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A Generic Turboprop Engine Model

Rajkumar Pant

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Rajkumar Pant*

Abstract

This report describes GENENG, a code developed to model the performance of a generic turboprop engine. Using published data from various sources, a database of 7 turboprop engines suitable for General Aviation, Commuter & Regional transport aircraft was developed. This database consists of the values of the SHP available, Fuel-flow, and Jet Thrust produced by the engines at specific altitudes between sea-level & 35000 ft and forward speeds between 0 & 350 knots (TAS), at max. take-off, max. Climb & max. Cruise ratings. GENENG can then be used to obtain realistic estimates of any of these three parameters for a generic engine that lies within this database at any operating condition, i.e. altitude, forward speed, and engine rating. The user has to specify the ball-parking criterion, i.e. the desired value of any one of the three parameters at a specific operating condition. The generic engine is then positioned in the database, by identifying the nearest two engines at the ball-parking criterion. The fractional ratio of the location of the generic engine from these two engines is then calculated. Assuming that the same fractional ratio would also apply at all the other data points, the values of all the parameters at all engine ratings are then generated at specific combinations of forward speed and altitude. Using Bicubic Spline interpolation routines, the the value of any of the three parameters at any forward velocity and altitude can then be obtained.

*Doctoral Student, Department of Aerospace Technology, College of Aeronautics, Cranfield University, Cranfield, Bedfordshire, MK43 0AL

1 Introduction

Since General Aviation, Commuter & Regional transport aircraft are usually employed over short stages (100-500 nm), a considerably large fraction of their mission consists of the climb and descent phases. Accurate estimates of the shaft horsepower available, fuel-flow and the thrust developed due to the jet exhaust at a specific operating condition (i.e. altitude, forward speed & engine rating) are required for determination of the fuel consumed, horizontal distance travelled and the time spent during all phases of the mission.
Although some *rules-of-thumb* are available for estimating these quantities for an engine whose baseline performance is known, these can be very vague and inaccurate. Further, it is often necessary to size the the engine to meet a specific condition (for example the second stage climb gradient at a particular altitude, speed and engine rating). The values of SHP available, Fuel-flow and the jet thrust developed at other operating conditions are then required for performance estimation.
This report outlines the generic turboprop engine model GENENG developed to meet this need. To avoid repetition, the words *three parameters* in the remainder of this report refer to SHP available (HP), Fuel-flow (lb/hr), and the Jet Thrust produced (lb). Similarly, the words *three ratings* refer to max. take-off, max. climb & max. cruise ratings, and the words *operating conditions* refer to the altitude, forward speed, & engine rating.

2 Engines in the current Database

The model is based on published data of existing turboprop engines from various sources. At present, there are 7 engines in the database, for which the available sea-level static SHP ranges from 550 to 2000 HP, at max. take-off rating. These engines are :-

- PT6A-25 from Pratt & Whitney Canada Inc.
- PT6A-27 from Pratt & Whitney Canada Inc.
- PT6A-41 from Pratt & Whitney Canada Inc.
- TPE-331-15 from Allied Signal Garrett Engines.
- T5321A from Avco Lycoming.
- PW-120 from Pratt & Whitney Canada Inc.
- RTM-322-06 from Rolls Royce PLC.

3 Conversion of data to a uniform format

Because the information was obtained from various sources, there was no uniformity in the way it was reported. For five of these engines, the equivalent power due to the jet thrust at sea-level static conditions, and the curves for SHP available and Fuel-flow at the three ratings at a few altitudes were available. For the remaining two (T5321A & RTM-322-06) the values of the three parameters were listed in tabular form for various altitudes and TAS. In the case of RTM-322-06, the data was listed at steps of increasing Mach Number, rather than TAS. To begin with, it was essential to generate data for all engines at the same altitude and speed conditions. This was done by plotting the points for all the engines using the altitudes and TAS conditions at which data were provided, and then extrapolating and interpolating to fill the gaps in data. The trend of variation of the parameters was such that simple interpolation and curve fitting techniques were not considered suitable. Hence, bicubic spline interpolation routines listed in Ref.[1] were used. These routines were found to be very robust and powerful, hence they were used wherever a need for interpolation & extrapolation arose. A brief description of these routines is provided in the Appendix.

4 Description of data available for each engine

4.1 PT6A-25

This is, at present, the smallest engine in the database. It is one of the many versions of the very successful PT6A free turbine series developed by Pratt & Whitney Canada Inc. for the General Aviation and Commuter aircraft, and has been used on *Beechcraft T-34C*, *Pilatus PC-7*, and *NAC Firecracker* aircraft. The curves for variation of SHP and Fuel-flow with TAS between 80 knots and 260 knots at altitudes between sea-level and 35000 ft (at every 5000 ft interval) were obtained from an unpublished report by Hunting Engineering Corporation. In the absence of any detailed information, these curves were assumed to apply at all the three ratings, except for SHP at max. take-off rating, which was assumed to be flat rated at 550 SHP (580 ESHP) to 33^o C at sea-level, as reported in Ref. [2]. In continuation with the trend of the curves, data for an TAS of 350 knots and static condition (0 knots) were extrapolated at all altitudes. The data-points at intermediate altitudes and forward speeds were then interpolated. This data was then used to obtain the curves for all operating conditions. The resulting SHP and Fuel-flow variations at all ratings are shown in Fig. 1, with the data points obtained from the report superimposed. The efficacy of bicubic spline interpolation routines in faithfully following the trend of variation is clearly established.

4.2 PT6A-27

The specifications and un-installed performance data for this engine were obtained from Ref. [3]. It has been installed on *Beech 99A*, *de Havilland Twin Otter*, and *Pilatus Turbo Porter* aircraft. It is flat rated at max. take-off rating at 680 SHP (715 ESHP) at sea-level static conditions to 21^o C. Thereafter, the SHP decreases linearly, and the curves for this variation at 1000 ft altitude intervals above sea-level till 6000 ft are cited in Ref. [3]. Curves for variation of SHP available and Fuel-flow with TAS (between 0 & 300 knots) at a few altitudes (between Sea-level & 30000 ft) at max.

cruise and max. climb ratings were also available. Using these data-points, the interpolated variation obtained (with the data points from Ref. [3] superimposed) is shown in Fig 2.

4.3 PT6A-41

The un-installed performance data for this engine was obtained from Ref.[4]. The variation of take-off SHP with the ambient temperature (between 50^o F and 110^o F) at static conditions was available in graphical form at sea-level and 5000 ft. At sea-level, it was seen that this engine is flat rated to 850 HP till 104^o F, after which SHP linearly decreases to 830 HP at 110^o F. At 5000 ft, however, the reduction in SHP starts at 84^o F itself, and it falls to 755 HP at 110^o F.
For the max. cruise conditions, curves for the variation of the SHP available and Fuel-flow with TAS at a few altitudes between sea-level and 30000 ft. were also available. The ESHP at sea level static conditions at the three ratings was also listed. The engine behaviour at max. climb and Max. cruise ratings was assumed to be identical in the absence of detailed data, and due to the fact that the sea-level static ESHP (& SHP) at these two conditions was given to be identical. Further, the Fuel-flow at all the three ratings was assumed to be same as that for the max. cruise rating, for which the data was available. Fig. 3 shows the the curves for SHP available & Fuel-flow for max. climb & max. cruise ratings for this engine, with the data-points obtained from Ref. [4] superimposed.

4.4 TPE-331-15

Certified in April 1984 and produced by Garrett Aircraft Engine Company, this modern engine is quite suitable for small commuter aircraft such as *Jetstream Super 31*, *Fairchild Metro 23*, and *Piper Cheyenne 400*. The un-installed performance data of this engine was also obtained from Ref.[4]. At sea-level static conditions and max. take-off rating, it is flat rated at 1645 SHP to ISA conditions, after which SHP reduces linearly to 1180 HP at 50^o C. Curves for the SHP available and Fuel-flow at max. cruise condition were available at 10000 ft and then at every 10000 ft interval till 30000 ft. Due to absence of relevant data, it was assumed that the same variation would be applicable at max. cruise rating also. As for the other engines, the relevant data points were extrapolated and interpolated to generate the data at other altitude and TAS conditions between sea-level and 35000 ft and 0 to 350 knots. The variation of SHP available and Fuel-flow so obtained and the corresponding data points from Ref. [4] are shown in Fig. 4.

4.5 T5321A

The data for this engine from Avco Lycoming was available in tabular form in Ref. [5]. This was the only engine that was not flat rated, and variation of the three parameters & ESHP with TAS for altitudes ranging from sea-level to 25000 ft (in steps of 5000 ft) and TAS ranging from 0 to 300 knots (in steps of 100 knots) was available for the three ratings. However, no data were available on the variation of SHP available with ambient temperature at max. take-off rating, hence it was assumed that it remains invariant with ambient temperature at the sea-level static value of 1800 SHP. Fig. 5 shows the variation of SHP available and Fuel-flow at max. cruise rating, with the corresponding data points from Ref. [5] superimposed.

4.6 PW-120

The PW120 engine manufactured by Pratt & Whitney Canada is representative of the latest technology for turboprop engines of its size, and was certificated in 1983. It is a member of the PW-100 engine series, many of which have been used for present day commuter and regional aircraft such as *Embraer EMB-120*, *Dornier Do-328*, *ATR-42* & *de Havilland Dash-8* series aircraft. The performance specifications and data for this engine was obtained from Ref. [6]. At max. take-off condition at sea-level, the engine is flat rated to 2000 SHP to 21^o C after which the SHP reduces linearly to 1000 HP at 45^o C. Similar curves for the max. take-off power and fuel consumption were provided at every 1000 ft altitude above sea-level till 6000 ft.
Curves for SHP and Fuel-flow at max. climb rating were provided only upto 10000 ft, at every

2000 ft from sea-level. Extrapolation of these curves to 35000 ft lead to very erroneous results, as can be expected, so another method had to be employed. Ref. [7] lists an algorithm for obtaining the three parameters for this engine in terms of non-linear functions of altitude, speed & ambient temperature, based on data supplied by the engine manufacturer. But the values of the SHP available & Fuel-flow so obtained do not match very well with the curves reported in Ref. [6]. This mismatch is quite clear in Fig. 6 for SHP and Fuel-flow, respectively, at max. climb rating, and might be due to the fact they correspond to two different versions of the same engine. The version reported in Ref. [6] appears to be flat rated at sea-level, while the one reported in Ref. [7] is not.

However, a close inspection of the above figures reveal that the trend of variation of these parameters is very much similar, especially at higher altitudes. Hence, in the absence of detailed information, it was decided to obtain the variation for max. cruise rating till 10000 ft using the data reported in Ref. [6], and to continue with the trends reported in Ref. [7] for altitudes between 10000 ft & 35000 ft. The resulting variation of SHP and Fuel-flow are shown in Fig 7, with the data points from Ref. [6] superimposed.

As far as the max. cruise rating was concerned, the curves were available in Ref. [6] for altitudes between 5000 ft and 30000 ft, at every 5000 ft interval, and the curves for sea-level and 35000 ft were extrapolated.

4.7 RTM-322-06

This is a turboshaft engine developed essentially for helicopter applications by Rolls-Royce PLC, but it can also be used for regional turboprop aircraft as well. The data points for the three parameters at altitudes between sea-level and 30000 ft (in steps of 10000 ft) were provided in a tabular format against increasing values of Mach Number in Ref. [8]. The effect of ambient temperature on the max. take-off rating was also provided at sea-level conditions; it was seen that this engine also is flat rated to 2000 HP to 25^o C, after which it decreases linearly to 1597 HP at 45^o C. Fig. 8 shows the interpolated variation of SHP available and Fuel-flow for this engine at max. climb rating, with the data-points from Ref. [8] superimposed.

5 Variation of jet thrust

While the data for the variation of SHP and Fuel-flow were explicitly provided for all the engines in various references as outlined above, only for two of the seven engines, there was some data on the variation of Jet thrust produced with forward speed and altitude. Perhaps this is due to the fact that the equivalent power due to the jet thrust tends to be only about 3 to 7 % of the SHP at all conditions, hence it is neglected in most cases. For all the engines, however, the ESHP at Sea-level static conditions was mentioned in the relevant references and in Ref. [2]. For T5321A & RTM-322-06, the value of jet thrust at various forward speeds and altitudes were provided in a tabular form in Ref. [5] and Ref. [8], respectively.

In Ref. [7], formulae for jet thrust variation with SHP available, altitude and forward speed for PW-120 & CT7-5A2 engine (developed by General Electric Corporation) were provided, based on the data supplied by the engine manufacturers. Using these formulae, the jet thrust variation obtained for these two engines at max. take-off and max. climb ratings is shown in Fig. 9.

This figure shows that the jet thrust reduces linearly with forward speed, with decreasing slope as altitude increases. At higher speeds, in many cases, the value of jet thrust produced is negative, perhaps because the forward speed exceeds the jet exhaust velocity. Further, at a given engine rating, there appears to be a forward speed at which the jet thrust is almost the same at all altitudes. This might be the design operating speed for the engine at that rating.

