HELICOPTER MOUNTAIN RESCUE

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Abstract
The founder and namesake of Sikorsky Aircraft had a vision; "*If a man is in need of rescue, an airplane can come in and throw flowers on him, and that's just about all. But a direct lift aircraft could come in and save his life.*" Igor Sikorsky's dream was realized on the stormy afternoon of November 29th, 1945, when the chief pilot of the company, Dimitry "Jimmy" Viner along with Army Air Corps Captain Jack Beighle took a production line R-4 helicopter out into the calamity and hoisted two crewmembers from a sinking barge off of the coast of Connecticut[1]. Since that fateful day, rescues by rotary wing aircraft have been covered regularly by television news channels as the life flight helicopter landing at the scene of a highway wreck, the Blackhawk flying into a combat zone to lift out the wounded, or the Coast Guard performing rescue missions in weather conditions that most pilots would never attempt.

With any type of aviation, but more especially rotary wing operations, there is a level of risk involved. When the mission is HEMS, Helicopter Emergency Medical Service, DUSTOFF, the tactical call sign for Army medical evacuation missions, or SAR, Search and Rescue, the risk count expands. The pressure of timeliness adds factors because at the other end of the operation is a person in desperate need of mission success. There are environmental factors; the expected as in operations under night vision goggles, to the unexpected such as going inadvertent IMC, or suddenly taking fire from enemy combatants. Flying out to land on unknown terrain adds factors that makes every crewmember an observer that is being ever watchful for wires, poles, trees, never mind the FOD/brown-out conditions that can be induced by rotor downwash when landing on unimproved surfaces.

When undertaking these types of rescue missions, the 8-Ball is already in play and the last hole in the Swiss cheese model is big enough to fly the Empire State Building through. What makes these missions successful is not just the piloting skills of the crew and the robustness of the airframe but all the checks and balances that are put in place to act as roadblocks and mitigators before reaching that last act.

In May of 2020, a Sikorsky helicopter was dispatched on a SAR mission to rescue a hiker from mountainous terrain. Ultimately, the mission was unsuccessful and resulted in the aircraft impacting terrain with a singular loss of life amongst the ground personnel at the scene. Initially, a probable cause was perpetuated which would be refuted based upon the results of sound spectrum analysis. In the aftermath, the ongoing investigation revealed a number of factors, that when aligned, allowed the events surrounding the accident to unfold.

The Aircraft

The Sikorsky S-76™ is a commercial intermediate twin helicopter that had its first flight on March 13th, 1977. The aircraft is certified for one pilot VMC, dual pilot IMC, and can carry 12-13 passengers depending on pilot count. The first iteration of the aircraft, the "A" model, was powered by a pair of Allison 250-C30 turboshaft engines of 650shp (Takeoff Power) each and had a maximum takeoff gross weight (MTOGW) of 10,500lbs.

The "B" model was certificated in 1985 and saw an upgrade at the engines with the Pratt & Whitney Canada PT6B-36A to 982shp (Takeoff), an increase in rotor speed by 7%, and an increase of the MTOGW to 11,700lbs. The S-76, no matter the series, was delivered in numerous configurations to support customer missions such as Executive Transport (VIP), Offshore Airliner (OSA), Search and Rescue (SAR), Helicopter Emergency Medical Service (HEMS) as well as Reconnaissance Attack (RAH).

The Mission

On May 1st, 2020, an S-76B was dispatched on a rescue mission for a hiker who had experienced a cardiac event while trekking in steep mountainous terrain. The helicopter was equipped with dual sliding cabin doors, an external rescue hoist, an onboard medical kit and assorted rescue equipment. For this flight, the aircraft was operated by two pilots and the crew included a mechanic/winch operator and a rescue technician.

The aircraft departed Gyeongnam Firefighting Station, Republic of Korea at 11:28hrs local for a flight of 28nm to the location of the hiker up near Chiri-san peak which lies within Jirisan National Park. The park, which is approximately 160 miles south of Seoul, was designated as the first national park in Korea and spreads across four counties in three provinces.

The aircraft made its initial approach (APP-1) to the mountain site but aborted that direction of flight due to what the pilot determined were "adverse winds". On the second approach (APP-2), the aircraft entered a hover and the rescue technician along with a litter were deployed via the external hoist. The aircraft then departed the area to loiter while the patient was prepared for transport. On a signal from the ground crew, the aircraft made its third approach to the site (APP-3), entered a hover, lowered the hoist, and recovered the rescue technician. The hoist was then lowered again and during recovery of the patient, the aircraft descended into terrain resulting in fatal injuries to a person on the ground.

