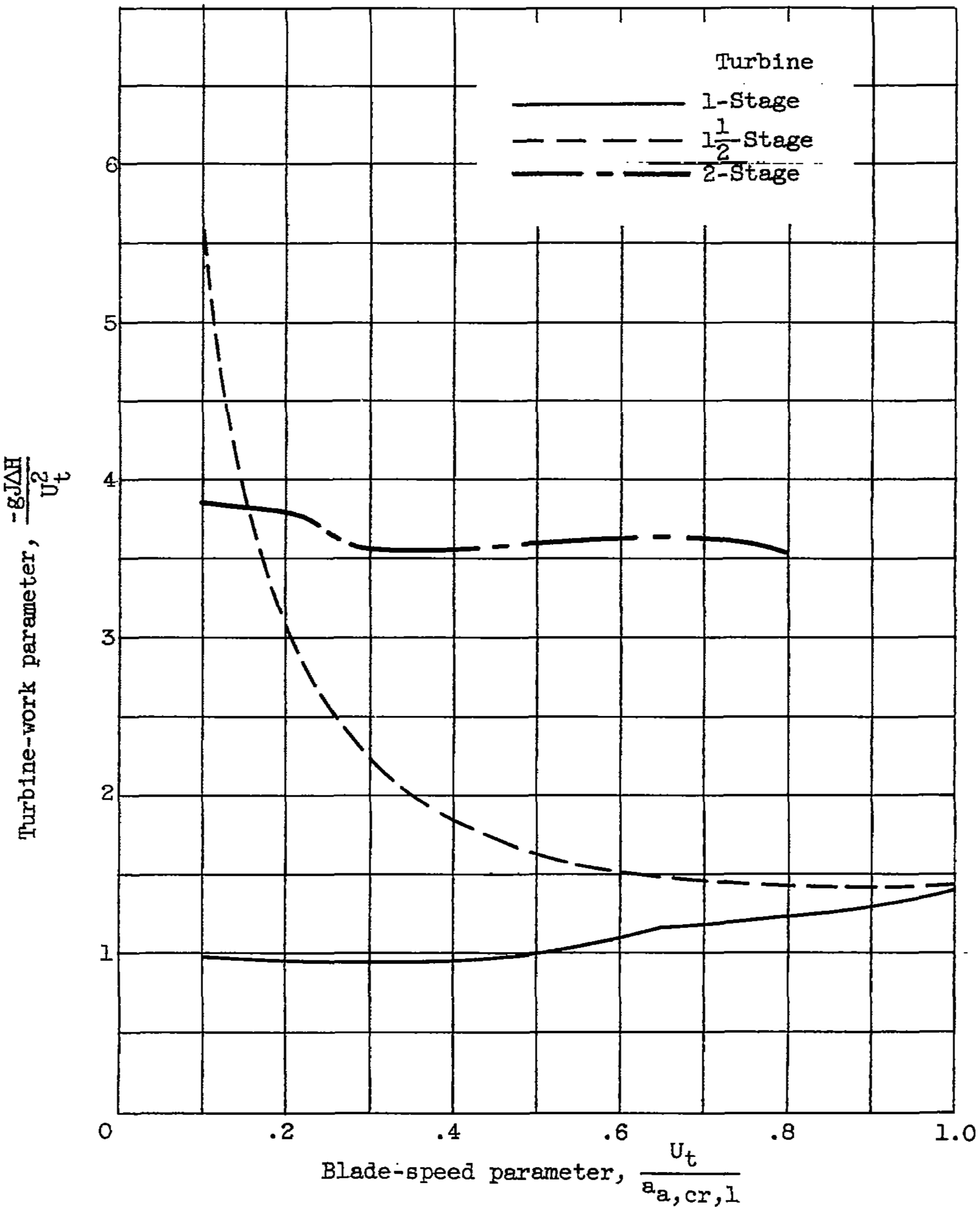

Figure 10. - Comparison of work available in 1- $1\frac{1}{2}$-, and 2-stage turbines for selected aerodynamic limits. $\left(\frac{V_z}{a}\right)_{o,m} = 0.6$; $\left(\frac{r_h}{r_t}\right)_o = 0.5$; $\left(\frac{V'}{a}\right)_{in,R,h}$ limit = $\left(\frac{V}{a}\right)_{in,S,h}$ limit = 0.8; $\left(\frac{V'_{in}}{V'_o}\right)_{R,h}$ limit = $\left(\frac{V_{in}}{V_o}\right)_{S,t}$ limit = 1.0.

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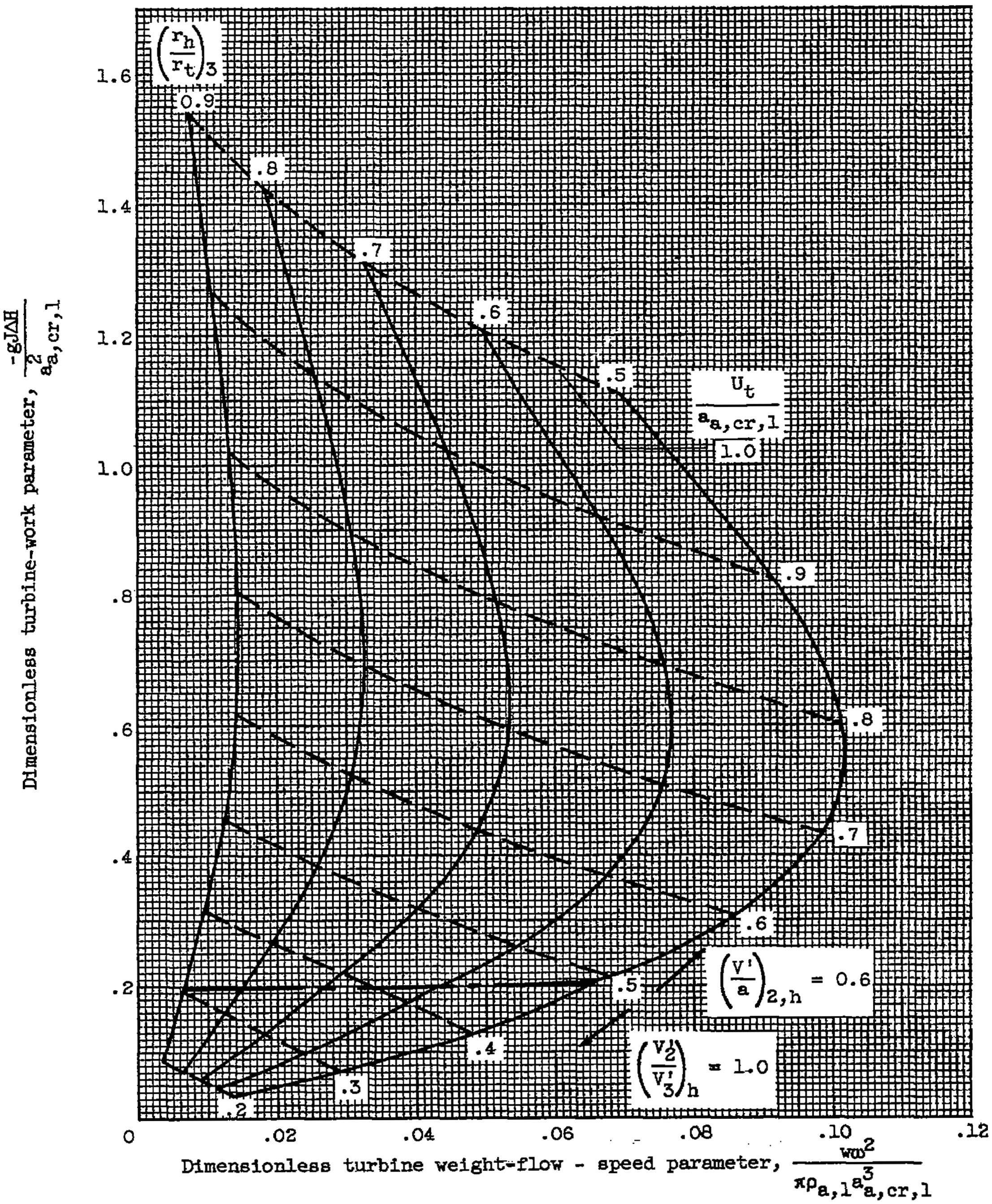

1. $\left(\frac{V'}{a}\right)_{2,h} \leq 0.6;\ \left(\frac{V_2'}{V_3'}\right)_h \leq 1.0.$

(a) $\left(\frac{V_z}{a}\right)_{3,m} = 0.5.$

Chart I. - 1-Stage turbines.

