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

Performance Study

Specialist Report
Marie Moler

A. ACCIDENT

Location:	Big Grand Cay, Bahamas
Date:	July 4, 2019
Time:	01:53 eastern daylight time (EDT)
Aircraft:	Agusta AW139, N32CC
NTSB Number:	ERA19FA210

B. GROUP

No vehicle performance group was formed.

C. SUMMARY

On July 4, 2019, about 01:53 EDT, an Agusta S.p.A. AW139, N32CC, owned and operated by Challenger Management LLC, impacted the Atlantic Ocean near Big Grand Cay, Abaco, Bahamas. The commercial pilot, airline transport rated co-pilot, and five passengers were fatally injured. The helicopter was substantially damaged. The helicopter was being operated under the provisions of Title 14 *Code of Federal Regulations* Part 91 as a personal flight. Dark night visual meteorological conditions prevailed at the time and an instrument flight rules (IFR) flight plan was filed for a flight from Walker's Cay Airport (MYAW), Walker's Cay, Bahamas, to Fort Lauderdale/Hollywood International Airport (FLL), Fort Lauderdale, Florida. The flight originated about 01:52 from a concrete pad located at Big Grand Cay, Abaco, Bahamas.

D. PERFORMANCE STUDY

The helicopter was equipped with a flight data recorder (FDR) [1] and cockpit voice recorder (CVR) [2]. Both devices recorded the accident flight and prior flights of the aircraft. All data in this report are from the onboard recorders.

Weather Observations

The closest weather report was from Grand Bahama International Airport (MYGF), Freeport, Bahamas, located approximately 45 miles south of the accident site, at an elevation of 6 ft. The airport has an Automated Weather Observation System (AWOS). The latest observation before the accident flight was recorded at 2000, local time, on July 3rd. That observation reported winds at 4 kts from 160°, an altimeter setting of 29.95 inHg, few clouds at 2,500 ft, and broken clouds at 25,000 ft. The NTSB Weather Study [3] contains more information.

The aircraft also recorded outside air temperature (OAT), barometric pressure, and winds. For the accident flight at takeoff, OAT was 29°C (84°F), barometric pressure was 1015 mbar (29.97 inHg), and winds were about 9 kts from between 0° and 70°.

Aircraft Flightpath

Figure 1 shows the flight, departing the helipad at 01:52:20 to the end of data at 01:53:28. Figure 2 shows the recorded longitudinal (N_X), vertical (N_Z), and lateral (N_Y) acceleration and the aircraft radio altitude above ground level (AGL). The altitude began to increase with takeoff at 01:52:20, and water impact was determined from the abrupt changes in acceleration parameters to be at or just after 01:53:22. The length of the flight was 62 seconds, and it covered approximately 1.4 NM.

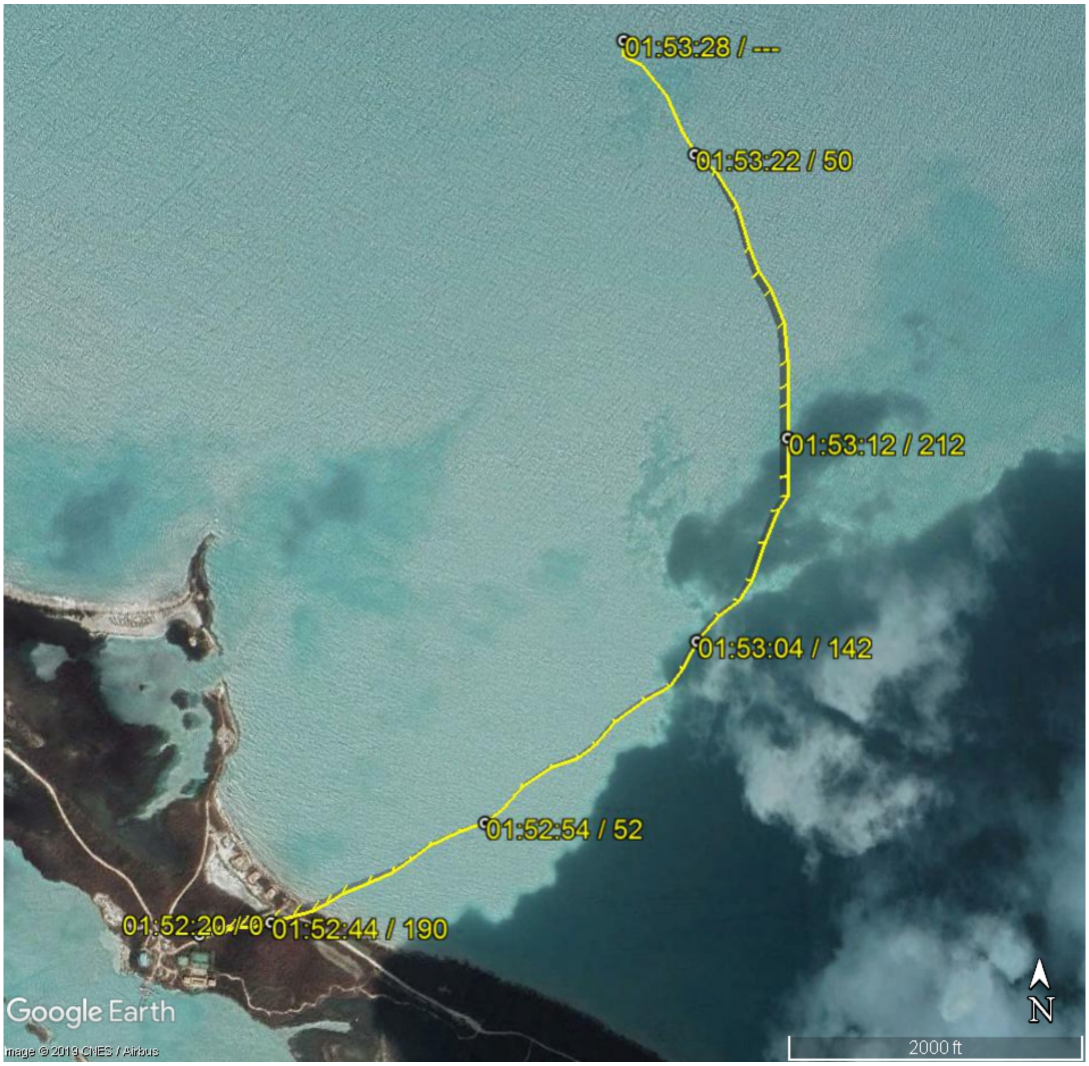

Figure 1. Accident flight, with select times and radio altitudes annotated.

