American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-03, Issue-05, pp-296-305
www.ajer.org

Research Paper Open Access

Design Study for Single Stage High Pressure Turbine of Gas Turbine Engines

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Abstract: **-** The research paper is a design study to reduce multiple stages of High Pressure Turbine (HPT) to maintain the same thrust – to – weight ratio of gas turbines. This current approach of gas turbine design is to reduce cost and weight of the component. The preliminary design for the turbomachinery features three different gas turbines such as AL-2LF-3, GT – 26, and SK30 – GT. The research survey used to fulfill this task is an Advance Mathematical Modeling Principles; based on the Inlet Annulus Design Analysis, Prediction of Turbine Efficiency using Smith's Efficiency Correlation Chart, Design Analysis for the Outlet Annulus and a design study for Turbine Free Vortex. The ability to determine this aerodynamic geometry of the HPT stage(s) of gas turbine is the peak of the research.

Nevertheless, study results revealed that a single stage HPT deriving a corresponding compressor can produce the same and needed aerodynamic performance of the gas turbine. Thus, all conditions required in the design of HPT stage were met having turbine stage efficiency within the range of $1.0 < (\Delta H/U^2) < 2.5$ and $0.5 < (Va/U) < 0.8$; fulfilling Smith's Efficiency Prediction Law. A corresponding Mach number for the three engines of study are 0.51, 0.46 and 0.52 respectively. This is a clear indication to prevent the choking condition of the compressible flow at the minimum area along the duck of the gas turbine.

Keywords: **-** *HPT, Mach Number, stage isentropic efficiency, Thrust(Power), Turbomachinery*

I. INTRODUCTION

Developing and acquiring good knowledge of the functions of an axial high pressure turbine (HPT) component is important to its designers and proficient users that are accessible to the performance of gas turbine engines. The ambitious performance role of any axial turbine component of gas turbine engine is to drive a corresponding axial compressor for gas pipeline or external load purposes. Thus, this understanding will expose designers the advantages and limitations likely to be encounter in its design/manufacturing processes. One major objective of these preliminary aerodynamic design studies of the axial turbine is targeted to yield high isentropic efficiency for the turbine, because the technical quality of any machine is best described by its efficiency [1]. Another challenging constrains leading to this study is the weight, cost, fuel consumption, emissions from engine, durability and how reliable the gas turbine engine is, regardless of its area of application.

Considerable solution to remedy these limitations is the reduction of turbine stages to produce the same output thrust or power for aero and industrial gas turbine machines respectively. To maintain availability of the designed axial high pressure turbine component of gas turbine, the test and comparison of specific fuel consumption to the initially manufactured engine is necessary. Many scholars have contributed excellently on the design analysis for gas turbine components. According to [2] preliminary detail calculation of gas turbine components helps the designer to understand the characteristic dimensions and gas angles in compressor stages using a real gas turbine model. This analysis allows the estimation of inlet and outlet cross-sectional area and number of the corresponding stages needed in a compressor. However, designing a turbine component to attain high thermodynamic efficiency, heat addition into the inlet temperature of the component should be as high as possible [3]. This employs a corresponding cooling component to cater for any excess or over-heating problems. Meanwhile, there is an inherent exchange between increasing a cycle temperature and the cooling penalties in the cycle; knowing that cooling flows can impact the overall thermal efficiency of the engine, therefore losses that increase cooling flow can have a cycle penalty [3].

The current approach in aero gas-turbine engine design is to increase the thrust-to-weight ratio and stage pressure ratio leading to compressor design with higher aerodynamic loads and reducing the number of blades and stages and thus diminishing the overall size and weight of the machine. Hence, the pressure rise per stage and the efficiency must be increased and aerodynamic stability of a compressor is limited by the behavior of the tip leakage flows or the hub corner stall when the operating point gets closer to the stall or surge limit [4,5]. Knowing the performance role of a turbine component in gas turbine engine as a compressor driving mechanism, may also needs a corresponding design to meet the target of its counterpart. The advancement of turbo-compression technology is a reflection of a higher work capacity per stage as a result of increases in rotor speed, aerodynamic loading; meanwhile an incremental performance enhancement can be made through geometric optimization and improved design methods [6,7].

The optimization techniques give direct control on the performance parameters of the gas turbine which allows the designer to explore the design space to achieve a given objective. One possible design objective is to minimize flow losses, which can be measured by the total pressure loss (or entropy generation) [8]. Thus, minimizing flow losses can be achieved by proper reshaping of the blade profile. The consistency in gas turbine operation relies on the structural integrity of its rotating parts. Thus, the design analysis and testing of component cycle is intensely a rigorous phase that ensures the well-being of the final product satisfying the requirement of the manufacturer [9]. This design process of an axial flow turbine still remains a very complex, fussy, multidisciplinary task where aero-thermodynamic issues, aero-mechanical, technological, structural, noise related cases, emission and other prevalent matters are considered simultaneously which leads to very challenging problems for the designer. This is true fact mostly for aircraft engines with stringent demands for low weight, high strength and extended life [10,11].

In respect of handling this complexity, the stage designing process of an axial high pressure turbine component of gas turbine engine as treated in this paper is supported with an Advance Mathematical Modeling Principles and conclusion is drawn based on Smith's Efficiency Correlation method of turbine stage efficiency prediction.

II. GEOMETRIC DESCRIPTION OF ENGINES OF STUDY

The general arrangement for turbine component representing a HPT used for model development is shown in figure 1 below. Both single and double spool aero gas turbines are considered for the purpose of this study. The importance of this research is to carry out a feasibility test for a single stage preliminary design for the HPT.

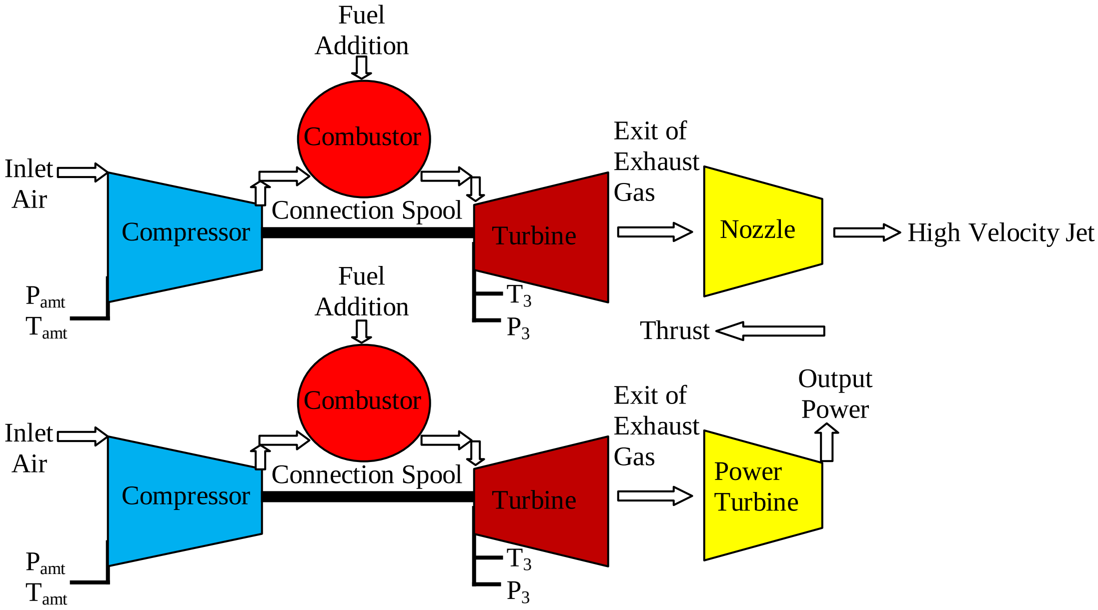

Figure 1: *A simple Gas Turbine Cycle as Aero and Industrial one Spool Gas Turbine Engines*

III. DESIGN SPECIFICATIONS

The design specifications for the engines of study are in table 1 which are available in [12,13,14] highlights the needed parameters for subsequent design analysis. However, in the design process of the axial turbine, some assumptions were considered. They are such as:- Constant Vortex Flow, 50% Reaction at Blade Mid Height, Straight Sided Annulus Walls, Constant Axial Velocity, Constant Mean Diameter and a Constant Shaft Speed.

