Sikorsky
A United Technologies Company

ACCIDENT INVESTIGATION SUBMISSION
NTSB Accident File: LAX08PA259

OPERATOR: Carson Helicopters Inc.

MODEL: S-61N AIRCRAFT: 61297 (FAA Reg: N612AZ)

Date of Mishap:	05 August 2008
Location of Mishap:	Shasta-Trinity National Forest, near Weaverville, California, USA
Report Date:	28 May 2010
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ABSTRACT

The data that follows has been derived from a combined and extensive investigation involving aircraft wreckage review and detailed engineering analyses performed by the National Transportation Safety Board (NTSB), Sikorsky Aircraft, and several other parties. This report was compiled for the sole purpose of accident prevention.

On 05 August 2008, at approximately 19:41 pacific daylight time (PDT), a Sikorsky Aircraft Corporation S-61N, serial number 61297, owned by Carson Helicopters Inc., and operated by Carson as a Public-Use Firefighting aircraft under contract to the United States Forest Service (USFS), impacted trees and terrain just after takeoff from helispot H-44 near Weaverville, California. As a result of the mishap, nine occupants on board the aircraft were fatally injured, the other four occupants sustained serious injuries, and the helicopter was destroyed by impact and post-crash fire.

The helicopter was examined in situ by NTSB, FAA, USFS, Carson Helicopters, General Electric Aircraft Engines (GEAE), and Sikorsky Aircraft Corporation (SAC) investigators from 07 to 11 August 2008. Recovery of the wreckage (except for the two engines and the two main gearbox input freewheel units) was delayed by the forest fires in the area. The investigation was based in Redding, CA from 07-11 August, and in Aurora, OR from 12-15 August. The NTSB was the cognizant investigating authority.

A cockpit voice recorder (CVR) and a helicopter usage/monitoring system (HUMS) unit were removed from the wreckage and held in the custody of the NTSB. The NTSB conducted a raw-data download of the CVR at the manufacturer, Penney & Giles, in the UK, on 19 August. A CVR/Sound Spectrum Group was convened at NTSB on 26-27 August 2008. The NTSB and Honeywell determined that the HUMS unit was too thermally damaged to attempt a download.

Both engines and both the left and right input freewheel units (IFWUs) were airlifted from the scene on 11 August. The engines were shipped to Columbia Helicopters, Inc, Aurora, OR on 12 August for disassembly evaluations.

The IFWUs were shipped to Helicopter Support Incorporated, a wholly-owned subsidiary of Sikorsky Aircraft Corporation in Trumbull, CT, for additional evaluations, which were conducted, with all parties except the FAA present, on 03-04 September 2008.

The remainder of the wreckage was later recovered to Plain Parts, Sacramento, CA and was re-examined by all parties to the investigation on 28-29 October 2008.

Evidence that ***power required*** exceeded ***power available*** prior to impact was observed, however, no contributory pre-existing material or mechanical anomalies were found.

Substantial inaccuracies were found in Carson's pre-flight planning material, including the Aircraft Empty Weight data, the Power Available charts, and the Power Required charts. These inaccuracies led the flight crew to believe that there was adequate performance margin for flight operations out of H-44. Further, the flight crew experienced and should have detected the lack of performance margin on two prior flights from H-44 by noting that the engines had reached their topping power and the rotor speed had drooped more than expected during the takeoffs. The flight crew's attempted departure with insufficient power available resulted in impact with trees and ground and a subsequent post-crash fire.

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I. INTRODUCTION

The purpose of this report is to make a determination as to the various factors that may have played a role in the cause of the accident. All aspects of a safety investigation were explored to identify primary cause factors that may have contributed to this accident in an attempt to prevent the same accident from occurring again.

The National Transportation Safety Board (NTSB) was the cognizant investigating authority, and conducted the investigation as a 'Field Major' with James F. Struhsaker of the Western Pacific Regional Office as the Investigator-In-Charge. Several specialized groups were stood up and were led by NTSB personnel from the Western Pacific Regional Office and Washington, DC Headquarters.

This report is based on observations made during a limited field investigation on-site, teardown of both engines conducted at Columbia Helicopters, in Aurora, OR; and disassembly of both input freewheel units conducted at HSI and Sikorsky Aircraft Corporation in Trumbull and Stratford, CT. Further analytical research and analysis was conducted by all parties and the NTSB.

II. BACKGROUND

A. Mission

The flight was intended as a 14 CFR 91 Public-Use USFS firefighter transport flight. The aircraft began flight operations on 05 August 2008 at approximately **1320** local, according to USFS and Carson records. The aircraft performed five water drop missions, landing to refuel from a Carson fuel truck at the Shasta-Trinity Helibase at **1513** local before beginning the firefighter transport series of flights at **1707** local. The aircraft had completed two transport flights from Helispot H-44 to Helispot H-36, and had refueled again at Trinity Helibase from **1906** to **1923** local just before the mishap flight. The takeoff point from H-44 was located at **40° 54.849'N 123° 15.128'W**, and approximately **5945** ft MSL in elevation, based on witness statements and a post-crash survey.[1]

B. Mishap Sequence

NTSB-conducted interviews with personnel on the ground who were waiting for the next aircraft indicated that the aircraft lifted off the helispot slower than normal, transitioned to forward flight, and then descended, contacting several trees in sequence, and then crashed into the ground. The NTSB later reported that additional witnesses to the first two H-44 takeoffs stated that the aircraft never vertically cleared the trees to the south, but rather maneuvered around them and then departed. The NTSB Operations Group Chairman's report[2] indicated that the takeoff began with an increase in collective pitch at **19:40:42**, and the CVR data ended at **19:41:38**.

C. Mishap Site Description

The wreckage was located on a steep, partly wooded slope near the top of a ridge in rough and hilly terrain. Most of the trees in the area were estimated to be about fifty to sixty feet tall. The lat-long coordinates of the mishap site (main rotor head) as established by the post-crash survey were **40° 54.781' N 123° 15.096' W**. The terrain is approximately **5882** ft MSL in elevation. The aircraft's main rotors impacted at least four trees between the helispot and the mishap site. The debris field was confined to a relatively small area, not much larger than the aircraft. The only debris found outside the immediate area was several pieces of main rotor blade, which were all within several hundred feet of the aircraft. The aircraft from the nose back to the transition section was completely burned. Portions of the transition section were partially burned/melted. The tail pylon, intermediate, and tail gearboxes were not burned.

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[1] Helicopter Crash Site Survey – Sharrah Dunlap Sawyer, per NTSB Airworthiness Group Chairman's Report, page 3, footnote 4. http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/426650.pdf

[2] NTSB Operations Group Chairman's Report: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/426753.pdf

III. EVALUATION

A. Aircraft Configuration

The aircraft was an S-61N reconfigured and modified for firefighting operations[3] by Carson Helicopters, Inc. It was equipped with a Carson-manufactured conformal firefighting water tank with snorkel and fire pump installed in accordance with Carson Supplemental Type Certificate (STC). The aircraft was flown in the FAA Part 91 Public Use Category. The aircraft was equipped with two General Electric Aircraft Engines (GEAE) CT58-140-1 engines. The aircraft was fitted with the S-61L type fixed landing gear without sponsons in place of the original amphibious sponson-mounted retractable landing gear. The aircraft transmission was an S6135-20600-046, however, the input freewheel units (IFWU) were not standard for this transmission. The installed IFWU components were originally designed for the USAF HH-3E main gearbox (61350-23000 series), and were installed in accordance with Carson STC. The composite main rotor blades (CMRB) were not Sikorsky-designed or manufactured components. The CMRBs were designed by Carson and manufactured by Ducommun AeroStructures, a division of Ducommun Incorporated. The CMRBs were installed in accordance with Carson STCs.[4]

B. Weather

Weather at the time of the mishap was Visual Meteorological Conditions (VMC). Smoke in the area did not appreciably restrict visibility; however, the first landing at the site that day produced a brown-out[5] condition, requiring a go-around, according to eyewitnesses. Temperature at the site was determined by the NTSB to be approximately 23°C (73°F). Winds were determined by the NTSB to be light and variable.[6]

C. Aircraft History

The aircraft was manufactured in 1965, originally registered to Sikorsky Aircraft Division on 02 June 1965. Following its sale in 1969, it was owned by Okanagan Helicopters Limited in British Columbia, Canada.

On 03 April 1970, this aircraft (s/n 61297) was involved in an accident off Halifax, Nova Scotia. The aircraft was on a helideck on an oil rig that was under tow at about 5 knots. With 14 passengers on board and a port quartering tailwind of 5 knots, at a gross weight of 18,200 lbs, the crew lifted off. The pilot began a left hovering turn to turn into the wind. The aircraft then began to spin to the right. After spinning 360 degrees, the aircraft impacted the deck and settled on its left side. The accident was attributed to a phenomenon known as 'tail rotor buzz' which was subsequently addressed by mandatory changes to the tail rotor control system and tail rotor blades.

Okanagan later became a part of CHC Helicopters International. CHC sold the aircraft to Carson Helicopters Incorporated (CHI) on 25 June 2007. At the time of the Weaverville accident, the aircraft had logged **35396.4** hours total time, not including the approximately **3.62** hours flown on the date of the mishap.

D. Aircraft Maintenance

The aircraft was maintained by CHI in accordance with an FAA-approved Continuous Airworthiness Maintenance Program. The NSTB established a Maintenance Group to evaluate the aircraft's maintenance history. Sikorsky Aircraft was not a member of the Maintenance Group.