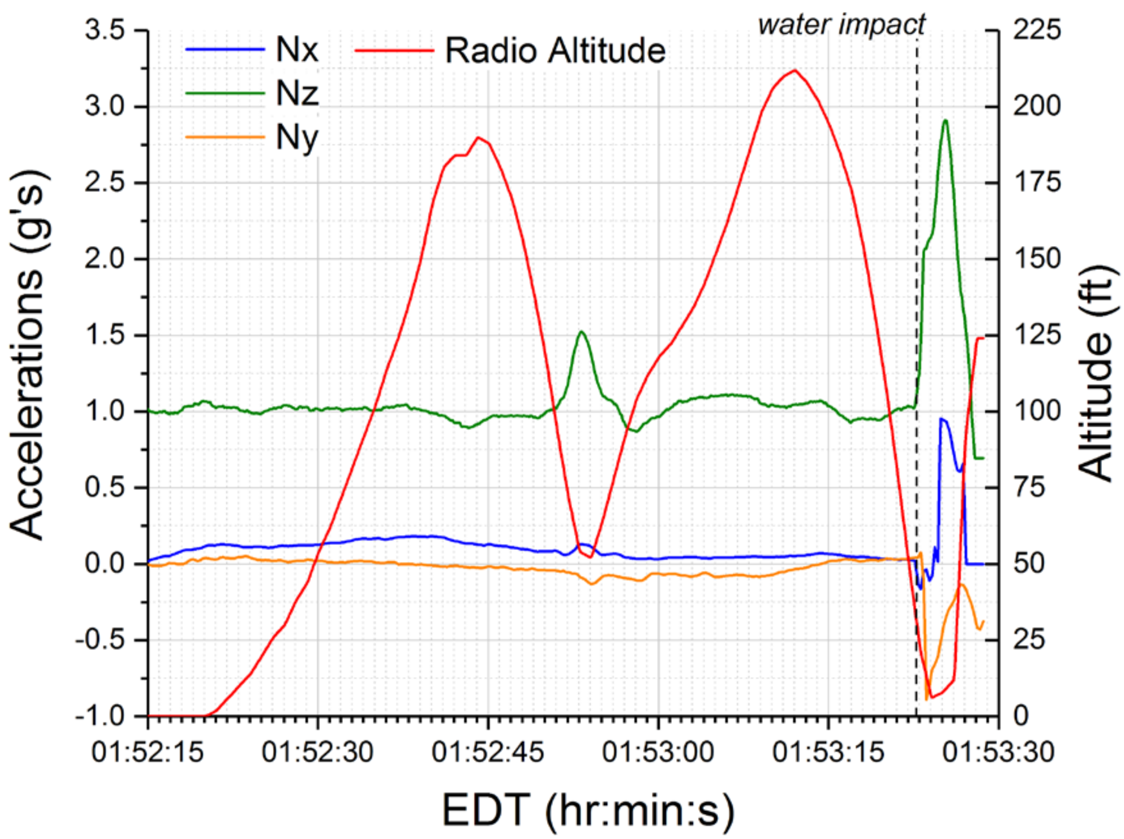

Figure 2. Accelerations and radio altitude from accident flight.

At 01:52:07, collective pitch was increased[1] and at 01:52:20 the aircraft began to climb away from the helipad (Figure 3). The longitudinal cyclic was advanced and at 01:52:30, at an altitude of 53 ft, the helicopter began gaining forward speed. Initially nose up, the aircraft was pitched nose down starting at 01:52:35. The helicopter climbed to an initial maximum altitude of 190 ft at a groundspeed of 55 kts, an indicated airspeed of 68 kts, and a collective position of 72%. At 01:52:44 the aircraft, now -13° nose down, began descending. Speed increased (groundspeed to 110 kts, airspeed to 116 kts) while collective remained relatively constant near 72%. During the initial climb and descent, the helicopter was on a heading of approximately 68°.

From 01:52:50 to 01:52:56, the longitudinal cyclic was reduced and advanced twice from a minimum value of 52% to a maximum of 80% (forward cyclic) before settling near 65%. The helicopter pitch went from -10° nose down at 01:52:51 to 6.8° nose up by 01:52:53. At 01:52:54, the aircraft began to climb again and by 01:52:57 the longitudinal cyclic was decreasing from 65% towards 60%. The speed dropped slightly to near 100 kts.

[1] The mechanism for control inputs and whether they were pilot- or computer-commanded will be discussed in the *Automatic Flight Control System* section of the report.

At 01:53:09, as the helicopter climbed, the longitudinal cyclic began to again advance forward as collective reached its minimum of 46%. Just after 01:53:11, the helicopter pitched nose down and collective began to increase at a rate of about 5% per second. The helicopter reached a maximum altitude of 212 ft at 01:53:12 while banking left 30°. At 01:53:15, when at 70%, the rate of collective increase slowed and collective remained below 76% for the duration of the flight.

The aircraft was losing altitude, gaining speed, and in a nose down attitude. At water impact (01:53:22), the helicopter was on a heading of about 330°, was -7° nose down, in a 12° left bank, and its groundspeed was 141 kts. The change in vertical acceleration at impact was about 2 g's in two seconds.

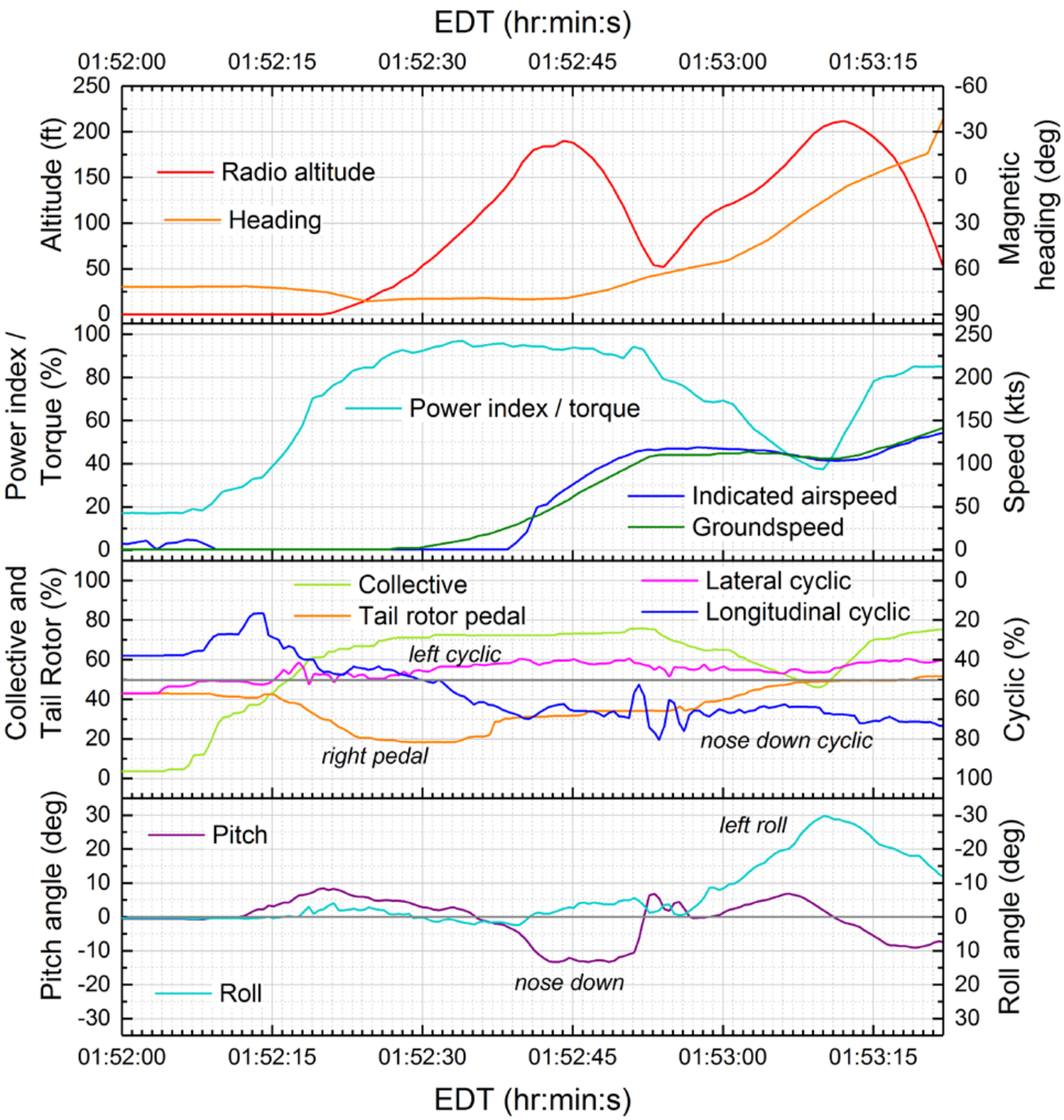

Figure 3. Flight profile, power, collective, tail rotor pedal, and cyclic inputs, and aircraft pitch and roll.

