On August 7, 1997, at approximately 1234 EDT, Fine Air Flight #101, a Douglas DC-8 series 61 (registration N27UA), lifted off from runway 27R at Miami International Airport bound for Santo Domingo in the Dominican Republic. According to witness reports, the aircraft pitched up quickly to an extreme nose-high attitude, the right wing dropped slightly and the aircraft descended undergoing several pitch oscillations with the wings rocking about an approximately wings-level bank angle. The aircraft was seen impacting the ground in a slightly nose high, right-wing down attitude. The aircraft contacted the ground near the middle marker for Runway 9L, crossed a road, and came to rest in front of a warehouse. The aircraft started to break apart almost immediately upon ground contact, and a fire erupted as the wing fuel tanks were ruptured. The fire consumed large portions of the wing and forward fuselage.

All four crew members and one person in a vehicle on the ground received fatal injuries in this accident.
The NTSB investigation organizational meeting for this accident was held in Miami on 8/8/97, wherein the various investigative groups were formed and parties to the investigation were identified.

The purpose of the Aircraft Performance Group (ACPG) is to determine and analyze the motion of the aircraft and its response to control inputs. In particular, the ACPG attempts to define the aircraft position and attitude throughout the flight, and determine its flight path with respect to the air and to the ground. The data the ACPG uses to obtain this information includes but is not limited to the following:

- Ground impact scars and markings.
- Damage/markings on surface structures.
- Examination of departure runway for signs of tail strikes, unusual tire markings, aircraft parts or other evidence.
- Approach and airport surveillance (ASR) radar data.
- Digital Flight Data Recorder (DFDR) data.
- Cockpit Voice Recorder (CVR) information.

This aircraft performance study describes the results of using the data listed above in defining, as far as possible, the motion of Fine Air 101. Ideally, the aircraft motion is almost completely described by the parameters recorded on the DFDR. In this accident, however, several important parameters were not recorded properly by the DFDR and so are not available for analysis (for details on the DFDR readout for this accident, see the Flight Data Recorder Specialist's Factual Report). Consequently, reconstruction of the aircraft motion relies heavily on other sources of information, in particular the Miami Airport ASR radar and the ground impact scars and markings. This information is not as accurate nor as abundant as that normally available from the DFDR, and so the results obtained from it are qualitative and not as quantitatively precise as those that would follow from a complete set of DFDR data.

With these limitations in mind, it is possible to conclude that the available DFDR data, the ASR radar data, and the ground impact scars and markings are consistent with the eyewitness reports and with the information recorded on the CVR, and describe a takeoff rotation with no tailstrike followed by a pitch-up to an extreme nose-high attitude, a subsequent stall, and a rapid and steep descent to a nose high, right wing low ground impact.

The remainder of this study presents the aircraft motion data collected during the investigation, details the data analysis methods used to derive additional aircraft motion information from the collected data, and describes the results of these analyses.
D. DETAILS OF THE INVESTIGATION

I. Impact Scars and Markings

The ACPG is interested in determining the flight path of the aircraft, and therefore only those ground scars and markings and wreckage components that are relevant to this task are documented by the ACPG. These items include the first ground contact marks of the various airplane components. The final location and condition of these components is of less interest to the ACPG, but is of primary interest to the Structures Group. Refer to the Structures Group Factual Report for this information.

Impact Mark Description

The impact scars and markings are documented in Figure 1, which shows the location of the scars and the ground swath of the aircraft relative to the Middle Marker antenna for MIA Runway 9L. The fencing illustrated in Figure 1 is the pre-accident, undamaged fence configuration. After the accident, the fencing was extensively damaged, as follows:

The fencing 20 ft. on either side of the Aft Fuselage Impact Scar shown in Figure 1 was flattened, with the fence poles on the Eastern perimeter of the fence line pulled out of the ground and those on the Western perimeter bent to within 1 ft. of the ground. The fence lines and fence poles running East-West (parallel to the ground swath) were extensively damaged, with the North fence line completely flattened to the ground and the South fence line relatively intact at its Eastern end but completely flattened within 30 ft. to the West of its Eastern end. The rest of the fence line was undamaged, except for the upper part of the fence line immediately to the East of the right wingtip ground scar. Here, the 9 foot fence received damage consistent with the right wingtip clipping its top as the aircraft passed overhead.

The approximately 18 ft. high Middle Marker antenna (MM) was undamaged. The tip of the left horizontal stabilizer was lodged in the Northeast corner of the Middle Marker radio house about 4.5 ft. from the ground, as shown in Figure 1.