The Analysis

As worldwide travel at the time of this mishap was restricted due to COVID-19, an investigator from the company was not able to be deployed to the scene. As such, the investigating authority sent Sikorsky a copy of the Cockpit Voice Recorder (CVR) for sound spectrum analysis.

There are some differences in the methodologies that are employed in an acoustic analysis as opposed to what is done during an evidentiary analysis with aircraft parts in the field or in the laboratory. The physical evidence of a mishap is examined using positivist or deductive methods in that there is a bodily examination of parts. Sound Spectrum Analysis utilizes interpretive or inductive methods in that the analyst starts with data and works to derive a theory about a phenomenon of interest. The positivist would use a statement similar to, "the

Servo Housing Cover failed in fatigue with an origin denoted at this location", based upon the physical examination of the component. The interpretive analyst uses phraseology that suggests a likely identifier of that which is being observed, "that sound has the characteristics of the Ball Defect Frequency of the Main Shaft Duplex Bearing of the S-76 Main Transmission operating at 107% Rotor Speed". Because of the differences in these two methodologies, sound spectrum analysis is not typically utilized to directly determine probable cause but acts to provide supporting evidence to the physical examination.

The CVR that was installed on the mishap aircraft was an older model Fairchild A100 which uses magnetic tape for recordings instead of today's method of writing digital data to computer chips. With such an old recorder type, the bandwidth, or the low frequency to high frequency capability of the device is very limited as is the dynamic range, or the ability to simultaneously record both quiet and loud. With the noise signature of a helicopter widely ranging in frequency and amplitude, these limitations of recorder capability can hamper an investigation.

The initial examination of the CVR data from this mishap reveals a limit to the low frequencies where rotor blade pass frequencies appear and then another cutoff at the high end at just over 3000Hz. This reduced bandwidth limits the amount of frequency peaks in the data to only those pertaining to certain components within the geared drivetrain. Even with these restrictions, this analysis discovered frequency identifiers that were consistent with the normal noise signature of the S-76B main transmission and the tail rotor system. Inclusive were non-aircraft related frequencies that were identified as electrical interference artifacts of the recorder.

The analysis then employed the sonogram feature of the digital audio workstation to analyze the recording for spectral content and change over time. This analysis yielded three rotor speed anomalies in the data which were explored in-depth. Anamoly-1 corresponded to the timeline of flight for APP-1 when the aircraft made its first approach to the mountain site but aborted due to winds. During this event, rotor speed (N_R) drooped ~3% and then recovered across a period of 28 seconds. Anamoly-2 corresponded to the timeline for APP-2 where the aircraft arrived on-scene, pulled into a hover and deployed the rescue technician and the litter. During this event, N_R again drooped ~3% and recovered across a time period of 33 seconds. Anamoly-3 corresponds to two points in the timeline where the aircraft returned to the scene and recovered the rescue technician as well as the period where there was the attempt to hoist the patient (APP-3). During this event, N_R initially drooped down to 97%, was restored to 107% and then drooped again down ~74% where the recorder shutoff either by loss of electrical supply or by trigger of the inertia switch when terrain was contacted. These variations in rotor speed were determined to be unique as the PT6 engine employs an Electronic Engine Controller (EEC) to maintain rotor speed at a constant 107% when the throttles are set to FLY.

At this point in the analysis, the investigating authority perpetuated a theory that the aircraft encountered a phenomenon called Mountain Wave. For this singularity to occur, the aircraft has to be operating close to the ridgeline of a mountain and be operating on the leeward side of the crest. Winds have to be greater than 15 knots and within 30° of being perpendicular to the ridgeline. Under these conditions, wind rotors form on the leeward side which can reduce the amount of lift being generated by the helicopter. These downdrafts are not sufficient per se to force the aircraft to descend into terrain but enough to rob the main rotor of performance at an altitude where maximum lift is critical. Perhaps the most famous helicopter incident as a result of Mountain Wave was the US Air Force HH-60G mishap from Mount Hood in Oregon from 2002.