Annunciations and CVR

The CVR recorded the crew conversation and cockpit annunciations heard during the flight. Figure 4 shows just the cockpit annunciations on the flight path. Figure 5 shows some of the crew conversation and all the annunciations during the flight with altitude and groundspeed for reference. The greyed-out area at the end was after the sudden increase in accelerations that indicated water impact. The pilot-in-command is noted as PIC and the co-pilot or second-in-command is noted as SIC. Commentary indicated that the PIC was flying the aircraft.

Figure 4. Annunciations on accident flightpath.

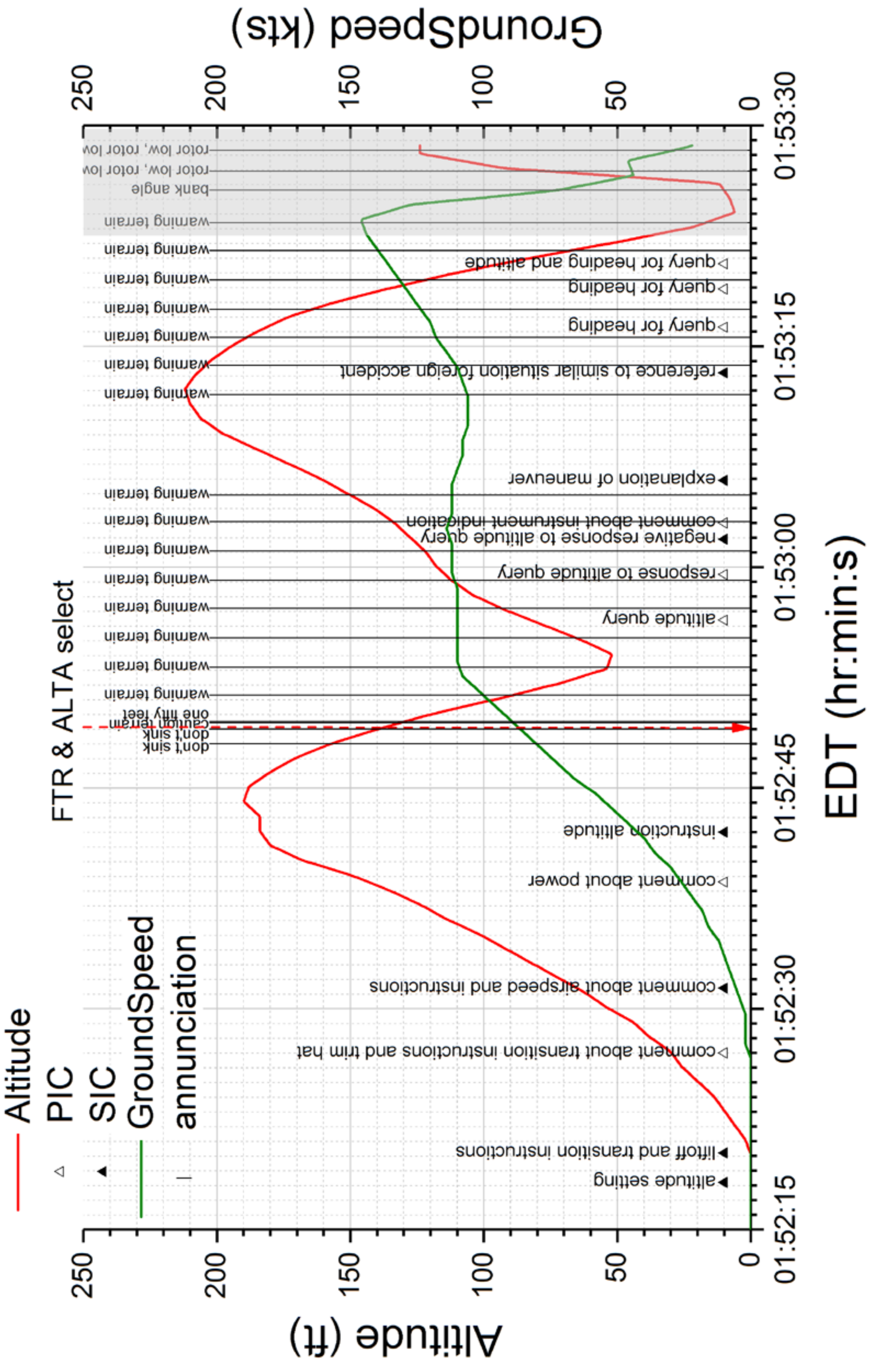

Figure 5. Annunciations and crew conversation with altitude and groundspeed.

The first warning was at 01:52:48 when the enhanced ground proximity warning system (EGPWS) twice annunciated "don't sink" as the helicopter's descent rate passed 1000 ft/min. These were followed by "caution terrain" and "one fifty feet" at 01:52:49.4 and 49.5. During these initial annunciations ALTA (altitude acquire mode) was selected in the autopilot and the collective FTR (force trim release) was depressed, which will be discussed in greater detail in the *Auto pilot modes and power limitations* section. The EGPWS announced "warning terrain" eight times until the aircraft climbed above 150 ft again (01:53:04).

Just as the helicopter's ascent slowed and it reached its maximum altitude, "warning terrain" annunciations resumed from 01:53:11.7 to after the impact with the water. The PIC asked for the helicopter heading three times during the second descent with no response. The final annunciations of "bank angle" and "rotor low, rotor low" occurred after the aircraft entered the water.

Apparent Angles and Spatial Disorientation

The vestibular system of the inner ear allows a person to have a sense of balance and spatial orientation. However, like all accelerometers, the vestibular system cannot distinguish between load factors due to motion versus load factors due to gravity. Simply put, on its own, the inner ear cannot differentiate between accelerations and tilt. Additional sensory inputs, such as visual cues, are needed to correctly perceive attitude and acceleration. When a pilot misperceives attitude and acceleration it is known as the "somatogravic illusion" and can cause spatial disorientation. Further information is available in the Human Performance Report [4].

Figure 6 shows the orientation of the resultant load factor vector $\vec{n}$ for two cases. In the left image, the airplane is unaccelerated, and $\vec{n}$ is aligned with the gravity vector g, along the earth's vertical axis (z_e). In the right image, the airplane is in accelerated flight, and $\vec{n}$ has a component along the x_b axis (n_x). In both cases, the angle of the vector $\vec{n}$ relative to the airplane's vertical axis (z_b) is the same: θ_{APP}, or the "apparent" pitch angle. While in the left image, θ_{APP} is the actual pitch angle of the airplane ($\theta_{APP} = \theta$), in the right image the actual pitch angle is less than θ_{APP}. However, in both cases the pilot's vestibular/kinematic system alone would perceive the pitch angle as θ_{APP}.