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[3] Carson refers to this configuration as the "Fire King" aircraft.

[4] NTSB Airworthiness Group Chairman's Report: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/426650.pdf

[5] A 'brown-out' occurs when a helicopter's main rotor downwash lifts dirt/dust from the landing zone and obstructs visibility.

[6] NTSB Meteorology Group Chairman's Report: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/421009.pdf

According to the Maintenance Group Chairman's factual report,[7] the following maintenance was recorded:

The last scheduled maintenance was a preflight inspection, conducted on the day of the mishap (as reported by interview – the records were destroyed in the accident).

The last phased maintenance was a Phase 4 inspection, which was completed on 28 July 2008 at 35,384.7 hours TSN. Other recent maintenance included a Safety Inspection on 30 July 2008 at 35,389.8 hours, and a 25-hour inspection on 27 July 2008 at 35,380.2 hours. These inspections were all conducted at Trinity Helibase.

Other recent unscheduled maintenance included replacement of the #2 engine tach generator, replacement of the center fuel tank overflow sensor, and adjustment of the sliding cabin door open warning light switch.

Several FAA airworthiness directives (ADs) were noted by Carson as not applicable due to pending Alternate Means of Compliance (AMOC) requests. Carson reported having sent the AMOC letters to the FAA in May of 2006 and not having received approval prior to the accident. The FAA stated that Carson was expected to comply with the ADs until written approval of the AMOC is received. In July 2008, the FAA issued Letters of Investigation regarding these ADs. However, after the accident, the FAA located, reviewed, and approved the AMOC letters. The reason for the two year delay in approval was not clear.

Numerous discrepancies were noted in the review of the maintenance records. For example, two removals of an engine fuel control unit were recorded using the part number instead of the serial number. Further, the NTSB's Operations Group review of the aircraft's weighing records revealed many additional discrepancies, including failure to properly document changes in aircraft configuration that affect weight and balance, and evidence that many weight and balance sheets had been improperly recorded. See Section III E below for more detail.

A fuel control unit (FCU), serial number 89674BR, was reportedly removed from the mishap aircraft on 11 May 2008. The FCU was evaluated by Columbia Helicopters, who concluded that the FCU was 'fully contaminated'. The nature of the contamination was not documented, nor were any samples of the contamination retained.

E. Aircraft Weight & Balance

The NTSB Operations Group found numerous discrepancies related to documentation of the aircraft's basic empty weight. This is fully documented in the Operations Group Chairman's report.[8] The load calculations performed by the flight crew on the day of the mishap used the Carson-reported helicopter empty equipped weight of 12,408 lbs.

However, based on the conclusions of the Operations Group, the empty equipped aircraft weighed 13,845 lbs at a CG of 263.19 inches, a discrepancy of 1437 lbs.

Carson's *own* post-accident estimate of the equipped aircraft weight, which was provided to the NTSB by email on 21 October 2009[9] was 13,450 lbs, a discrepancy of 1042 lbs.

The aircraft had reportedly been fueled to 1200 lbs in each of the forward and aft tanks, and 100 lbs in the center auxiliary tank. The flight from Trinity to H-44 was approximately 12.7 minutes, and including ground operations, would have consumed about 349 pounds of fuel.

Based on these numbers and reported flight crew, passenger, and cargo weights, the NTSB determined that the aircraft weighed 19,008 lbs at a CG of 258.71 inches at the time of the accident. The forward CG limit at that weight is 258.0 inches.

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[7] NTSB Maintenance Group Chairman's Report: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/426264.pdf
[8] NTSB Operations Group Chairman's Report, Op. Cit., pp 24-44.
[9] NTSB Operations Attachment 103 – Email from CHI: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/432026.pdf

F. Performance Charts

1. Power Available

The NTSB's Operations Group conducted a routine review of the performance charts in the Carson Flight Manual supplements.[10] During comparison of these charts to those supplied to the NTSB by the FAA, the Operations Group chairman noted a substantial discrepancy. She determined that the Rotorcraft Flight Manual Supplement (RFMS) No.8 chart labeled:

> **POWER AVAILABLE - TAKEOFF POWER 5 MIN TWIN, 30 MIN OEI POWER CT-58-1, -2 ENGINE(S) 103% NR SPECIFICATION POWER** *actually contained the data for the chart:* **POWER AVAILABLE - 2½ MINUTE CT-58-1 ENGINE 100% NR SPECIFICATION POWER** which is a single-engine (OEI) configuration.

This would result in the *appearance* of approximately 8% more torque available; or an *apparent* equivalent weight capability of ~1250 lbs under the accident ambient conditions.

When asked about the chart discrepancy, Carson's Vice President originally stated that the mislabeled chart originated from CHI in Perkasie, PA. Later, he opined that the change had been made in an act of sabotage by a terminated disgruntled employee. Carson's law firm engaged a forensic information technology consultant to look for evidence of such. No further information on the results of this investigation was provided to the NTSB or the other parties.[11]

Carson, more than two years prior to the accident, requested permission from the USFS to use this **POWER AVAILABLE 2½ MINUTE** chart for normal takeoff planning. The USFS, after consultation with Sikorsky Aircraft, GEAE and FAA, rejected this request on 20 March 2006.[12]

2. Power Required

Sikorsky Aircraft, prior to the accident, had been contracted by the United States Navy (USN) to evaluate the Carson/Ducommun Composite Main Rotor Blade (CMRB) for use on certain military aircraft. During initial flight testing of the blades, a comparison of the legacy Sikorsky aluminum MRB to the Carson-Ducommun CMRB showed that the actual performance gain was less than had been predicted by Carson, both in their RFMS performance charts and in their published rotorcraft industry technical papers.

Using Carson's RFMS No.8 charts predicted about 2000 pounds of additional lift as compared to Sikorsky's S-61N Power Required to Hover Out-of-Ground Effect (HOGE) chart for the same conditions. Using USN/Sikorsky flight test data, *before correction* for differences in the airframes, showed that at 6000 feet pressure altitude and 23°C, and a gross weight of 19,008 lbs, the comparison of performance shows approximately 1000 pounds of additional lift. Further, Carson's RFMS No.8 charts did not account for the ~103 lb vertical drag[13] of the Fire King tank. Sikorsky's analysis, using the USN/SAC flight test data, corrected for differences in airframe length and landing gear, as well as the additional Fire King tank drag, determined that Carson's RFMS No.8 over-predicted the HOGE capability by about 645 lbs.

No back-to-back comparison testing on identical aircraft was documented during Carson's STC testing for FAA approval of the CMRBs. Sikorsky Aircraft plans approximately six months of further flight testing of the Carson-designed CMRBs in late 2010-early 2011. This testing will include an instrumented main rotor blade and instrumented controls (pushrods, scissors, servos, etc) recorded via telemetry in controlled and measured ambient conditions in order to fully document the actual performance of the CMRBs and their effect on the aircraft airframe and control loads and in-flight handling qualities.

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[10] NTSB Operations Attachment 40 – CHSI RFMS No.8: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/419051.pdf & NTSB Operations Attachment 41 – FAA RFMS No.8: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/422288.pdf

[11] NTSB Operations Group Chairman's Report – Op. Cit., page 51, footnote 101.

[12] NTSB Operations Attachment 101 – USFS Letter: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/432022.pdf

[13] Sikorsky Aircraft Analytical Vertical Drag calculations based on NTSB-provided tank dimensions.

G. Aircraft Examination

The helicopter was examined in situ on 07-11 August 2008 by NTSB, FAA, USFS, GEAE,[14] Sikorsky, and Carson investigators. The engines were examined at Columbia Helicopters Inc, Aurora, OR on 13-15 August 2008 by NTSB, FAA, USFS, GEAE, SAC, Carson, and Columbia personnel. The IFWUs were examined at HSI and Sikorsky in Connecticut on 03-04 September 2008. NTSB, USFS, Sikorsky, Carson, and HSI representatives were in attendance. GEAE attended on the second day only. The FAA was invited by the NTSB, but did not send a representative for the IFWU examination. The wreckage was re-examined by all parties on 28-29 October 2008, at Plain Parts, Inc. in Sacramento, CA.

1. Airframe

The airframe was destroyed by impact forces and subsequent post-crash fire. The post-crash fuel-fed fire melted most of the aluminum in the forward and main cabin sections of the aircraft. Exceptions included the nose avionics bay door, the water drop tank doors, part of the water snorkel hose, a portion of the transition section, and the tail cone and pylon, which were recovered with partial charring and burns. Resolidified molten aluminum was noted in several areas of the wreckage and running downhill from the impact area.

The tail landing gear area was intact and was sooted, but did not burn. The tail cone from STA 580 aft was charred and burned in several areas, primarily the forward portion. The vertical pylon was fractured with forward directionality, it was unburned and uncharred, and sustained a main rotor blade strike to the horizontal stabilizer, probably from the White[15] blade, based on blue paint transfer marks observed in the center section of the blade. The White blade was found nearly intact on the ground just behind the aft section of the aircraft, with impact damage at the tip and between blade stations 256 and 270.

The tail landing gear (TLG) remained attached to its airframe mount at STA 493. The TLG tire was still inflated. The TLG shock strut was intact. The left and right main landing gear (MLG) were found in the impact area. The right MLG was destroyed and heavily burned, including the wheels and tires, which were completely burned away. The left MLG was destroyed by impact, but was unburned, as it came to rest below and slightly southwest of the burn area. Both MLG shock struts were fractured into several pieces.

