APPENDIX 1. POWER AVAILABLE

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1. GENERAL. The purpose of this appendix is to provide guidance regarding the power considerations for various kinds of powerplants. The power output of each airplane/engine configuration requires special considerations when determining test day performance corrections and providing the performance expansions for the AFM. The types of powerplants discussed in this appendix are:

a. Reciprocating Engines.

(1) Normally aspirated engine with a fixed pitch propeller;
(2) Normally aspirated engine with a constant speed propeller; and
(3) Turbocharged engine with a constant speed propeller.

b. Turbopropeller Engines.

2. RECIPROCATING ENGINES.

a. Power Charts. The horsepower being developed by reciprocating engines is usually identified by horsepower charts that are provided by the engine manufacturer. These charts are developed from results of ground runs using a brake-type dynamometer in a test facility and may have no direct correlation to any particular airplane or flight condition. The variations of power with altitude and temperature are the result of theoretical relationships involving air density, fuel/air ratios, and so forth. These charts nearly always assume a “best power” fuel to air ratio that can rarely be consistently used in service under normal operating conditions. Many installations, for example, intentionally use fuel to air ratios that are on the fuel-rich side of best power so that the engine will not overheat. Providing sufficient cooling airflow over each cylinder to ensure adequate cooling may be more difficult than cooling with a rich fuel mixture. These horsepower charts were also developed while maintaining a constant temperature on each cylinder. This is not possible in service. The charts are developed assuming the following:

(1) There is no ram airflow due to movement through the air; or

(2) There are not losses due to pressure drops resulting from intake and air filter design; or

(3) There are no accessory losses.

b. Chart Assumptions. Regardless of the test stand conditions that are not duplicated in service, it is necessary to assume that each given pressure altitude temperature, engine speed, and manifold pressure combination will result in horsepower that can be determined from the engine power chart. To accomplish this requires certain procedures and considerations.

c. Tolerances. Each engine power chart specifies a horsepower tolerance from rated horsepower. These are commonly ±2 ½ percent, +5 percent, -2 percent, or +5 percent, -0 percent. This means that with all the variables affecting power being held constant (that is, constant manifold pressure, engine speed, temperature, and fuel to air ratio), the power could vary this much from engine to engine. For this reason, it is appropriate to account for these variations. Calibration of the test engine(s) by the engine manufacturer is one way to accomplishing this. During engine calibration, the test engine is run on a test stand at the engine manufacturer's facility to identify how it compares with the power output at conditions under which it was rated. The result is a single point comparison to the rated horsepower.

d. Test Day Power.

(1) *Calibrated Engines*. If an engine, for example, is rated at 200 BHP, the calibration results might show the particular serial numbered engine to develop 198.6 BHP. This is 0.7 percent below the rated power. For this engine, each of the horsepower values obtained from the engine manufacturer's chart should be adjusted downward by 0.7 percent to obtain test day horsepower.

(2) *Uncalibrated Engines.* If the engine is not calibrated, an acceptable method of accounting for the unknown factors is to assume that the test engine is putting out rated horsepower plus the plus tolerance. For example, if the rated horsepower was 350 and the tolerance was ±2 ½ percent, test day sea level chart horsepower would be assumed to be 350 + .025 (350), or 358.8.

(3) *Humidity.* Section 23.45(e) requires performance to be based on 80 percent relative humidity on a standard day. Experience has shown that conditions such as 80 percent relative humidity on a standard day at sea level have a very small effect on engine power because this condition results in a very low specific humidity. The engine is affected directly by specific humidity (pounds of water per pounds of air) rather than relative humidity. For test day power, dry air should be assumed unless the applicant has an approved method for measuring and determining the effect of humidity.

e. Chart Brake Horsepower. A chart brake horsepower (BHPc) should be determined for expansion of the flight test data in the AFM. BHPc is the horsepower at a particular pressure altitude, manifold pressure and r.p.m. Appropriate inlet temperature corrections should be applied, in accordance with the manufacturer's engine power chart. An 80 percent relative humidity correction should be applied if the engine manufacturer has an acceptable method and the correction is significant.

f. Variations in Methods. Peculiarities of the various types of reciprocating engines require special considerations or procedures to determine installed power. These procedures are discussed in subsequent paragraphs.