Table 1: Turbine Design Specifications

Manufacturer	Model	Turbine Inlet Flow Mach No	Mean Diameter (Dm) m	Shaft Speed (rpm)	Polytropic Efficiency	TET (K)	Turbine Inlet Mass Flow(kg/s)	Turbine Work (TW) (MW)	Specific Heat (Cp) KJ/KgK	Gamma
LYULKA	AL-2LF-3	0.3	1.72	3000	0.9	562	25.497	3.84	1277	1.29
ALSTOM	GT-26	0.3	2.95	3000	0.9	1757	622.79	288.3	9756	1.4
ROLLS-ROYCE	SK30 - GT	0.3	2.75	3001	0.9	1158.34	93.6	20	3562	1.32

IV. DESIGN ANALYSIS

The designing of HP turbine with high engine thermal efficiency is usually constrained by high temperature environment, thereby needs a subsequent cooling effect. Also, the load carrying capacity of the turbine disc is a major concern. Therefore, designing this component needs some harmonizing technology to put all these limitations into consideration for suitable and effective design work. With respect to this study, some design parameters were calculated from the performance specifications of the real engine as classified on table 1 above.

They are the hot mass flow from the combustor to the inlet of the turbine, the turbine entry temperature (TET), turbine work (TW) etc; whereas a preliminary assumption of the engine ambient condition and fuel caloric value (FCV) are taken as 101.325KPa, 288K and 43MJ/Kg, respectively. Meanwhile, a 5% combustor pressure loss and 2% pressure drop at turbine exit are considered likewise.

V. INLET ANNULUS GEOMETRY

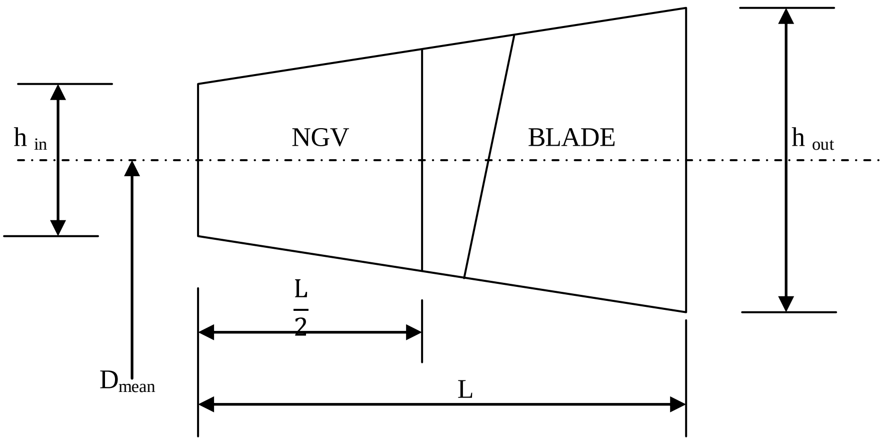

Figure 2: *High Pressure Turbine Annulus Diagram*

The governing equations with respect to the calculation of the Inlet Annulus Geometry of an axial HP turbine is given in equations (i) to (v):

$P_3 = PR \cdot P_{amt} \cdot$ Percentage of combustor pressure loss ……………………… . . . . . (i)

$A = \frac{W \cdot \sqrt{T3}}{Q \cdot P3}$ ………………………………………………………………….(ii)

$h = \frac{A}{\pi \cdot Dm}$ …………………………………………………………………….(iii)

$Dtip = Dm + h$ ………………………………………………………………….(iv)

$Dhub = Dm - h$ ……………………………………………………………..(v)

VI. ANALYSIS FOR THE PREDICTION OF TURBINE EFFICIENCY

The isentropic efficiency of the component is generally used as a true measure of the engine's performance. Hence, Smith's chart correlation method of turbine efficiency prediction is considered for the study. This industrial based technique recognized that whilst the designer would always attempt to minimize loss components, the major factors affecting turbine efficiency would always be design levels of gas velocity and deflection.

According to the Smith's correlated turbine efficiency chart, measurements from stage loading coefficient ($\Delta H/U^2$) and flow coefficient (Va/U) are connected and traced to the efficiency correlation curves; where the best turbine efficiency are taken. Meanwhile, Smith's Chart correlation always recommends a value of minus 2% from the read value for a test of accuracy and best stage design efficient for turbine. Equations (vi) to (viii) are analytical expressions used for the determination of axial turbine efficiency:

$$\Delta T = \frac{\text{Turbine Power}}{W \bullet Cp} \quad \ldots\ldots(vi)$$

$$Umean = \frac{RPM \bullet \pi \bullet Dm}{60} \quad \ldots\ldots(vii)$$

$$\Delta H/U^2 = Cpgas \bullet \Delta T / U2 \quad \ldots\ldots(viii)$$

VII. OUTLET ANNULUS GEOMETRY

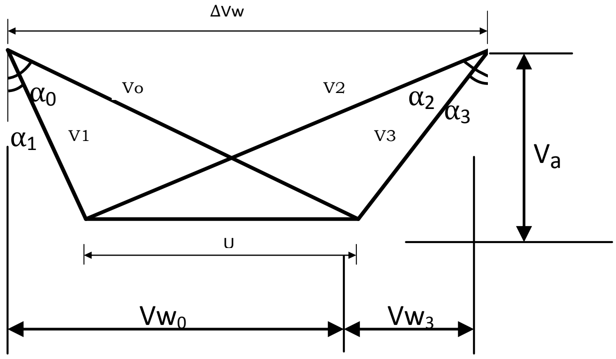

Figure 3: *Velocity Diagram*

$$\Delta Vw = \left[\frac{\Delta H}{U^2} \right] \bullet \frac{U}{\Omega} \quad \ldots\ldots(ix)$$

$$Vw_3 = \Delta Vw - Umean/2 \quad \ldots\ldots(x)$$

$$\alpha_3 = \tan^{-1}(Vw_3/V_a) \quad \ldots\ldots(xi)$$

$$v_3 = V_a / \cos\alpha_3 \quad \ldots\ldots(xii)$$

$$R = \left[1 - \frac{\Delta T}{\eta isent\ .\ x\ Tin}\right]^{\Upsilon/(\Upsilon-1)} \quad \ldots\ldots(xiii)$$

$$P3 = Pin \times R \quad \ldots\ldots(xiv)$$

$$Aann = A_3/\cos\alpha_3 \quad \ldots\ldots(xv)$$

In order to increase a design power, there will be increase in NGV turning and exit whirl angle. However, the process stage require cooling for the production of high thermal efficiency will keep the trailing edge of the high (α_0) NGV to be thinner and this occurrence happens when α_0 = 70 - 72° approximately [11]. The above mathematical expressions, equations (ix) – (xv)] are the basic will-power for outlet annulus geometry analysis.

VIII. RESULTS

Results are presented in the tables (tables 2 – 5) using the relationships provided from the governing equations above. Meanwhile, appropriate values of the mass flow function Q or ($W\sqrt{T}/AP$), velocity function ($Va/\sqrt{T_3}$) and stage isentropic efficiency (ηisent) of turbine component are extracts from isentropic flow chart of dry air and Smith's Efficiency correlation chart [15]. These charts are equally presented in Annex – A; whereas, a work done factor (Ω) of 0.98 was considered in the analysis.

Table 2: Inlet Annulus Design

Engine Model	Pressure Ratio	Ambient Pressure (P_1)	5% Pressure loss @ CC	Turbine Inlet Pressure (P_{in})	Values of Q For M = 0.3	Turbine Inlet Mass Flow	TET	Annulus Area A	Annulus Mean Diameter Dm	Height of Annulus h	Tip Diameter Dtip	Hub Diameter Dhub	Dhub/Dtip Ratio
LYULKA AL-21F-3	3.6	101325	0.95	346532	0.019	25.5	562	0.09	1.72	0.017	1.74	1.71	0.981
ALSTOM GT - 26	33.9	101325	0.95	3263172	0.020	622.8	1757	0.41	2.95	0.044	2.99	2.91	0.971
Rolls Royce SK30 GT	11.0	101325	0.95	1058846	0.019	93.6	1158	0.16	2.75	0.018	2.77	2.73	0.987

Table 3: Prediction of Turbine Efficiency

Engine Model	power (MW)	Mass flow (kg/s)	Specific Heat CP; (kJ/kgK)	Temp Drop ΔT; (°K)	Shaft Speed (rpm)	Dmean (m)	Umean (m/s)	$\Delta H/U^2$	$V_a/\sqrt{T_3}$ from table	TET	Va	Va/Umean	ηisent (%) (from Smith's Chart)
LYULKA AL-21F-3	3.84	25.5	1277	117.94	3000	1.72	270.21	2.062	5.74	562	135.96	0.503	89.0
ALSTOM GT - 26	288.3	622.8	9756	47.45	3000	2.95	463.45	2.155	5.96	1757	249.82	0.539	88.5
Rolls Royce SK30 GT	40	93.6	1158.34	368.93	3000	2.75	432.03	2.290	5.80	1545.3	227.92	0.528	87.9

