National Transportation Safety Board
Office of Research and Engineering
Washington, D.C. 20594

Performance Study

Specialist Report
Marie Moler
August 30, 2013

A. ACCIDENT

Location:	Soldotna, AK
Date:	September 5, 2012
Time:	18:42 UTC (10:42 Alaska Daylight Time)
Aircraft:	DHC-8-100, N886EA, ERA Flight 874
NTSB Number:	DCA12IA141

B. GROUP

Marie Moler, chairman
Office of Research and Engineering
National Transportation Safety Board

Mike Muratore, member
New York Aircraft Certification Office
Federal Aviation Administration

C. HISTORY OF FLIGHT

On September 5, 2012, at about 10:42 Alaska Daylight Time, 18:42 UTC, Era Aviation (d.b.a. Era Alaska) Flight 874, a Bombardier DHC-8-103, registration N886EA, experienced an uncommanded left roll and uncontrolled descent during climb at about 12,000 ft. The flight crew regained control of the airplane at about 7,000 ft and the flight returned to Ted Stevens Anchorage International Airport (ANC), Anchorage, Alaska. There were no injuries to the 12 passengers or 3 crew members, and the airplane was not damaged. The flight was operating under the provisions of 14 Code of Federal Regulations Part 121 as a regularly scheduled passenger flight between ANC and Homer Airport (HOM), Homer, Alaska. Daylight, instrument meteorological conditions prevailed at the time of the incident.

The aircraft was equipped with a flight data recorder (FDR) [Reference 1], cockpit voice recorder (CVR), and Tropospheric Airborne Meteorological Data Reporting (TAMDAR) instrumentation [Reference 2]. Data collected by the FDR and TAMDAR will be referenced in this report. The CVR overwrote the record of the loss of control event and is therefore not referenced. Additionally, a record of the air traffic control (ATC) communication between Anchorage Center and the incident aircraft will be referenced, along with the radar returns from the Anchorage approach radar, ANX [Reference 3].

D. LOSS OF CONTROL SEQUENCE

The parameters recorded by the FDR aboard N886EA are discussed in the FDR Factual Report [Reference 1]. These parameters were used to investigate the performance of the aircraft during the incident flight. The FDR recording was not synchronized to any external time standard, so the data was time correlated to the ATC report using FDR microphone clicks as shown in Figure 1. The UTC times reported throughout this document reflect this time correlation. The radar data from the Anchorage approach was time correlated by comparing the altitude with the FDR data, a portion of which is shown in Figure 2. Altitudes from the ANX radar shown in Figure 3 are only reported in 100-foot increments and at wider time intervals, so they are approximate compared to FDR reported altitudes.

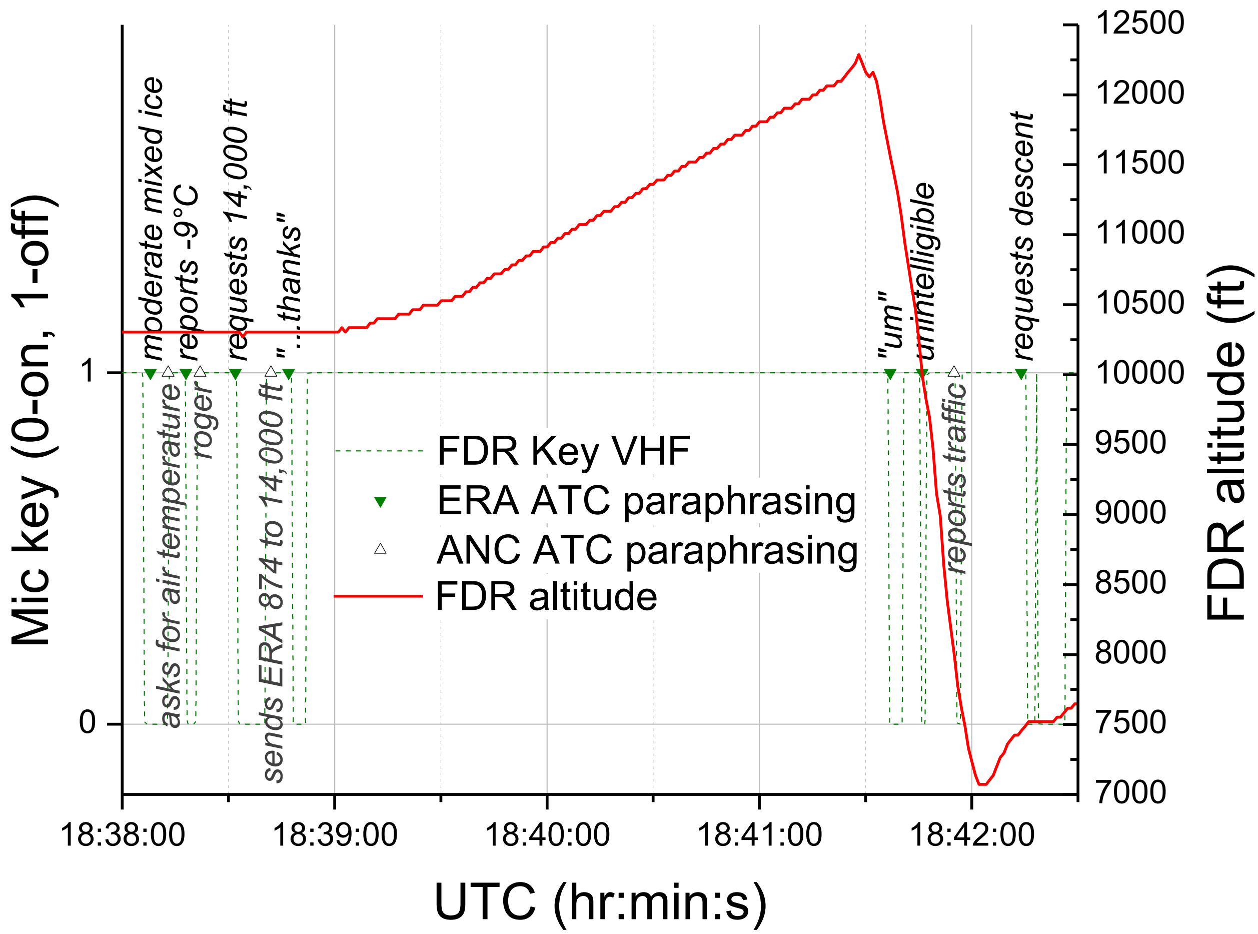

Figure 1. Time correlation between FDR recorded microphone clicks and ATC transcript.

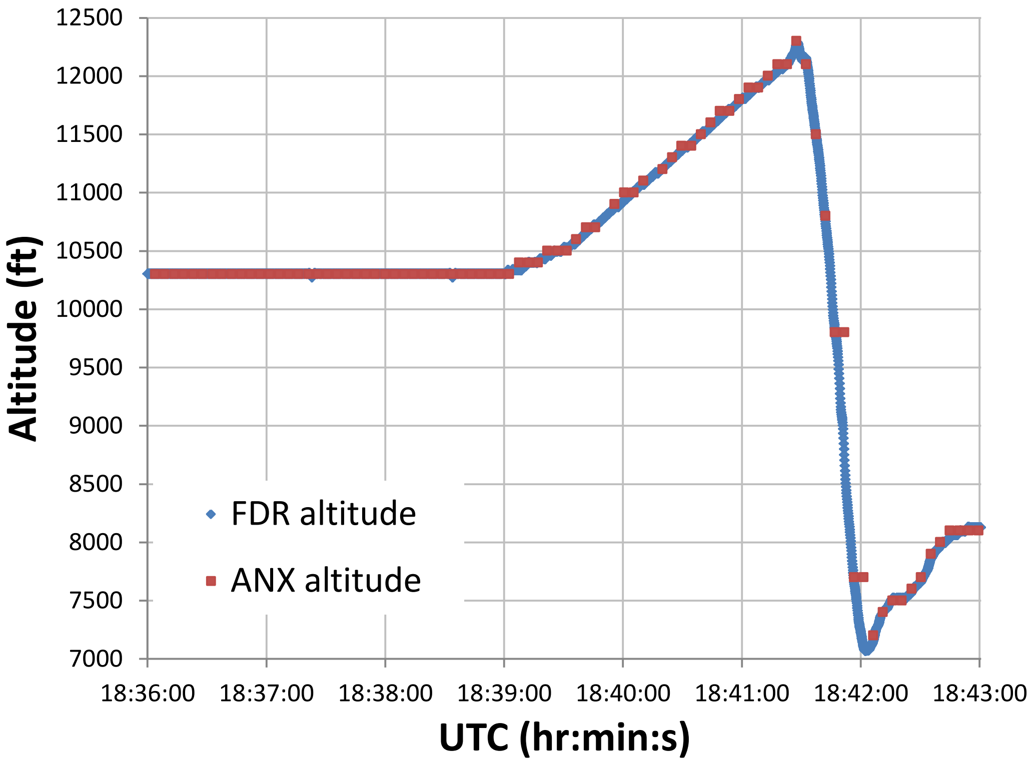

Figure 2. Time correlation between FDR altitude and Mode C altitude recorded at ANX**.**

The aircraft took off from Anchorage at 18:29 UTC and climbed to a cruising altitude of about 10,000 ft as shown in Figure 4 and Figure 5. Once the aircraft reached its cruising altitude its airspeed was reduced from approximately 190 kts to a constant 170 kts. At 18:38:42 the aircraft reported moderate mixed ice and requested a new altitude of 14,000 ft. Anchorage Center cleared the request and the aircraft began to climb at 18:39:03.