Other important ground scars shown in Figure 1 include:

- A thin scrape 85 ft. East and 53 ft. North of the MM consistent with right horizontal stabilizer ground contact.
- An extensive scar starting 70 ft. East and 29 ft. North of the MM consistent with the ground impact of the lower fuselage.
- An oblique scar starting 4 ft. West and 102 ft. North of the MM and extending to the Southeast consistent with the trailing edge of the right wing impacting the ground.
- An extensive fuel burn pattern to the Northwest of the ground swath that appears to outline the shape of the right wing.
- 7 ft. by 3 to 4 ft. Engine impact craters for all four engines, located as shown in Figure 1.
Small debris showing the start of the disintegration of the aircraft starting about 15 ft. East and 30 ft. North of the MM.

*Inspection of the Departure Runway (MIA 27R)*

Personnel from the Miami NTSB Field Office examined the departure runway shortly after the accident and did not find any evidence of a tail strike or of parts leaving the airplane. However, the tail skid found later at the crash site had scrape marks and paint loss consistent with a tail strike, so the runway was searched again. Early witness reports stated that the aircraft rotated between taxiways Zulu and Mike 1; this area was searched and no evidence of a tail strike was found. Furthermore, at least one witness insists that the aircraft did not tailstrike.

Later witness reports from control tower personnel state that rotation occurred earlier than taxiway Zulu, between Mike 3 and Zulu. This portion of the runway was not re-examined. However, the tower witnesses did not report observing a tailstrike.

The cockpit voice recorder (CVR) indicates that one of the crew members had observed the scraped condition of the tail skid on the aircraft prior to departure.

Given this evidence, it is assumed that the aircraft did not strike its tail on the runway during rotation and that damage to the tail skid pre-dated the accident.

*Estimation of Impact Flight Path and Attitude*

The ground impact scars and markings documented above and in Figure 1 can be used to estimate the aircraft flight path and attitude at impact. This information is useful because it can help in determining whether or not the aircraft was in controlled flight at impact.

The strongest evidence of the aircraft flight path at impact is the location of the right wing tip scar shown in Figure 1 and the damage to the top of the fence immediately to the East of this scar. The scar is 17 ft. to the West of the damaged fence, and the fence when undamaged would have been 9 ft. high. Assuming the wing tip clipped the fence about half a foot from the fence top, the flight path angle (γ) of the wing tip (and the rest of the aircraft) would have to be approximately -27° in order to create the scar at its measured location.

For the aircraft to have descended at γ ≈ -27° where it did without contacting the MM antenna requires a bank angle of at least 10° right wing down. In fact, given the γ ≈ -27° information from the right wing tip scar and fence damage, the pitch angle (θ) and bank angle (ϕ) that place the other ground scars in their proper locations can be estimated. Using the right horizontal stabilizer scrape, the right wing tip scrape, and the four engine craters for this purpose, the θ and ϕ that best match the measured impact marks are θ ≈ 23° (nose up) and ϕ ≈ 20° (right wing down).

To calculate the angle of attack (α) at impact, sideslip angle (β) must be known, as well as γ, θ, and ϕ. While the ground scar markings provide an estimate of the latter three parameters, there is no way of determining β other than to note that, qualitatively, the ground swath of the aircraft does not appear to have any motion along the aircraft's lateral axis, which is consistent with a small sideslip angle at impact. However, it is
hard to know how much evidence of lateral motion even a significant $\beta$ (such as 20°) would leave in the ground scars documented in Figure 1. It is therefore better to leave $\beta$ at impact as unknown and determine a range of $\alpha$ corresponding to a range of possible $\beta$. The results of such a calculation are shown in Figure 2, which shows $\alpha$ at impact as a function of $\beta$ at impact for the values of $\gamma$, $\theta$, and $\phi$ estimated from the ground scars. Figure 2 shows that at $\beta = 0^\circ$, $\alpha = 53^\circ$, with $\alpha$ increasing for negative values of $\beta$ and decreasing for positive $\beta$. Given the right-wing-low attitude of the aircraft, the actual $\beta$ at impact is probably somewhere in the range of 0° to +10°, resulting in an $\alpha$ of at least 49°. This is an extremely high angle of attack and indicates the aircraft was in a deep stall upon impact, which is consistent with the stick shaker warning and engine surge sounds recorded by the CVR in the final seconds of the flight.

II. Radar Data

Description of ASR Radar Data

Miami International Airport is serviced by an Airport Surveillance Radar (ASR) that assists tower controllers in maintaining traffic separation in the vicinity of the airport. Targets tracked by the ASR are recorded by a Continuous Data Recording (CDR) system. In order to be recorded by the CDR, a target must be at least 1.125 miles from the ASR antenna.