The jet thrust produced at Sea-level static condition at max. take-off rating by all the engines could be obtained, since the SHP and ESHP for this condition were available in the relevant references and also in Ref. [2]. It was decided to generate the variation of jet thrust produced for all the using the sea-level static jet thrust value, superimposing the trends from formulae listed for the appropriate engines in Ref. [7] and other sources. For e.g., the curves for the three PT6A series engines and TPE-331-15 were obtained using the trends for PT6A-67 engine obtained from the principal author of Ref. [7], since they are all the engines of the same family or similar power output. The jet thrust variation so obtained for RTM-322-06 & T5321A engines are shown in Fig. 10, with the data-points from Ref. [5] & [8] superimposed. Reasonably good co-relation is seen, except for a few points for RTM-322-06 engine.

6 Compilation of the Database

The data related to variation of the three parameters at the three ratings for all the engines described above was compiled together, resulting in a uniform database, consisting of the values of these parameters at altitudes between Sea-level & 35000 ft (at every 5000 ft) & forward speed from 0 to 350 knots TAS (at every 50 knots). This database was then used to obtain the characteristics of a generic engine at any operating condition. A part of this database, viz. variation of these parameters for all engines at max. climb rating is shown in Fig. 11, 12, 13 & 14. For ease in comparison, the ordinate and the abscissae have been kept the same in all these figures.

7 Methodology for ball-parking the Generic Engine

As outlined above, the main aim of this model was to obtain the three parameters for a generic engine that lies within the confines of the smallest and the largest engine of the database, at any of the three ratings and at any forward speed (between 0 and 350 knots TAS) and altitude (between sea-level & 35000 ft). The generic engine is assumed to be sized to meet a user specified requirement, i.e. it is required to have a specific value for any one of the three parameters at a specific operating condition. In the description that follows, SHP available is used as the parameter for ball-parking the engine, but it could well be Fuel-flow or jet thrust developed, if so desired. To *ball-park* the required generic engine, it was necessary to bracket it by identifying the two engines in the database within which this engine was positioned for the given altitude and forward speed and the engine condition. The next step was to determined the *ball-parking fraction* using the formula :-

$$\mathcal{F} = \frac{SHP_{req} - SHP_1}{SHP_2 - SHP_1} \qquad (1)$$

Where SHP_{req} represents the desired SHP for the ball-parked engine at the specified rating, forward speed and altitude, & SHP_1 and SHP_2 are the SHP for the two engines just below and above the generic engine in the database at the same operating condition. Using the value of $\mathcal{F}$ from Eqn.1, the three parameters at all the three ratings for this generic engine were generated. The values of any of the three parameters at any of the three ratings at any operating condition can then be obtained, by interpolating within the data points in the database. The implicit assumption in the above ball-parking methodology is that the generic engine is considered to lie at the same fractional location in the database for all parameters at all conditions. This methodology also ensures that if the generic engine happens to be very much similar or near any of the engines in the database, then the resulting variation of parameters would very closely match the variation for that engine. As a test of the above ball-parking methodology and the efficacy of the bicubic spline interpolation techniques, a few generic engines so obtained are described below.

8 Some typical generic engines

8.1 Ball-parking at Max. Climb rating

Let us assume that a generic engine is required that develops SHP of 245 HP at max. climb rating at an altitude of 30000 ft and forward speed of 50 knots. This condition could result from a constraint imposed on the climb gradient of the aircraft at this altitude and forward speed combination, and is labelled as *Design Point* in Fig. 15. A look at the database revealed that this requirement would be met by an engine roughly halfway between PT6A-25 & PT6A-27 engines, with $\mathcal{F} = 0.48418$. The next step was then to obtain the SHP variation of this generic engine at all altitudes between sea-level and 35000 ft, in steps of 5000 ft, and forward speeds between 0 and 350 knots, so that the three parameters could then be estimated at any operating condition. Using the bicubic spline interpolation routines, the SHP available for the generic engine was calculated at every 25 knots speed increment (between the range of 0 - 350 knots) at altitudes of 25000 ft, 30000 ft & 35000 ft. This variation, along with the variation of SHP available for PT6A-25 & PT6A-27 engine for the corresponding altitude is shown in Fig. 15. It can be seen that the variation for the generic engine is roughly halfway between the corresponding variation for the two engines between which it lies, as desired. A few points representing the variation of SHP available for the generic engine at 29000 ft & 31000 ft are also plotted on Fig. 15, and they are seen to follow the trend quite faithfully.

8.2 Ball-parking at Max. Cruise rating

Another ball-parking criterion could be to ensure that the performance requirement of a specific cruising speed at a specific altitude is met. This requirement could result, for example, in the need for a generic engine that develops 740 SHP at an altitude of 35000 ft and forward speed of 300 knots. In the present database, such an engine would be positioned between PW-120 and RTM-322-06 engines, with $\mathcal{F} = 0.28563$. Fig. 16 shows the SHP variation for these two engines and the generic engine sized to meet this requirement (labelled as *Design Point*). This figure also reveals the robust nature of the ball-parking methodology, since even at those conditions at which PW-120 is seen to develop higher power than RTM-322-06 engine (i.e. the trends are reversed), the ball-parked engine follows the correct trend between the two. The SHP variation of the generic engine at 32500 ft altitude has also been superimposed on this figure, which is seen to follow the trends observed at other altitudes.

8.3 Ball-parking at Max. take-off rating

Finally, let us look at perhaps the the most commonly applicable ball-parking criterion, i.e., to obtain a generic engine developing a specific horsepower at sea-level static conditions at max. take-off rating. As an example, consider a requirement for an engine developing 1600 HP at these conditions. This engine was found to be in between the flat rated TPE-331-15 & T5321A (which is not flat rated), with $\mathcal{F} = 0.44444$. As can be seen in Fig. 17, the generic engine follows the trend between the two engines correctly. The interpolated SHP values at a few altitudes between Sea-level and 10000 ft for the generic engine are also superimposed in this figure, and they are seen to follow the expected trend.

9 Limitations & recommendations for further work

The accuracy of the results obtained from GENENG naturally depends on the accuracy of the database which it uses. In the absence of detailed data, assumptions were made for some of the engines regarding applicability of the data for engine ratings other than the one for which it was provided, which could lead to erroneous results if these assumptions were unsubstantiated. A large gap exists in the database between PT6A-41 engine (with a sea-level static SHP available at max. take-off rating of 850 HP) and the next engine in the current database, i.e. TPE-331-15 (with a sea-level static SHP available at max. take-off rating of 1440 HP). The above limitations can be reduced by adding reliable data for more engines in the database. In the absence of any more data, it may be better to divide the database in two parts; the lower half that contains the data for the three engines of the PT6A series, and the upper half consisting of the remaining 4 engines.

Doubts may be expressed about the validity of interpolating in a database containing data of engines of different technological level, designed with different applications in mind, and of differing types (some flat-rated, others not). But it

is felt that at least the parameter variations obtained by this method would be far more accurate than the ones obtained by *rules-of-thumb*, since the database consists of data related to real life engines.
A different methodology might be adopted for ball-parking the engine; for instance, the behaviour of all the engines at the ball-parking condition may be used for locating the generic engine in the database, (rather than just the two engines immediately above & below the generic engine, as in the present case). However, one of the positive points of the present ball-parking methodology is that if one of the engines in the database exactly (or very nearly) meets the ball-parking criterion, then the parameter variations predicted would also be exactly matching with (or very near to) that engine. Only when reliable data for several other turboprop engines is made available can one comment on which ball-parking methodology would lead to overall better results.

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A Description of the GENENG code

A.1 Main program & Subroutines

The GENENG code consists of the main program, 6 subroutines and 9 data files. [1] A brief description of the main program & the subroutines follow.

1. Main Program GENENG
   A few commented lines in the beginning of the main program describe the various input and output parameters of the code. The grid of altitudes & forward speeds (at which the data for all engines in the database is available) is then initialized. A few other parameters related to the database are specified, and the subroutine BPARK is called, which ball-parks the generic engine in the database, based on the ball-parking criterion. Finally, subroutine GENDAT is called to calculate the value of any parameter at any specific operating condition.

2. Subroutine BPARK
   Using the ball-parking criterion, this subroutine determines the rank of the engines in the database that are just below & above the generic engine, if they are ranked in the ascending order of the SHP available at Sea-level static condition, at max. takeoff rating. It also determines the fractional location of the generic engine within these two engines.

3. Subroutine GENDAT
   Once the engine has been ball-parked, this subroutine is used to generate the value of any of the three engine related parameters (i.e. SHP available, Fuel-flow or Jet Thrust produced), at any specific engine rating (viz. max. takeoff, max. climb & max. cruise) at any forward speed & altitude condition.

   Table 1 describes the arguments of Subroutine BPARK & GENDAT.

4. Subroutine SPLIE2
   This (and the remaining 3 subroutines) relate to bicubic spline interpolation technique, and have been taken from Ref. [1]. This subroutine has 6 arguments, viz. $X1A, X2A, YA, M, N \& Y2A$, of which only the last one is output. Given an M by N tabulated function YA, and tabulated independent variables $X1A$ (M values) & $X2A$ (N values), this routine constructs one-dimensional natural cubic splines for the rows of YA and returns the second derivatives in the array $Y2A$. The auxiliary second derivative table is p recomputed and stored for use in the subroutine SPLIN2 described below.

5. Subroutine SPLIN2
   This subroutine has 9 arguments, 6 of which are the same as for subroutine SPLIE2. Given a desired interpolating point with Cartesian coordinates $X1 \& X2$, this routine returns an interpolated function Y by bicubic spline interpolation.

6. Subroutine SPLINE
   This subroutine is called by the above two subroutines, and consists of 6 arguments. Given arrays X & Y of length N containing a tabulated function, i.e. $Y_i = f(X_i)$, with $X_1 \leq X_2 \leq \ldots \leq X_N$, and given values $YP1$ and YPN for the first derivative of the interpolating functions at points 1 & N, respectively, this routine returns an array $Y2$ of length N which contains the second derivatives of the interpolating function at the tabulated points X_i. If $YP1$ and/or $YPN \geq 10^{30}$, the routine is signalled to set the corresponding boundary condition for natural spline, with zero second derivative on that boundary.

7. Subroutine SPLINT
   This subroutine has 6 arguments, and is called in subroutine SPLIN2 described above. It is used for cubic spline interpolation, using the array $Y2A$ generated by subroutine

[1] The source code & datafiles are available on request from the author, or from The Department Secretary, Department of Aerospace Technology, College of Aeronautics, Cranfield University, Cranfield, Bedfordshire, MK 43 0AL, UK. Phone +44-(0)1234-750111-extn-5126, Fax +44-(0)1234-751550.

SPLIN2. Given the arrays XA, YA of length N, which tabulate the function (with the XA_i's in order), and array $Y2A$, the cubic spline interpolated value Y is returned for any input value of X.

Further details of the above interpolation routines are given in Ref. [1].

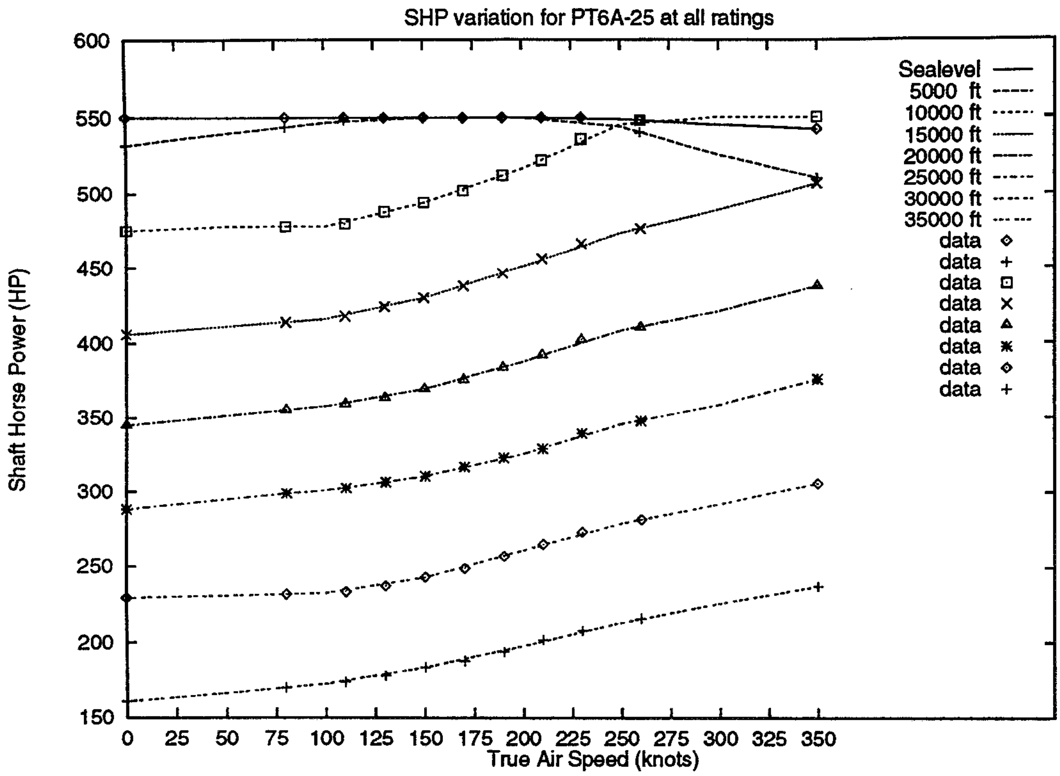
A.2 Database files

Subroutine BPARK & GENDAT use 9 data files that constitute the database for GENENG. Table 2 lists a few details of these files, which contain the values of the three parameters at all the three ratings for all the seven engines at altitudes between sea-level & 35000 ft (at every 5000 ft) and forward speed between 0 & 350 knots TAS (at every 50 knots).

