

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, DC

Nov 24, 2014

Soldotna Kinematics Study

Dennis Crider

A. ACCIDENT: DCA13MA121

Location:	Soldotna, Alaska
Date:	July 7, 2013
Time:	1120 ADT
Airplane:	DHC-3, Registration N93PC
NTSB Number:	DCA13MA121

B. GROUP IDENTIFICATION:

No group was formed for this activity.

C. SUMMARY

On July 7, 2013, about 1120 Alaska daylight time, a DeHavilland DHC-3 “Otter” airplane, N93PC, was destroyed after a collision with terrain shortly after takeoff from the Soldotna Airport (SXQ), Soldotna, Alaska. The airplane was registered to Rediske Family Limited Partnership, Nikiski, Alaska, and was operated by Rediske Air, Inc. under the provisions of 14 CFR Part 135, as an on-demand charter flight. The commercial pilot and nine passengers were fatally injured. Visual meteorological conditions prevailed and no flight plan was filed for the flight destined to Bear Mountain Lodge, approximately 90 miles southwest of Soldotna.

D. DETAILS OF INVESTIGATION

Purpose of Study

It was desired to estimate the weight and center of gravity (c.g.) for the accident flight from the motion of the aircraft described in the video study as an additional method to that used in the “Weight and Balance Study”.

Method

Per standard industry practice, pitching moment coefficients for the DeHavilland DHC-3 are provided about the quarter chord of the wing and the moment transferred to the aircraft c.g. in the pitching moment buildup using the following equation element.

$$C_L (x_{cg}/c_{wing} - 0.25)$$

A kinematics parameter extraction was done to obtain the pitching moment coefficient required for the aircraft's motion and the difference between the pitching moment required and the pitching moment from the simulation model. A value of x_{cg}/c_{wing} was then obtained to eliminate this difference. The study assumed that the pilot applied full down pitch control as soon as the tendency to pitch up was detected. Calculations showed that stick forces at these low speeds would have been well within the pilot's capabilities. The stabilizer was assumed to have remained at 1.91 deg as found in the wreckage examination for the flight.

Motion data was obtained from the Video Study which accordingly set the time base for this report. Motion data was developed up to the time the aircraft rolled off. Inertial speed and pitch from this study are reproduced in figure 1. Vertical load factor was calculated from inertial speed and pitch rate and is presented in figure 2.