3. NORMALLY ASPIRATED ENGINES WITH CONSTANT SPEED PROPELLERS.

a. Manifold Pressure Versus Altitude. As a first step to determine installed horsepower, flight tests should be conducted to determine manifold pressure versus pressure altitude for the engine installation. The test manifold pressures would be compared to the engine manufacturer's chart values, as shown on Figure A1-1. Figure A1-1 shows an example of test manifold pressure and chart manifold pressures versus pressure altitude. In this example, the observed manifold pressures are lower than the chart values. This means that the induction system pressure losses exceed the ram pressure rise. An induction system in which manifold pressures exceed the zero ram chart values would reflect an efficient induction system. The term chart brake horsepower indicates that the horsepower values have yet to be corrected for inlet temperature conditions.

b. Example Calculation. The overall corrections to determine installed test day brake horsepower and chart brake horsepower (BHPc) to be used in the expansion of performance would be as follows (refer to Figure A1-1):

Known:
- Pressure Altitude....................4,000 feet
- Manifold Pressure....................24.9 in Hg.
- Outside Air Temperature....................+55 ºF
- Inlet Temperature....................+63 ºF
- Engine Speed....................2,650 r.p.m.
- Engine Calibration....................-0.7 %
- Engine Tolerance....................±2 ½ %

Calculated Test Day BHP for a Calibrated Engine:

Standard Temperature @ 4,000 ft....................44.7 ºF
Installed Chart Brake Horsepower....................335 BHP
(from Figure A1-1)
Engine Calibration Correction = (335)(-.007)....................-2.3 BHP
Correcting for Inlet Temperature

$$\text{Test Day BHP} = (335-2.3)\sqrt{\frac{460+44.7}{460+63.0}} \quad \ldots\ldots\ldots\ldots 326.8 \text{ BHP}$$

Calculated Test Day BHP for an Uncalibrated Engine:

Standard Temperature @ 4,000 ft....................44.7 ºF
Installed Chart Brake Horsepower....................335 BHP
(from Figure A1-1)

$$\text{Test Day BHP} = [335 + .025(335)]\sqrt{\frac{460+44.7}{460+63}} \quad \ldots\ldots\ldots\ldots 337.3 \text{ BHP}$$

Calculated BHPc for Test Day Density Altitude (Hd):

Hd at 4,000 ft. and 55 ºF....................4,670 ft.
Installed BHPc (from Figure A1-1)....................326 BHP
Standard Temperature at 4,670 ft....................42 ºF
Correcting for Inlet Temperature Rise

$$\text{BHPc} = 326\sqrt{\frac{460+42}{460+42+8}} \quad \ldots\ldots\ldots\ldots 323.4 \text{ BHP}$$