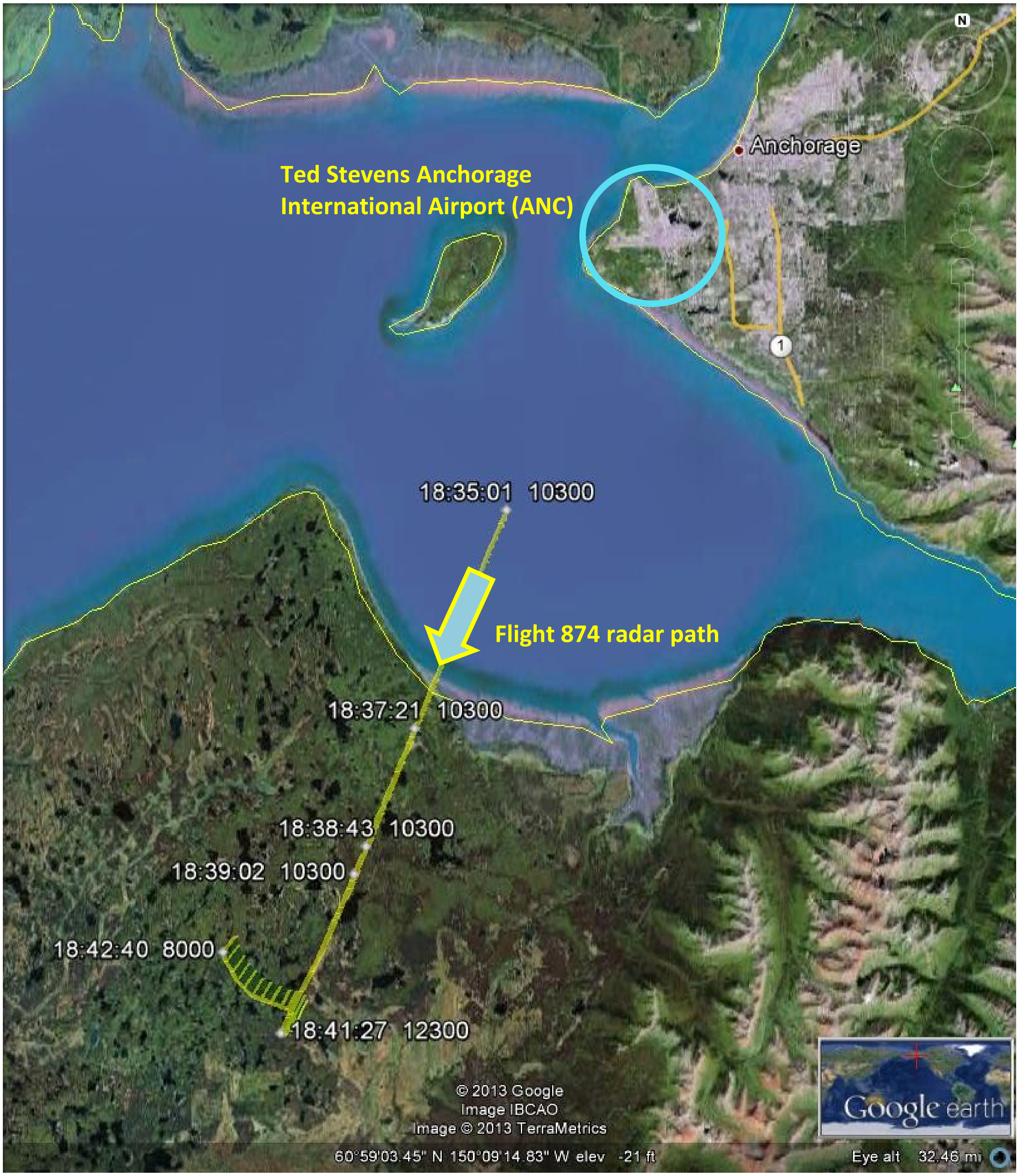

Figure 3. ANX radar path of Flight 874, UTC time.

During the climb to 14,000 ft, the aircraft gained altitude at a steady rate of 850 ft/min. For the duration of the climb, the aircraft was steadily slowing, from an initial airspeed of 170 kts down to 97 kts when it started to roll off left. Figure 5 shows the recorded high pressure compressor speed (NH) throughout the climb.

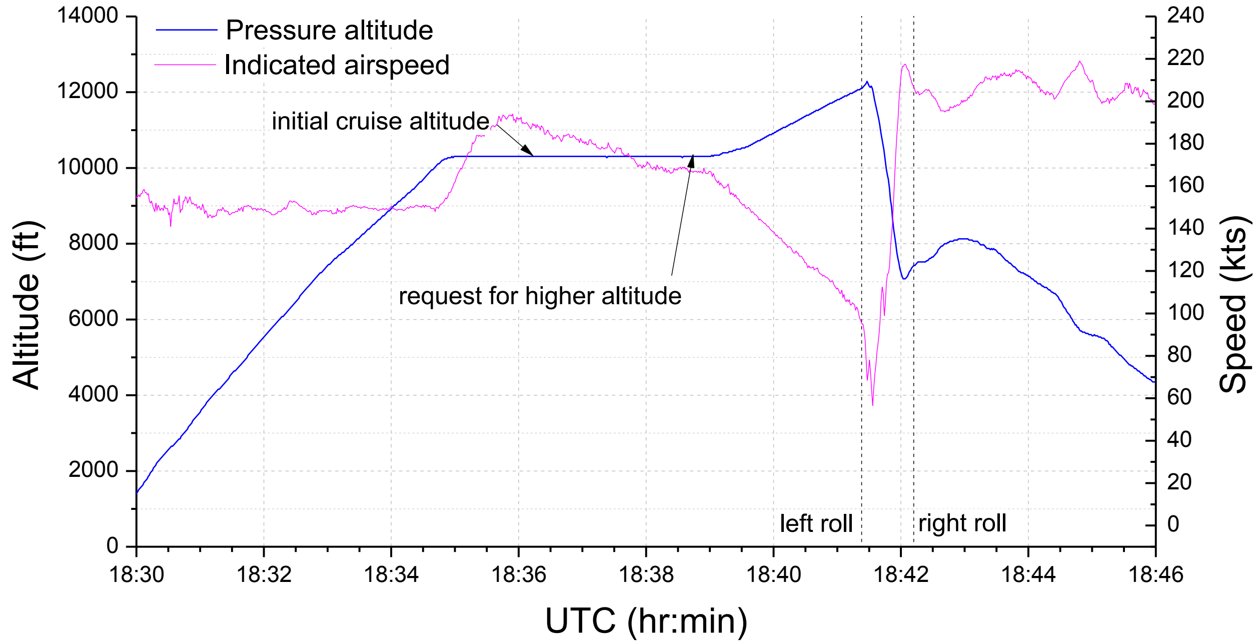

Figure 4. Altitude and airspeed for take-off, climb, and the loss of control event indicated by the left roll.

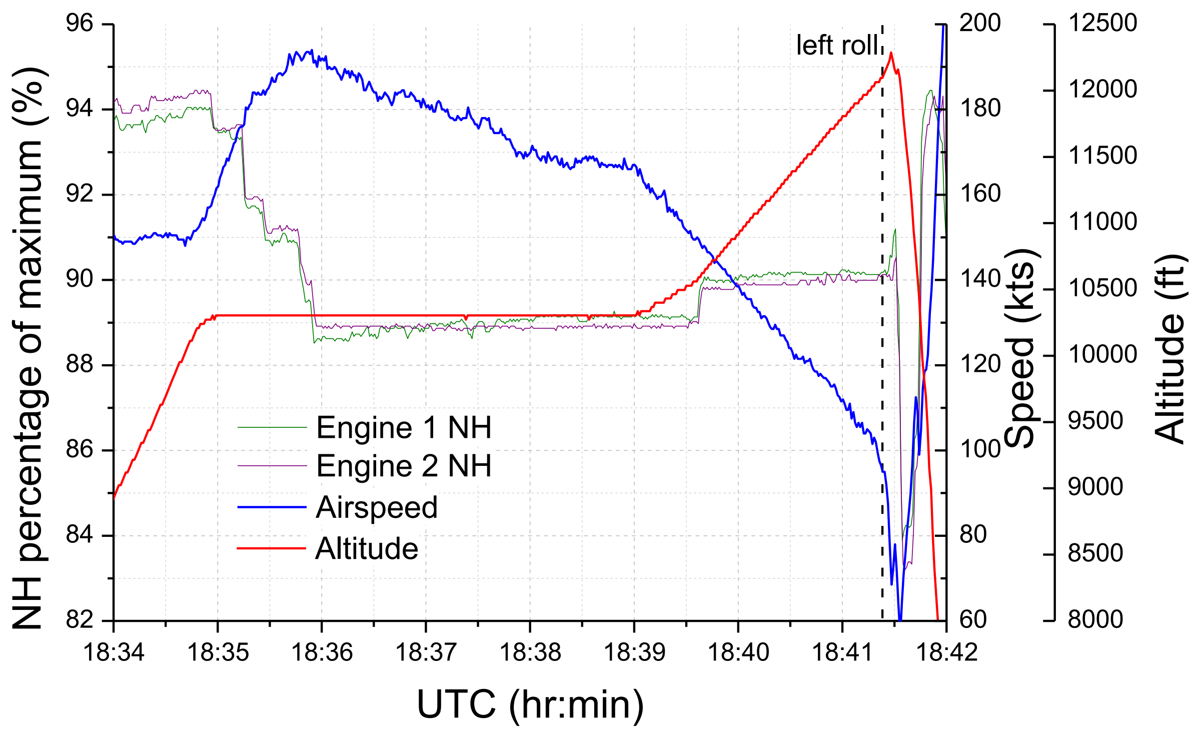

Figure 5. NH as a percentage of maximum, airspeed, and altitude for level flight and climb to loss of control.

Figure 6 details the loss of control event. At 18:41:23, the aircraft, which during the climb was holding a right roll of approximately 2.5°, began to roll left, reaching a bank of -47° in about 11 seconds for a roll rate of 4.5°/s. The crew opposed the roll with wheel (see Figure 8, discussed in more detail later). The aircraft recovered slightly before rolling further left to -55°. During the roll event the aircraft completed a 270° turn from an initial southerly heading to a westerly heading (also illustrated in Figure 10). The aircraft initially continued to climb before descending from 12,288 ft to 7072 ft in about 30 seconds.

At 18:42:04, the aircraft reached its lowest local altitude and began to level out and stabilize. Then at 18:42:17, the aircraft began to roll right to 58°. The airspeed at the onset of the right roll was 205 kts and there was no significant loss of altitude during the right roll.

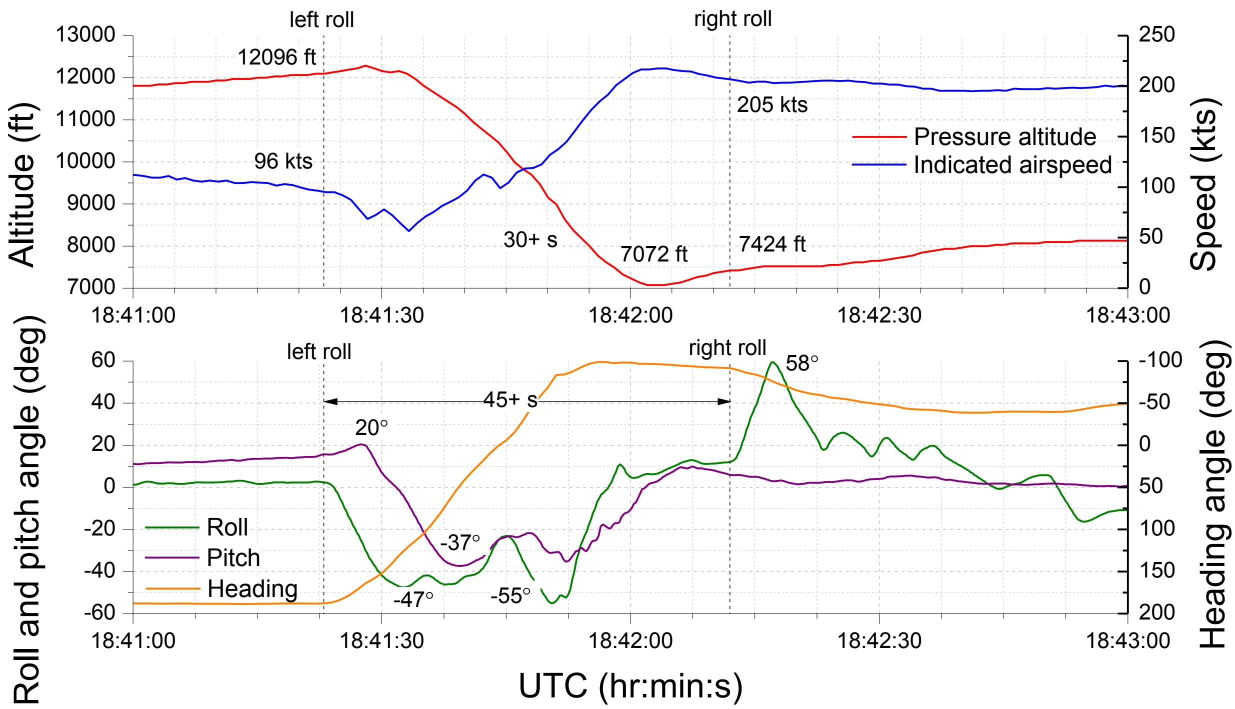

Figure 6. Altitude, speed, roll, pitch and heading for loss of control event.