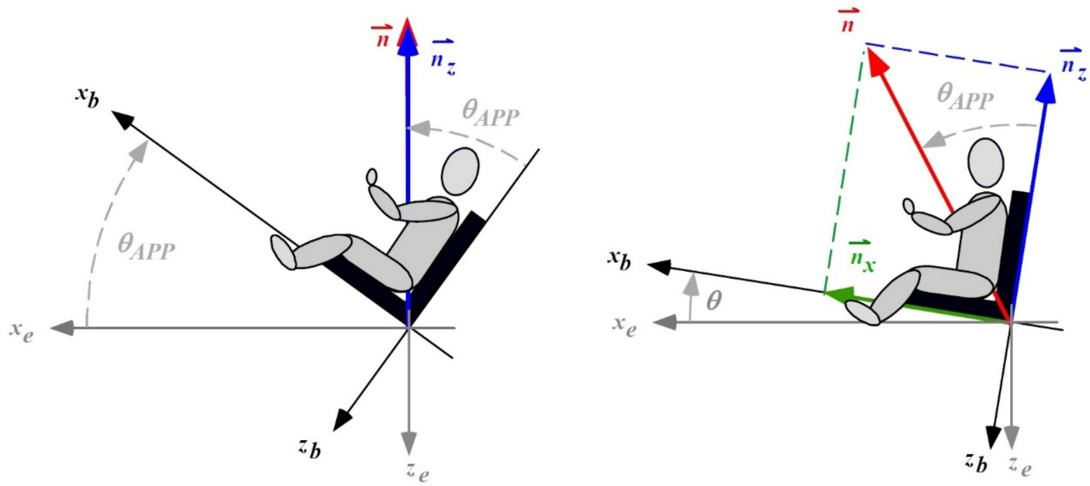

Figure 6. Apparent angles in an unaccelerated (left) and accelerated (right) reference frame.

The following equations represent the apparent pitch and roll angles for a worst-case scenario where acceleration is wholly mis-equated for gravity, but the actual pilot perception could range between an accurate attitude to one where the airplane attitude is wholly mis-equated. The pitch and roll angles in an unaccelerated axis system that will produce a vector $\vec{n}$ parallel (in airplane body axes) to the vector $\vec{n}$ in the accelerated system are needed to compute θ_{APP} and ϕ_{APP}. In the unaccelerated system, $\vec{n}$ has Earth-axis components {0, 0, -g}, or equivalently

$$\vec{n} = \begin{pmatrix} 0 \\ 0 \\ -|\vec{n}| \end{pmatrix}_{EARTH}$$

Where

$$|\vec{n}| = \sqrt{(n_x)^2 + \left(n_y\right)^2 + (n_z)^2} = g$$

Transforming these components into airplane body axis for the unaccelerated system gives

$$\vec{n} = -|\vec{n}| \begin{pmatrix} -\sin\theta \\ \sin\phi\cos\theta \\ \cos\phi\cos\theta \end{pmatrix}_{BODY}$$

For the accelerated system, θ_{APP} and ϕ_{APP} are such that when the airplane body axis is aligned with these angles in an unaccelerated system, the resulting body-axis components of $\vec{n}$ will match the load factors n_x, n_y, and n_z from the accelerated case. So, the last equation is set as

$$|\vec{n}|\begin{pmatrix} -\sin\theta_{APP} \\ \sin\phi_{APP}\cos\theta_{APP} \\ \cos\phi_{APP}\cos\theta_{APP} \end{pmatrix}_{BODY} = \begin{pmatrix} n_x \\ n_y \\ n_z \end{pmatrix}$$

And θ_{APP} and ϕ_{APP} can be calculated as

$$\theta_{APP} = \sin^{-1}\left(\frac{n_x}{|\vec{n}|}\right)$$

$$\phi_{APP} = \sin^{-1}\left(\frac{-n_y}{|\vec{n}|\cos\theta_{APP}}\right)$$

Figure 7 shows the actual pitch angle and calculated apparent pitch angle along with the longitudinal cyclic inputs. The helicopter began the initial climb nose up, but as the longitudinal cyclic was pushed forward, the nose lowered and the cyclic was commanding nose down by 1:52:32. However, due to the helicopter's increasing forward speed, the pitch angle had the potential to be misinterpreted to the point that the pilot could have perceived a nose up attitude for the entirety of the flight, even while nose down and descending rapidly. Despite the descents and nose down attitudes greater than -10° while approaching terrain, the longitudinal cyclic stayed forward throughout the flight and was only briefly less than 60% throughout the EGPWS warnings and descents.

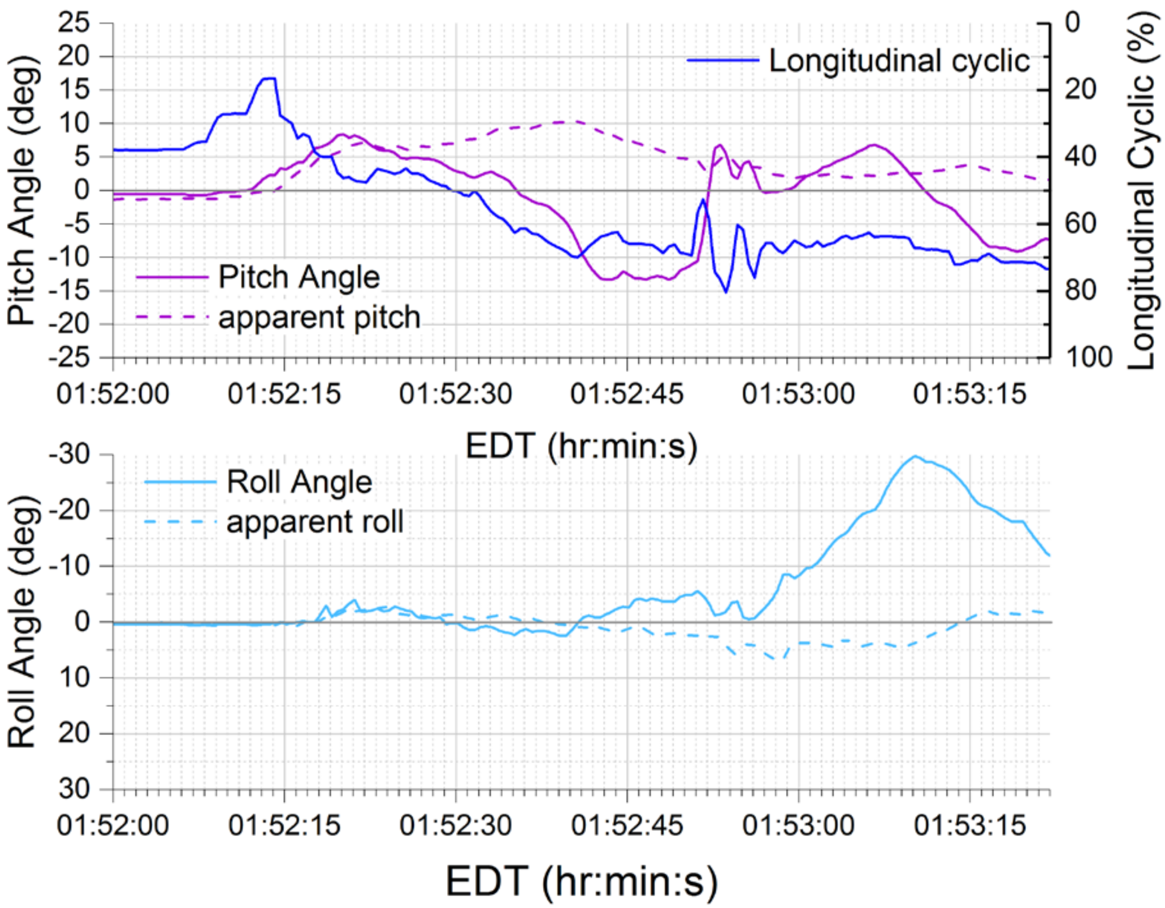

Figure 7. Actual and apparent pitch angles with longitudinal cyclic inputs and actual and apparent roll angles.

Additionally, the apparent roll angle could have been interpreted as a slight right roll rather than a roll to the left. However, as later discussed in *Previous island take-offs* the helicopter's turn after take-off was consistent with prior flights and likely deliberate.