A.3 Sample Input & Output

Table 3 lists the values of the input & output parameters used for ball-parking the three sample generic engines described in the report. Values of the three parameters obtained using GENDAT at a few operating conditions for these generic engines are also listed in this table.

List of Figures



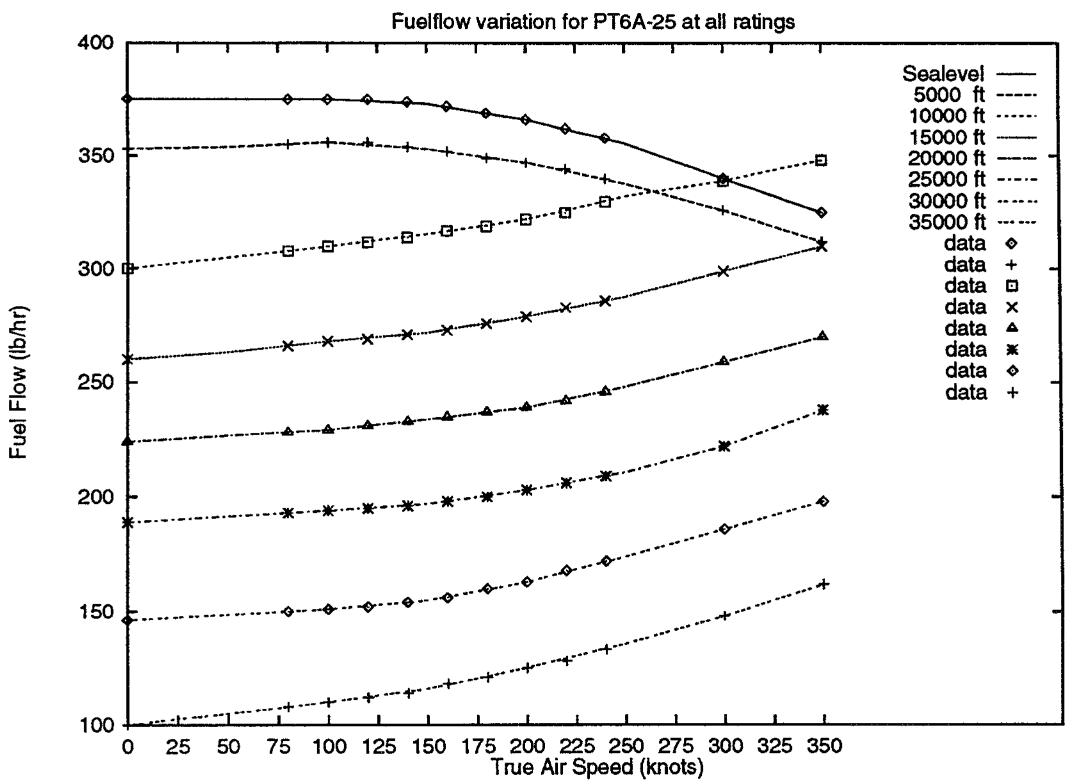
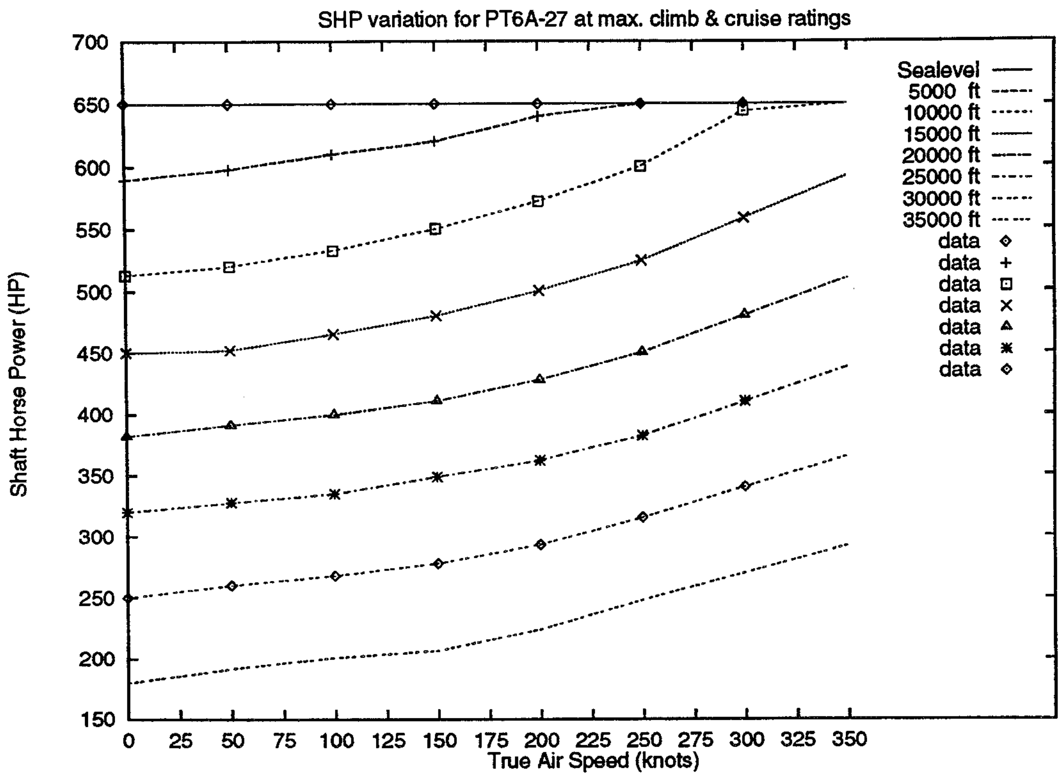


Figure 1: SHP & Fuel-flow variation for PT6A-25 engine



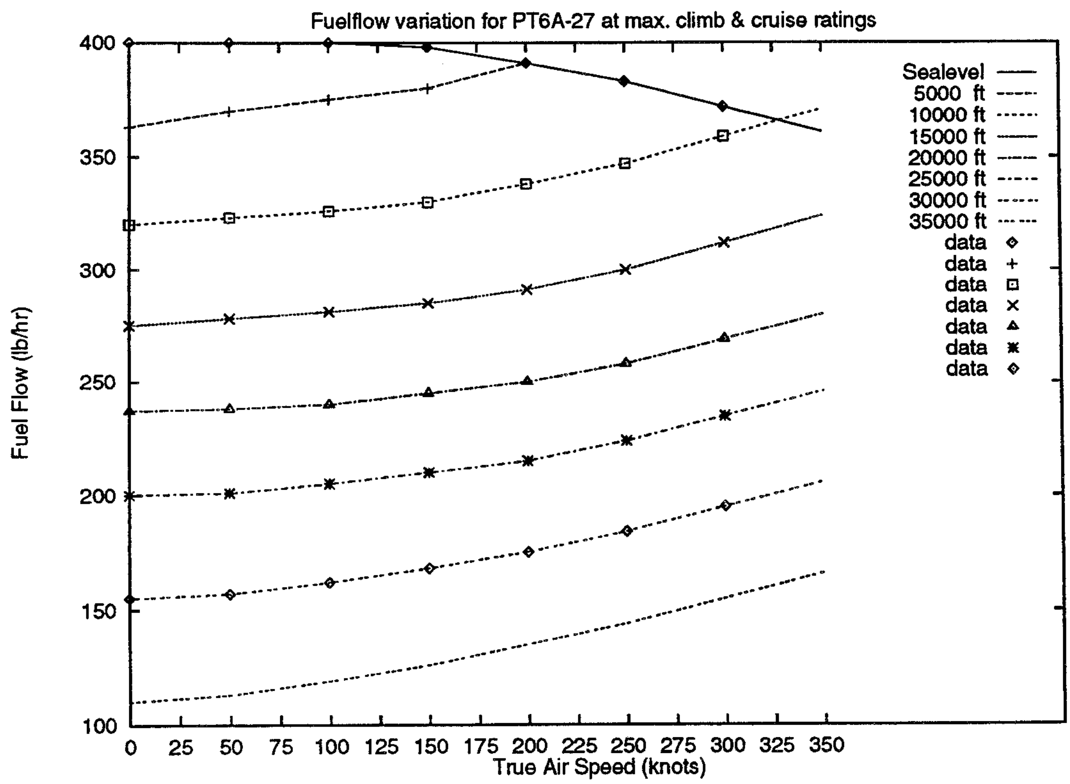
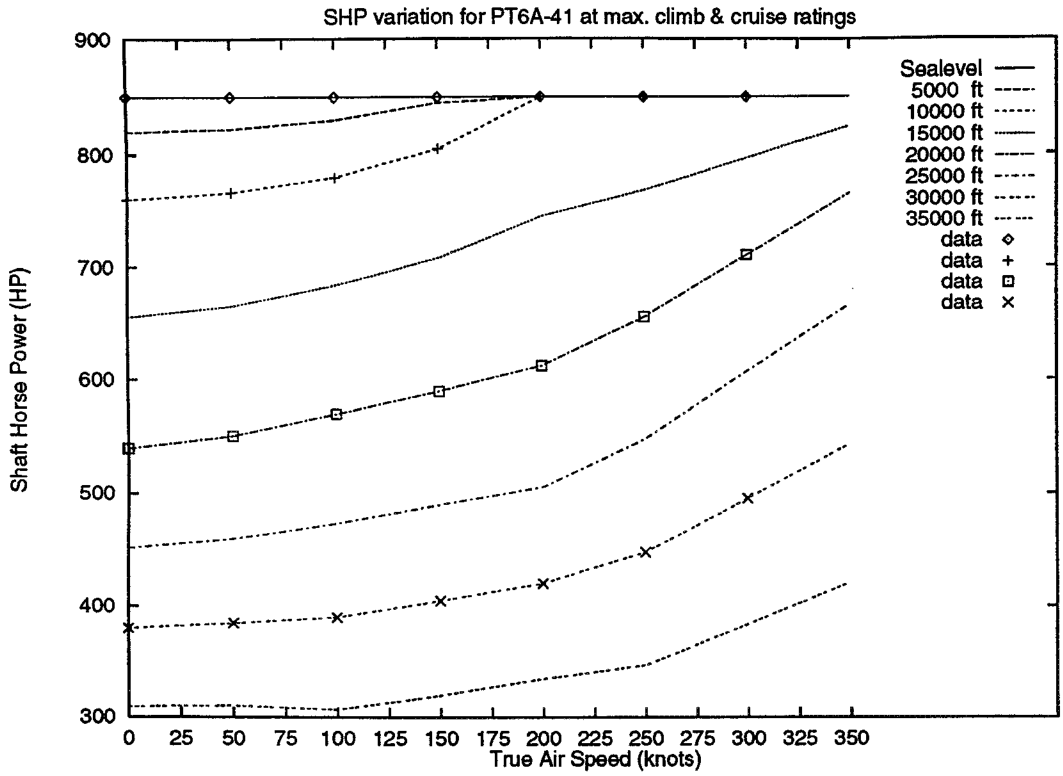