To determine the credibility of the theory, a forensic wind study was performed. The data that was supplied shows that during APP-1 the aircraft heading was such that the wind was on the beam of the aircraft and coming across the ridgeline at 8kts placing the aircraft on the leeward side of the mountain. While the wind direction and aircraft position met the criteria for Mountain Wave, the windspeed fell short. The next period in the wind study, which occurred during APP-2, showed that the aircraft heading had changed to bring the aircraft's nose into the wind. While the aircraft remained on the leeward side of the ridgeline, the windspeed of 8kts again fell short of the requirement for Mountain Wave. The wind for the period of APP-3 was shown to now be from behind the aircraft and at rate of 10kts which places the aircraft operating on the windward side of the mountain. With the results of this study, the theory of Mountain Wave was dispelled.

The next phase of the investigation focused on the weight of the aircraft and the altitude at which the mission was executed. To support this study, the investigating authority supplied the empty weight of the aircraft, the fuel load at takeoff, the weight of all four crewmembers as well as the weight of the rescue equipment and the medical kit. From these data, a TOGW of 10,675lbs was derived which is well within the MTOGW of the S-76B of 11,700lbs. The GPS coordinates that were supplied placed the rescue site along with the 35ft hover height of the aircraft to be 5,935ft MSL with an OAT at altitude of +17°C. With the rotor diameter for the S-76 being 44ft and the limit for Hover in Ground Effect (HIGE) to be 1.5 times that diameter, a 35ft hover would normally be inside the 66ft HIGE limit. Because the terrain at the rescue site was steep and had uneven topographical features, the Hover Out of Ground Effect (HOGE) performance charts should have been utilized for mission planning to determine the maximum weight limitation to hover at altitude. The value depicted in the S-76B Rotorcraft Flight Manual (RFM) for HOGE gross weight for 5,935ft and +17°C was determined to be 10,300lbs[2]. After calculating the total aircraft weight for the various stages of the mission, the data shows that during APP-1 that aircraft exceeded the HOGE limit by 109lbs (cross wind), during APP-2 the limit was exceeded by 87lbs (nose wind) and when the aircraft picked up the weight of the patient plus the litter, the aircraft exceeded the HOGE limit by 142lbs (tail wind).

From these analyses the theory of power demand to perform the mission exceeding the power available was perpetuated. To attempt to give further credence to this theory, Sikorsky contacted the investigating authority with a request. When the mishap first occurred, there was footage on a local television news channel that was acquired by a bystander with a cellphone. Sikorsky requested that the investigating authority impound the video as the audio signature of the aircraft could be heard in the background of the news story. The ultimate purpose behind the request was to perform a sound spectrum analysis on the audio track from the phone as the bandwidth and dynamic range of the audio recording capabilities of today's cellphones are significantly greater than the capabilities of the outdated Fairchild A100 CVR.

The requested video file was provided, and the analysis showed that the phone had indeed captured the higher frequencies of the engine N1 compressor blade pass frequency. The sound spectrum analysis revealed that when the aircraft was experiencing the decreasing rotor speed which led to the impact with terrain that the N1 frequency was constant and at maximum RPM. When rotor speed is drooping and engine gas generator speed is at maximum, the probability of power demand exceeding power available increases in likelihood.

<u>The Engines</u>

The engines in the S-76B have three limiters that govern the maximum power output under normal conditions: Gas Generator RPM (N1), Main Transmission Torque (Q) and Interturbine Temperature (T5). When bumping up against any of these limiters, minor exceedances will cause a temporary decrease in rotor speed across an approximate three percent range. Should N_R droop below 98% or should rotor speed decrease at a rate greater than 3% per second, a feature called blowaway power is triggered within the engine which opens temporary thresholds that increases the maximum values achievable for all three limiters. During the sequences of APP-1 and APP-2, the aircraft rotor speed behaved similarly to that of the engines being up against one or more of the limiters (~3% droop). During APP-3, rotor speed drooped to 97%. This criterion met the requirements for the blowaway feature of the engine to be activated and rotor speed was restored. As soon as N_R was back at 107%, the transcript reveals that the crew begins to hoist the patient which increased the weight of the aircraft to the maximum beyond the RFM HOGE limit by 142lbs, and on this occurrence induced a rotor speed droop that was unrecoverable.

When the engines were taken to their manufacturer for further investigation, both motors failed the test cell power assurance procedure for T5 criteria. On teardown each showed noticeable levels of corrosion while engine number two displayed significantly more soot buildup as well as substantial erosion at the root ends of the primary compressor blades. Another discovery was made when the engine records were being examined. The S-76B RFM details that an Engine Power Assurance Check (EPAC) be performed prior to each flight[3]. From the data that was supplied, it was discovered that an EPAC was not executed as such. When the question was raised, the reply was that the aircraft was an emergency response helicopter and an EPAC before each flight was not realistic.

