CONCEPTUAL GAS TURBINE HYBRID ENGINE DESIGN FOR HIGH SPEED RAIL LOCOMOTIVE PROPULSION

By

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ABSTRACT

CONCEPTUAL GAS TURBINE HYBRID ENGINE DESIGN FOR HIGH SPEED RAIL LOCOMOTIVE PROPULSION

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The modern experimental jet train developed by Bombardier Transportation was designed to partner with the present day electrified Acela high speed trains. The Jet train would provide transportation to areas (Rural etc.), as well as transcontinental capabilities to existing towns and cities where electrified propulsion units are not feasible. The Bombardier Jet Train utilizes petroleum-based fuel, diesel engine power, and multiple turboshaft engines, for higher speeds. The Pratt and Whitney PW150 engine design parameters will be used to develop the Conceptual Hybrid Turbo Shaft Engine (CHTS).

The newer Conceptual Hybrid Turbo Shaft Engine (CHTS) should increase engine performance, lower specific fuel consumption, and extend traveling distance by at least 12 percent. The CHTS will be capable of operating at altitudes of at least 6000 feet, with the least amount of degradation in performance. The (CHTS) design shall incorporate a Superconducting Magnetic Energy Storage (SMES) Coil, which will reduce trip time and improve fuel efficiency. Modeling of the CHTS is based on four design engineering criteria; Design, Development, Test and Evaluation (DDT&E). The design phase is dictated by customer (Civilian), functional requirements (Environmental adaptability, structural integrity, performance output, fuel efficiency, horsepower, thrust and vehicle integration etc.).

The development phase involves developing the prototype to include computer aided design (CAD) drawings, applied engineering principles (Thermodynamics, heat transfer, fluid mechanics, mechanics of materials, machine design, turbomachinery etc.), and manufacturing techniques. Testing phase requires evaluating the prototype's ability to perform to design specifications, as outlined by customer requirements. This involves using testing facilities (Engine test bed, wind tunnel, data measuring equipment, etc.), and appropriate test software, to extrapolate data that validates design performance specifications. This phase probably represents the most important criteria of this modeling concept; since if the output data doesn't represent the design specifications then the development stage of the prototype must be re-evaluated. The final phase involves evaluating (Quality real time performance, etc.), within an operational environment (Public/Private transportation etc.). Time frames (One to two years etc.) may be required to fully evaluate the prototype's operational integrity. Upon successful prototype evaluation, the prototype model is used as a baseline to produce and manufacture, the final operational system.

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Chapter 1

INTRODUCTION

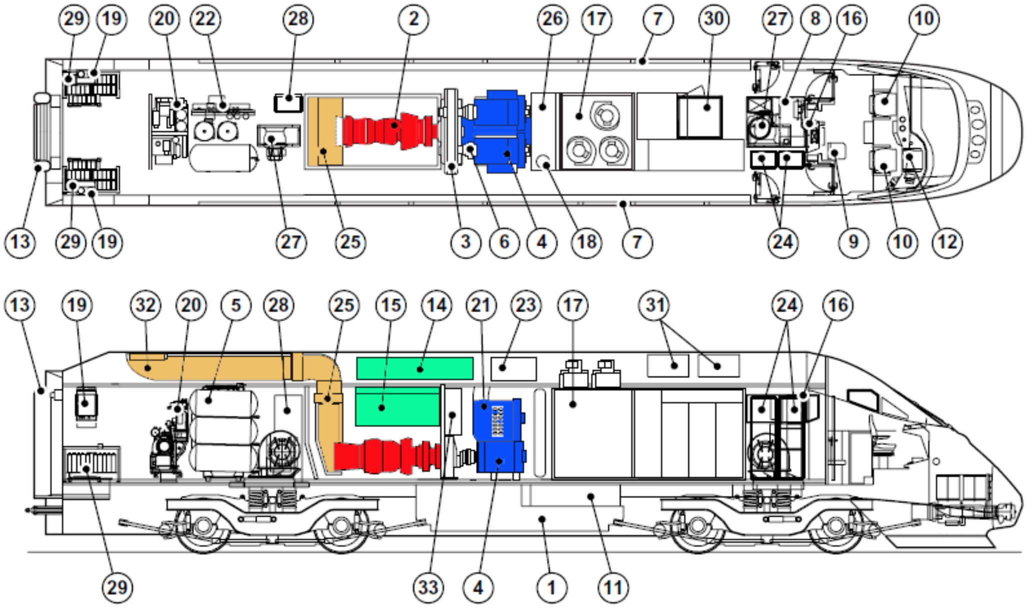
The Gas turbine Jet Train built by the Bombardier Company was an experimental high speed Jet Train that would complement the existing AMTRAK Northeast Corridor Trains (Acela Express); where electrical power overhead systems (Catenary) are not feasible, in rural towns and cities. The Jet Train was designed to utilize petroleum based fuels, to power a Gas Turbine Engine (Turboshaft, Diesel etc.), compatible with Acela Train performance (High speed, tilting carriage etc.).

Figure 1 Bombardier Experimental High Speed

Jet Train

1.1 Experimental Gas Turbine Jet Train History Overview

The Jet Train power car (two each) contains a two spool four stage turboshaft gas turbine engine, generating 3,750 Kilowatts (Kw) which equates to 5029 Shaft Horsepower (SHP), for each power car. The Jet Train incorporates Head End Power (HEP), a widespread standardization that provides electrical power for running various systems (environmental controls, etc.). This eliminates problems with turbine fuel efficiency, at low power settings. Power requirements remain steady, while the train is parked (Passenger station or switchyard). The power turbine shaft is geared together to a single gearbox, which powers alternators (rotating generators), that provides power to four traction motors, and passenger cars as required. With the presence of two power cars (Front and rear of the train), speeds can reach between 149 to 165 miles per hour (Minimum/Maximum respectively). The new Conceptual Engine Design CHTS would provide for lower specific fuel consumption (SFC), which would increase the traveling distance of the Jet train. This new CHTS design shall incorporate two Superconducting Magnetic Energy Storage (SMES) Coils, which aid in engine performance (Distance Travel, increased fuel efficiency). Figures 2 and 3 represent the power cars and the SMES coil respectively. [1]



1 Fuel Tank
2 Gas Turbine Engine
3 Gear Box
4 Alternators
5 Air Reservoirs
6 Flexible Couplings
7 Car body Louvers
8 ATC Unit
9 Cushion Shelf
10 Engineer's Seat
11 Auxiliary Transformer
12 Engineer's Console
13 Diaphragm
14 Inertial Filters & Silencer
15 Engine Secondary Filters
16 HVAC System
17 Motor Block
18 Fire Suppression
19 Battery Charger
20 Air Compressor/Air Dryer
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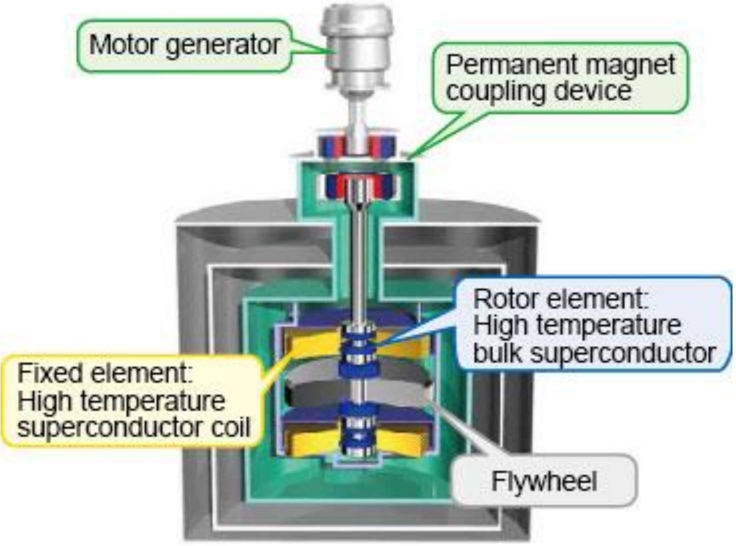
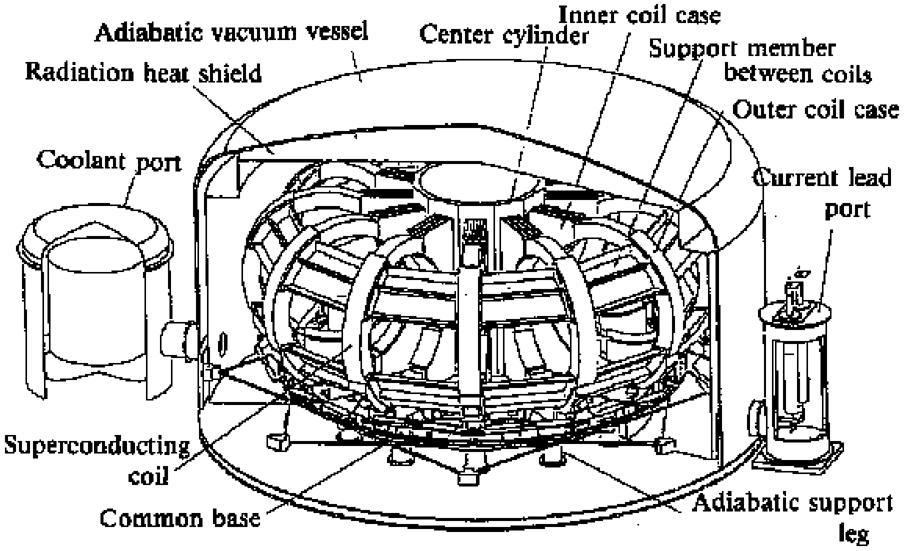
26 Turbine Equipment Rack
27 Traction Motor Blower
28 Turbine Power & Controls
29 SMES Coils
30 Toilet Room
31 Rheostat Grids
32 Exhaust Silencer
33 Gearbox Equipment Rack

Figure 2 Jet Train Power Car Schematic



Superconductor Coil Flywheel Configuration [2]



Superconductor Coil Non-Flywheel Configuration [3]

Figure 3 Superconducting Magnetic Energy Storage Coils

1.2 Conceptual Hybrid Turbo Shaft (CHTS)

Design Criteria

1.2.1 High Speed Rail Route Criteria

This criterion focuses on CHTS engine development, based on real specifications and assumptions. Criteria will include, hypothetical high speed rail route parameters, SMES coil and CHTS interface requirements, and CHTS Modeling.

1. Denver Colorado, elevation (From Denver International Airport) = 5280 Feet.
2. Colorado Springs, Intermediate stop, elevation = 6272 Feet.
3. Albuquerque New Mexico, elevation = 5312 Feet.

Specific city variables (distance between cities.

Denver to Colorado Springs = 70.8 miles

Colorado Springs to Albuquerque = 379.3 miles

Total high speed trip miles, for this route = 450.1 miles

Total high speed round trip miles, for this route = 900.2 miles.

The Thrust Specific Fuel Consumption (TSFC) associated with gas turbine engine design, is affected by atmospheric temperature and altitude. Hot temperatures and high altitudes are not favorable to the TSFC; however to fully maximize the CHTS design an average altitude of 6000 feet and hot day atmospheric conditions, are chosen for this analysis. For this analysis, assume a high speed experiment straight away test track is built.

1.2.2 SMES Coil and CHTS Interface

Real engine performance may be enhanced by incorporating a SMES Coil into the CHTS design process. Interfacing the SMES coil will allow the CHTS to operate within specific ranges (Power and speed etc.), for peak efficiency. This conceptual design provides for high speed acceleration, reduction of power rating and weight, reduction of travel time and fuel efficiency improvement. There are two specific methods for charging and storing energy within the SMES coil, regenerative braking and dynamic braking. Regenerative braking is the process of converting kinetic energy into electrical energy, by utilizing the train’s traction motors. Traction motors are designed to function as an electric motor for vehicle propulsion, and as a generator used to generate electricity which is fed back into the supply system. Regenerative braking involves altering traction motor connections, so the motors become generators. This process takes place during dynamic braking. Dynamic braking is the process of controlling locomotive braking power, by traction motors becoming generators. Braking power is controlled by varying magnetic field strength which involves the armature and magnetic field rotating against each other, based on power shaft and wheel rotation. Both processes take place at the same time. Dynamic braking uses electrical energy to slow locomotion and regenerative braking stores electrical energy. Ideally flywheel design was considered as an alternative to mechanical energy storage, which is used primarily for acceleration starting from rest or climbing steep grades; however size and weight of flywheel components may require a separate storage car.

The SMES coil is lighter than the flywheel and is more efficient in storing and transferring energy (electrical), which provides for high efficiency. The SMES coil interfaces with the locomotive’s common direct current (dc) bus, through a dc/dc converter. The DC-to-DC converter (Electronic switch mode DC to DC), is used to convert a source of direct current (DC), from one voltage level (Low to high) to another. Generally, input energy is stored temporarily, then released for a different voltage. Voltage output will be determined, based on the peak energy and transfer rate, desired for regenerative braking and vehicle acceleration. Figure 4 depicts the CHTS and SMES coil interface.

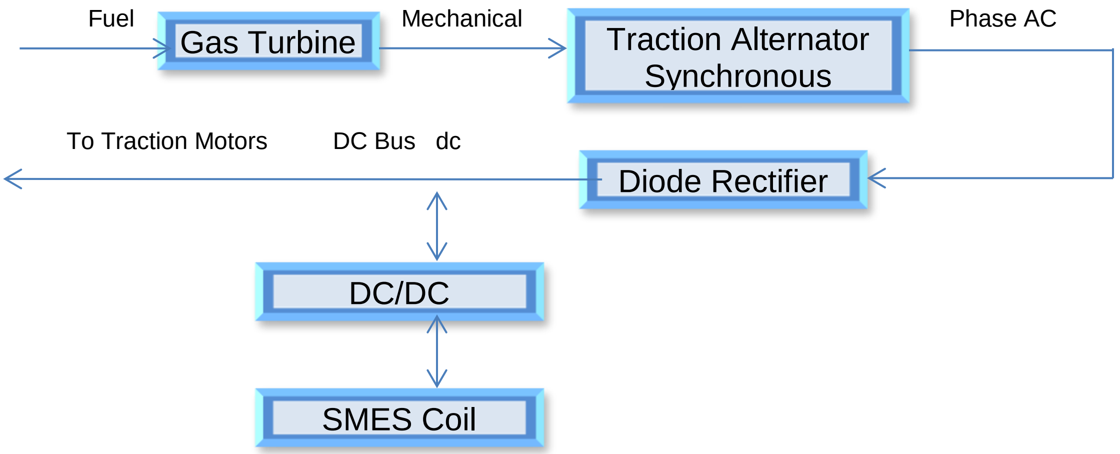


Figure 4 SMES Coil and CHTS Electrical Interface

1.2.3 CHTS Modeling Conditions

Analysis of the CHTS design dictates that specific modeling conditions be implemented to effectively analyze, verify and validate CHTS performance against PW150 baselines (Equivalent shaft horsepower, shaft horsepower' and maximum shaft revolutions per minute output). Engine properties (Table 4) associated with the PW150 engine will be the baseline model, for analyzing CHTS performance.

1.2.3.1 Gas turbine operational parameters

Specific gas turbine engine generic parameters used in the majority of turbine design will be employed in CHTS performance analysis. Table 2 depicts operational engine sequence.

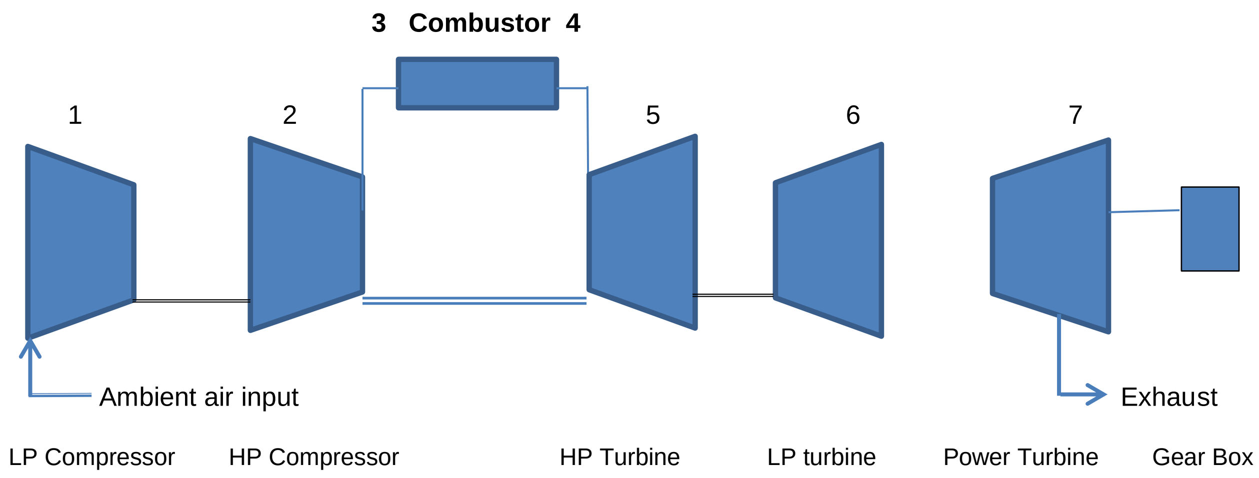
Table 1 Gas Turbine Turboshaft Real Parameter Inputs

Symbol	Nomenclature	Performance Equation/Values
a_0	Speed of Sound	$a_0 = \sqrt{\gamma g_c R T}$
γ	Ratio of Specific Heats	Cp/Cv = 1.4 for air
R	Gas constant	R=53.3 ft-lbf/lbm ^{0}R

g_c	Acceleration Gravity	g_c = 32.2 Ft/Sec^2
V_0	Freestream Velocity	ft/sec
M	Mach Number	V_0 / a_0
P_0	Standard Pressure	P_0 = 14.7 psi
T_0	Standard Temperature	T_0 = 518.69 ^{0}R

1.2.3.2 Engine Modeling Specifications

To perform performance analysis of the CHTS, the PW150 is selected as a baseline model. CHTS performance (Parametric specific fuel consumption, power output etc.), is based on using PW150 real on design modeling specifications and PW150 off design output properties. The PW150 and the CHTS incorporate a twin-spool design, with a free powered turbine. The turbine is connected, to a gearbox, which is configured to drive an electric alternator. Figure 5 depicts a block diagram, of station operations. Each component (Turbine or compressor) operates within a high pressure (HP), or low pressure (LP) mode.