During the climb, the aircraft's vertical load factor remained constant at 1 g, before suddenly beginning to decrease at 18:41:18 and then increase during the loss of altitude. The vertical, longitudinal, and lateral load factors are shown in Figure 7. The magnitude of the longitudinal load factor was steadily increasing during the climb as pitch attitude increased. The lateral load factor was also steadily increasing from near zero to about -0.04 g at the time of the upset. While the left roll began at 18:41:23, the onset of the loss of control event can be marked at the point when the vertical load factor suddenly decreases at 18:41:18. This loss of vertical load factor indicated a sudden degradation of lift.

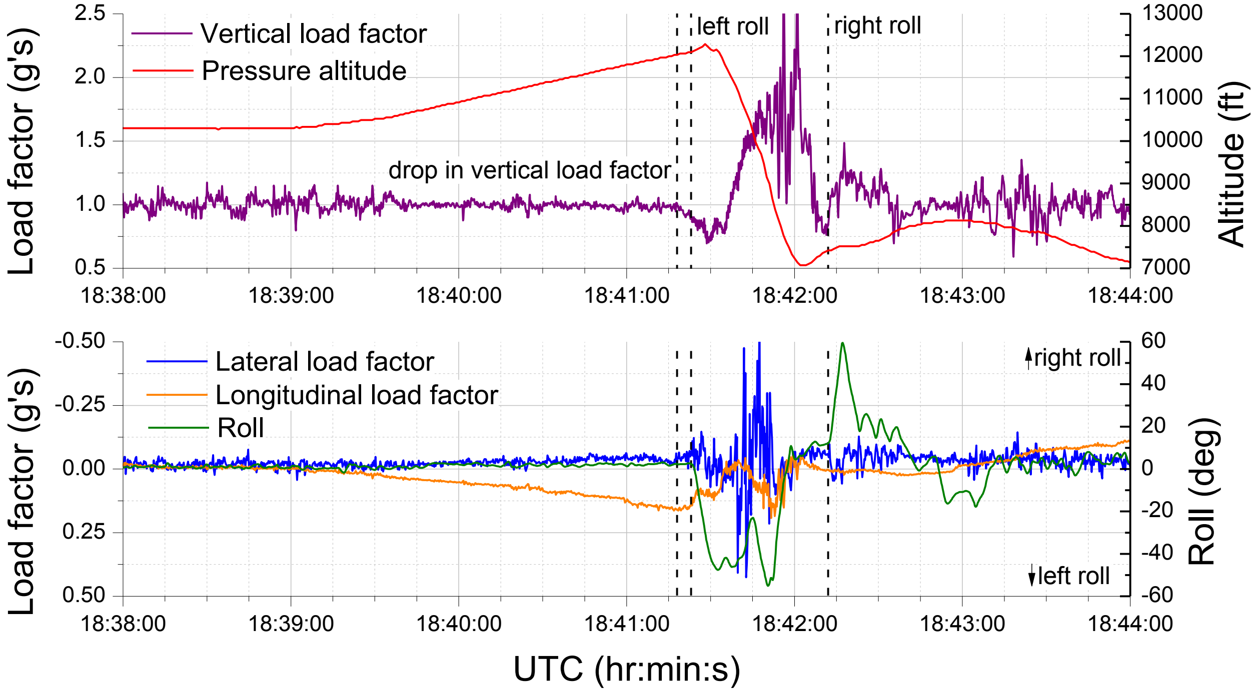

Figure 7. Load factors during climb and loss of control event.

After the vertical load factor began to drop, indicating a loss of lift, the column began to move back, briefly increasing the pitch of the aircraft as shown in Figure 8. The FDR only recorded total wheel and column position and did not distinguish between captain, first officer, or autopilot input. The constant climb rate and the smooth increase in column from 18:41:18 until the autopilot disconnect is consistent with the actions of the autopilot in vertical speed mode. At 18:41:27, the autopilot disconnected. The autopilot could have disconnected for a number of reasons: it could have been manually disconnected by the pilots, by the onset of stick shaker, or when the force on the column or wheel exceeded a set maximum. Once the autopilot disconnected, the column position increased from about 8° to 32° to nose up while the aircraft's pitch decreased from 20° nose up to -37° (nose down). The aircraft recovered when the force on the column was released.

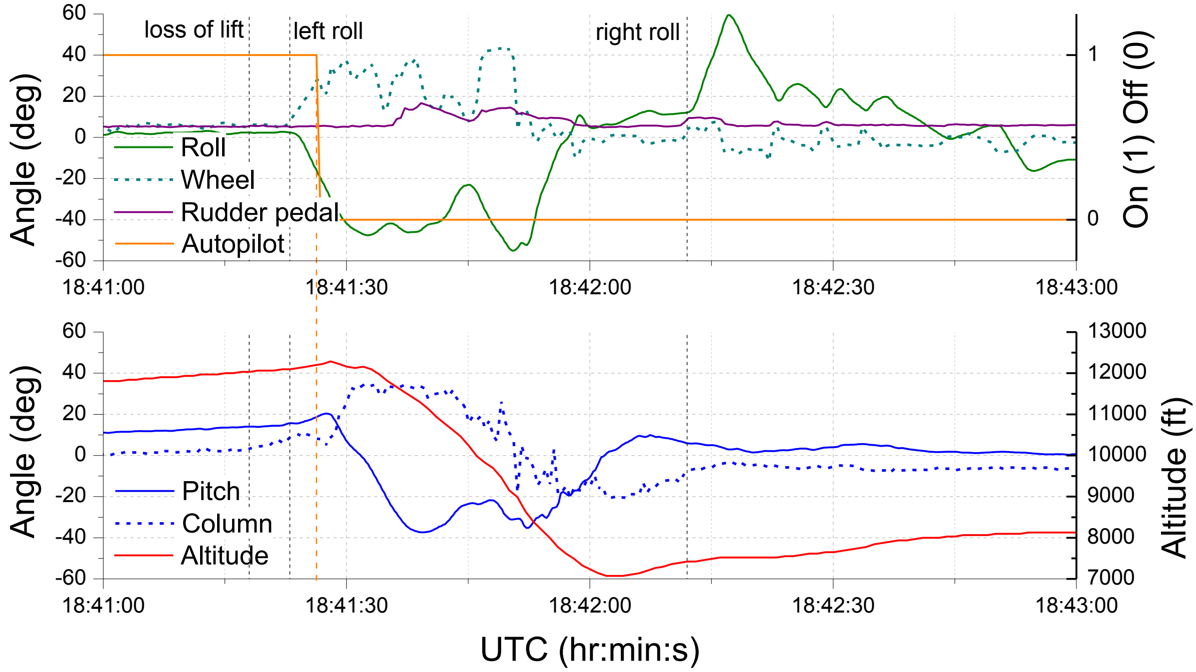

Figure 8. Roll, wheel, rudder, autopilot, pitch, column, and altitude during loss of control event.

Once the aircraft began to roll left, engine power increased until the apex of the climb, before being reduced from about 91% to 83% of the NH maximum as shown in Figure 9. The engine power was increased later in the roll upset.

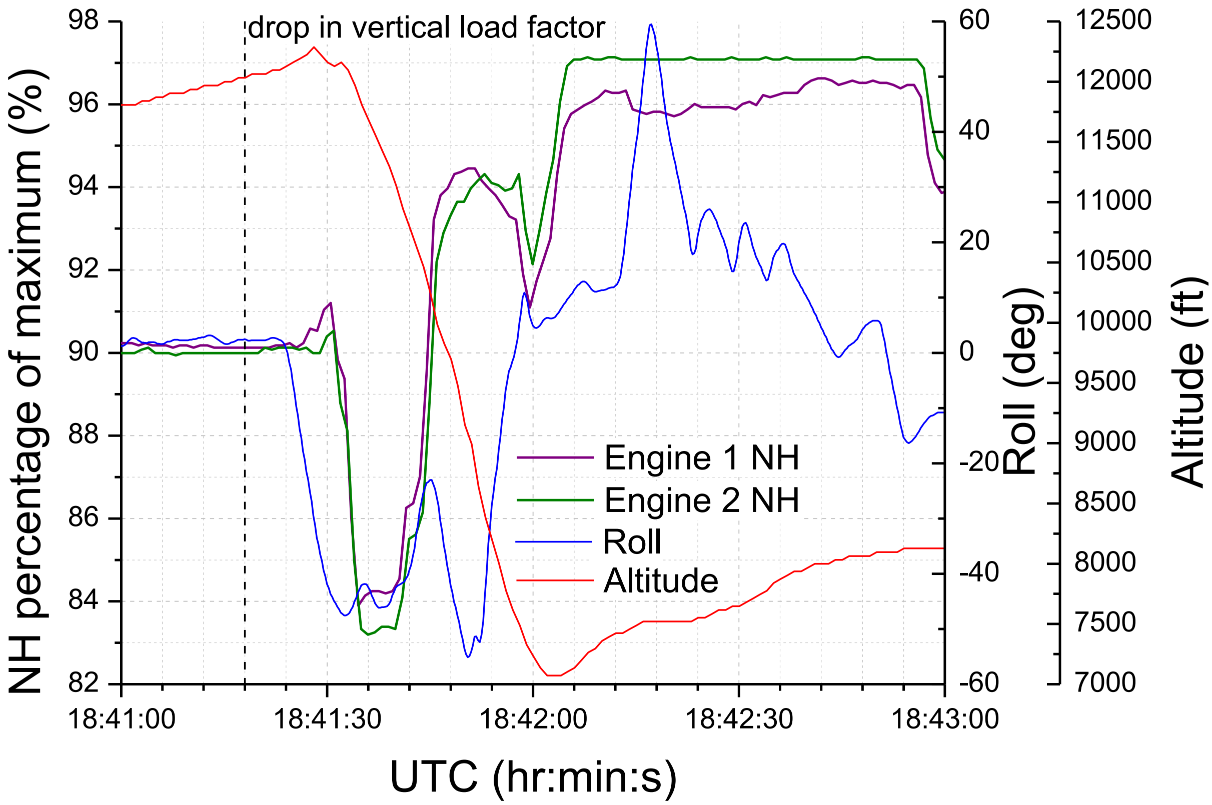

Figure 9. NH as a percentage of maximum, roll, and altitude during loss of control event.

Approximate radar positions corresponding to some of the events discussed above are shown below in Figure 10. A tabular time history of the described loss of control event for ERA Flight 874 is shown in Table 1. The drop in vertical load factor has been selected to be the onset of the loss of control event.