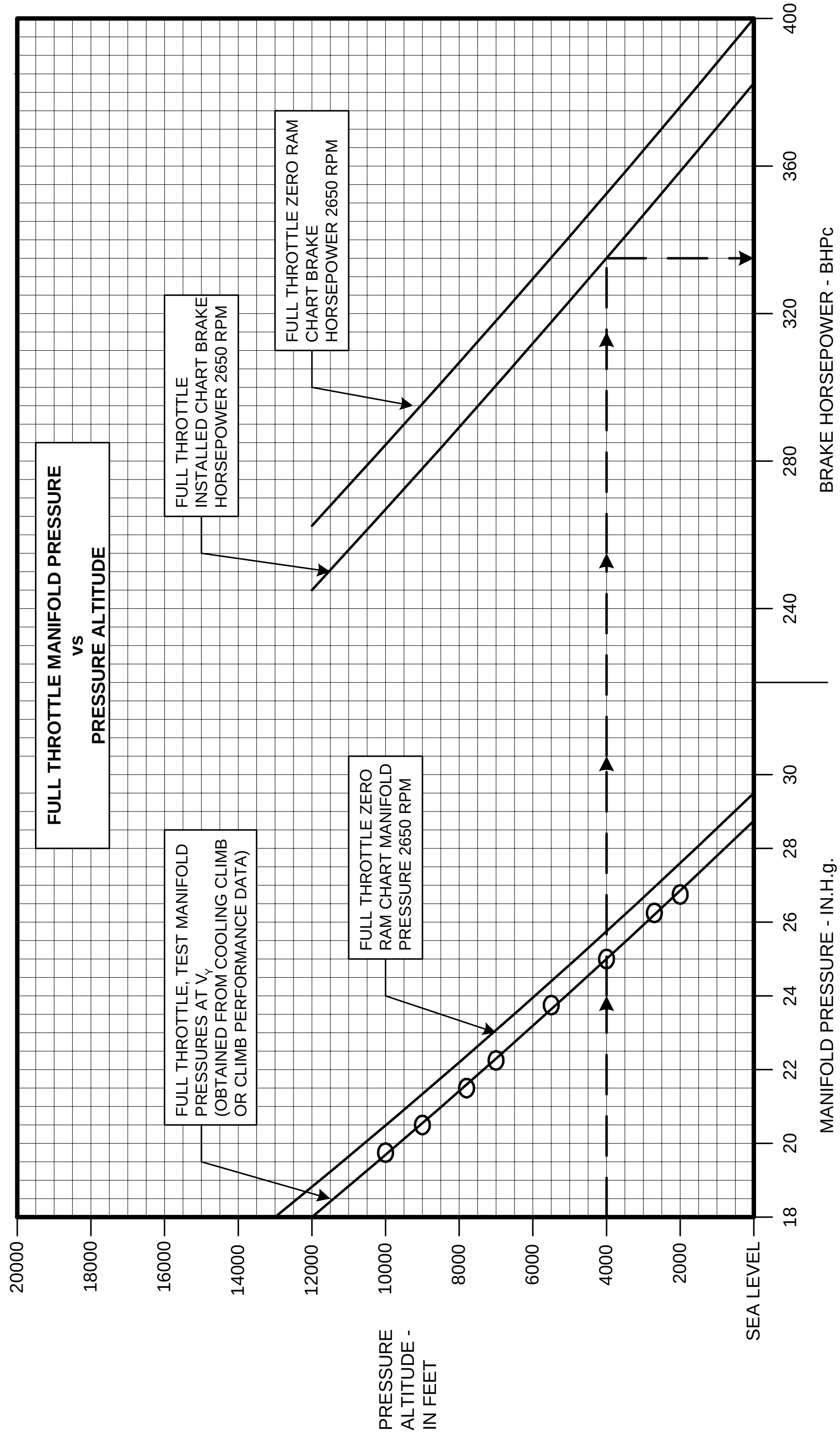

FIGURE A1-1 – BRAKE HORSEPOWER VERSUS PRESSURE ALTITUDE

Calculated Test Day BHPc for the AFM Expansion:

For the Same Conditions as Test Day,...335 BHP
BHP (from Figure A1-1)..335 BHP
Correcting for Inlet Temperature,
expansion

$$BHP - 335\sqrt{\frac{460 + 44.7}{460 + 63}}$$ ....329.1 BHP

4. TURBOCHARGED ENGINES WITH CONSTANT SPEED PROPELLERS.

a. Manifold Pressure Versus Altitude. From flight tests, it is appropriate to plot manifold pressure versus pressure altitude used to demonstrate satisfactory cooling and climb performance demonstrations. The engine manufacturer’s chart brake horsepower should be entered at these manifold pressure values. The result is the chart brake horsepower to be utilized in data expansion. For some installations, the manifold pressure and fuel flows are limited by the airplane manufacturer’s design schedule. For these, the full throttle values must be identified. Whenever the manifold pressures and fuel flows must be manually set to a schedule, corresponding limitations must be established.

b. Horsepower. Refer to Figure A1-2 for an illustration of manifold pressure and horsepower versus pressure altitude. It is rare for the horsepower values to be constant below the critical altitude. The horsepower ratings are not necessarily limited and it is common to observe chart horsepower values at the intermediate altitudes higher than rated power. As with normally aspirated engines, the term chart brake horsepower indicates that the horsepower values have yet to be corrected for inlet temperature conditions. The corrections for temperature are usually greater for turbocharged than normally aspirated. A 1 percent decrease in power for each 10 ºF increase in temperature above standard temperature conditions at a constant specific fuel consumption (SFC) is common. The apparent effects for a particular installation could be more or less than this. Manufacturer’s data for the particular engine should be used.

c. Example Calculation. The overall corrections to determine installed test brake horsepower and brake horsepower to be used in the expansion of performance would be as follows (refer to Figure A1-2):

Known:
Pressure Altitude...9,500 feet
Manifold Pressure...44.3 in. Hg.
Outside Air Temperature.......................................53.0 ºF
Compressor Inlet Temperature..............................67 ºF
Engine Speed...2,575 r.p.m.
Engine Calibration...+1.7%
Engine Tolerance...±2 1/2%

APPENDIX 2. CLIMB DATA REDUCTION

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1. DRAG POLAR METHOD. This is one method to develop the airplane's drag polar equation directly from climb flight test data. It is a simplified method that assumes climb speeds where the compressibility drag is negligible (usually Mach numbers below 0.6), climb angles of less than 15 degrees, and no propeller slipstream effects on the wing lift and drag characteristics.

a. Cautions. Propeller airplanes are susceptible to slipstream drag, and all airplanes are susceptible to trim drag. This is most noticeable on airplanes with wing-mounted engines and when one engine is inoperative. Care should be given so that drag results are not extended from one flight condition to another. Examples of this are:

(1) Drag obtained in level cruise configuration cannot be extended to a climb configuration.