Fine Air Flt. #101 never traveled further than 1.125 miles from the MIA ASRS antenna, and so was never recorded by the CDR. However, returns from the aircraft were still received by ASR9 and stored as part of a different system. This second system uses targets within the 1.125 mile boundary to "fine tune", or calibrate the ASR radar so that unwanted returns are not displayed to tower controllers.

The data recorded by the ASR9 antenna for the accident flight are tabulated in Figure 3. The information of interest in this Figure is as follows:

- **RNG** = Range (Distance) from the ASR9 antenna in miles & 64ths of a mile. For example,
  
  $1/13$: Denotes the target is $1 + 13/64 = 1.203$ miles from the antenna. The resolution of this data is then $\pm 1/128$ mile $\approx \pm 40$ ft.

- **AZ** = Azimuth to target. Values range from 0 to 4096, where 0 = 0° magnetic and 4096 = 360° magnetic. Thus, the magnetic bearing to the target would be
  
  $MB = (360/4096) \cdot AZ \approx (0.08789) \cdot AZ$. The resolution of this data is about $\pm 0.04$ degrees.

- **ALT** = Altitude in ft. The resolution of this data is $\pm 50$ ft.

- **TIME** = Miami ATC time in hours, minutes, seconds. A radar return is received every 4.6 seconds. The time resolution is 0.05 sec.
Presentation of the ASR Radar Data

Figure 4 shows the raw data in Figure 3 transformed to and plotted in the coordinate system of Figure 1. Figure 4 plots the location of each radar return, the location of the ASR9 radar antenna, the layout of Runway 27R/9L, and the impact point in feet West and North (magnetic) of the Middle Marker antenna for Runway 9L. Relevant items from the CVR recording are indicated in Figure 4 at the points in the radar trace at which they occur. The legend for the numbered CVR items is shown in Figure 5, which indicates the content of the item, the time it was recorded, and its source. Note that because of space constraints, not all the items listed in Figure 5 are plotted in Figure 4.

It is important to understand that the resolution of the radar data described above is not the same as the accuracy of the data. The resolution of the radar indicates how small of a difference in the recorded parameters (range, azimuth, and time) the system is able to measure; it does not indicate how correct or accurate the absolute values of the recorded parameters are. The resolution does not even guarantee that the relative positions of the radar hits are absolutely correct. Thus, for example, the radar hits plotted in Figure 4 have been shifted from the recorded radar returns by 120 ft. to the East and 288 ft. to the North in order to place the aircraft on Runway 27R. Even so, looking at the position of the final radar hit and the position of ground impact in Figure 4 it appears that in the final 2.5 seconds between the last radar hit and ground impact the aircraft would have had to make a jog to the South and then realign its flight path with Runway 27R in order to match the impact point and ground swath heading. Such a maneuver is unlikely; it is more probable that the radar data suffers from unknown inaccuracies that incorrectly position the aircraft at the points shown in Figure 4. The final radar hit would need to be shifted perhaps as much as ±400 ft. in the North and East directions in order to be consistent with the known aircraft impact point. The ASR data provides a good indication of the general position of the aircraft in time, but as Figure 4 suggests, it may be taxing the capabilities of the system to define the absolute position of the aircraft to within 500 ft.. This limitation is an important consideration when using the radar data and impact point together to define the aircraft velocity, as described in a later section.
III. Digital Flight Data Recorder (DFDR) and Cockpit Voice Recorder (CVR) Data

DFDR and CVR Data Description

The aircraft cockpit voice recorder (CVR) and flight data recorder (FDR) were found by Miami NTSB personnel shortly after the accident and sent to Washington, DC for readout.

Descriptions of the DFDR and CVR on board the aircraft and the recorder readout processes can be found in the Factual Reports of the Flight Data Recorder and Cockpit Voice Recorder Groups, respectively. The DFDR readout results in tabulated and plotted values of the recorded flight parameters versus time. The CVR readout results in a transcript of the CVR events, a partial list of which is shown in Figure 5.

On the accident DFDR, only five channels from the 11 channel recorder are usable:

- DFDR Time (seconds)
- Altitude (ft.)
- Magnetic Heading (degrees)
- Longitudinal Load Factor (g's)
- Differential Control Column Movement (degrees)

These parameters are plotted in Figure 6, with selected CVR events overlaid on the plots. The “Elapsed Time” independent variable in these plots represents a convention selected to coordinate the times associated with the radar, DFDR, and CVR data. This convention is described below.