Table 4: Design Analysis for Outlet Annulus

Engine Engine Model	Temp Drop (ΔT)	T_3	ΔVw	Vw_3	α_3	V_3	$V_3/\sqrt{T_3}$	M_3 = value matching to $V_3/\sqrt{T_3}$ From table	Q_3 = value matching to $V_3/\sqrt{T_3}$ From table	P_3	A_3	Area of Annulus (Aann)	Annulus height h	Dtip	Dhub	hub/tip ratio
LYULKA AL-21F-3	117.90	444	568.74	149.26	47.67	201.90	9.58	0.51	0.029	105093.85	0.174	0.259	0.048	1.77	1.67	0.946
ALSTOM GT - 26	47.45	1710	1019.24	277.90	48.05	373.76	9.04	0.46	0.028	2927745.95	0.310	0.464	0.050	3	2.9	0.967
Rolls Royce SK30 GT	368.90	1176	1009.37	288.67	55.64	403.83	11.77	0.62	0.034	286984.61	0.332	0.589	0.068	2.82	2.68	0.952

Table 5: Turbine Free Vortex Design

Engine Model LYULKA - AL-21F-3	ROOT	BMH	TIP
D (NGV Exit)	1.69	1.72	1.75
D (ROOT Exit)	1.67	1.72	1.77
Va	135.96	135.96	135.96
Vw_3 mean	149.26	149.26	149.26
Vw_0 Mean	419.48	419.48	419.48
$Vw_0 = Vw_0$ Mean • (Dmean /D) D @ NGV Exit	427.53	419.63	411.72
$\alpha_0 = \tan^{-1}(Vw_0/Va)$	72.36	72.05	71.73
$Vw_3 = Vw_3$ Mean • (Dmean /D) D @ Rotor Exit	153.54	149.38	145.22
$\alpha_3 = \tan^{-1}(Vw_3/Va)$	48.48	47.69	46.89
U = Umean • (D /Dmean); D @ Rotor Exit	262.23	269.74	277.25
$V_0 = Va / \cos\alpha_0$	563.91	432.25	300.59
Nozzle Acceleration, $Va / V_{in} = V_0 / V_a$	4.15	3.18	2.21
$V_1 = \sqrt{[V_a^2 + (Vw_0 - U)^2]}$	214.03	202.63	191.22
$\alpha_1 = \cos^{-1}(Va / V_1)$	50.56	47.62	44.68
$V_2 = \sqrt{[V_a^2 + (U + Vw_3)^2]}$	437.43	440.62	443.81
$\alpha_2 = \cos^{-1}(Va / V_2)$	71.89	72.03	72.16
Rotor Acceleration, V_2 / V_1	2.04	2.18	2.32
Engine Model ALSTOM - GT - 26	**ROOT**	**BMH**	**TIP**
D (NGV Exit)	2.90	2.95	2.99
D (ROOT Exit)	2.89	2.95	3.01
Va	249.82	249.82	249.82
Vw_3 mean	277.90	277.90	277.90
Vw_0 Mean	741.34	741.34	741.34
$Vw_0 = Vw_0$ Mean • (Dmean /D) D @ NGV Exit	753.31	741.53	729.75
$\alpha_0 = \tan^{-1}(Vw_0/Va)$	71.65	71.38	71.10
$Vw_3 = Vw_3$ Mean • (Dmean /D) D @ Rotor Exit	282.72	277.98	273.25
$\alpha_3 = \tan^{-1}(Vw_3/Va)$	48.53	48.05	47.56
U = Umean • (D /Dmean); D @ Rotor Exit	265.15	269.74	274.34
$V0 = Va / \cos\alpha_0$	1036.18	794.26	552.34
Nozzle Acceleration, $Va / V_{in} = V_0 / V_a$	4.15	3.18	2.22
$V_1 = \sqrt{[V_a^2 + (Vw_0 - U)^2]}$	548.38	533.91	519.43
$\alpha_1 = \cos^{-1}(Va / V_1)$	62.90	62.08	61.25
$V_2 = \sqrt{[V_a^2 + (U + Vw_3)^2]}$	602.13	602.01	601.88
$\alpha_2 = \cos^{-1}(Va / V_2)$	65.49	65.49	65.48
Rotor Acceleration, V_2 / V_1	1.10	1.13	1.16

Engine Model Rolls Royce - SK30 GT	ROOT	BMH	TIP
D (NGV Exit)	2.71	2.75	2.79
D (ROOT Exit)	2.66	2.75	2.84
Va	227.92	227.92	227.92
Vw_3 mean	288.67	288.67	288.67
Vw_0 Mean	720.70	720.70	720.70
$Vw_0 = Vw_0$ Mean • (Dmean /D) D @ NGV Exit	732.17	720.88	709.58
$\alpha_0 = \tan^{-1}(Vw_0/Va)$	72.71	72.45	72.19
$Vw_3 = Vw_3$ Mean • (Dmean /D) D @ Rotor Exit	298.74	289.00	279.26
$\alpha_3 = \tan^{-1}(Vw_3/Va)$	56.55	55.65	54.75
U = Umean • (D /Dmean); D @ Rotor Exit	260.65	269.74	278.83
$V0 = Va / \cos\alpha_0$	945.35	724.64	503.92
Nozzle Acceleration, $Va / V_{in} = V_0 / V_a$	4.15	3.18	2.21
$V_1 = \sqrt{[V_a^2 + (Vw_0 - U)^2]}$	514.23	492.60	470.97
$\alpha_1 = \cos^{-1}(Va / V_1)$	67.43	66.33	65.23
$V_2 = \sqrt{[V_a^2 + (U + Vw_3)^2]}$	593.17	592.56	591.95
$\alpha_2 = \cos^{-1}(Va / V_2)$	67.40	67.375	67.35
Rotor Acceleration, V_2 / V_1	1.15	1.20	1.26

IX. DISCUSSION OF RESULTS

The preliminary design results for the axial HPT component performance of the turbomachinery as shown above conforms yielding the best stage efficiency performance from the Smith's chart where the stage loading coefficient ($\Delta H/U^2$) is plotted against the flow coefficient (Va/U). As seen on the tabulated results and in Annex – A; the stage isentropic efficiency for the three engine of study; AL-2LF-3, GT – 26 and SK30 – GT are 89.0%, 88.5% and 87.9% respectively. Also, this moderate values implies low gas velocities and reduction of excessive frictional losses. This satisfies a single stage arrangement in the HPT component design. It is an indication that multiple stage can be replaced with a single stage arrangement of axial HPT using the ideas of the above systematic design study.

Another point of concern is the corresponding Mach numbers for the three engine of study; that is M_3 = 0.51, 0.46 and 0.52 for AL-2LF-3, GT – 26 and SK30 – GT from the outlet annulus design which is less than 1. This shows that the inlet mass flow of the HPT and TET is in order. Thus, acknowledging that one key phenomenon for compressible flow is choking; where a Mach number of 1 is reached at the minimum area along a duck. Again, is the modality of increasing the design power of the component which has to do with the exit whirl angle and the effect of turns in the NGV. In order to maintain these conditions to keep high thermal efficiency production; the gas angle, α_0 design analyses were ensured to be at an approved range of (70 – 72°) according to literature review [11]. Therefore, an estimated result of α_0 from table 5 above for AL-2LF-3 is 72.71° at Root, 72.45° at Blade Mid Height (BMH) and 72.19° at tip; while for GT – 26 is 71.65° at Root, 71.38° at BMH and 71.1° at tip and for SK30 – GT is 72.71° at Root, 72.45° at BMH and 72.19° at tip.

X. CONCLUSION

The line of best efficiency for turbine design indicates that the optimum turbines are at the ranges of:- $1.0 < (\Delta H/U^2) < 2.5$ and $0.5 < (Va/U) < 0.8$; and the maximum range efficiency line follows the Smith's efficiency prediction law: $(\Delta H/U^2) = 6.5(Va/U) – 2.90$. Results of the HP turbine stage efficiency from study responds to Smith's efficiency figures quoted in his correlation. The HP turbine stages frequently appear on the left hand side of the Smith's chart of the best efficiency line; consequently, it is expected that turbine efficiency appears on same side and this is accomplished from the research study. The Mach number at the blade inlet hub from the design analysis of the study is less than 0.7 as stated in [16] is to ensure that there is acceleration relative to the blade all the way through the blade passage.

Results of NGV exit angle is satisfied because it maintains the range angle of 65° - 73° to guarantees decrease in pressure losses. Meanwhile, the analysis of the hub – tip ratio is greater than 0.5 from its design to minimize secondary losses; however, less than 0.85 though with reduced blade height. Therefore, the redesigning of a multiple stages to a single stage HPT component achieves the same performance as the original engine.