Figure 2: SHP & Fuel-flow variation for PT6A-27 engine



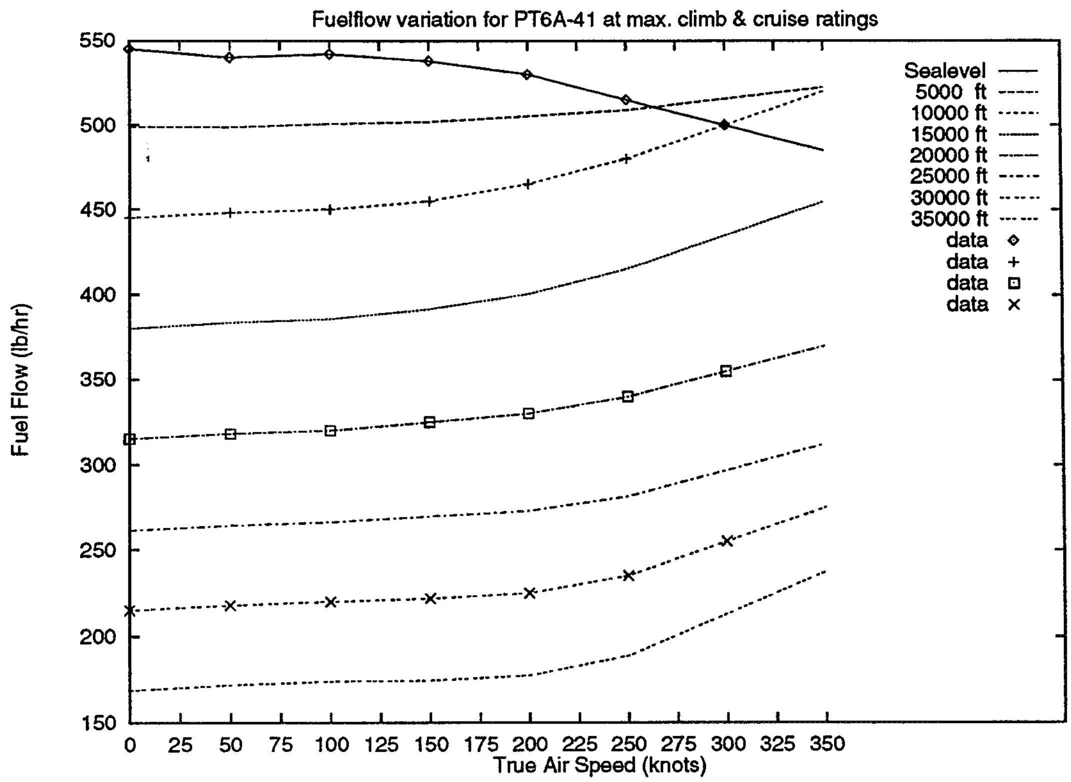
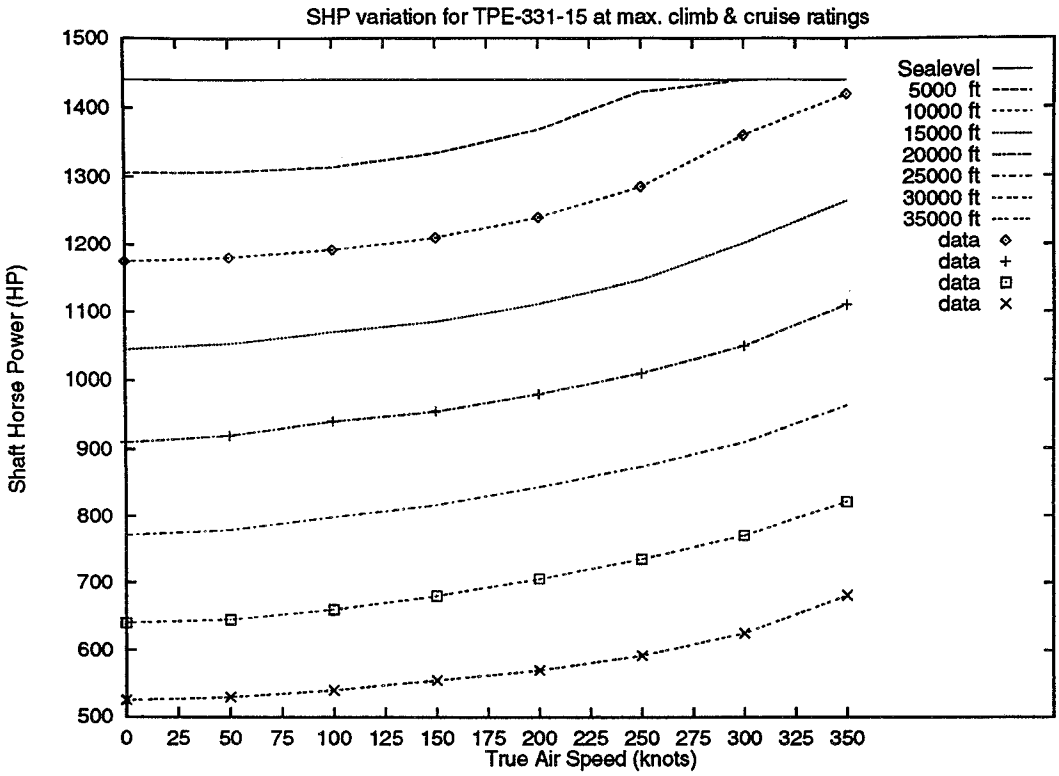


Figure 3: SHP & Fuel-flow variation for PT6A-41 engine



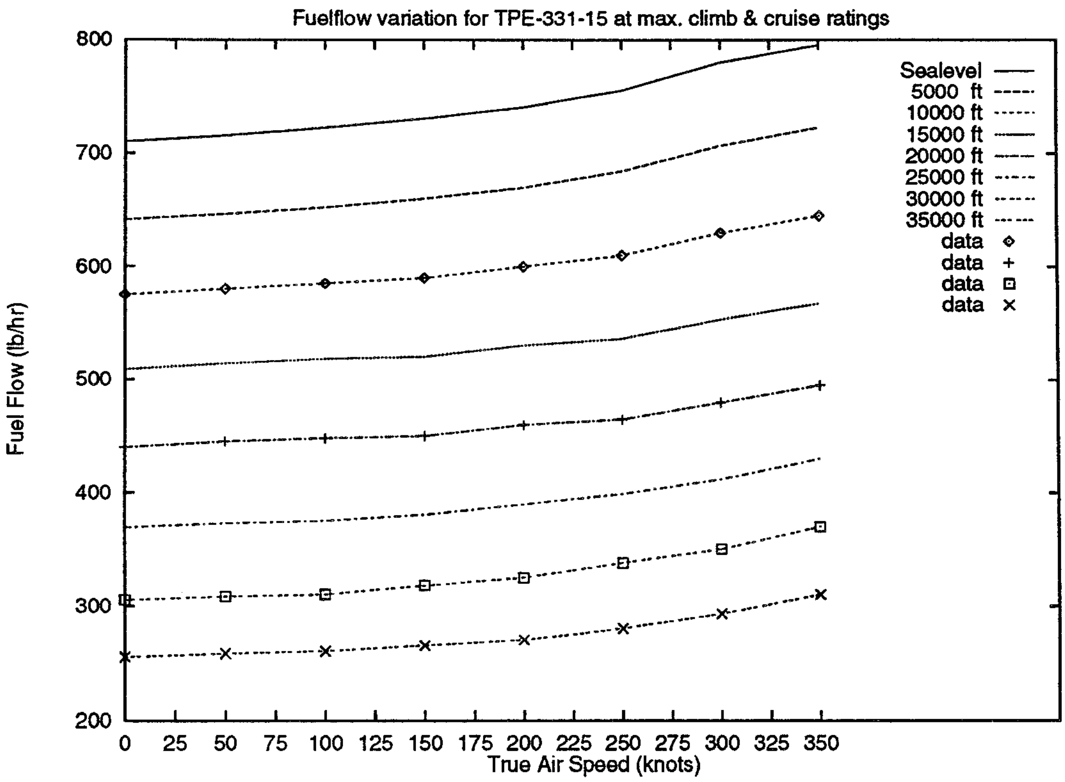
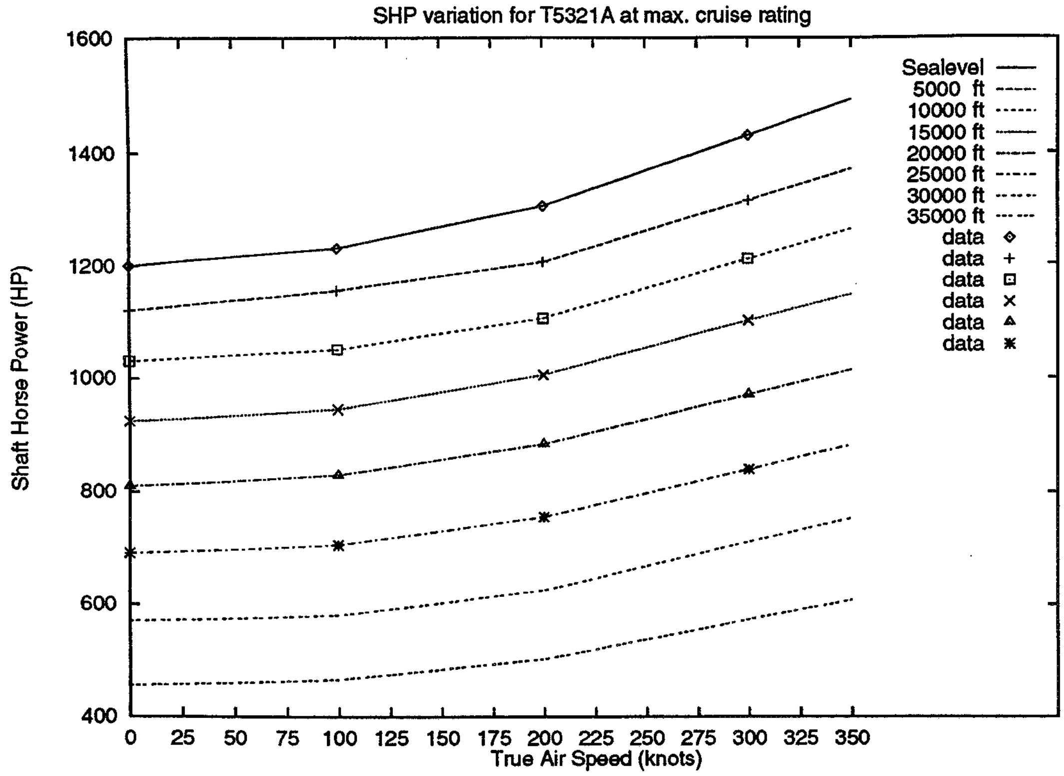


Figure 4: SHP & Fuel-flow variation for TPE-331-15 engine



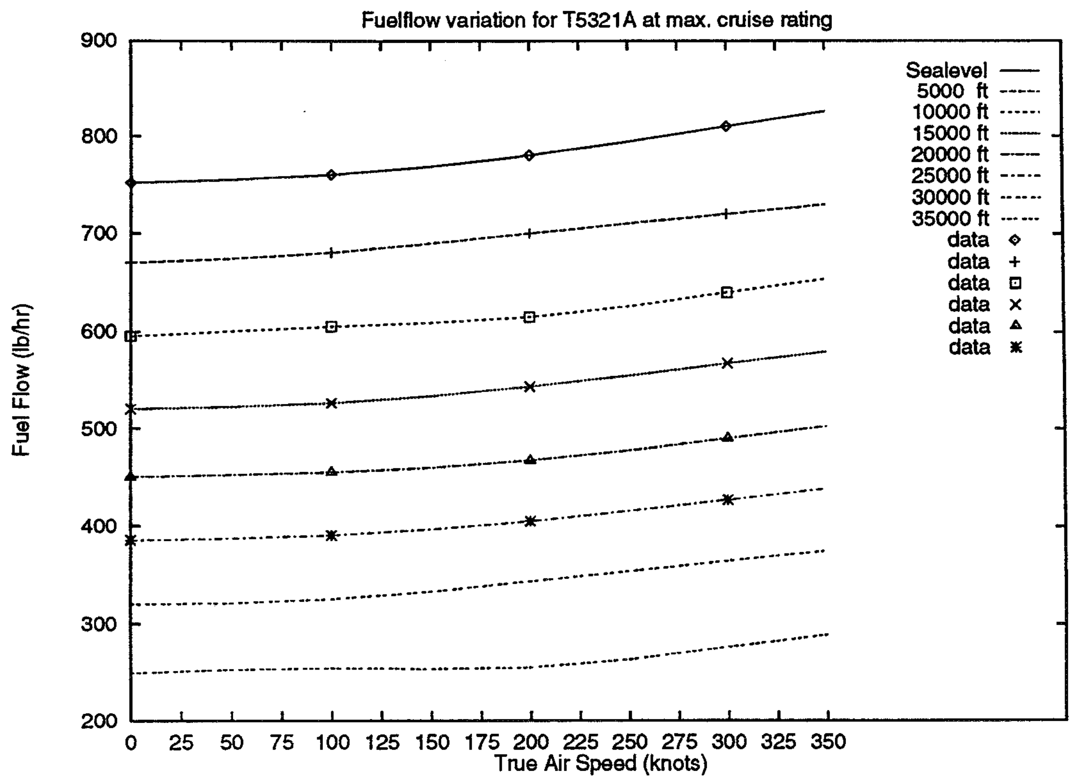
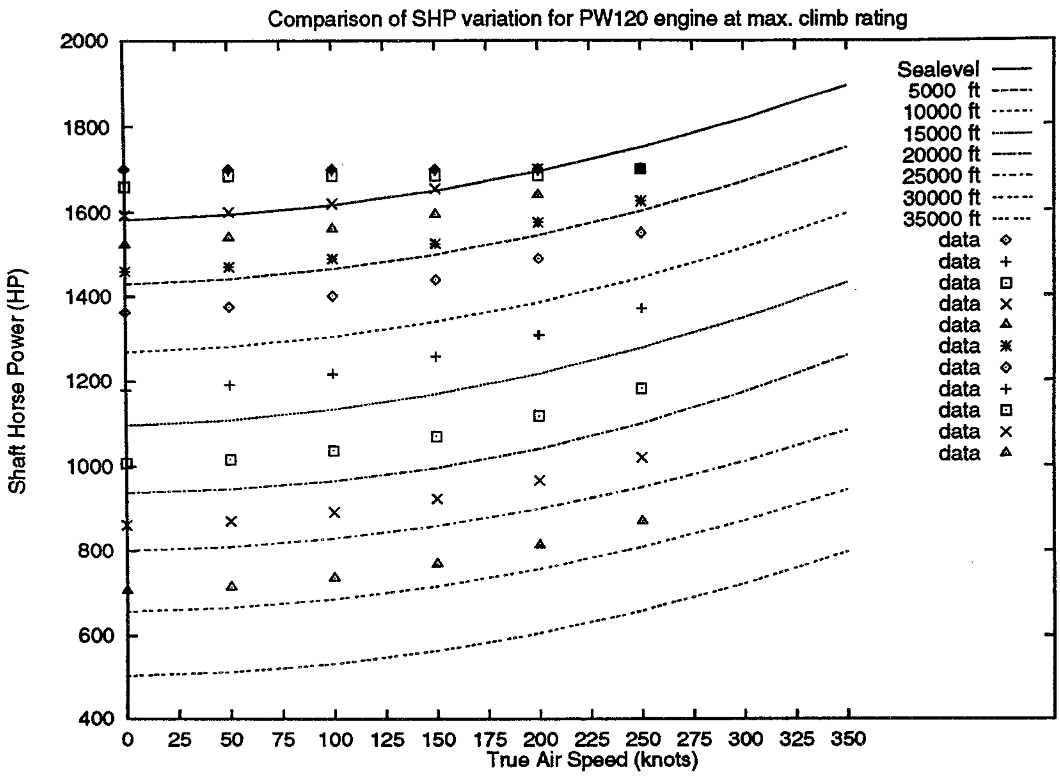