While examining the EPAC data that was provided, Sikorsky found an error on at least one part of the calculation for every check that was done. Several were related to translating the nomograph in the RFM where interpolation errors were introduced where attempts were made to calculate with decimal place accuracy that the charts do not support. Others were mathematical errors where values were calculated incorrectly. For almost all of these, the amount of error did not cause an issue for passing the EPAC. On one occasion however, the check reported that there was a +16/+11 margin on T5 for the #1 and #2 engines respectively. The actual calculations should have shown +4/-1 for which the negative margin on the #2 engine should have grounded the aircraft that day for an engine maintenance action.

<u>Other Factors</u>

Maintenance: The discoveries made during the engine teardown raised questions as to the maintenance practices used on the aircraft in the area of engine cleaning and preservation.

According to the engine manufacturer, if there are periods of inactivity greater than seven days the engine should be rotated. If that period is to be longer than twenty-eight days, the engine should be preserved. When the gaps in dates between EPAC and maintenance actions were examined and showed extended times without operation, no information was offered as to whether or not the engine preservation requirements were undertaken.

Mission Planning: The discovery of performance at altitude raises the question of adequate mission planning that would have preceded the launch of the aircraft. There was no evidence in the transcript that was supplied that aircraft performance at altitude was examined when the helicopter arrived at the scene other than to abort APP-1 due to adverse winds. With the aircraft displaying characteristics of operation up against a limiter, a scan of the cockpit instruments on any of the approaches to the mountain should have revealed that there was a performance limitation.

Crew Coordination: The transcript of events when the aircraft was executing the lowering and hoisting of personnel and equipment consists mostly of steering directions from the mechanic who was operating the hoist to tell the pilot on the controls to move the aircraft in certain directions. On the occasion of the aircraft bumping up against the limiters on both APP-1 and APP-2, there was no mention of N1, T5 or Torque by any crewmember. When the events occurred for APP-3, the droop in rotor speed to 97% elicited no comment from either pilot though there would have been a noticeable change in pitch of the internal noise signature of the aircraft. The only reference to torque came from the copilot and only after the aircraft had begun to lift the patient where altitude had started to decrease, and N_R had dropped below 100%

Time in Type: Sikorsky has noted a recurring trend in a number of mishaps across the product line. Several accidents have happened of late where the pilots have greater than 3000 hours of rotary wing flight experience, but the Time-in-Type hours have begun to show up as low values. For this accident, both pilots had just over 3500hrs total with 68 and 35hrs for time in the S-76.

<u>Summation</u>

While certain types of missions have more risks than others, flying at the edge of the envelope increases risk realization and operating near the corner of the envelope means that the likelihood of flying in jeopardy is closing in from two sides. This mission was on the cusp of the S-76Bs capabilities at the onset. While the HOGE values in the RFM may have some conservativism built in, they should be treated as values set in stone when performing mission planning. There would have been some HIGE capability with this flight profile even with the type of terrain, it would be of an unknown level and should not be used in planning. When the electrical hoist is operated in the aircraft, the DC power load is placed on the #1 engine, a motor that may have already been at or near its maximum power. The tail wind that was present at the time the patient was being lifted could have brought hot exhaust gasses to the engine inlets which may have caused a power degradation. The signs were there that the aircraft was up against the limiters, but it appears that it was not noticed by the pilots. The amount of soot, corrosion and erosion in the engines coupled with a lack of a power assurance check before takeoff questions the amount of above minimum specification power might have been available.

The cause of any accident is rarely any one singular thing to go wrong but a culmination of a number of bad things happening at the same time. This mishap is an example of how that can happen.

Be that as it may, the helicopter continues to play a most vital role for those in need of rescue around the world championing our founder's dream. As Sikorsky celebrates its 100th year of rotary wing innovations, one final quote seems proper; *"It would be right to say that the helicopter's role in saving lives represents one of the most glorious pages in the history of human flight."* — Igor Sikorsky

[1] Sikorsky Archives, Sikorsky Aviation History, The World's First Helicopter Civilian Rescue https://sikorskyarchives.com/first-helicopter-civilian-rescue/

[2] SA4047-76B-1 FAA Approved Rotorcraft Flight Manual Sikorsky Model S-76B, Part-1, Section IV Performance Information, Hover Out of Ground Effect, EAPS Off, PT6B-36A Engines

[3] SA4047-76B-1 FAA Approved Rotorcraft Flight Manual Sikorsky Model S-76B, Part-1, Section IV Performance Information, Engine Power Assurance