Results from SP2, Analysis of the Westinghouse J-30 Turbojet using Gasturb

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Introduction and Problem Description

The Westinghouse J-30 was the first American made turbojet engine. In order to study the affect of altitude, Mach number, and ambient pressure on the J-30 it was modelled in Gasturb. The design specifications for the J-30 were obtained from a J-30 that is in the basement of Randolph hall on Virginia Tech campus. This Report will first discuss the components of the J-30 with respect to the station numbers that Gasturb uses in its modelling. Then, it will show that a working model of the J-30 was created and verified against the rated thrust and TSFC at sea level. After the model was created, this model was used to predict the thrust, thrust specific fuel consumption, and propulsive efficiency at different flight conditions.

Station Identification

In order to understand the process that Gasturb is using to find the performance of the J-30, it was first necessary to match the station numbers internal to Gasturb with the components of the actual engine. Figure 1 below shows the station numbers that Gasturb uses, while figure 2 shows a photo of the J-30 with the corresponding station numbers and component names.

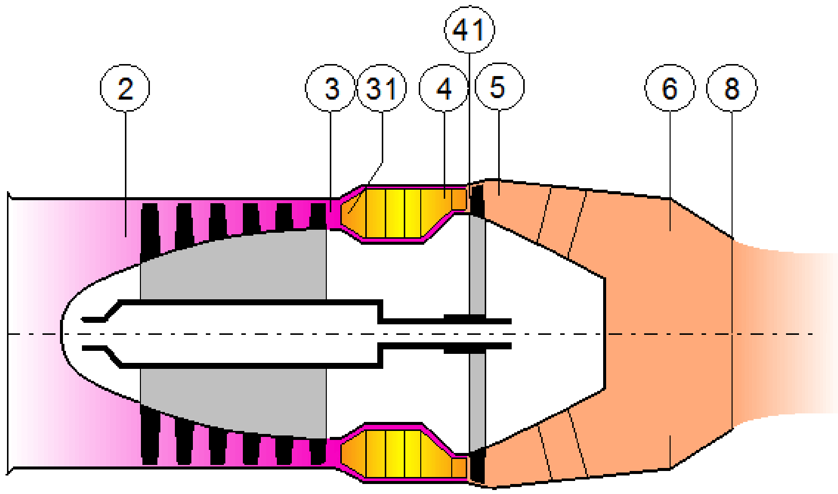

Figure 1: Station numbers and locations from Gasturb

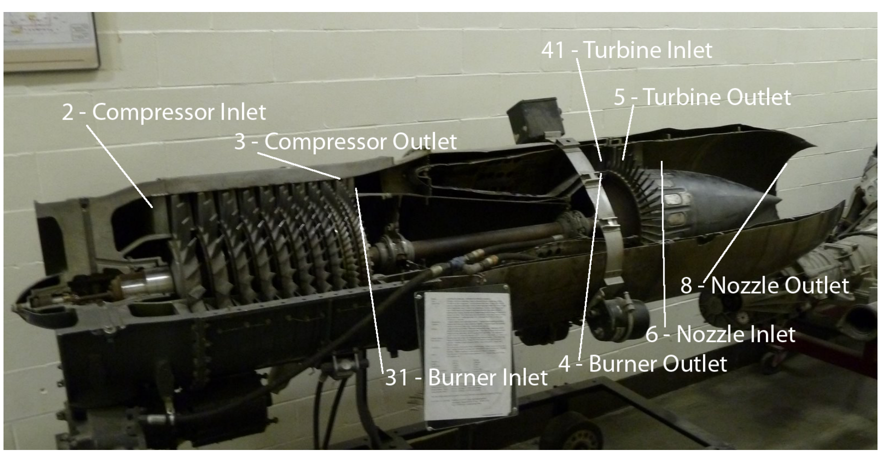

Figure 2: J-30 Engine with stations labeled

Table 1 presents a list of all of the station numbers associated with the J-30 engine as well as a short description as to what is happening to the flow in each station. The total pressure, P_0, and total Temperature, T_0, changes corresponding to each station are also presented in table 1.