Figure 5: SHP & Fuel-flow variation for T5321A engine



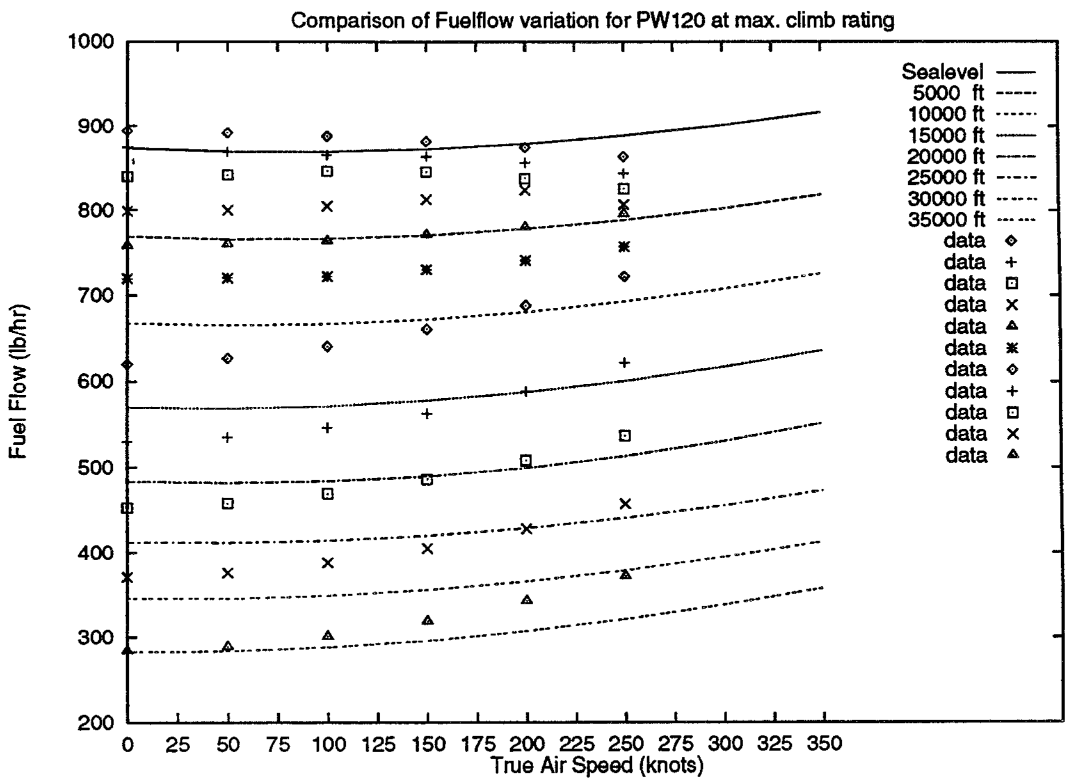
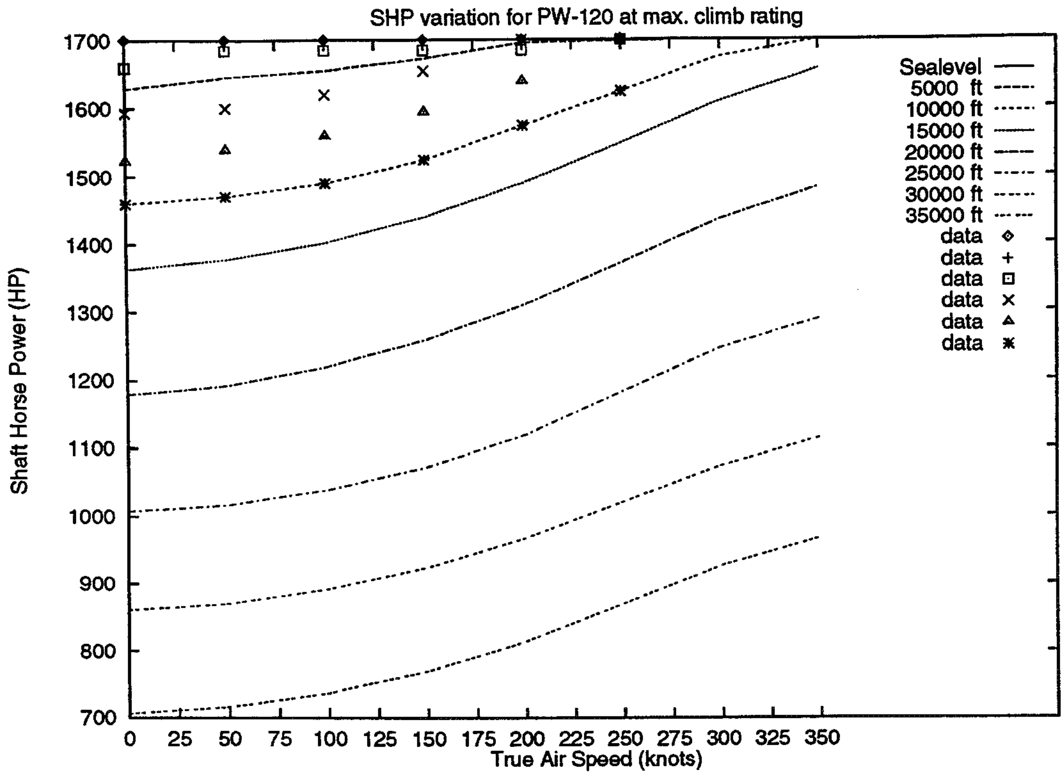


Figure 6: Trends v/s actual data for PW-120 engine from Ref.[7]



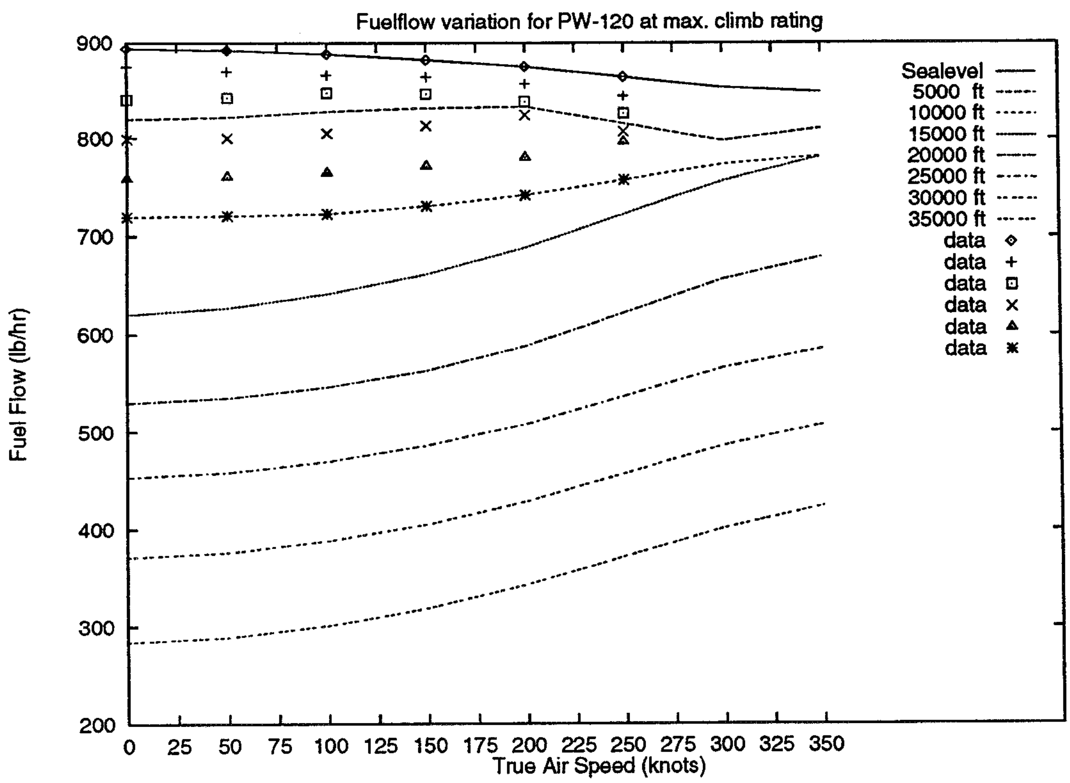
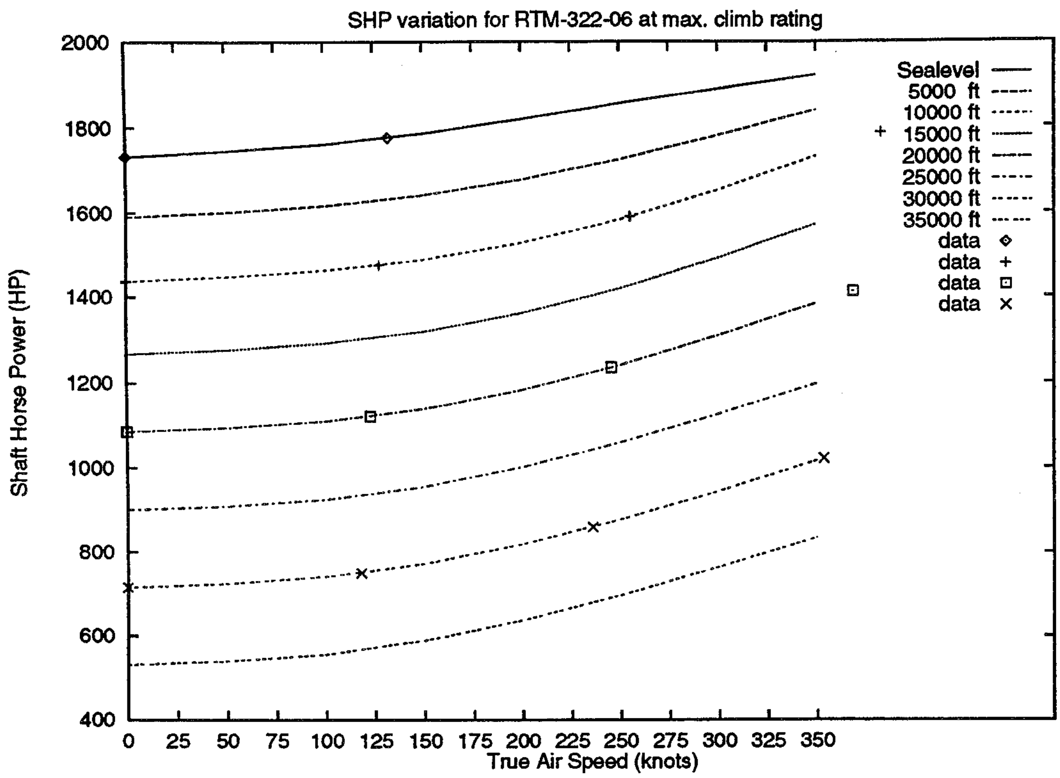