[redacted]

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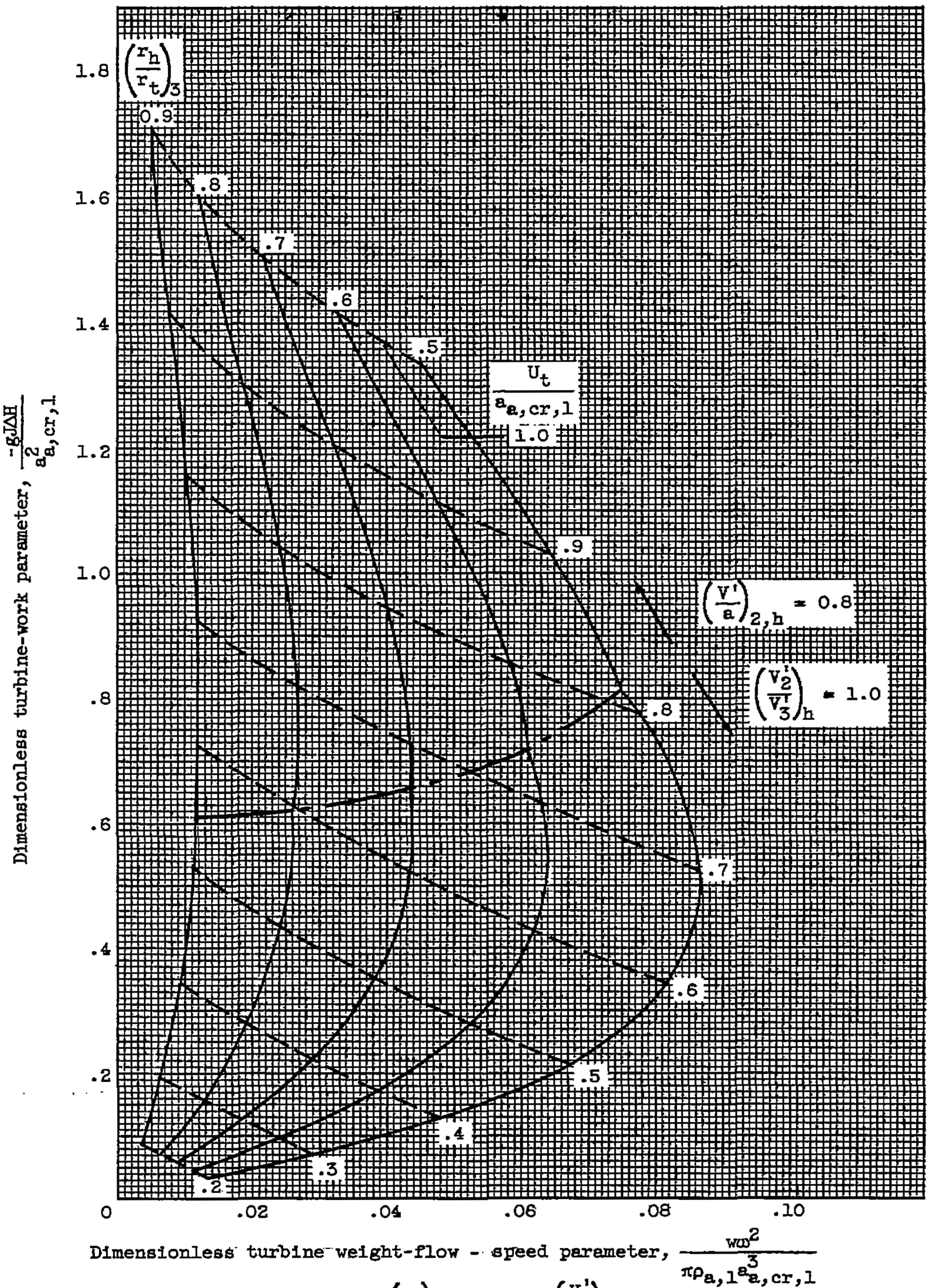

2. $\left(\frac{V'}{a}\right)_{2,h} \leq 0.8$; $\left(\frac{V_2'}{V_3'}\right)_h \leq 1.0$.

(a) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.5$.

Chart I. - Continued. 1-Stage turbines.

[redacted]

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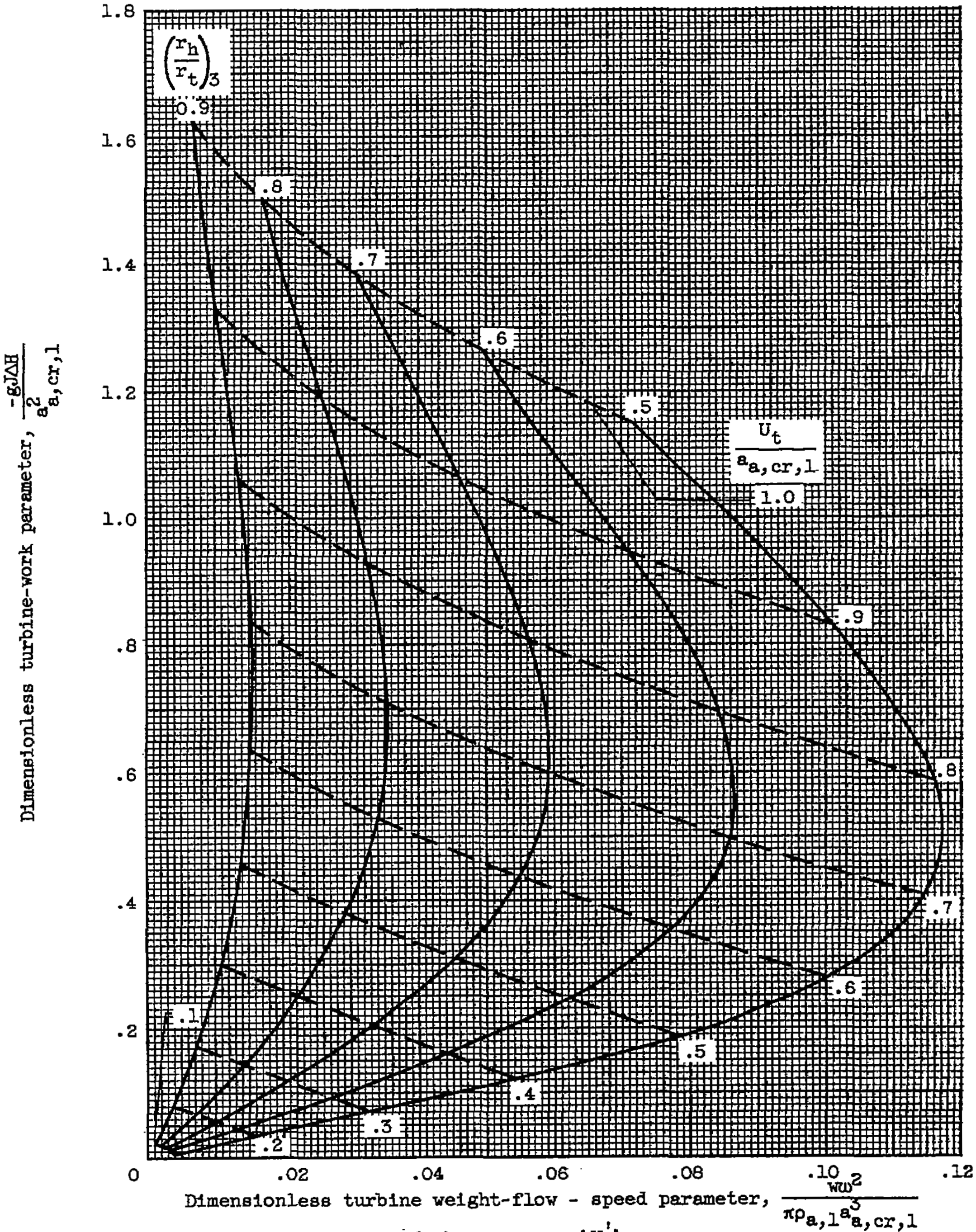

$$1. \left(\frac{V'}{a}\right)_{2,h} = 0.6; \left(\frac{V_2'}{V_3'}\right)_h < 1.0.$$

$$(b) \left(\frac{V_z}{a}\right)_{3,m} = 0.6.$$

Chart I. - Continued. 1-Stage turbines.