XI. ACKNOWLEDGEMENT

I sincerely appreciate all staff and colleagues of the department of Mechanical Engineering and the entire faculty of Engineering in my university, Niger Delta University for their encouragement.

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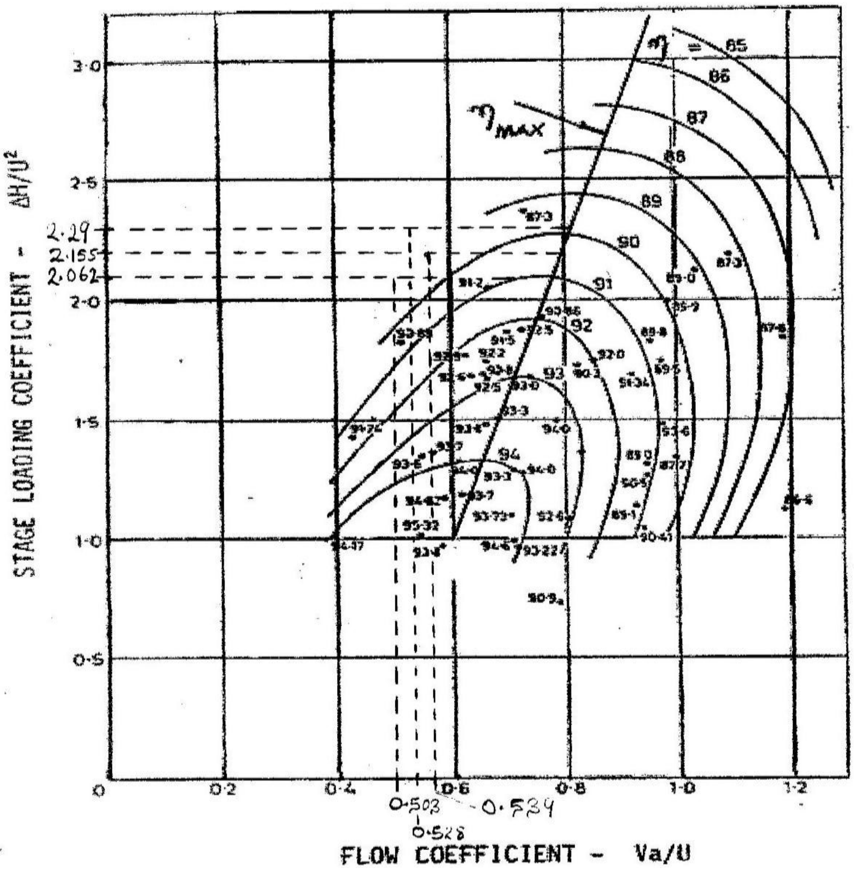
Notation and Units

A = the Cross sectional Area of the Annulus (m^2)
h = the height of the Annulus (m)
W = mass flow (Kg/s)
T_3 = turbine entry temperature (K)
P_3 = Inlet pressure to the turbine (KPa)
Q = mass flow function (JKg/K)
PR = Pressure Ratio
Pamt = Ambient Pressure (KPa)
Dm = Mean diameter of the Annulus (m)
U = Blade Speed (m/s)
V = velocity (m/s)
W= Mass Flow (kg/s)
BHM = Blade Mid Height

ANNEX – A

Efficiency Correlation Chart

(SINGLE STAGE TURBINES)



Isentropic Flow of Dry

GAS CONSTANT = 287 GAMMA = 1.29

Mach No	T/t	P/p	V/Root.T	1000 Q	1000 q	A/A*
0.000	1.0000	1.0000	0.000	0.000	0.000	infinity
0.005	1.0000	1.0000	0.096	0.335	0.335	117.1807
0.010	1.0000	1.0001	0.192	0.670	0.670	58.5928
0.015	1.0000	1.0001	0.289	1.006	1.006	39.0647
0.020	1.0001	1.0003	0.385	1.341	1.341	29.3015
0.025	1.0001	1.0004	0.481	1.675	1.676	23.4442
0.030	1.0001	1.0006	0.577	2.010	2.011	19.5399
0.035	1.0002	1.0008	0.673	2.345	2.347	16.7516
0.040	1.0002	1.0010	0.770	2.679	2.682	14.6608
0.045	1.0003	1.0013	0.866	3.013	3.017	13.0350
0.050	1.0004	1.0016	0.962	3.347	3.353	11.7347
0.055	1.0004	1.0020	1.058	3.681	3.688	10.6711
0.060	1.0005	1.0023	1.154	4.014	4.024	9.7851
0.065	1.0006	1.0027	1.250	4.347	4.359	9.0356
0.070	1.0007	1.0032	1.346	4.680	4.695	8.3934
0.075	1.0008	1.0036	1.443	5.012	5.030	7.8371
0.080	1.0009	1.0041	1.539	5.344	5.366	7.3506
0.085	1.0010	1.0047	1.635	5.675	5.702	6.9214
0.090	1.0012	1.0052	1.731	6.006	6.037	6.5402
0.095	1.0013	1.0058	1.827	6.336	6.373	6.1992
0.100	1.0015	1.0065	1.923	6.666	6.709	5.8926
0.105	1.0016	1.0071	2.019	6.995	7.045	5.6153
0.110	1.0018	1.0078	2.115	7.324	7.381	5.3633
0.115	1.0019	1.0086	2.211	7.652	7.717	5.1334
0.120	1.0021	1.0093	2.307	7.979	8.054	4.9228
0.125	1.0023	1.0101	2.402	8.306	8.390	4.7292
0.130	1.0025	1.0109	2.498	8.632	8.726	4.5506
0.135	1.0026	1.0118	2.594	8.957	9.063	4.3854
0.140	1.0028	1.0127	2.690	9.281	9.399	4.2321
0.145	1.0030	1.0136	2.786	9.605	9.736	4.0895
0.150	1.0033	1.0146	2.882	9.928	10.073	3.9565
0.155	1.0035	1.0156	2.977	10.250	10.410	3.8322
0.160	1.0037	1.0166	3.073	10.571	10.747	3.7158
0.165	1.0039	1.0177	3.169	10.891	11.084	3.6065
0.170	1.0042	1.0188	3.264	11.211	11.421	3.5038
0.175	1.0044	1.0199	3.360	11.529	11.759	3.4071
0.180	1.0047	1.0211	3.456	11.846	12.096	3.3158
0.185	1.0050	1.0223	3.551	12.163	12.434	3.2295
0.190	1.0052	1.0235	3.646	12.479	12.771	3.1479
0.195	1.0055	1.0248	3.742	12.793	13.109	3.0705
0.200	1.0058	1.0261	3.837	13.106	13.447	2.9971
0.205	1.0061	1.0274	3.933	13.418	13.786	2.9274
0.210	1.0064	1.0288	4.028	13.729	14.124	2.8611
0.215	1.0067	1.0302	4.123	14.039	14.462	2.7979
0.220	1.0070	1.0316	4.218	14.348	14.801	2.7377
0.225	1.0073	1.0331	4.314	14.655	15.140	2.6803
0.230	1.0077	1.0346	4.409	14.962	15.479	2.6254
0.235	1.0080	1.0361	4.504	15.267	15.818	2.5729
0.240	1.0084	1.0377	4.599	15.571	16.157	2.5227
0.245	1.0087	1.0393	4.694	15.873	16.497	2.4746
0.250	1.0091	1.0409	4.789	16.174	16.837	2.4286