2. Rotor Blades

Main Rotor Blades

The composite main rotor blades (CMRB) were a Carson-designed, Ducommun-manufactured, all composite construction with a nickel leading edge abrasion strip and a steel cuff. The blade's D-shaped spar, in appearance, is a composite replica of the original aluminum extruded D-spar. A continuous composite-laminate blade pocket consisting of RC(4)-12, RC(4)-10, and RC(3)-10 cambered (asymmetric) airfoils replaces the segmented, individually-bonded aluminum pockets of the original NACA0012 symmetric airfoil. The blade twist is increased from a 6° linear twist to a non-linear twist total of 9.48°, including a 2° 'untwist' of the inboard section. The Carson CMRB has the same chord and span dimensions as the original aluminum blade, but has an aft swept tip, and is approximately nine pounds heavier. Carson received an FAA STC (SR01585NY) from the FAA's New York Aircraft Certification Office on 17 January 2003. A separate STC (SR02057NY) provides additional performance credit for the CMRB installation.

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[14] The GEAE investigator was delayed en route due to flight delays and arrived on-site on 08August 2008.

[15] Main and tail rotor blades and associated rotating components are identified by color codes for track and balance purposes. The counter-clockwise sequence is Red, Blue, Yellow, White, Black (looking down on main rotor and inboard on tail rotor).

As discussed in Section III F 2 of this report, Sikorsky Aircraft was contracted by the US Navy (USN) to evaluate the CMRB for potential use on USN aircraft. [redacted] The backwall is a highly stressed area of the spar. Nearly all cracks that have been observed in the legacy aluminum blade spars have originated in the lower surface to backwall radius. As a result of this evaluation, Sikorsky Aircraft recommended significant changes to the design and layup of the blades, including changing the backwall scarf joint to an interleaved ply joint as well as imposing tighter acceptance criteria for the backwall corner radius geometry.

All five CMRBs were recovered from the immediate impact area. The blades showed evidence of multiple leading edge impacts with trees.

One three foot tip-end section (identified on scene as 'A') was located under a tree about 100' southwest of the initial takeoff point. This tip end was missing the outboard ~six inches of the outboard tipcap. At the inboard portion, the spar was fractured in a broomstraw[16] fashion. Two pieces of blade skin and two fragments of leading edge were positively matched to this section. All four matched pieces were found in the immediate area of the first observed tree strike.

Two blades had separated from the bolted connection at their cuffs.

One of these cuff-separated blades (identified as 'G') was the Black blade, S/N CHI-0140, and was fractured near mid-span and draped over a tree branch approximately 75 feet from the wreckage. The outboard section (approximately 6 ft) was heavily damaged, with only spar remnants remaining. It had separated from the cuff by shearing nine of the ten retention bolts on both the upper and lower airfoils. The outboard lag-side bolts remained intact with a remnant of the cuff under the bolt head. The leading edge sheath was missing from blade station[17] BS 73 (start of sheath) to the fracture at BS 102.

A six foot section of blade spar only (identified as 'Q'), was matched to the Black blade, and was located about 100' west-northwest of the aircraft. This section was entangled in a purple Mylar-type film that was tentatively identified as a mold-release film from the central spar cavity. It was reported by Ducommun, the blade manufacturer, that this film is used during the spar build process and is not an interlaminar film, but is used to prevent the internal spar inflatable bladder from adhering to the spar during the autoclaving process. A fragment of leading edge was positively matched to this blade. The matched piece was located just below the tree in which the blade came to rest.

The other cuff-separated blade (identified as 'H') was the entire White blade, S/N CHI-0133 from cuff to tipcap, which was laying on the ground just behind and uphill of the aircraft. Blue paint transfer from the horizontal stabilizer was noted between BS 118 and 142. This blade showed a rough surface contamination (a black ash or soot) inboard of about BS 90. This contamination was noted on both the upper and lower airfoil surfaces, more heavily along the leading edge. It was sandpaper-rough in appearance, and evidence of some streaming in a combined chordwise and radial outward direction was apparent. It could be removed by fingertip pressure. This was not apparent on any of the other blades. For example, the Black blade inboard section had a dirty film appearance, but was not raised or rough in appearance as was the White blade. The Black blade dirty film could also be removed by fingertip pressure.

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[16] 'Broomstraw' is a term used to describe a fracture of unidirectional composite material in a fashion that resembles the uneven ends of a straw broom. It is typically associated with a combination of bending and tensile fractures that occur while the composite fiber is under tensile loads, in the case of rotor blades, centrifugal loads.

[17] Blade Station (BS) is a measurement in inches from the cuff of the blade towards the tip.

A leading edge impact was also noted from BS 256-270 on the White blade. The leading edge abrasion strip was separated in this region and was found nearby and matched. There was pocket damage and a section of skin missing in this section. The trailing edge and trim tab in this section were noted to be 'popped'.[18] The outboard ~6 inches of tip cap were not recovered, however, a section of the most outboard tip cap leading edge abrasion strip was found and matched. The White blade was saw-cut at BS 66, 118, 190, and 264 during recovery.

Several sections of root end blade were located immediately adjacent to the wreckage.

- The Blue blade, S/N CHI-0018, (identified as 'J'), a 16' section with the outboard end burned, and the inboard end heavily damaged (only spar remaining), located just east of the tail cone.
- Unknown blade (identified as 'K'), a 9.5' section with a fracture at a CG stripe, and the other end burned, located near the tail cone.
- Unknown blade (identified as 'L'), a 14' section, heavily burned, with leading edge intact, next to the aircraft.
- Unknown blade (identified as 'M'), a 16' section, of mostly burned blade with leading edge intact, pocket burned away, next to the aircraft.

Other sections of blade were located generally west of the main wreckage.

- A three foot section of tip end leading edge abrasion strip (identified as 'N'), about 75' west of the aircraft, with numerous brown streaks, consistent with tree strikes, in the direction of normal rotor rotation.
- A six foot tip end section, with the outer four feet nearly intact (identified as 'O'), about 150' west of the aircraft. The inboard two feet of this section were bare spar only (no leading edge, no pocket). The tip cap leading edge was intact, with some pocket damage to the outer section of trailing edge.
- An eight foot section of blade (identified as 'P') about 250' west of the aircraft. There was a clean break at one end of this section, with intact leading edge and pocket, and a broomstraw break at the other end. The broomstraw damage was about three feet long, with no pocket or leading edge remaining.
- A six foot section of outboard blade, with leading edge and pocket (identified as 'U'), about 250' southwest of the aircraft. This section had a broomstraw fracture at both ends, the outboard end was broomstrawed about three feet, and the inboard end was broomstrawed about six inches. The pocket area was 'popped' including the trim tab section. (note: this blade was originally mislabeled as 'T' and may appear in several photographs with the incorrect 'T' label)

Several pieces of leading edge abrasion strip were located along the flight path.

- An 18 inch section of leading edge only (identified as 'B'), located directly under the first topped tree.
- A 15 inch section of leading edge with red and white skin attached (identified as 'E'), located directly under the second topped tree.
- A 21 inch section of leading edge and spar (identified as 'I'), with no pocket or skin, located directly under the last (large) topped tree, just above the wreckage.
- A 22 inch section of leading edge only (identified as 'R'), about 100' west of the second topped tree.

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[18] 'Popped' is a term used to describe a specific type of trailing edge bond separation that occurs with rapid deceleration, as typically occurs when striking a fixed object.

- A 20 inch section of leading edge only (identified as 'S'), about 150' west northwest of the second topped tree. This was located near a six inch section of tip cap without its leading edge (identified as 'S1'). These two pieces did NOT match each other. (the leading edge was outboard blade, but not tipcap, in the area of the outboard abrasion strip overlay joint, which is 54" from the tip)
- A 10 inch section of leading edge only (identified as 'T'), about 75' west southwest of the first topped tree.

Tail Rotor Blades

The tail rotor blades showed very little evidence of rotation. There was minimal tip cap and leading edge damage. Because the TRBs rotate so rapidly, they frequently sustain extensive damage during a mishap. In this case, the absence of damage is significant and indicates a very low energy state. The TRBs were unburned and their paint was intact. Several areas of trailing edge were damaged by ground impact, while not rotating.

a) **Red Blade:** The Red blade was bent flatwise outboard at BS 22, punctured at BS 35 and 39, with no evidence of leading edge damage and a minor damage on the trailing edge of the tip cap. The pitch change link was bent about 15° at the inboard end and about 30° at the outboard end. The grease fitting was sheared off the hub.

b) **Blue Blade:** The Blue blade was bent flatwise outboard at BS 18, torn at BS 35 (outboard side) and was otherwise intact, with minor damage on the inboard and outboard surface of the tipcap, but no damage to the leading edge. The pitch change horn inner flange had separated allowing the nut and cotter pin to separate from the attach bolt. The outboard pitch link was bent about 25°. The grease fitting was sheared off the hub.

c) **Yellow Blade:** The Yellow blade was bent flatwise at BS 22, and folded under the tail gearbox. The pitch change link and pitch change horn were missing. The tipcap was intact.

d) **White Blade:** The White blade was severed at BS 9. The remainder of the blade was found about 10 feet aft of the horizontal stabilizer, with no leading edge or tip end damage, although the tip cap was separated. There was a flatwise bend at BS 22. About six inches of pocket was missing from the tip end. There was a spanwise pocket tear from BS 22-35. The tip cap was found about 25 feet aft of the stabilizer, with no leading edge damage. One pitch change horn flange had separated from the horn. The grease fitting was sheared off the hub.

e) **Black Blade:** The Black blade (colored identifying tape was missing) was not bent flatwise like the other four blades. The blade pocket was crushed on both sides for almost the entire length of the blade. There was a puncture on both sides at BS 48. The tip cap was intact.