Table 1: J-30 Station Process Names and Descriptions

Station	**Name**	P_0	T_0	**Description**
1-2	Diffuser	=	=	Incoming air diffuses down to a speed suitable for compressor input
2-3	Compressor	↑	↑	Air from the diffuser is compressed by rotating compressor blades to a higher pressure and, consequently, temperature
31-4	Combustor	=	↑	Fuel is added and ignited in order to add energy to the flow
41-5	Turbine	↓	↓	The flow expands through a turbine, which extracts the work to run the compressor, this has the effect of lowering the temperature and pressure
5-6	Turbine to Nozzle Duct	=	=	The flow travels from the turbine outlet to the nozzle inlet through a duct
6-8	Nozzle	=	=	Flow is nozzled to a higher speed in order to increase the output thrust

Engine Parameters

The design specifications for the J-30 were taken from a description that is with the engine itself. All of these parameters were directly imputed into Gasturb. Some of the specifications that Gasturb expects to have were not available, so they were estimated. They were estimated by varying the unavailable parameters using the slider function in Gasturb until the thrust and TSFC at sea level matched the rated thrust and TSFC from the specifications.

Table 2 shows the values that were imputed into Gasturb. The values in bold were not available and so they were iterated until the rated thrust and tsfc, in italics, were matched.

Table 2: Overview of J-30 Specifications and Gasturb Settings

Parameter	**J-30**	**Gasturb**
Compressor Pressure Ratio	3.8	3.8
Air Mass Flow Rate (lbm/s)	30	30
Turbine Inlet Temperature (R)	1958.67	1958.67
Intake Pressure Ratio	–	**0.96**
Compressor Efficiency	–	**0.7455**
Burner Efficiency	–	**0.99**
Burner Pressure Ratio	–	**0.97**
Fuel Heating Value(BTU/lbm)	–	**20270**
Turbine Efficiency	–	**0.808**
Turbine Exit Duct Pressure Ratio	–	**0.96**
Mechanical Efficiency	–	**0.96**
TSFC($lbm/lbf - hr$)	1.15	*1.1596*
Net Thrust(lbf)	1340	*1339.96*

Another check that was done to ensure that our model was accurately predicting the performance of the J-30 was to compare the measured nozzle exit area to that predicted by Gasturb. The results of this comparison are presented in table 3.

Table 3: Comparison of Predicted and Measured A8 Values

Predicted A8 (in^2)	**Measured A8** (in^2)
113.86	107.99

Although there is relatively good agreement between the values, it should be noted that the area was measured by hand using a measuring tape. Since the nozzle exit was not circular as expected, the two largest diameters were measured and then the area was approximated as an ellipse. It is possible that the area is not truly an ellipse, but some odd shape. Also the nozzle exit could have been deformed when the engine was cut in order to reveal its components as shown in figure 2. Both of these factors increase the uncertainty in the measured area.

The complete results for sea level operation as computed by Gasturb are found in appendix A.

Effect of Blacksburg Elevation on J-30 Performance

Using the Gasturb model previously developed, the effect of running the J-30 at the elevation of Blacksburg Virginia was also studied. Knowing the elevation of Blacksburg, the air pressure was obtained from the table that accompanies Hill and Peterson[1, p. 700]. The results from this study are presented in table 4. As can be seen from the table, the thrust decreased when the engine was operated at its new elevation. This is due to the decrease in air pressure and density that accompanies the increase in elevation. This trend is also seen in the next section of the report when the model is used to simulate flight conditions at altitudes from 0 to 40,000 ft.

Table 4: Effect of Blacksburg's elevation on Thrust and TSFC

	Sea level	**Elevation of Blacksburg**
Thrust (lbf)	1339.96	1244.12
TSFC ($lbm/lbf - hr$)	1.1596	1.1596

The complete results for the operation of the J-30 at the elevation of Blacksburg as computed by Gasturb are found in appendix B.

Results from Flight Test

In order to better understand the effect of altitude and Mach number on the performance of the J-30, a parametric study was conducted. This study varied altitude and Mach number and recorded their effects on thrust, TSFC, and propulsive efficiency. Before examining the effect of altitude and Mach number on the chosen performance metrics, it is helpful to review what effect these have on input variables such as pressure temperature, and mass flow.

As altitude increases, Total inlet pressure, total inlet temperature, and mass flow rate all decrease. The mass flow rate decreases because the density of air decreases as altitude increases. As Mach number increases, initially only the inlet velocity increases, but once compressibility effects start to become important, the total inlet pressure and total inlet temperature also increase. The mass flow rate would also increase as the inlet velocity increases. The increase in inlet velocity also increases what is called ramdrag, or the amount that the total thrust is reduced due to the inlet velocity.