Automatic Flight Control System and Power Limitations

The Automatic Flight Control System includes the autopilot and the flight director; both of which are duplicated for redundancy. When the autopilot is engaged, the default mode is attitude hold (ATT), and the autopilot maintains the helicopter attitude without pilot input. If the autopilot is coupled to the flight director, the autopilot can change the attitude to respond to flight director commands. The Stability Augmentation System (SAS) is active whenever the autopilot is engaged; the SAS damps the effects of the short-term external aircraft disturbances. A Force Trim clutch allows the flight controls to be disengaged from the ATT mode of the autopilot. If the SAS mode is selected in the autopilot, or the Force Trim is released, either using a switch on the panel or the Force Trim Release (FTR) switches on the cyclic or collective sticks, the pilot is flying hands-on with assistance from the SAS. During this time, the attitude of the helicopter can be changed, and the new attitude will be held when the Force Trim is re-engaged or the autopilot is returned to ATT mode. Similarly, while SAS mode is selected or the Force Trim is released, any other engaged flight director mode is ignored and, when the Force Trim is re-engaged or ATT mode selected, the reference target parameters for many flight director modes are reset according to the present value (e.g. indicated airspeed, vertical speed). While the FDR recorded autopilot and flight director modes, it did not differentiate between PIC and SIC inputs. However, the CVR indicated the PIC was the pilot flying.

Figure 8 shows the flight profile, collective and longitudinal cyclic inputs, and FTR switch engagement and flight director mode selection. The FTR switch was engaged for pitch and roll for the entirety of the flight. Therefore, all cyclic inputs for the accident flight were controlled by the pilot flying. The collective FTR was engaged from about 01:52:03 until 01:52:28 as the collective was raised from 4% to 71%, at which point the aircraft was about 40 ft off the ground and moving forward with 2 kts of groundspeed. It was engaged twice more during the first ascent and the collective was adjusted to about 72%.

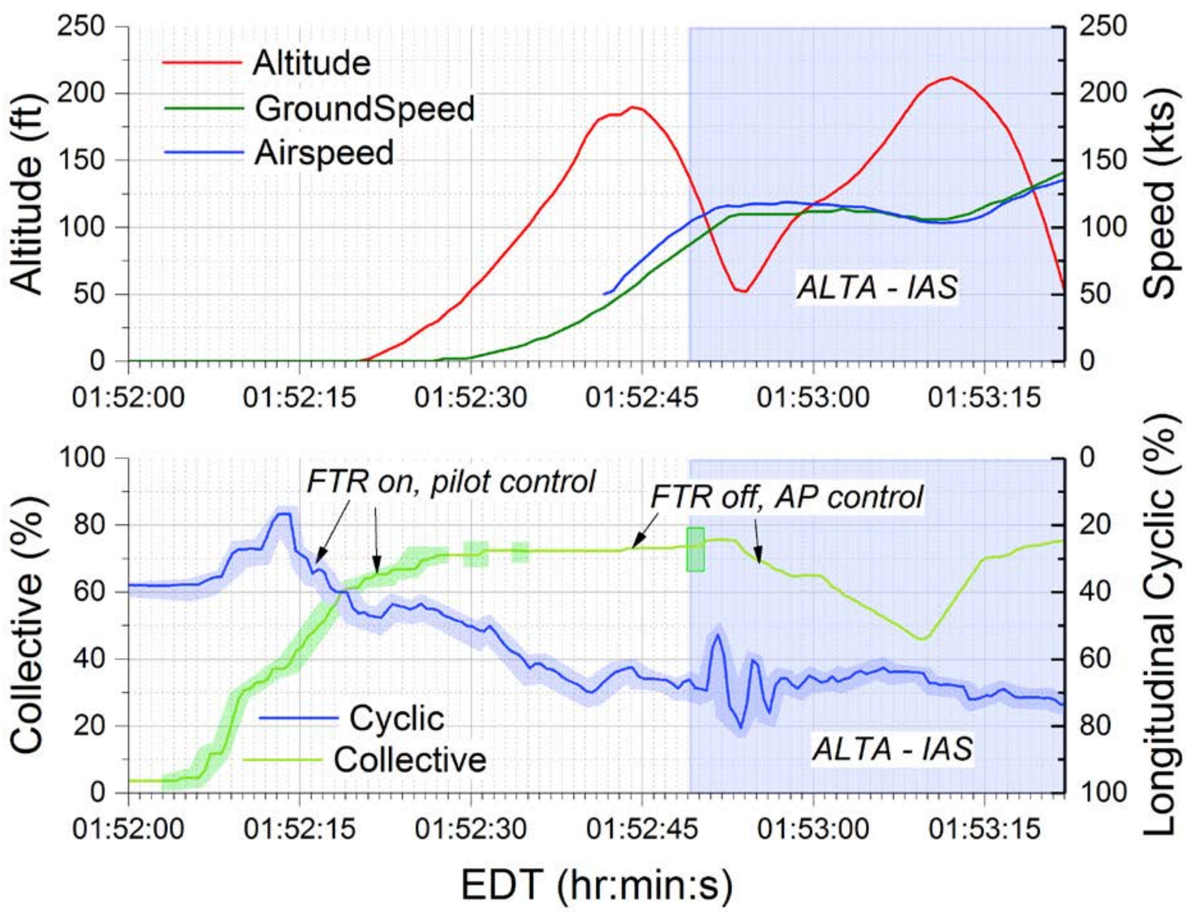

Figure 8. Altitude, speed, and controls with selected modes and FTR selection. When the collective and cyclic data is highlighted, the FTR has been engaged and the pilot is flying hands-on.

Before 1:52:49, the flight director was in standby mode. At 1:52:49, as the helicopter was descending, the ALTA (altitude acquire) mode became active for the collective and the IAS (indicated airspeed) mode became active for pitch, and the collective FTR was briefly engaged. When ALTA is selected IAS mode automatically engages. IAS mode is meant to generate pitch commands to maintain the airspeed existing at the time of engagement. However, since the pitch and roll FTR were engaged for the entirety of the flight, IAS did not control the airspeed and attitude, the pilot did. For the ALTA setting, the selected altitude was 1,000 ft and the usual rate of climb for this mode is 1000 ft/min. However, since ALTA mode was engaged when the collective FTR was briefly pressed during the descent it changed the mode settings. Specifically, since the helicopter was descending when the FTR was pressed, the ALTA rate of climb logic changed from 1000 ft/min to 100 ft/min (Figure 9).

