Experiment 2:

Performance Test of The Beech Baron 58

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Flight Test Group 7:

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Introduction

The purpose of this experiment was to observe and analyze the performance characteristics of the twin-engine Beech Baron 58 aircraft. The experiment was performed in a Frasca 242 fixed-base simulator designed to simulate actual aircraft properties of the Baron 58 as well as various flight conditions. Specifically, the flight test dealt with the glide and climb performance of the aircraft at different velocities. This was done using a series of “sawtooth” climbs and descents. Using information gathered in these tests, best glide speed (V_{bg}) and best angle of climb (V_X) could be determined. The team was also to determine the maximum speed of the aircraft in steady, level flight (V_M).

In addition to these three values, nine “bootstrap parameters” were either given or computed using available information and data collected during the flight. These parameters are as follows: wing area (S); aspect ratio (A); engine brake horsepower at sea level (P_0); altitude drop-off parameter (C), propeller diameter (d), parasite drag coefficient (C_{D0}), Oswald’s efficiency factor (e), propeller polar slope (m); and, propeller polar intercept (b).

Using these results, one could plot the “propeller polar” and compare engine thrust data from plot with that computed using the MATLAB function Gengine.m, a program used to compute performance data for a generic piston aircraft engine. Comparisons of glide and climb speeds could also be made with those published in the aircraft’s Pilot’s Operating Handbook.

Experimental and Analytical Procedures

As in previous flight tests, there were three distinct roles for each of the team members to fulfill in order to properly conduct this experiment. These included the pilot of the aircraft, the copilot, and the flight engineer. The pilot was responsible for maintaining the aircraft in flight, and ensuring that the proper flight conditions were met. The copilot was in charge of ensuring all of the proper checklists were completed as well as assisting in any flight maneuvers in which the pilot required help. The flight engineer was primarily responsible for identifying the speed and altitude of the aircraft during the experiment, as well as ensuring that all other aircraft parameters were logged.

The first step of the procedure was to take off from the Purdue University airport (KLAF), and climb to a predetermined altitude. Before takeoff, the copilot read the applicable checklist in order to ensure that the aircraft was in the proper configuration and condition for flight. While KLAF is located at an elevation of 606 feet MSL, the altimeter was set for standard conditions (29.92 mm Hg). Once airborne, the pilot set a course for the west practice area in which the tests were to be conducted. In order to ensure that the experiment could be concluded in the given amount of time, the simulator controller "flew" the aircraft to the practice area instantaneously. Because previous flights had given the pilot adequate experience in controlling the aircraft, flying the aircraft the entire way to the practice area was not essential.

Once the practice area was reached, it the flight test began. The pilot leveled the aircraft at 5500 feet MSL and prepared for the first glide test. During this test, the aircraft was to glide down with a specified velocity. At 5500 feet, the throttles were set to idle and the propeller blades feathered. The airspeed began to decrease and once the airspeed reached the specified value, the glide maneuver was executed. Elevator control was then used to pitch the aircraft down and maintain this speed. While gliding, several measurements were recorded. Once the glide test was completed, the pilot leveled off at 4500 feet and prepared for a climb test.

The climb test was performed in a similar manner to that of the glide test. However, instead of using idle power, full power was used. At 4500 feet, the throttles were set to full power and the airspeed began to increase. Again, once the airspeed reached the specified value, the pilot pitched the aircraft up and maintained this speed throughout the climb. Measurements were recorded and at the end of the climb test, the pilot established an altitude of 5500 feet. While the range of altitude used for both tests was 1000 feet, the tests “occurred” for the middle 400 feet (between 4800 and 5200 feet). This was done in order to give the pilot time to establish the specified airspeed and prepare to sustain that speed throughout the maneuver.

This entire test was conducted two more times, using different airspeeds for glide and climb. These three glide tests and three climb tests would provide enough data for subsequent data analysis. The flight engineer was a key player in this part of the experiment, and was responsible for recording the various speeds, altitudes, and other flight data throughout the rest. This data was produced and recorded from the GIST console of the simulator. The copilot also assisted by aiding the pilot in maintaining constant speed and monitoring roll, yaw, and altitude changes. This allowed the pilot to concentrate solely on airspeed.

The maximum level flight speed was also recorded. The pilot established an altitude of 5030 feet, which was approximately midway between the starting altitudes for the climbs and descents. At this altitude, the throttles were set to full power, increasing airspeed. Once the airspeed stabilized, the value was recorded on the flight data card.