[redacted]

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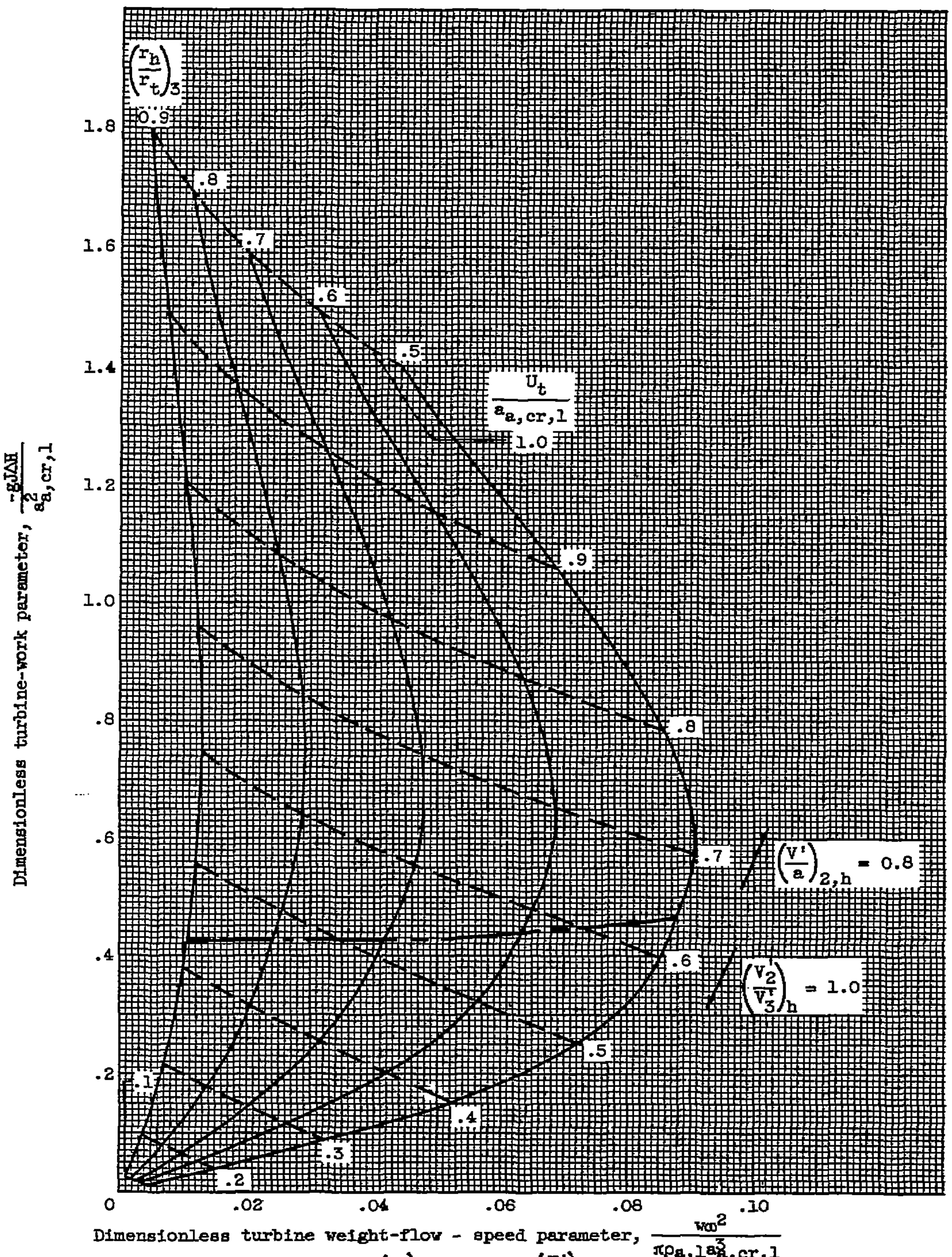
CW-10

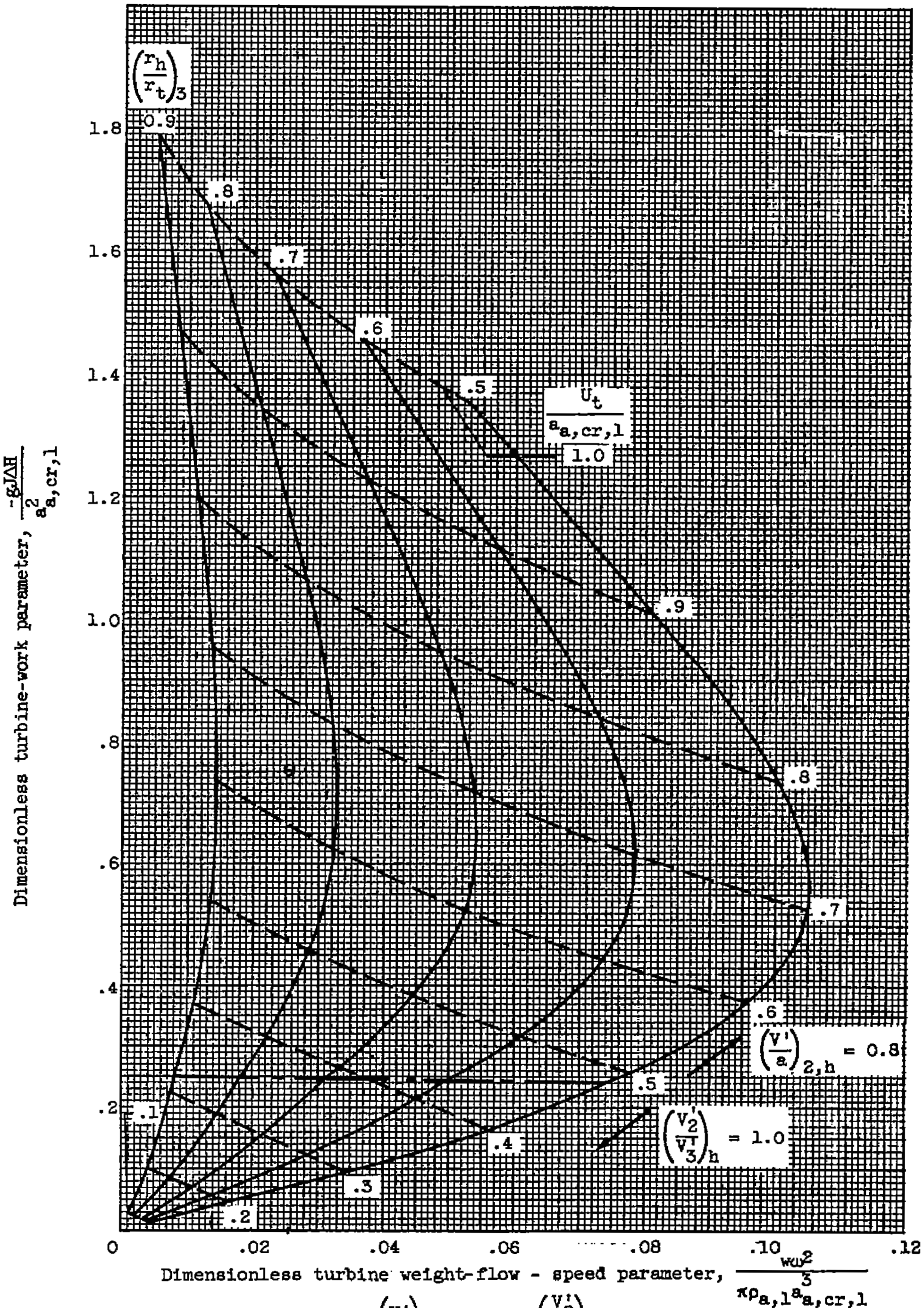


2. $\left(\frac{V'}{a}\right)_{2,h} \leq 0.8$; $\left(\frac{V_2'}{V_3'}\right)_h \leq 1.0$.

(b) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.6$.

Chart I. - Continued. 1-Stage turbines.

4575



1. $\left(\frac{V'}{a}\right)_{2,h} \leq 0.8$; $\left(\frac{V'_2}{V'_3}\right)_h \leq 1.0$.