Station	**Location**
1	**LP Compressor Inlet**
2	**LP Compressor Outlet**
3	**HP Compressor Outlet**
4	**Combustor Outlet**
5	**HP Turbine Outlet**
6	**LP Turbine Outlet**
7	**Power Turbine Outlet**

Figure 5 PW150 and CHTS engine stage compartments.

To full understand stage operations, associated with the engine model, certain variables are incorporated to facilitate the process. Table 3 depicts the variables (Pressure, Temperature etc.), that are used to estimate engine performance. Figure 6, depicts a typical turboshaft two spool engine.

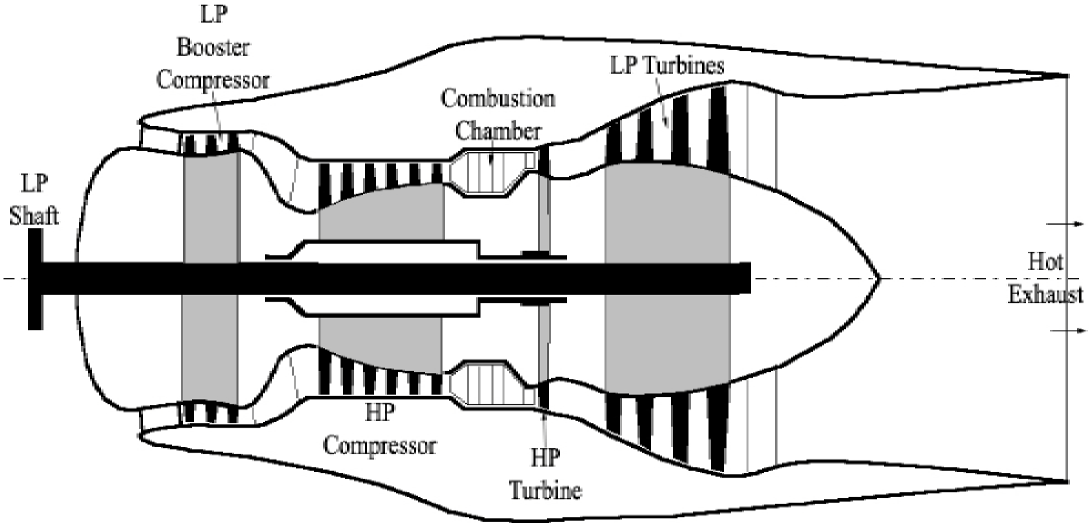


Figure 6 Typical Turboshaft Two Spool Gas Turbine

Engine

Table 2 Operational Engine Stage Sequence

T_0 = ambient Temperature, P_0 = ambient Pressure, entrance free stream Properties.

$T_1 = T_0$,	$P_1 = P_0$,	entrance 1,	Low Pressure Compressor (LPC), inlet.
T_2,	P_2,	output 2,	Low Pressure Compressor (LPC), outlet.
T_2,	P_2,	entrance 2,	High Pressure Compressor (HPC), input
T_3,	P_3,	output 3,	High Pressure Compressor (HPC), output.
T_3,	P_3,	entrance 3,	Input Combustor.
T_4,	P_4,	output 4,	Output Combustor.
T_4,	P_4,	entrance 4,	High Pressure Turbine (HPT), Inlet
T_5,	P_5,	output 5,	High Pressure Turbine (HPT), output.
T_5,	P_5,	entrance 5,	Low Pressure Turbine (LPT), Inlet
T_6,	P_6,	output 6,	Low Pressure Turbine (LPT), output.
T_6,	P_6,	entrance 6,	Power Turbine
T_7,	P_7,	output 7,	Power Turbine Shaft Output Power

Table 3 Operational Engine Stage Parameters

Pt_3/Pt_2	Compressor Pressure Ratio
Pt_4/Pt_3	Burner Pressure Ratio
Pt_5/Pt_4	Turbine Pressure Ratio
Tt_3/Tt_2	LP Compressor Temperature Ratio
Tt_4/Tt_3	HP Burner and Compressor Temperature Ratio
Tt_5/Tt_4	HP Turbine Temperature Ratio
Tt_6/Tt_5	L P Turbine Temperature Ratio
Tt_7/Tt_6	Power Turbine Temperature Ratio

2. Engine Off Design Performance Analysis

To fully address off design performance analysis the procedure is to use an algorithmic approach for developing, testing, and validating the performance of the new Conceptual Hybrid Turboshaft Engine (CHTS). This approach involves using pertinent input design data from the PW150 engine, and the output performance data of the PW150. This will establish the new design properties for the new CHTS engine.

Ideally the new output properties (Shaft Horsepower, Equivalent shaft horsepower, Kilowatts etc.), should exceed the performance of the original PW150. The CHTS is the enhanced version of the PW150 which incorporates the SMES coil, to increase performance. Proceeding with verifying and validating performance analysis assumptions, involves identifying input variables, defining engineering tools (Mattingly) [4] and off design output design data.

2.1 Real Design Analysis Sequence

The sequence of steps is to:

1. Institute the required Mass Flow Parameter (MFP), which is an important factor in determining the required performance qualities of both engines, at various altitudes. The MFP is defined as a function that is derived based on an independent (assumed) Mach number (M), of a calorically perfect gas. The function is equal to M $\sqrt{\frac{\gamma g_c}{R}}\frac{\frac{P}{Pt}}{\sqrt{\frac{T}{Tt}}}$ [5].

The properties represented within the MFP consist of pressure ratio (P/Pt), the square root of the temperature ratio ($\sqrt{\frac{T}{Tt}}$), and various constants (R=53.3, γ = 1.4, g_c = 32.2 Ft/sec^2).

2 Assume a general mass flow rate baseline value, of 100 lb/sec, for both engines. This value is generally applicable with respect to parametric on design analysis, rather than 200 lbm/sec [4] for performance off design analysis. A mass flow rate of 200 lbm/sec is generally applicable to high performance engines (Turbojet, Turbofan, Turbofan with afterburner etc.).

3 The next sequence involves selecting a range of Mach numbers and CHTS compressor stages along with performance tools [13] that should validate PW150 and CHTS performance information. (See table 4)

Table 4 Pratt & Whitney (PW150) Technical Specifications

Specifications	PW150
Equivalent Shaft Horsepower (HP)	6200
Shaft horsepower	5026
Estimate Engine Efficiency	η_c $5026/6200 = .810$
Shaft Speed	1020 Revolutions/ Min (RPM)
Compressor Pressure Ratio π_c	18
Compressor Stage	4

Generally Mach numbers for turboprop/turboshaft engines in industry varies anywhere from 0.5 to 0.6 Mach. Validating design specifications concerning the CHTS' compressor pressure ratio and the compressor stage, involves assessing additional engine design specifications (PW120 and PW150). The PW120 engine design employs a two-spool, two stage centrifugal compressor design, while the PW150 employs a two-spool four stage (Three-stage axial, single centrifugal) design.[6], [7]. Note: The PW120 and the PW150 have compressor pressure ratios of 12.14 and 18 respectively [6], [7]. To justify increasing the compressor pressure ratio and stage values to optimize CHTS performance over the PW150; there is a need to compare the performance properties of the PW120 and the PW150 engines. The compressor ratio/stage of the PW120 is 12.14/2 = 6.1, and the compressor ratio/stage of the PW150 is 18/4 = 5 (combined axial and centrifugal compressor). Assuming the compressor pressure ratio increases by 6 between engines, then the assumed compressor ratio for the CHTS would be 24. Typical axial compressor characteristics are depicted in table 5.[8]

Table 5 Axial flow Compressor Characteristics

Type of Application	Type of Flow	Inlet Relative Velocity Mach number	Pressure Ratio Per Stage	Efficiency Per stage
Industrial	Subsonic	0.4-0.8	1.05-1.2	88%-92%
Aerospace	Transonic	0.7-1.1	1.15-1.6	80%-85%
Research	Supersonic	1.05-2.5	1.8-2.2	75%-85%

Based on technical specifications (Tables 4 and 5 and knowing that increasing compressor stages increases the compressor pressure ratio, a stage of 5 would be appropriate for the CHTS engine. The CHTS compressor stage will consist of a two-spool five stage (Three-stage axial, double centrifugal) design. Note: More than two centrifugal stages are not practical, because of losses in turns between stages. Optimal compressor pressure ratio/stage for the CHTS can be selected, by utilizing the engineering equation $R = R_t^{1/h}$, where R= compressor pressure ratio/stage, R_t represents the total compressor pressure ratio, and 1/h is the exponential value of the stages (h). With h= to 5, R_t = 24, then R is = to 1.9.

2.2 Real Design Analysis Results

1. Off design engine (PW150 and CHTS) performance test results were obtained using engine performance analysis tools [13]. Off design performance of both engines is represented using tabulated data (Table and plots.); based on assumed referenced engine turboprop inputs, component efficiencies, gas/fuel properties and input parameters (Mach numbers, total turbine temperature/Tt4 etc.). PW150 performance tabulated data (Table 6 and 7) at Mach number 0.4 is included in this analysis. Engine efficiency at this Mach number is less than the industry standard. ($\eta \leq 81$); however relative PW150 numerical tabulated data values (Thrust, thrust specific fuel consumption, total temperature, compressor pressure ratio, plots etc.), at Mach number 0.4, will not be represented within this analysis.

2. Relative Off-Design Performance Analysis results, are depicted in Tables 6 thru 11 and Figures 6 thru 10 respectively.

Table 6 PW150 & CHTS Off-Design Performance Data

PART 1

PERF (Ver. 5.0) Turboprop
Engine File: PW150 Engine Data

Input Constants

π Diffuser ratio = 0.9600 π Burner ratio = 0.9500 η burner efficiency = 0.9990
π Nozzle ratio = 0.9700 cpc (specific heat at constant pressure) = 0.2400
cpt (specific heat at constant temperature) = 0.2950
γ c (specific heat compressor ratio) = 1.4000 γ t (specific heat turbine ratio)= 1.3000
η c (Compressor efficiency) = 0.8540 η tH (High turbine efficiency)= 0.9051
η tL(Low turbine efficiency) = 0.9035 hPR (Fuel heating value) = 18485

Control Limits: Tt4 = 2805 R π c (Engine Compressor ratio) = 18.00

Parameters	PW150 Off-Design Performance Test Data
Mach Number	0.4000
Temperature	562.68 R
Pressure	14.6960 psia
Altitude	0 ft
Total Temp	2805.00 R
Mass Flow Rate	35.30 lbm/s
Corr Mass Flow	33.45 lbm/s
Flow Area	1.077 ft^2
Flow Area*	0.677 ft^2
Flow Area @ 8	0.462 ft^2
MB - Fuel/Air Ratio (f)	0.02275
Specific Thrust (F/m0)	125.77 lbf/(lbm/sec)
Thrust Spec Fuel Consumption (S)	0.6512 lbm/(hr-lbf)
Thrust (F)	4440 lbf
Power	3755 kW
Fuel Flow Rate	2891 lb/hr
Propulsive Efficiency (%)	65.07
Thermal Efficiency (%)	17.88
Overall Efficiency (%)	11.63

Table 7 PW150 & CHTS Off-Design Performance Data

PART 2

PERF (Ver. 5.0) Turboprop
Engine File: PW150 Engine Data

Input Constants

π Diffuser ratio = 0.9600 π Burner ratio = 0.9500 ηburner efficiency = 0.9990
π Nozzle ratio = 0.9700 cpc (specific heat at constant pressure) = 0.2400
cpt (specific heat at constant temperature) = 0.2950
γc (specific heat compressor ratio) = 1.4000 γt (specific heat turbine ratio)= 1.3000
ηc (Compressor efficiency) = 0.8540 η tH (High turbine efficiency)= 0.9048
η tL(Low turbine efficiency) = 0.9037 hPR (Fuel heating value) = 18485

Control Limits: Tt4 = 2730 R π c (Engine Compressor ratio) = 18.00

Parameter	PW150 Off-Design Performance Test Data
Mach Number	0.4000
Temperature	539.64 R
Pressure	11.7778 psia
Altitude	6000 ft
Total Temp	2730.00 R
Mass Flow Rate	35.30 lbm/s
Corr Mass Flow	40.88 lbm/s
Flow Area	1.316 ft^2
Flow Area*	0.827 ft^2
Flow Area @8	0.569 ft^2
MB - Fuel/Air Ratio (f)	0.02229
Specific Thrust (F/m0)	128.55 lbf/(lbm/sec)
Thrust Spec Fuel Consumption (S)	0.6242 lbm/(hr-lbf)
Thrust (F)	4538 lb
Power	3759 kW
Fuel Flow Rate	2833 lb/hr
Propulsive Efficiency (%)	65.26
Thermal Efficiency (%)	18.26
Overall Efficiency (%)	11.92

Table 8 PW150 & CHTS Off-Design Performance Data

PART 3

PERF (Ver. 5.0) Turboprop
Engine File: PW150 Engine Data

Input Constants
π Diffuser ratio = 0.9600 π Burner ratio = 0.9500 ηburner efficiency = 0.9990
π Nozzle ratio = 0.9700 cpc (specific heat at constant pressure) = 0.2400
cp t (specific heat at constant temperature) = 0.2950
γ_c (specific heat compressor ratio) = 1.4000 γt (specific heat turbine ratio)= 1.3000
ηc (Compressor efficiency) = 0.8540 η tH (High turbine efficiency)= 0.9074
η tL(Low turbine efficiency) = 0.9011 hPR (Fuel heating value) = 18485

Control Limits: Tt4 = 2540.0 R πc (Engine Compressor ratio) = 18.00

Parameter	PW150 Off-Design Performance Test Data
Mach Number	0.5500
Temperature	562.68 R
Pressure	14.6960 psia
Altitude	0 ft
Total Temp	2540.00 R
Mass Flow Rate	44.70 lbm/s
Corr Mass Flow	39.03 lbm/s
Flow Area	0.992 ft^2
Flow Area*	0.790 ft^2
Flow Area @8	0.505 ft^2
MB - Fuel/Air Ratio (f)	0.01726
Specific Thrust (F/m0	71.83 lbf/(lbm/sec)
Thrust Spec Fuel Consumption (S)	0.8649 lbm/(hr-lbf)
Thrust (F)	3211 lb
Power	3734 kW
Fuel Flow Rate	2777 lb/hr
Propulsive Efficiency (%)	80.43
Thermal Efficiency (%)	18.51
Overall Efficiency (%)	14.86

Table 9 PW150 & CHTS Off-Design Performance Data

PART 4

PERF (Ver. 5.0) Turboprop
Engine File: PW150 Engine Data

Input Constants
π Diffuser ratio = 0.9600 π Burner ratio = 0.9500 ηburner efficiency = 0.9990
π Nozzle ratio = 0.9700 cp c (specific heat at constant pressure) = 0.2400
cp t (specific heat at constant temperature) = 0.2950
γc (specific heat compressor ratio) = 1.4000 γt (specific heat turbine ratio)= 1.3000
ηc (Compressor efficiency) = 0.8540 η tH (High turbine efficiency)= 0.9072
η tL(Low turbine efficiency) = 0.9014 hPR (Fuel heating value) = 18485