Once all tests were completed, the pilot once again maintained a steady altitude and heading back to the Purdue University airport. The pilot then landed the aircraft as the copilot verified that the landing checklist was followed and completed.

Results

During the flight experiment, several different values were recorded for both gliding and climbing tests, as well as when achieving the maximum level flight speed. These values included altitude, velocity, and weight measurements, as well as temperature and time recordings. Propeller RPM and manifold pressure were also recorded during the flight test.

Table 1 in Appendix I gives the values recorded during the flight experiment. They come directly from the flight data card (see Appendix III). Table 2 in Appendix I shows miscellaneous given data regarding the aircraft, as well as the bootstrap parameters that were known. Tables 3 through 5 in Appendix I are data reductions for the climb test, glide test, and maximum level flight speed test. The main findings of the experiment are as follows: best glide speed is 139 knots, speed for best climb angle is 111 knots, and the maximum level flight speed is 189 knots. Other values are shown in Appendix I. Appendix II shows several plots created using given and computed data.

In addition to numerical data recording, both the pilot and copilot made several observations while flying the aircraft. The pilot's main focus during the tests was to maintain a constant airspeed. The copilot assisted the pilot in this and also monitored the aircraft's roll and direction and altitude changes. At first, the pilot struggled to keep the airspeed constant while climbing and descending, but later was able to effectively control the aircraft's speed. The pilot noted that it was very difficult to pitch the aircraft in the proper direction in order to either increase or decrease speed. The pilot also observed that by the time a constant speed was established, the aircraft had reached its ending altitude and the test was already over. In later tests, these problems were minimized as the pilot became more familiar with the testing procedure.

Discussion

The flight data was used to compute several other values, including the unknown bootstrap parameters. MATLAB code supplied by Dr. Dominick Andrisani assisted in this analysis. This information allowed the formation of plots that supplied us with useful data. The first part of the lab required us to calculate the best glide angle of the aircraft. By using Equation 1, shown below, this was found to be about seven degrees, at an airspeed of approximately 139 knots.

$$g = \sin^{-1}\frac{\Delta H}{V\Delta t} \qquad \text{(Eqn. 1)}$$

According to the Pilot Handbook for the Beech Baron 58, the craft should be able to glide for two nautical miles for every 1000 feet of altitude (see Appendix IV). This means that in our experiment a gliding distance of approximately 10 nautical miles was expected. Because the handbook was using 115 knots as its base speed, the actual distance that could be traversed by the Beech Baron maintaining an airspeed of 139 knots is much greater than 10 nautical miles. This is helpful for pilots to know because if there is in a engine failure during flight it is nice to know how far the plane can glide and for how long.

The best climb angle was calculated, again using Equation 1. This angle was found to be 33 degrees, at an airspeed of 188 ft/s or 111 knots. Compared to the Pilot's Operating Handbook, this speed is slightly faster (see Appendix IV). The reason for this difference is most likely due to the fact that the speed in the handbook is for an aircraft with a weight of 5500 pounds, while at the time of the experiment the aircraft weighed approximately only 5000 pounds.

The last part of the lab required studying the maximum level speed of the aircraft as well as studying the propeller performance data, and to construct a drag polar for the aircraft. The drag polar was found by using Equations 2, 3, and 4. These equations are given below:

$$C_{D_0} = \frac{W_{bg} \sin G_{bg}}{r_{mid-glide} S V_{bg}^2} \qquad \text{(Eqn. 2)}$$

$$e = \frac{4C_{D_0}}{pA \tan^2 G_{bg}} \qquad \text{(Eqn. 3)}$$

$$C_D = C_{D_0} + \frac{1}{pAe} C_L^2 \qquad \text{(Eqn. 4)}$$

Equation 3 was used to calculate the Oswald's Efficiency factor of the airplane. This factor was found to be approximately 0.2. This number is close to what was expected for aircraft of this configuration.