Mach No	T/t	P/p	V/Root.T	1000 Q	1000 q	A/A*
0.255	1.0094	1.0426	4.884	16.474	17.176	2.3844
0.260	1.0098	1.0443	4.978	16.773	17.516	2.3419
0.265	1.0102	1.0461	5.073	17.070	17.857	2.3012
0.270	1.0106	1.0479	5.168	17.366	18.197	2.2620
0.275	1.0110	1.0497	5.263	17.660	18.538	2.2243
0.280	1.0114	1.0516	5.357	17.953	18.878	2.1880
0.285	1.0118	1.0535	5.452	18.244	19.219	2.1530
0.290	1.0122	1.0554	5.546	18.534	19.561	2.1194
0.295	1.0126	1.0574	5.641	18.822	19.902	2.0869
0.300	1.0131	1.0594	5.735	19.109	20.244	2.0556
0.305	1.0135	1.0614	5.829	19.395	20.586	2.0253
0.310	1.0139	1.0635	5.924	19.678	20.928	1.9961
0.315	1.0144	1.0656	6.018	19.960	21.270	1.9679
0.320	1.0148	1.0678	6.112	20.241	21.612	1.9406
0.325	1.0153	1.0699	6.206	20.520	21.955	1.9143
0.330	1.0158	1.0722	6.300	20.797	22.298	1.8887
0.335	1.0163	1.0744	6.394	21.073	22.641	1.8640
0.340	1.0168	1.0767	6.488	21.347	22.985	1.8401
0.345	1.0173	1.0791	6.582	21.619	23.329	1.8169
0.350	1.0178	1.0815	6.675	21.889	23.673	1.7946
0.355	1.0183	1.0839	6.769	22.158	24.017	1.7727
0.360	1.0188	1.0863	6.863	22.425	24.361	1.7516
0.365	1.0193	1.0888	6.956	22.690	24.706	1.7312
0.370	1.0199	1.0914	7.050	22.954	25.051	1.7113
0.375	1.0204	1.0939	7.143	23.215	25.396	1.6920
0.380	1.0209	1.0966	7.236	23.475	25.742	1.6733
0.385	1.0215	1.0992	7.330	23.733	26.087	1.6551
0.390	1.0221	1.1019	7.423	23.989	26.434	1.6374
0.395	1.0226	1.1046	7.516	24.243	26.780	1.6203
0.400	1.0232	1.1074	7.609	24.496	27.127	1.6036
0.405	1.0238	1.1102	7.702	24.746	27.473	1.5873
0.410	1.0244	1.1131	7.795	24.994	27.821	1.5716
0.415	1.0250	1.1160	7.887	25.241	28.168	1.5562
0.420	1.0256	1.1189	7.980	25.486	28.516	1.5413
0.425	1.0262	1.1219	8.073	25.728	28.864	1.5267
0.430	1.0268	1.1249	8.165	25.969	29.212	1.5126
0.435	1.0274	1.1280	8.257	26.208	29.561	1.4988
0.440	1.0281	1.1311	8.350	26.444	29.910	1.4854
0.445	1.0287	1.1342	8.442	26.679	30.259	1.4723
0.450	1.0294	1.1374	8.534	26.912	30.609	1.4596
0.455	1.0300	1.1406	8.626	27.142	30.959	1.4472
0.460	1.0307	1.1439	8.718	27.371	31.309	1.4351
0.465	1.0314	1.1472	8.810	27.598	31.660	1.4233
0.470	1.0320	1.1506	8.902	27.822	32.011	1.4118
0.475	1.0327	1.1540	8.994	28.044	32.362	1.4006
0.480	1.0334	1.1574	9.085	28.265	32.714	1.3897
0.485	1.0341	1.1609	9.177	28.483	33.066	1.3791
0.490	1.0348	1.1644	9.268	28.699	33.418	1.3687
0.495	1.0355	1.1680	9.360	28.913	33.771	1.3586
0.500	1.0363	1.1716	9.451	29.125	34.124	1.3487

GAS CONSTANT = 287 GAMMA = 1.29

Mach No	T / t	P / p	V / Root.T	1000 Q	1000 q	A / A*
0.500	1.0363	1.1716	9.451	29.125	34.124	1.3487
0.505	1.0370	1.1753	9.542	29.335	34.477	1.3390
0.510	1.0377	1.1790	9.633	29.542	34.831	1.3298
0.515	1.0385	1.1828	9.724	29.748	35.185	1.3204
0.520	1.0392	1.1866	9.815	29.951	35.539	1.3115
0.525	1.0400	1.1904	9.906	30.152	35.894	1.3027
0.530	1.0407	1.1943	9.996	30.351	36.249	1.2942
0.535	1.0415	1.1983	10.087	30.548	36.605	1.2859
0.540	1.0423	1.2023	10.177	30.742	36.961	1.2777
0.545	1.0431	1.2063	10.268	30.935	37.317	1.2698
0.550	1.0439	1.2104	10.358	31.125	37.674	1.2620
0.555	1.0447	1.2145	10.448	31.313	38.031	1.2544
0.560	1.0455	1.2187	10.538	31.499	38.388	1.2470
0.565	1.0463	1.2230	10.628	31.682	38.746	1.2398
0.570	1.0471	1.2272	10.718	31.863	39.104	1.2328
0.575	1.0479	1.2316	10.808	32.043	39.463	1.2259
0.580	1.0488	1.2360	10.897	32.219	39.822	1.2191
0.585	1.0496	1.2404	10.987	32.394	40.182	1.2126
0.590	1.0505	1.2449	11.076	32.565	40.541	1.2062
0.595	1.0513	1.2494	11.166	32.737	40.902	1.1999
0.600	1.0522	1.2540	11.255	32.904	41.262	1.1938
0.605	1.0531	1.2586	11.344	33.070	41.624	1.1878
0.610	1.0540	1.2633	11.433	33.234	41.985	1.1819
0.615	1.0548	1.2681	11.522	33.395	42.347	1.1762
0.620	1.0557	1.2729	11.610	33.554	42.709	1.1707
0.625	1.0566	1.2777	11.699	33.710	43.072	1.1652
0.630	1.0576	1.2825	11.788	33.865	43.436	1.1599
0.635	1.0585	1.2875	11.876	34.017	43.799	1.1547
0.640	1.0594	1.2926	11.964	34.167	44.163	1.1497
0.645	1.0603	1.2976	12.052	34.314	44.528	1.1447
0.650	1.0613	1.3028	12.141	34.460	44.893	1.1399
0.655	1.0622	1.3079	12.228	34.603	45.258	1.1352
0.660	1.0632	1.3132	12.316	34.744	45.624	1.1306
0.665	1.0641	1.3185	12.404	34.882	45.991	1.1261
0.670	1.0651	1.3238	12.492	35.019	46.358	1.1217
0.675	1.0661	1.3292	12.579	35.153	46.725	1.1174
0.680	1.0670	1.3347	12.666	35.285	47.093	1.1132
0.685	1.0680	1.3402	12.754	35.414	47.461	1.1092
0.690	1.0690	1.3457	12.841	35.541	47.830	1.1052
0.695	1.0700	1.3514	12.928	35.667	48.199	1.1013
0.700	1.0711	1.3571	13.015	35.789	48.569	1.0975
0.705	1.0721	1.3628	13.101	35.910	48.939	1.0938
0.710	1.0731	1.3686	13.188	36.028	49.310	1.0903
0.715	1.0741	1.3745	13.274	36.145	49.681	1.0868
0.720	1.0752	1.3804	13.361	36.258	50.052	1.0833
0.725	1.0762	1.3864	13.447	36.370	50.424	1.0800
0.730	1.0773	1.3925	13.533	36.480	50.797	1.0768
0.735	1.0783	1.3988	13.619	36.587	51.170	1.0736
0.740	1.0794	1.4048	13.705	36.692	51.544	1.0706
0.745	1.0805	1.4110	13.791	36.795	51.918	1.0676
0.750	1.0816	1.4173	13.876	36.896	52.293	1.0646