As can be seen in figure 3, as altitude is increased, thrust decreases. This is directly due to the decrease in mass flow rate. It can also be seen in 3 that thrust varied in a parabolic fashion with Mach number, first decreasing until a Mach number of approximately 3.5 and then steadily increasing after that. This is because ramdrag increases with increasing Mach number, but so do total inlet temperature and pressure. The inlet temperature, pressure have a positive impact on thrust, but their effect is not felt until compressibility effects become important, at about a Mach number of 0.3. After this point, the positive effect of increased pressure and temperature overcomes the negative effect of ramdrag and the thrust begins to steadily increase.

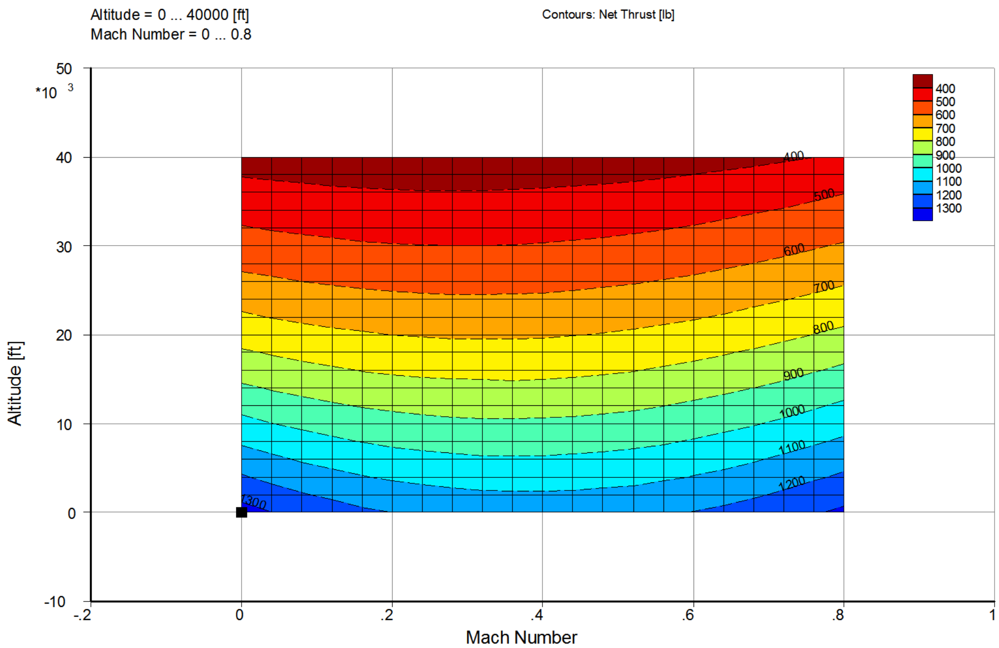

Figure 3: Effect of altitude and Mach number on thrust

As can be seen in figure 4, as altitude was increased, TSFC decreased. This is due to the decrease in mass flow. Since there is less air flowing through the engine, less fuel is needed to heat it to the desired turbine inlet temperature. It should be noted that the mass flow rate of fuel decreases at a faster rate than the thrust so the net effect on TSFC is negative. It can also be seen in figure 4 that as the Mach number increases, the TSFC increases. This is due to the increase in mass flow that is associated win an increase in inlet velocity. It should also be noted that at higher Mach numbers, where compressibility matters, TSFC does not increase as much, this is due to the thrust/Mach number relationship discussed previously.

Propulsive efficiency is the ratio of thrust power to the power associated with the kinetic energy as it flows through the engine. As can be seen in figure 5, as altitude increases propulsive efficiency decreases. This is due to thrust decreasing which causes the propulsive efficiency to also decrease. It should also be noted that as Mach number increases the effect of altitude becomes more pronounced. This is due to the emergence of compressibility effects. It can also be seen that as Mach number increases propulsive efficiency also increases. This is caused by an increase in thrust as well as an increase in inlet velocity which both positivity effect propulsive efficiency.