To create the propeller polar the MATLAB script, Proppolar.m was used. This code had to be modified slightly to account for the data for the engine that is used in a Beech Baron 58 aircraft. It was also necessary to scale the output of the code to a 285 horsepower engine, since the code is designed for a 300 horsepower engine. The propeller polar intercept was computed using Equation 5, while the slope of the polar is given in Equations 6 and 7. These equations are given below:

$$b = \frac{SC_{D_0}}{2d^2} - \frac{2W_x^2}{r_{mid-x}^2 d^2 SpeAV_X^4} \qquad \text{(Eqn. 5)}$$

$$m = \frac{2n_0 dW_{ave}^2}{\Phi(s)P_0 r\, SpeA}\left(\frac{1}{V_M^2} + \frac{V_M^2}{V_X^4}\right) \qquad \text{(Eqn. 6)}$$

$$\Phi(s) = \frac{s - C}{1 - C} \qquad \text{(Eqn. 7)}$$

When comparing the results between using Gengine.m and the propeller polar to find the thrust as a function of velocity it can be seen that for low speeds the data matches fairly close.

The error in the difference between the two is generally less than 5% up to a speed of bout 130 knots. After this speed the data starts to diverge, with the Gengine.m data remaining more or less constant while the data from the propeller polar starts to decrease. The reason for this is most likely do to Mach effects on the tips of the propeller blade.

Conclusions

In conclusion, this lab emphasized how the nine bootstrap parameters could be used to obtain all the necessary information about an aircraft. With these parameters, the drag polar and propeller polar were found as well as the best climb angle and speed, and the best descent angle and speed.

The team was able to see first hand exactly how an aircraft behaves when climbing and gliding. The pilot especially observed the difficulty in controlling the aircraft speed during such maneuvers. Subsequent analysis showed that there was an optimal climb speed in order gain the most altitude as possible in a given distance. At an airspeed either slower or faster than this, a smaller gain in altitude would be achieved. In the same way, there was an optimal airspeed in order to cover the greatest distance over a given loss in altitude. Again, traveling at an airspeed either slower or faster than this would allow a smaller distance to be covered.

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Appendix I: Tables from Experiment and Analysis

Table 1: Beech Baron 58 Performance Test – Experimental Flight Data

A. *GLIDE TEST*	*Test 1*	*Test 2*	*Test 3*
Weight of fuel ($W_{f\text{-}glide}$) [lbf]	**424.2**	**431.0**	**442.0**
Aim Airspeed (V_{aim}) [kts]	**120**	**125**	**130**
Aim Pressure Altitude at Top of Glide (H_{aim}) [ft]	**5500**	**5500**	**5500**
Pressure Altitude at Start of Glide ($H_{i\text{-}start}$) [ft]	**5216**	**5210**	**5204**
Indicated Airspeed at Start of Glide ($V_{i\text{-}start}$) [kts]	**121**	**128**	**134**
Watch Time at 5200 ft [sec]	**13**	**12**	**15**
Outside Air Temperature at 5000 ft (T_{mid}) [°C]	**5**	**5**	**5**
Watch Time at 4800 ft [sec]	**28**	**25**	**28**
Pressure Altitude at End of Glide($H_{i\text{-}end}$) [ft]	**4804**	**4807**	**4805**
Indicated Airspeed at End of Glide ($V_{i\text{-}end}$) [ft]	**124**	**131**	**138**
B. *CLIMB TEST*	*Test 1*	*Test 2*	*Test 3*
Initial Weight of Fuel (W_i) [lbf]	**424.2**	**431.0**	**442.0**
Aim Airspeed (V_{aim}) [kts]	**95**	**100**	**105**
Aim Pressure Altitude at Bottom of Glide (H_{aim}) [ft]	**4500**	**4500**	**4500**
Indicated Airspeed at 4800 ft ($V_{i\text{-}start}$) [ft]	**96**	**107**	**104**
Outside Air Temperature at 5000 ft (T_{mid}) [°C]	**5**	**5**	**5**
Indicated Airspeed at 5200 ft ($V_{i\text{-}end}$) [ft]	**97**	**100**	**107**
Final Weight of Fuel (W_f) [lbf]	**419.1**	**424.0**	**436.6**
Elapsed Time from 4800 to 5200 ft (?t_c) [sec]	**14**	**10**	**15**
C. *MAX LEVEL SPEED*	*Test*	-	-
Weight of Fuel (W_{fM}) [lbf]	**401.5**	**-**	**-**
Pressure Altitude (H_{pM}) [ft]	**5030**	**-**	**-**
Outside Air Temperature at Top of Glide (T_M) [°C]	**5**	**-**	**-**
Airspeed (V_{iM}) [kts]	**189**	**-**	**-**
Propeller RPM	**2750**	**-**	**-**
Manifold Pressure [in Hg]	**25**	**-**	**-**