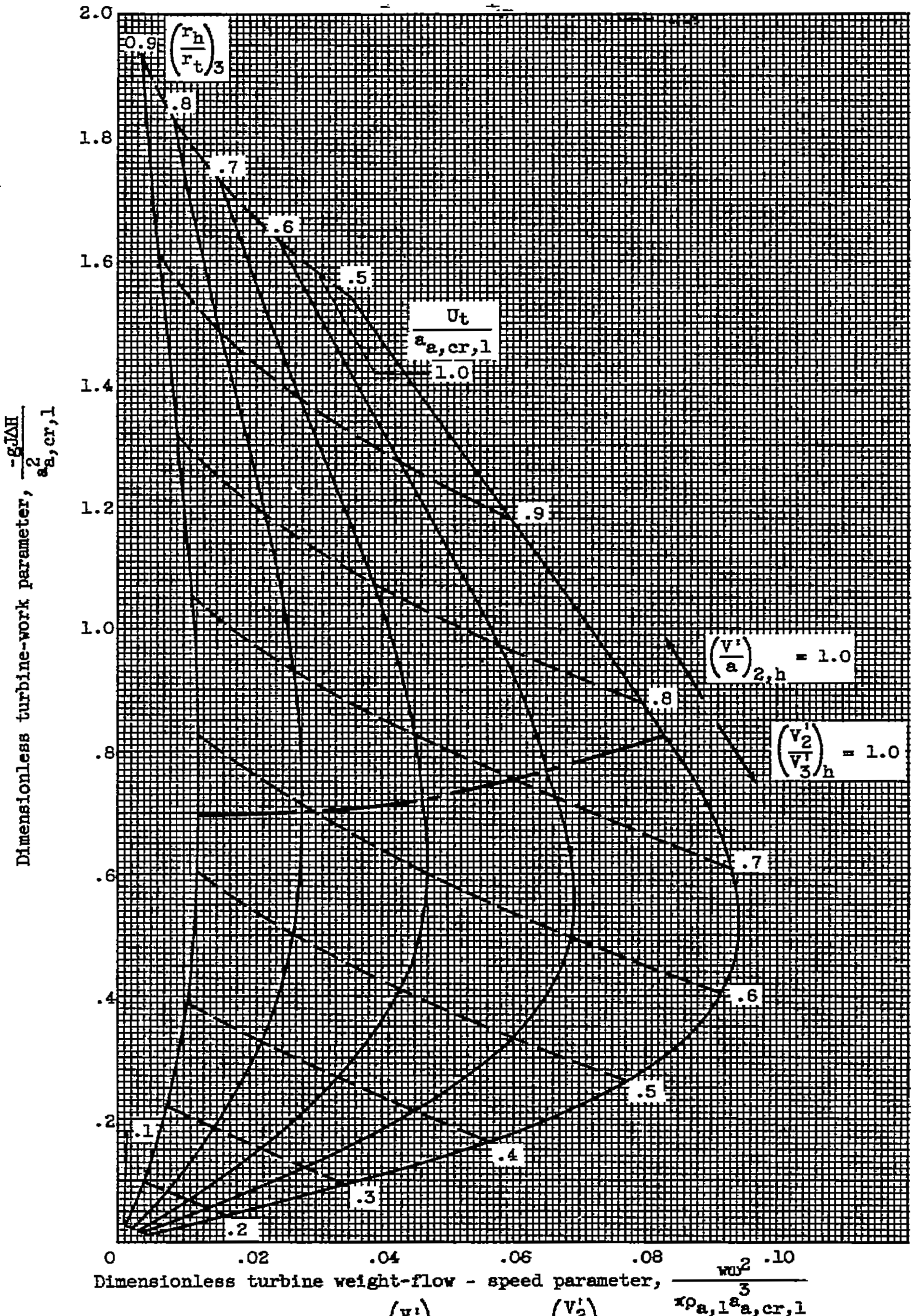
(c) $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$.

Chart I. - Continued. 1-Stage turbines.

[redacted]

4575

CW-10 back



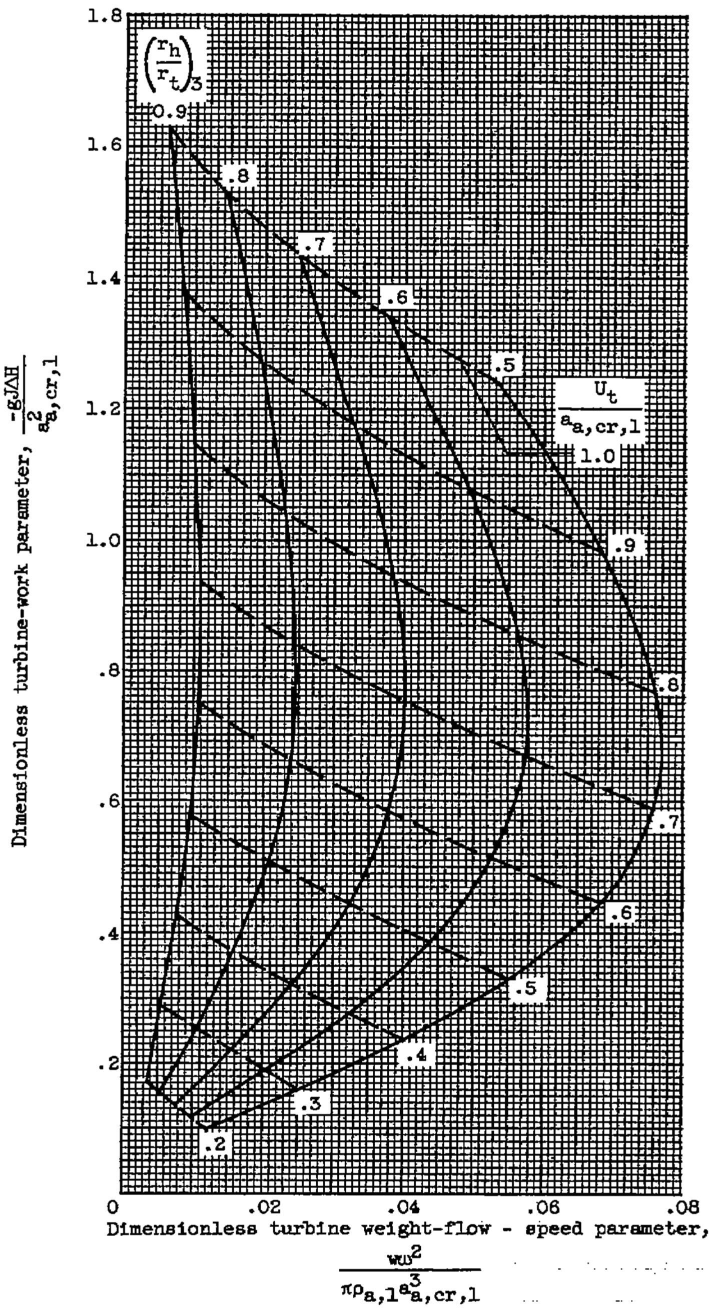
2. $\left(\frac{V'}{a}\right)_{2,h} \leq 1.0$; $\left(\frac{V_2'}{V_3'}\right)_h \leq 1.0$.

(c) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$.

Chart I. - Concluded. 1-Stage turbines.

[redacted]

4575



1. $\left(\frac{V'}{a}\right)_{2,h} = 0.6$; $\left(\frac{V'_2}{V'_3}\right)_h < 1.0$.

(a) $\left(\frac{V_z}{a}\right)_{3,m} = 0.5$.

Chart II. - $1\frac{1}{2}$-Stage turbines.

[redacted]

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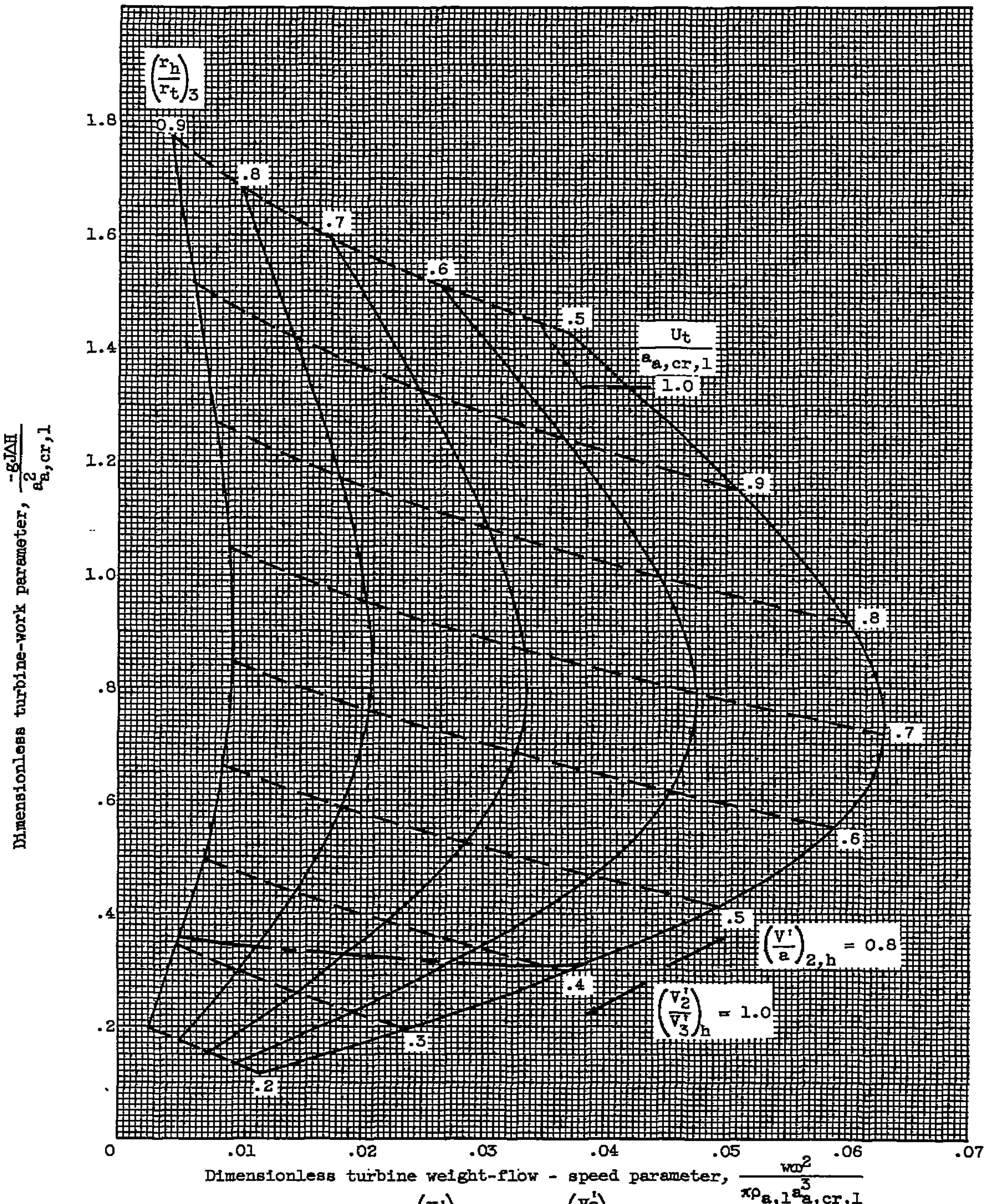


