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

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

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)

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

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

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

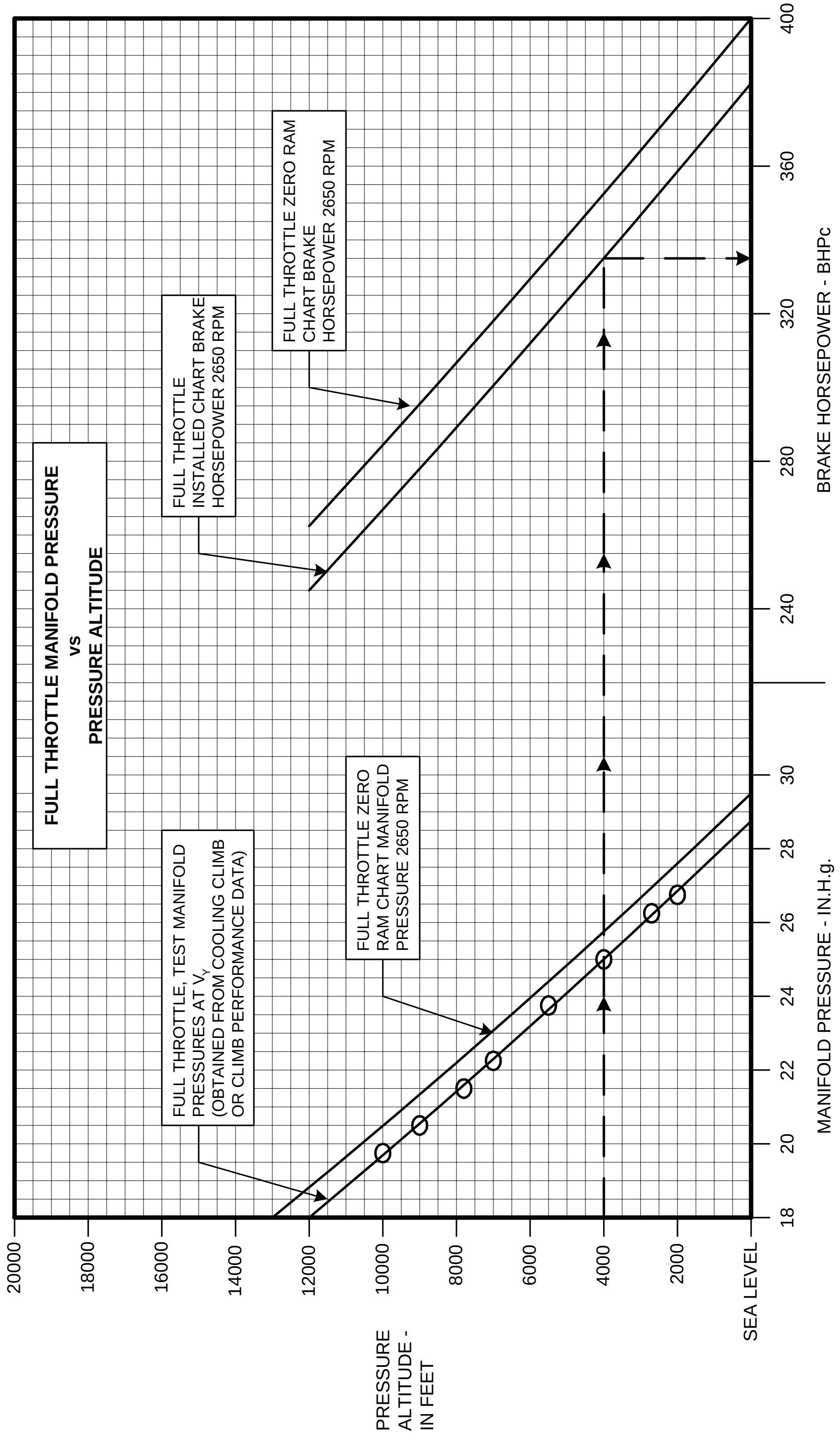

FIGURE A1-1 – BRAKE HORSEPOWER VERSUS PRESSURE ALTITUDE

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

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

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%

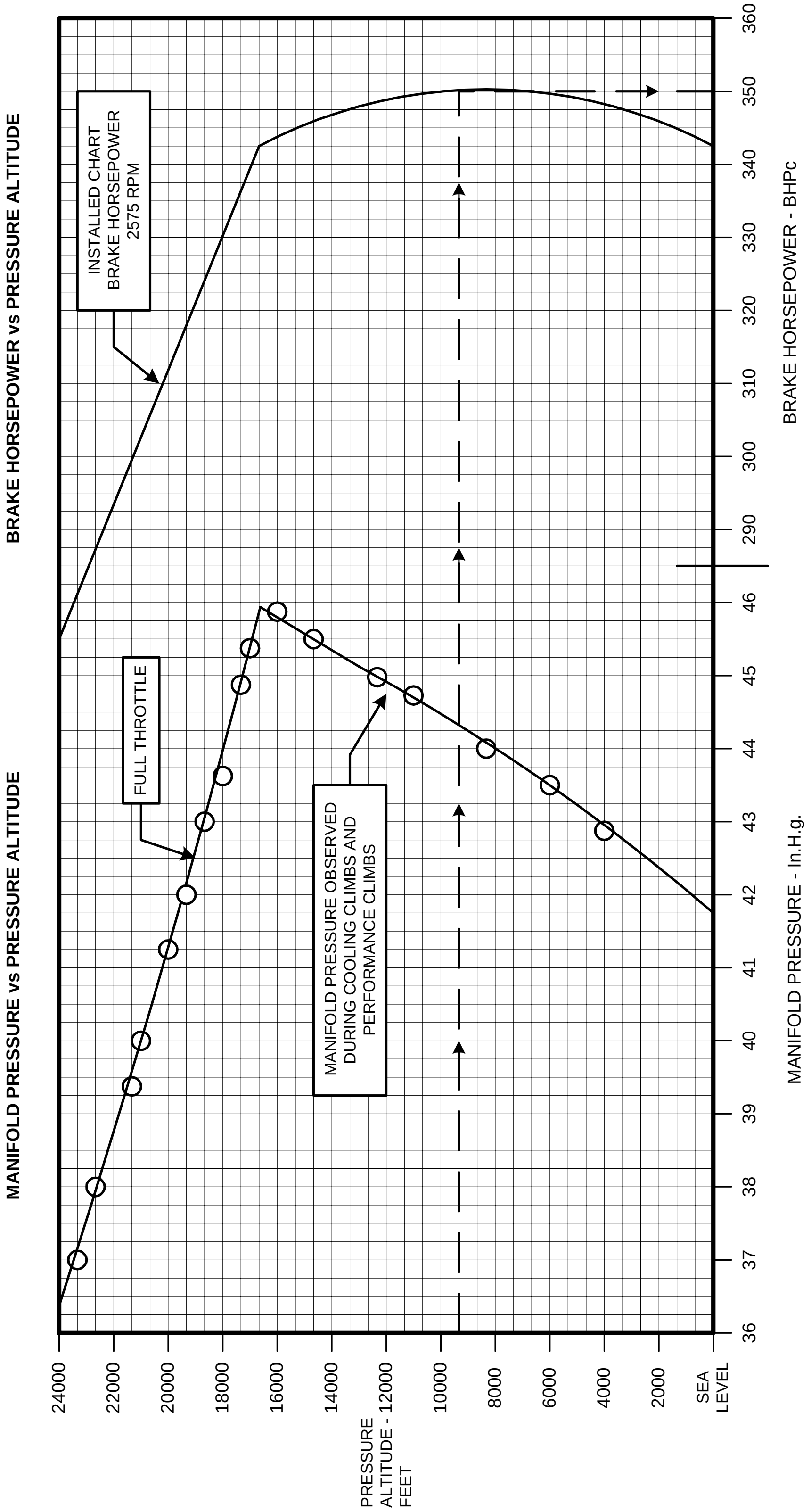

FIGURE A1-2 - TURBOCHARGED BRAKE HORSEPOWER VERSUS ALTITUDE

Calculated Test Day BHP for a Calibrated Engine:

Standard Temperature @ 9,500 ft..25.1 ºF
Power Correction Due to Temperature
at 1%/10 ºF..-4.2%
(Temperature rise = 67º -25.1 ºF)
Installed Chart Brake Horsepower
(from Figure A1-2)..351 BHP
Engine Calibration Correction (351)(.017)......................................+5.97 BHP
Test BHP = (351 + 5.97) - (.042)(356.97).....................................332.1 BHP

Calculated Test Day BHP for an Uncalibrated Engine:

Standard Temperature @ 9,500 ft..25.1 ºF
Power Correction at 1%/10 ºF...-4.2%
Installed Chart Brake Horsepower..351
(from Figure A1-2)
Test BHP = 351 - (351)(.042) + 351(.025).....................................335.3