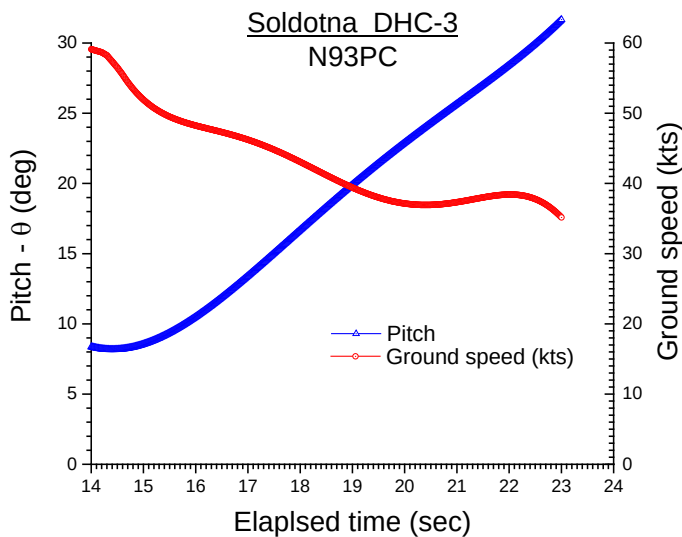


Figure 1 Pitch and ground speed

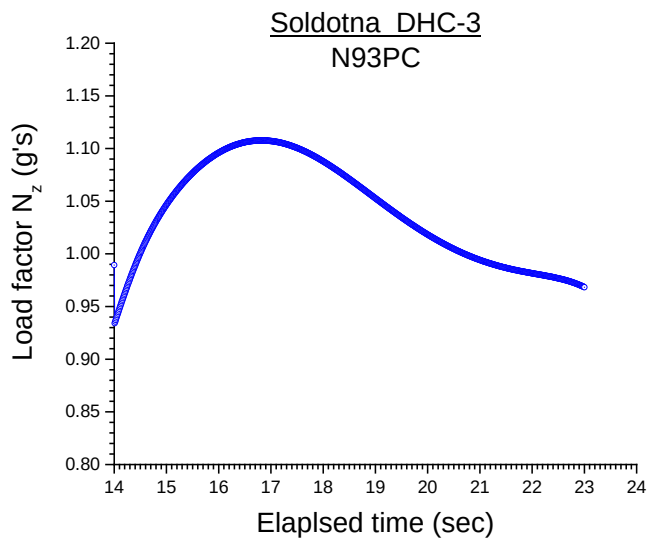


Figure 2 Load factor

Classically, ground effect affects the airplane up to an altitude of one half of the wing span or 29 ft altitude for the Otter. This is marked on the plot of altitude in figure 3 and in results plots to follow to indicate areas where the kinematic results are not expected to be valid as the model does not take ground effect into account.

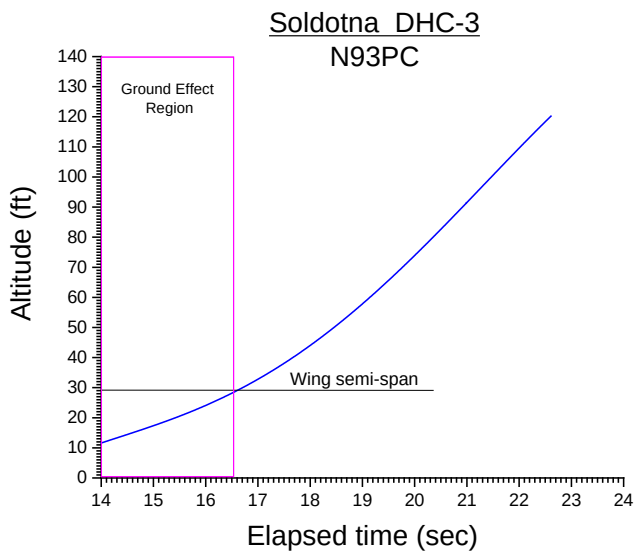


Figure 3 Altitude

Simulation Model

The math model for the original Otter Pratt & Whitney R-1340 engine was obtained from Viking Air. Validation data was limited to a couple of flaps down static stability cases where only stick force and trim stabilizer were available. Downwash was adjusted to match stabilizer and the derivative of elevator hinge moment with elevator adjusted to match stick force. The accident aircraft was modified with the Texas Turbine conversion and Baron STOL kit (a drooped leading edge and new wingtips). Accordingly, the baseline Otter simulation model was modified to account for the extended nose and power characteristics of the Texas Turbine (see Appendix A). The aerodynamic increments for the Baron STOL kit were obtained from Transport Canada certification data. The nose up pitching moment increment due to the modifications is significant, equivalent to approximately 7 inches of c.g. for this study.

Results

With perfect data (simulation model, angle of attack and airspeed) it would be possible to calculate the weight for the model to match the extracted lift coefficient. The basic lift parameters (C_{L0} and $\delta C_L / \delta \alpha$) are standard with expected values and considered reliable. As mentioned above, stabilizer was matched by adjusting downwash. The values of tail lift slope and elevator effectiveness were as expected and likewise considered reliable. Accordingly, the lift aero model was judged reliable for this purpose. The impact of the turbine conversion and the Baron STOL kit is, however, more significant in pitch. These uncertainties in pitch aerodynamics will be reflected in some uncertainty in the calculated c.g. For example, if the aerodynamic pitching moment coefficient increment for the modifications is 5% low, the c.g. required for the motion would shift forward 0.17 inches.

Angle of attack and airspeed were calculated from wind as well as ground speed, climb rate and pitch angle from the video. It was found that derived weight was very sensitive to wind speed. This was not surprising since lift is proportional to airspeed squared and low ground speed makes wind proportionally more important. Thus lack of precise winds precluded deriving weight. Accordingly, it was decided to derive wind for 7800 lbs and 8050 lbs based on likely weights from the “Weight and Balance Study.” Required center of gravity was then determined for each weight.