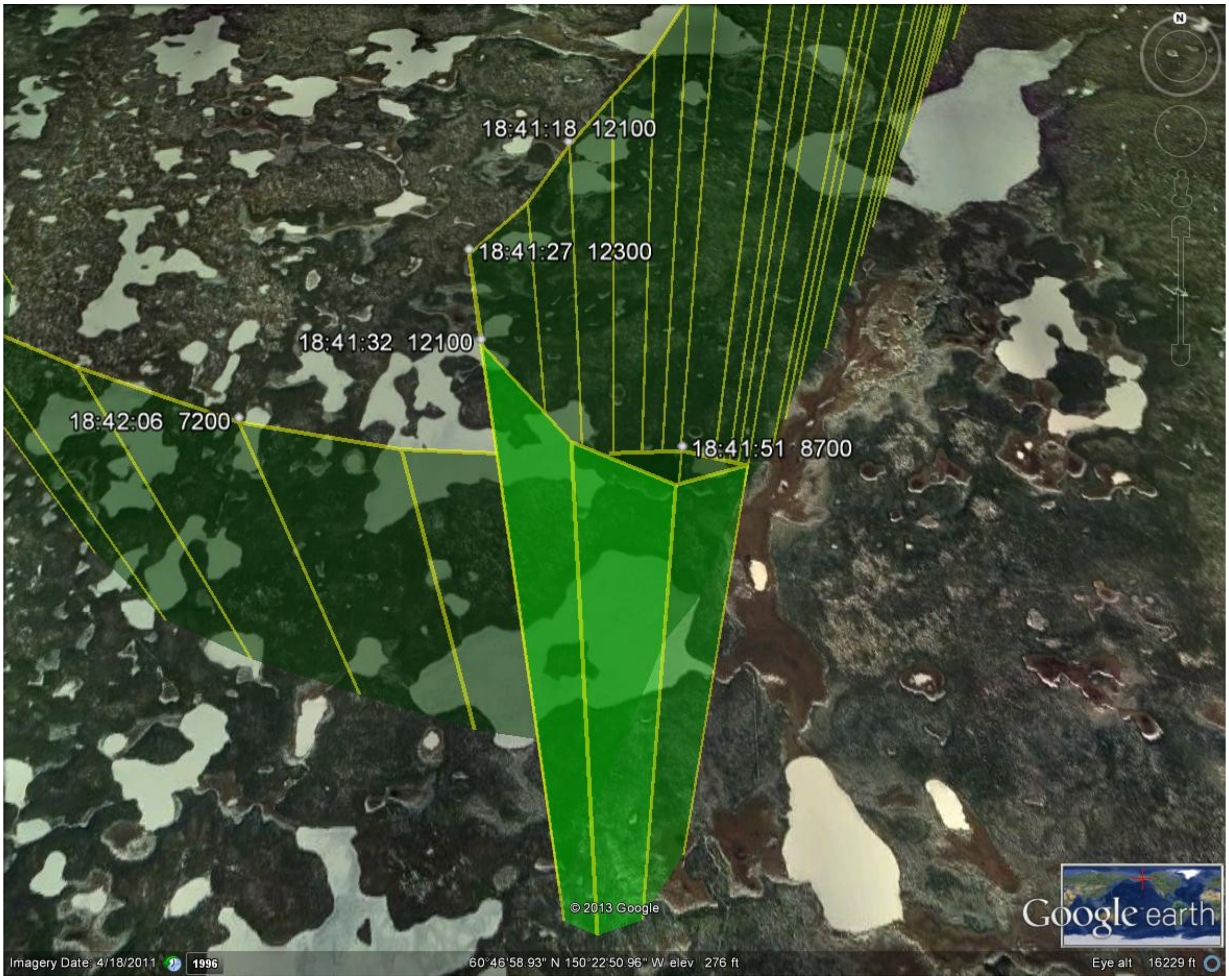

Figure 10. ANX radar path of Flight 874 during loss of control event, UTC time.

Table 1. Time history of loss of control event.

Time (UTC)	Event	Δtime from upset onset
18:39:03	Aircraft begins climb to 14,000 ft	- 2 min 35 s
18:41:18	Vertical load factor drops	0 s
18:41:23	Left roll begins	+ 5 s
18:41:27	Autopilot disconnects	+ 9 s
18:41:29	Aircraft begins to lose altitude	+ 11 s
18:41:31	Engine power is reduced from 91% of NH to 83%	+ 13 s
18:41:33	Aircraft is -47° left wing down	+ 15 s
18:41:40	Aircraft is -37° nose down (maximum nose down attitude)	+ 22 s
18:41:51	Aircraft is -55° left wing down (maximum left bank)	+ 33 s
18:42:04	Aircraft reaches an altitude of 7072 ft, the pitch becomes positive and the aircraft begins to gain altitude	+ 46 s
18:42:12	Aircraft begins to roll right	+ 54 s
18:42:17	Aircraft is 58° right wing down (maximum right bank)	+ 59 s
18:42:27	Controlled flight restored	+ 1 min 6 s

E. DISCUSSION

Climb rates

The initial climb rate of the aircraft as it ascended from 2,000 to 10,000 ft was about 1,800 ft/min. The rate of climb from 11,000 to 12,000 ft was about 850 ft/min. Climb rates for these portions of flight are shown in Figure 11.

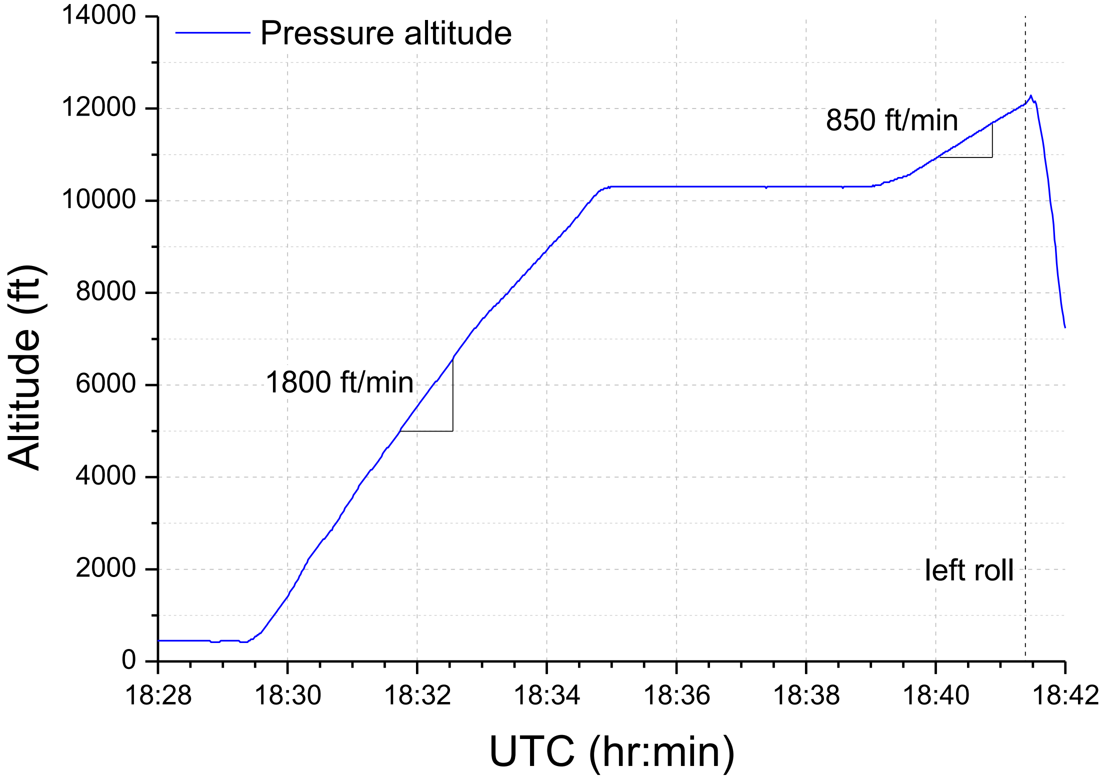

Figure 11. Climb rates.

Discussion of aerodynamic stall

The reduction in vertical load factor, uncommanded left roll, and loss of altitude are all consistent with aerodynamic stall. The angle of attack (AoA) of the aircraft was not recorded so it was calculated using the recorded pitch, airspeed, and altitude according to

$$AoA = pitch - sin^{-1}\ \frac{\Delta altitude}{airspeed_{average} \cdot \Delta time}$$

which is equivalent to pitch minus the aircraft flight path. Noise in the pitch, altitude, and airspeed measurements means that the calculated AoA is itself a somewhat noisy estimate of the aircraft's angle of attack at a specific time. For this calculation the altitude, airspeed, and pitch of the aircraft were smoothed using a Fast Fourier transform and a low-pass filter with a cutoff of 0.2Hz as shown in Figure 12.

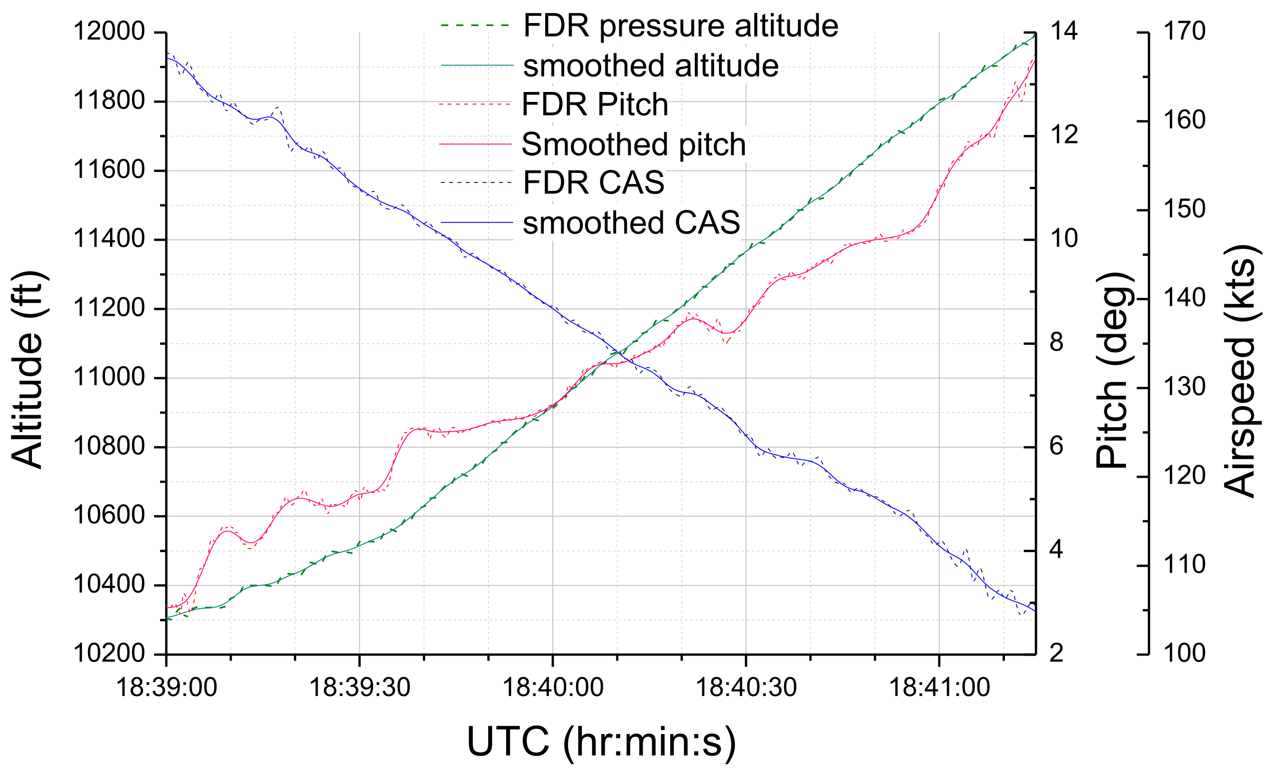

Figure 12. Smoothed altitude, pitch, and calibrated airspeed.