The Altitude plot in Figure 6 shows the aircraft being airborne for approximately half a minute before the end of the data. Note that the data does not end at the runway altitude, but approximately 550 ft. above the runway, and shows the aircraft in a climb as the data ends. This erroneous altitude data is evidence that the static pressure ports that service the altimeter and the DFDR altitude sensor are not measuring the correct freestream static pressure, but a lower pressure. This condition is consistent with a disruption of airflow over the static ports due to an unusual flight condition, such as an extreme angle of attack and/or sideslip. Thus the DFDR altitude trace supports the ground scar evidence of a deep stall at impact.

The altitude data shows the runway at approximately -100 ft.. This is because the DFDR measures pressure altitude (i.e., it assumes Sea Level static pressure is always 29.92 inches of mercury). The altitude data shown in Figure 4 is received from the aircraft's Mode C transponder, which transmits the altitude displayed to pilot on his altimeter and which is based on the local altimeter setting. The ATIS report recorded by the CVR indicates that the current altimeter setting was 30.04" Hg, which results in a 100 ft. difference from a setting of 29.92" Hg.

The Heading trace in Figure 6 shows a turn to the right of the runway heading at Elapsed Time (ET) = 60 seconds, followed by a return to runway heading at 67 seconds, and finally some wandering about the runway heading during the last few
seconds of the recording. This data is consistent with the radar data in Figure 4 showing the aircraft drifting to the right of the runway after liftoff, and with the witness reports describing the wings rocking as the aircraft descended.

**Coordination of Radar, DFDR, and CVR Times**

The Miami Airport ASR9 radar, the DFDR, and the CVR record their information with respect to time but these times are generally not synchronized. To use these data sources together, the times they record must be synchronized to a single reference time. This reference time is the Elapsed Time shown in Figure 6.

Microphone keying information is not available, therefore to synchronize the DFDR and CVR data, it is assumed that the end of the DFDR and CVR recordings occur simultaneously and coincide with the time of impact. The CVR time called out on the CVR transcript is referenced to the Miami ATC Time by the CVR Group and shows the end of the CVR recording at 12:36:25.4. The DFDR time at the end of the DFDR recording is 670 seconds. Arbitrarily selecting the Elapsed Time (ET) to equal 0.0 seconds at 12:35:00 Miami ATC Time (= CVR Time), we have:

\[(\text{Impact Time}) = (12:36:25.4 \text{ CVR}) = (670 \text{ sec. DFDR})\]

\[(0. \text{ ET}) = (12:35:00 \text{ CVR}) = (\text{Impact Time}) - 85.4 \text{ sec.}\]

\[(0. \text{ ET}) = (670 \text{ sec. DFDR}) - 85.4 \text{ sec.} = (584.6 \text{ sec. DFDR})\]

\[\text{ET} = \text{DFDR} - 584.6 \text{ seconds} \quad [1]\]

\[(0.0 \text{ ET}) = (12:35:00 \text{ CVR (MIA ATC))} \quad [2]\]

Equations [1] and [2] convert CVR and DFDR times to Elapsed Time. To synchronize the radar data with these times, the altitude traces recorded by the DFDR and the ASR9 radar are aligned as shown in Figure 7 and the radar time adjusted accordingly. In this way, a DFDR time of 570 sec. aligns with an ASR9 time of 12:39:00, and therefore, using Equation [1],

\[(0.0 \text{ ET}) = (12:39:14.6 \text{ ASR9})\]

Note that the 100 ft. altitude difference between the pressure altitude recorded by the DFDR and the absolute altitude recorded by the radar has been removed in Figure 7.

**IV. Analysis of Radar and DFDR Data**

**Aircraft Speed**

While the DFDR did not record values of airspeed or pitch angle, an estimate of these parameters can be made using the radar data and the DFDR recorded longitudinal load factor. The known impact point can theoretically be used as a final "radar hit" in these calculations, but the above mentioned lack of consistency between the final radar hits and the impact point render the results of this step questionable.

The absolute velocity and ground speed of the aircraft can be calculated by taking the derivative of the West, North, and Altitude positions of the radar hits with respect to time. The total velocity is the vector sum of all three of these velocity components; the
ground speed is the vector sum of just the West and North velocity components. The results of this calculation are shown in Figure 8, and include the known impact point as a final “radar hit.” The sudden jump in velocity between the first and last points of the total velocity and groundspeed in Figure 8 confirm the mismatch between the radar data and the known impact point, and do not indicate a sudden, physically impossible acceleration at this point. The wandering of the slope of the groundspeed trace during the takeoff roll is further evidence of the inaccuracy of the radar data.