7800 lb Results

The lift coefficient required for a 7800 lb weight is shown plotted with angle of attack calculated with the required winds in figure 4. Winds were iterated to minimize the difference between the lift coefficient required for the motion and the lift coefficient from the simulation model shown in figure 5. The associated headwind is shown in figure 6 and airspeed shown in figure 7.

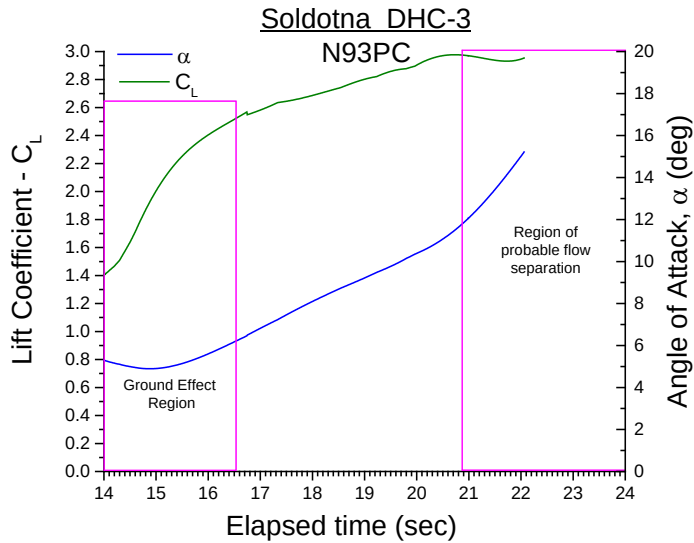


Figure 4 Lift coefficient and angle of attack for 7800 lb case

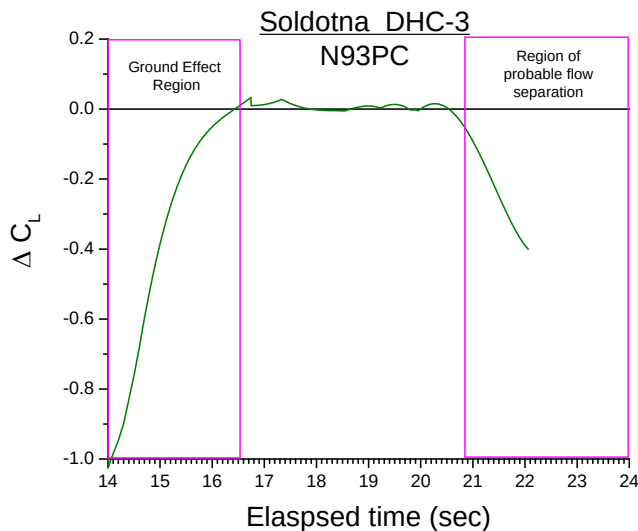


Figure 5 Lift coefficient difference (7800 lb case).

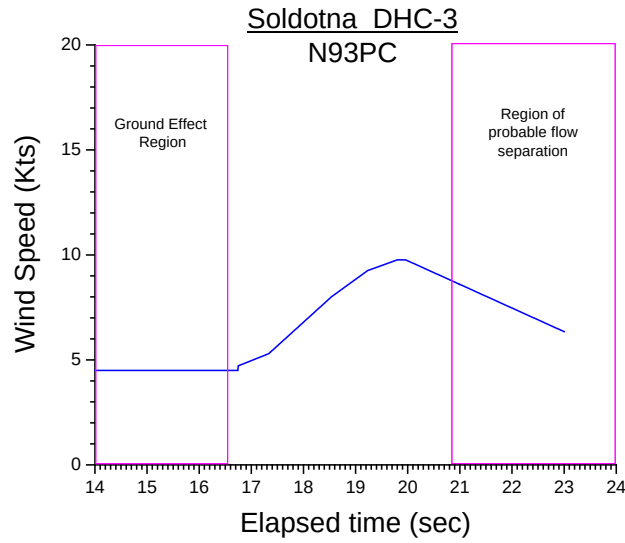


Figure 6 Wind speed (7800 lb case)