3. Rotor Heads

Main Rotor Head

The main rotor head was located in the central wreckage area, and remained attached to the main rotor shaft and main gearbox. The appearance of the main rotor blades and head was consistent with tree and ground impacts at a significantly reduced N_R. All components were heavily burn damaged.

a) **Spindles:** All five spindles remained attached to the main rotor head and were fire damaged. They could not be moved by hand, except the Black spindle, which could be moved in the flapping direction only.

b) **Dampers:** The Red damper separated from the sleeve & spindle assembly and the horizontal hinge pin. The Blue, Yellow, and Black dampers separated from the horizontal hinge pin. The White damper was fractured at the piston rod itself.

c) **Pitch Change Rods (PCR):** The Red PCR was fractured from the pitch change horn fitting and was not located. The Blue PCR was found in the unburned initial ground impact area. The Yellow PCR was intact but separated from the rotorhead. The Yellow PCR pitch change horn attachment fittings had fractured from the horn, and both lower lugs had fractured off the rotating swashplate. The White PCR was intact and remained attached to the rotating swashplate. The Black PCR was intact.

d) **Pitch Change Horns:** The Red, Blue, and Black pitch change horns were intact. The Yellow horn was completely burned away. The White horn was separated from the White sleeve and spindle, but remained attached to the White PCR, which remained attached to the rotating swashplate.

e) **Droop/Flap Stops:** The Red, White, and Black droop stops appeared to be in the retracted (ground) position. The Blue droop stop was missing, and the Yellow droop stop itself was separated and located on the sleeve in a clump of resolidified aluminum. The Red, Blue, and Yellow flap stops appeared to be in the retracted (ground) position. The White and Black flap stops appeared to be in the extended (flight) position. There was damage to several of the flap stop leading edge arms, and the lead-side flap stop return springs were missing from Red, White, and Black.

f) **Bifilars:** One bifilar weight (from between Yellow and White) was separated from the head and was found impacted into the ground in the central initial ground impact area. Its arm was damaged in a downward direction and opposite main rotor rotation. The bifilar arm between Blue and Yellow was also bent downward, but did not separate. Several bifilar fairings were located just below the final wreckage area.

Tail Rotor Head

The tail rotor head was located in the impact area still mounted on the unburned vertical pylon section. The tail rotor controls appeared to be intact. The tail rotor head was intact and unburned.

4. Transmissions and Driveshafts

a) **Tail Rotor Gearbox (TGB):** The TGB appeared to be intact and was still mounted to the unburned vertical pylon. Rotational continuity could not be verified because of the position of the pylon and gearbox. There was no visible damage and no signs of leakage. Safety wire was intact. The chip detector was installed and did not appear to have any indication of oil leaks. The chip detector was not inspected in the field.

b) **Intermediate Gearbox (IGB):** The IGB appeared to be intact and was still mounted to the base of the vertical pylon. Rotational continuity could not be verified as above. There was no visible damage and no signs of leakage. Safety wire was intact. The wire to the chip detector was observed separated. The input flange was intact, with all hardware installed. The flexible coupling was slightly deformed. The chip detector was installed and did not appear to have any indication of oil leaks. The chip detector was not inspected in the field.

c) **Tail Rotor Driveshafts (TRDS):** Continuity of drive was evaluated from tail takeoff to tail gearbox input and several impact related breaks were noted as described below.

- # 1 TRDS – The forward flange remained connected to the main gearbox (MGB) tail takeoff. The tail takeoff connection was found intact, and the tail takeoff gear was distorted out of plane by heat.

- # 2 TRDS – The shaft remained connected with all hardware intact. The flexible couplings were distorted in bending because the airframe in this area had been consumed by fire, and the hanger bearing mounts were missing.

- # 3 TRDS – The entire shaft was heavily burned, but was intact. All hanger bearings were accounted for, but were also heavily burned, completely consuming some of the hanger bearing mounts.
- # 4 TRDS – The forward flange remained connected to the aft end of the # 3 shaft, all hardware was intact, and the flexible coupling was burned, but was not heavily distorted. The shaft had pulled out of the forward flange. There were no signs of rubbing or distortion of the shaft or the flange. The forward bearing had been pulled out of the hanger bearing mount, and was heavily burned. The hanger bearing mounting assembly was distorted and cracked, but the flange alignment marks remained aligned. One of the hanger bearing bolts was missing where the mount had fractured.
- # 5 TRDS lower flange remained connected to the intermediate gearbox output flange, however, due to an airframe fracture in the area, there was about a 45° angle between the IGB output and the centerline of the #5 TRDS. One of the three TRDS lobes was broken. The flexible coupling was heavily distorted in bending. The mounting hardware was intact. The shaft was distorted but intact at the tail gearbox (TGB) input flange. The mounting hardware was also intact.

d) **Main Gearbox (MGB):** The MGB housings were completely destroyed by fire. As a result, it was not possible to verify continuity, however, no damage to gear teeth was evident on any of the visible gears and continuity existed from both input couplings through the sleeve bearings to the input spur pinions. No evidence of distress was noted on any of the visible gears, bearings, or the rotor brake disk, with the exception of the tail takeoff gear, which was distorted out of plane by thermal exposure. Both input freewheel units (IFWU) were removed from the wreckage, airlifted out, and sent to Helicopter Support Inc. (HSI), a subsidiary of Sikorsky Aircraft, for further examination. Both IFWUs were -23000 series assemblies installed in the -20600 MGB under the terms of a FAA-approved Carson STC (SR02057NY).

e) **Input Freewheel Unit Examination - Left Hand (**conducted at HSI and Sikorsky**)**

The left hand IFWU was covered in white magnesium oxide ash. It appeared to have sustained significant high temperature exposure over a long duration. The through-shaft was still attached to the aft splined connection. It was removed by several strikes from a dead-blow hammer. The gear housing nut retention safety features were intact. The roller bearing was removed, and no abnormalities were noted. The roller retainer pin extension was measured at about ¼" (from tang to pin housing).

Disassembly of the IFWU normally requires a press of typically less than 8,000 lbs to separate the gear housing from the camshaft. In this case, more than 16,000 lbs was applied, and the parts did not move. Heat was applied to the gear housing with no success. The parts were soaked in penetrating oil overnight, heat reapplied, and in sequence, increasing press loads of more than 36,000 lbs of force were applied without movement. During these attempts, the threaded end of the shaft was 'mushroomed' indicating that the hardened 9310 steel had softened due to long-term high temperature exposure. Because the parts could not be separated, it was decided to section the entire left hand IFWU using a carbide bandsaw.

Following sectioning, the rollers, roller retainer (cage), and camshaft were examined for wear. While a 'heat shadow' of where the roller had come to rest existed on the cam flats and on the gear housing, no visible wear pattern of any depth was noted on any of the components. The parts were not dimensionally measured, due to the change in dimensions from heat exposure and the sectioning process. The 'heat shadow' marks were located about 0.080" from the base of the camshaft ramps, and were about 0.030" wide and the length of the rollers. The Oilite™ bushings were thermally destroyed, no remnants were observed.

There was no evidence of any wear and no evidence of any slippage or spitout observed on the left hand IFWU.

f) **Input Freewheel Unit Examination - Right Hand** (conducted at HSI and Sikorsky)

The right hand IFWU was covered in magnesium oxide, similar to the left hand. There is no through shaft on the right hand IFWU. The camshaft locknut had one ear that had been bent about 90° to the shaft. That ear was bent back and the locknut and lock washer were removed. Similar to the left hand IFWU, the gear housing was heated, and with up to 16,000 lbs of force applied, there was no separation of the parts. The parts were soaked in penetrating oil overnight. After heating the gear housing again, and applying up to 32,000 lbs of force, and then tapping the gear housing, a loud noise was heard, and the parts began to separate. Repeated hammer blows while under more than 25,000 lbs of force, allowed the parts to be separated.

Visual examination showed that three sequential rollers were heat-welded to the camshaft, and could not be removed by hand tools (brass drift and steel hammer). These three rollers prevented removal of the roller retainer. The roller retainer pin extension was measured at about ¼" (from tang to pin housing).

In order to inspect the camshaft flats, the roller retainer was removed, using a cutoff saw to make two diametrically opposed cuts through the retainer. After the cut, the less heat-damaged side (without the welded rollers) was removed by tapping lightly with a brass drift. This allowed inspection of the cam flats. While a 'heat shadow' of where the roller had come to rest existed on the cam flats and on the gear housing, no visible wear pattern of any depth was noted on any of the components. The parts were not dimensionally measured, due to the change in dimensions from heat exposure. The 'heat shadow' marks were located about 0.100" from the base of the camshaft ramps, and were about 0.030" wide and the length of the rollers. The Oilite™ bushings were thermally damaged and darkened, however, remnants of the flat and the 'hat' section bushings were observed in their proper locations (the channel on the camshaft).

There was no evidence of any wear and no evidence of any slippage or spitout observed on the right hand IFWU.