Table 2: Beech Baron 58 Performance Test – Miscellaneous Data and Known Bootstrap Parameters

Number of Engines	**2**
Horsepower per Engine	**285**
Nominal RPM	**2700**
Sea Level Brake Horsepower (P_0) [RPM]	**313500**
Sea Level Engine Rotation (n_0) [rev/sec]	**45**
Sea Level Engine Rotation [rad/sec]	**282.743**
Wing Area (S) [ft^2]	**199.2**
Aspect Ratio (A)	**7.17**
Rated Mean Sea Level Torque [ft-lbf/rad]	**1108.78**
Altitude Drop-off Parameter (C)	**0.12**
Propeller Diameter [ft]	**6.333**

Table 3: Beech Baron 58 Performance Test – Glide Test Data Reduction

	Test 1	*Test 2*	*Test 3*
Indicated Airspeed (V_i) [kts]	**122.5**	**129.5**	**136**
Calibrated Airspeed (V_c) [kts]	**122.5**	**129.5**	**136**
Equivalent Airspeed (V_e) [kts]	**122.4**	**129.4**	**135.9**
True Airspeed (V_T) [kts]	**131.8**	**139.4**	**146.3**
Indicated Pressure Altitude at Start of Glide ($H_{i-start}$) [ft]	**5216**	**5210**	**5204**
Calibrated Pressure Altitude at Start of Glide ($H_{c-start}$) [ft]	**5211**	**5205**	**5204**
Indicated Pressure Altitude at End of Glide (H_{i-end}) [ft]	**4804**	**4807**	**4805**
Calibrated Pressure Altitude at End of Glide (H_{c-end}) [ft]	**4799**	**4802**	**4799**
Atmospheric Pressure at 5000 ft (P_{mid}) [lbf/ft^2]	**1761**	**1761**	**1761**
Outside Air Temperature at 5000 ft (T_{mid}) [°R]	**500.67**	**500.67**	**500.67**
Density at 5000 ft (?$_{mid-glide}$) [slug/ft^3]	**.002**	**.002**	**.002**
Density Ratio at 5000 ft (s $_{mid}$)	**.86**	**.86**	**.86**
Change in Calibrated Pressure Altitude for Glide (?H_c) [ft]	**-411.9**	**-402.9**	**-398.9**
Standard Temperature for 5000 ft (T_s) [°R]	**501**	**501**	**501**
True Change in Altitude (? H) [ft]	**-411.8**	**-402.8**	**-398.8**
Aircraft Weight (W_{glide}) [lbf]	**4891**	**4898**	**4909**
Elapsed Time of Glide from 5200 to 4800 ft (?t) [sec]	**28**	**25**	**28**

Table 4: Beech Baron 58 Performance Test – Climb Test Data Reduction

	Test 1	*Test 2*	*Test 3*
Indicated Airspeed (V_i) [kts]	**96.5**	**103.5**	**105.5**
Calibrated Airspeed (V_c) [kts]	**96.5**	**103.5**	**105.5**
Equivalent Airspeed (V_e) [kts]	**96.4**	**103.4**	**105.4**
True Airspeed (V_T) [kts]	**103.9**	**111.4**	**113.6**
True Airspeed (V_T) [ft/sec]	**175.4**	**188.0**	**191.8**
Indicated Pressure Altitude at Start of Climb ($H_{i\text{-}start}$) [ft]	**4500**	**4500**	**4500**
Calibrated Pressure Altitude at Start of Climb ($H_{c\text{-}start}$) [ft]	**4496**	**4496**	**4496**
Indicated Pressure Altitude at End of Climb ($H_{i\text{-}end}$) [ft]	**5500**	**5500**	**5500**
Calibrated Pressure Altitude at End of Climb ($H_{c\text{-}end}$) [ft]	**5496**	**5496**	**5496**
Change in Calibrated Pressure Altitude for Climb (?H_c) [ft]	**999.8**	**999.8**	**999.8**
Outside Air Temperature at 5000 ft (T_{mid}) [°R]	**500.67**	**500.67**	**500.67**
Atmospheric Pressure at 5000 ft (P_{mid}) [lbf/ft^2]	**1761**	**1761**	**1761**
Density at 5000 ft (?$_{mid}$) [slug/ft^3]	**.002**	**.002**	**.002**
Density Ratio at 5000 ft (s $_{mid}$)	**.86**	**.86**	**.86**
Standard Temperature for 5000 ft (T_s) [°R]	**501**	**501**	**501**
Change in Altitude for Standard Day (?$H_{standard}$) [ft]	**999.5**	**999.5**	**999.5**
Average Aircraft Weight for Test (W_{ave}) [lbf]	**4817**	**4823**	**4834**