The proximity of the total velocity and groundspeed traces in Figure 8 shows that the contribution of the vertical velocity component to the total velocity is very small.

Also shown in Figure 8 is the velocity obtained by integrating the longitudinal load factor (nx) recorded by the DFDR with respect to time. Prior to rotation, nx is an accurate measurement of the rate of change of velocity along the longitudinal axis. After rotation, other terms contribute to nx and the velocity obtained from integrating nx no longer reflects the actual velocity of the aircraft (more on this below). The integral of nx shown in Figure 8 has been shifted so as to match the velocity obtained from the radar traces in the period from -10 sec. < ET < 10. sec.

Figure 8 also indicates the times and values of the airspeed callouts recorded by the CVR. Thus, for example, V-1, which based on early CVR comments is 130 KIAS, is called out at ET = 43 sec., and so is plotted at (43,130) in Figure 8. The ATIS information recorded by the CVR reported a wind from 250° at 7 kts. This is consistent with the airspeed callouts in Figure 8, which are about 5 to 10 kts. above the ground speed resulting from the integration of the nx data.

Prior to rotation, the integrated nx trace is a better estimate of ground speed than the time derivative of the radar data. The variation between the integrated nx trace and the radar-derived traces shows the unreliability of the radar data for accurate velocity estimates; the radar data shows the acceleration dropping to zero at 43 seconds, 7 seconds prior to rotation, while the nx trace shows steady, smooth acceleration through rotation.

**Flight Path Angle and Rate of Climb**

The vertical and horizontal components of the velocity obtained from the radar traces can be used to calculate the flight path angle γ and the rate of climb. Figure 9 shows the results of such calculations. Because the pressure measured at the static ports is inaccurate while the aircraft is stalled, the altitude reported to the ASR9 radar by the aircraft Mode C transponder at these points is incorrect. Thus the vertical component of velocity derived from the radar data is also incorrect in the stall regime. Consequently, the sudden decrease in rate of climb and γ at the last point (the impact point) shown in Figure 9 is not realistic. Furthermore, the last data point recorded by the radar (the penultimate point shown in Figure 9) has an artificially high altitude; in reality, the altitude is lower, resulting in a lower γ at that point than is shown in Figure 9. Even with all these inaccuracies, the trend of the γ trace shown in Figure 9 is reasonable, and is consistent with the value of γ ≈ -27° obtained from the ground scars.
Load Factor During Rotation

The speed and flight path angle traces shown in Figures 8 and 9 can be used to estimate the vertical load factor the aircraft experienced during the initial takeoff rotation.

During rotation, the aircraft must develop enough lift to overcome the weight of the aircraft and to support it through an approximately circular pull-up maneuver. The additional lift required to perform the pull-up is proportional to the velocity of the aircraft and the rate of change of the flight path angle. The total normal load factor during rotation is then approximately

\[ n_z = L/W \equiv 1 + \left( \frac{\omega v}{g} \right) \]  

with \( \omega = \frac{dy}{dt} = 2 \text{ deg/sec.}, v = \text{velocity} = 140 \text{ kts.} = 237 \text{ ft/s}, \) and \( g = \text{acceleration due to gravity} = 32.2 \text{ ft/s}^2, \) the resulting \( n_z \) is about 1.3 g’s. This is a moderate g level for rotation and initial climb and is consistent with a rotation with no tailstrike.

Pitch Angle and Angle of Attack

Bearing the limitations of the radar data in mind, it is still possible to obtain a rough estimate of the pitch angle by comparing acceleration computed from the radar data with the \( n_x \) measured by the DFDR.

The acceleration along the longitudinal axis is given by

\[ a_x = \dot{u} - vR + wQ = n_x g + g_x \]  

where

- \( u = \text{velocity component along longitudinal axis} \)
- \( v = \text{velocity component along lateral axis} \)
- \( w = \text{velocity component along vertical axis} \)
- \( R = \text{angular velocity about vertical axis (yaw rate)} \)
- \( Q = \text{angular velocity about lateral axis (pitch rate)} \)
- \( n_x = \text{longitudinal load factor (measured by DFDR)} \)
- \( g_x = \text{component of gravity along longitudinal axis} \)