Although the calculated AoA did exhibit fluctuations due to noise in the signal, as shown in Figure 13, the aircraft's AoA was increasing throughout the climb until the drop in vertical load factor.

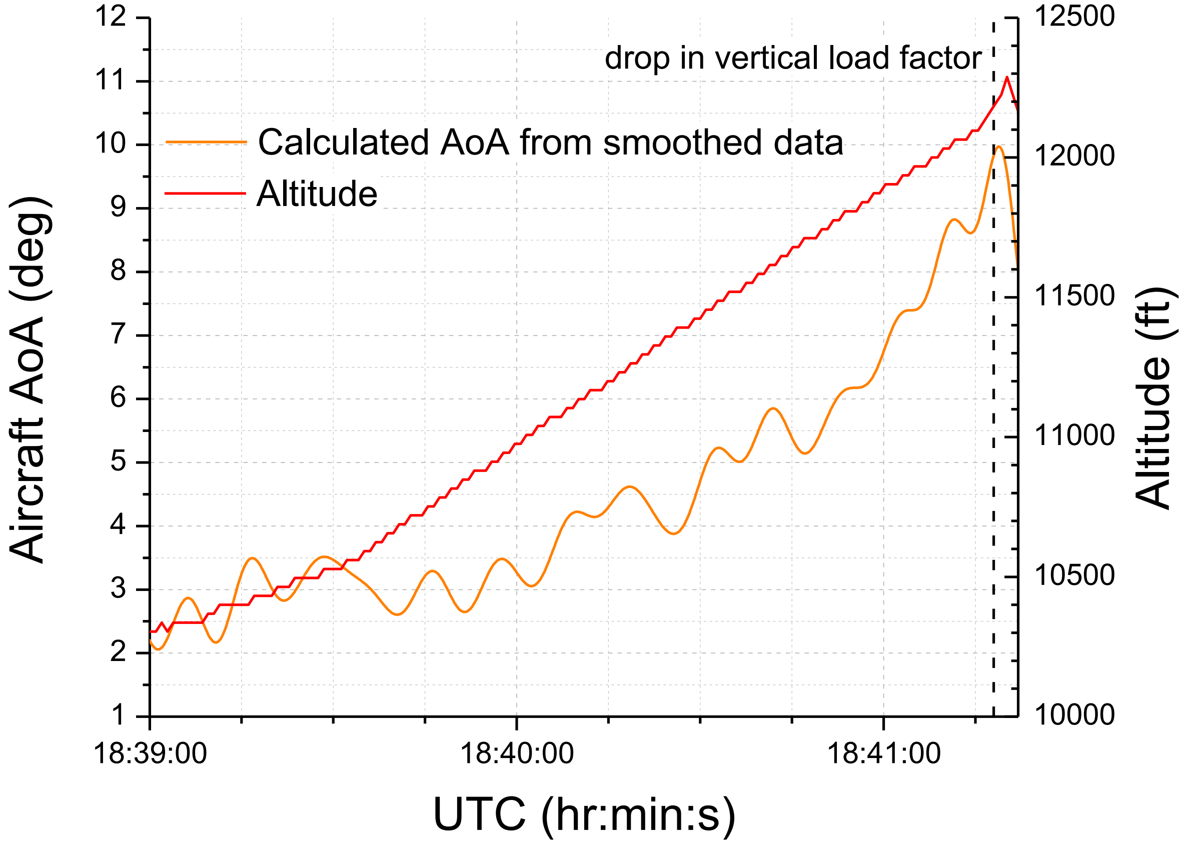

Figure 13. Calculated angle of attack (AoA) and altitude during climb.

The lift a wing can generate is a function of AoA and lift increases with AoA up to a point. At this point, known as the critical angle of attack, lift begins to decrease and the aircraft has suffered an aerodynamic stall. The decrease in the vertical load factor at 18:41:18 indicated a reduction in lift and the beginning of aerodynamic stall. It is important to note that a *reduction* in the rate of lift increase with AoA begins at the stall point, but for many airplanes the initial decrease in lift may be gradual. The aircraft may still be able to gain altitude after stall until the dynamics of the increase in drag and loss of lift stop the climb.

Five seconds after the drop in vertical load factor, the aircraft began to rapidly roll to the left. Due to asymmetries in the aircraft including the shape of the wings, the control surfaces, engine power and possibly sideslip, aircraft can lose lift more quickly on one wing compared to the other. The sudden, uncommanded roll was indicative of the asymmetric aspect of an aerodynamic stall.

Dash-8-100 aerodynamic stall predictions

Bombardier provided the stall speeds for the power off condition for the Dash-8-100, shown below in Figure 14. At take-off, the aircraft's weight was reported as 30,325 lbs and its estimated landing weight was 29,327 lbs [Reference 4]. Flaps at the time of the upset were zero. According to Figure 14, the calibrated airspeed at stall for a 30,000 lb aircraft at flaps 0° would be 89 kts. Since this is the conservative power-off condition, the actual speed at which an aircraft under power in the clean wing configuration would stall would be slightly lower. For a turboprop with wing-mounted engines, an increase in power can delay the onset of flow separation and stall in the area of the wing behind the propellers.

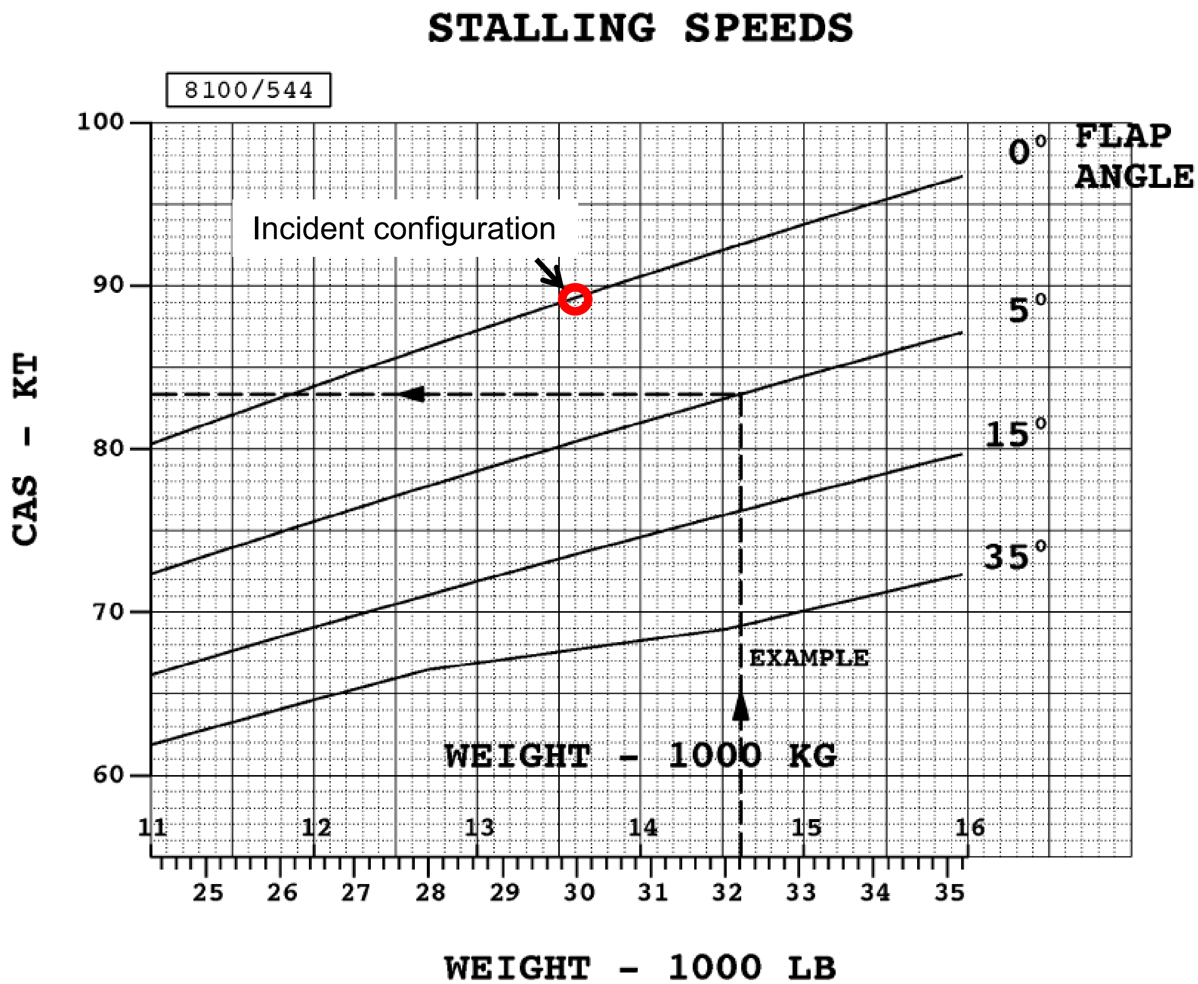

Figure 14. Power off stall speeds from de Havilland Inc. Dash 8 Flight Manual (Figure 5-1-1) [Reference 5] The incident configuration is noted with a red circle.

Figure 15, below, shows the aircraft's indicated airspeed and calibrated airspeed during the stall event. Calibrated airspeed was calculated using Honeywell Technical Newsletter data on the Dash-8 [Reference 6]. The difference between calibrated and indicated airspeed at the time of the upset was ≤ 1 kts. At the time of the drop in vertical load factor when stall began, the aircraft's airspeed was approximately 103 kts, 14 kts above the predicted stall speed shown in Figure 14. After roll-off, the aircraft's pitot-static system may not be as accurate, so speeds after the drop in vertical load factor have higher uncertainty.