Mach No	T / t	P / p	V / Root.T	1000 Q	1000 q	A / A*
0.755	1.0827	1.4237	13.962	36.964	52.668	1.0618
0.760	1.0838	1.4301	14.047	37.030	53.044	1.0591
0.765	1.0849	1.4366	14.132	37.164	53.420	1.0564
0.770	1.0860	1.4432	14.217	37.276	53.796	1.0538
0.775	1.0871	1.4498	14.302	37.365	54.174	1.0512
0.780	1.0882	1.4565	14.387	37.453	54.551	1.0488
0.785	1.0894	1.4633	14.472	37.538	54.930	1.0464
0.790	1.0905	1.4701	14.556	37.621	55.309	1.0441
0.795	1.0916	1.4770	14.641	37.702	55.688	1.0419
0.800	1.0928	1.4840	14.725	37.781	56.068	1.0397
0.805	1.0940	1.4911	14.809	37.858	56.448	1.0376
0.810	1.0951	1.4982	14.893	37.932	56.829	1.0355
0.815	1.0963	1.5054	14.977	38.005	57.211	1.0336
0.820	1.0975	1.5126	15.061	38.075	57.593	1.0316
0.825	1.0987	1.5199	15.144	38.143	57.976	1.0298
0.830	1.0999	1.5273	15.228	38.210	58.359	1.0280
0.835	1.1011	1.5348	15.311	38.274	58.743	1.0263
0.840	1.1023	1.5423	15.394	38.336	59.127	1.0246
0.845	1.1035	1.5500	15.477	38.396	59.512	1.0230
0.850	1.1048	1.5577	15.560	38.453	59.897	1.0215
0.855	1.1060	1.5654	15.643	38.509	60.283	1.0200
0.860	1.1072	1.5733	15.726	38.563	60.670	1.0186
0.865	1.1085	1.5812	15.808	38.615	61.057	1.0172
0.870	1.1098	1.5892	15.891	38.664	61.445	1.0159
0.875	1.1110	1.5973	15.973	38.712	61.833	1.0147
0.880	1.1123	1.6054	16.055	38.758	62.222	1.0135
0.885	1.1136	1.6136	16.137	38.801	62.612	1.0123
0.890	1.1149	1.6220	16.219	38.843	63.002	1.0113
0.895	1.1161	1.6303	16.300	38.883	63.393	1.0102
0.900	1.1175	1.6388	16.382	38.921	63.784	1.0092
0.905	1.1188	1.6474	16.463	38.956	64.176	1.0083
0.910	1.1201	1.6560	16.545	38.990	64.568	1.0074
0.915	1.1214	1.6647	16.626	39.022	64.961	1.0066
0.920	1.1227	1.6735	16.707	39.052	65.355	1.0058
0.925	1.1241	1.6824	16.787	39.080	65.749	1.0051
0.930	1.1254	1.6914	16.868	39.106	66.144	1.0044
0.935	1.1268	1.7005	16.948	39.131	66.540	1.0038
0.940	1.1281	1.7096	17.029	39.153	66.936	1.0032
0.945	1.1295	1.7188	17.109	39.174	67.333	1.0027
0.950	1.1309	1.7282	17.189	39.192	67.730	1.0022
0.955	1.1322	1.7376	17.269	39.209	68.128	1.0018
0.960	1.1336	1.7471	17.349	39.224	68.527	1.0014
0.965	1.1350	1.7566	17.428	39.237	68.926	1.0011
0.970	1.1364	1.7663	17.508	39.249	69.326	1.0008
0.975	1.1378	1.7761	17.587	39.258	69.727	1.0006
0.980	1.1393	1.7860	17.667	39.266	70.128	1.0004
0.985	1.1407	1.7960	17.746	39.272	70.530	1.0002
0.990	1.1421	1.8060	17.824	39.277	70.932	1.0001
0.995	1.1436	1.8161	17.903	39.279	71.335	1.0000
1.000	1.1450	1.8263	17.982	39.280	71.738	1.0000

GAS CONSTANT = 287 GAMMA = 1.32

Mach No	T / t	P / p	V / Root.T	1000 Q	1000 q	A / A*
0.000	1.0000	1.0000	0.000	0.000	0.000	infinity
0.005	1.0000	1.0000	0.097	0.339	0.339	116.7820
0.010	1.0000	1.0001	0.195	0.678	0.678	58.3936
0.015	1.0000	1.0001	0.292	1.017	1.017	38.9319
0.020	1.0001	1.0003	0.389	1.356	1.356	29.2019
0.025	1.0001	1.0004	0.487	1.695	1.696	23.3645
0.030	1.0001	1.0006	0.584	2.033	2.035	19.4736
0.035	1.0002	1.0008	0.681	2.372	2.374	16.6946
0.040	1.0003	1.0011	0.778	2.710	2.713	14.6111
0.045	1.0003	1.0013	0.876	3.048	3.052	12.9908
0.050	1.0004	1.0017	0.973	3.386	3.392	11.6950
0.055	1.0005	1.0020	1.070	3.723	3.731	10.6350
0.060	1.0006	1.0024	1.167	4.061	4.070	9.7520
0.065	1.0007	1.0028	1.265	4.397	4.410	9.0051
0.070	1.0008	1.0032	1.362	4.734	4.749	8.3652
0.075	1.0009	1.0037	1.459	5.070	5.089	7.8108
0.080	1.0010	1.0042	1.556	5.405	5.428	7.3259
0.085	1.0012	1.0048	1.653	5.740	5.768	6.8983
0.090	1.0013	1.0054	1.751	6.075	6.108	6.5183
0.095	1.0014	1.0060	1.848	6.409	6.447	6.1786
0.100	1.0016	1.0066	1.945	6.743	6.787	5.8730
0.105	1.0018	1.0073	2.042	7.076	7.127	5.5966
0.110	1.0019	1.0080	2.139	7.408	7.467	5.3455
0.115	1.0021	1.0088	2.236	7.740	7.807	5.1165
0.120	1.0023	1.0095	2.333	8.071	8.148	4.9066
0.125	1.0025	1.0104	2.430	8.401	8.488	4.7137
0.130	1.0027	1.0112	2.527	8.730	8.828	4.5357
0.135	1.0029	1.0121	2.624	9.059	9.169	4.3711
0.140	1.0031	1.0130	2.721	9.387	9.509	4.2183
0.145	1.0034	1.0139	2.818	9.715	9.850	4.0762
0.150	1.0036	1.0149	2.914	10.041	10.191	3.9437
0.155	1.0038	1.0160	3.011	10.367	10.532	3.8199
0.160	1.0041	1.0170	3.108	10.691	10.873	3.7039
0.165	1.0044	1.0181	3.205	11.015	11.214	3.5950
0.170	1.0046	1.0192	3.301	11.338	11.556	3.4926
0.175	1.0049	1.0204	3.398	11.660	11.897	3.3962
0.180	1.0052	1.0216	3.494	11.981	12.239	3.3053
0.185	1.0055	1.0228	3.591	12.300	12.581	3.2193
0.190	1.0058	1.0240	3.687	12.619	12.923	3.1380
0.195	1.0061	1.0253	3.784	12.937	13.265	3.0609
0.200	1.0064	1.0267	3.880	13.254	13.607	2.9878
0.205	1.0067	1.0280	3.977	13.569	13.949	2.9183
0.210	1.0071	1.0294	4.073	13.883	14.292	2.8523
0.215	1.0074	1.0309	4.169	14.197	14.635	2.7893
0.220	1.0077	1.0323	4.266	14.509	14.978	2.7294
0.225	1.0081	1.0338	4.362	14.819	15.321	2.6721
0.230	1.0085	1.0354	4.458	15.129	15.664	2.6175
0.235	1.0088	1.0370	4.554	15.437	16.008	2.5652
0.240	1.0092	1.0386	4.650	15.744	16.351	2.5152
0.245	1.0096	1.0402	4.746	16.050	16.695	2.4673
0.250	1.0100	1.0419	4.842	16.354	17.039	2.4214

Mach No	T / t	P / p	V / Root.T	1000 Q	1000 q	A / A*
0.255	1.0104	1.0436	4.938	16.657	17.383	2.3774
0.260	1.0108	1.0454	5.033	16.958	17.728	2.3351
0.265	1.0112	1.0472	5.129	17.258	18.072	2.2945
0.270	1.0117	1.0490	5.225	17.557	18.417	2.2554
0.275	1.0121	1.0509	5.320	17.854	18.762	2.2179
0.280	1.0125	1.0528	5.416	18.150	19.108	2.1818
0.285	1.0130	1.0547	5.511	18.444	19.453	2.1470
0.290	1.0135	1.0567	5.607	18.737	19.799	2.1134
0.295	1.0139	1.0587	5.702	19.028	20.145	2.0811
0.300	1.0144	1.0608	5.798	19.318	20.491	2.0499
0.305	1.0149	1.0628	5.893	19.606	20.838	2.0198
0.310	1.0154	1.0650	5.988	19.892	21.185	1.9907
0.315	1.0159	1.0671	6.083	20.177	21.532	1.9628
0.320	1.0164	1.0693	6.178	20.460	21.879	1.9354
0.325	1.0169	1.0716	6.273	20.742	22.226	1.9092
0.330	1.0174	1.0739	6.368	21.022	22.574	1.8837
0.335	1.0180	1.0762	6.463	21.300	22.922	1.8591
0.340	1.0185	1.0785	6.557	21.576	23.270	1.8353
0.345	1.0190	1.0809	6.652	21.851	23.619	1.8123
0.350	1.0196	1.0834	6.747	22.124	23.968	1.7899
0.355	1.0202	1.0858	6.841	22.395	24.317	1.7682
0.360	1.0207	1.0883	6.935	22.664	24.666	1.7472
0.365	1.0213	1.0909	7.030	22.932	25.016	1.7268
0.370	1.0219	1.0935	7.124	23.197	25.366	1.7071
0.375	1.0225	1.0961	7.218	23.461	25.716	1.6879
0.380	1.0231	1.0988	7.312	23.723	26.067	1.6692
0.385	1.0237	1.1015	7.406	23.983	26.418	1.6511
0.390	1.0243	1.1043	7.500	24.241	26.769	1.6335
0.395	1.0250	1.1071	7.594	24.498	27.120	1.6164
0.400	1.0256	1.1099	7.688	24.752	27.472	1.5998
0.405	1.0262	1.1128	7.781	25.004	27.824	1.5837
0.410	1.0269	1.1157	7.875	25.255	28.177	1.5680
0.415	1.0276	1.1187	7.968	25.503	28.530	1.5527
0.420	1.0282	1.1217	8.062	25.750	28.883	1.5378
0.425	1.0289	1.1247	8.155	25.995	29.236	1.5234
0.430	1.0296	1.1278	8.248	26.237	29.590	1.5093
0.435	1.0303	1.1309	8.341	26.478	29.944	1.4956
0.440	1.0310	1.1341	8.434	26.716	30.299	1.4822
0.445	1.0317	1.1373	8.527	26.953	30.653	1.4692
0.450	1.0324	1.1406	8.620	27.187	31.009	1.4566
0.455	1.0331	1.1439	8.713	27.419	31.364	1.4442
0.460	1.0339	1.1472	8.806	27.649	31.720	1.4322
0.465	1.0346	1.1506	8.898	27.878	32.076	1.4205
0.470	1.0353	1.1540	8.990	28.104	32.433	1.4090
0.475	1.0361	1.1575	9.083	28.328	32.790	1.3979
0.480	1.0369	1.1611	9.175	28.549	33.147	1.3870
0.485	1.0376	1.1646	9.267	28.769	33.505	1.3765
0.490	1.0384	1.1682	9.359	28.987	33.863	1.3661
0.495	1.0392	1.1719	9.451	29.202	34.222	1.3560
0.500	1.0400	1.1756	9.543	29.415	34.581	1.3462