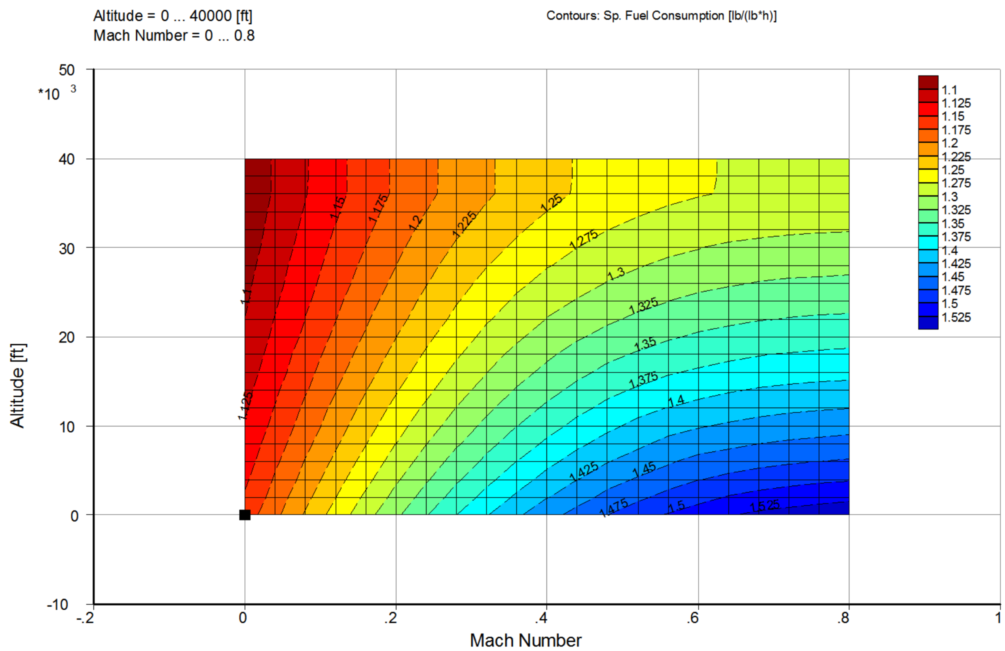

Figure 4: Effect of altitude and Mach number on TSFC

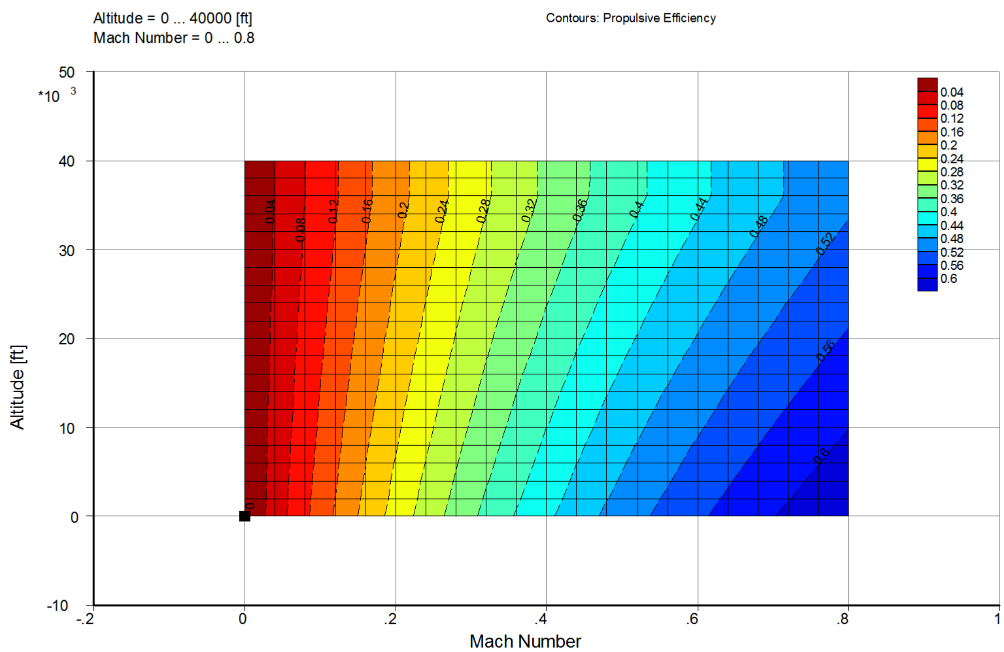

Figure 5: Effect of altitude and Mach number on propulsive efficiency

Conclusion

This report has shown that a Westinghouse J-30 turbojet engine can be successfully modelled using Gasturb. After iterating on several of the parameters that were unavailable, a model of the J-30 was made and verified against the rated sea level thrust and TSFC. Once the model was made and verified, the effect of Blacksburg elevation as well as the general case of increasing altitude and Mach was studied.