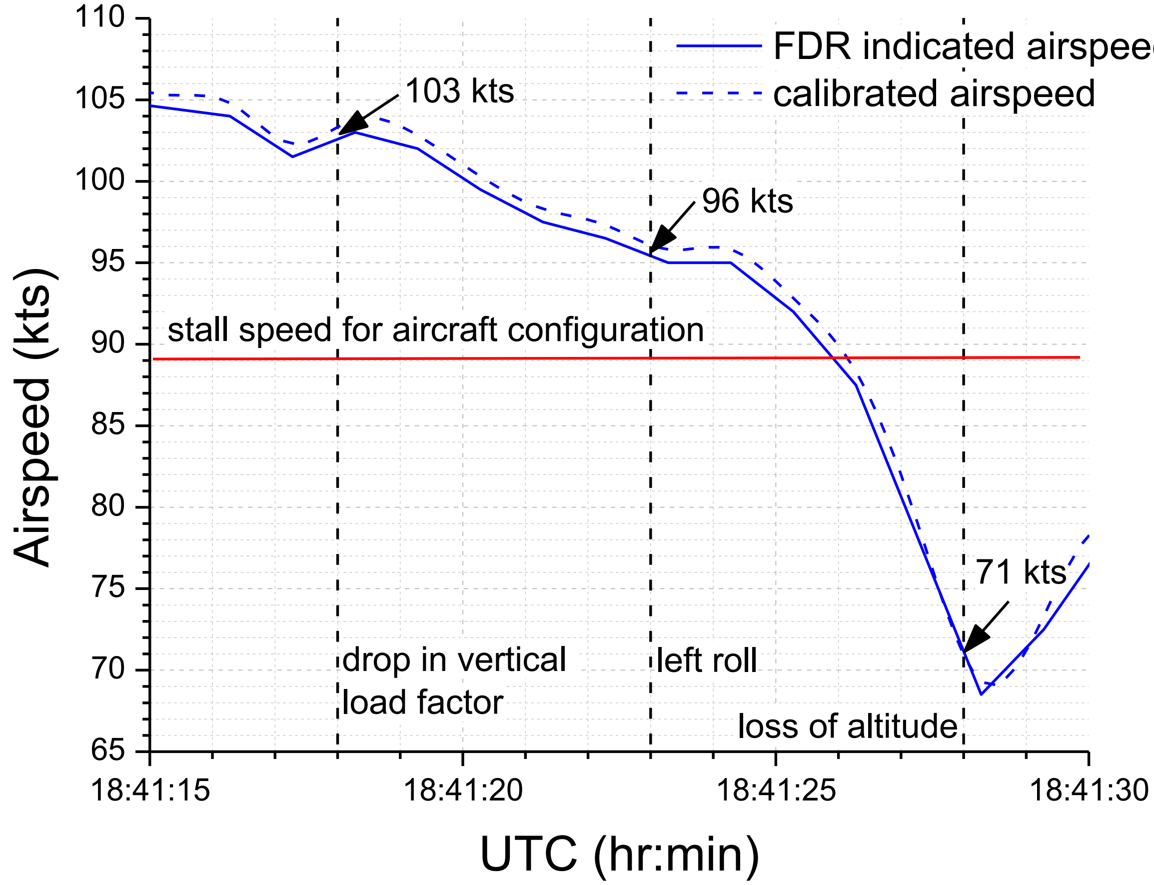

Figure 15. Aircraft airspeed for upset events.

Bombardier reported that the declared maximum lift coefficient at 1g vertical load factor (C_{L1gmax}) with retracted flaps is 1.71 for the Dash-8-100. Bombardier also reported a maximum lift coefficient at 1g vertical load factor of 1.65 for a stall entry of -0.5 kts/s and flight idle power [Reference 7]. The stall entry rate of -0.5 kts/s is similar to the deceleration observed for ERA Flight 874, but the climb power setting during the incident would be expected to lead to a higher maximum 1g lift coefficient compared to the flight idle conditions of the test. Additionally, Bombardier analyzed previous power-on and power-off flight test stalls (from de Havilland Aircraft of Canada data) to compare to the incident flight [Reference 7]. Data was corrected for position errors and center of gravity differences but note that a number of different factors affected the accuracy of comparing the flight test data to the incident event data. Namely, that upwash may have affected the flight test measured AoA (the AoA was measured during flight testing using a wing-mounted boom), position error with power on and low airspeeds may not have been well defined, and that the incident aircraft's pitot-static system does not accurately record airspeed once the aircraft has rolled off and side slip has developed. Figure 16, below, shows Bombardier's calculations of the lift coefficient and angle of attack for the incident flight and two power-on stall test flights. During the incident flight, the loss in vertical load factor (N_Z loss) occurred at a C_L of about 1.46 and the left roll occurred at a C_L of 1.59. As a result, both the loss in N_Z and the left roll occurred at C_L values below the quoted maximum C_Ls.

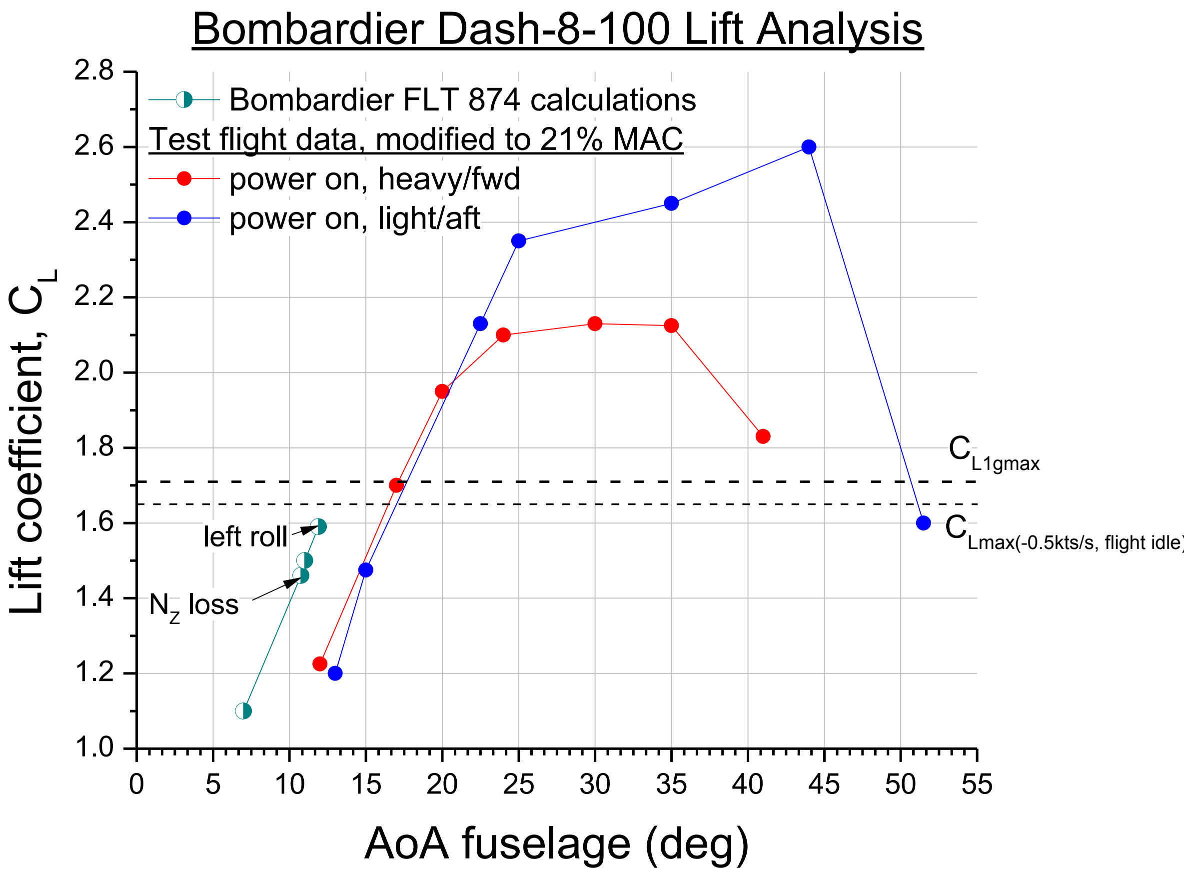

Figure 16. Bombardier Dash-8-100 lift analysis for incident flight and stall flight testing.

As stated earlier, the NTSB AoA calculations were for fuselage AoA while the Bombardier flight tests reported a boom measured AoA. Therefore, it was reasonable to shift the AoAs of the lift curve for the test flight data so that the gradient of the incident flight and the test data were aligned as shown in Figure 17. Also included in this figure is the lift coefficient calculated by the NTSB for the incident flight. The NTSB calculated the lift curve using the ERA provided weight and CG; Bombardier provided Ixx, Iyy, Izz, Ixz, and geometry; and a representative engine model driven by FDR recorded torque and RPM data. This lift coefficient was calculated up to the time of the apparent aerodynamic stall. After the aircraft has rolled off data from the pitot-static system becomes too uncertain to make a reasonably accurate prediction of the lift coefficient or aircraft AoA. However, the NTSB lift curve and Bombardier's calculations for Flight 874 were in good agreement up to the time of the loss of N_z and the left roll and did not require any shifting of the AoA to align with one another.

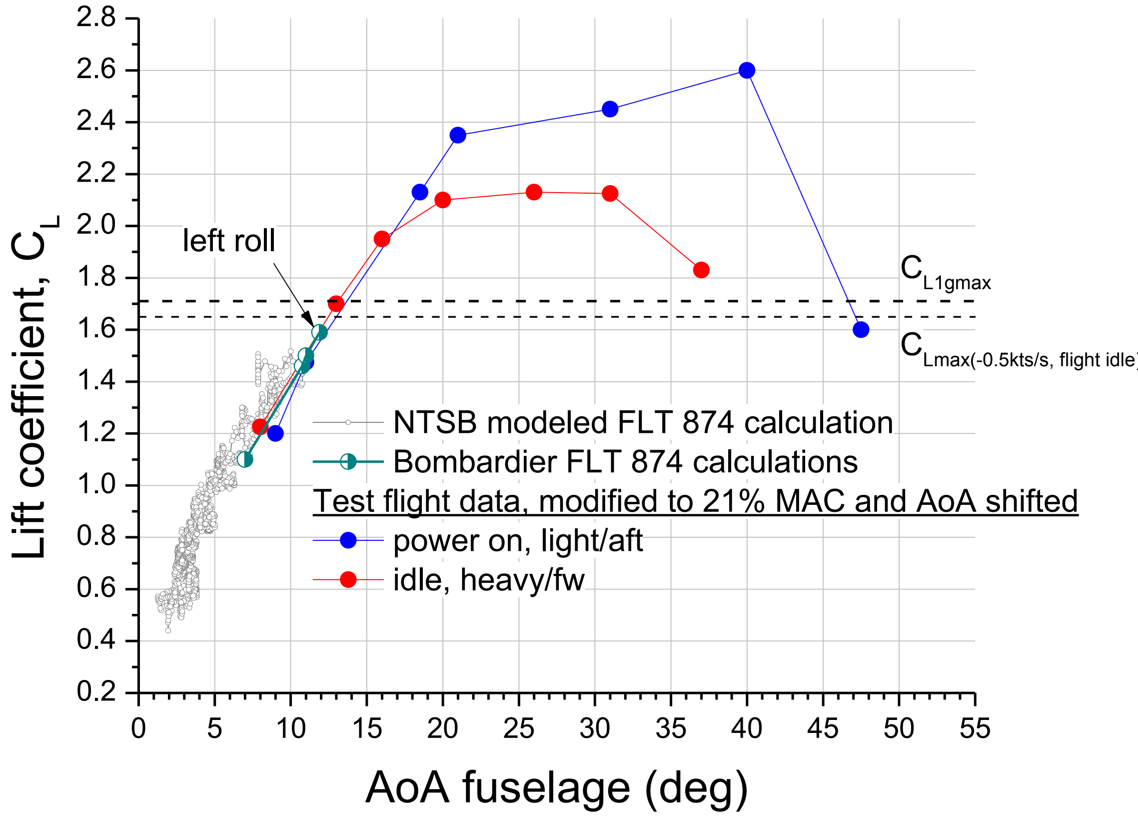

Figure 17. Shifted Bombardier Dash-8-100 lift analysis for incident flight and stall flight testing and NTSB modeling of the aircraft.