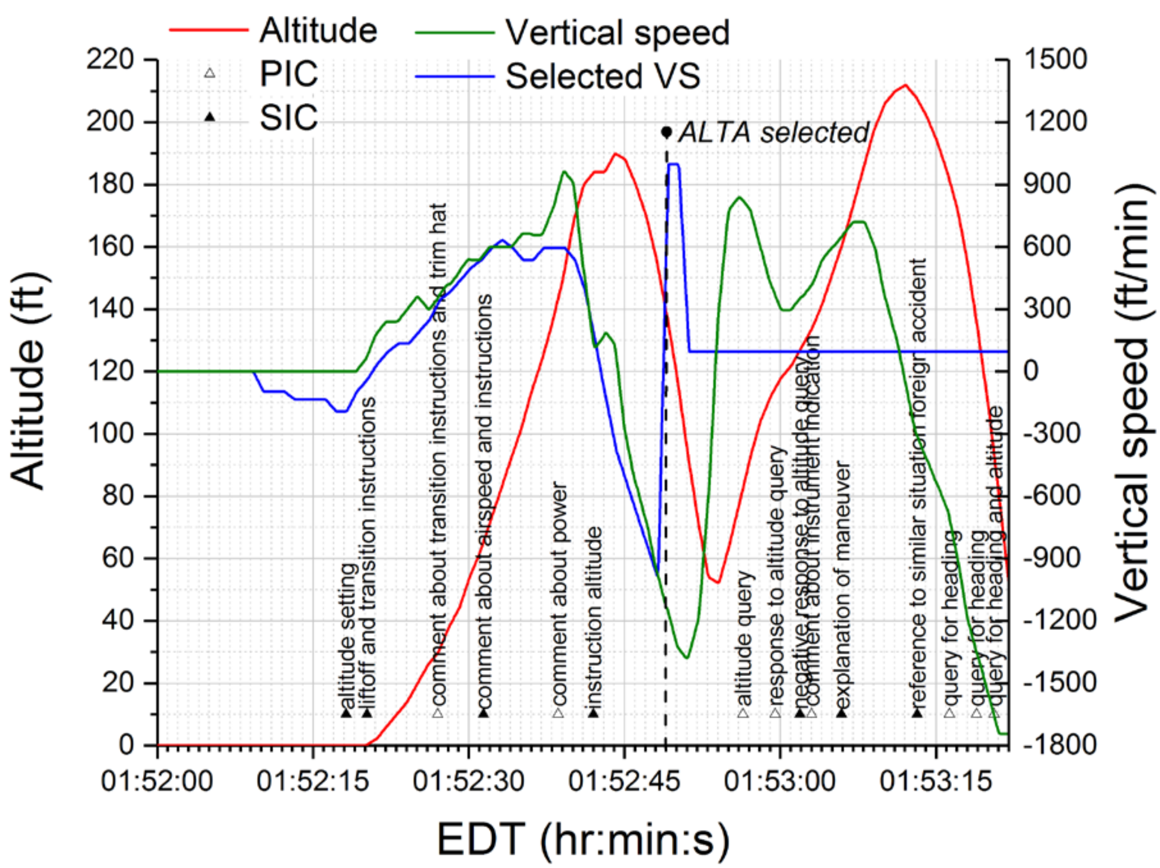

Figure 9. Altitude, vertical speed, and selected vertical speed (target).

As seen in Figure 9, while the target vertical speed was 100 ft/min, as the helicopter transitioned from descending to ascending the helicopter's actual vertical speed increased momentarily to nearly 1000 ft/min at 1:52:53. The PIC commented about an instrument display value of "300" shortly after the helicopter's vertical speed passed 300 ft/min. With a target VS of 100 ft/min being commanded by the flight director, the autopilot began to lower the collective in response (Figure 3 and Figure 8) from 75% at 1:52:53 (altitude 53 ft) to 46% at 1:53:09 (altitude 200 ft). Airspeed during this time was between 110 and 120 kts. The helicopter reached its peak altitude of 210 ft three seconds later at 1:53:12, when it began to descend.

The autopilot responded to the loss of altitude by increasing collective at a rate of 5%/second until 1:53:15 when the collective was at 70%. At this point, the helicopter was 194 ft above ground level and descending at a rate of 700 ft/min. However, the power index (PI) shown in Figure 10 had reached 80% (here, PI was directily proportional to engine torque). Since the pilot was controlling the cyclic, which was at 70% nose down, the autopilot reduced the rate of collective increase to protect the engines from overtorque. The collective continued to increase, but the aircraft's descent was not arrested. At 1:53:22, when the helicopter impacted the water, the PI was 85%, the collective 75% (and increasing), and the longitudinal cylic was 73%.

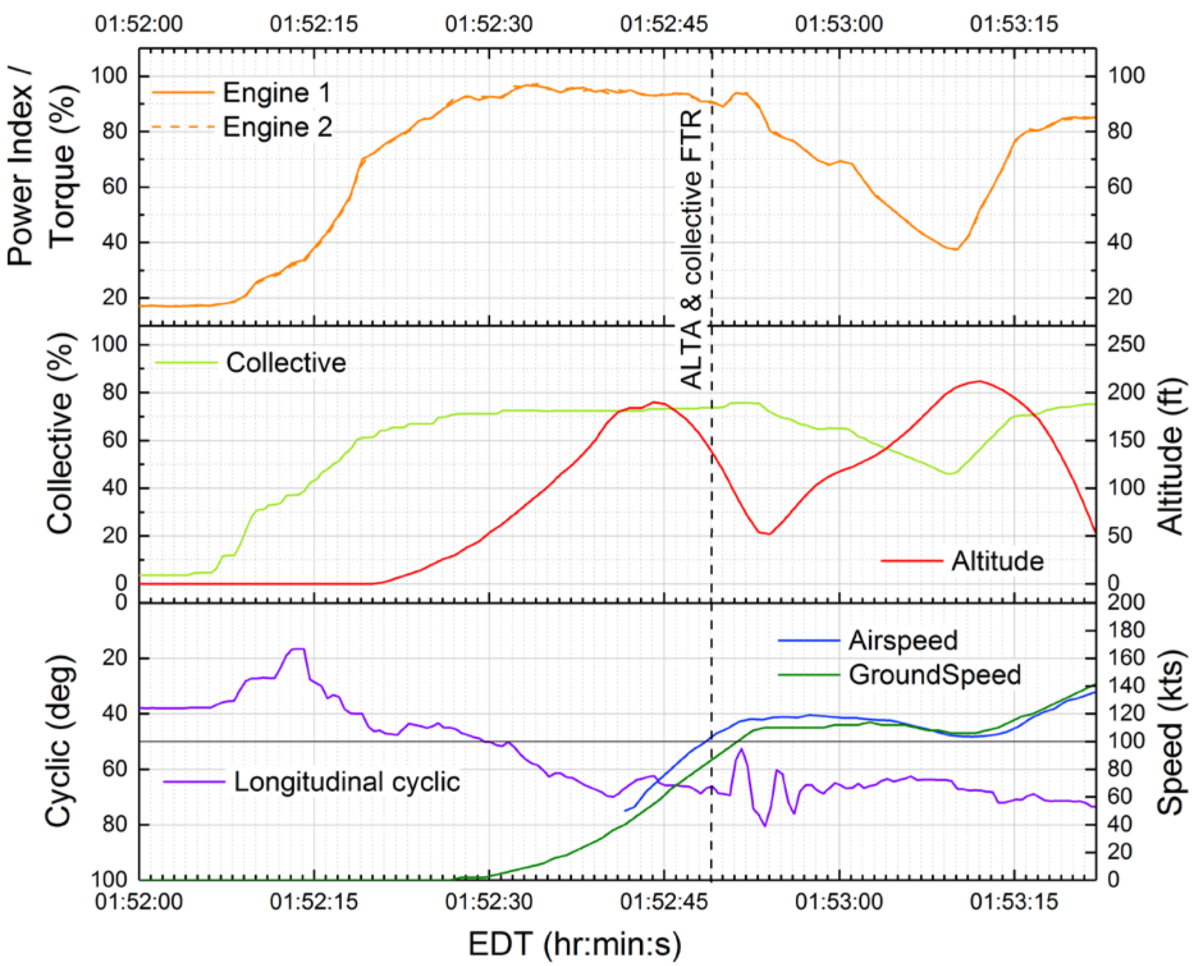

Figure 10. Power index and engine torque.

Previous island take-offs

Ten prior take-offs from the island were recorded and are labeled TO1-TO10. Most of the take-offs began on headings between the accident heading of 80° and a heading of 180°, with two (TO7 and 8) on headings of 336° and 304° respectively. Within one minute after take-off, all prior flights had turned onto a south-westerly heading as shown in Figure 11. Five of the prior take-offs turned clock-wise, and five counter-clock-wise. The direction of the turn and crosswind direction[2] showed no correlation (Table 1). The accident flight stayed on the take-off heading for longer than the prior flights before beginning to turn. All of the prior flights were during the day.