Control Limits: Tt4 = 2470.0 R π c (Engine Compressor ratio) = 18.00

Parameter	PW150 Off-Design Performance Test Data
Mach Number	0.5500
Temperature	539.64 R
Pressure	11.7778 psia
Altitude	6000 ft
Total Temp	2470.00 R
Mass Flow Rate	44.70 lbm/s
Corr Mass Flow	47.70 lbm/s
Flow Area	1.212 ft^2
Flow Area*	0.965 ft^2
Flow Area @8	0.621 ft^2
MB - Fuel/Air Ratio (f)	0.01696
Specific Thrust (F/m0)	73.88 lbf/(lbm/sec)
Thrust Spec Fuel Consumption (S)	0.8267 lbm/(hr-lbf)
Thrust (F)	3302 lb
Power	3761 kW
Fuel Flow Rate	2730 lb/hr
Propulsive Efficiency (%)	80.07
Thermal Efficiency (%)	18.96
Overall Efficiency (%)	15.18

Table 10 PW150 & CHTS Off-Design Performance Data

PART 5

PERF (Ver. 5.0) Turboprop
Engine File: CHTS Engine Data

Input Constants
π Diffuser ratio = 0.9600 π Burner ratio = 0.9500 ηburner efficiency = 0.9990
π Nozzle ratio = 0.9700 cp c (specific heat at constant pressure) = 0.2400
cp t (specific heat at constant temperature) = 0.2950
γc (specific heat compressor ratio) = 1.4000 γt (specific heat turbine ratio)= 1.3000
ηc (Compressor efficiency) = 0.8490 η tH (High turbine efficiency)= 0.9077
η tL(Low turbine efficiency) = 0.9009 hPR (Fuel heating value) = 18485

Control Limits: Tt4 = 2900 R π_c (Engine Compressor ratio) = 24.00

Parameter	CHTS Off-Design Performance Test Data
Mach Number	0.5600
Temperature	562.68 R
Pressure	14.6960 psia
Altitude	0 ft
Total Temp	2900.00 R
Mass Flow Rate	45.20 lbm/s
Corr Mass Flow	39.22 lbm/s
Flow Area	0.985 ft^2
Flow Area*	0.794 ft^2
Flow Area @8	0.408 ft^2
MB - Fuel/Air Ratio (f)	0.02154
Specific Thrust (F/m0)	82.20 lbf/(lbm/sec)
Thrust Spec Fuel Consumption (S)	0.9432 lbm/(hr-lbf)
Thrust (F)	3715 lb
Power	4399 kW
Fuel Flow Rate	3504 lb/hr
Propulsive Efficiency (%)	84.08
Thermal Efficiency (%)	17.28
Overall Efficiency (%)	14.53

Table 11 PW150 & CHTS Off-Design Performance Data

PART 6

PERF (Ver. 5.0) Turboprop
Engine File: CHTS Engine Data

Input Constants

π Diffuser ratio = 0.9600 π Burner ratio = 0.9500 ηburner efficiency = 0.9990

π Nozzle ratio = 0.9700 cp c (specific heat at constant pressure) = 0.2400

cp t (specific heat at constant temperature) = 0.2950

γc (specific heat compressor ratio) = 1.4000 γt (specific heat turbine ratio)= 1.3000

ηc (Compressor efficiency) = 0.8490 η tH (High turbine efficiency)= 0.9074

η tL(Low turbine efficiency) = 0.9011 hPR (Fuel heating value) = 18485

Control Limits: Tt4 = 2820 R π c (Engine Compressor ratio) = 24.00

Parameter	CHTS Off-Design Performance Test Data
Mach Number	0.5600
Temperature	562.68 R
Pressure	11.7778 psia
Altitude	6000 ft
Total Temp	2820.00 R
Mass Flow Rate	45.20
Corr Mass Flow	47.93 lb/sec
Flow Area	1.203 ft^2
Flow Area*	0.970 ft^2
Flow Area @ 8	0.502 ft^2
MB - Fuel/Air Ratio (f)	0.02112
Specific Thrust (F/m0)	84.44 lbf/(lbm/sec)
Thrust Spec Fuel Consumption (S)	0.9006 lbm/(hr-lbf)
Thrust (F)	3817 lb
Power	4426 kW
Fuel Flow Rate	3437 lb/hr
Propulsive Efficiency (%)	83.53
Thermal Efficiency (%)	17.72
Overall Efficiency (%)	14.81

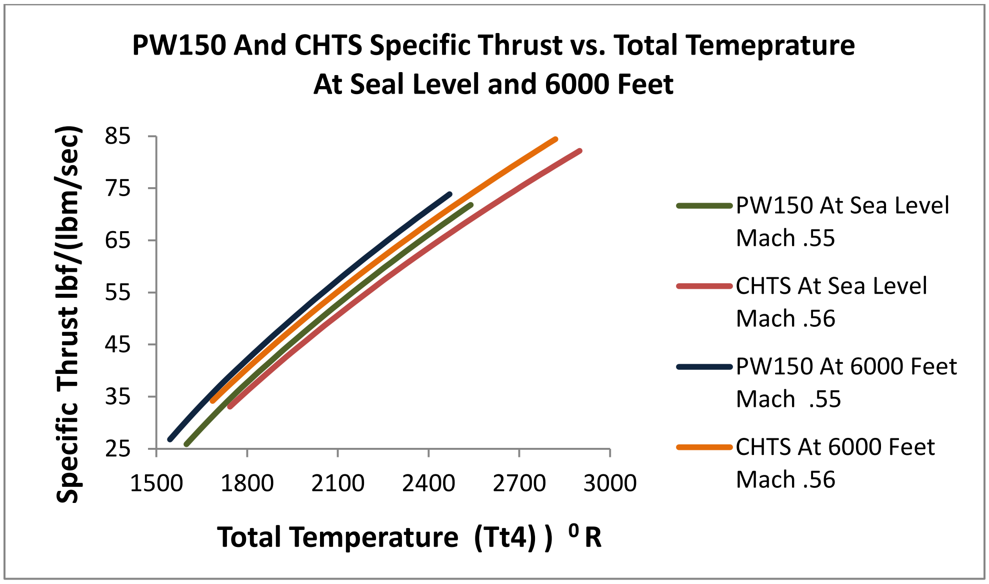


Figure 7 Engine Specific Thrust vs Total Temperature

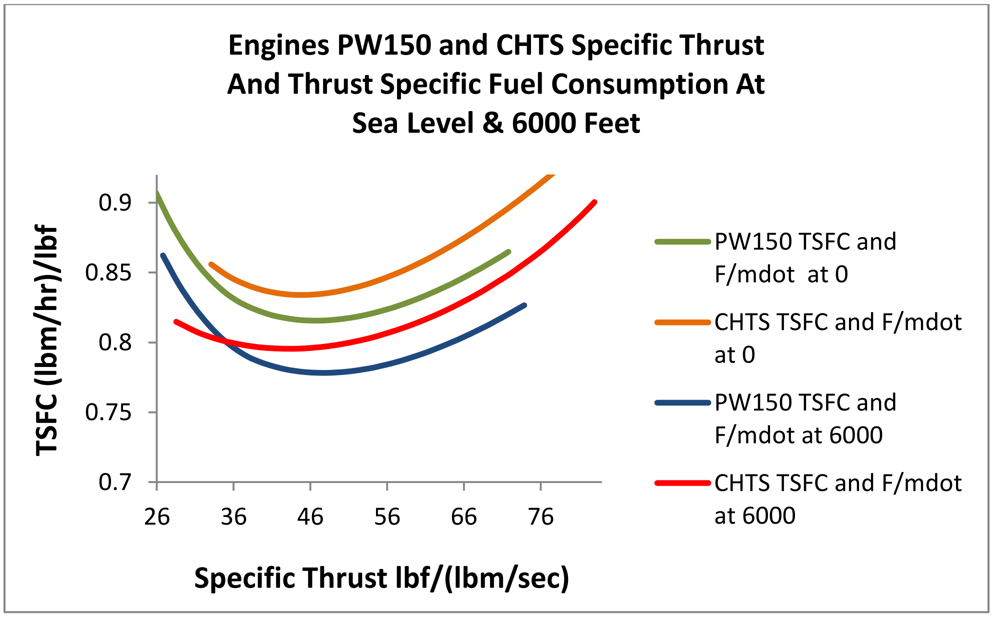


Figure 8 Engine Specific Thrust vs Thrust Specific Fuel Consumption

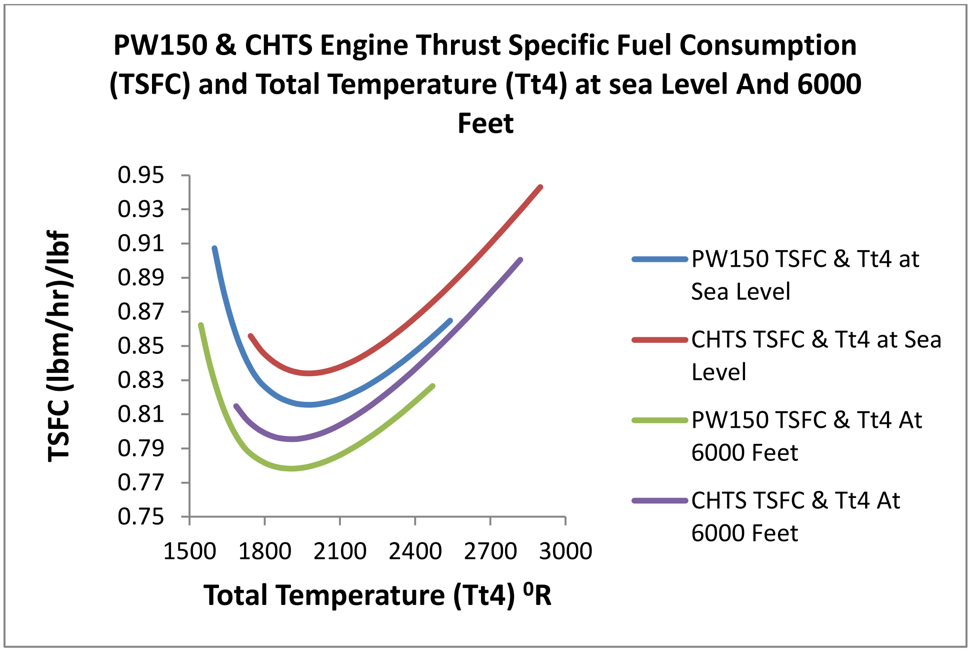


Figure 9 Engine Thrust Specific Fuel Consumption vs Total Temperature

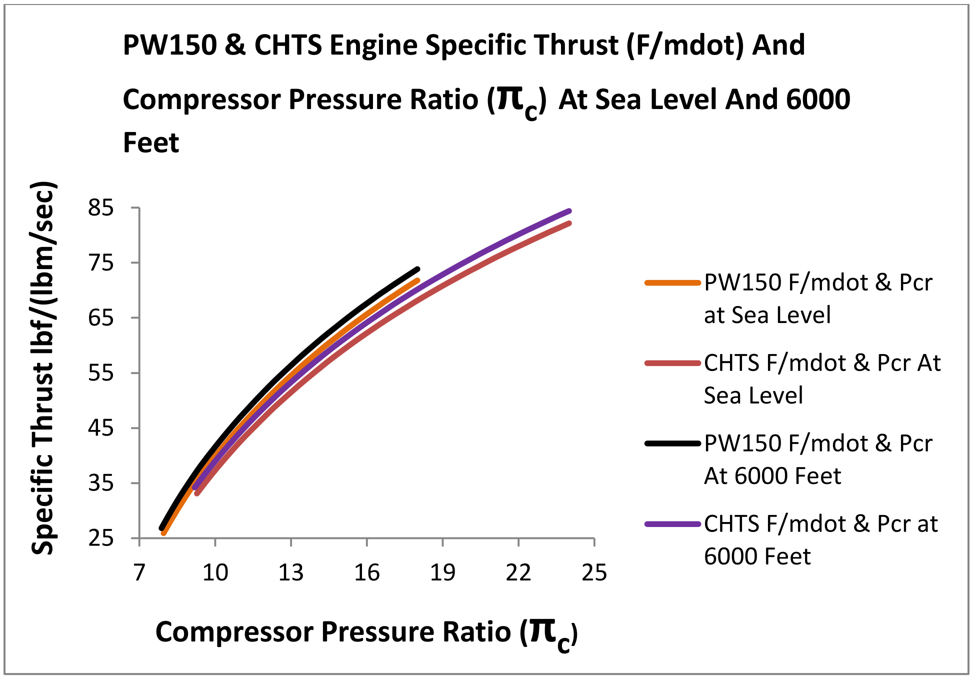


Figure 10 Specific Thrust vs Compressor Pressure Ratio

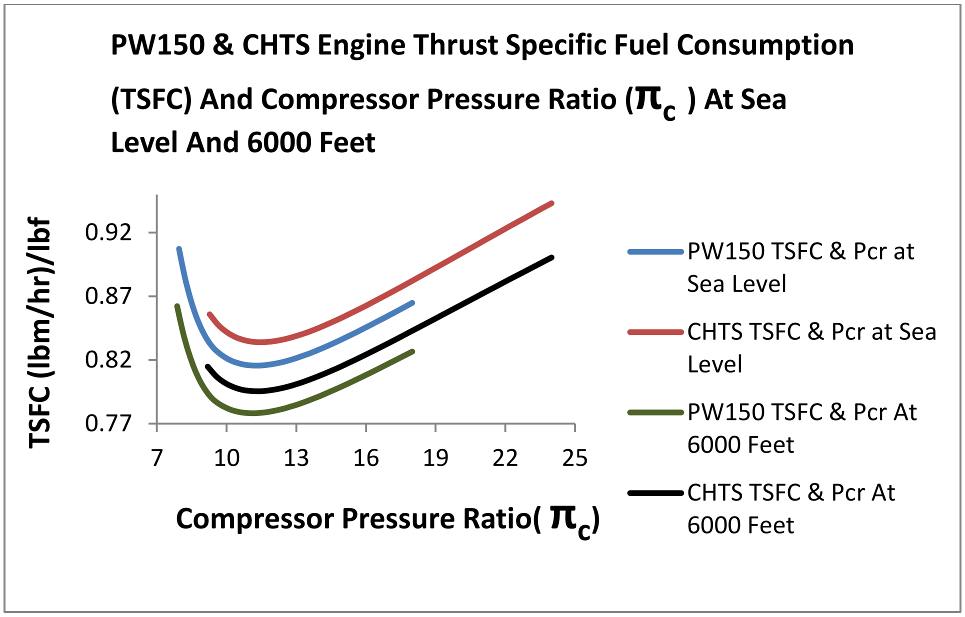


Figure 11 Engine Thrust Specific Fuel Consumption vs Compressor Pressure Ratio

Table 12 PW150 & CHTS Pertinent Data Comparison

MACH Number	$\sqrt{\frac{\gamma g_c}{R}}$	P/Pt	T/Tt	$\sqrt{T/Tt}$	Mass Flow Parameter (MPF) $M\sqrt{\frac{\gamma g_c}{R}}\frac{P/Pt}{\sqrt{T/Tt}}$	Mass Flow Rate MFP x 100 lbm/sec
.4	.92	.895614	.968992	.984374	.3348	33.5
.55	.92	.814165	.942951	.971056	.4242	42.4
.56	.92	.808228	.940982	.970042	.4292	42.9

Note: The mass flow rate values depicted in this tabulation, are depicted for a standard day. For a hot day there is a 5.3% increase in the mass flow rates; thus the actual flow rates, are depicted below.

Mach Number	Mass Flow Rates lbm/sec	Flow Rate 5.3% Increase by	Mass Rate + 5.3% increase lbm/sec
.4	33.5	1.774	35.3
.55	42.4	2.25	44.7
.56	42.9	2.27	45.2

PW150 At Sea Level	CHTS At sea Level
Mach Number M =.55	Mach Number M =.56
Propulsion Efficiency η_p = 80.43 %	Propulsion Efficiency η_p = 84.08 %
Specific Fuel Consumption = .8649	Specific Fuel Consumption = .9432
PW150 At 6000 Feet	CHTS At 6000 Feet
Mach Number M =.55	Mach Number M =.56
Propulsion Efficiency η_p = 79.93 %	Propulsion Efficiency η_p = 83.53 %
Specific Fuel Consumption = .8267	Specific Fuel Consumption = .9006

According to Pratt & Whitney specifications, the propulsion efficiency is equal to the Shaft Horsepower/Equivalent Shaft Horsepower. Note: SHP/ESHP = η_p. Now SHP = 5000, and the ESHP = 6200. The η_p = 5000/6200 = 80.6 %. This is based on PW150 data. Upon close examination of the data (Tables 8 thru 11) provided, the PW150 and CHTS efficiencies are near or exceed this value. Values obtained were a result of increasing the Mach numbers, the mass flow rate, and total temperature (Tt4), associated with each engine (Tables 6 thru 11). By increasing the compressor pressure ratio from 18 to 24, the CHTS engine's horsepower (In kilowatts) increased by 17.68. The test column (Tables 6 thru 11), represents a more accurate assessment of engine performance. Note: At mean sea level the CHTS Engine efficiency value increased by 4.53 %, compared to the PW150 value at 6000 Feet. The CHTS Engine efficiency value increased by 4.5 %, compared to the PW150 value. This represents a slight propulsion efficiency change. Regarding the fuel consumption at sea level, the CHTS Engine fuel consumption increased by 9 %, at 6000 Feet.