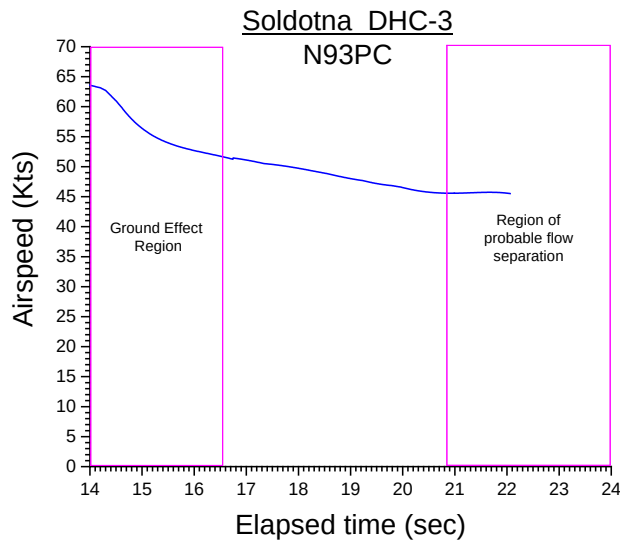


Figure 7 Airspeed (7800 lb case winds)

The required pitching moment coefficient for a 7800 lb weight is shown in figure 8 and the required drag coefficient is shown in figure 9.

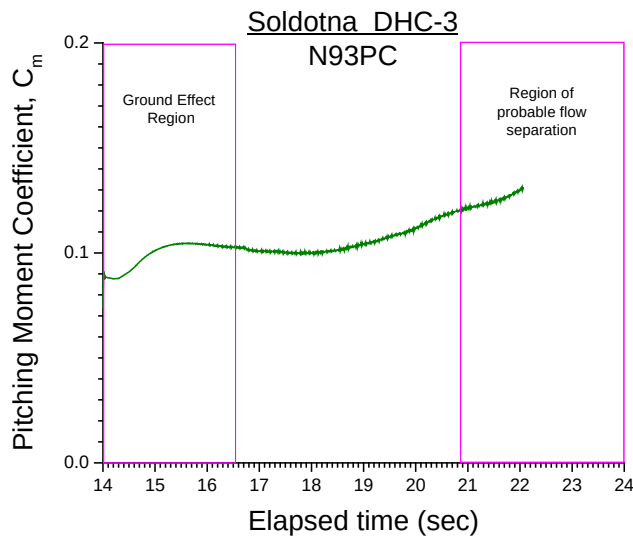


Figure 8 Required pitching moment coefficient (7800 lb)

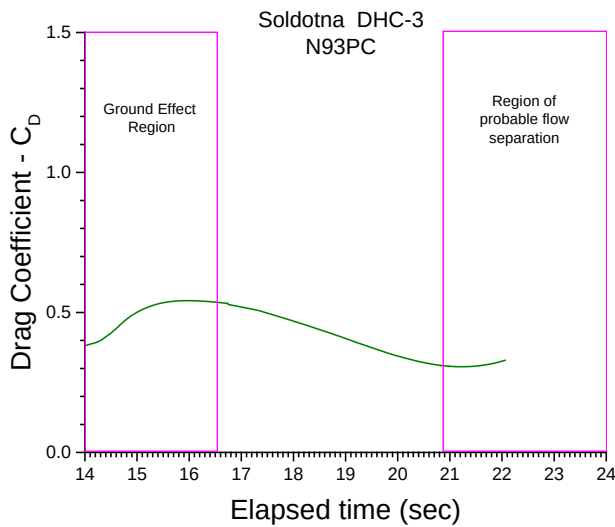


Figure 9 Required drag coefficient (7800 lbs)

Center of gravity was adjusted to minimize the difference between the pitching moment coefficient required for the motion and the pitching moment coefficient from the simulation model divided by lift coefficient as shown in figure 10. This parameter corresponded directly to a difference in c.g. as a percent of mean aerodynamic chord.