Figure 7: Modified SHP & Fuel-flow variation for PW-120 engine



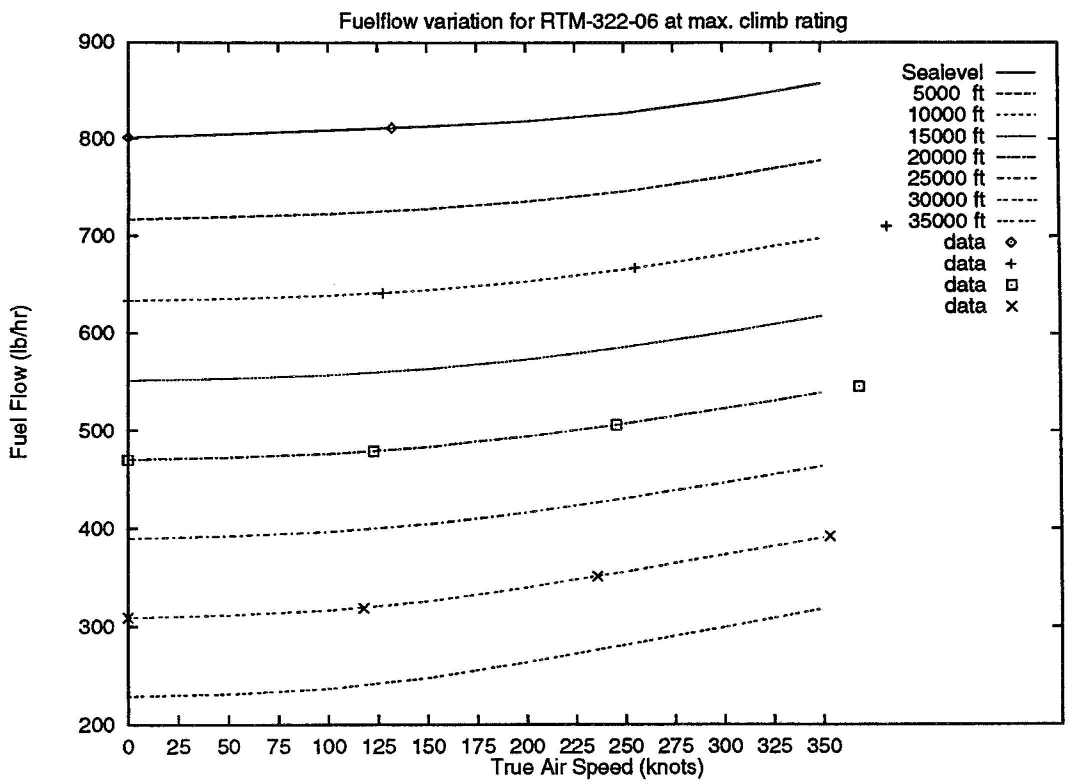


Figure 8: SHP & Fuel-flow variation for RTM-322-06 engine

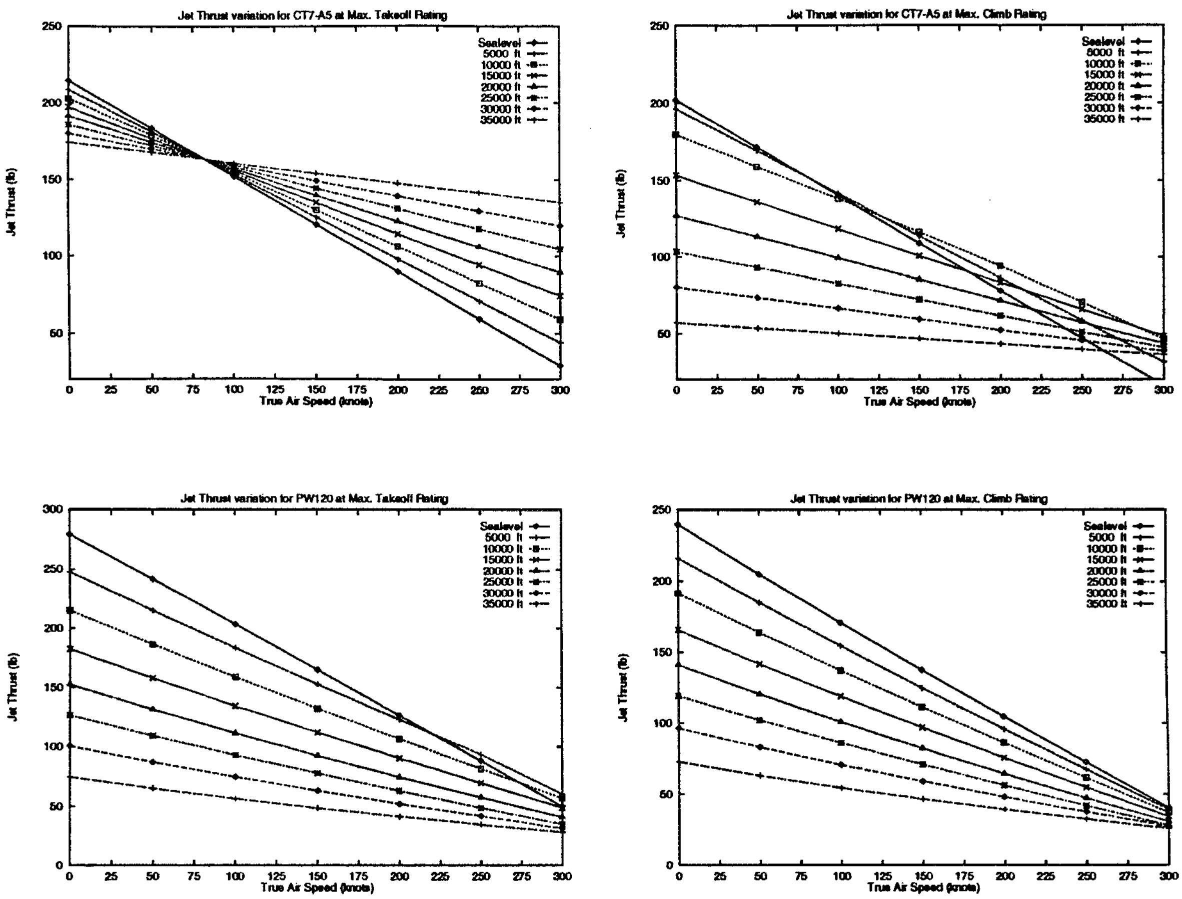


Figure 9: Jet thrust variation for PW-120 & CT75A2 engine reported in Ref. [7]