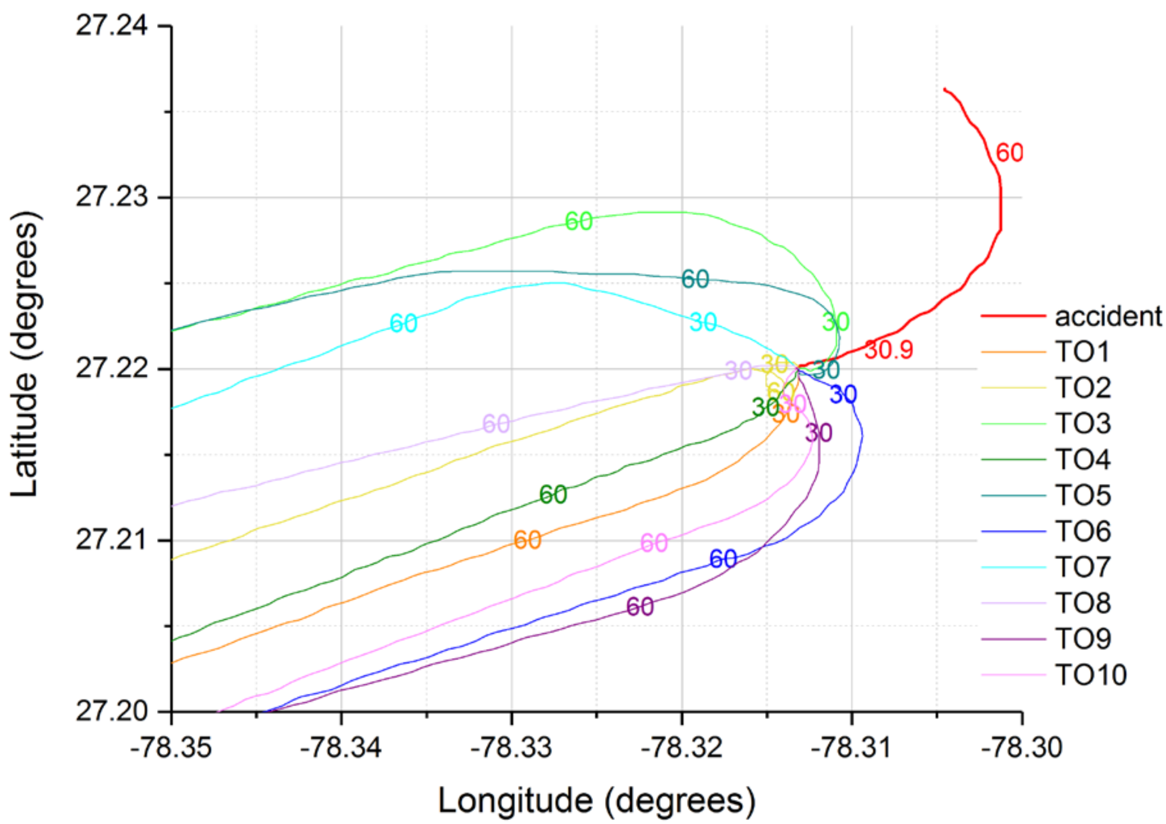

Figure 11. Prior island takeoffs. 30 and 60 seconds after weight-off-wheels annotated on each flightpath.

[2] Winds were recorded on the aircraft FDR.

Table 1. Description of prior island take-offs, plus the accident take-off.

TO #	Time of day, EDT	Initial heading, degrees	Turn direction	Wind speed, kts	Wind Direction, degrees
1 —	17:0:56	109°	Right to 256°	5	280°
2 —	13:35:28	85°	Left to 258°	10	0°
3 —	13:10:37	95°	Left to 262°	9	40°
4 —	15:03:19	170°	Right to 256°	15	270°
5 —	12:16:37	180°	Left to 256°	12	240°
6 —	12:34:51	105°	Right 256°	11	70°
7 —	12:27:19	336°	Left to 259°	12	360°
8 —	14:41:13	304°	Left to 270°	28	290°
9 —	11:11:19	148°	Right to 253°	18	170°
10 —	13:29:56	139°	Right to 251°	9	120°
Accident	01:53	80°	Left	8	40°

Figure 12 shows the first minute of flight for the ten prior take-offs and the accident flight. The initial altitude and speed gain of the accident flight were not unusual. However, the accident flight had the most collective input and highest power index for much of the first 30 seconds of flight. Additionally, the attitude of the accident helicopter was about 10° more nose down than any of the prior flights during each loss of altitude.

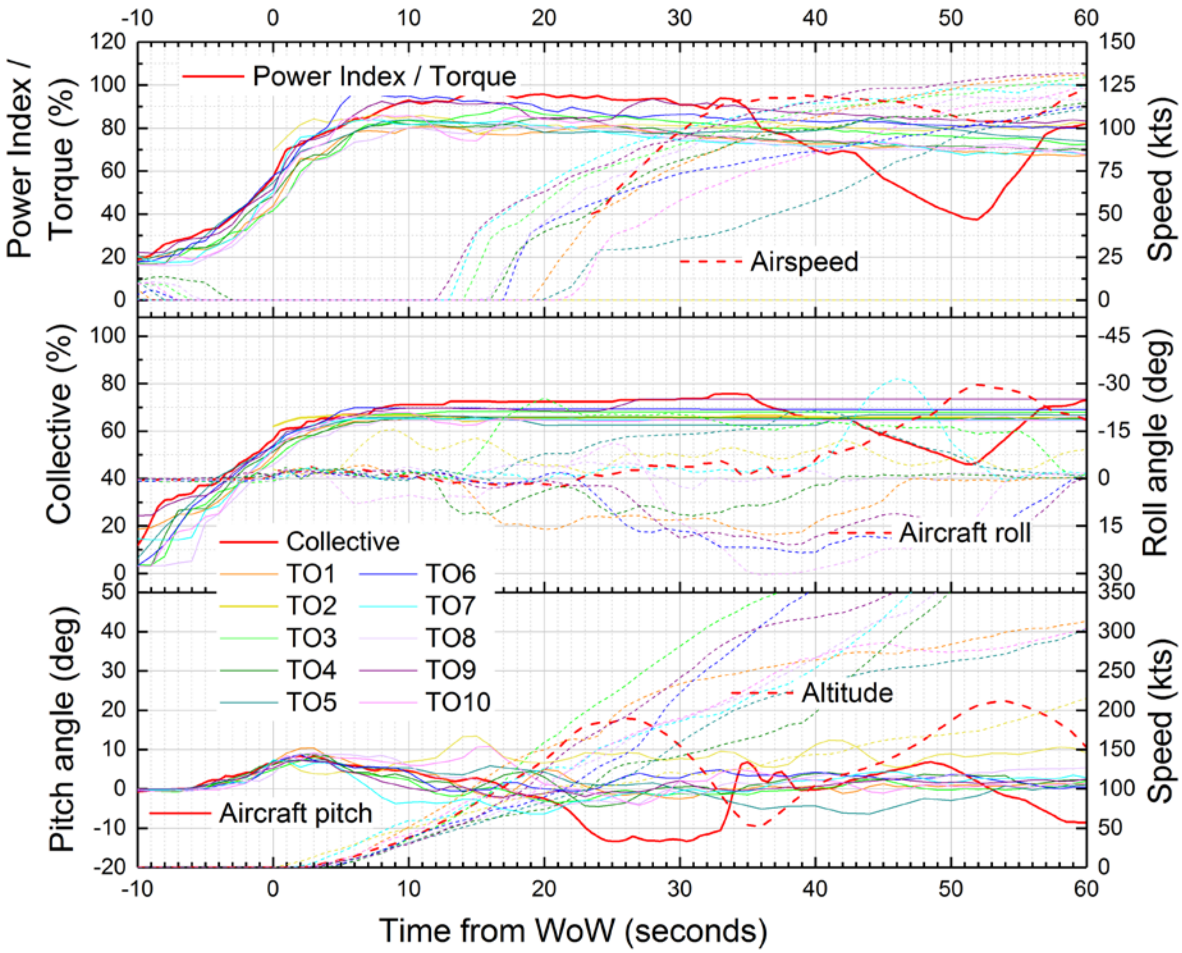

Figure 12. Prior island takeoffs, plus the accident takeoff in red. Power index, collective input, altitude, aircraft pitch and roll, and airspeed are plotted versus a standardized time.