5. Propulsion

Engines: The engines were examined by the NTSB and all parties, including the GEAE representative, at the Columbia Helicopters facility in Aurora, OR. They were then re-examined by the team, including an additional NTSB Propulsion Specialist, on 28-29 October 2008 at Plain Parts in Sacramento, CA.

a) **#1 Engine:** The engine was disassembled and inspected. There was visible damage to all stages of compressor blades. The damage to the compressor blades in the engine indicated that the #1 engine was rotating at the time of impact. The core of the engine could be turned freely, indicating that the bearings were intact. A tan-colored layer of fine dust/dirt, similar to that noted at the accident site, coated the entire gas path of the engine, and was particularly obvious in the compressor section and the bypass/cooling air path surrounding the combustion liner. The power turbine could not be turned, because a large amount of resolidified molten aluminum was restricting the power turbine wheel.

   The #1 engine fuel control unit (FCU) was removed and disassembled. Details are discussed in the NTSB's material lab reports.[19]

b) **#2 Engine:** The engine was disassembled and inspected. There was minor visible FOD damage to one compressor blade (tip curl) and the back side of four inlet guide vanes. The core rotated freely. The power turbine could not be rotated more than a small amount, until working it back and forth allowed it to rotate about 60°. Disassembly of the input shaft torque tube revealed that a lump of resolidified aluminum was restricting rotation of the input shaft flange bolts. Once the aluminum lump was removed, the power turbine rotated freely, indicating that the #4 and #5 bearings were intact.

   The #2 FCU was removed and disassembled. Details are discussed in the NTSB's material lab reports.[20]

Throttles: Both throttles were found at or near the full-forward position, which is consistent with Carson's takeoff procedures. Emergency throttles were mismatched, with #1 in shutoff and #2 advanced about half way. The position of emergency throttles is not necessarily representative, as they are friction-detented only.[21]

Fuel System: The forward and aft main fuel tanks, the center auxiliary tank, and associated cells and lines were destroyed by impact and burned in the post-crash fire. No fuel was noted in the wreckage, due to the post-crash fire. According to statements by Carson and USFS employees, the aircraft had completed a single flight from Shasta-Trinity Helibase to Helispot H-44 since refueling (16 minutes of ground time at Shasta-Trinity, 12 minutes of flight enroute, and 5 minutes of ground time at H-44). At the time of the mishap the aircraft was calculated to have had approximately 2158 pounds[22] of fuel onboard. The fuel source (Jet-A) at Shasta-Trinity was sampled for water and debris contamination by the FAA/NTSB. This aircraft and several others had been serviced by the same truck before the accident. The fuel obtained from the truck was observed to be clear and bright, with no visible water contamination. The NTSB materials lab further documented the fuel condition.[23]

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[19] NTSB Materials Lab Factual Report: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/430172.pdf
[20] NTSB Materials Lab Factual Report: Ibid.
[21] NTSB Airworthiness Factual Report: Op. Cit.; p. 21.
[22] NTSB Operations Group calculated 2158 lbs of fuel remaining. GEAE calculated 2260 lbs of fuel remaining.
[23] NTSB Materials Lab – Fuel Testing Report: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/424163.pdf

6. Flight Control Systems – Hydraulic/Mechanical

The majority of the flight control system was destroyed by impact and post crash fire. Due to the level of destruction, it was not possible to establish flight control system continuity, however, where possible, bolted connections were verified. No loose or unsafetied hardware was found.

The 'fore & aft' and 'right lateral' primary servos remained attached to their stationary swashplate connection points. The lower connection hardware integrity for all three servos was verified, however, the MGB housing was consumed by fire.

The swashplate was impact and fire damaged, the 'left lateral' servo mounting lugs were completely burned away. Between the Red and Yellow arms, it was possible to visually inspect the lower swashplate duplex bearing. It was evident that, in that area, the rolling elements were properly spaced and the cage had been intact and undistorted prior to being exposed to the post-crash fire. The stationary servo mounting lugs were fractured and burned. The rotating scissors was intact. The stationary scissors was burned away. The auxiliary servo package was found in the wreckage heavily burned.

The tail rotor control forward quadrant cable end attachment swages were intact and appeared in good condition, however, they had separated from the melted forward quadrant. The cables were intact from the forward quadrant area to the forward turnbuckles. The forward turnbuckles were separated in an area of high thermal damage with portions of the middle link missing from each turnbuckle. The cables were intact from the forward turnbuckles to the aft turnbuckles. Both aft turnbuckles were observed connected and safety wired. The aft quadrant was intact with both side cables still connected. Continuity was confirmed with a slight pull on cables at the tail cone attach point moving the push tube at the pylon end indicating integrity through the tail cone. The negative force gradient spring and its attachment hardware were intact.

7. Flight Instrumentation

Only a few components were recovered with readable indications:[24]

Gauge	Indication	Units	Comments
Cockpit Torquemeter	#1: 62% #2: 58%	Percent Torque	Either LEFT or RIGHT
Cockpit Torquemeter	#1: 62% #2: 50%	Percent Torque	Either RIGHT or LEFT
External Torquemeter	#1: 70% #2: 36%	Percent Torque	Left side window
MGB Oil Pressure	168 psi	PSI (normal ~50psi)	Center Instr. Panel
Primary Hyd Pressure	1100 psi	PSI (normal ~1500 psi)	Center Instr. Panel
Fuel Quantity	900 lbs	Lbs	Either FWD or AFT
Airspeed Indicator	50 KIAS	Knots	Either LEFT or RIGHT
Eight Day Clock	7:50	Time (h:mm)	Location unknown

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[24] NTSB Airworthiness Group Chairman's Report: Op. Cit., pp 22-24.

H. Flightcrew Information

Both pilots were type-rated and current in the S-61. The pilot flying held an airline transport pilot (ATP) certificate with rotorcraft-helicopter ratings, with type ratings for BV-107, BV-234, and SK-61 aircraft (SK is the FAA designator for Sikorsky type ratings). He had logged more than 20,000 total rotorcraft flight hours, and more than 8000 hours in the S-61. He was seated in the left seat, wearing the lap seat belt, but not the shoulder harness.[25] The pilot held a current second-class medical certificate (20 Jan 2008) with a limitation mandating possession of corrective glasses for near vision. The pilot completed his last Part 135 FAA check ride on 23 June 2008.[26]

The copilot, who was the pilot not flying, held a commercial pilot certificate with a rotorcraft helicopter rating and an SK-61 type rating. He had logged over 2800 hours of total rotorcraft flight time, with more than 700 hours in the S-61. He was seated in the right seat, wearing the lap seat belt, but not the shoulder harness. The copilot held a current second-class medical certificate (12 May 2008) with no limitations. The copilot completed his last Part 135 FAA check ride on 03 May 2008.[27]

I. Survivability

The aircraft impacted several trees and rough downhill-sloping terrain in a left wing low attitude. This impact was partially survivable. Impact forces were estimated to be near the level of human G-load tolerance, depending upon location of the occupant within the aircraft. The aft fuselage section impacted and dislodged a large boulder, which may have ruptured the aft fuel tank, which in turn may have caused or accelerated the subsequent post-crash fire. The post-crash fire adversely affected survivability. The NTSB Survivability Group prepared a Factual Report.[28] Sikorsky Aircraft was not a member of the Survivability Group.[29]

While the aircraft fuel system was considered state-of-the-art in regard to crashworthiness at the time of manufacture, the severity of this accident would likely have led to the rupture of even a modern state-of-the-art crashworthy fuel tank.

The copilot (right hand seat) received extensive burns to the lower half of his body, but did not sustain any long bone fractures. The pilot (left hand seat) was fatally injured and his remains were located in the approximate relative position of his crew station. The USFS inspector pilot was seated in the 1L seat and was fatally injured.

The Grayback Company contract firefighters seated in seats 2L, 3L, 3C, 3R, and 4R were fatally injured, while those seated in seats 2C, 2R, and 4C; sustained serious injuries.

The aircraft was equipped with an Artex Model C406-N HM 406 MHz Emergency Locator Transmitter, serial number 02413, which reportedly functioned as designed.

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[25] Most Sikorsky helicopters are designed for the pilot to fly from the right seat and the copilot from the left seat, however, many heavy lift/external load pilots routinely fly from the left seat, without a shoulder harness, in order to directly observe the load while maintaining their left hand on the collective control.

[26] NTSB Operations Attachment 04 - Pilot Records: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/426688.pdf

[27] NTSB Operations Attachment 06 - Copilot Records: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/426691.pdf

[28] NTSB Survival Factors Group Factual Report: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/427652.pdf

[29] The NTSB has a policy of disallowing contractors from Group membership. Sikorsky Aircraft advised the NTSB that the only experienced S-61 Survivability Engineer was a Sikorsky contractor (a former full-time employee) who was, at the time, working on another project. An exception to this policy was initially granted and was later revoked by the NTSB.

J. Aircraft Rescue Fire Fighting Response (ARFF)

The NTSB performed a specialist evaluation of the emergency response.[30]

This was an off-airport accident with no ARFF accessibility. The post-crash fire and a small surrounding forest fire triggered by the accident were extinguished by USFS ground crews and aerial water drops, but remained hot for about two days after the mishap. The ground crews in the area were unable to approach the aircraft to assist in emergency egress due to the intensity of fire. All remnants of fuel were burned, and all of the MGB magnesium housings were completely consumed by fire.

The four survivors were transported by air to Mercy Medical Center, in Redding, CA and University of California Davis Medical Center, in Sacramento, CA.