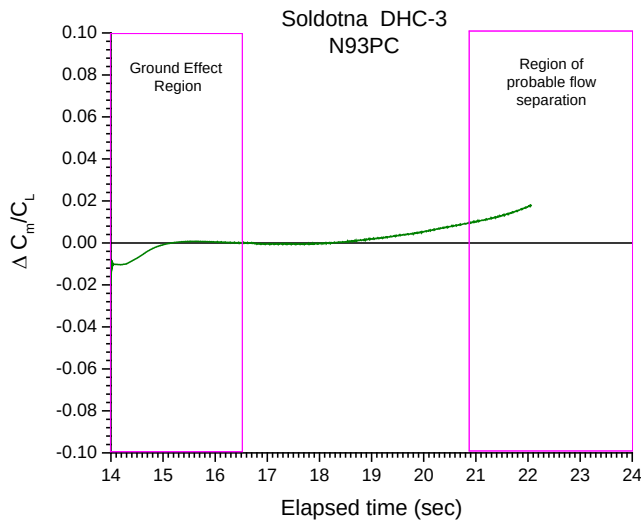


Figure 10 Change in pitching moment/lift coefficient (7800 lb)

The center of gravity required for the recorded motion with a 7800 lb aircraft and the pilot applying full pitch down yoke with 1.91 deg stabilizer is 52.5% mean aerodynamic chord. This is 161.1 inches which is aft of the 152.2 inch (41% mean aerodynamic chord) aft limit for the aircraft.

8050 lb Results

The lift coefficient required for an 8050 lb weight is shown plotted with angle of attack calculated with the required winds in figure 11. Winds were iterated to minimize the difference between the lift coefficient required for the motion and the lift coefficient from the simulation model shown in figure 12. The associated headwind is shown in figure 13 and airspeed shown in figure 14.

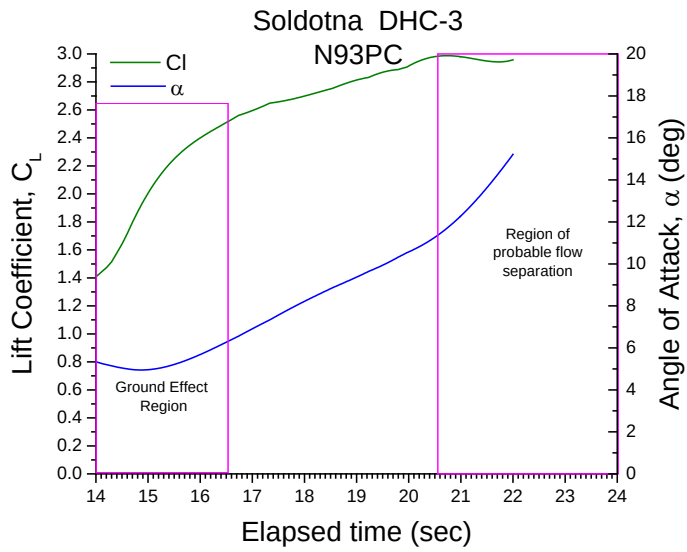


Figure 11 Lift coefficient and angle of attack for 8050 lb case

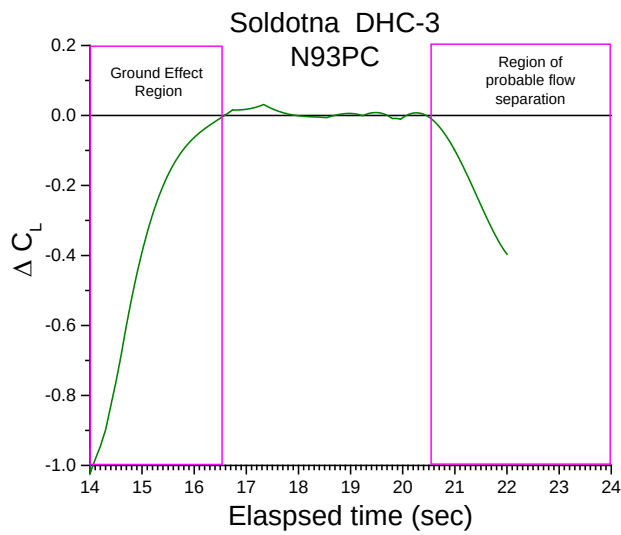


Figure 12 Lift coefficient difference (8050 lb case).