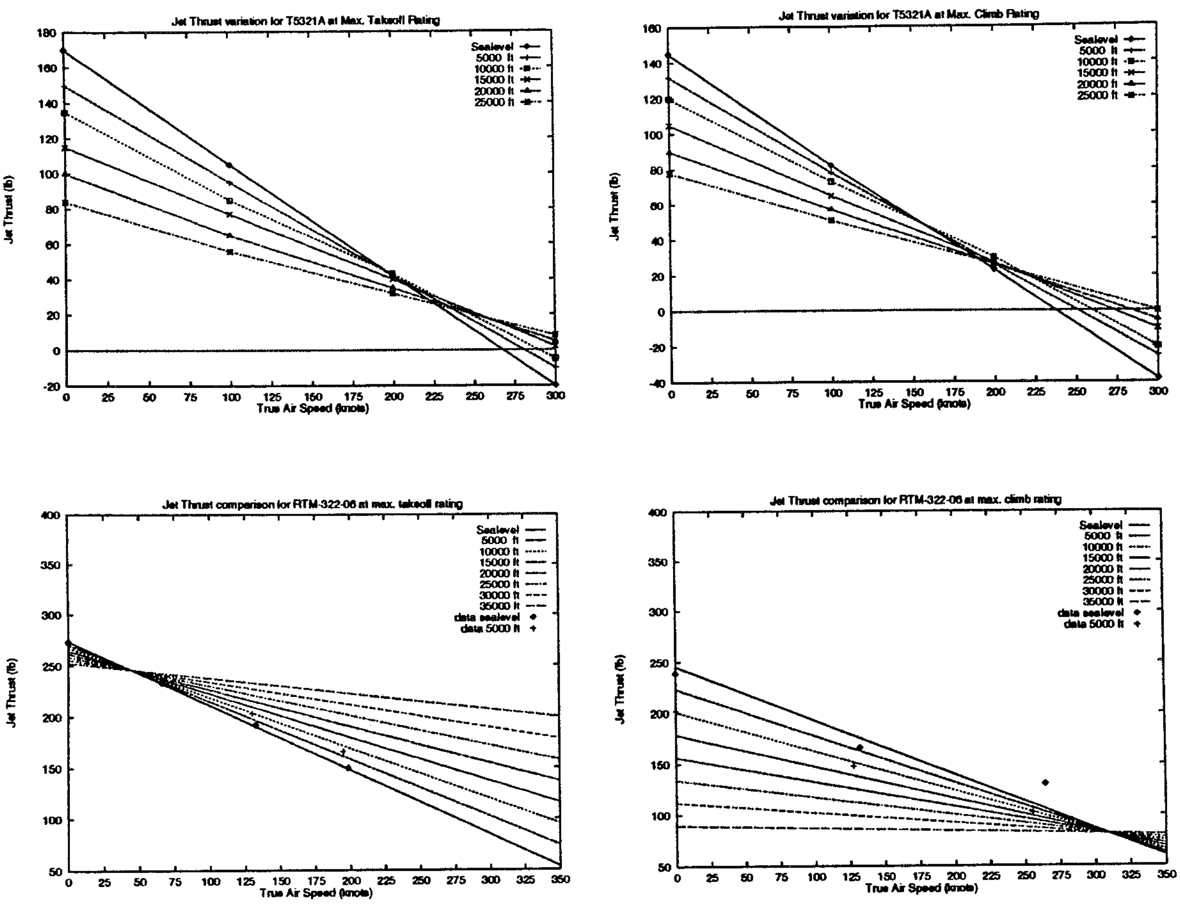


Figure 10: Jet thrust variation for T5321 & RTM-322-06 engines

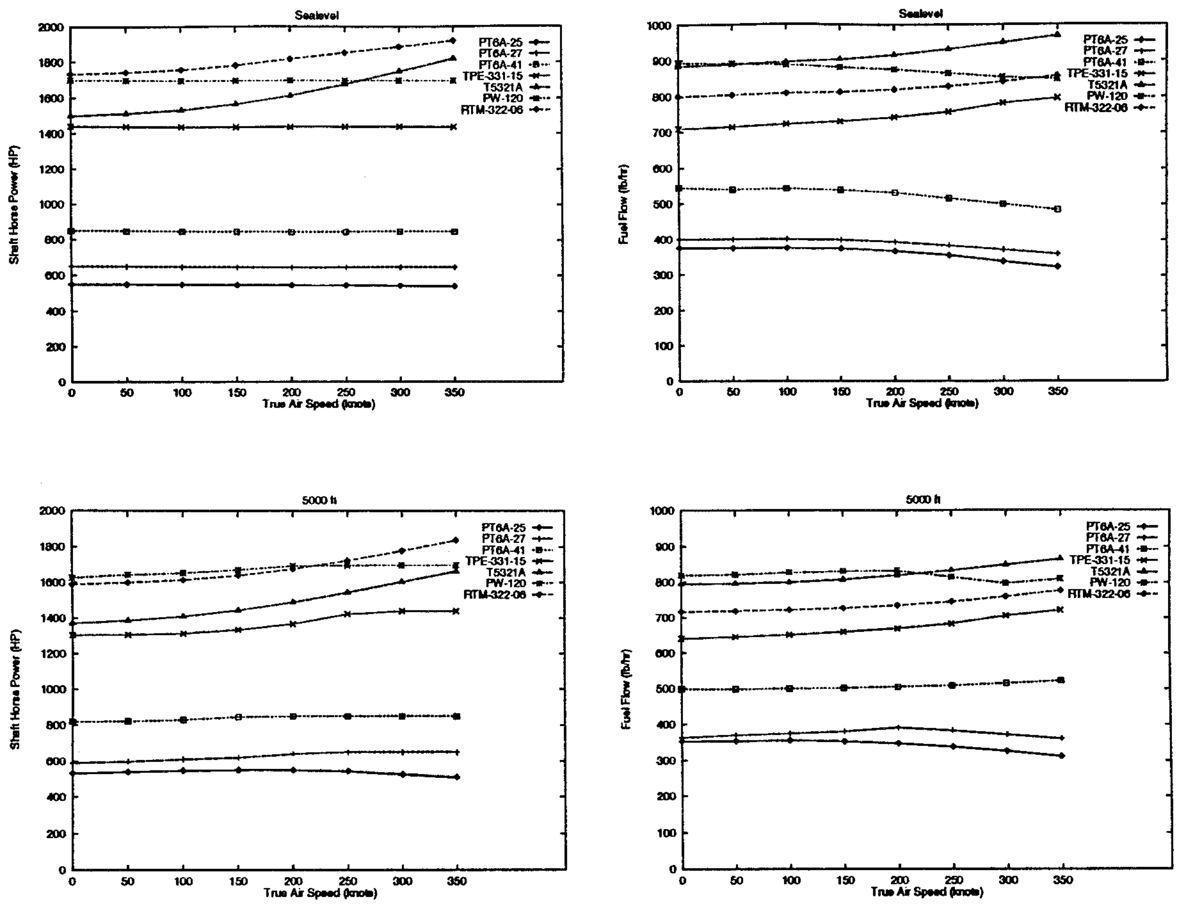


Figure 11: SHP & Fuel-flow variation at Max. Climb rating, Sea-level & 5000 ft

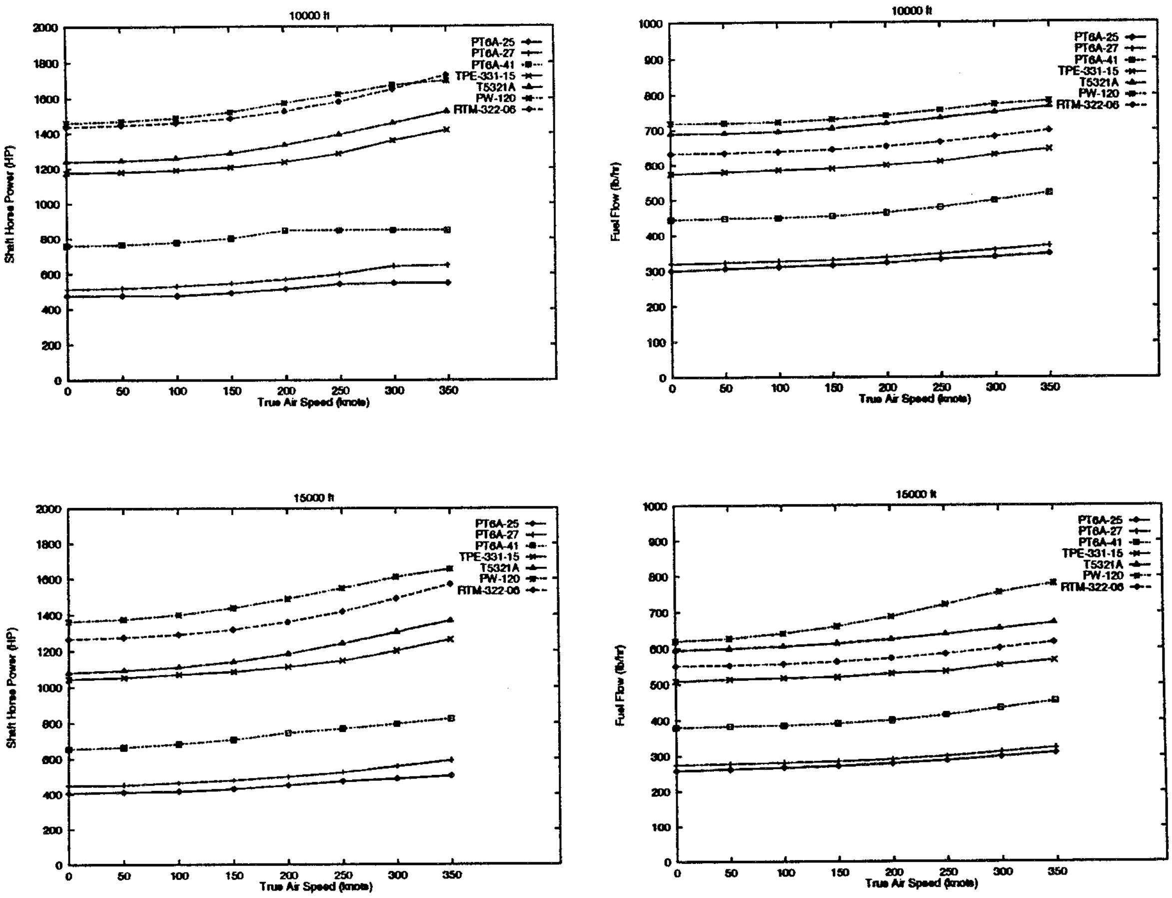


Figure 12: SHP & Fuel-flow variation at Max. Climb rating, 10000 ft & 20000 ft

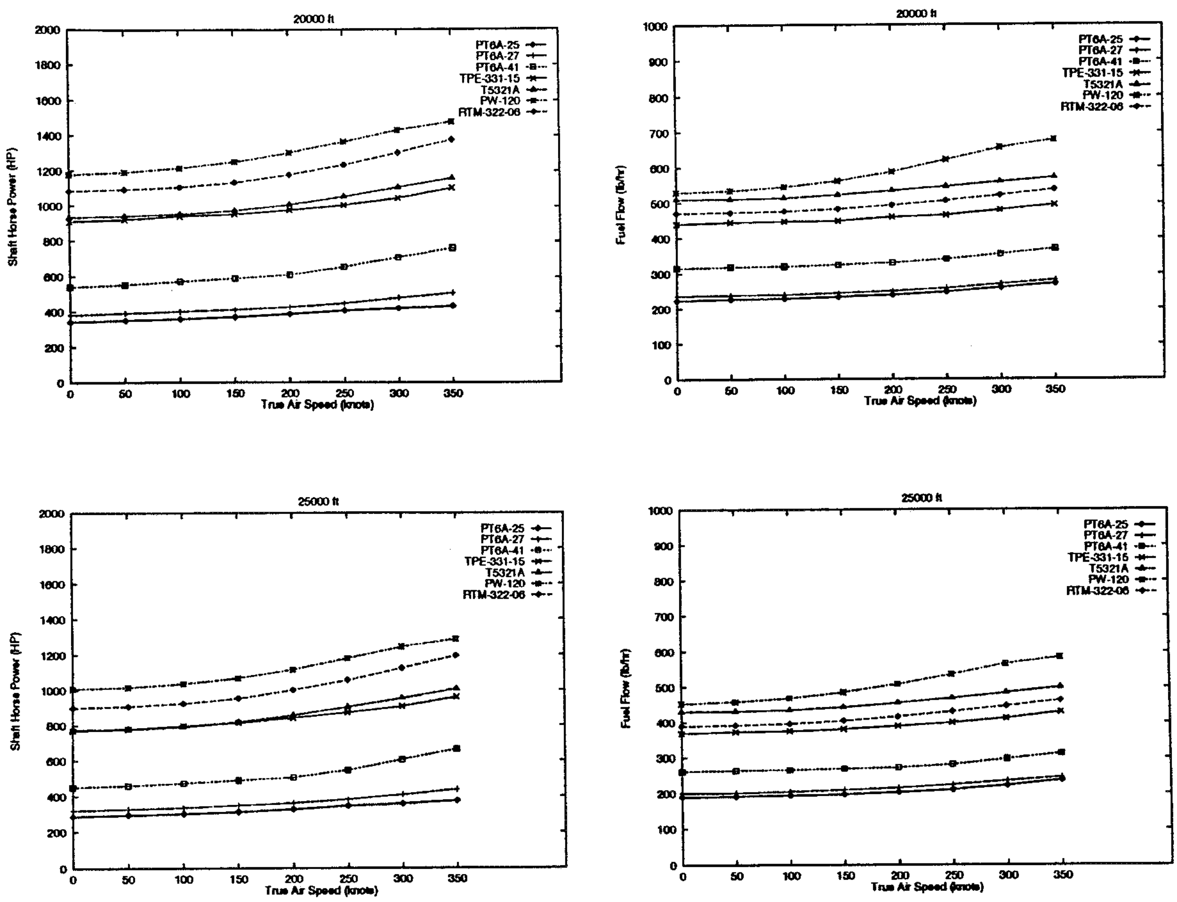


Figure 13: SHP & Fuel-flow variation at Max. Climb rating, 20000 ft & 25000 ft

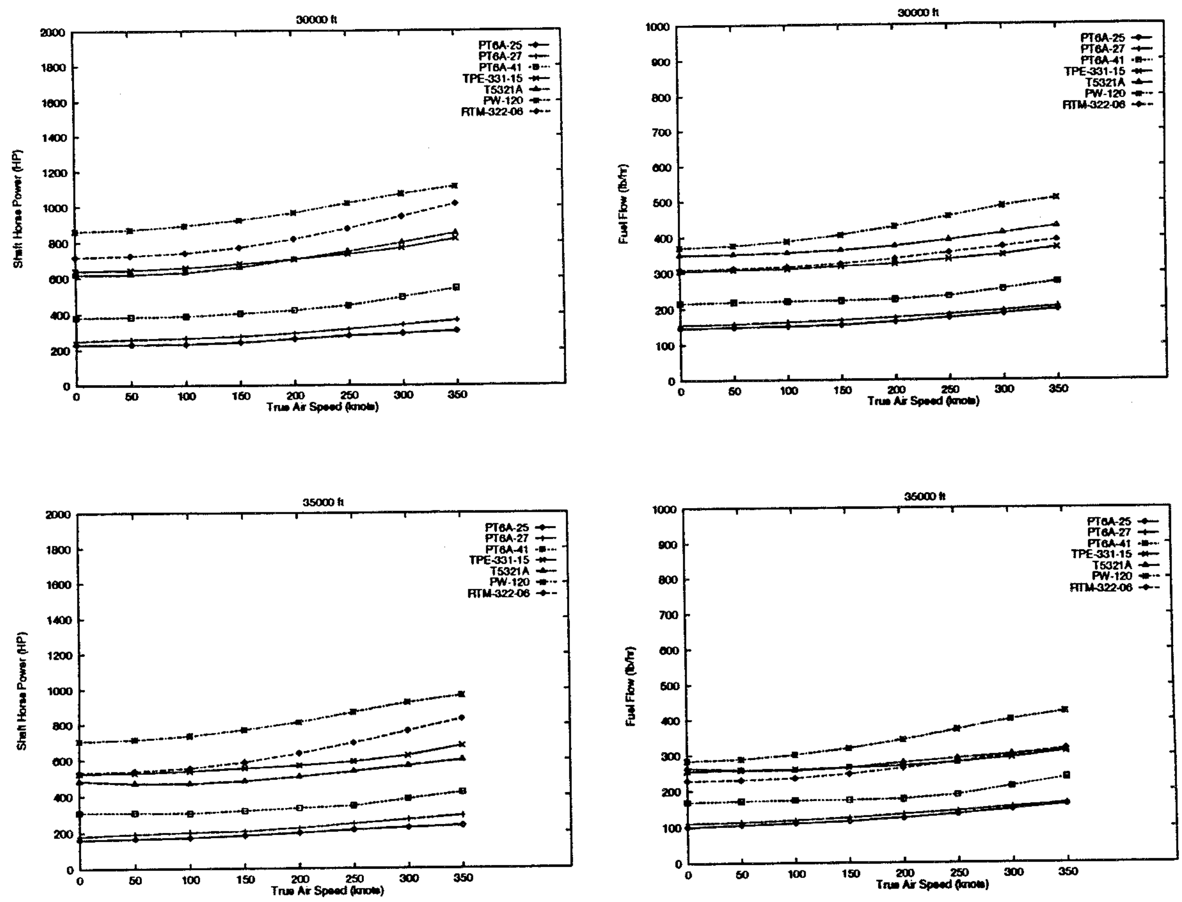


Figure 14: SHP & Fuel-flow variation at Max. Climb rating, 30000 ft & 35000 ft

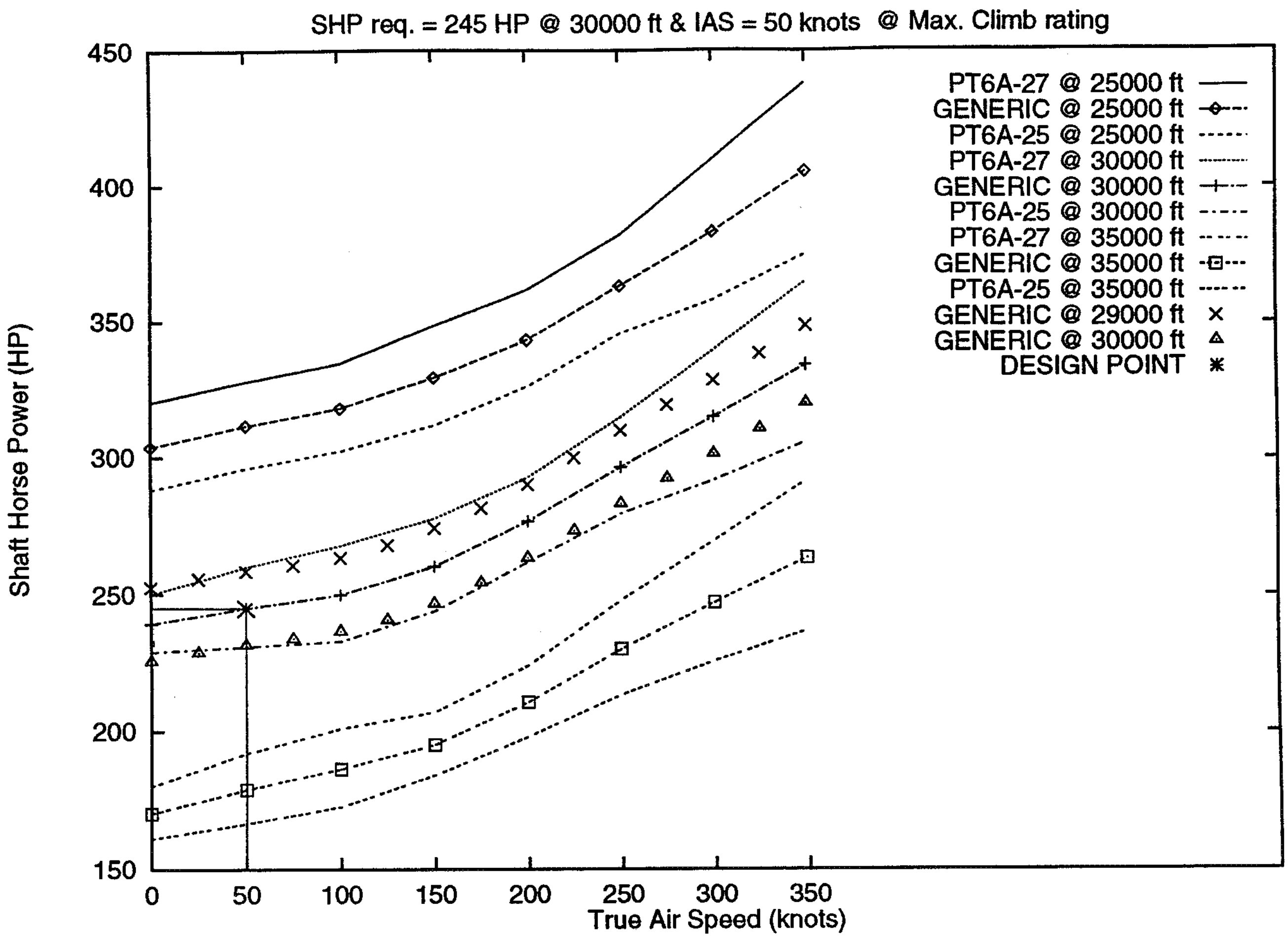


Figure 15: A generic engine ball-parked using climb requirements

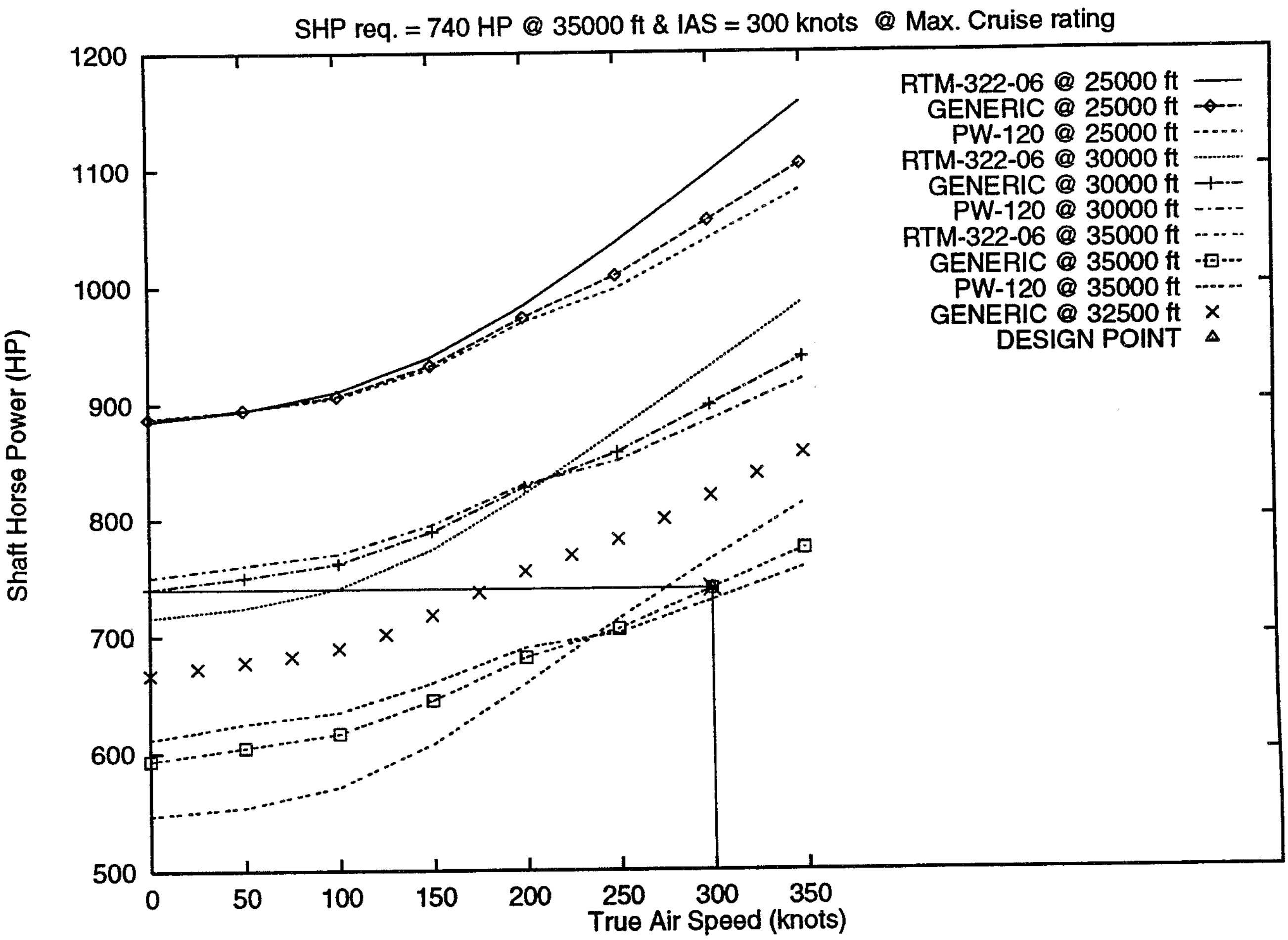


Figure 16: A generic engine ball-parked using cruise requirements

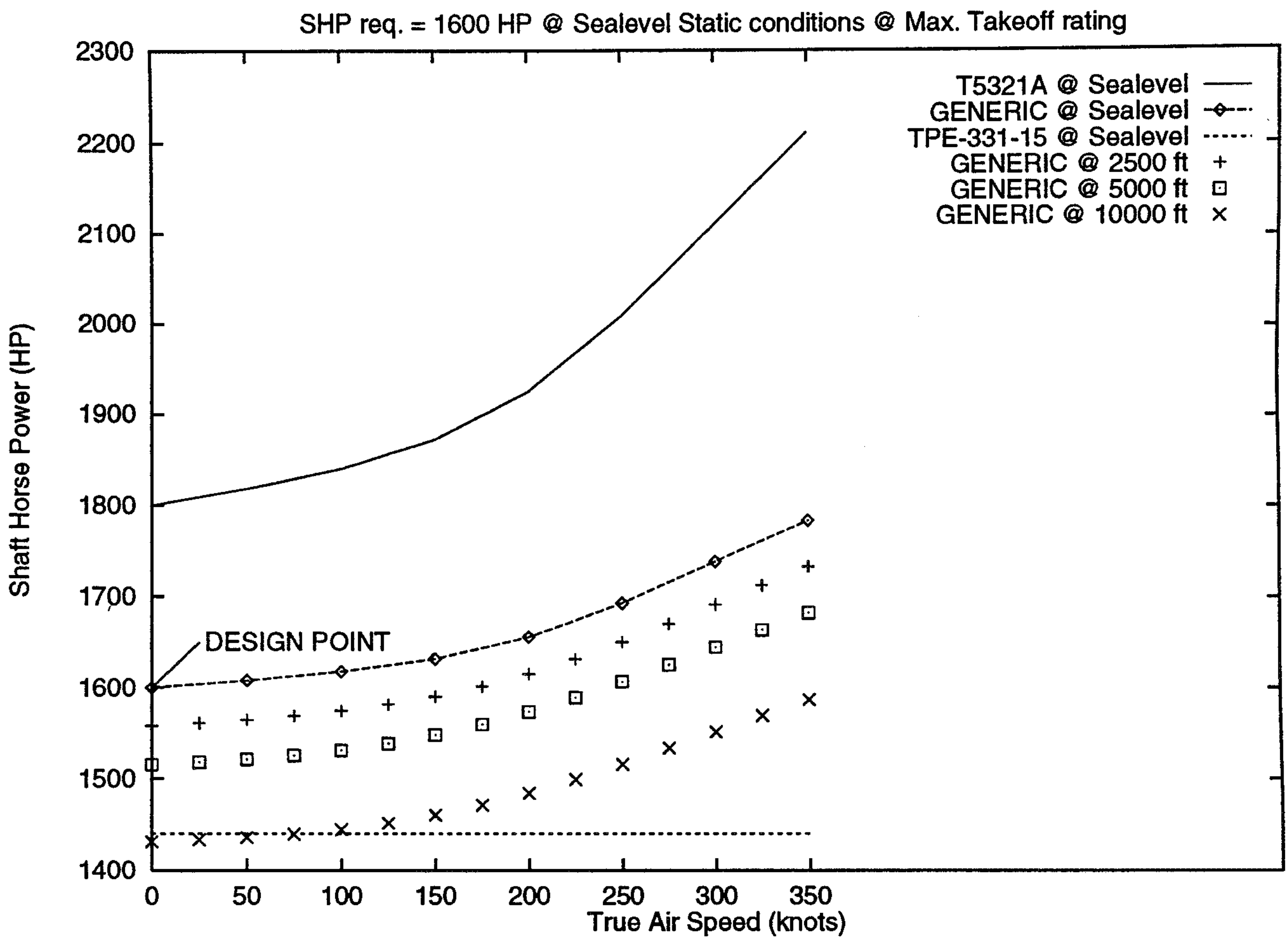


Figure 17: A generic engine ball-parked using take-off requirements

List of Tables

Arguments of BPARK			
Argument	Type	Description	Value
ipb	Input	Parameter used for ball-parking criterion	
		Shaft Horsepower available (HP)	0
		Fuel-flow (lb/hr)	1
		Jet Thrust produced (lb)	2
irb	Input	Engine rating at ball-parking criterion	
		Max. Takeoff Rating	0
		Max. Climb Rating	1
		Max. Cruise Rating	2
balt	Input	Altitude (ft) at ball-parking criterion	
btas	Input	TAS (knots) at ball-parking criterion	
bval	Input	Parameter value at ball-parking criterion	
ilow	Output	Rank of the engine just below the generic	
ihi	Output	Rank of the engine just above the generic	
frac	Output	Fractional location of the generic engine	
Arguments of GENDAT			
ipd	Input	Parameter whose value is desired	
		Shaft Horsepower available (HP)	0
		Fuel-flow (lb/hr)	1
		Jet Thrust produced (lb)	2
ird	Input	Engine rating at operating condition	
		Max. Takeoff Rating	0