The final phase (Test & Evaluation) of engine off design performance requires developing a performance test scenario (Hypothetical high speed rail route) in real time, validating CHTS improved performance over the baseline engine (PW150). This issue will be addressed in the next section of this project.

3. ENGINE PERFORMANCE TEST AND VALIDATION

Developing a real world algorithm (Test performance scenario) for both engines (PW150 & CHTS) involves incorporating practical assumptions and applying hypothetical high speed rail route data in real time. This is depicted in section 1.2.1.

3.1 Engine Performance Design Test Factors

Before addressing specific test assumptions, additional engine performance design test factors (Fuel flow rate, train fuel capacity and fuel weight (pounds/gallon), train weight, gallons/horsepower (HP), engine revolutions per minute (rpm) etc.), are derived from specific off design output data. A brief explanation regarding test factor derivations and calculations required for engine test performance is depicted in Appendix A. Table13 below represents the test performance factor data, used in this simulation.

Table 13 Engine Design Test Factors

PW150	CHTS
Shaft Speed 1020 RPM	Shaft Speed 1200 RPM
JP-5 Fuel Specific fuel Consumption .59 lbf/hr/hp Weight 6.8 lbf/gallon	JP-5 Fuel Specific fuel Consumption .59 lbf/hr/hp Weight 6.8 lbf/gallon
Average train fuel consumption 437 Gallons/Hour (GPH)	Average train fuel Consumption 514 Gallons/ Hour (GPH)
Power Car Fuel Tank Capacity 2200 Gallons	Power Car Fuel Tank Capacity 2400 Gallons
Maximum power car fuel time before fuel tank depletion; no reserves t = 5.03 hours	Maximum power car fuel time before fuel tank depletion; no reserves t = 4.7 hours
Maximum train speed based on horsepower and turboshaft speed 150 miles/hour (mph)	Maximum train speed based on horsepower and turboshaft speed 180 miles/hour (mph)

3.2 CHTS SMES Coil Operational Analysis

Analysis of the SMES Coil which interfaces with the CHTS, is based on similar characteristics of a mechanical rotating energy storing flywheel. The primary purpose of the flywheel is to collect and store initial kinetic energy of a moving vehicle. The kinetic energy (KE) equation is depicted as KE $=mv^2/2$, where m is the total mass of the train and v is the initial velocity of the train. Note the equation $m = W/g$, where W represents the total weight of the train and g equates to the acceleration of gravity; thus KE $= Wv^2/2g$ as well. Kinetic energy converts to rotational energy, of the flywheel. This flywheel is attached to a generator, which converts this energy to electrical energy. As explained previously (Section 1.2.2) the SMES coil utilizes the regenerative braking process. The regenerative electrical output of the traction motor/generators generally equals the kinetic energy of the train; thus KE $= Wv^2/2g$ measured in ft-lbf), is converted into watt-hours. The approximate weight of the train (two Locomotives and six coach cars), weighs 1,204,000 pounds. Assuming the average speed is180 mph (264 ft/sec), Appendix A and the gravity acceleration = 32.2 Ft/Sec^2; then the KE is equal to1,204,000 * (264)*^{2} /(2 * 32.2) = to 1,303,012,174 ft-lbf.

The number of watt hour equates to ft-lbf (1,303,012,174) * (3.766 x 10^{-4}) = 490,714 watt hours. This is the total kinetic energy of the train that can be utilized for regenerated braking. Assume both locomotives utilize 245,357 watt hours (Half of 490,714 watt hours), needed for regenerated braking. The SMES coil selected is capable of storing and discharging 2MW SMES. Coil capabilities will be addressed in sections 3.3.1 and 3.3.2.

3.3 Real Time Engine Performance Test Criteria

The final DDT&E phase involves testing and validating the CHTS engines' high speed rail performance against the PW150 engine, within an operational scenario environment. Brief assumptions, test methodologies and software code make up the test criteria necessary to generate and validate CHTS operational performance.

3.3.1 Test Assumptions

1. Average high speed train acceleration =.984 ft/sec^2 [10]
2. Average high speed train deceleration = -1.64 ft/sec^2 [10]
3. SMES coil charging time to 2,000,000 Watts (2MW) t= 3 seconds [10]
4. SMES coil discharge time to 2,000,000 Watts (2MW) t =186 seconds [10]
5. One intermediate stop (Colorado Springs, CO) for 20 minutes, SMES coil charging.
6. Test track with no steep hill climbs, no tight curves etc.
7. Total trip time includes train acceleration to operational speed, constant trip speed time, and train deceleration from operational speed.
8. During the train stop at the Colorado Springs station, duration time shall be 15 minutes. Based on the gallons/hr (PW150 at 437.4, and CHTS at 514.8), the number of gallons utilized for engine idling is 109.35 and 128.7 gallons respectively.

9. High speed dynamic and regenerative braking is based on the average braking distance of 10000 meters (32800 feet), average stopping time of 3.3 minutes (200 seconds), and deceleration of -1.64 ft/sec^2 [10]. Note: This is based on speeds between 360- 300 km/hr (316-264 ft/sec), within most European and Asian countries [11]. Since the PW150 locomotive has a top maximum speed of 150 miles/hr (220 feet/sec), and the CHTS locomotive has a top estimate speed of 180 miles/hr (264 feet/sec), the speed range equates between 220-264 feet/sec; thus the stopping time and distance for both trains should be less. Table 14 depicted below, represents interpolation of braking distance, speed, and braking stopping times.

Table 14 Engine Deceleration Braking Data

Dynamic Braking Specifications	PW150	CHTS	European/Asian Countries Dynamic Braking Data
Train Braking Speed Initial velocity value	150 Miles/Hours (220 Feet/Sec	180 Miles/Hours (264 Feet/Sec	216 Miles/Hours (316 Feet/Sec
Stopping Time	2.28 minutes (137.5 seconds)	2.75 minutes (165 seconds)	3.33 minutes (137.5 seconds)
Deceleration value	-1.61 feet/sec^2	-1.6 feet/sec^2	-1.58 feet/sec^2
Braking Distance	2.86 Miles	4.134 Miles	5.9 Miles

10. Each power car contains 2 Megawatt (2681 Horsepower) SMES coils; then when one coil is discharging, the other coil is charging, which would help to maintain a constant horsepower (HP) of 2681 HP. The HP generated by

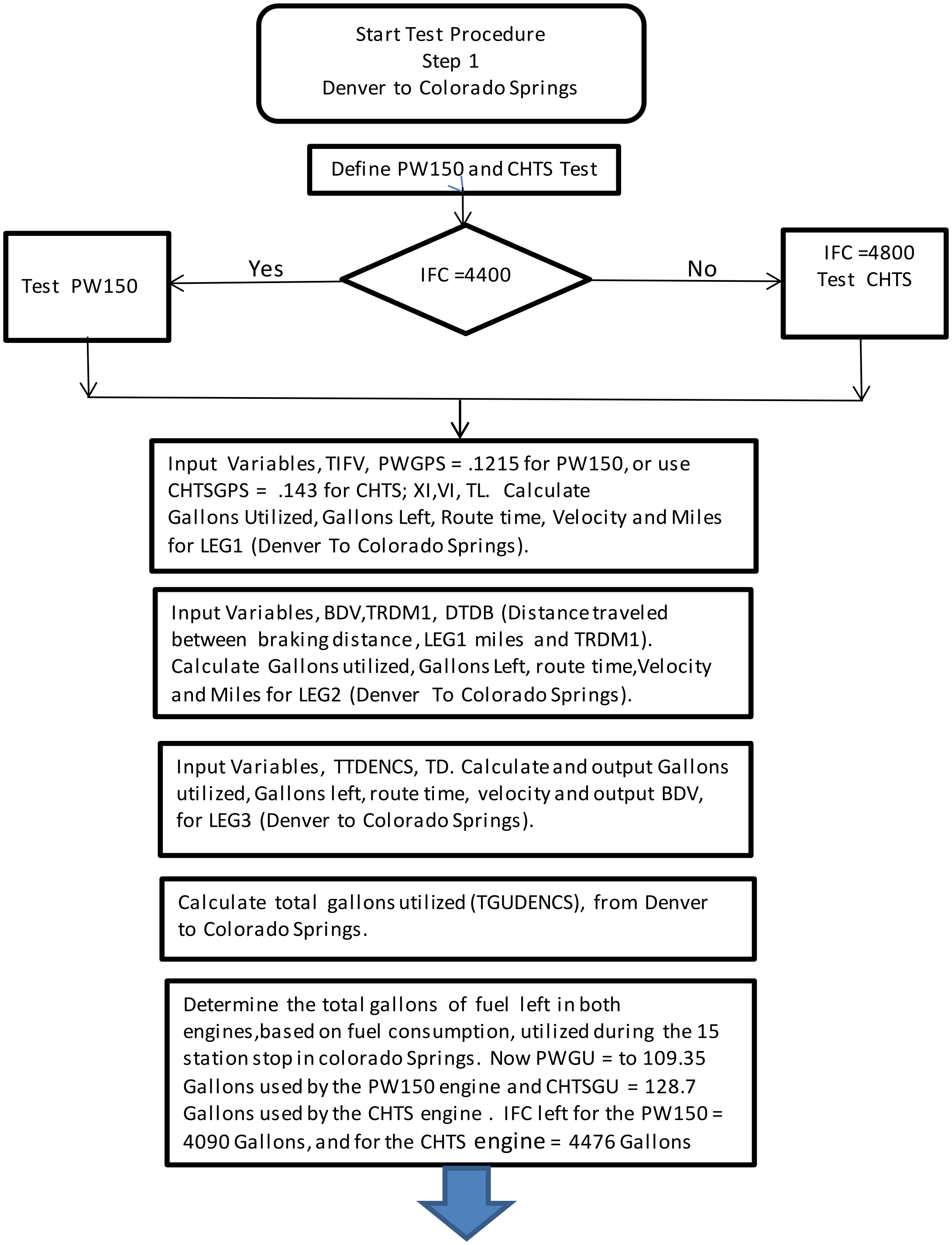
each power car for the CHTS Engine is 5933 HP. If the SMES coils are utilized, then the power cars can utilize just 3252 HP. The gallons/hr then equates to (3252 x .59)/6.8 = 282 gallons/hr (.078 gallons/sec.). Without the coils, the CHTS power cars utilizes .143 gallons/sec.

11. Assume that each CHTS power car fuel capacity increased by 200 gallons; thus fuel capacity for both engines equals 2400 gallons, rather than 2200 gallons. Total fuel capacity of the jet train is 4800 gallons.

3.3.2 Test Methodology

The final phase of the DDT & E process involves testing and evaluating the performance (Fuel utilized, fuel left, etc.) of the PW150 engine, against the CHTS engine (With and without the SMES Coil). Table 15 below depicts the various input and output test variables, associated with testing PW150 and CHTS engine performance. MATLAB code is utilized to test and validate engine performance. Flowcharts represent the sequence of steps used to test and validate engine performance, based on MATLAB code generation.

3.3.3 Test Methodology Flowcharts



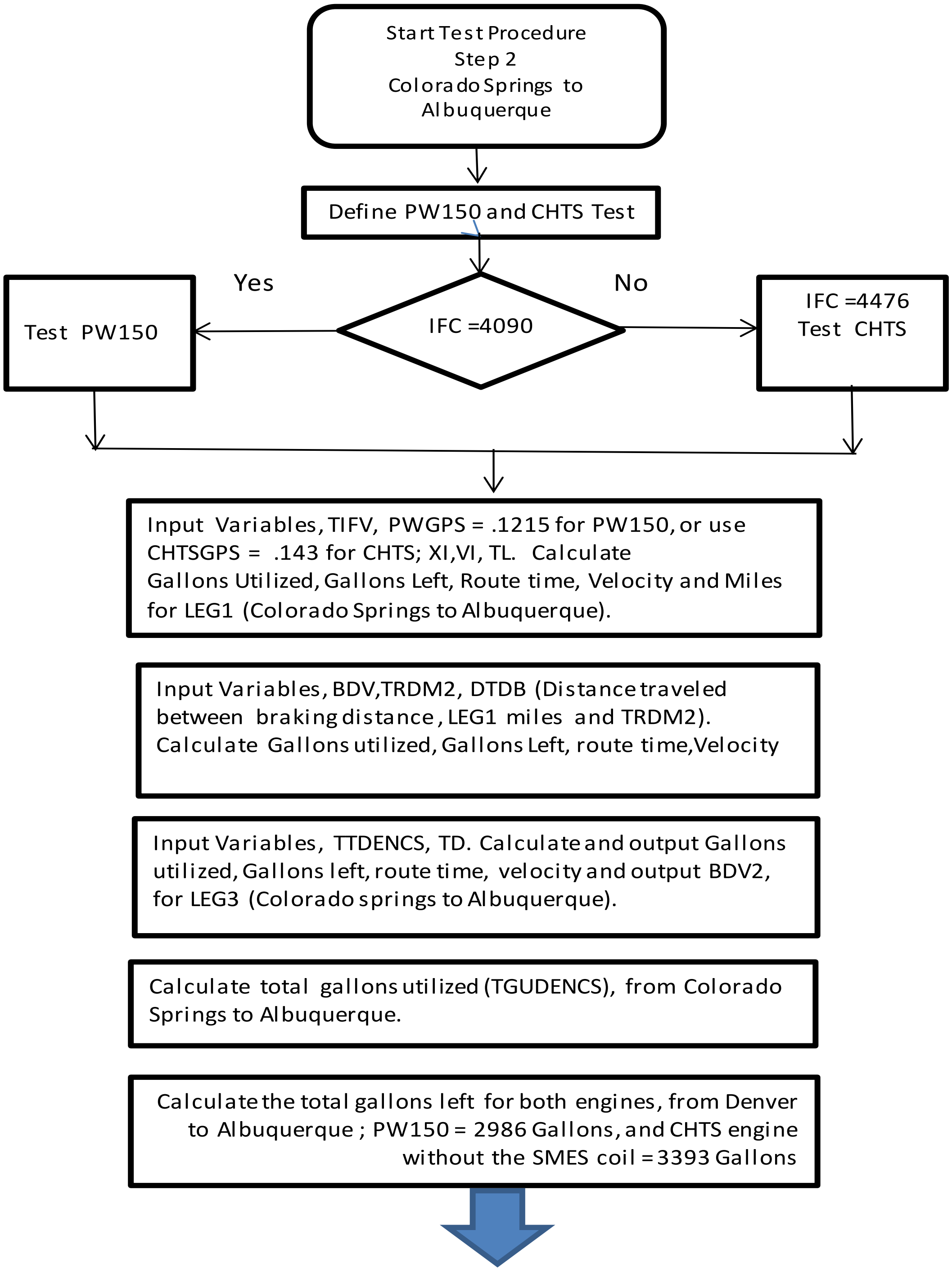
Input Variables, TIFV, PWGPS = .1215 for PW150, or use CHTSGPS = .143 for CHTS; XI,VI, TL. Calculate Gallons Utilized, Gallons Left, Route time, Velocity and Miles for LEG1 (Denver To Colorado Springs).