K. CVR/Sound Spectrum Analysis

The aircraft was equipped with a Penney & Giles combination CVR/DFDR. The flight data recorder was not operational, nor was it required by FAA regulation. The CVR was operational, and despite thermal damage, the data was recovered by Penney & Giles in the United Kingdom. The CVR data was analyzed by the NTSB's CVR/Sound Spectrum group.[31] A verbatim transcript of the mishap flight was also prepared by the CVR/Sound Spectrum Group.[32]

The sound spectrum group determined that on the takeoff of the mishap flight, both engines' core speeds (N_G) initially accelerated normally, in response to the increased demand for power. On a spectral waterfall plot, this is seen as two parallel lines climbing together as power is initially applied, until the topping fuel flow limit is reached and the lines become horizontal. At topping, the fuel control is 'wide open' and no further increase in N_G is possible. This is the absolute maximum power available from the engines under the existing ambient conditions.

It should be noted because there is no type of communication between the two engines; that ANY change in load-sharing between the engines, for any reason, would be visible in the sound spectrum as variation of the individual N_G speeds. The fact that both engine cores were seen tracking linearly, simultaneously, and similarly to the previous takeoffs indicates that fuel flow and air flow to the engines were both within normal limits. Any interruption or decrease in fuel or air flow to an engine would be seen as erratic, fluctuating, or delayed acceleration of the affected engine, accompanied by the other engine's attempt to pick up the remaining load.

Once the engine topping levels were reached, the rotor speed (N_R) began a slow decay at approximately 0.35% per second, which continued (with one short-duration upspeed) until the final recorded impact. The CVR transcript indicated that the pilots were aware of the N_R droop, but did not reject the takeoff. The transcript did not indicate that pilots had observed any 'torque split' or any other unusual indications, only the droop of main rotor speed.

Reaching topping power indicates that the ***Power Required*** has exceeded the ***Power Available.*** The slow rotor speed decay is consistent with the lower rotational speeds and damage signatures observed late in the impact sequence. The slow decay is NOT consistent with other potential causes for loss of power such as engine failure, input driveshaft failure, or freewheel unit 'slip' or 'spitout'. These occurrences typically produce a sudden or more rapid decay of rotor speed.

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[30] NTSB Emergency Response Specialist Report: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/429285.pdf

[31] NTSB CVR Group Sound Spectrum Study: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/419427.pdf

[32] NTSB CVR Group Factual Report: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/426746.pdf

L. Sikorsky Aircraft Performance Assessment

Aircraft Gross Weight was ***higher*** than estimated during the flight planning phase (by between +1042 lbs[33] and +1437 lbs[34]) because the aircraft's basic weight was incorrectly reported. See Section III E of this report for details.

Power Available was ***lower*** than was estimated during the flight planning phase. This may occur for several different reasons:

1. Atmospheric conditions – Density altitude calculations incorrect
2. Environmental conditions – Contamination/erosion of engines with dirt/ash
3. Operational conditions – Engine power baseline calculations incorrect
4. Material conditions – Engines producing less than rated power
5. Performance planning – Charts incorrect or incorrectly utilized

Sikorsky concludes that in this accident, at least factor 5 was involved. Factor 1 was not applicable, as the planning was conducted for a higher ambient temperature (more conservative). Factors 2 and 4 were determined to be unlikely to be contributory, based on post-accident examination of the engines. Although some ash and soot deposits were noted, the slope of the engine accelerations and the fact that similar N_G speeds were achieved as compared to prior day's operations; indicates that the engines were both performing nominally. Further, factors 2, 3, and 4 were assessed based on previous topping checks. Both engines reached similar topping speeds to those noted on the previous topping checks, which tends to reduce the likelihood of Factors 2, 3, and 4 as considerations.

Performance Planning: The performance planning was incorrect. As noted in Section III F 1; the NTSB's Operations Group Chairman's report indicated that Carson's RFMS No.8 charts contained the data for 2½ minute single engine (OEI) at 100% N_R performance on a page that was labeled as 5 minute dual-engine power at 103% N_R. Thus the crew was led to believe that there was substantially more power available to them. This was estimated to be the equivalent of approximately 1250 lbs of additional weight capability.

Power Required may be ***higher*** than was estimated during the flight planning phase for several reasons:

1. Atmospheric conditions – Density altitude calculations incorrect, or over-reliance upon beneficial wind effects
2. Environmental conditions – Contamination of main rotor blades with dirt/ash
3. Operational conditions – Gross weight calculations incorrect
4. Performance planning – Chart performance data incorrect or incorrectly utilized

Sikorsky concludes that in this accident, at least factors 2, 3, and 4 were involved. Factor 1 was discounted based on the pre-mishap planning using a higher ambient temperature than existed at the time of the accident. It is not known if the flight crew had planned for a beneficial wind effect.

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[33] NTSB Operations Attachment 103, Op. Cit.

[34] NTSB Operations Group Chairman's Factual Report. Op. Cit., pp 24-44.

Environmental Conditions: At least one main rotor blade was found to have areas of leading edge contamination following the accident. A maintainer stated that the aircraft and its main rotor blades were covered with a thick layer of ash at the refueling stop just prior to the accident, as documented in the NTSB's Operations Group Chairman's report.[35] No contamination flight testing was conducted by Carson for these high-performance RC(4)-12, RC(4)-10, and RC(3)-10 cambered airfoils, to compare them to the legacy symmetric NACA0012 airfoils. It is thus an unknown factor that cannot be quantified at this time.[36]

Operational Conditions: Gross weight calculations were incorrect. The NTSB's Operations Group Chairman's report identified a systemic inaccuracy of aircraft basic weight data within Carson's maintenance organization. This led to the NTSB's assessment that the aircraft actually weighed 1437 lbs more than indicated on the Carson paperwork. Even using Carson's *own* post-accident assessment of the aircraft weight, the aircraft would have actually weighed 1042 lbs more than was indicated by the charts, as noted in Section III E of this report.

Performance Planning: Sikorsky/USN engineering flight test data indicates that Carson's blade performance charts documenting the power required to hover are incorrect. This is discussed in detail in Section III F 2 of this report. In addition, Carson's RFMS No.8 Charts did not account for the estimated 103 lbs of vertical drag produced by the Fire King tank. The combined effect of these discrepancies was estimated to be an over-prediction of approximately 645 lbs of weight capability.

Summary: There were three separate and distinct contributing factors involved in this accident. Carson's incorrect pre-flight assessments of *Gross Weight*, *Power Available*, and *Power Required* led the crew to incorrectly believe they had substantially more performance capability (equivalent to more than 3000 lbs of lift), and as a result, the aircraft was unable to clear the trees during the attempted departure from H-44.

M. Sikorsky Aircraft Performance/Handling Qualities Analysis

In cooperation with the NTSB Performance Group, which was formed in November 2008, Sikorsky Aircraft Handling Qualities performed numerous analyses.

Sikorsky Aircraft uses a program called GenHel to model the aircraft's response to various scenarios. GenHel was originally developed by Sikorsky Aircraft and has been improved over the last 35 years to increase fidelity and improve the user interface. The major features of the GenHel simulation are its generic formulation and the continuous verification and validation by comparison to hundreds of hours of Engineering Flight Test Data. GenHel is a total force, large-angle model with the forces and moments on all components calculated on every pass and summed about the center of gravity. The resultant vehicle response is then used to update the motion inputs for the next pass.

GenHel operates in the time domain with main and tail rotor rotating in space as on the actual aircraft. All six degrees-of-freedom of the airframe are accounted for, in addition to modeling the individual flap, lag, and pitch motion for each rotor blade.

A control system model calculates the inputs to the main and tail rotor from both the pilots' stick inputs as well as the AFCS. This provides a complete simulation of the aircraft's trajectory through space.

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[35] NTSB Operations Group Chairman's Factual Report: Op. Cit., p.9

[36] History has shown that other advanced airfoils used on fixed-wing aircraft such as the ATR-72 (modified NACA 43018/ 43013) have reacted to leading edge contamination very differently than did older, simpler airfoils. Similarly, the Cessna C-177 Cardinal was originally designed with an advanced, laminar-flow NACA 65A015 airfoil. The laminar flow wing worked well until leading edge contamination or roughening tripped the flow early, resulting in unpredictable performance under near-stall conditions. The wing was later redesigned for the C-177B to use a more conventional airfoil (Cessna created a hybrid airfoil using the traditional leading edge section of a NACA 2415 and the advanced trailing edge section of the NACA 65A015).

GenHel is used at Sikorsky Aircraft for handling qualities analysis, loads prediction, pilot-in-the-loop simulation, flight control law development, and incident/accident investigation.

Utilizing the aircraft weights and environmental data provided by the NTSB, Sikorsky ran hundreds of hours of CPU time modeling the aircraft's departure from H-44 in many different flight profiles, attempting to optimize performance. The model was configured to represent the accident as closely as possible.

The GenHel model was specifically corrected for the accident case using the USN/SAC flight test data from the back-to-back analytical comparison of the legacy and Carson blades, which showed about 1000 lbs of added lift at 19,008 lb at 6100'Hp/23°C. The aircraft model was then corrected for the long-fuselage (the USN testing used a short-fuselage aircraft) as well as the fixed gear vertical and horizontal drag and the added vertical and horizontal flat plate drag[37] of the Fire King tank.

Sikorsky Aircraft's first set of modeling efforts used the H-44 3rd takeoff environmental conditions as stated by the NTSB, at full topping power from both engines (2364shp).

In the first six attempts, the aircraft was unable to gain enough altitude to clear the trees in the available distance.