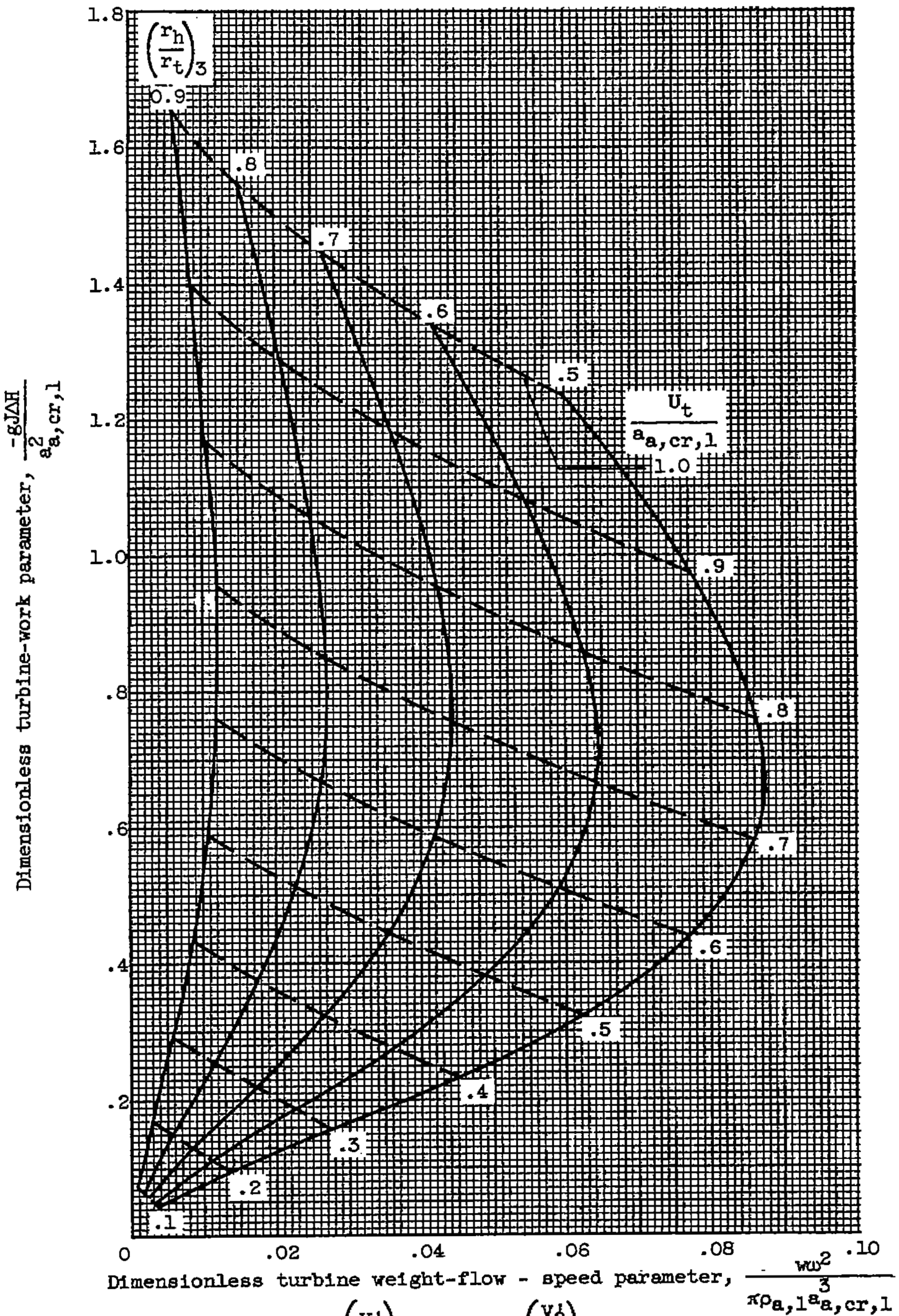
2. $\left(\frac{V'}{a}\right)_{2,h} \leq 0.8$; $\left(\frac{V_2'}{V_3'}\right)_h \leq 1.0$.

(a) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.5$.

Chart II. - Continued. $1\frac{1}{2}$-Stage turbines.

[redacted]

4575



1. $\left(\frac{V'}{a}\right)_{2,h} = 0.6;\ \left(\frac{V'_2}{V'_3}\right)_h < 1.0.$

(b) $\left(\frac{V_z}{a}\right)_{3,m} = 0.6.$

Chart II. - Continued. $1\frac{1}{2}$-Stage turbines.

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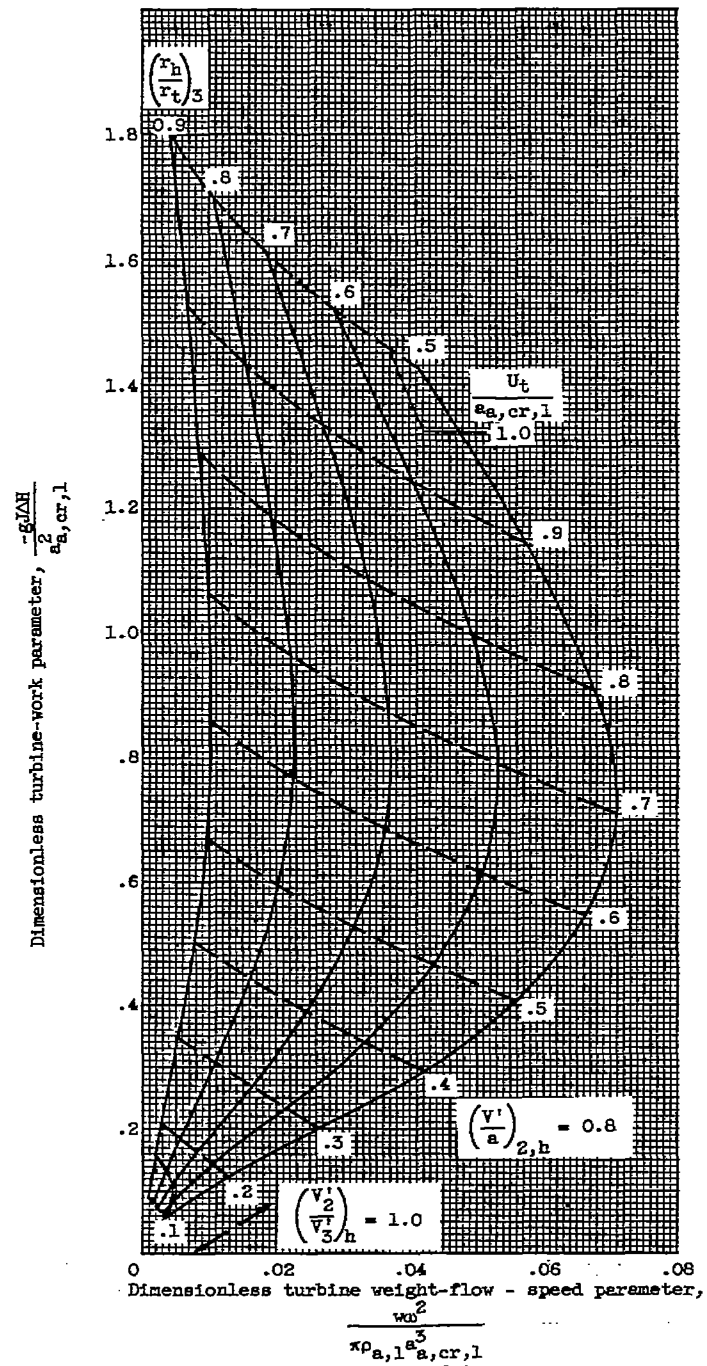

2. $\left(\frac{V'}{a}\right)_{2,h} \leq 0.8$; $\left(\frac{V'_2}{V'_3}\right)_h \leq 1.0$.

(b) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.6$.

Chart II. - Continued. $1\frac{1}{2}$-Stage turbines.