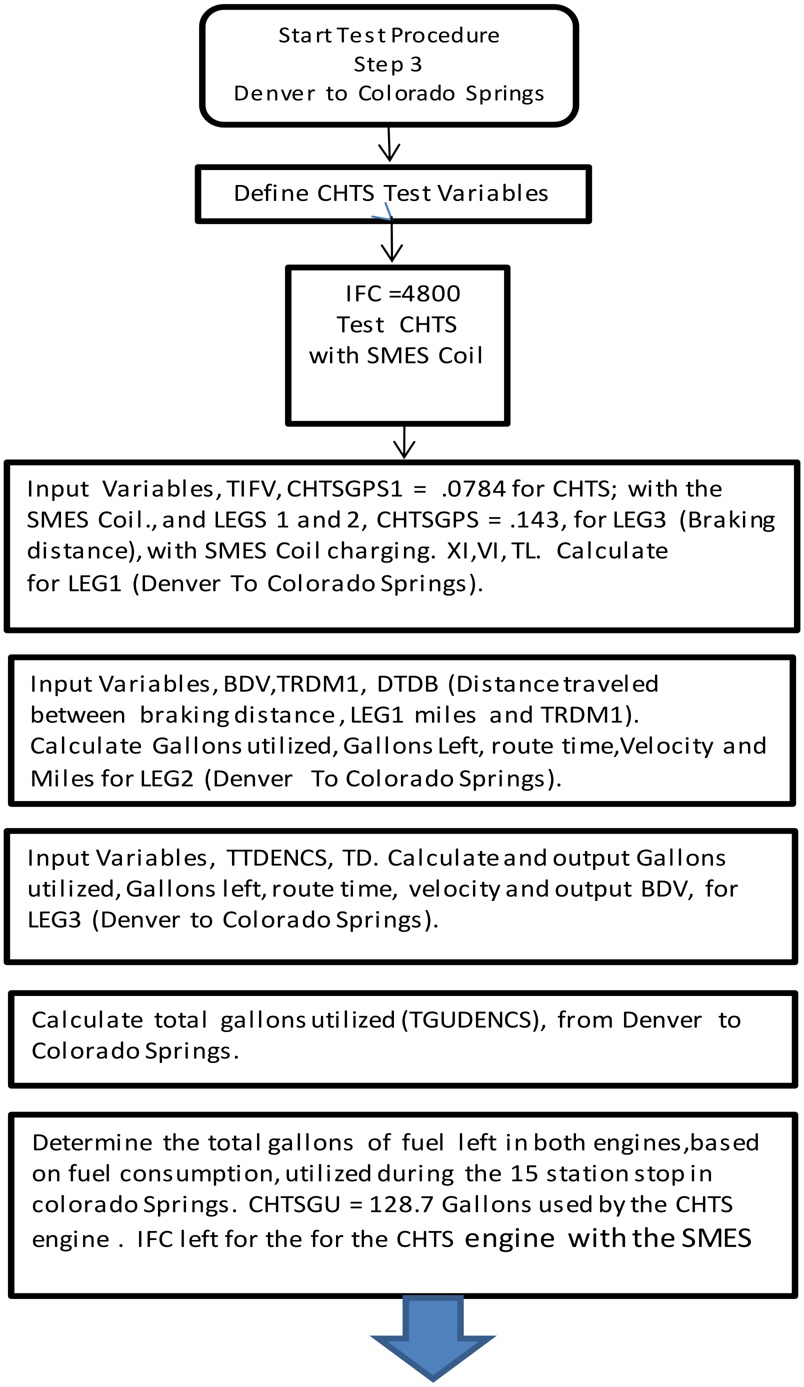
Input Variables, BDV,TRDM1, DTDB (Distance traveled between braking distance, LEG1 miles and TRDM1). Calculate Gallons utilized, Gallons Left, route time,Velocity and Miles for LEG2 (Denver To Colorado Springs).

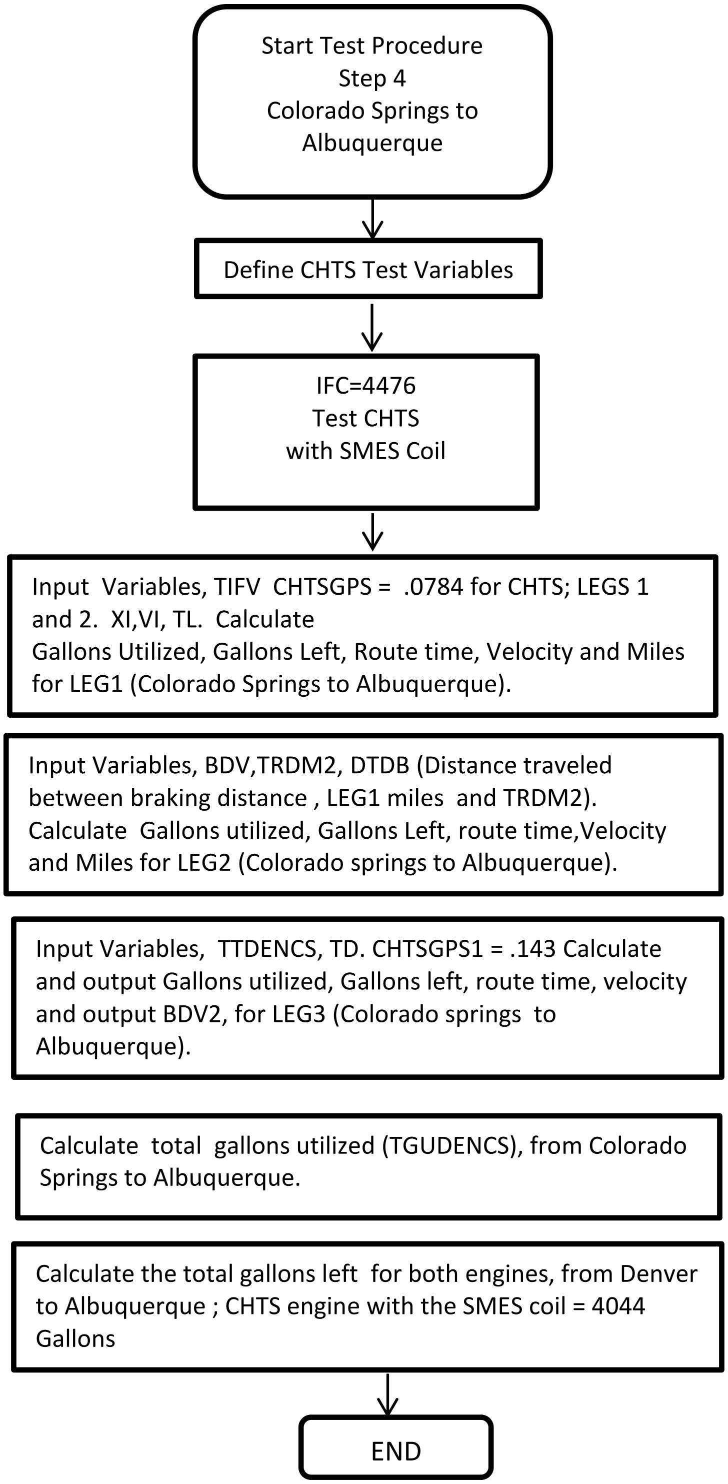
Input Variables, TTDENCS, TD. Calculate and output Gallons utilized, Gallons left, route time, velocity and output BDV, for LEG3 (Denver to Colorado Springs).

Calculate total gallons utilized (TGUDENCS), from Denver to Colorado Springs.

Determine the total gallons of fuel left in both engines,based on fuel consumption, utilized during the 15 station stop in colorado Springs. Now PWGU = to 109.35 Gallons used by the PW150 engine and CHTSGU = 128.7 Gallons used by the CHTS engine . IFC left for the PW150 = 4090 Gallons, and for the CHTS engine = 4476 Gallons


Start Test Procedure
Step 2
Colorado Springs to
Albuquerque
Define PW150 and CHTS Test
Yes
No
IFC =4090
Test PW150
IFC =4476
Test CHTS
Input Variables, TIFV, PWGPS = .1215 for PW150, or use CHTSGPS = .143 for CHTS; XI,VI, TL. Calculate Gallons Utilized, Gallons Left, Route time, Velocity and Miles for LEG1 (Colorado Springs to Albuquerque).
Input Variables, BDV,TRDM2, DTDB (Distance traveled between braking distance, LEG1 miles and TRDM2). Calculate Gallons utilized, Gallons Left, route time,Velocity
Input Variables, TTDENCS, TD. Calculate and output Gallons utilized, Gallons left, route time, velocity and output BDV2, for LEG3 (Colorado springs to Albuquerque).
Calculate total gallons utilized (TGUDENCS), from Colorado Springs to Albuquerque.
Calculate the total gallons left for both engines, from Denver to Albuquerque ; PW150 = 2986 Gallons, and CHTS engine without the SMES coil = 3393 Gallons


Start Test Procedure
Step 3
Denver to Colorado Springs
Define CHTS Test Variables
IFC =4800
Test CHTS
with SMES Coil
Input Variables, TIFV, CHTSGPS1 = .0784 for CHTS; with the SMES Coil., and LEGS 1 and 2, CHTSGPS = .143, for LEG3 (Braking distance), with SMES Coil charging. XI,VI, TL. Calculate for LEG1 (Denver To Colorado Springs).
Input Variables, BDV,TRDM1, DTDB (Distance traveled between braking distance, LEG1 miles and TRDM1). Calculate Gallons utilized, Gallons Left, route time,Velocity and Miles for LEG2 (Denver To Colorado Springs).
Input Variables, TTDENCS, TD. Calculate and output Gallons utilized, Gallons left, route time, velocity and output BDV, for LEG3 (Denver to Colorado Springs).
Calculate total gallons utilized (TGUDENCS), from Denver to Colorado Springs.
Determine the total gallons of fuel left in both engines,based on fuel consumption, utilized during the 15 station stop in colorado Springs. CHTSGU = 128.7 Gallons used by the CHTS engine . IFC left for the for the CHTS engine with the SMES


Start Test Procedure
Step 4
Colorado Springs to
Albuquerque
Define CHTS Test Variables
IFC=4476
Test CHTS
with SMES Coil
Input Variables, TIFV CHTSGPS = .0784 for CHTS; LEGS 1 and 2. XI,VI, TL. Calculate Gallons Utilized, Gallons Left, Route time, Velocity and Miles for LEG1 (Colorado Springs to Albuquerque).
Input Variables, BDV,TRDM2, DTDB (Distance traveled between braking distance , LEG1 miles and TRDM2). Calculate Gallons utilized, Gallons Left, route time,Velocity and Miles for LEG2 (Colorado springs to Albuquerque).
Input Variables, TTDENCS, TD. CHTSGPS1 = .143 Calculate and output Gallons utilized, Gallons left, route time, velocity and output BDV2, for LEG3 (Colorado springs to Albuquerque).
Calculate total gallons utilized (TGUDENCS), from Colorado Springs to Albuquerque.
Calculate the total gallons left for both engines, from Denver to Albuquerque ; CHTS engine with the SMES coil = 4044 Gallons
END

3.4 Test and Validation Results

Tables (16 thru 19), and Figures (12 thru 13) depicts the testing and validation phase associated with PW150 and CHTS engine performance.

Table 15 PW150 Pertinent Data

Test Data Parameters PW150	Route Leg	Gallons Utilized	Route Time In Seconds
Denver to CS	1	27.095	223
	2	156.865	1291
	3	16.6455	137
Station Stop	Engine Idle	109.35	900
CS to ALQ	1	27.095	223
	2	1057.1715	8701
	3	16.6455	137
Total time from Den to ALQ			11612
Total Gallons Utilized		1410.86	
Total Gallons Left		2989.14	
Total Route Time in Hours			3.235

Table 16 CHTS Pertinent Data

Test Data Parameters CHTS	Route Leg	Gallons Utilized	Route Time In Seconds
Denver to CS	1	38.181	267
	2	133.133	931
	3	23.595	165
Station Stop	Engine Idle	128.7	900
CS to ALQ	1	38.181	267
	2	1015.433	7101
	3	23.595	165
Total time from Den to ALQ			9796
Total Gallons Utilized		1406.244	
Total Gallons Left		3393	
Total Route Time in Hours			2.72

Table 17 CHTS (SMES Coils) Pertinent Data

Test Data Parameters CHTS SMES Coil	Route Leg	Gallons Utilized	Route Time In Seconds
Denver to CS	1	20.9328	267
	2	72.9904	931
	3	23.595	165
Station Stop	Engine Idle	128.7	900
CS to ALQ	1	20.9328	267
	2	556.7184	7101
	3	23.595	165
Total time from Den to ALQ			9796
Total Gallons Utilized		847.47	
Total Gallons Left		3953	
Total Route Time in Hours			2.72

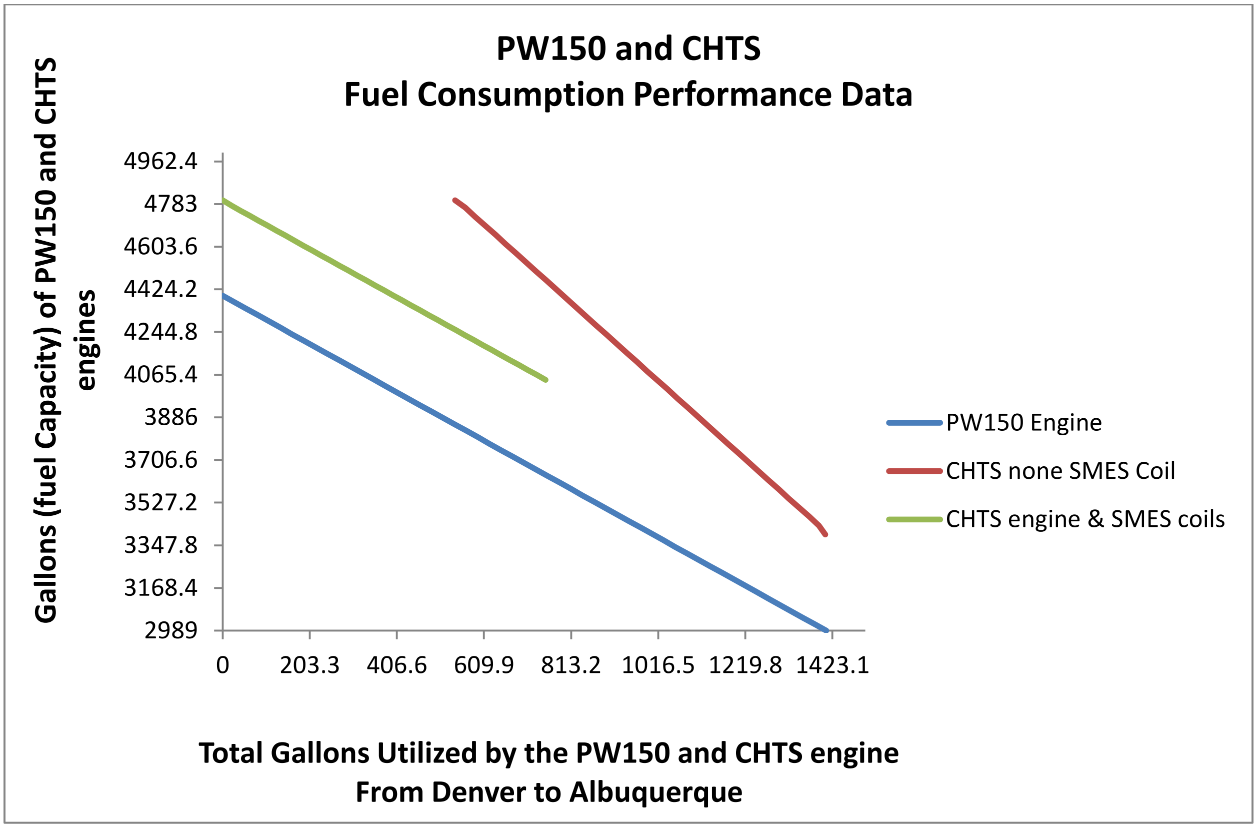


Figure 12 Engine Gallons Utilized and Fuel Capacity Comparison

MATLAB code Generated (appendix B)

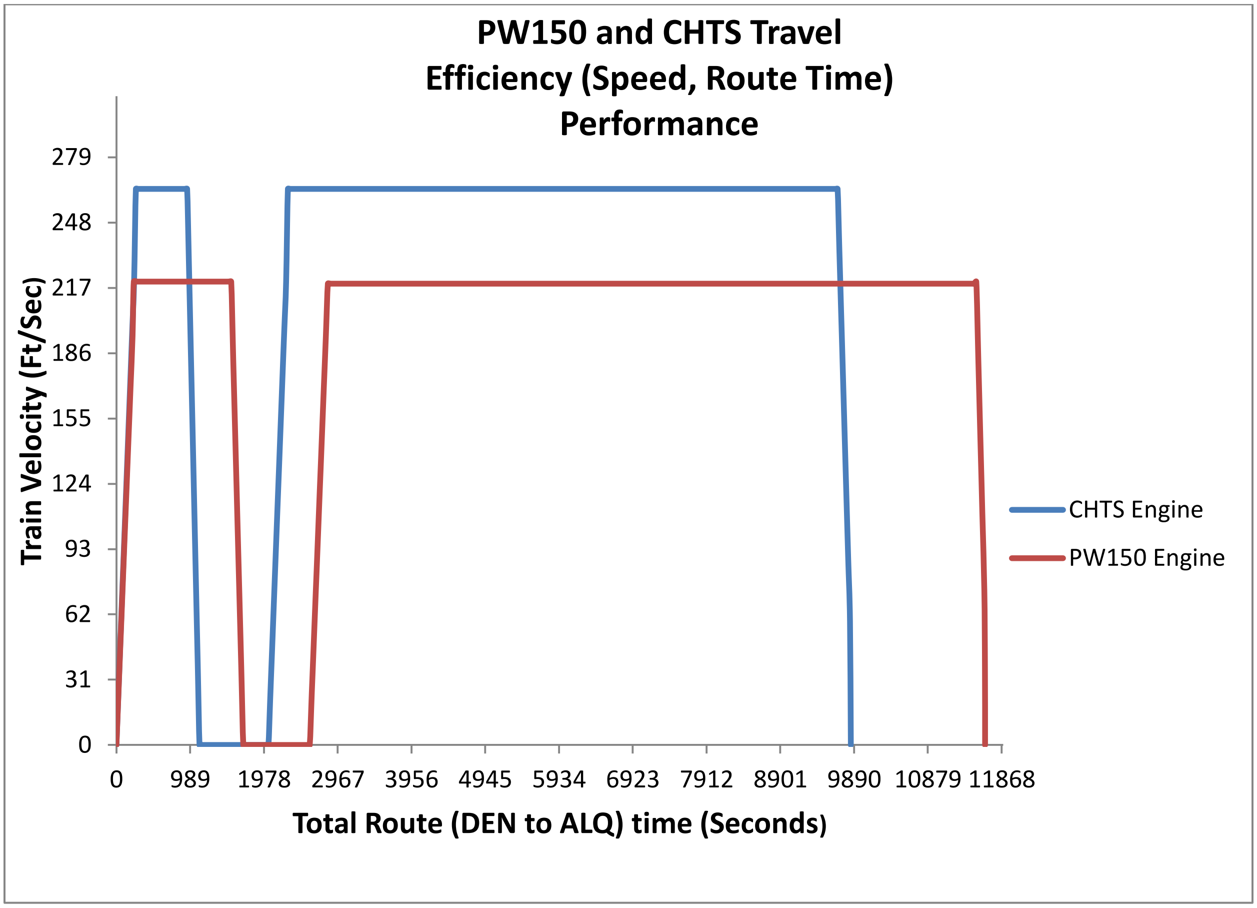


Figure 13 Engine Route Time Comparison

MATLAB code Generated (appendix B)