Calculated BHPc for Test Day Density Altitude (Hd):

Hd at 9,500 ft and 53 ºF..11,280 ft
Installed BHPc (from Figure A1-2)...350 BHP
Power Correction Due to Inlet
Temperature Rise at 1%/10 ºF
(temperature rise = 14 ºF)..-1.4%
BHPc = 350-(350)(.0233)..341.8 BHP

Calculated BHPc for the AFM Expansion:

For the Same Conditions as Test Day,...351 BHP
BHPc (from Figure A1-2)
Temperature Correction to BHPc =..326.5 BHP
350-(.042)(351)

5. NORMALLY ASPIRATED ENGINES WITH FIXED PITCH PROPELLERS. (RESERVED).

6. TURBOPROPELLER ENGINES.

a. Power Measurement. Turbopropeller engines (turboprops) are gas turbine engines that drive a propeller. Power output is a function of the gas turbine airflow, pressure, and temperature. Power measurement is made by measurement of the propeller shaft speed and torque, from which the shaft horsepower can be obtained by a simple calculation. Torque is measured by an integral device that may be mechanical, hydraulic, or electrical and connects to the indicator required by Part 23, § 23.1305(m). Shaft horsepower is the same as brake horsepower, that is, the power developed at the propeller shaft. The total thrust horsepower, or equivalent shaft horsepower (ESHP) is the sum of the shaft horsepower and the nominal horsepower equivalent of the net exhaust thrust.

b. Power Available. The prediction of power available is obtained from the engine manufacturer as a computer program. Each installation must be evaluated to identify:

Generator Loads (all engine and one engine inoperative)
Bleed Air Extractions (with and without ice protection)
Accessory Pad Extractions
Engine Air Inlet Efficiency (with and without ice protection)
Engine Exhaust Efficiency
Effect of Specific Humidity

With these values as input to the computer program, installed power available and fuel flows at various airspeeds, temperatures, and altitudes can be calculated.

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:

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

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

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 ($C_{L\ \text{vs.}}\ C_D$) to a straight line relationship. These procedures should be used to establish C_{DP} and e for each configuration where climb data is obtained.

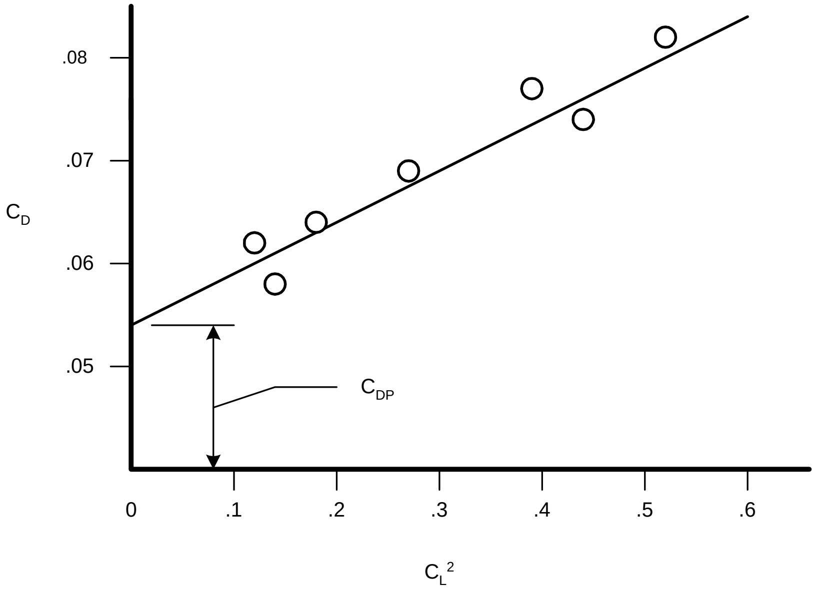

FIGURE A2-1 - COEFFICIENT OF DRAG VERSUS COEFFICIENT OF LIFT

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. $\mathrm{Hd} = 145539\left[1-\left(\sqrt{\sigma}\right)^{.4699}\right]$
5.	Std. Temp. @ Hp (T_S) – °F + 460
6.	IAS – knots
7.	CAS – knots
8.	TAS = $\dfrac{\textcircled{7}}{\sqrt{\textcircled{3}}}$
9.	Observed rate of climb – ft/min
10.	$T/T_S = \dfrac{\textcircled{2} + 460}{\textcircled{5}}$