In the regime where the aircraft is not stalled and the sideslip angle is small, to a good approximation \( v \equiv R \equiv 0. \) Furthermore, in this region

\[ u = V_e \cos(\alpha) \cos(\beta) \equiv V_e \cos(\alpha) \]  
\[ w = V_e \sin(\alpha) \cos(\beta) \equiv V_e \sin(\alpha) \]  

where \( V_e = \text{freestream speed}. \) The pitch rate \( Q \) is given by

\[ Q = \dot{\psi} \sin(\phi) \cos(\theta) + \dot{\theta} \cos(\phi) \]  

where \( \psi \) is the heading angle. Because the estimate of pitch angle will at best be very rough, for simplicity it can be assumed that during the flight the bank angle \( \phi \) is small enough that Equation [7] simplifies to

\[ Q \equiv \dot{\theta} \]
The assumption of small bank and sideslip angles also implies that
\[ \gamma \equiv \theta \pm \alpha \]  
[9]

The component of gravity along the longitudinal axis is given by
\[ g_x = -g \sin(\theta) \]  
[10]

Taking the time derivative of Equation [5] gives
\[ \dot{u} = \dot{V}_e \cos(\alpha) - V_e \sin(\alpha) \hat{\alpha} \]  
[11]

Substituting Equations [11], [10], [8], and [6] into Equation [4], we have
\[ \dot{V}_e \cos(\alpha) - V_e \sin(\alpha) (\hat{\alpha} - \dot{\theta}) \equiv n_x g - g \sin(\theta) \]  
[12]

The time derivative of Equation [9] gives
\[ \dot{\alpha} - \dot{\theta} \equiv -\dot{\gamma} \]  
[13]

Finally, substituting Equation [13] into Equation [12] and solving for \( \theta \) gives
\[ \theta \equiv \sin^{-1} \left\{ n_x - \left( \frac{\dot{V}_e \cos(\alpha) + V_e \dot{\gamma} \sin(\alpha)}{g} \right) \right\} \]  
[14]

Equation [14] gives \( \theta \) in terms of the aircraft speed, longitudinal load factor, flight path angle, and angle of attack. From the radar and DFDR data, an estimate of all these parameters except for \( \alpha \) can be made. However, in evaluating Equation [14] an arbitrary guess at \( \alpha \) can be used, and then the resulting \( \theta \) used in Equation [9] to solve for a new \( \alpha \), which can then be used in Equation [14] to solve for a new \( \theta \). Iterating in this way, an estimate of both \( \alpha \) and \( \theta \) can be made.

Table 1 shows the result of such an iteration for various points in the flight. The points shown were selected based on the ability to use the radar-based velocity trends shown in Figure 8 to obtain an estimate of aircraft acceleration; beyond ET=76 seconds, the radar data is useless for obtaining acceleration information.

<table>
<thead>
<tr>
<th>Elapsed Time (sec.)</th>
<th>( \theta ) Estimate (deg.)</th>
<th>( \alpha ) Estimate (deg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>58</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>62</td>
<td>19</td>
<td>11</td>
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<tr>
<td>66</td>
<td>31</td>
<td>19</td>
</tr>
<tr>
<td>72</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>76</td>
<td>13</td>
<td>16</td>
</tr>
</tbody>
</table>
The $\alpha$ and $\theta$ estimates shown in Figure 1 suggest that about 16 seconds after rotation (at ET=66 sec.) the aircraft achieved an extremely high nose attitude (31°) and an angle of attack that would result in stall (19°). The estimates at 72 and 76 sec. suggest a slight recovery from the stall ($\alpha$ and $\theta$ down to 12° and 18°, respectively), followed by another increase of $\alpha$ into the stall region ($\alpha = 16^\circ$). This trend is consistent with the stick shaker sound recording on the CVR, which activates at ET = 62 sec., deactivates at ET = 72 sec., and then reactivates for the duration of the flight at ET = 78 sec.. It is also consistent with the recorded incremental column position shown in Figure 6, which indicates a push at about 59 sec. followed by a reversal of the push at 72 sec..

Table 1 suggests that during the final seconds of the flight $\theta$ is decreasing (even though $\alpha$ is increasing), yet based on the impact marks it is probable that sometime before impact the pitch angle increased to 23°, while the flight path angle continued to steepen, resulting in the extremely high angle of attack at impact. Such pitch angle activity is consistent with witness reports of the aircraft undergoing several "pitch oscillations" during the flight.

**Bank Angle Estimate**

The DFDR heading data, and the aircraft impact almost exactly on the extended centerline of Runway 27R, suggest that there was very little lateral-directional activity during the flight. However, the DFDR heading data does show a jog to the right around ET = 66 seconds, and the radar data shows the aircraft drifting to the right of the runway, indicating that some banking of the aircraft may have occurred.