Table 5: Beech Baron 58 Performance Test – Maximum Level Speed Test Data Reduction

Indicated Airspeed (V_{iM}) [kts]	**189**
Calibrated Airspeed (V_c) [kts]	**189**
Equivalent Airspeed (V_e) [kts]	**189**
True Airspeed (V_M) [kts]	**203**
True Airspeed (V_M) [ft/sec]	**343**
Indicated Pressure Altitude (H_{iM}) [ft]	**5030**
Calibrated Pressure Altitude (H_c) [ft]	**5022**
Pressure for Calibrated Pressure Altitude (P_M) [ft]	**1759**
Outside Air Temperature (T_M) [°R]	**500.67**
Density (?$_M$) [slug/ft^3]	**.002**
Density Ratio (s_M)	**.86**
Weight of Aircraft (W_M) [lb]	**4797**

Appendix II: Figures from Experimental Analysis

Figure 1: Beech Baron 58 Performance Test – Plot of Glide Angle vs. True Airspeed

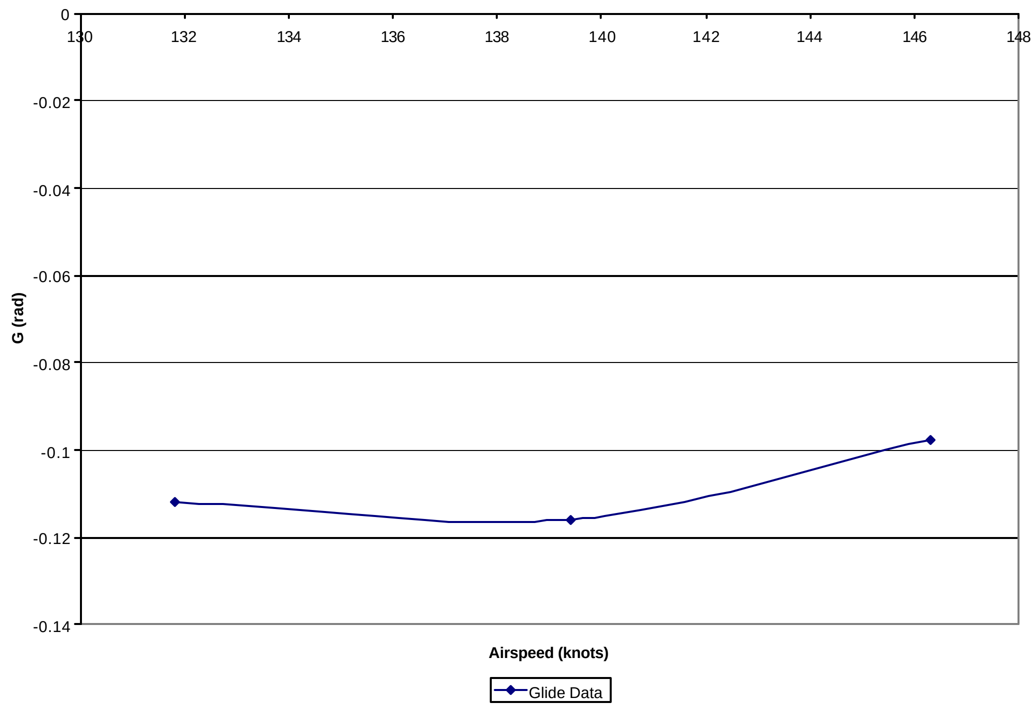

Figure 2: Beech Baron 58 Performance Test – Plot of Climb Angle vs. True Airspeed