Synopsis: Upon reviewing PW150 and CHTS (SMES Coil/Non Coil) test data (Table and charts) provided, shows that for the number of gallons utilized by the PW150 and the CHTS engine without the SMES Coil, there was a slight decrease by 0.3%. By increasing the compressor pressure ratio of the CHTS (enhanced PW150), from 18 to 24, and the compressor stage from 4 to 6, train speed velocity increased by a factor of 20%. Fuel capacity of the CHTS was increased from 4400 to 4800 gallons. By

Implementing SMES coil design with the CHTS, engine gallons utilized decreased by a factor of approximately 40%. To fully validate additional PW150, CHTS, and CHTS (SMES Coil) data, it became necessary to examine the route time data for both engines. PW150 trip time from Denver to Albuquerque is 3.23 hours and the CHTS (Coil/non coil.) is 2.73 hours; thus it takes 15.5% less time (30 minutes) for the CHTS to complete the trip from Denver to Albuquerque. Note: This is based on a train velocity of 150 miles/ hour for the PW150 and 180 miles/hour for the CHTS. To fully validate PW150 and CHTS (Coil/Non Coil) data, table 19 depicted below shows a Simulated PW150 and CHTS (Coil/Non Coil) performance test run.

Table 18 PW150 and CHTS Simulated Test Run

Hypothetical Test Parameters	PW150	CHTS	CHTS(SMES Coils)
Gallons left (Fuel Capacity)	2989	3393	3905.8. Exclude Braking distance of 47.2 gallons
Traveling hours left Calculations	2989/(.1215 x3600) = 6.8 hrs.	3393/(.143 x3600) = 6.6 hrs.	3905/(.0784x3600) = 13.84 hrs.
Train speed velocity in hours	150 miles/hour	180 miles/hour	180 miles/hour
Hypothetical distance Traveled, based on fuel used and a fuel reserve of one hour.	Assume 870 miles (5.8 hrs. x 150 miles/hr.) Fuel reserve 1.0 hr	Assume 1008 miles (5.6 hrs. x 180 miles/hr.) Fuel reserve 1.0 hr	Assume 1098 miles (6.1 hrs. x 180 miles/hr.) Fuel left: 7.74 hrs., Includes 1.0 fuel reserve

4. CONCLUSION AND CHTS DESIGN VALIDATION

4.1 CHTS Engine Design Selection Criteria

CHTS engine design selection over the PW150 engine design involves meeting specific future industry criteria (Project standards). This includes but not limited to,(1) CHTS and PW150 technical design comparison, (2) CHTS and SMES coil interface design benefits, over the PW150 (3) Performing a design cost analysis related to the CHTS Engine and SMES coil interface. Project cost analysis may be an additional factor in validating and selecting the CHTS engine design.

4.1.1 CHTS and PW150 Design Comparison

Similarities relative to the PW150 and CHTS engines are, (1) The CHTS engine is an enhanced design prototype of the PW150 engine, (2) The CHTS houses 5 compressor stages as opposed to 4 compressor stages for the PW150, (3)The CHTS can generate 3817 lbf of thrust while the PW150 generates 3302 lbf of thrust, (4) Horsepower output of the CHTS engine equates to 4426 Kilowatts while the PW150 horsepower output equates to 3761Kilowatts . Lastly CHTS propulsion efficiency is equal to 83.53% while the PW150 efficiency is equal to 80.07%. Tables 12 and 13 depict additional CHTS and PW150 design similarities.

4.1 2 CHTS and SMES coil interface Design Benefits

CHTS and SMES coil interface design benefits can be attributed to recent testing and validating CHTS engine performance data. CHTS engine design benefits include but not limited to, (1) Train velocity increased by 20% (From 150 to 180/mph.), (2) Increased engine efficiency and horsepower (Tables 6 thru 11), (3) Increased fuel capacity by 9%, (4) A decrease in fuel consumption (Gallons utilized), by 24.4%
with SMES coil interface, and 13.51% with the non SMES coil interface. Tables 15 through 17 validate this data, (6) Travel time decreased by 18.75 %, and hypothetical distance traveled would increase by 15.86 % without SMES coil integration, and 26.2 % with SMES coil integration. Ongoing CHTS and SMES coil design research requires additional future development, testing, evaluation and validation.

4.1 3 CHTS SMES coil interface Design Cost Analysis

Implementation of an effective cost analysis assessment of the CHTS and SMES coil design is required, for final selection and design certification. Fundamental engineering economic factors [12] exclusive, but not limited to this cost analysis are Present Worth (PW) Future Worth (FW), and Annual Worth (AW). Future Worth refers to the future amount of funding associated with the design, development, test, and evaluation of the CHTS/SMES coil project, accumulated cost over a specific period time.

$F = P(1+i)^n$ where P= principal CHTS project cost, F= future project cost, i = interest of the project, and n= the amount of time (Years, months, etc.), accumulated. This factor represents the most simple method for determining future project cost; thus project managers can predict what future funding will be allocated. This method isn't the most popular of the three factors. [12]

Annual Worth refers to the annual equivalent uniform of all estimated receipts and disbursements of CHTS project cost. This method represents the best analysis used by engineers, as compared to Present Worth (PW) and Future Worth (FW) analysis. Annual Worth represents the equivalent of PW and FW, based on the Minimum Attractive Rate of Return (MARR). Note: MARR reflects capital cost, risk etc. The symbolic equation for $AW = \mathrm{P}\ \frac{i(1+i)^n}{(1+i)^n - 1)}$ where P= principal CHTS project cost, i= interest of the project, and AW Annual Worth of the project. [12] Present Worth (PW) refers to discounted cash flow and capitalized cost, associated with evaluating and selecting a project (For example the CHTS project.), which is mutually exclusive to other project alternatives. Project selection is predicated on PW>0. The symbolic equation for PW is $P = A\frac{(1+i)^n - 1)}{i(1+i)^n}$; which can be represented as the inverse of AW. Engineering Economic factors are crucial to the successful DDT &E of the CHTS project. [12]

5. Rail Transportation Perspective

5.1 Future Rail Transportation Outlook

The future outlook of rail transportation involves many factors, public acceptance of modern rail transportation, more research and development associated with projects such as Magnetic Levitation (MAGLEV), gas propulsion rail engine designs, and cost reduction of engineering materials. These are the factors needed for future rail transportation.

Appendix A

Off-Design PW150 & CHTS Engine Performance Tabulated Data.

Engine throttle tabulated test data [13], associated with engine performance results (Tables 8 thru 11), are depicted below. Specific tabulated performance parameters (Thrust, TSFC, etc.) are illustrated in plots (pages 28 thru 30), which give a more accurate account of the performance comparison of both engines.

PW150 at Mach .55, at Altitude Sea level (0 Feet).

Thrust F	TSFC S	mass flow rate mdot	compressor ratio Pic	Total Temp Tt4	Specific thrust F/mdot
3209	0.8649	44.69	17.995	2539.6	71.80577
3145	0.8624	44.23	17.747	2521.8	71.10558
3081	0.86	43.78	17.502	2503.9	70.3746
3020	0.8577	43.34	17.269	2486.8	69.68159
2955	0.8553	42.88	17.02	2468.3	68.91325
2891	0.8529	42.41	16.773	2449.8	68.16788
2827	0.8506	41.95	16.528	2431.2	67.38975
2762	0.8482	41.48	16.278	2412.1	66.58631
2699	0.8459	41.02	16.032	2392.9	65.79717
2635	0.8436	40.55	15.785	2373.6	64.9815
2571	0.8413	40.08	15.538	2354	64.14671
2506	0.8391	39.6	15.286	2333.8	63.28283
2442	0.8369	39.13	15.037	2313.7	62.40736
2377	0.8347	38.65	14.788	2293.3	61.50065
2313	0.8326	38.17	14.539	2272.6	60.59733
2250	0.8306	37.69	14.29	2251.7	59.69753
2184	0.8286	37.2	14.037	2230.1	58.70968
2120	0.8267	36.72	13.786	2208.5	57.7342
2056	0.8249	36.23	13.536	2186.6	56.74855
1992	0.8233	35.74	13.285	2164.4	55.73587
1928	0.8217	35.25	13.034	2141.9	54.69504
1863	0.8202	34.75	12.779	2118.7	53.61151
1799	0.8189	34.25	12.526	2095.4	52.52555
1735	0.8178	33.75	12.274	2071.7	51.40741
1671	0.8169	33.25	12.021	2047.8	50.25564
1606	0.8162	32.74	11.764	2023	49.05315
1542	0.8157	32.23	11.51	1998.1	47.84362
1478	0.8156	31.72	11.256	1972.8	46.59521
1414	0.8158	31.2	11.002	1947.1	45.32051
1351	0.8164	30.69	10.747	1920.9	44.02085
1285	0.8176	30.16	10.487	1893.7	42.6061
1221	0.8192	29.64	10.231	1866.5	41.19433
1158	0.8216	29.11	9.975	1838.7	39.78014

1094	0.8248	28.59	9.718	1810.4	38.26513
1029	0.829	28.04	9.456	1780.9	36.69757
965	0.835	27.52	9.202	1751.7	35.06541
901	0.8432	26.99	8.95	1722.3	33.38273
837	0.8538	26.47	8.7	1692.5	31.6207
772	0.8678	25.94	8.448	1661.7	29.76099
708	0.8852	25.41	8.2	1630.9	27.86305
644	0.9073	24.89	7.952	1599.4	25.87384

PW150 at Mach .55, at Altitude 6000 Feet

Thrust F	TSFC S	mass flow rate mdot	compressor ratio Pic	Total Temp Tt4	Specific thrust F/modt
3301	0.8266	44.69	17.995	2469.6	73.8644
3234	0.8243	44.23	17.746	2452.2	73.11779
3168	0.822	43.77	17.498	2434.7	72.37834
3105	0.8198	43.33	17.262	2417.7	71.65936
3039	0.8175	42.86	17.013	2399.8	70.90527
2973	0.8152	42.4	16.765	2381.6	70.11792
2908	0.8129	41.93	16.518	2363.4	69.35368
2841	0.8106	41.46	16.266	2344.7	68.52388
2775	0.8084	40.99	16.018	2326	67.69944
2710	0.8062	40.52	15.769	2307	66.88055
2643	0.804	40.04	15.516	2287.5	66.00899
2577	0.8018	39.56	15.266	2268	65.14156
2511	0.7997	39.09	15.016	2248.2	64.23638
2445	0.7976	38.61	14.765	2228.2	63.32556
2379	0.7956	38.12	14.514	2207.9	62.40818
2314	0.7936	37.64	14.263	2187.4	61.47715
2247	0.7916	37.15	14.008	2166.2	60.48452
2181	0.7898	36.66	13.756	2145	59.49264
2115	0.788	36.16	13.503	2123.5	58.49004
2049	0.7863	35.67	13.25	2101.7	57.44323
1983	0.7847	35.18	12.997	2079.6	56.36725
1916	0.7833	34.67	12.739	2056.8	55.26392
1851	0.7819	34.17	12.485	2033.9	54.17032

1785	0.7808	33.66	12.23	2010.7	53.0303
1719	0.7798	33.16	11.975	1987.1	51.83957
1652	0.779	32.64	11.716	1962.7	50.61275
1586	0.7785	32.13	11.46	1938.2	49.36197
1520	0.7782	31.61	11.204	1913.3	48.08605
1455	0.7783	31.09	10.947	1888	46.79961
1389	0.7787	30.57	10.69	1862.2	45.4367
1322	0.7796	30.04	10.428	1835.4	44.00799
1256	0.781	29.51	10.169	1808.5	42.56184
1190	0.7831	28.98	9.91	1781.1	41.0628
1125	0.7858	28.45	9.651	1753.2	39.54306
1058	0.7896	27.9	9.387	1724.2	37.92115
992	0.7953	27.37	9.131	1695.4	36.24406
926	0.8028	26.84	8.877	1666.4	34.50075
861	0.8127	26.31	8.625	1637	32.7252
794	0.8257	25.77	8.37	1606.6	30.81102
728	0.8418	25.24	8.12	1576.1	28.84311
662	0.8623	24.71	7.87	1545	26.79077

CHTS at Mach .56, at Altitude Sea level (0 Feet).

Thrust F	TSFC S	mass flow rate mdot	compressor ratio Pic	Total Temp Tt4	Specific thrust F/mdot
3714	0.9431	45.19	23.993	2899.6	82.18632
3639	0.9396	44.68	23.635	2878.8	81.44584
3565	0.936	44.16	23.276	2857.7	80.72917
3494	0.9325	43.67	22.934	2837.3	80.00916
3420	0.9289	43.15	22.577	2815.9	79.2584
3345	0.9253	42.63	22.216	2793.9	78.46587
3271	0.9216	42.1	21.855	2771.7	77.69596
3197	0.9179	41.58	21.496	2749.4	76.88793
3123	0.9143	41.05	21.137	2726.8	76.07795
3048	0.9105	40.52	20.773	2703.5	75.22211
2973	0.9068	39.99	20.412	2680.3	74.34359
2899	0.9031	39.45	20.051	2656.6	73.48542
2825	0.8994	38.92	19.689	2632.7	72.58479

2751	0.8957	38.38	19.328	2608.5	71.67796
2676	0.892	37.83	18.96	2583.5	70.73751
2602	0.8883	37.29	18.597	2558.4	69.77742
2528	0.8846	36.74	18.233	2533	68.80784
2454	0.8809	36.19	17.869	2507.2	67.80879
2379	0.8772	35.64	17.5	2480.6	66.75084
2305	0.8736	35.08	17.134	2453.9	65.70696
2231	0.87	34.52	16.768	2426.7	64.6292
2157	0.8665	33.96	16.402	2399.2	63.5159
2082	0.8629	33.39	16.03	2370.7	62.354
2008	0.8595	32.82	15.662	2342	61.18221
1934	0.8562	32.25	15.294	2312.9	59.96899
1860	0.8529	31.68	14.925	2283.2	58.71212
1785	0.8498	31.09	14.55	2252.4	57.41396
1710	0.8468	30.51	14.179	2221.5	56.0472
1636	0.844	29.93	13.809	2189.9	54.66088
1561	0.8414	29.33	13.432	2157.3	53.22196
1487	0.8392	28.74	13.059	2124.3	51.73974
1413	0.8372	28.14	12.685	2090.6	50.21322
1339	0.8356	27.53	12.306	2055.6	48.63785
1264	0.8345	26.92	11.931	2020.2	46.95394
1190	0.834	26.31	11.555	1984	45.22995
1117	0.8342	25.69	11.178	1946.8	43.47995
1042	0.8354	25.06	10.795	1908	41.58021
968	0.8377	24.44	10.416	1868.8	39.6072
893	0.8416	23.8	10.031	1827.8	37.52101
819	0.8473	23.16	9.651	1786.1	35.36269
745	0.8559	22.52	9.27	1743.3	33.08171

CHTS at Mach .56, at Altitude 6000 Feet

Thrust F	TSFC S	mass flow rate mdot	compressor ratio Pic	Total Temp Tt4	Specific thrust F/mdot
3815	0.9005	45.19	23.993	2819.6	84.42133
3739	0.8971	44.67	23.633	2799.2	83.70271
3663	0.8937	44.16	23.277	2778.9	82.94837