(2) Two-engine climb data cannot be extended to the one-engine-inoperative case.

In summary, the power and trim conditions must remain very close to those existing for the actual test conditions. Drag results are only as accurate as the available power information and propeller efficiency information. The cooling airflow through the engine is also a factor.

b. Calculation of C_D and C_L. Flight test data for various climb airspeeds, weights, and altitudes should be used to calculate C_D and C_L. The equations are as follows:

$$C_D = \left[BHP_T(\eta_P) - \frac{T_{AT}(AF)(R/C_O W_T)}{(T_{AS})33{,}000}\right]\left[\frac{96209\sqrt{\sigma}}{(V_e)^3 S}\right]$$

$$C_L = \frac{295(W_T)\sqrt{1-\left[\frac{\sqrt{\sigma}}{(101.27V_C)}\frac{T_{AT}(AF)R/C_O}{T_{AS}}\right]^2}}{(V_e)^2 S}$$

Where:

BHP_T = test day horsepower (see Appendix 1)
η_P = propeller efficiency (obtain from propeller manufacturer or may be estimated)
T_{AT} = test air temperature - ºKelvin
T_{AS} = standard air temperature - ºKelvin

R/C_O = observed rate of climb - feet/minute
W_T = airplane test weight - pounds
V_e = equivalent airspeed - knots
S = wing area - square feet
σ = atmospheric density ratio (see Appendix 7, figure 1)
AF = acceleration factor (may be insignificant at lower speeds)

$$AF = \frac{\left(1 + 0.2M^2\right)^{3.5} - 1}{\left(1 + 0.2M^2\right)^{2.5}} - 0.133M^2 + 1$$

Where: M = Mach number
V_C is constant, altitude below 36,089 feet

c. Data Plotting. Once C_D and C_L^2 are calculated from various climb tests at many altitudes, weights, and airspeeds, a plot is made of C_D versus C_L^2. This choice of parameters reduces the parabolic drag polar (C_L vs. C_D) to a straight line relationship. These procedures should be used to establish C_{DP} and e for each configuration where climb data is obtained.

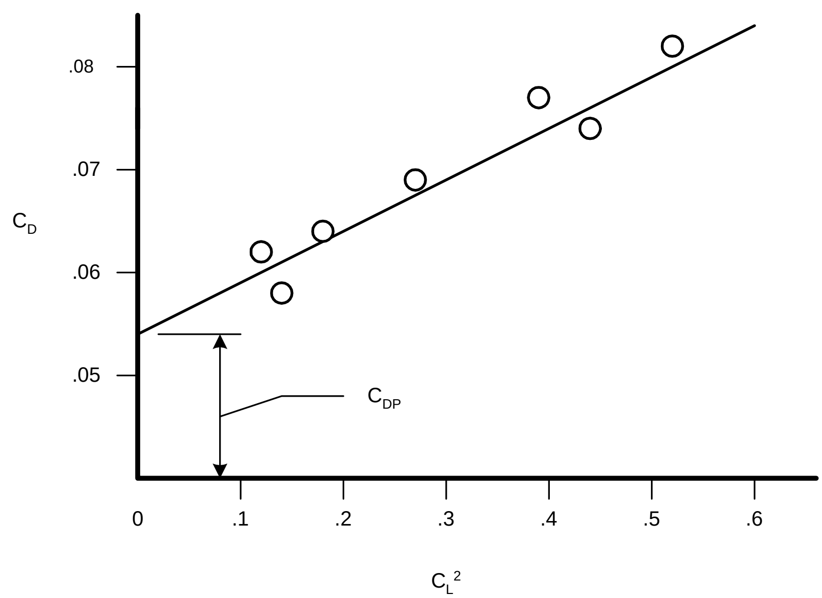

FIGURE A2-1 - COEFFICIENT OF DRAG VERSUS COEFFICIENT OF LIFT

From this plot, the profile drag coefficient (C_{DP}) can be determined graphically and Oswald's efficiency factor (e) can be calculated.