Appendix A - Complete Sea Level Results

Turbojet Alt= 0ft ISA -0 F

Station	W lb/s	T R	P psia	WRstd lb/s
amb		518.40	14.696	
1	28.807	518.40	14.696	
2	28.807	518.40	14.108	30.000
3	28.807	838.67	53.610	10.042
31	28.519	838.67	53.610	
4	28.951	1958.67	52.002	15.899
41	28.951	1958.67	52.002	15.899
49	28.951	1671.04	22.988	
5	28.951	1671.04	22.988	33.220
6	28.951	1671.04	22.069	
8	28.951	1671.04	22.069	15.696
Bleed	0.288	838.67	53.610	

P2/P1 = 0.9600 P4/P3 = 0.9700 P6/P5 0.9600

Efficiencies:	isentr	polytr	RNI	P/P
Compressor	0.7455	0.7874	0.961	3.800
Burner	0.9900			0.970
Turbine	0.8080	0.7917	0.744	2.262

Spool mech Eff 0.9600 Nom Spd 15700 rpm

FN	=	1339.96	lb
TSFC	=	1.1596	lb/(lb*h)
FN/W2	=	1496.57	ft/s
Prop Eff	=	0.0000	
eta core	=	0.1605	
WF	=	0.43162	lb/s
s NOx	=	0.07667	
XM8	=	0.7992	
A8	=	113.86	in
P8/Pamb	=	1.5017	
WBld/W2	=	0.01000	
Ang8	=	20.00	
CD8	=	0.9352	
W_NGV/W2	=	0.00000	
WCL/W2	=	0.00000	
Loading	=	100.00	%
e45 th	=	0.80800	
far7	=	0.01513	
PWX	=	0.00	hp

hum [%]	war0	FHV	Fuel
0.0	0.00000	20270.0	Generic

Input Data File:
C:\Users\khoopes\Dropbox\School\Classes\5135 - Propulsion\sp2\round1_jet.CYJ (modified)

Figure 6: Gasturb results for sea level operation of the J-30

Appendix A - Complete Results for Blacksburg Elevation

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   Turbojet  Alt= 2039ft   ISA + 7 F

              W         T         P        WRstd
Station     lb/s        R       psia        lb/s          FN        =    1244.12 lb
 amb                 518.40    13.645                     TSFC      =     1.1596 lb/(lb*h)
  1       26.747     518.40    13.645                     FN/W2     =    1496.57 ft/s
  2       26.747     518.40    13.099     30.000
  3       26.747     838.67    49.776     10.042          Prop Eff  =     0.0000
 31       26.479     838.67    49.776                     eta core  =     0.1605
  4       26.880    1958.67    48.283     15.899
 41       26.880    1958.67    48.283     15.899          WF        =    0.40075 lb/s
 49       26.880    1671.04    21.344                     s NOx     =    0.07443
  5       26.880    1671.04    21.344     33.220          XM8       =     0.7992
  6       26.880    1671.04    20.490                     A8        =     113.86 in
  8       26.880    1671.04    20.490     15.696          P8/Pamb   =     1.5017
Bleed      0.267     838.67    49.776                     WBld/W2   =    0.01000
-----------------------------------------------           Ang8      =      20.00
P2/P1 = 0.9600  P4/P3 = 0.9700  P6/P5 0.9600              CD8       =     0.9352
Efficiencies:     isentr   polytr    RNI    P/P           W_NGV/W2  =    0.00000
 Compressor       0.7455   0.7874   0.892  3.800          WCL/W2    =    0.00000
 Burner           0.9900                   0.970          Loading   =     100.00 %
 Turbine          0.8080   0.7917   0.690  2.262          e45 th    =    0.80800
-----------------------------------------------           far7      =    0.01513
Spool mech Eff    0.9600  Nom Spd      15700 rpm          PWX       =       0.00 hp
-----------------------------------------------

hum [%]     war0       FHV      Fuel
  0.0     0.00000   20270.0   Generic

Input Data File:
C:\Users\khoopes\Dropbox\School\Classes\5135 - Propulsion\sp2\round1_jet.CYJ (mo
dified)
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Figure 7: Gasturb results for operation of the J-30 at Blacksburg elevation. The pressure for blacksburg was taken from Hill and Peterson[1, p. 700]

References

[1] Philip Hill & Carl Peterson, *Mechanics and Thermodynamics of Propulsion.* Addision Wesley Longman, 2nd Edition, 1992.