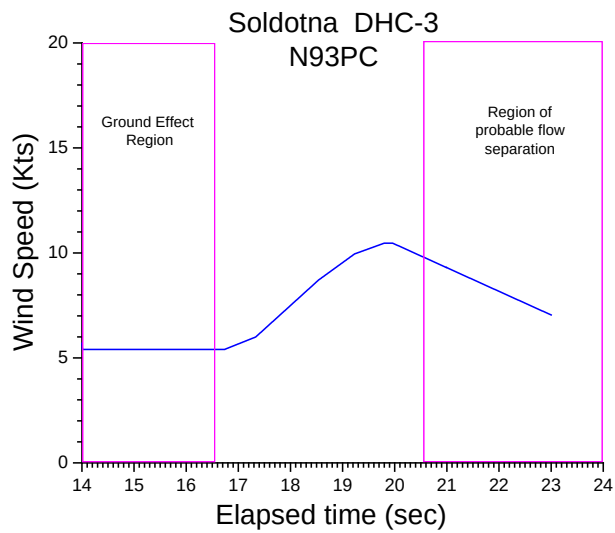


Figure 13 Wind speed (8050 lb case)

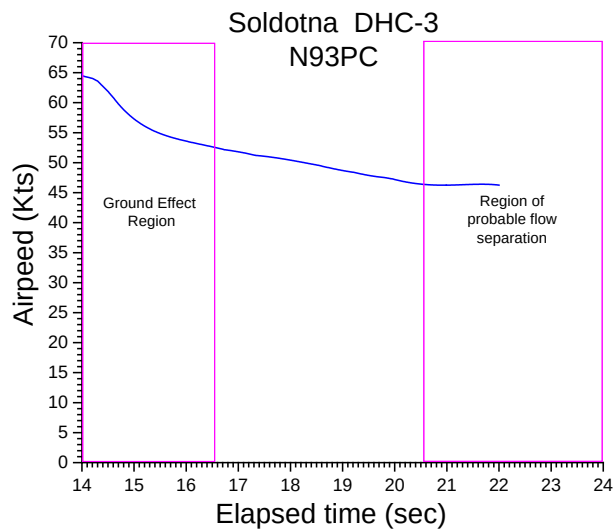


Figure 14 Airspeed (8050 lb case winds)

The required pitching moment coefficient for an 8050 lb weight is shown in figure 15 and the required drag coefficient is shown in figure 16.

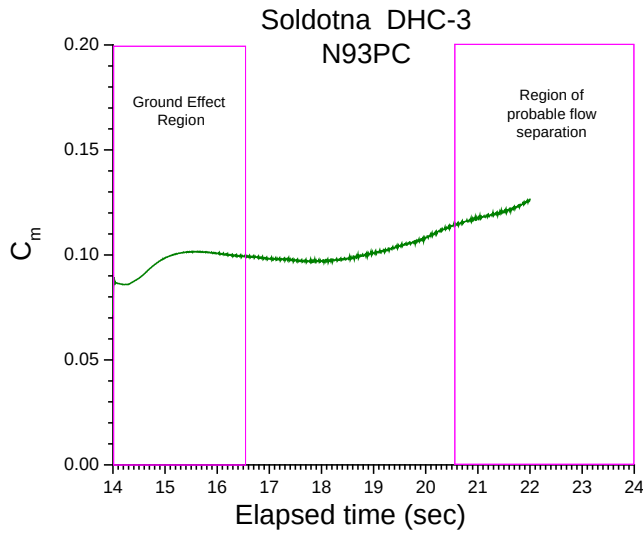


Figure 15 Required pitching moment coefficient (8050 lb)

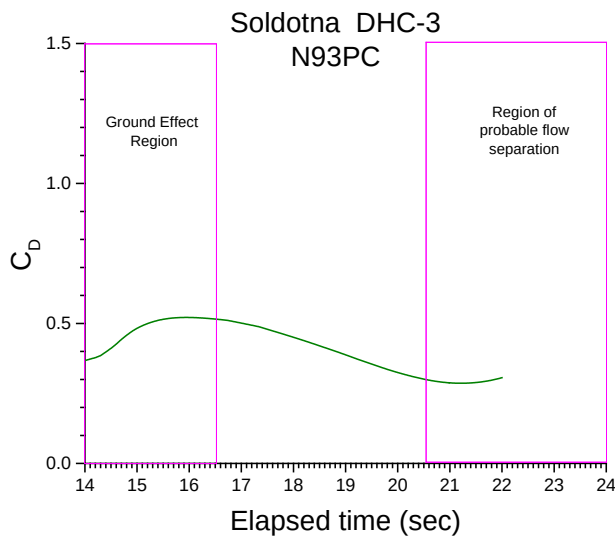


Figure 16 Required drag coefficient (8050 lbs)

Center of gravity was adjusted to minimize the difference between the pitching moment coefficient required for the motion and the pitching moment coefficient from the simulation model divided by lift coefficient as shown in figure 17. This parameter corresponded directly to a difference in c.g. as a percent of mean aerodynamic chord.