3589	0.8904	43.66	22.929	2758.7	82.20339
3513	0.887	43.14	22.571	2737.9	81.43255
3437	0.8836	42.62	22.209	2716.4	80.64289
3360	0.8801	42.09	21.846	2694.7	79.82894
3284	0.8766	41.56	21.486	2672.9	79.01829
3208	0.8732	41.04	21.126	2650.8	78.16764
3131	0.8696	40.5	20.759	2628.1	77.30864
3055	0.8661	39.97	20.397	2605.4	76.43232
2978	0.8626	39.43	20.034	2582.3	75.52625
2902	0.8591	38.89	19.671	2558.9	74.62073
2826	0.8556	38.35	19.308	2535.2	73.6897
2749	0.852	37.8	18.939	2510.8	72.72487
2673	0.8485	37.25	18.574	2486.3	71.75839
2597	0.845	36.7	18.208	2461.4	70.76294
2521	0.8415	36.15	17.842	2436.1	69.73721
2444	0.8379	35.59	17.471	2410.1	68.67097
2368	0.8344	35.03	17.103	2384	67.5992
2291	0.831	34.47	16.735	2357.4	66.46359
2215	0.8276	33.91	16.367	2330.4	65.31996
2138	0.8242	33.33	15.993	2302.5	64.14641
2062	0.8209	32.76	15.623	2274.4	62.94261
1986	0.8177	32.19	15.252	2245.8	61.69618
1910	0.8145	31.61	14.881	2216.7	60.42392
1833	0.8115	31.02	14.504	2186.6	59.09091
1757	0.8086	30.44	14.131	2156.2	57.72011
1681	0.8059	29.85	13.758	2125.3	56.31491
1604	0.8033	29.25	13.379	2093.2	54.83761
1528	0.801	28.65	13.003	2060.8	53.33333
1452	0.799	28.04	12.627	2027.7	51.78317
1376	0.7974	27.44	12.25	1993.8	50.14577
1299	0.7962	26.82	11.867	1958.6	48.434
1223	0.7955	26.2	11.488	1922.9	46.67939
1147	0.7956	25.58	11.109	1886.3	44.83972
1070	0.7964	24.95	10.723	1848.2	42.88577
994	0.7984	24.31	10.341	1809.5	40.88852
918	0.8017	23.68	9.958	1769.7	38.76689
841	0.8069	23.02	9.569	1728.1	36.53345
765	0.8148	22.38	9.186	1685.9	34.18231

Appendix B

Off Design PW150 & CHTS Test Factor Calculations

1. Developing the required fuel flow rate values requires understanding jet engine fuel (JP-5) properties. Jet fuel JP-5 is considered a safe fuel. This fuel is generally used for military applications and is adaptable for both the PW150 and CHTS engine. JP-5 has a specific fuel consumption of 0.59 pounds/hour/horsepower (lbf/hr/hp), and weighs 6.8 lbs/gallon.

2. Calculation of the test factor Gallons/Hour is derived by utilizing the formula shown below :(Engine Horsepower (hp) x JP-5 lbf/hour/hp)/JP-5 lbf/gallon.
For the PW150 with a maximum hp of 5041, JP-5: .59 lbf/hour/hp, and JP-5 weight is 6.8 lbf/gallon; then gallons/hour = (5041 x .59)/6.8 = 437 gallons/hr.
For the CHTS with a maximum hp of 5933, JP-5: .59 Lbs/hour/hp, and JP-5 weight is 6.8 lbs/gallon; then gallons/hour = (5933 x .59)/6.8 = 514.8 gallons/hr. Note: The gallons/hr values apply to both jet train power cars.

3. The maximum time in hours each engine can obtain, based on gallons/hr and the amount of power car fuel capacity, can be represented as gallons/gallons/hr; thus for the PW150, 2200 gallons/437 gallons/hr = 5.03 hrs, and the CHTS, 2400/514.8 =

approximately 4.7 hrs. These values are based on a test scenario and aren't practical in real world applications. All locomotives have fuel reserve requirements.

4. The jet train with the PW150 engine can obtain a maximum speed of 150 miles per hour (mph). Given an increase in CHTS engine efficiency and horsepower, the jet train should be capable of generating a higher train speed, than 150 mph. Engine design variables such as the PW150 shaft speed in revolutions per minute (rpm), the engine's gearbox torque, and CHTS horsepower, are utilized to determine the percentage increase in train velocity.

5. The equation for finding the torque of a vehicle is depicted as $T = \frac{5252xHP}{N}$, where HP and N represent horsepower and rpm respectively.[13] Given PW150's rpm of 1020 rpm [14], and an off design value of 5041 hp; the gearbox torque is approximately equal to (5252 x 5041)/1020 = 25,956 FT-LBS. Assuming the gearbox torque value remains constant, then CHTS rpm is equal to $N = \frac{5252xHP}{T}$ or

(5252 x 5933)/25956. The CHTS rpm is approximately equal to 1200 rpm. A general rule is a change in engine rpm, is proportional to a change in vehicle velocity; however finding the rpm percentage increase depicts accurate results. Percentage increase in rpm is 1020 +1020x =1200, or (1200-1020)/1020 = x; thus 180/1020 = .176 or 17.6 %

Taking PW150 maximum velocity of 150, then the CHTS velocity = (150 x 0.176) + 150 is equal to 176. 4 mph. Note: Considering the proportional method $\frac{150mph}{x} = \frac{1020rpm}{1200rpm}$

and (150 x 1200)/1020 = 176.4 mph. A more realistic value would be 180 mph, based on practical vehicle speed scales in industry.

Appendix C

MATLAB Code for Performance Testing of PW150 and CHTS Engines

1. Code GASHYBD6611RVN, PW150 and CHTS Performance Testing, without the CHTS SMES Coils.

```
% GASHYBD6611RVN: Developed and written by Mr. Frank R Tennyson
%
% Purpose
% To test, verify and validate the Conceptual Hybrid Turboshaft(CHTS)
% engine performance, against the existing Pratt & Whitney 150 (PW150)
% gas turbine engine design.
%
% The CHS engine incorporates a Superconductivity Magnetic Energy
% Storage (SMS) Coil.
%
% Define the input variables and constants
% Average initial acceleration of high speed trains = .3 meters/sec^2
AIVA = (.3* 3.28); %Average Initial vehicle acceleration for high speed trains
(Feet/second ^2)
%IFC = 2200 (Initial fuel Capacity (gallons) of each power car.Total = 4400,
% for the PW150, or 2400 for the CHTS engine; total = 4800
%Gallons.
IRD = 450; % Initial Route distance to be covered; Denver to Albuquerque.
PWGPS = .1215; %PW150 Fuel Consumption in gallons/second, each power car
CHTSGPS = .143;%CHTS Fuel Consumption in gallons/second, each power car
PW150TMAXS = (18108)/60; % Maximum number of minutes PW150 Power cars can travel
% before fuel exhaustion. (5.03 hrs x 3600) = 18100 seconds
CHTSTMAXS = (15480)/60; % Maximum number of minutes CHTS Power cars can travel
% before fuel exhaustion. (4.30 hrs x 3600) = 15480 seconds
PW150GU = 109.35; % Number of gallons utilized with station stop for
% 15 minutes, for the PW150.
CHTSGU = 128.7; % Number of gallons utilized with station stop for
% 15 minutes, for the CHTS with the SMES coil.
% vf is the maximum speed of the train for this test. normally 150 mph (220
% Feet/sec), for the PW150 engine and 180 mph (264 feet/sec) for the CHTS
```

```
% engine
XI=0; % Initial distance of train in the station
VI=0; % Initial velocity of train in the station
vf = input ('Enter the coefficient vf, which is either 220 for the PW150, or 264 for
the CHTS: ');
TIFV = (vf-VI)/(AIVA); % time it takes to go from initial velocity to final velocity
for starting from the Depot.
FC = input('Fuel capacity for PW150 or CHTS, either 1 for PW150, or 2 for the
CHTS:');
if FC==1
    IFC =4400;% Total Gallons of fuel, for PW150 power cars (2200 gallons/car)
else
    IFC=4800; % Total Gallons of fuel, for CHTS power cars (2200 gallons/car)
end
FCTL = input ('Fuel consumption test loop value;1 for PW150, or 2 for CHTS:');
fprintf(' Gallons utilized,   Gallons left, Trip time,  Velocity  and Miles traveled,
for leg one:\n')
%TL is the time loop.
for TL = 1:2:TIFV;
    vt =VI+(AIVA*TL);
    xt = XI + (vt*TL) + (.5*AIVA*(TL^2));
    MT=(xt/5280); % Number of miles traveled, for PW150, or CHTS.
    if FCTL == 1
    ENGU = (PWGPS*TL);
    else
    ENGU = (CHTSGPS*TL);
    end
    ENGL = (IFC-ENGU);
   fprintf('%f    %f    %f    %f    %f\n', ENGU, ENGL,  TL, vt, MT)
   TL=TL+1;
end
% Determine breaking distance for the PW150 engine from a constant
% velocity of 220 feet/sec to zero.
% Determine breaking distance for the CHTS engine from a constant
% velocity of 264 feet/sec to zero.
% Average Service Braking Distance (SBD) for high speed trains varies.
% Table 14, braking distance data, varies with velocity.
BDV = input ('Enter the Braking distance value; 2.86 for the PW150 and 4.134 for the
CHTS:');
TRDM1=70.8; % Total route distance in miles, from Denver to Colorado Springs
DTDB = TRDM1-(BDV + MT); % Distance traveled between dynamic braking distance plus
% number of miles from initial train acceleration (MT) minus total route distance
(TRDM1)
DTDBF = (DTDB * 5280); % DTDB value in Feet.
% For DTDBF the acceleration = 0, with a const velocity of 220 Feet/sec,or
% 264 feet/sec.
% for leg 2 of this route; D = v*t
CRTL2 = (DTDBF/vt); %Constant route time of leg two in seconds
% Find the number of seconds the train brakes to a stop
ADECL = 1.64; % average deceleration = .5m/sec^2 * 3.28 ft/m = 1.64 Feet/second^2
% kinematic equations (2*a* s) = (v^2-u^2)and a =(v-u)/t
% a= acceleration v = final velocity and u = initial velocity. s = distance
```

```
% traveled. Re-writing 2*((v-u)/t *s =(v^2-u^2)
% t=(2*s * (v-u))/(v^2-u^2)
LEG2 = input('Test Loop, for Gallons and time utilized; 1 for for PW150 and 2 for
CHTS:');
fprintf(' Gallons utilized, Gallons left, Route time, velocity  Distance for leg
two:\n')
for RT2 = 1:30:CRTL2; % Route time for leg 2 in seconds
    if LEG2 == 1
       GLEG2 = (RT2 * PWGPS);
    else
        GLEG2 = (RT2 * CHTSGPS);
    end
     ENGL2 = (ENGL-GLEG2);
     DTR2 = ((vt*RT2)/(5280)); % distance travel in route 2
        fprintf('%f   %f    %f     %f     %f\n', GLEG2, ENGL2, RT2, vt, DTR2)
        RT2=RT2+1;
end
u= vt;
v=VI;
BDV1=(BDV*5280);
TD = ((2* BDV1 * (v-u))/(v^2-u^2)); % Time in seconds for train to decelerate to a
stop
fprintf(' Braking distance in miles,   velocity, second leg time, Braking leg
time:\n\n')
fprintf('%f    %f    %f   %f\n', BDV, u, CRTL2, TD)
TTDENCS = ((TL + CRTL2 + TD)/(60)); % total time from Denver to Colorado Springs.
fprintf(' Total time from Denver to Colorado Springs in minutes = %f\n', TTDENCS)
%fprintf('%f    %f    %f  \n\n', MT, DMTB, SBD)
DT = (BDV + MT + DTDB); % Total distance from Denver to Colorado springs
fprintf(' Total Distance from Denver to Colorado springs in miles = %f\n',DT)
LEG3 = input('Gallons and time utilized Loop in Leg 3; 1 for PW150 and 2 for CHTS:');
fprintf(' Gallons utilized, Gallons left and the route time,,Velocity deceleration,
and miles for leg three:\n')
for RT3 = 1:2:TD; % Route time for leg 3 in seconds
    if LEG3 == 1
       GLEG3 = (RT3 * PWGPS);
    else
        GLEG3 = (RT3 * CHTSGPS);
    end
     ENGL3 = (ENGL2-GLEG3);
     VT3 = ((vt-(1.6*RT3)));
        fprintf('%f   %f    %f    %f    %f\n', GLEG3, ENGL3, RT3, VT3, BDV)
        RT3=RT3+1;
end
%TGUDENCS = total gallons utilized for Denver to Colorado Springs
TGUDENCS=(ENGU + GLEG2 + GLEG3);
fprintf ('Total Gallons utilized, total gallons left: Denver to Colorado Springs:\n')
fprintf('%f    %f\n',TGUDENCS, ENGL3)
% Determine the total gallons of fuel left in both engines, based on fuel
% consumption utilized during the 15 minute station stop in Colorado Springs
PWGU = 109.35; % Number of gallons utilized by the PW150 engine with a 15 minute
% station stop in Colorado Springs.
```

```
CHTSGU = 128.7; % Number of gallons utilized by the CHTS engine with a 15 minute
%stop in Colorado Springs.
TGURDENCS = input ('Loop for determining total gallons utilized/remaining, Den to CS;
1 for PW150, 2 for CHTS:');
if TGURDENCS ==1
    PWTGL = (ENGL3-PWGU); % PW150 Gallons remaining, after Colorado Springs stop
before start
        if PWTGL >=0
        fprintf ('PW150 Gallons remaining, after station stop is = %f\n', PWTGL)
        end
        else
            CHTSGL = (ENGL3-CHTSGU); % CHTS Gallons remaining, after Colorado Springs
stop before start
            if CHTSGL >=0
          fprintf ('CHTS Gallons remaining after station stop is = to %f\n', CHTSGL)
     end
end
TRM2=379.3; % Total route distance from Colorado Springs to Albuquerque.
XIN=70.8; % New Initial start distance of train in the Colorado Springs station
VI=0; %Initial velocity at Colorado Springs station.
REGLOOP = input('Remaining engine gallons Loop, for the PW150 and CHTS; 1 for PW150,
2 for CHTS:');
if REGLOOP == 1
    RENGL = PWTGL;
else RENGL = CHTSGL;
end
vf = input ('Enter the coefficient v; 220 for PW150 or 264 for CHTS: ');
FCTL = input ('Fuel consumption test loop value; 1 for PW150 or 2 for CHTS:');
fprintf(' Gallons utilized,  Gallons left,  Time,  velocity  and Miles traveled, for
leg one:\n')
    for TL = 1:2:TIFV;
    vt =VI+(AIVA*TL);
    xt = XIN + (vt*TL) + (.5*AIVA*(TL^2));
    MT=(xt/5280); % Number of miles traveled, for PW150 velocity ( 0 to 220
feet/sec), or CHTS (0 to 264 feet/sec)
    if FCTL == 1
    ENGU = (PWGPS*TL);
    else
    ENGU = (CHTSGPS*TL);
    end
    ENGL = (RENGL-ENGU);
   fprintf('%f    %f    %f   %f   %f\n', ENGU, ENGL,  TL, vt,  MT)
   TL=TL+1;
end
% Determine breaking distance for the PW150 engine from a constant
% velocity of 220 feet/sec to zero.
% Determine breaking distance for the CHTS engine from a constant
% velocity of 264 feet/sec to zero.
% Average Service Braking Distance (SBD) for high speed trains varies.
% Table 14, braking distance data, varies with velocity.
BDV = input ('Enter the Braking distance value; 2.86 for the PW150 and 4.134 for the
CHTS:');
```

```
TRDM2=379.3; % Total route distance from Denver to Colorado springs
DTDB = TRDM2-(BDV + MT); % Distance traveled between dynamic braking distance plus
% number of miles from initial train acceleration (MT) minus total route distance
(TRM1)
DTDBF = (DTDB * 5280); % DTDBF value in Feet.
% For DTDBF the acceleration = 0, with a const velocity of 220 Feet/sec,or
% 264 feet/sec.
% for leg 2 of this route; D = v*t
CRTL3 = (DTDBF/vt); %Constant route time of leg two in seconds
% Find the number of seconds the train brakes to a stop
ADECL = 1.64; % average deceleration = .5m/sec^2 * 3.28 ft/m = 1.64 Feet/second^2
% kinematic equations (2*a* s) = (v^2-u^2)and a =(v-u)/t
% a= acceleration v = final velocity and u = initial velocity. s = distance
% traveled. Re-writing 2*((v-u)/t *s =(v^2-u^2)
% t=(2*s * (v-u))/(v^2-u^2)
LEG2 = input('Test Loop,for Gallons and time utilized; 1 for for PW150 and 2 for
CHTS:');
fprintf(' Gallons utilized, Gallons left,  route time, velocity,  distance for leg
two:\n')
for RT2 = 1:100:CRTL3; % Route time for leg 2 in seconds
    if LEG2 == 1
       GLEG2 = (RT2 * PWGPS);
    else
        GLEG2 = (RT2 * CHTSGPS);
    end
     ENGL2 = (ENGL-GLEG2);
     DTR2 = ((vt*RT2)/(5280)); % distance travel in route 2
        fprintf('%f   %f    %f     %f     %f\n', GLEG2, ENGL2, RT2, vt, DTR2)
        RT2=RT2+1;
end
FCTL =input('Final ICR time count loop for this specific leg required, 1 for PW150 or
2 for CHTS:');
if RT2<CRTL3
    if FCTL==1
   GLEG2 =(CRTL3*PWGPS);
else
   GLEG2 =(CRTL3*CHTSGPS);
   ENGL2 = (ENGL-GLEG2);
 fprintf('%f   %f    %f\n', GLEG2, ENGL2, CRTL3)
    end
else
end
u= vt;
v=VI;
BDV2=(BDV*5280);
TD = ((2* BDV2 * (v-u))/(v^2-u^2)); % Time in seconds for train to decelerate to a
stop
fprintf(' Braking distance in miles,   velocity, second leg time, Braking leg
time:\n\n')
fprintf('%f    %f    %f   %f\n\n', BDV, u, CRTL3, TD)
TTCSALQ = ((TL + CRTL3 + TD)/(60)); % total time from Colorado Springs to Albuquerque
```

```
fprintf(' total time from Colorado springs to Albuquerque in minutes = %f\n',
TTCSALQ)
%fprintf('%f    %f    %f  \n\n', MT, DMTB, SBD)
DT = (BDV + MT + DTDB); % Total distance from Colorado springs to Albuquerque
fprintf(' Total Distance from Colorado springs to Albuquerque in miles = %f\n',DT)
LEG3 = input('Gallons and time utilized Loop in Leg 3; 1 for PW150 and 2 for CHTS:');
fprintf(' Gallons utilized, Gallons left, Route time, Velocity,  Braking distance for
leg three:\n')
for RT3 = 1:2:TD; % Route time for leg 3 in seconds
    if LEG3 == 1
       GLEG3 = (RT3 * PWGPS);
    else
        GLEG3 = (RT3 * CHTSGPS);
    end
     ENGL3 = (ENGL2-GLEG3);
     VT3 = ((vt-(1.6*RT3)));
        fprintf('%f   %f    %f    %f    %f\n', GLEG3, ENGL3, RT3, VT3, BDV)
        RT3=RT3+1;
end
%TGUCSALQ = total gallons utilized for Colorado Springs to Albuquerque
TGUCSALQ=(ENGU + GLEG2 + GLEG3);
fprintf ('Total Gallons utilized, total gallons left: Colorado Springs to
Albuquerque:\n')
fprintf('%f    %f\n',TGUCSALQ,  ENGL3)
TRT = ((2*TIFV)+ (CRTL2+ CRTL3)+(2*TD)+(900)); % Total route time including station
stop of 900 seconds.
fprintf('Total route time from Denver to Albuquerque = %f\n', TRT)
TGRT = input ('final total gallons utilized from Denver to Albuquerque, 1 for PW150
and 2 for CHTS:');
if TGRT == 1
TGALU = ((TGUDENCS +TGUCSALQ)+ 109.35);
else
  TGALU = ((TGUDENCS +TGUCSALQ)+ 128.7);
end
fprintf('Total gallons utilized from Denver to Albuquerque = %f\n', TGALU)
TGALF = ((IFC-TGALU)); % Total Fuel left for both engines.
fprintf('Total fuel left for both engines from Denver to Albuquerque = %f\n', TGALF)
```