The slope of the lift curves for the incident flight calculations and the test flights show good agreement. Both the NTSB and Bombardier calculations have the aircraft roll off at a C_L of less than 1.6, below both the 1.71 and 1.65 of the reported C_{L1gmax} and $C_{Lmax(-0.5kts/s,\ flight\ idle)}$, respectively. This corresponds to the incident aircraft experiencing aerodynamic stall (loss of N_Z) at an AoA of 10.75° from Bombardier's calculations. Extrapolating using the flight test data leads to the $AoA_{max(-0.5kts/s,\ flight\ idle)}$ and AoA_{1gmax} being 13° and 14° respectively.

The calculations showed that the incident aircraft entered aerodynamic stall at a higher speed than the stall speed reported in the manual and at a C_L below the reported C_{Lmax}. Aircraft may stall before clean-wing stall predictions due to icing. A build-up of ice can change the aerodynamic shape of the wing and leave it susceptible to stall at a lower AoA (or a higher speed) than expected.

Aircraft drag coefficients

The NTSB calculated the drag coefficient (C_d) for the incident flight and a number of previous flights using the ERA provided weight and CG; Bombardier provided Ixx, Iyy, Izz, Ixz, and geometry; and a representative engine model driven by FDR recorded torque and RPM data. Again, the absolute value of the drag coefficient during the roll off event should not be considered as accurate due to higher uncertainty in the airspeed and altitude data during this time. Figure 18 shows how the C_d calculated for the incident flight begins to increase during the climb from 10,000 feet until it spikes after the drop in vertical load factor (N_Z).

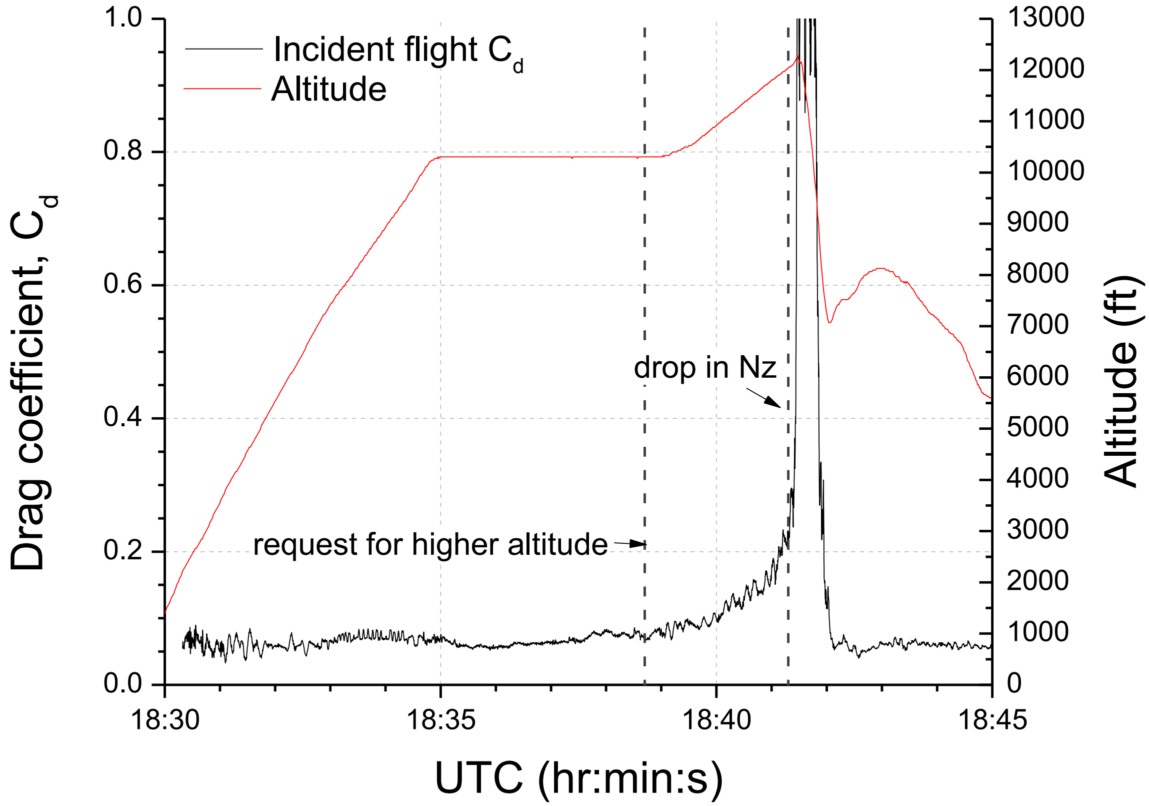

Figure 18. Drag coefficient (C_d) and altitude versus time for incident flight.

Additionally, the NTSB also analyzed four previous flights of the incident aircraft as shown in Figure 19. Cd is plotted against elapsed time to compare events from different times to one another. The drag coefficient for the previous flights and the incident flight generally stay in the range of 0.05 to 0.1 with some variation due to other affecting factors such as thrust and controls. However, during the climb from 10,000 feet the incident flight C_d begins to increase steadily. After the upset, the C_d returns to the original range.

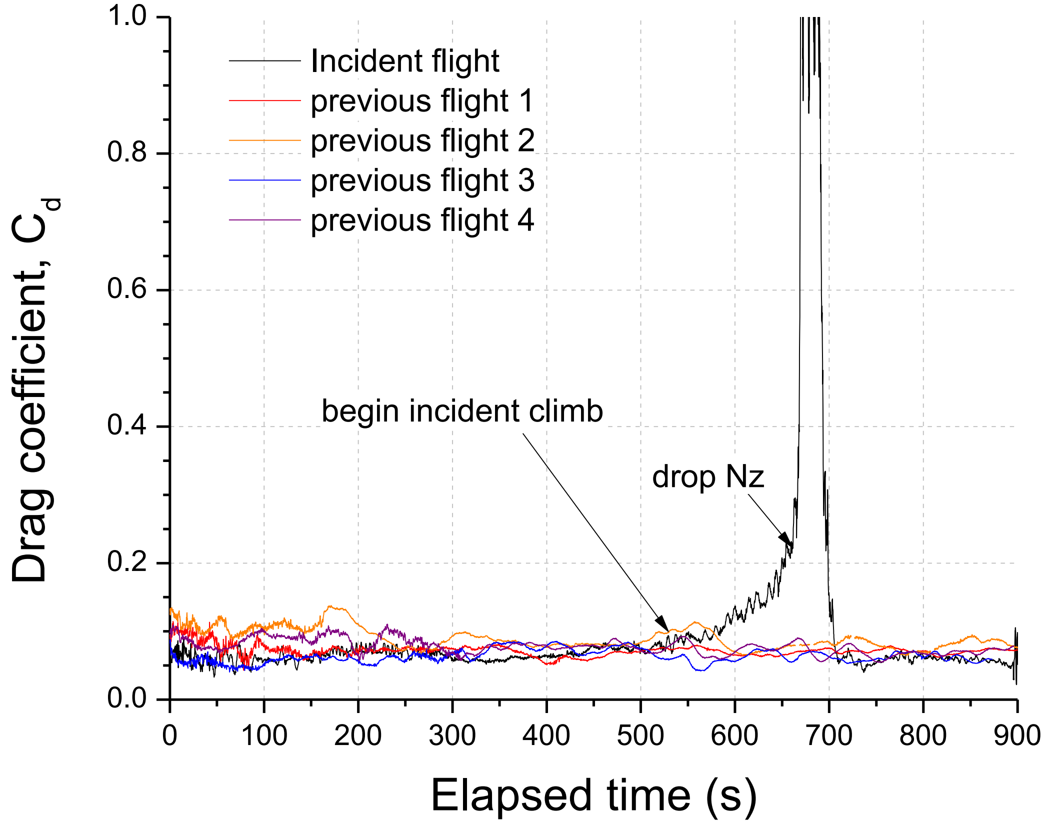

Figure 19. Drag coefficient (C_d) versus elapsed time for the incident flight and four previous flights of the same aircraft.

The analysis shown in Figure 18 and Figure 19 imply that the aircraft's drag characteristics changed during the climb from 10,000 feet until the upset. The changes in the aircraft's speed, thrust, and control surface positions during the climb do not explain an increase in drag. A build-up of ice can change the aerodynamic shape of the wing and cause an increase in drag compared to the clean-wing configuration. The drag analysis indicates that the aircraft entered into increased ice as it climbed above 10,000 feet.

On-board meteorological data

The aircraft was equipped with an in-situ atmospheric sensor called Tropospheric Airborne Meteorological Data Reporting (TAMDAR). TAMDAR records a number of weather parameters including wind, temperature, relative humidity, and icing and is described further in the NTSB Meteorology Factual Report [Reference 2] and shown with a more complete table of data. Table 2 shows the TAMDAR data for temperature and icing for the time leading up to the upset and through the stall. As stated in the Meteorology Factual Report, the Chief Scientist at

AirData, the company that developed the TAMDAR system, noted that the data indicated a light icing encounter.

Table 2. TAMDAR icing data from incident flight.

Time	Temperature °C	Icing
18:34:16	-8	No icing or heaters, data is good
18:34:26	-8.8	No icing or heaters, data is good
18:34:38	-9.5	No icing or heaters, data is good
18:34:54	-10.6	No icing or heaters, data is good
18:35:39	-11.7	Icing initiation
18:38:39	-9.6	Cool – no icing and heaters are off, but data is still suspected
18:39:01	-6.7	Port (static) icing
18:44:18	3.5	Cool – no icing and heaters are off, but data is still suspected
18:44:38	0.5	Cool – no icing and heaters are off, but data is still suspected
18:45:46	0.4	No icing or heaters, data is good
18:46:30	2.8	No icing or heaters, data is good

Additionally, as discussed earlier, the pilot had at 18:38:42 reported moderate mixed ice to ATC and had requested a higher altitude. The pilots stated in interviews [Reference 8] that the full anti-ice and de-ice system was on during the climb from 10,000 to 14,000 ft and seemed to be working normally.

Stick shaker activation

The FDR did not include stick shaker activation as a recorded parameter and the cockpit voice recorder (CVR) overwrote the incident sequence. Consequently there was no record to indicate whether the stick shaker activated during the incident, and if so, when. The stick shaker activation on the Dash-8-100 is based on a correlation between a wing-mounted force transducer and the aircraft's AoA. Bombardier was unable to provide documentation of this correlation and it was therefore not possible to determine when the stick shaker was set to activate. Additionally, the activation of the stick shaker cannot be changed to provide more protection when flying in icing conditions.