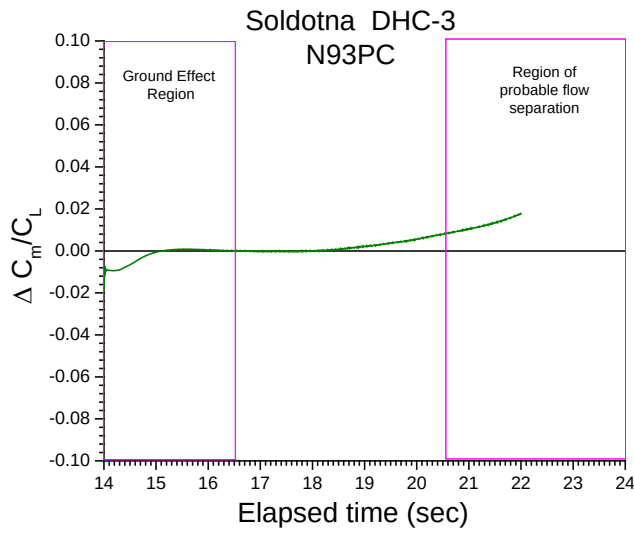


Figure 17 Change in pitching moment/lift coefficient (8050 lb)

The center of gravity required for the recorded motion with an 8050 lb aircraft and the pilot applying full pitch down yoke with 1.91 deg stabilizer is 52.4% mean aerodynamic chord. This is 161.1 inches which is aft of the 152.2 inch (41% mean aerodynamic chord) aft limit for the aircraft.

Conclusions

It was not possible to estimate the weight of the accident aircraft utilizing this method due to the high sensitivity of the solution to wind speed, which was not known precisely. Derived center of gravity however was not very sensitive to weight. With the pilot applying full pitch down yoke with 1.91 deg stabilizer, the center of gravity required for the motion, subject to some uncertainty as outlined above, was about 52.4% mean aerodynamic chord (just past 161 inches) for both possible weights examined. The center of gravity was significantly aft of the 152.2 inch (41% mean aerodynamic chord) aft limit for the aircraft.

Appendix A

Aerodynamic Estimates

Some of the original aerodynamic workbooks sheets for the DHC-3 were made available to the Board for use in the investigation. These workbooks contained some redundancy but it was often difficult to determine what superseded what.

Fig 3 to fig 8 (pg 13 to pg 18) of AEROC 3.2.G.1 contains tail off pitching moment at forward and aft c.g.'s, horizontal tail lift curves and stabilizer incidence for trim. The structure of these plots imply that a flight test match was done. Drag data was obtained from AEROC 3.2.G.2 sec 6-2 pg 4 issue 9 which was labeled as derived from flight test. Tail off lift was obtained by linearizing the lift curve from AEROC 3.2.W.2 page 27, Issue 1 fig 15. Downwash was obtained from AEROC 3.2.T.1 The model constructed from these references matched flight test stabilizer for the available cases.

To convert from the baseline DHC-3 to the Texas Turbine Otter with the Baron STOL kit the following aerodynamic adjustments to the original DeHavilland aerodynamic model were made.

The change in pitching moment due to the longer nose for the Turbine Otter was calculated using Multhopp's method.

$$\delta M / \delta \alpha = (q/36.5) \int w_f^2 \delta \beta / \delta \alpha \delta x$$

Accounting for the nose as one piece we have the following.