11. Actual $R/C = \textcircled{9} * \textcircled{10}$

12. Test Weight, 2- lbs.

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

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

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

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. $\Delta D_8 = \frac{\left(Wc - \textcircled{12}^{\,2}\right)}{\textcircled{14}}$

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

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

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

24. $R/C_{STD} = \textcircled{11} - \textcircled{13} - \textcircled{16} + \textcircled{24}$

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

APPENDIX 3. STATIC MINIMUM CONTROL SPEED EXTRAPOLATION TO SEA LEVEL

APPENDIX 3. STATIC MINIMUM CONTROL SPEED EXTRAPOLATION TO SEA LEVEL

1. GENERAL. The purpose of this appendix is to identify one method of extrapolating minimum control speeds (V_{MC}) observed during flight tests, to sea level, standard temperature conditions. There is a geometric relationship between the yawing moment about the c.g. caused by the operating engine, and the rudder deflection necessary to offset this tendency and cause an equilibrium.

2. CALCULATION METHOD. This method involves calculating a geometric constant (C_2) for each observed test value, averaging the results, and calculating a sea level V_{MC}. The equations are as follows:

$$V_{MC} = [(C_2)(\sqrt{\sigma})(THP)]^{1/3}$$

or;

$$C_2 = \frac{{V_{MC}}^3}{(\sqrt{\sigma})(THP)}$$

Where: C_2 = a geometric constant

$\sqrt{\sigma}$ = the square root of the density ratio

THP = thrust horsepower (test shaft horsepower or brake horsepower times propeller efficiency)

3. CAUTIONS AND ASSUMPTIONS. This method has the following associated cautions and assumptions:

a. This method is limited to airplanes with a V_{MC} due to lack of directional control. Each test value of V_{MC} must be observed with full rudder deflection. If, for example, the test conditions result in reaching the force limit (150 pounds rudder force) prior to achieving full rudder deflection, then observed V_{MC} values would require special consideration.

b. The effects of wing lift in the 5 degree bank angle are ignored.

c. Do not use this method for fixed-pitch or windmilling propellers.

d. Any altitude effects that may result from drag on a rotating feathered propeller on the inoperative engine are ignored.

e. Computing a V_{MC} value at sea level involves raising to the power of 1/3 (use 0.33333333). The number of significant digits used affects the resulting computations. For this reason, use at least 8 significant digits.

f. Propeller efficiencies should be reasonable. They may be obtained from propeller efficiency charts provided by the propeller manufacturer, or from other acceptable sources.

4. SAMPLE CALCULATIONS. Test data from two-engine turbopropeller airplanes have been used for illustration. Observations for one takeoff flap setting are presented. The procedures should be repeated for each additional approved takeoff flap setting. Table A3-1 presents five data points that were collected at various altitude and temperature conditions, and the resulting C_2 values that were calculated. For these tests, the inoperative propeller was feathered (auto-feather available).

RUN	PRESSURE ALTITUDE (FEET)	O.A.T. (°F)	TORQUE (FT-LB)	PROPELLER RPM	V_{MC} (KCAS)	$\sqrt{\sigma}$	SHAFT HORSE-POWER	η_p (2)	C_2
1	3500	86.3	3219	1700	91.2	.914243	1041.95	.590	1349.657
2	4200	88.3	3219	1700	91.2	.900795	1041.95	.585	1381.516
3	4800	87.3	3219	1700	90.7	.891588	1041.95	.580	1384.786
4	5500	85.2	3219	1700	90.7	.881668	1041.95	.575	1412.544
5	6300	83.2	3219	1700	90.7	.870083	1041.95	.570	1443.907

TABLE A3-1 - FLIGHT TEST DATA

(1) Calculated from observed torque and propeller rpm

(2) Obtained from propeller manufacturer

The propeller efficiencies were obtained from power coefficient versus advance ratio map, which was obtained from the propeller manufacturer. The 4-blade propellers were assumed for these calculations to have an activity factor = 80; and an integrated lift coefficient = 0.700.

The five C_2 values from Table A3-1 were averaged as 1394.482. The sea level, standard temperature maximum shaft horsepower was 1050. At low speeds, the propeller efficiency changes fairly significantly with speed. For this reason, it is appropriate to determine propeller efficiencies at several speeds near the estimated sea level V_{MC} value. Table A3-2 presents the thrust horsepower values determined for calibrated airspeeds of 90, 95, 100, and 105 knots and the V_{MC} values calculated using these thrust horsepower values and the average C_2 (1394.482).