An estimate of the bank angle from the heading trace is difficult in this case because there are ways of changing the heading angle other than banking the aircraft. A sideslip-inducing yaw, for example, will have this effect. At the beginning of the heading excursion (ET $\geq$ 62 sec.), Table 1 shows the aircraft starting to pitch up into a stall. If, in the nose high, stalled condition, the nose of the aircraft slices to the right (which can easily happen), the heading angle will increase and a negative sideslip angle will develop without the aircraft necessarily rolling to the right about the longitudinal axis.

Nonetheless, a measure of the magnitude of the heading change is the bank angle required to produce such a change assuming a level, coordinated turn. The maneuver performed by the accident aircraft was probably something in between a coordinated turn and the nose-high yaw described above, and so the coordinated turn bank angle provides an estimate of the maximum bank angle the aircraft could have experienced.

For an aircraft in a level, coordinated turn, the bank angle is given by

$$\phi \equiv \tan^{-1} \left( \frac{V_r \psi}{g} \right)$$

Figure 10 shows Equation [15] evaluated based on a cubic spline curve fit through the DFDR heading data, and aircraft velocity based on the radar hits. The Figure shows that the heading jog recorded by the DFDR would have required a coordinated aircraft in level flight at the speed recorded by the radar data to bank 45° to the right, then 30°
to the left, and then return to wings level, at roll rates up to 18 deg/s. Since it is unlikely that the aircraft in or near a stall condition could generate such roll performance, the $\phi$ trace shown in Figure 10 provides a boundary or limit for the bank angles achieved during the flight.

Near the end of the flight, Figure 10 shows the aircraft in a left bank. Since the ground scars indicate that impact was in a right bank, this is further evidence the assumption of coordinated flight with no sideslip used in generating Figure 10 is not very good in the final, stalled flight condition, and that much of the heading change in this region results from mechanisms other than coordinated turning flight.

E. CONCLUSIONS

The impact scars and markings, damage to surface structures, examination of the departure runway, and radar and available FDR data described in this study are consistent with witness reports of the aircraft lifting off with no tailstrike, climbing rapidly to an extreme nose high attitude, then descending and impacting the ground in a nose high, right wing down attitude. Rough estimates of the pitch angle and angle of attack during the flight based on the radar data and the DFDR longitudinal load factor data are consistent with the CVR recordings in providing evidence that after rotation the aircraft pitched up quickly into a stall, recovered briefly, then stalled again. The stall recovery period coincides with a 10 second push on the control column recorded by the DFDR. The ground scars are consistent with an impact in a deep stall condition.
Figure 1. Impact Scars and Markings.
Fine Air Flight 101 - Angle of Attack at Impact vs. Sideslip Angle

Assumes $\gamma = -27^\circ$; $\theta = 23^\circ$; $\phi = 20^\circ$
(Based on Ground Scars and Markings)

\[ \alpha = \tan^{-1} \left( \frac{\tan(\theta)}{\cos(\phi)} \right) - \sin^{-1} \left( \frac{\sin(\gamma) + \sin(\beta) \cos(\theta) \sin(\phi)}{\cos(\beta) \sqrt{1 - \cos^2(\theta) \sin^2(\phi)}} \right) \]

**Figure 2.** Angle of Attack at impact as a function of Sideslip Angle at impact.
Figure 4. ASR9 Radar Data plotted with Cockpit Voice Recorder events.
### Cockpit Voice Recorder Events