2. Code GASHYBD7CHTS7711RVN, CHTS Performance Testing, with SMES Coils

```
% GASHYBD7CHTS7711RVN, was developed and written, by Mr. Frank R Tennyson
%
% Purpose
% To test, verify and validate the Conceptual Hybrid Turboshaft(CHTS)
% engine performance, with the Superconductivity Magnetic Energy Storage Coil.
%
% The CHS engine incorporates a Superconductivity Magnetic Energy
% Storage (SMS) Coil (SMES)
%
% Define the input variables and constants
% Average initial acceleration of high speed trains = .3 meters/sec^2
AIVA = (.3* 3.28); %Average Initial vehicle acceleration for high speed trains
(Feet/second ^2)
%IFC = 2400 Initial fuel Capacity (gallons) of each power car; total 4800
%Gallons
IRD = 450; % Initial Route distance to be covered
CHTSGPS = .143;%CHTS Fuel Consumption in gallons/second, each power car
CHTSGPS1 = .0784; % CHTS fuel consumption based on SMES coil (2680 HPx.59/6.8) = .065
gallons/sec minus
%the HP of the CHTS engine which is 5933 and (5933x.59/6.8 = .143
%gallons/sec
CHTSTMAXS = (15480)/60; % Maximum number of minutes CHTS Power cars can travel
% before fuel exhaustion. (4.30 hrs. x 3600) = 15480 seconds
CHTSTMAXS1 = (22516)/60; % Maximum number of minutes CHTS Power cars can travel
%based on smes coil assistance. CHTSMAXS1 value increased by 45.5% This
%equates to (22516/3600) = 6.25 hours
CHTSGU = 128.7; % Number of gallons utilized with station stop for % 15 minutes
% vf is the maximum speed of the train for this test. normally 180 mph (264
% Feet/sec), for the CHTS engine
XI=0; % Initial distance of train in the station
VI=0; % Initial velocity of train in the station
vf = input ('Enter the coefficient vf, 264:');
TIFV = (vf-VI)/(AIVA); % time it takes to go from initial velocity to final velocity
for starting from the Depot.
IFC = 4800; % Total Gallons of fuel, for both power cars (2400 gallons/car)
FCTL = input ('Fuel consumption test loop value, which is 1:');
fprintf(' Gallons utilized, Gallons left  time, velocity and Miles traveled, for leg
one:\n')
for TL = 1:2:TIFV;
    vt =VI+(AIVA*TL);
    xt = XI + (vt*TL) + (.5*AIVA*(TL^2));
    MT=(xt/5280); % Number of miles traveled, for CHTS velocity, (0 to 264 feet/sec)
    if FCTL == 1
     ENGU = (CHTSGPS1*TL);
    else
    end
    ENGL = (IFC-ENGU);
    fprintf('%f    %f    %f    %f    %f\n', ENGU, ENGL, TL,  vt,  MT)
    TL=TL+1;
```

```
end
% Determine breaking distance for the CHTS engine from a constant
% velocity of 264 feet/sec to zero.
% Average Service Braking Distance (SBD) for high speed trains varies.
% Table 14, braking distance data, varies with velocity.
BDV = input ('Enter the Braking distance value, which is 4.134:');
TRM1=70.8; % Total route distance from Denver to Colorado springs
DTDB = TRM1-(BDV + MT); % Distance traveled between dynamic braking distance plus
% number of miles from initial train acceleration (MT) minus total route distance
(TRM1)
DTDBF = (DTDB * 5280); % DTDBF value in Feet.
% For DTDBF the acceleration = 0, with a const velocity of 264 Feet/sec
% for leg 2 of this route; D = v*t
CRT = (DTDBF/vt); %Constant route time of leg two in seconds
% Find the number of seconds the train brakes to a stop
ADECL = 1.64; % average deceleration = .5m/sec^2 * 3.28 ft/m = 1.64 Feet/second^2
% kinematic equations (2*a* s) = (v^2-u^2)and a =(v-u)/t
% a= acceleration v = final velocity and u = initial velocity. s = distance
% traveled. Re-writing 2*((v-u)/t *s =(v^2-u^2)
% t=(2*s * (v-u))/(v^2-u^2)
LEG2 = input('Test Loop for Gallons and time utilized in Leg 2, use 1:');
fprintf(' Gallons utilized, Gallons left and the route time for leg two:\n')
for RT2 = 1:30:CRT; % Route time for leg 2 in seconds
    if LEG2 == 1
       GLEG2 = (RT2 * CHTSGPS1);
    else
 end
     ENGL2 = (ENGL-GLEG2);
     DTR = ((vt*RT2)/(5280)); % distance travel in route 2
        fprintf('%f   %f    %f     %f     %f\n', GLEG2, ENGL2, RT2, vt, DTR)
        RT2=RT2+1;
   end
u= vt;
v=VI;
BDV1=(BDV*5280);
TD = ((2* BDV1 * (v-u))/(v^2-u^2)); % Time in seconds for train to decelerate to a
stop
fprintf(' Braking distance in miles,   velocity, second leg time, Braking leg
time:\n\n')
fprintf('%f    %f    %f   %f\n', BDV, u, CRT, TD)
TTDENCS = ((TL + CRT +TD)/(60)); % total time from Denver to Colorado springs
fprintf(' total time from denver to Colorado springs in minutes = %f\n', TTDENCS)
DT = (BDV + MT + DTDB); % Total distance from Denver to Colorado springs
fprintf(' Total Distance from Denver to Colorado springs in miles = %f\n',DT)
LEG3 = input('Gallons and time Loop utilized in Leg 3, use 1:');
fprintf(' Gallons utilized, Gallons left and the route time, Velocity, acceleration
and miles for leg three:\n')
for RT3 = 1:2:TD; % Route time for leg 3 in seconds
    if LEG3 == 1
       GLEG3 = (RT3 * CHTSGPS);
    else
  end
```

```
     ENGL3 = (ENGL2-GLEG3);
     VT3 = ((vt-(1.6*RT3)));
        fprintf('%f   %f    %f    %f    %f\n', GLEG3, ENGL3, RT3, VT3, BDV)
        RT3=RT3+1;
end
%TGUL is the Total Gallons utilized and left
% The first and second legs of the route have a gallons/sec of .078 and
% since the SMES coil isn't discharging and recharging during the braking
% distance; than the gallons/sec utilized reverts back to .143 gallons/sec,
% during the braking distance.
%TGU =Total Gallons utilized for the complete Denver to Colorado Springs Trip
TGUDENCS =(ENGU + GLEG2 + GLEG3);
fprintf ('Total Gallons utilized, total gallons left: Denver to Colorado Springs:\n')
fprintf('%f    %f\n\n',TGUDENCS,  ENGL3)
% Determine the total gallons of fuel left in the CHTS based on fuel
% consumption utilized during the 15 minute station stop in Colorado Springs
CHTSGU = 128.7; % Number of gallons utilized by the CHTS engine with a 15 minute
%stop in Colorado Springs.
TGLCS = input ('Total Gallons Remaining after Colorado Springs Station Stop,use 1:');
if TGLCS ==1
     CHTSGL = (ENGL3-CHTSGU); % CHTS Gallons remaining, after Colorado Springs stop
before start
        fprintf ('CHTS Gallons remaining is = to %f\n', CHTSGL)
   else
end
%
TRM2=379.3; % Total route distance from Colorado Springs to Albuquerque.
XIN=70.8; % New Initial start distance of train in the Colorado Springs station
VI=0; %Initial velocity at Colorado Springs station.
RENGL = CHTSGL;
vf = input ('Enter the coefficient vf, which is 264: ');
TIFV = (vf-VI)/(AIVA); % time it takes to go from initial velocity to final velocity
for starting ffom the Depot.
FCTL = input ('Fuel consumption test loop value,1:');
fprintf(' Gallons utilized, Gallons left  time velocity and Miles traveled, for leg
one:\n')
    for TL = 1:2:TIFV;
    vt =VI+(AIVA*TL);
    xt = XIN + (vt*TL) + (.5*AIVA*(TL^2));
    MT=(xt/5280); % Number of miles traveled, for CHTS (0 to 264 feet/sec)
    if FCTL == 1
    ENGU = (CHTSGPS1*TL);
    else
    end
    ENGL = (RENGL-ENGU);
    fprintf('%f    %f    %f    %f     %f\n', ENGU, ENGL, TL, vt,  MT)
    TL=TL+1;
end
% Determine breaking distance for the CHTS engine from a constant
% velocity of 264 feet/sec to zero.
% Average Service Braking Distance (SBD) for high speed trains varies.
% Table 14, braking distance data, varies with velocity.
```

```
BDV = input ('Enter the Braking distance value, which is 4.134:');
TRM2=379.3; % Total route distance from Denver to Colorado springs
DTDB = TRM2-(BDV + MT); % Distance traveled between dynamic braking distance plus
% number of miles from initial train acceleration (MT) minus total route distance
(TRM1)
DTDBF = (DTDB * 5280); % DTDBF value in Feet.
% For DBTDF the acceleration = 0, with a const velocity of 264 Feet/sec
% for leg 2 of this route; D = v*t
CRT2 = (DTDBF/vt); %Constant route time of leg two in seconds
% Find the number of seconds the train brakes to a stop
ADECL = 1.64; % average deceleration = .5m/sec^2 * 3.28 ft/m = 1.64 Feet/second^2
% kinematic equations (2*a* s) = (v^2-u^2)and a =(v-u)/t
% a= acceleration v = final velocity and u = intial velocity. s = distance
% traveled. Re-writing 2*((v-u)/t *s =(v^2-u^2)
% t=(2*s * (v-u))/(v^2-u^2)
LEG2 = input(' Test Loop Gallons time utilized in Leg 2, use 1:');
fprintf(' Gallons utilized, Gallons left and the route time for leg two:\n')
for RT2 = 1:100:CRT2; % Route time for leg 2 in seconds
    if LEG2 == 1
      GLEG2 = (RT2 * CHTSGPS1);
    else
 end
     ENGL2 = (ENGL-GLEG2);
     DTR = ((vt*RT2)/(5280)); % distance travel in route 2
        fprintf('%f    %f    %f     %f     %f\n', GLEG2, ENGL2, RT2, vt, DTR)
        RT2=RT2+1;
end
FCTL = input('The final timce count for this leg two, us 1:')
if FCTL ==1
    if RT2<CRT2
        GLEG2 = (CRT2*CHTSGPS1);
        ENGL2=(ENGL-GLEG2);
       fprintf('%f   %f    %f\n', GLEG2, ENGL2, CRT2)
    end
else
end
u= vt;
v=VI;
BDV1=(BDV*5280);
TD = ((2* BDV1 * (v-u))/(v^2-u^2)); % Time in seconds for train to decelerate to a
stop
fprintf(' Braking distance in miles,   velocity, second leg time, Braking leg
time:\n\n')
fprintf('%f    %f    %f   %f\n', BDV, u, CRT2, TD)
TTCSALQ = ((TL + CRT2 +TD)/(60)); % total time from Colorado Springs to Albuquerque
fprintf(' total time from Colorado springs to Albuquerque in minutes = %f\n',
TTCSALQ)
DT = (BDV + MT + DTDB); % Total distance from Colorado springs to Albuquerque
fprintf(' Total Distance from Colorado springs to Albuquerque in miles = %f\n',DT)
LEG3 = input('Loop for Gallons and time utilized in Leg 3, use 1:');
fprintf(' Gallons utilized, Gallons left and the route time for leg three:\n')
for RT3 = 1:2:TD; % Route time for leg 3 in seconds
```

```
    if LEG3 == 1
       GLEG3 = (RT3 * CHTSGPS);
    else
  end
     ENGL3 = (ENGL2-GLEG3);
     VT3 = ((vt-(1.6*RT3)));
        fprintf('%f   %f    %f    %f    %f\n', GLEG3, ENGL3, RT3, VT3, BDV)
        RT3=RT3+1;
end
%TTCSALQ = total gallons utilized for Denver to Colorado Springs
TTCSALQ=(ENGU + GLEG2 + GLEG3);
fprintf ('Total Gallons utilized, total gallons left: Colorado Springs to
Albuquerque:\n')
fprintf('%f    %f\n\n',TTCSALQ,  ENGL3)
TRT = ((2*TIFV)+ (CRT + CRT2)+(2*TD)+(900)); % Total route time including station
stop of 900 seconds.
fprintf('Total route time from Denver to Albuquerque = %f\n', TRT)
TGALU = ((TTDENCS +TTCSALQ)+ 128.7);
fprintf('Total gallons utilized from Denver to Albuquerque = %f\n', TGALU)
TGALF = ((4800-TGALU)); % Total Fuel left for both engines.
fprintf('Total fuel left for both engines from Denver to Albuquerque = %f\n', TGALF)
```

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BIOGRAPHICAL INFORMATION

Frank R. Tennyson received his Bachelor of Science Degree in Mechanical Engineering (74), from the California State University at Los Angeles; Post Graduate studies in Aeronautical Engineering and advanced engineering mathematics, from the Naval Postgraduate School‘s independent studies for military reserve officers.
Mr. Tennyson has over 30 plus years of engineering experience (Civilian and military). His military career includes over 31 years (Ten years enlisted and twenty-one years as an officer), in the United States Air Force (USAF), Air National Guard (ANG), and the USAF Reserves. Employment history includes,(1) Space Shuttle Program, (2) USAF Flight Test, (3) Department of the Navy,(4), B-1 Bomber program, (4) Los Alamos National Laboratories, (5), Lockheed Martin, and Northrop Grumman. Frank enjoys flying (Private Pilot), Model Railroading, Swimming, and Tai-Chi.