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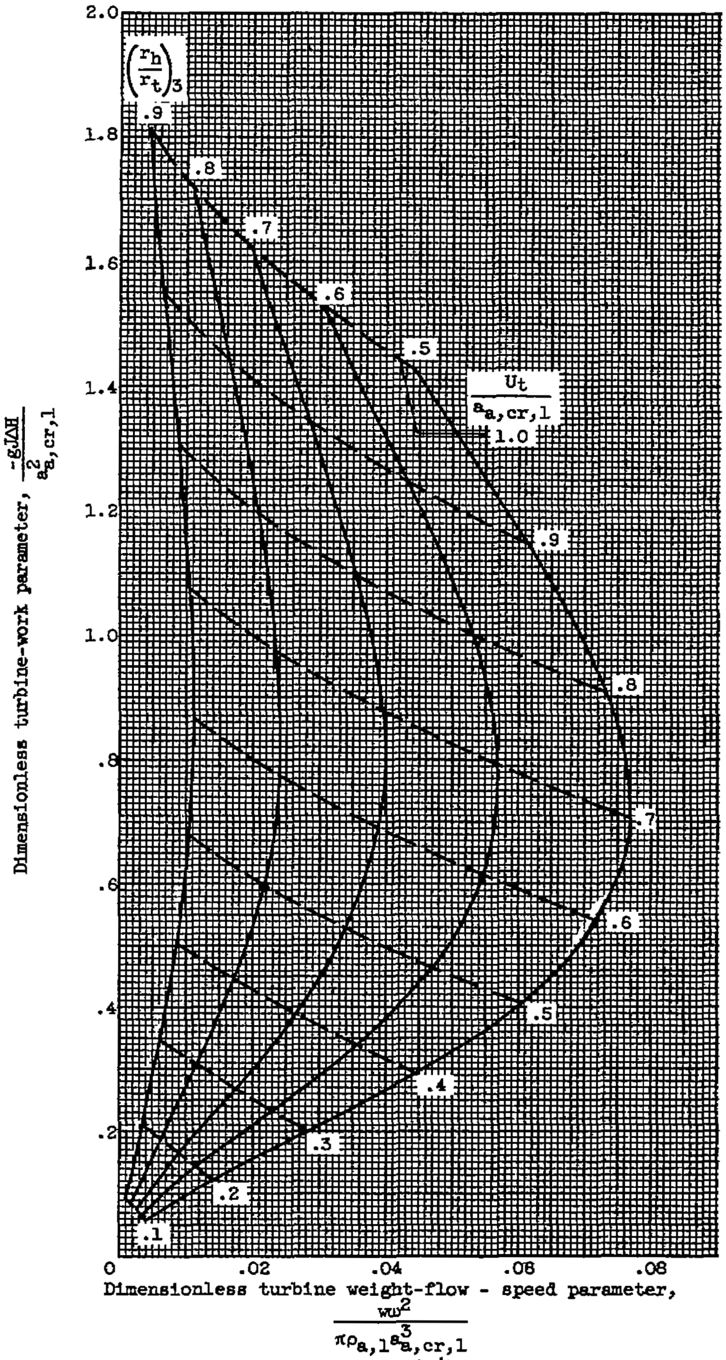
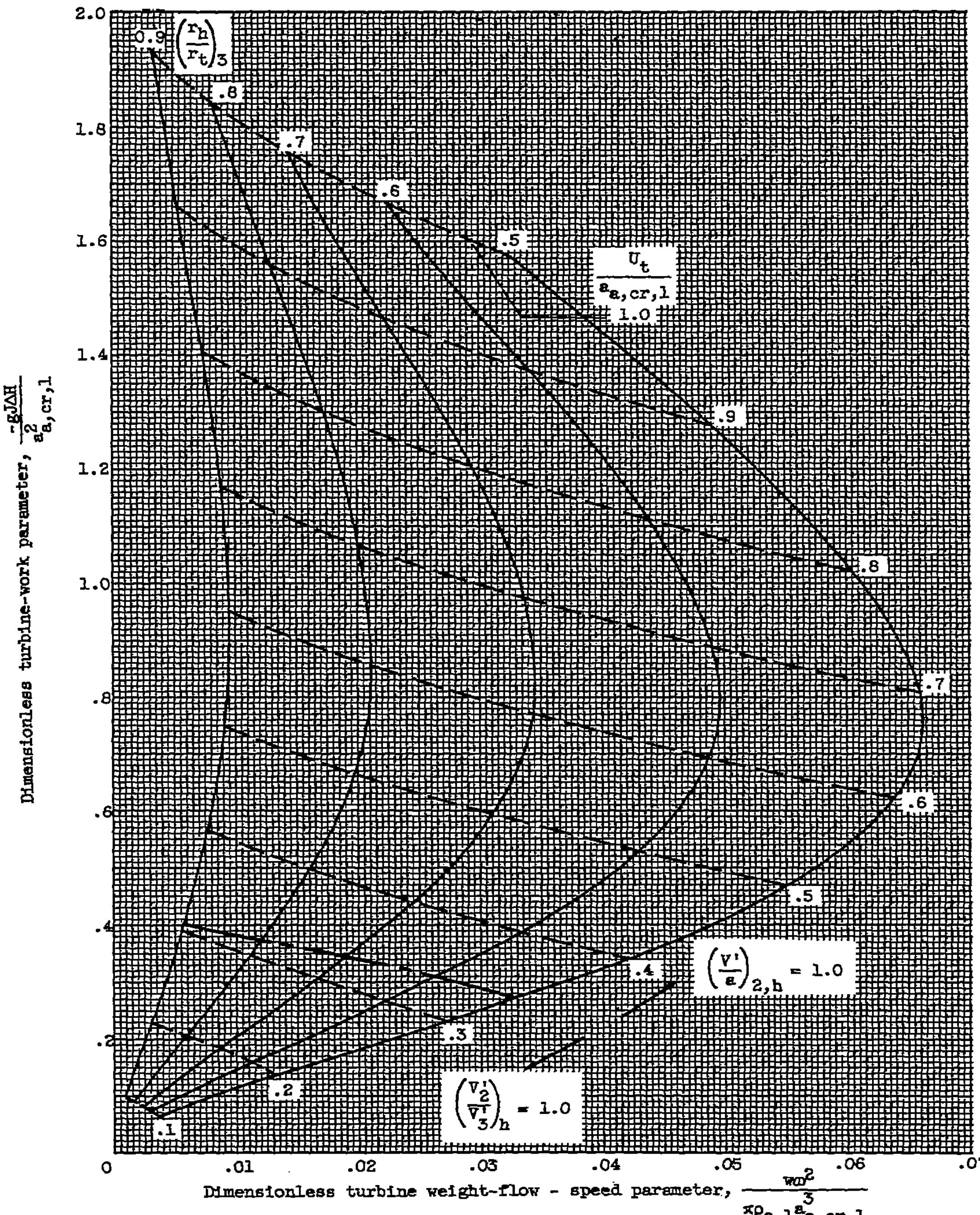


1. $\left(\frac{V'}{a}\right)_{2,h} = 0.8;\ \left(\frac{V_2'}{V_3'}\right)_h < 1.0.$