<table>
<thead>
<tr>
<th>Event #</th>
<th>Time</th>
<th>Description</th>
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<th>Time</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12:35:02.1</td>
<td>CAM: ((Increasing engine sounds))</td>
<td>25</td>
<td>12:36:05.6</td>
<td>CAM: ((sound of trim-in-motion tone))</td>
</tr>
<tr>
<td>2</td>
<td>12:35:07.6</td>
<td>CAM-3: okay four spooled and ah stable.</td>
<td>26</td>
<td>12:36:07.4</td>
<td>CAM-1: oh no # no.</td>
</tr>
<tr>
<td>3</td>
<td>12:35:10.6</td>
<td>CAM-2: max power.</td>
<td>27</td>
<td>12:36:07.5</td>
<td>CAM: ((sound of trim-in-motion tone)).</td>
</tr>
<tr>
<td>4</td>
<td>12:35:13.2</td>
<td>CAM-1: just like autothrottles.</td>
<td>28</td>
<td>12:36:08.8</td>
<td>CAM-1: ((sound of trim-in-motion tone)).</td>
</tr>
<tr>
<td>5</td>
<td>12:35:15.2</td>
<td>CAM-2: yeah.</td>
<td>29</td>
<td>12:36:09.3</td>
<td>CAM-1: oh no # no.</td>
</tr>
<tr>
<td>6</td>
<td>12:35:17.3</td>
<td>CAM-2: airspeed on the right.</td>
<td>30</td>
<td>12:36:12.0</td>
<td>CAM: ((stick shaker stops))</td>
</tr>
<tr>
<td>7</td>
<td>12:35:19.5</td>
<td>CAM-1: okay comin' up on sixty knots power's set.</td>
<td>31</td>
<td>12:36:13.3</td>
<td>CAM-1: ###.</td>
</tr>
<tr>
<td>8</td>
<td>12:35:26.2</td>
<td>CAM-1: eighty, you got the steer on the rudders.</td>
<td>32</td>
<td>12:36:15.1</td>
<td>CAM-1: hold on hold on keep it light easy #.</td>
</tr>
<tr>
<td>9</td>
<td>12:35:36.7</td>
<td>CAM-3: okay number four's is (heatin' up a little)</td>
<td>33</td>
<td>12:36:17.6</td>
<td>GPWS: too low gear.</td>
</tr>
<tr>
<td>10</td>
<td>12:35:39.6</td>
<td>CAM: ((sound of thump))</td>
<td>34</td>
<td>12:36:17.8</td>
<td>CAM: ((stall warning starts and continues until end of recording)).</td>
</tr>
<tr>
<td>11</td>
<td>12:35:43.1</td>
<td>CAM-1: vee one.</td>
<td>35</td>
<td>12:36:19.2</td>
<td>CAM-1: oh #.</td>
</tr>
<tr>
<td>13</td>
<td>12:35:49.9</td>
<td>CAM-1: rotate.</td>
<td>37</td>
<td>12:36:20.73</td>
<td>CAM: ((sound similar to engine surge))</td>
</tr>
<tr>
<td>14</td>
<td>12:35:51.5</td>
<td>CAM-1: easy easy easy easy.</td>
<td>38</td>
<td>12:36:20.8</td>
<td>CAM-1: oh ##.</td>
</tr>
<tr>
<td>15</td>
<td>12:35:55.6</td>
<td>CAM-1: vee two.</td>
<td>39</td>
<td>12:36:20.81</td>
<td>CAM: ((sound similar to engine surge))</td>
</tr>
<tr>
<td>16</td>
<td>12:35:56.9</td>
<td>CAM-1: positive rate.</td>
<td>40</td>
<td>12:36:20.88</td>
<td>CAM: ((sound similar to engine surge))</td>
</tr>
<tr>
<td>18</td>
<td>12:36:00.0</td>
<td>CAM-2: what's goin' on.</td>
<td>42</td>
<td>12:36:21.95</td>
<td>CAM: ((sound similar to engine surge))</td>
</tr>
<tr>
<td>19</td>
<td>12:36:01.3</td>
<td>CAM-1: whoa #.</td>
<td>43</td>
<td>12:36:22.73</td>
<td>CAM: ((sound similar to engine surge))</td>
</tr>
<tr>
<td>20</td>
<td>12:36:01.7</td>
<td>CAM-1: ##.</td>
<td>44</td>
<td>12:36:22.85</td>
<td>CAM: ((sound similar to engine surge))</td>
</tr>
<tr>
<td>23</td>
<td>12:36:02.8</td>
<td>CAM: ((sound of trim-in-motion tone)).</td>
<td>47</td>
<td>12:36:25.4</td>
<td>end of recording.</td>
</tr>
<tr>
<td>24</td>
<td>12:36:04.5</td>
<td>CAM: ((sound of trim-in-motion tone)).</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.** Cockpit Voice Recorder Events.
Fine Air Flight 101 - DFDR Data with Cockpit Voice Recorder Events

Figure 6. DFDR Data.

Elapsed Time = DFDR Time - 584.6 (sec.)
Miami ATC Time (HH:MM:SS)
Figure 7. DFDR and Radar Altitude Comparison.
Fine Air Flight 101 - Aircraft Velocity based on Radar Data, Impact Point and Integration of Longitudinal Acceleration

Figure 8. Speed Calculations.
Fine Air Flight 101 - Flight Path Angle and Rate of Climb
Based on Radar Data and Impact Point

Figure 9. Flight Path Angle and Rate of Climb calculations.
Fine Air Flight 101 - Bank Angle Based on Coordinated, Level Turn and DFDR Heading Data

Figure 10. Bank Angle Estimate.