The seventh scenario obtained the best results after several weeks of optimization, with a three-second initial collective pull to the stop, causing the rotor speed (N_R) to droop to 97%. This departure resulted in the aircraft just barely clearing the trees. This required a very aggressive pitch-over maneuver four seconds after takeoff, lowering the nose to 20° down for two seconds, then rapidly pulling back to 30° nose up. This is an aggressive maneuver for any helicopter, and especially for an aircraft in a passenger transport mission.

In all the evaluated scenarios, a light headwind of only 5 knots makes the takeoff possible.

It is most likely that the presence or absence of headwind was the most important factor on why the first and second takeoffs from H-44 were possible and the third takeoff was not. This is further addressed by the NTSB Hover Performance Sensitivity Study.[38]

A second set of studies was requested by the NTSB and were performed by Sikorsky Aircraft using the 'actual' power available of 2300shp. This value was calculated by the NTSB Performance Group Chairman, using the GEAE engine deck[39] with the aircraft's ambient conditions and the CVR-recorded N_G speeds.

In all of the studies run with the actual gross weight of 19,008 lbs, with the actual power available of 2300shp, and the corrected CMRB performance data (USN/SAC derived data) it was not possible to successfully depart H-44 under the third takeoff ambient conditions.

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[37] The 'flat plate' drag is used, because Sikorsky does not possess wind-tunnel data on Carson's Fire King tank installation. Sikorsky has provided the Fire King drag analysis to the NTSB who distributed it to all parties to the investigation.

[38] NTSB Hover Performance Study – http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/426604.pdf

[39] The GEAE 'engine deck' is a computer simulation of the engine power output based on ambient conditions and engine speeds.

Six of the 'actual power available' studies conducted are of particular interest:
(all six were conducted at 2300shp/23°C/6106' Hp/Calm Winds as determined by NTSB)

1. 'Analytical' Gross Weight[40] – 16,100 lbs. [USN/SAC Data] This is the maximum HOGE weight (minus the USFS 550 lbs Weight Reduction Factor [WRF]) as calculated by Sikorsky Aircraft using the correct 5 Minute Power Charts and the USN/SAC-derived Power Required data. At this weight and power [2030shp], the aircraft can HOGE with 550 lbs of margin. Departure would have been successful using either a vertical or angled profile. At the actual topping power [2300shp], the aircraft has **+2675 lbs** of positive margin.
2. 'Proper' Gross Weight[41] – 17,000 lbs. [RFMS No. 8 Data] This is the maximum HOGE weight (minus WRF) as calculated by the NTSB using the correct 5 Minute Power Charts and the Carson RFMS No.8 Power Required data. At this weight and power [2030shp], the aircraft is *predicted* to HOGE with 550 lbs of margin. Departure would have been successful, using either a vertical or angled profile. At the actual topping power [2300shp], the aircraft has **+1775 lbs** of margin.
3. 'Crew' Gross Weight[42] – 17,571 lbs [RFMS No. 8 Data]. This is the crew's perception of the weight as flight planned, based on the *incorrect* equipped weight of the aircraft plus the actual fuel and payload. At this weight, with the Carson RFMS No.8 Power Required data, the aircraft is *predicted* to HOGE with **+1204 lbs** of margin. The departure at this gross weight is successful, because the aircraft has HOGE capability.
4. 'Crew' Gross Weight – 17,571 lbs. [USN/SAC Data] This is the crew's perception of the weight as flight planned, based on the *incorrect* equipped weight of the aircraft plus the actual fuel and payload. At this weight, with the USN/SAC-derived Power Required, the aircraft can HOGE with **+559 lbs** of margin. The departure at this gross weight is successful, because the aircraft has HOGE capability.
5. 'Actual' Gross Weight – 19,008 lbs [RFMS No. 8 Data]. This is the actual takeoff gross weight, based on the Operations Group build-up. Using Carson's RFMS No.8 Power Required data, the aircraft *cannot* HOGE, because it has a *negative* margin (**-233 lbs**), but accelerating from hover in ground effect can perform a slow climb due to the added performance gained through *translational lift*,[43] allowing the rotor tip-path plane to clear the trees, but will drag the fuselage through the tops of the trees.
6. 'Actual' Gross Weight – 19,008 lbs. [USN/SAC Data] This is the actual takeoff gross weight, based on the Operations Group build-up. Using the USN/SAC-derived Power Required data, the aircraft *cannot* HOGE, because it has a *negative* margin (**-878 lbs**) and in all departure scenarios, the rotor tip-path cannot clear the trees and the aircraft crashes.

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[40] The NTSB referred to this as the 'analytical' weight, as it is the maximum takeoff weight that *would have been calculated* if the correct Power Available charts *and* the USN/SAC-corrected Power Required data had been used.

[41] The NTSB referred to this as the 'proper' weight, as it is the maximum takeoff weight the crew *would have calculated* if the correct Power Available charts had been used with the Carson RFMS No.8 Power Required data.

[42] This is referred to as the 'crew' weight, as it would have been *the crew's perception* of their takeoff weight, based on the incorrect Power Available charts and using the incorrect aircraft-equipped weight of 12,408 lbs, plus 2158 lbs of fuel, 440 lbs of crew, and 2565 lbs of payload. Note that the inspector pilot's weight of 210 lbs *is* included in the payload, in order to be conservative, although his weight had not been included by the USFS on the manifest, nor by the pilots in their flight planning.

[43] *Translational lift* refers to additional rotor performance gained from added inflow to the rotor. The replacement of turbulent, recirculating air as seen in a no-wind hover with 'clean' air due to horizontal movement (translation) of the rotor increases the rotor efficiency and thus increases the thrust produced at the same power.

Regardless, had the flight crew made the calculations in accordance with the Carson RFMS No.8 data and the Carson-provided weight, their takeoff would have had an incorrectly predicted large power margin. On the first two takeoffs from H-44, the crew (and/or inspector pilot) should have noted that they had NO margin (versus at least +11% predicted[44]), as they reached topping power limits on both engines and drooped the main rotor speed on both prior H-44 departures.

This should have alerted them that either their mission planning was incorrect or the aircraft performance was seriously degraded. Inadequate real-time risk assessment, complacency, and over-confidence in the aircraft were likely factors in their overlooking this important observation. This is discussed in further detail in Section III N of this report.

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[44] NTSB Hover Performance Study – Op. Cit.; Note that this hypothetical prediction also incorporates the RFMS No.8 CMRB performance data. The margin would be lower using the corrected USN/SAC CMRB performance data.

Sikorsky Addition to NTSB Hover Performance Study and GEAE Power Study:

Both the NTSB Hover Performance Study[45] and the GEAE Power Study[46] used the Carson RFMS No.8 CMRB Power Required data, without correction for Fire King tank vertical drag. Correcting this data to account for the lower CMRB performance as determined by USN/SAC analysis and adding the Fire King tank vertical drag, the performance numbers show near-zero or negative margins for *all three* H-44 takeoffs. As expected, the third takeoff has the most negative margin.

The fact that all three H-44 takeoffs have a near-zero or negative margin is consistent with the known conservatism built into Sikorsky Aircraft performance charting methodology, as well as the potential for light winds providing some lift benefit during the first H-44 takeoff. Had the margins been as predicted by the original NTSB and GEAE numbers, the aircraft would *not have been expected* to reach topping power on the 2nd H-44 takeoff. (predicted positive margin from +3.6% to +4.2%)

The GEAE Power Study estimated actual gross weight varies slightly from the NTSB's Hover Performance Study. GEAE used a different methodology to account for the amount of fuel consumed between the refueling at Trinity Helibase to the accident take-off from H-44. This resulted in a 102 lb increase in the aircraft's takeoff gross weight on the H-44 third departure.

The GEAE Power Study also calculated slightly different dual-engine HOGE gross weight capabilities. This resulted in a reduction of HOGE weight capability ranging from 48 to 91 lbs.

Sikorsky Aircraft summarizes the NTSB Hover Performance and GE Power Studies, providing a column to show predicted weight margin (comparing the calculated gross weight vs. the predicted [RFMS 8] HOGE weight), and adding a column to show the GenHel predicted USN/SAC corrected data HOGE weight margin:

NTSB Hover Performance Study Results

Takeoff	Time PDT	OAT °C	Winds	Hp (ft)	Gross Wt	HOGE Wt	RFMS 8 Margin	USN/SAC HOGE Wt	USN/SAC Margin
H-44 1st	18:14	29	Calm	6106	18368	18598	**1.2%**	18060	**-1.7%**
H-44 2nd	18:43	27	Calm	6106	18001	18791	**4.2%**	18085	**0.5%**
H-44 3rd	19:40	23	Calm	6106	19008	19098	**0.5%**	18130	**-4.8%**

[redacted]

GEAE Power Study Results

Takeoff	Time PDT	OAT °C	Winds	Hp (ft)	Gross Wt	HOGE Wt	RFMS 8 Margin	USN/SAC HOGE Wt	USN/SAC Margin
H-44 1st	18:14	29	Calm	6106	18385	18550	**0.9%**	18060	**-1.8%**
H-44 2nd	18:43	27	Calm	6106	18025	18700	**3.6%**	18085	**0.3%**
H-44 3rd	19:40	23	Calm	6106	19110	19050	**-0.3%**	18130	**-5.0%**

In all cases using the USN/SAC-derived blade performance data, the calculated weight margin ranges from **+0.5** to **-5.0%**. Based on the aircraft's *actual* gross weight, the *actual* power available, and the *actual* power required; with the *required* USFS Weight Reduction Factor of 550 lbs, NONE of the departures from H-44 should have been attempted. This is consistent with the fact that aircraft reached topping power during all three takeoffs, which should *not* occur during normal operations.