GAS CONSTANT = 287   GAMMA = 1.32

Mach No	T / t	P / p	V / Root.T	1000 Q	1000 q	A / A*
0.500	1.0400	1.1756	9.543	29.415	34.581	1.3462
0.505	1.0408	1.1794	9.635	29.626	34.940	1.3366
0.510	1.0416	1.1832	9.726	29.835	35.300	1.3273
0.515	1.0424	1.1870	9.818	30.042	35.660	1.3181
0.520	1.0433	1.1909	9.909	30.246	36.020	1.3092
0.525	1.0441	1.1948	10.000	30.448	36.381	1.3005
0.530	1.0449	1.1988	10.092	30.649	36.742	1.2920
0.535	1.0458	1.2029	10.183	30.846	37.104	1.2836
0.540	1.0467	1.2070	10.274	31.042	37.466	1.2757
0.545	1.0475	1.2111	10.364	31.236	37.829	1.2676
0.550	1.0484	1.2153	10.455	31.427	38.192	1.2600
0.555	1.0493	1.2195	10.546	31.616	38.555	1.2525
0.560	1.0502	1.2238	10.636	31.802	38.919	1.2452
0.565	1.0511	1.2281	10.727	31.987	39.284	1.2380
0.570	1.0520	1.2325	10.817	32.169	39.646	1.2310
0.575	1.0529	1.2369	10.907	32.349	40.014	1.2241
0.580	1.0538	1.2414	10.997	32.527	40.379	1.2174
0.585	1.0548	1.2460	11.087	32.702	40.745	1.2109
0.590	1.0557	1.2505	11.177	32.875	41.112	1.2045
0.595	1.0566	1.2552	11.268	33.046	41.479	1.1983
0.600	1.0576	1.2599	11.358	33.216	41.846	1.1922
0.605	1.0586	1.2646	11.445	33.381	42.214	1.1863
0.610	1.0595	1.2694	11.535	33.546	42.583	1.1805
0.615	1.0605	1.2743	11.624	33.707	42.952	1.1748
0.620	1.0615	1.2792	11.713	33.867	43.321	1.1693
0.625	1.0625	1.2841	11.802	34.024	43.691	1.1639
0.630	1.0635	1.2891	11.890	34.179	44.061	1.1586
0.635	1.0645	1.2942	11.979	34.332	44.432	1.1534
0.640	1.0655	1.2993	12.068	34.482	44.803	1.1484
0.645	1.0666	1.3045	12.156	34.630	45.175	1.1435
0.650	1.0676	1.3097	12.244	34.778	45.547	1.1387
0.655	1.0686	1.3150	12.333	34.919	45.920	1.1340
0.660	1.0697	1.3204	12.421	35.061	46.294	1.1294
0.665	1.0708	1.3258	12.508	35.200	46.667	1.1250
0.670	1.0718	1.3312	12.596	35.336	47.042	1.1206
0.675	1.0729	1.3368	12.684	35.471	47.416	1.1164
0.680	1.0740	1.3424	12.771	35.603	47.792	1.1122
0.685	1.0751	1.3480	12.859	35.733	48.168	1.1082
0.690	1.0762	1.3537	12.946	35.861	48.544	1.1043
0.695	1.0773	1.3594	13.033	35.986	48.921	1.1004
0.700	1.0784	1.3653	13.120	36.108	49.299	1.0967
0.705	1.0795	1.3711	13.207	36.230	49.677	1.0930
0.710	1.0807	1.3771	13.294	36.349	50.055	1.0894
0.715	1.0818	1.3831	13.380	36.465	50.434	1.0860
0.720	1.0829	1.3892	13.467	36.579	50.814	1.0826
0.725	1.0841	1.3953	13.553	36.691	51.194	1.0795
0.730	1.0853	1.4015	13.639	36.800	51.575	1.0761
0.735	1.0864	1.4077	13.725	36.908	51.956	1.0729
0.740	1.0876	1.4140	13.811	37.013	52.338	1.0699
0.745	1.0888	1.4204	13.897	37.116	52.720	1.0669
0.750	1.0900	1.4269	13.982	37.217	53.103	1.0640

Mach No	T / t	P / p	V / Root.T	1000 Q	1000 q	A / A*
0.755	1.0912	1.4334	14.068	37.316	53.487	1.0612
0.760	1.0924	1.4400	14.153	37.411	53.871	1.0585
0.765	1.0936	1.4466	14.238	37.505	54.256	1.0558
0.770	1.0949	1.4533	14.323	37.597	54.641	1.0532
0.775	1.0961	1.4601	14.408	37.687	55.027	1.0507
0.780	1.0973	1.4669	14.493	37.774	55.413	1.0483
0.785	1.0986	1.4739	14.577	37.860	55.800	1.0459
0.790	1.0999	1.4808	14.662	37.943	56.188	1.0437
0.795	1.1011	1.4879	14.746	38.024	56.576	1.0414
0.800	1.1024	1.4950	14.830	38.103	56.965	1.0393
0.805	1.1037	1.5022	14.914	38.179	57.354	1.0372
0.810	1.1050	1.5095	14.998	38.254	57.744	1.0352
0.815	1.1063	1.5168	15.082	38.326	58.135	1.0332
0.820	1.1076	1.5242	15.165	38.397	58.526	1.0313
0.825	1.1089	1.5317	15.249	38.465	58.918	1.0295
0.830	1.1102	1.5393	15.332	38.531	59.310	1.0277
0.835	1.1116	1.5469	15.415	38.595	59.703	1.0260
0.840	1.1129	1.5546	15.498	38.657	60.097	1.0244
0.845	1.1142	1.5624	15.581	38.717	60.491	1.0228
0.850	1.1156	1.5703	15.664	38.775	60.886	1.0213
0.855	1.1170	1.5782	15.746	38.830	61.282	1.0198
0.860	1.1183	1.5862	15.829	38.884	61.678	1.0184
0.865	1.1197	1.5943	15.911	38.936	62.075	1.0170
0.870	1.1211	1.6025	15.993	38.985	62.472	1.0158
0.875	1.1225	1.6107	16.075	39.033	62.871	1.0145
0.880	1.1239	1.6190	16.156	39.078	63.269	1.0133
0.885	1.1253	1.6274	16.238	39.122	63.669	1.0122
0.890	1.1267	1.6359	16.319	39.163	64.069	1.0111
0.895	1.1282	1.6445	16.401	39.203	64.470	1.0101
0.900	1.1296	1.6532	16.482	39.241	64.871	1.0091
0.905	1.1310	1.6619	16.563	39.276	65.273	1.0082
0.910	1.1325	1.6707	16.644	39.310	65.676	1.0074
0.915	1.1340	1.6796	16.724	39.342	66.079	1.0065
0.920	1.1354	1.6886	16.805	39.372	66.483	1.0058
0.925	1.1369	1.6977	16.885	39.400	66.888	1.0051
0.930	1.1384	1.7068	16.965	39.426	67.294	1.0044
0.935	1.1399	1.7161	17.046	39.450	67.700	1.0038
0.940	1.1414	1.7254	17.125	39.473	68.106	1.0032
0.945	1.1429	1.7348	17.205	39.493	68.514	1.0027
0.950	1.1444	1.7443	17.285	39.512	68.922	1.0022
0.955	1.1459	1.7540	17.364	39.528	69.331	1.0018
0.960	1.1475	1.7636	17.443	39.543	69.741	1.0014
0.965	1.1490	1.7734	17.522	39.557	70.151	1.0011
0.970	1.1505	1.7833	17.601	39.569	70.562	1.0008
0.975	1.1521	1.7933	17.680	39.578	70.973	1.0005
0.980	1.1537	1.8033	17.759	39.586	71.386	1.0003
0.985	1.1552	1.8135	17.837	39.591	71.799	1.0002
0.990	1.1568	1.8237	17.916	39.596	72.213	1.0001
0.995	1.1584	1.8341	17.994	39.598	72.627	1.0000
1.000	1.1600	1.8445	18.072	39.599	73.042	1.0000