Second roll event

The second roll to the right at 18:42:12 was difficult to analyze due to the prior upset orientation of the aircraft which increased uncertainty of the airspeed measurements. Therefore it was not possible to create a lift curve like the one in Figure 17 for the second roll event. This roll event was not accompanied by a loss of altitude, but it was a significantly large (60° right) roll. Two other right banking maneuvers from the incident flight were analyzed to compare to the 60° right roll and are shown in Figure 20 with the right roll from the upset in Figure 21. During the two routine right wing down maneuvers, the pilot inputs about a 10° right wheel input to produce a 25° right wing down roll. However, Figure 21 shows how during the upset, the pilot entered less than 10° of right wheel but the aircraft rolled 60° right wing down.

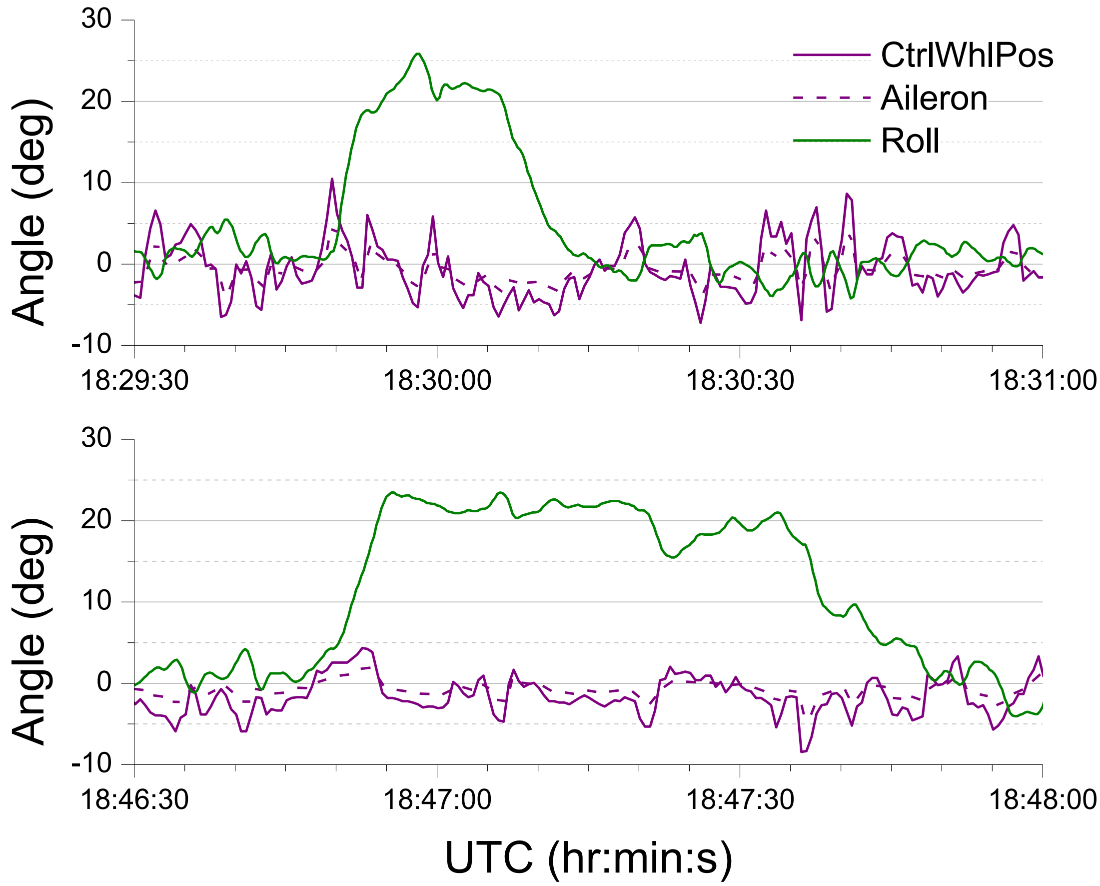

Figure 20. Two right banking maneuvers from prior to and after the upset.

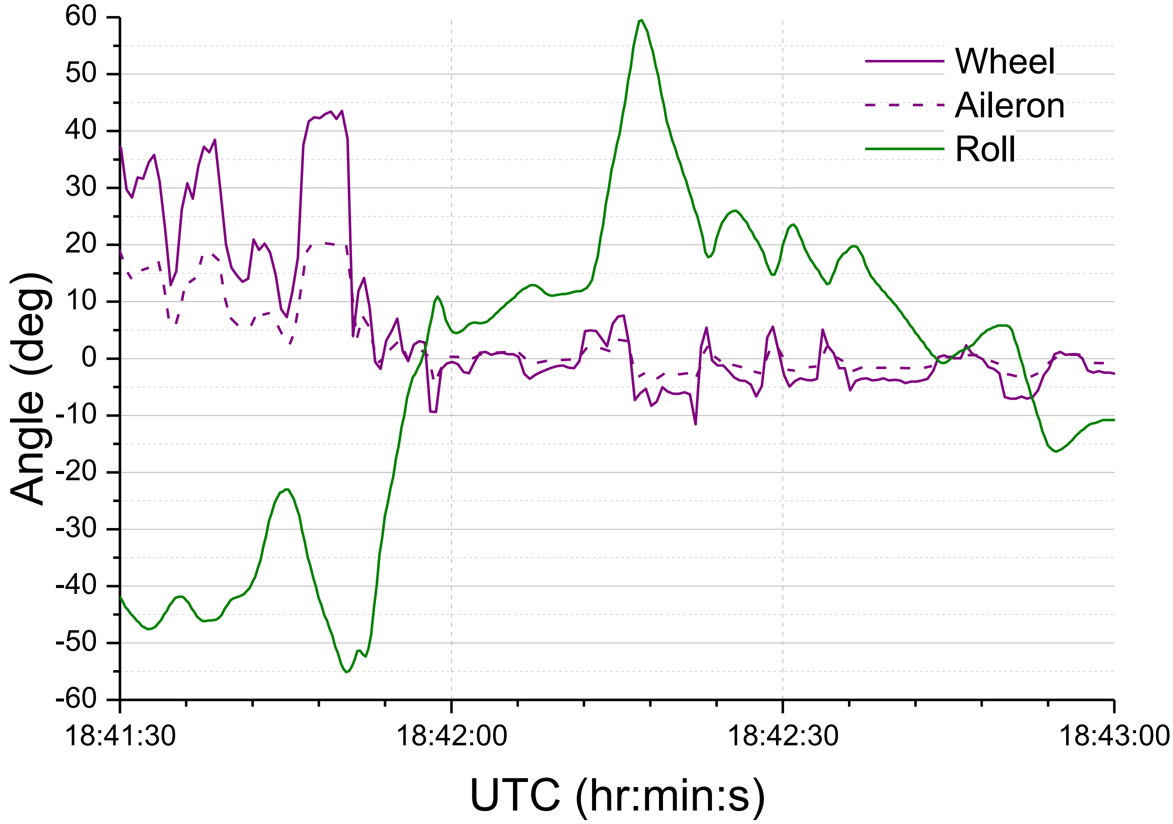

Figure 21. Upset right roll, wheel, and aileron position.

While the pilot did put in wheel to begin the second roll to the right, the response was much too large. A 60° bank attitude falls into the Federal Aviation Administration's (FAA) definition of aerobatic flying [9] and would not be an intentional maneuver by a commercial pilot. The magnitude of the roll then indicates that the aircraft was not stable, despite gaining altitude since the initial left roll stall upset. It is possible that an accumulation of ice on the wing was still affecting the aircraft's aerodynamic response to control inputs.

Crew Response

After the airplane experienced a loss of lift at 18:41:18, the column was pulled back for a nose-up attitude gradually from 3° to 8.5° over the next 8 or 9 seconds. The FDR recorded that the autopilot disconnected at 18:41:26.7. At 18:41:27 (about the same time the aircraft reached its maximum altitude), the column was pulled back rapidly from 8.5° to 33° in three seconds. The crew held greater than 33° of aft column until 18:41:43 before beginning to release the column. During this time the aircraft lost 1600 ft of altitude. However, the column was not pushed nose down for another 7 seconds until 18:41:50. More than 3100 ft of altitude were lost over 23 seconds before the crew pushed the column forward. This sequence is shown in Figure 8.

Aerodynamic stall recovery requires the crew to reduce the aircraft's angle of attack by pushing the nose down so that proper air flow across the wing and control surfaces can be restored. Pulling on the column in an attempt to keep the aircraft pitched up would resist recovery. Additionally, the crew reduced the engine power from 90% (NH) at the time of stall to 83% for about 10 seconds before increasing the power again to the point of over-rotating the propellers (indicated in Figure 9 when Engine 2 NH levels out at 97%). Reducing engine power would also exacerbate the loss of attached airflow across the wing and resist stall recovery.

F. CONCLUSIONS

At 18:38:42, ERA Flight 874 reported moderate mixed ice and requested a new higher altitude of 14,000 ft. At 18:39:03 the aircraft began climbing at a rate of 850 ft/min, steadily lost airspeed from an initial 170 kts, and steadily increased pitch and angle of attack (AoA). At 18:41:18 at 103 kts of airspeed, the vertical load factor (N_Z) began to decrease and five seconds later the aircraft entered a sudden roll to the left. This series of events was consistent with an aerodynamic stall of the aircraft.

Analysis of Bombardier flight test data showed that the incident aircraft stalled at a lower angle of attack (or higher airspeed) than predicted. The aircraft stalled at 103 kts of airspeed, 14 kts above the 89 kts stall speed reported in the Dash-8-100 flight manual. Additionally, calculations of the aircraft's lift curve from flight testing demonstrated that the aircraft stalled below the declared C_{L1gmax} and $C_{Lmax(-0.5kts/s,\ flight\ idle)}$. An aircraft can stall at an angle of attack lower than that predicted for clean-wing configurations if ice builds up on the wings. Calculations of an increase in the aircraft's drag coefficient also support the presence of increased ice beginning as the aircraft climbed from 10,000 feet. At 18:38:42 the pilot reported moderate icing to ATC and the onboard TAMDAR data recorded light icing from 18:35:39 to 18:44:38.

The FDR did not record a parameter for stick shaker activation, and the CVR overwrote the data recorded during the upset, so it is not known if the stick shaker activated to warn of incipient stall. Due to lack of stick shaker programing information for the Dash-8-100, it is not known when the stick shaker was programmed to activate to warn of incipient stall. The activation of the stick shaker cannot be changed to provide more protection when flying in icing conditions.

The response to the aerodynamic stall delayed aircraft recovery. Pulling back on the column and reducing engine power kept the aircraft from achieving the necessary AoA for air flow and lift to be restored.

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G. REFERENCES

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4. ERA Flight 874 Weight and balance form

5. De Havilland Inc. Dash 8 Flight Manual. Section 5, Figure 5-1-1: Stalling Speeds.

6. Honeywell Technical Newsletter, 23-1980-04. Revision 9, March 12/92. Figure 7: SSEC Function for the DeHavilland DHC-8.

7. Bombardier memo, 13 February 2013. Era Flight 874 Stall Incident, reference number FSMEMO/2013/D8100/003/TP

8. Operations Factual Report, National Transportation Safety Board

9. FAA Regulation Part 91 (General Operating and Flight Rules), Subpart D, Sections 303 and 307