Figure 13 shows the control inputs for the flights. Cyclic input for the accident flight seemed generally similar to the ten prior flights. Right tail rotor pedal was applied for all flights, to counter the yaw imparted by the main rotor, which varied from 45% to less than 20%. All flights held a slight left cyclic (between 55% and 45%). The accident flight showed significant early right pedal input and the collective input, as earlier stated, was more than prior flights. The higher collective input and right tail rotor pedal would have demanded more power and was consistent with the high power index levels seen during the accident flight.

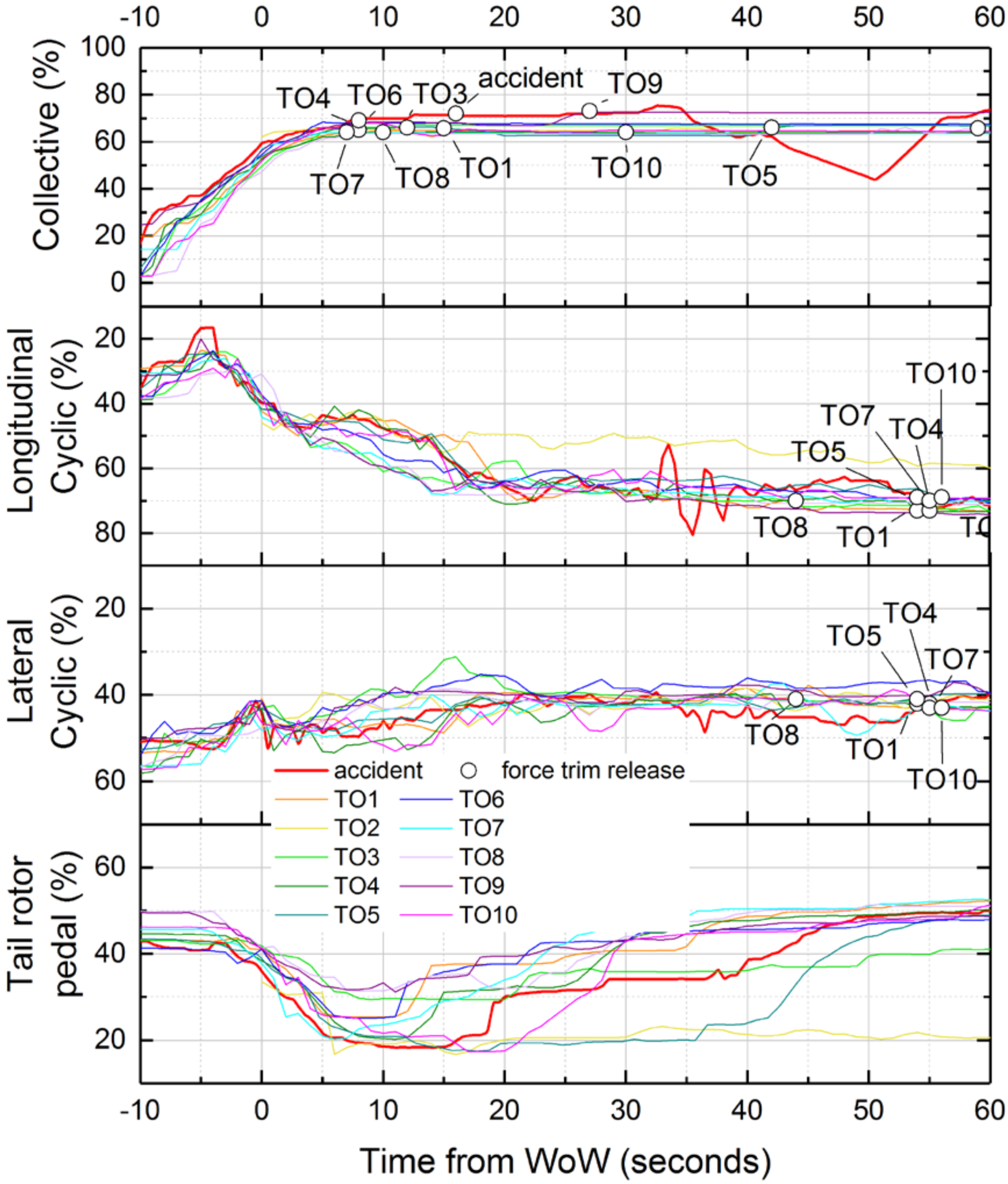

Figure 13. Control inputs of collective, cyclic, and tail rotor pedal for accident and prior island takeoffs. Force trim release disengagement (transferring the control to the autopilot) on collective and cyclic for each flight marked with an open circle.

Also shown in Figure 13 is the force trim release (FTR) disengagement for the flights. The collective FTR was generally disengaged after the collective had been raised to its flight position. Six of the ten prior flights and the accident flight released the collective FTR in the first 20 seconds of flight. The flight director mode for the collective then transitioned to ALTA for all flights. The cyclic FTR was disengaged later, generally about 55 seconds into flight. The flight director mode for pitch transitioned to IAS, and the flight director mode for roll became heading select, which later transitioned to LNAV. The cyclic FTR was never disengaged on the accident flight.

E. CONCLUSIONS

At 01:52:20, the helicopter departed the helipad and climbed 190 ft in 24 seconds, reaching an airspeed of 68 kts, before rapidly descending to 52 ft. The helicopter again climbed and began a left turn. It reached a maximum altitude of 212 ft by 01:53:12 and an airspeed of 100 kts. The helicopter again lost altitude while continuing the left turn. Water impact was determined to be at 01:53:22 at a speed of 141 kts.

During the initial climb out, the PIC was flying with both the collective and cyclic controls, as the FTR switches on both were depressed. The collective FTR was disengaged at 01:52:28, eight seconds after take-off, when the collective reached a value of 71%. It was briefly pushed twice more and the collective adjusted to 72%. This amount of collective was greater than any of the ten prior flights, though the time of disengagement of the FTR was about average. During the first descent, ALTA and IAS modes became active in the flight director and the collective FTR briefly engaged. Because the FTR was engaged when the vertical speed was negative, the ALTA selected rate of climb was reset from 1,000 ft/min to 100 ft/min. During the helicopter's second climb, the collective was lowered by the autopilot to slow the vertical speed from an initial 1,000 ft/min.

The longitudinal cyclic inputs were initially about average compared to earlier flights. The cyclic FTR was engaged for the entirety of the accident flight. While longitudinal input was not initially different from the prior ten flights, the combination of high collective input and increasingly forward longitudinal cyclic inputs lead to significant nose down attitudes during the flight that led to losses of altitude. A calculation of apparent pitch showed that it was possible for the pilots to have misinterpreted the helicopter's nose down attitude to be nose up for the entirety of the flight.

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F. REFERENCES

1. Flight Data Recorder Factual Report, ERA19FA210, National Transportation Safety Board, 2020.
2. Cockpit Voice Recorder Factual Report, ERA19FA210, National Transportation Safety Board, 2020.
3. Weather Study, ERA19FA210, National Transportation Safety Board, 2020.
4. Human Performance Factual Report, ERA19FA210, National Transportation Safety Board, 2020.