$$e = \frac{C_L^{\,2}}{(C_D - C_{DP})3.1416\left(\frac{b^2}{S}\right)} \qquad \text{or} \qquad e = \frac{\Delta C_L^{\,2} / \Delta C_D}{3.1416\left(\frac{b^2}{S}\right)}$$

Where: b = wing span - feet S = wing area - square feet

d. Standard Day Correction. Since the C_L^2 versus C_D data was developed from test day conditions of weight, altitude, temperature, and power, calculations will be required to determine standard day conditions.

$$R/C = \frac{(THP_A - THP_R)33{,}000}{W_C(AF)}$$

Where:
THP_A = thrust horsepower available
THP_R = thrust horsepower required
W_C = aircraft weight to which correction is to be made (pounds)
AF = acceleration factor (see paragraph b)

$$THP_A = BHPc\,(\eta_P)$$

Where: BHPc = chart brake horsepower at test day density altitude (see Appendix 1)
η_P = propeller efficiency

$$THP_R = \frac{\sigma(V_T)^3 C_{DP} S}{96209} + \frac{(0.2883)(W_C)^2}{e\sigma b^2 V_T}$$

Where:
σ = atmospheric density ratio
V_T = true airspeed - knots
C_{DP} = profile drag coefficient
S = Wing area - square feet
e = efficiency factor
b = wing span - feet
W_C = aircraft weight to which correction is to be made - pounds

e. Expansion to Non-standard Conditions. The methods in paragraph “d” can be used to expand the climb data by choosing weight, altitude, temperature, and the corresponding power available.

f. References. The following references may be of assistance in cases where compressibility drag is a factor, climb angles are greater than 15 degrees, or if the reader wishes to review the basic derivations of the drag polar method:

(1) "Airplane Aerodynamics and Performance" by C. Edward Lan and Jan Roskam. Published and sold by:

Roskam Aviation and Engineering Corporation
Route 4, Box 274
Ottawa, Kansas 66067

(2) Air Force Technical Report No. 6273, "Flight Test Engineering Handbook," by Russell Herrington, et al., dated May 1951. Corrected and revised June 1964-January 1966. Refer to NTIS No. AD 636.392. Available from:

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, Virginia 22161

2. DENSITY ALTITUDE METHOD. This method is an alternate to the Drag Polar Method. The Density Altitude Method is subject to the same cautions as the Drag Polar Method. Item numbers 1, 2, 6, 9, 12, 17, 18, and 19 are observed during flight tests and the remaining items are calculated.

Item No.	Item
1	Pressure Altitude (Hp) – feet
2	Outside Air Temperature – °F
3	Atmospheric Density Ratio – σ
4.	Density Altitude (Hd) – feet. $Hd = 145539\left[1-\left(\sqrt{\sigma}\right)^{.4699}\right]$
5.	Std. Temp. @ Hp (T_S) – °F + 460
6.	IAS – knots
7.	CAS – knots
8.	TAS = $\dfrac{(7)}{\sqrt{(3)}}$
9.	Observed rate of climb – ft/min
10.	$T/T_S = \dfrac{(2) + 460}{(5)}$

11. Actual R/C = (9) * (10)

12. Test Weight, 2- lbs.

13. $\Delta R/C\Delta_{W} =$ (11) (I - $\frac{(12)}{Wc}$

Where W_C = aircraft weight to which correction is to be made

14. $q\pi eb^2 =$ (7) 2 $\frac{\pi eb^2}{295}$

Where: b = wing span in feet
e = Oswald's efficiency factor (0.8 may be used if a more exact value cannot be determined)

15. $\Delta D_8 = \frac{(Wc - (12)^2)}{(14)}$

16. $\Delta(R/C)\ \Delta D_i = 101.27 \frac{(15)\ (8)}{W_S}$

17. Calibrated RPM (reciprocating engine)

18. Calibrated MP (reciprocating engine)
19. Inlet air temperature
20. Test day BHP corrected for temperature from Appendix 1 at Hd
21. η_P -- propeller efficiency (obtain from propeller manufacturer or may be estimated)

22. $\Delta THP =$ ((22) - (21)) (20)

23. $\Delta(R/C)\ \Delta P = \frac{(23)\ X\ 33,000}{W_C}$

24. $R/C_{STD} =$ (11) - (13) - (16) + (24)

Items 4, 7, and 24 are used to plot figure 25-2.