GAS CONSTANT = 287   GAMMA = 1.4

Mach No	T / t	P / p	V / Root.T	1000 Q	1000 q	A / A*
0.000	1.0000	1.0000	0.000	0.000	0.000	infinity
0.005	1.0000	1.0000	0.100	0.349	0.349	115.7425
0.010	1.0000	1.0001	0.200	0.698	0.698	57.8738
0.015	1.0000	1.0002	0.301	1.048	1.048	38.5856
0.020	1.0001	1.0003	0.401	1.397	1.397	28.9421
0.025	1.0001	1.0004	0.501	1.745	1.746	23.1568
0.030	1.0002	1.0006	0.601	2.094	2.095	19.3005
0.035	1.0002	1.0009	0.701	2.443	2.446	16.5465
0.040	1.0003	1.0011	0.802	2.791	2.794	14.4815
0.045	1.0004	1.0014	0.902	3.139	3.144	12.8757
0.050	1.0005	1.0018	1.002	3.487	3.493	11.5914
0.055	1.0006	1.0021	1.102	3.834	3.843	10.5410
0.060	1.0007	1.0025	1.202	4.182	4.192	9.6659
0.065	1.0008	1.0030	1.302	4.528	4.542	8.9257
0.070	1.0010	1.0034	1.402	4.875	4.891	8.2915
0.075	1.0011	1.0039	1.503	5.221	5.241	7.7421
0.080	1.0013	1.0045	1.603	5.566	5.591	7.2618
0.085	1.0014	1.0051	1.703	5.911	5.941	6.8378
0.090	1.0016	1.0057	1.803	6.255	6.291	6.4613
0.095	1.0018	1.0063	1.903	6.599	6.641	6.1247
0.100	1.0020	1.0070	2.002	6.943	6.991	5.8218
0.105	1.0022	1.0077	2.102	7.285	7.342	5.5480
0.110	1.0024	1.0085	2.202	7.627	7.692	5.2992
0.115	1.0026	1.0093	2.302	7.969	8.043	5.0722
0.120	1.0029	1.0101	2.402	8.309	8.393	4.8643
0.125	1.0031	1.0110	2.502	8.649	8.744	4.6732
0.130	1.0034	1.0119	2.601	8.988	9.095	4.4969
0.135	1.0036	1.0128	2.701	9.326	9.446	4.3337
0.140	1.0039	1.0138	2.801	9.664	9.797	4.1824
0.145	1.0042	1.0148	2.900	10.001	10.149	4.0416
0.150	1.0045	1.0158	3.000	10.336	10.500	3.9103
0.155	1.0048	1.0169	3.100	10.671	10.852	3.7877
0.160	1.0051	1.0180	3.199	11.005	11.203	3.6727
0.165	1.0054	1.0192	3.298	11.338	11.555	3.5649
0.170	1.0058	1.0204	3.398	11.670	11.908	3.4635
0.175	1.0061	1.0216	3.497	12.001	12.260	3.3680
0.180	1.0065	1.0229	3.598	12.330	12.612	3.2779
0.185	1.0068	1.0242	3.696	12.659	12.965	3.1928
0.190	1.0072	1.0255	3.795	12.987	13.318	3.1123
0.195	1.0076	1.0269	3.894	13.313	13.671	3.0359
0.200	1.0080	1.0283	3.993	13.639	14.024	2.9635
0.205	1.0084	1.0297	4.092	13.963	14.378	2.8947
0.210	1.0088	1.0312	4.191	14.286	14.732	2.8293
0.215	1.0092	1.0327	4.290	14.607	15.086	2.7670
0.220	1.0097	1.0343	4.389	14.928	15.440	2.7076
0.225	1.0101	1.0359	4.487	15.247	15.794	2.6509
0.230	1.0106	1.0375	4.586	15.565	16.149	2.5968
0.235	1.0110	1.0392	4.685	15.881	16.504	2.5451
0.240	1.0115	1.0409	4.783	16.196	16.859	2.4956
0.245	1.0120	1.0427	4.882	16.510	17.214	2.4482
0.250	1.0125	1.0444	4.980	16.822	17.570	2.4027

Mach No	T / t	P / p	V / Root.T	1000 Q	1000 q	A / A*
0.255	1.0130	1.0463	5.079	17.133	17.925	2.3591
0.260	1.0135	1.0481	5.177	17.442	18.282	2.3173
0.265	1.0140	1.0500	5.275	17.750	18.638	2.2771
0.270	1.0146	1.0520	5.373	18.056	18.995	2.2385
0.275	1.0151	1.0539	5.471	18.361	19.352	2.2013
0.280	1.0157	1.0560	5.569	18.664	19.709	2.1656
0.285	1.0162	1.0580	5.667	18.966	20.066	2.1311
0.290	1.0168	1.0601	5.765	19.266	20.424	2.0979
0.295	1.0174	1.0623	5.862	19.564	20.782	2.0659
0.300	1.0180	1.0644	5.960	19.861	21.141	2.0351
0.305	1.0186	1.0668	6.058	20.156	21.499	2.0053
0.310	1.0192	1.0689	6.155	20.449	21.858	1.9765
0.315	1.0198	1.0712	6.252	20.741	22.218	1.9487
0.320	1.0205	1.0735	6.350	21.031	22.577	1.9219
0.325	1.0211	1.0759	6.447	21.319	22.937	1.8959
0.330	1.0218	1.0783	6.544	21.606	23.298	1.8707
0.335	1.0224	1.0808	6.641	21.890	23.659	1.8464
0.340	1.0231	1.0833	6.738	22.173	24.020	1.8229
0.345	1.0238	1.0858	6.835	22.454	24.381	1.8001
0.350	1.0245	1.0884	6.931	22.733	24.743	1.7780
0.355	1.0252	1.0910	7.028	23.010	25.105	1.7566
0.360	1.0259	1.0937	7.124	23.285	25.467	1.7358
0.365	1.0266	1.0964	7.221	23.559	25.830	1.7156
0.370	1.0274	1.0992	7.317	23.830	26.193	1.6961
0.375	1.0281	1.1019	7.413	24.100	26.557	1.6771
0.380	1.0289	1.1048	7.509	24.368	26.921	1.6587
0.385	1.0296	1.1077	7.605	24.633	27.285	1.6408
0.390	1.0304	1.1106	7.701	24.897	27.650	1.6234
0.395	1.0312	1.1135	7.797	25.159	28.015	1.6065
0.400	1.0320	1.1166	7.893	25.418	28.381	1.5901
0.405	1.0328	1.1196	7.988	25.676	28.747	1.5742
0.410	1.0336	1.1227	8.084	25.931	29.113	1.5587
0.415	1.0344	1.1258	8.179	26.185	29.480	1.5436
0.420	1.0353	1.1290	8.274	26.436	29.847	1.5289
0.425	1.0361	1.1323	8.369	26.686	30.215	1.5146
0.430	1.0370	1.1355	8.464	26.933	30.583	1.5007
0.435	1.0378	1.1388	8.559	27.178	30.951	1.4872
0.440	1.0387	1.1422	8.654	27.421	31.320	1.4740
0.445	1.0396	1.1456	8.748	27.662	31.690	1.4612
0.450	1.0405	1.1491	8.843	27.900	32.059	1.4487
0.455	1.0414	1.1526	8.937	28.137	32.430	1.4365
0.460	1.0423	1.1561	9.032	28.371	32.801	1.4246
0.465	1.0432	1.1597	9.126	28.603	33.172	1.4131
0.470	1.0442	1.1634	9.220	28.833	33.544	1.4018
0.475	1.0451	1.1670	9.314	29.061	33.916	1.3908
0.480	1.0461	1.1708	9.407	29.287	34.288	1.3801
0.485	1.0470	1.1746	9.501	29.510	34.662	1.3697
0.490	1.0480	1.1784	9.594	29.731	35.035	1.3595
0.495	1.0490	1.1823	9.688	29.950	35.409	1.3495
0.500	1.0500	1.1862	9.781	30.167	35.784	1.3398