Baseline DHC-3:

$$w_f = 4.5 \text{ ft}$$

$$x_1 = 6 \text{ ft} \rightarrow x_1/c = 6/6.5 = 0.92 \rightarrow \delta \beta / \delta \alpha = 1.4$$

$$\delta x = 4 \text{ ft}$$

$$\delta M / \delta \alpha = (q/36.5)(113.4)$$

Texas Turbine Otter:

$$w_f = 4.0 \text{ ft}$$

$$x_1 = 7 \text{ ft} \rightarrow x_1/c = 7/6.5 = 1.08 \rightarrow \delta \beta / \delta \alpha = 1.2 \text{ (Ref P\&H pg 228)}$$

$$\delta x = 9 \text{ ft}$$

$$\delta M / \delta \alpha = (q/36.5)(172.8)$$

$$\Delta \delta C_m / \delta \alpha = (q/36.5)(172.8 - 113.4) / q S_w c$$

$$\Delta \delta C_m / \delta \alpha = (1/36.5)(172.8 - 113.4) / (375(6.5)) = 0.00067$$

The change in pitching moment due to normal force on the prop is calculated using the method from P&H pg 241 originally used by DeHavilland. Note the second term in this expression accounts for the change in downwash.

$$(\delta C_m / \delta C_L)_{T_c = 0} = ((\delta C_n / \delta \alpha)_{T_c = 0} \delta \beta / \delta \alpha l_p S_p) / (S_w c a_w) + a_t / a_w (V_h / 0.07) (\delta C_n / \delta \alpha)_{T_c = 0} \delta \beta / \delta \alpha$$

Baseline DHC-3:

$$(\delta C_n / \delta \alpha)_{T_c = 0} = 0.00235 \text{ (3 blade prop P\&H pg 241)}$$

$$l_p / c = 1.37 \text{ (Aeroc 3.2.G.1 pg 9)}$$

$$\delta \beta / \delta \alpha = 1.10 \text{ (Aeroc 3.2.G.1 pg 9, Fig 5-15 P\&H)}$$

$$S_p / S_w = 0.254 \text{ (Aeroc 3.2.G.1 pg 9)}$$

$$a_t = .057 \text{ (Aeroc 3.2.G.1 pg 10)}$$

$$a_w = 0.082 \text{ (Aeroc 3.2.G.1 pg 10)}$$

$$V_h = 0.85 \text{ (Aeroc 3.2.G.1 pg 10)}$$

$$(\delta C_m / \delta C_L)_{T_c = 0} = 0.033 \text{ (Aeroc 3.2.G.1 pg 10)}$$

Texas Turbine Otter:

$$(\delta C_n / \delta \alpha)_{T_c = 0} = 0.00296 \text{ (4 blade prop P\&H pg 241)}$$

$$l_p / c = 12.6 / 6.5 = 1.94$$

$$\delta \beta / \delta \alpha = 1.07 \text{ (Fig 5-15 P\&H)}$$

$$S_p = \pi D^2 / 4 = \pi 11^2 / 4 = 95 \text{ ft}^2$$

$$S_w = 375 \text{ ft}^2$$

$$a_t = .057 \text{ (Aeroc 3.2.G.1 pg 10)}$$

$$a_w = 0.082 \text{ (Aeroc 3.2.G.1 pg 10)}$$

$$V_h = 0.85 \text{ (Aeroc 3.2.G.1 pg 10)}$$

$$(\delta C_m / \delta C_L)_{T_c = 0} = 0.00296 (1.07) 1.94 (95) / 375 / 0.082 + (0.057 / 0.082) (0.85 / 0.07) 0.00296 (1.07)$$

$$(\delta C_m / \delta C_L)_{T_c = 0} = 0.019 + 0.027 = 0.046$$

$$\Delta(\delta C_m / \delta C_L)_{T_c = 0} = 0.046 - 0.033 = 0.013$$

Baron STOL kit

The Otter airfoil is a modified NACA 66(215)-216. A Baron Otter STOL kit adds a drooped leading edge approximately 0.35 ft (scaled from pictures). This results in an increase in the wing area of approximately 20 ft² to 395 ft² and an increase in chord from 6.5 ft to 6.85 ft (or about 5%). Lift was obtained by multiplying the base Otter lift coefficient by the ratio of the wing areas (1.053). The pitching moment increment due to the STOL kit was obtained from Transport Canada certification data as:

$$\Delta C_m = 0.032$$