(c) $\left(\frac{V_z}{a}\right)_{3,m} = 0.7.$

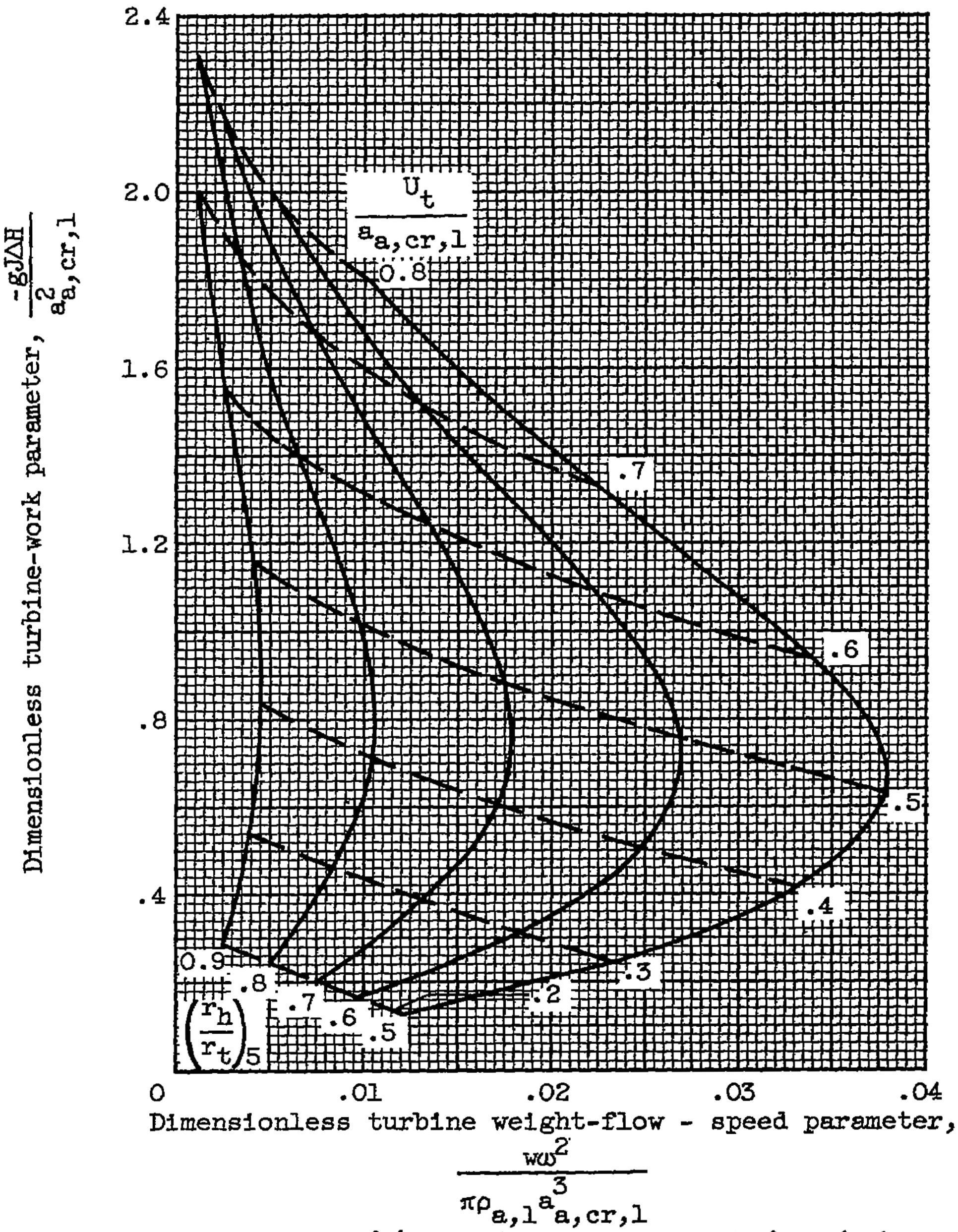
Chart II. - Continued. $1\frac{1}{2}$-Stage turbines.



2. $\left(\frac{V'}{a}\right)_{2,h} \leq 1.0$; $\left(\frac{V_2'}{V_3'}\right)_h \leq 1.0$.

(c) Concluded. $\left(\frac{V_z}{a}\right)_{3,m} = 0.7$.

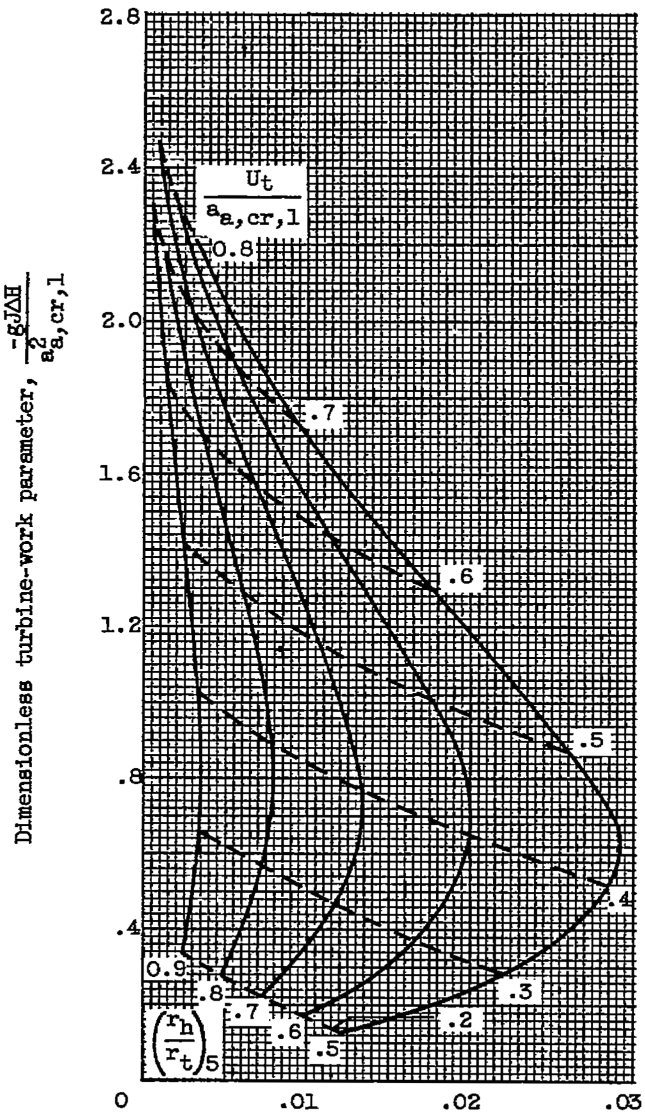
Chart II. - Concluded. $1\frac{1}{2}$-Stage turbines.



1. $\left(\frac{V'}{a}\right)_{2,h}$, $\left(\frac{V}{a}\right)_{3,h}$, $\left(\frac{V'}{a}\right)_{4,h} \leq 0.6$; $\left(\frac{V_2'}{V_3'}\right)_h$, $\left(\frac{V_3}{V_4}\right)_t$, $\left(\frac{V_4'}{V_5'}\right)_h \leq 1.0$.

(a) $\left(\frac{V_z}{a}\right)_{5,m} = 0.5$.

Chart III. - 2-Stage turbines.



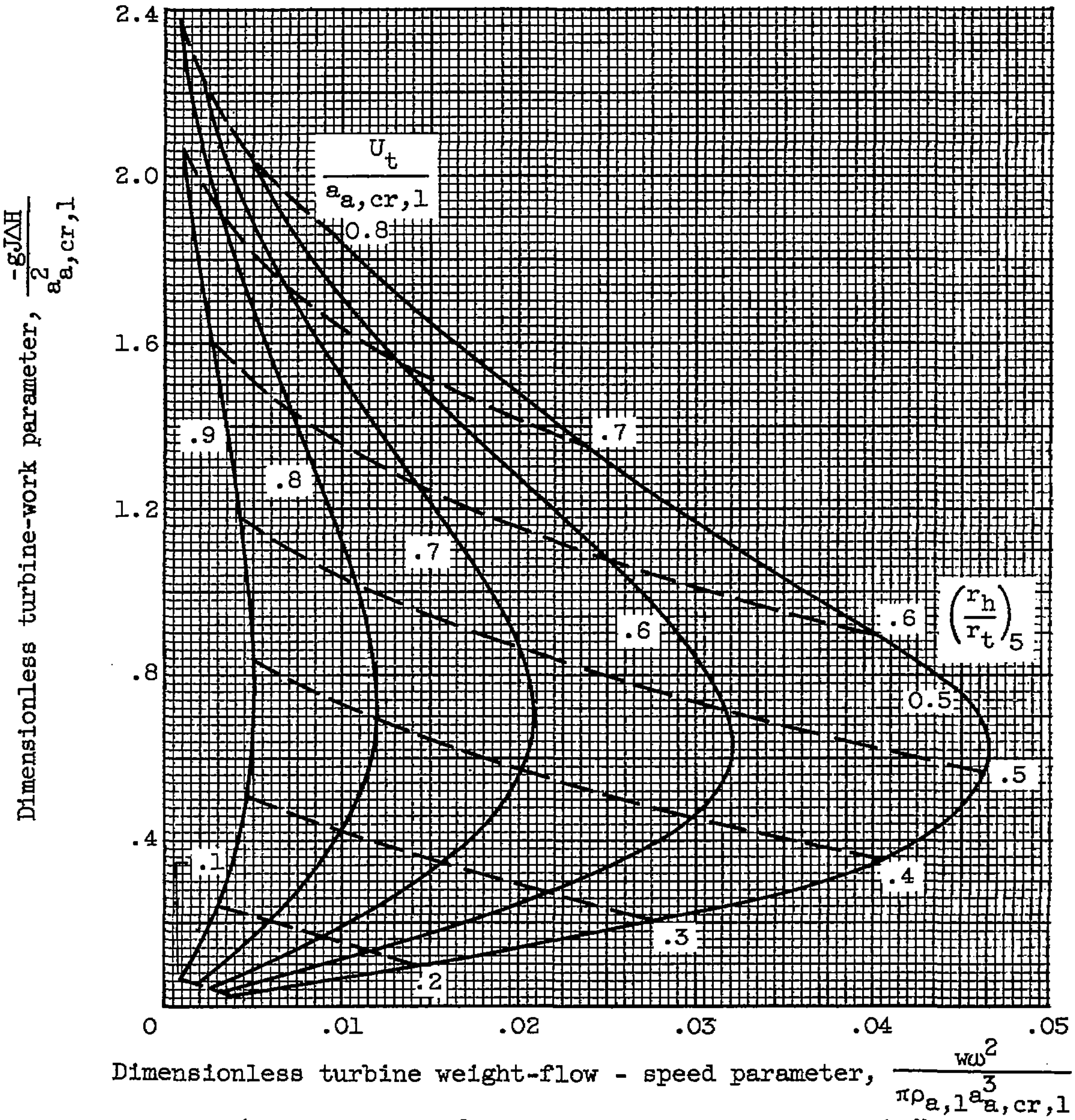
Dimensionless turbine weight-flow - speed parameter, $\frac{w\omega^2}{\pi \rho_{a,1} a_{a,cr,1}^3}$

2. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \leq 0.8;$

$\left(\frac{V_2'}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4'}{V_5'}\right)_h \leq 1.0.$

(a) Concluded. $\left(\frac{V_z}{a}\right)_{5,m} = 0.5.$

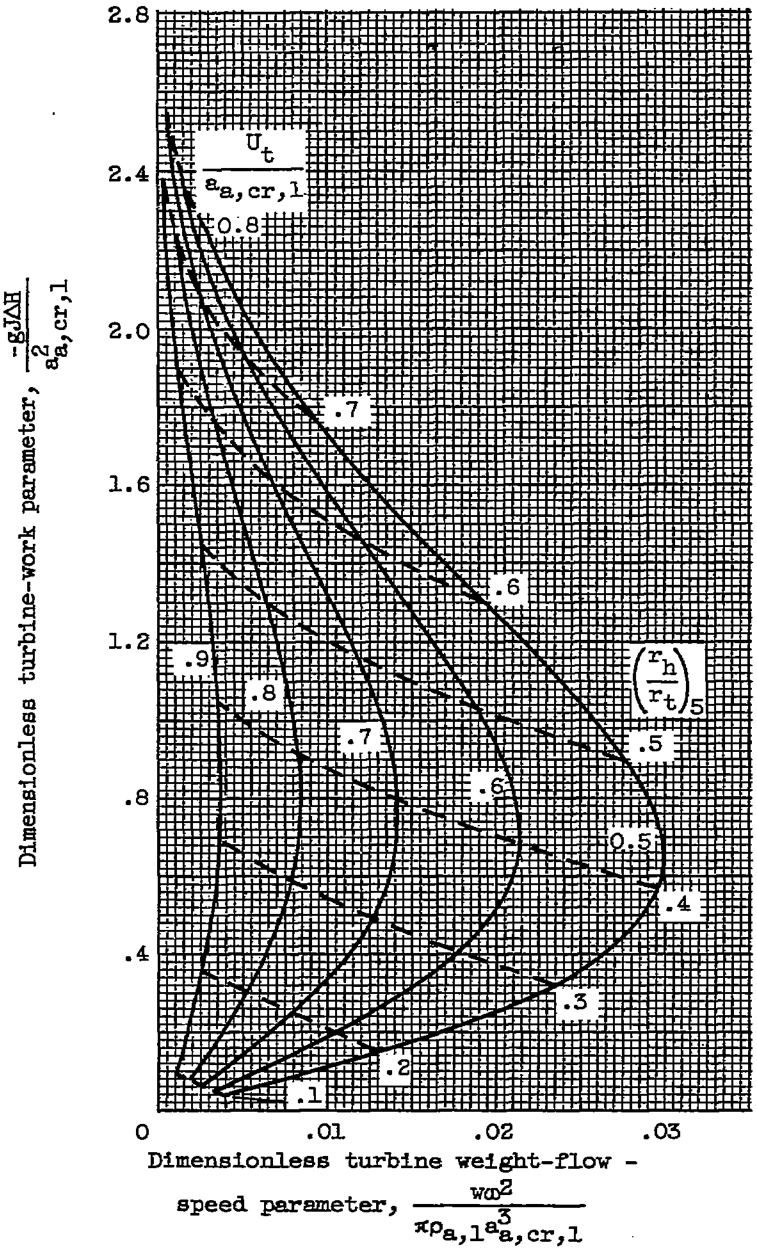
Chart III. - Continued. 2-Stage turbines.



1. $\left(\frac{V'}{a}\right)_{2,h}, \left(\frac{V}{a}\right)_{3,h}, \left(\frac{V'}{a}\right)_{4,h} \leq 0.6;\ \left(\frac{V_2'}{V_3'}\right)_h, \left(\frac{V_3}{V_4}\right)_t, \left(\frac{V_4'}{V_5'}\right)_h \leq 1.0.$

(b) $\left(\frac{V_z}{a}\right)_{5,m} = 0.6.$

Chart III. - Continued. 2-Stage turbines.



2. $\left(\frac{V'}{a}\right)_{2,h}$, $\left(\frac{V}{a}\right)_{3,h}$, $\left(\frac{V'}{a}\right)_{4,h} \leq 0.8$;

$\left(\frac{V_2'}{V_3'}\right)_h$, $\left(\frac{V_3}{V_4}\right)_t$, $\left(\frac{V_4'}{V_5'}\right)_h \leq 1.0$.

(b) Concluded. $\left(\frac{V_z}{a}\right)_{5,m} = 0.6$.

Chart III. - Continued. 2-Stage turbines.

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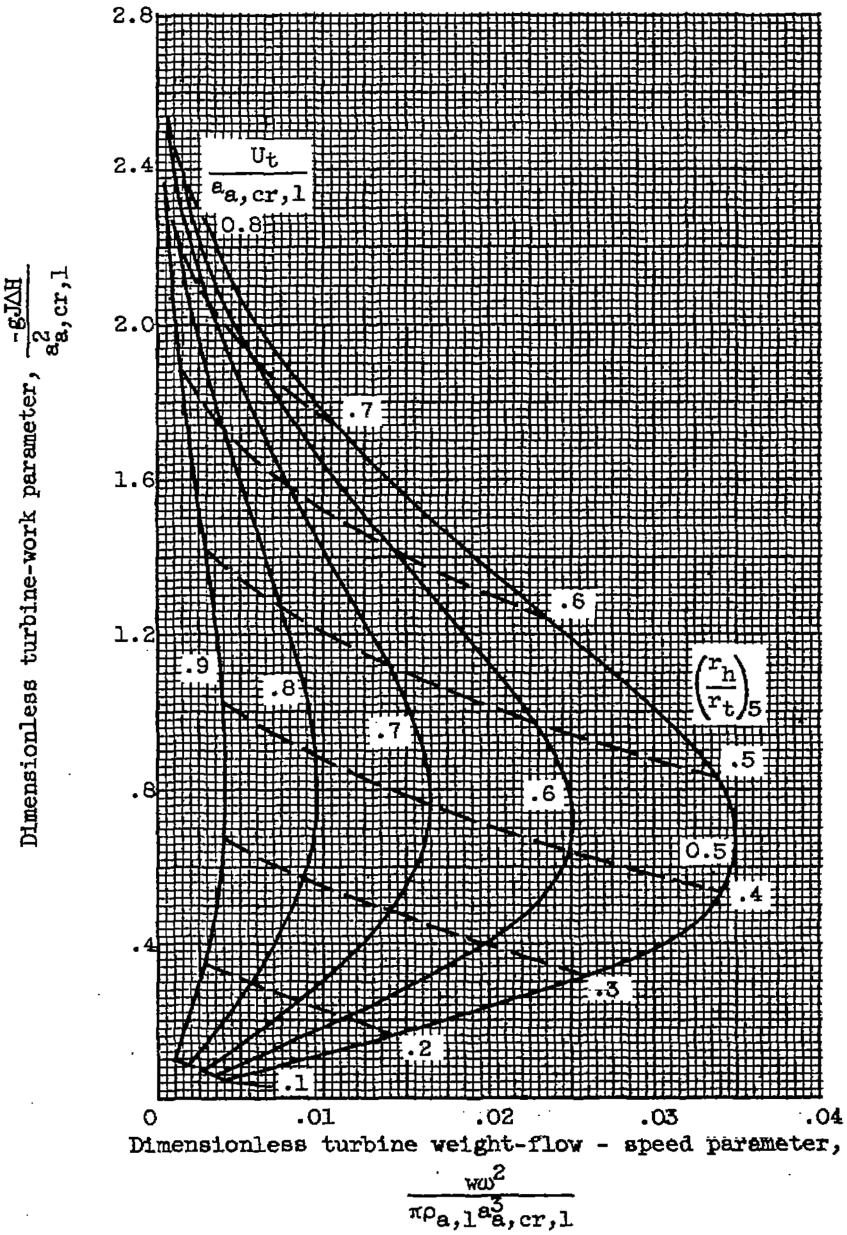

$\left(\frac{V'}{a}\right)_{2,h}$, $\left(\frac{V}{a}\right)_{3,h}$, $\left(\frac{V'}{a}\right)_{4,h} \leq 0.8$; $\left(\frac{V_2'}{V_3'}\right)_h$, $\left(\frac{V_3}{V_4}\right)_t$, $\left(\frac{V_4'}{V_5'}\right)_h \leq 1.0.$

(c) $\left(\frac{V_z}{a}\right)_{5,m} = 0.7.$

Chart III. - Concluded. 2-Stage turbines.

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