		Max. Climb Rating	1
		Max. Cruise Rating	2
dalt	Input	Altitude (ft) at operating condition	
dtas	Input	TAS (knots) at operating condition	
ilow	Input	Rank of the engine just below the generic	
ihi	Input	Rank of the engine just above the generic	
frac	Input	Fractional location of the generic engine	
bval	Output	Parameter value at operating condition	

Table 1: Arguments of Subroutine BPARK & GENDAT

No.	File Name	Parameter	Engine rating
1	hpto.dat	SHP available	Max. Takeoff
2	ffto.dat	Fuel-flow	Max. Takeoff
3	jtto.dat	Jet Thrust produced	Max. Takeoff
4	hpcl.dat	SHP available	Max. Climb
5	ffcl.dat	Fuel-flow	Max. Climb
6	jtcl.dat	Jet Thrust produced	Max. Climb
7	hpcr.dat	SHP available	Max. Cruise
8	ffcr.dat	Fuel-flow	Max. Cruise
9	jtcr.dat	Jet Thrust produced	Max. Cruise

Table 2: Data files needed by Subroutine BPARK & GENDAT

arguments of BPARK												
Input					Output							
					arguments of GENDAT							
					Input							Output
ipb	irb	balt	btas	bval	ilo	ihi	frac	ipd	ird	dalt	dtas	dval
0	0	0.0	0.0	1600.0	4	5	0.44444					
								0	0	0.0	350.0	1782.83
								0	1	0.0	350.0	1609.72
								0	2	0.0	350.0	1463.33
								1	1	1000.0	200.0	801.71
								1	2	1000.0	200.0	743.04
								2	1	2000.0	300.0	-24.76
								2	2	2000.0	300.0	-38.14
0	1	30000.0	300.0	245.0	1	2	0.48418					
								0	0	0	350.0	594.29
								0	1	0	350.0	594.29
								0	2	0	350.0	594.29
								1	1	1000.0	200.0	377.53
								1	2	1000.0	200.0	377.53
								2	1	2000.0	300.0	-9.24
								2	2	2000.0	300.0	-14.89
0	2	35000.0	50.0	740.0	6	7	0.28563					
								0	0	0	350.0	1785.69
								0	1	0	350.0	1763.21
								0	2	0	350.0	1685.57
								1	1	1000.0	200.0	850.34
								1	2	1000.0	200.0	828.30
								2	1	2000.0	300.0	47.70
								2	2	2000.0	300.0	32.73

Table 3: Sample Input & Output