Figure A3-1 illustrates the plot of airspeed versus thrust horsepower. One curve is of thrust horsepower available versus airspeed. The other represents the calculated V_{MC} values versus thrust horsepower available at sea level. The intersection of the two curves represents the V_{MC} value associated with sea level, standard temperature conditions. These calculations resulted in a final V_{MC} value of 98.8 knots calibrated airspeed.

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V_C (KCAS)	SHAFT HORSEPOWER	η_P	THRUST HORSEPOWER AVAILABLE AT SEA LEVEL	CALCULATED V_{MC} $C_2 = 1394.482$
90	1050	.610	640.5	96.3
95	1050	.640	672.0	97.9
100	1050	.665	698.3	99.1
105	1050	.688	722.4	100.2

TABLE A3-2 - TABULATED THRUST HORSEPOWER AVAILABLE AND CALCULATED V_{MC}

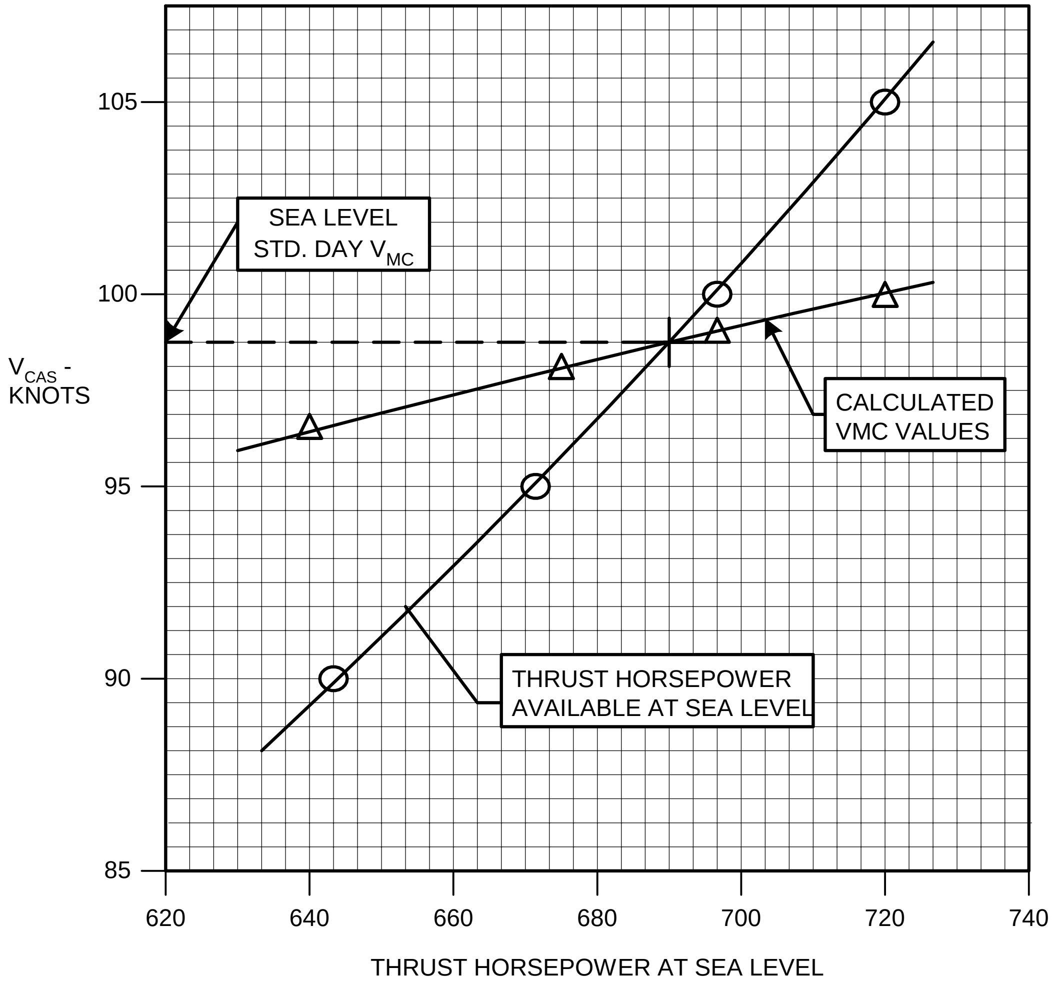

FIGURE A3-1 - THRUST HORSEPOWER AT SEA LEVEL

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