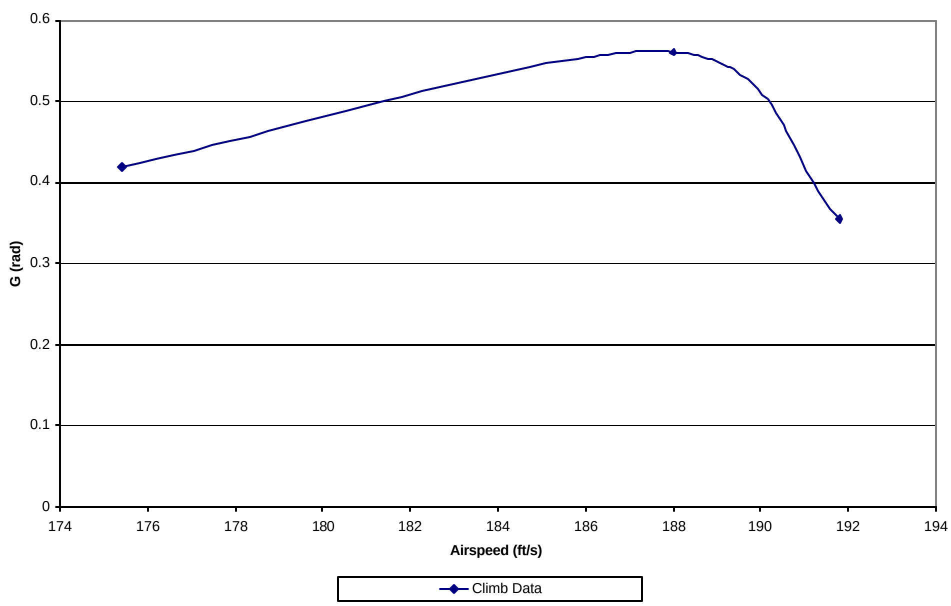

Figure 3: Beech Baron 58 Performance Test – Plot of Drag Polar (C_D vs. C_L)

(attached)

Figure 4: Beech Baron 58 Performance Test – Plot of Thrust vs. Velocity

(attached)

Appendix III: Flight Data Card

Bootstrap Approach Data Card						
Aircraft:	Operating Empty Weight (OEW, a/c wt - wt of fuel) lbf					
A. Glide	1	2	3	4	5	6
$W_{f\text{-glide}}$ Weight of fuel (lbf)	442			424.2	431	
V_{aim} Aim Airspeed (knots)	105	110	115	120	125	130
H_{aim} Aim Pressure Alt. top of glide (ft) (~5500 ft)	5500	5500	5500	5500	5500	5500
$H_{i\text{-start}}$ Pressure Alt. start of glide (ft) (~5200 ft)	5204			5216	5210	
$V_{i\text{-start}}$ Indicated Airspeed at start of glide (knots)	134			121	128	
Watch time at 5200 ft (sec)	15			13	12	
T_{mid} OAT 5000ft (degC)	5			5	25	
Watch time at 4800 ft (sec)	28			28	6	
$H_{i\text{-end}}$ Pressure Alt. end of glide (ft) (~4800 ft)	4805			4804	4807	
$V_{i\text{-end}}$ Indicated Airspeed at end of glide (knots)	138			124	131	
B. Climb						
W_i Initial weight of fuel(lbf)				424.2	431	442
V_{aim} Aim Airspeed (knots)	80	85	90	95	100	105
Pressure Alt. bottom of climb, ft (~4500 ft)	4500	4500	4500	4500	4500	4500
$V_{i\text{-start}}$ Indicated Airspeed at 4800 ft (knot)				96	107	104
T_{mid} OAT 5000 ft (degC)				5	5	5
$V_{i\text{-end}}$ Indicated Airspeed 5200 ft (knots)				97	100	107
W_f Final weight of fuel (lbf)				419.1	424	436.6
Δt_c Elapsed time from 4800 to 5200 ft (sec)				14	10	15

Bootstrap Approach Data Card (continued)	
Aircraft:	
C. Max Level Speed	
W_{fM} Weight of fuel (lbf)	401.5
H_{pM} Pressure Alt. (ft)	5030
T_M OAT top of glide (degC) watch units!	5
V_{iM} Airspeed (knots)	189
Propeller RPM	2750
Manifold Pressure (in Hg)	25

Appendix IV: Excerpts from *Pilot's Operating Handbook: Beech Baron 58*

Glide:

Propellers feathered, flaps up, gear up, indicated airspeed 115 knots. "The glide ratio in this configuration is approximately 2 nautical miles of gliding distance for each 1000 feet of altitude about the terrain" [p. 3-8]

Climb:

Two-Engine Best Angle of Climb V_X is 92 knots indicated airspeed for 5500 pound operation.