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[45] NTSB Hover Performance Study – Op. Cit.

[46] GEAE Power Study: http://www.ntsb.gov/Dockets/Aviation/LAX08PA259/440051.pdf

Historical Performance Case Study:

Any time an aircraft is operated close to the power available/power required margin, extremely small changes in atmospheric conditions can become the determining factor on success or failure.

This was clearly demonstrated on 30 May 2002; when a USAFR HH-60G aircraft crashed during a mountain climbing rescue attempt at an altitude above 10,000 feet on Mount Hood, Oregon. Raw high-quality[47] news video footage of the accident was obtained. Several selected sections, including the entire two minutes prior to the accident, were evaluated frame-by-frame.[48]

This analysis showed that the aircraft successfully hovered out of ground effect with no rotor droop during the first hover on the scene. During that hover, the aircraft lowered a 200 lb crewman and a litter and equipment weighing about 50 lbs to the surface.

The aircraft then departed the hover and orbited for about 15 minutes, consuming approximately 250 lbs of fuel. Then, at a gross weight about 500 lbs *lighter* than the previous hover, the aircraft returned to the *exact* same location and altitude to retrieve the litter (the patient had been loaded into the litter, but was not moved).

Sikorsky Aircraft Handling Qualities evaluated the aircraft's predicted performance in GenHel based on actual ambient conditions and aircraft gross weight vs. main rotor speed (N_R). GenHel analysis predicted a loss of tail rotor control would occur if N_R drooped to less than 91%.

While making very small control inputs to position the aircraft for the hoist recovery, the ***power required*** exceeded ***power available.*** As no further power can be extracted from the engines, N_R began to droop at a rate of approximately 1.18% per second.

As predicted by GenHel, when N_R drooped below 90.7%, tail rotor control was lost, and the aircraft crashed and rolled down the mountain. This clearly and visually demonstrates how very small changes in ambient airflow can affect marginal power flight operations.

Post-accident calculations of the ***power required*** and ***power available*** indicated that at that altitude and temperature, in calm winds, the aircraft would have had a positive HOGE margin of about +3.4%.

As predicted, in the initial hover, the aircraft was able to successfully hover.

In the second (accident) hover, the ambient airflow had shifted sufficiently to create a negative margin and subsequent rotor droop.

Note that the LOW wind condition is the most critical. The criticality of a 3-5 kt wind is related to main rotor and tail rotor interaction phenomena. At higher wind values, inflow to the main rotor is increased, regardless of the azimuth, which enhances hover performance.

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[47] A local television station news helicopter was orbiting the rescue scene. The USAF Safety Investigation Board obtained the raw camera tape for analysis. The standard NTSC video frame rate is 29.97 frames per second (fps). However, the Sony BetaCam SP video camera records at a 'double' frame rate of 59.94 fps. The 'double' frame rate was essential for the accurate calculation of rotor speed, because the minimum *Nyquist rate* is 34.4 Hz (Two times the main rotor blade-pass frequency of 17.2 Hz) which is required to avoid any 'aliasing' effects that would result in any 'missed' blades, as stated by the *Nyquist-Shannon Sampling Theorem.*

[48] The frame-by-frame analysis was conducted by counting blade passage by observation of the blade shadows below the aircraft in every frame of the video. A five-second rolling average of blade speed was used to track rotor speed.

N. Human Factors Analysis and Classification System (HFACS) Study

HFACS was developed by Shappell and Wiegmann at the US Naval Safety Center.[49] Based on the work of James Reason and his 'Swiss Cheese' model of accident causation, it is an algorithm and taxonomy used for assessing the human factor contributions to aircraft accidents. It begins with the active errors, and then evaluates precursor and latent conditions, supervisory environments, as well as organizational culture and environments.

Sikorsky Aircraft frequently conducts HFACS analysis in our accident investigations in order to obtain specific and actionable human factor-related root cause data for use in accident prevention strategies. This data may be used in future or modified designs, revisions to flight and maintenance manuals, and/or training syllabi for pilots and maintainers.

In this case, using the Naval Safety Center HFACS checklist[50] Sikorsky conducted a top-level evaluation of the failure of the flight crew to notice that both engine's topping limits were reached on the first two H-44 takeoffs as well as the accident takeoff. In order to complete the HFACS process, it would be necessary to review each one of these factors in detail.

HFACS Assessment

Judgment and Decision-Making Errors:	
AE201	Inadequate real-time risk assessment
Coordination/Communication/Planning Factors:	
PP111	Failure to re-assess risk and adjust to changing circumstances
PP112	Information is misinterpreted or disregarded
Awareness (Cognitive) Factors:	
PC102	Fixation ("channelized attention")
Psycho-Behavioral Factors:	
PC206	Overconfidence
PC208	Complacency
Inadequate Supervision:	
SI001	Command oversight inadequate
SI004	Failed to provide appropriate policy/guidance
Failure to Correct Known Problem	
SF002	Failed to correct unsafe practices
Planned Inappropriate Operations	
SP006	Performed inadequate risk assessment
Supervisory Violations	
SV001	Failure to enforce existing rules
SV003	Directed individual to violate existing regulations
Resource/Acquisition Management:	
OR008	Failure to provide adequate operational informational resources
Organizational Climate:	
OC001	Organizational culture (attitude/actions) allows for unsafe mission demand/pressure
OC003	Organizational over-confidence in equipment
Organizational Processes:	
OP003	Provided inadequate procedural guidance or publications

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[49] More information on the development of HFACS is available on-line at http://www.hfacs.com

[50] The Naval Safety Center HFACS pocket checklist is available on-line at http://www.safetycenter.navy.mil/aviation/aeromedical/downloads/human_factor_analysis_flip-book.pdf

IV. FINDINGS

A. Observations

All observed damage was consistent with impact with trees and terrain at near zero forward speed and less than nominal rotor speed.

The NTSB-led sound spectrum analysis indicated that during all three takeoffs from H-44, both engines accelerated simultaneously and without hesitation to or near their expected topping speeds as measured the day prior. During the accident takeoff, which was the heaviest of the three, the rotor speed began to droop as the aircraft transitioned out of ground effect, and aircraft performance was insufficient to successfully complete the takeoff. The rotor speed droop rate of ~0.35% per second was consistent with the predicted small negative margin between ***power required*** and ***power available.*** It was *not* consistent with a sudden power loss, nor with an engine or engines failing to produce rated power.

B. Analysis

(1) Carson's aircraft weight & balance records (historical and day of the mishap) were incorrect, both in aircraft configuration control and in actual weighing records. This resulted in the aircraft weighing from 1042 to 1437 lbs more than indicated by the weight and balance records.
Contributing Factor

(2) Carson's RFMS No.8 chart labeled **5 Minute Power Available at 103% N_R** (Figure 4) actually contained the performance data from the **2½ Minute Power Available** chart (Figure 1). This resulted in the flight crew's pre-flight performance planning accounting for substantially more power than was actually available.
Contributing Factor

(3) Carson's RFMS No.8 Power Required charts over-predicted the Composite MRB performance and did not account for the vertical drag of the Fire King tank. This resulted in the flight crew believing substantially more lift capability existed than actually did.
Contributing Factor

(4) A systemic pattern of insufficient detail and thoroughness in maintenance records, use of incorrect data, and incorrect application of correct data was found to be prevalent in Carson's Perkasie, PA and Grants Pass, OR facilities. Further, the FAA's operational and maintenance oversight programs failed to identify this pattern.
Contributing Factor

(5) The flight crew (including the USFS Inspector Pilot) either did not detect, or detected but did not respond to, the lack of margin (as indicated by reaching topping N_G and subsequent excessive droop of rotor speed) on the two prior takeoffs from H-44.
Contributing Factor

(6) The incorrect aircraft equipped weight and balance data, the incorrect RFMS No.8 Power Available charts presented to the flight crew, coupled with the performance over-prediction in the RFMS No.8 Power Required charts, led the flight crew to believe that they had sufficient power margin to depart H-44 at the ambient conditions that existed at the time.

Nonetheless, the flight crew (including the USFS Inspector Pilot) should have detected the lack of power margin on the previous two takeoffs, as well as the excessive power required to hover in ground effect and should have aborted the third takeoff attempt prior to committing to a horizontal departure.
Causal Factor

V. RECOMMENDATIONS/STATUS

Sikorsky Aircraft recommends that the NTSB:

1. Ensure adequate FAA Principal Operations Inspector and Principal Maintenance Inspector oversight and monitoring of Part 133 and 135 operator maintenance and weight and balance records.

   STATUS: OPEN. Action – NTSB

2. Review the FAA's STC process for the Composite Main Rotor Blade. [redacted]

   STATUS: OPEN. Action – NTSB

3. Recommend the FAA require installation of modern crash-survivable Digital Flight Data Recorders (DFDR) in all large (TOGW greater than 12,500 lbs) Part 133 or 135 aircraft. DFDRs enable more accurate accident investigations and can provide information that would otherwise be lost, including aircraft systems status, as well as aircraft attitudes, velocity, and descent rates. As an interim measure, for aircraft already equipped with HUMS, provide either a crash-survivable backup recording device or real-time telemetry download for the HUMS data. Further, if an aircraft is already equipped with a combination CVR/FDR (as this aircraft was) require that the FDR section be maintained in an active recording status, regardless of any FDR requirement waivers that would otherwise apply.

   STATUS: OPEN. Action – NTSB

4. Recommend the FAA require that all large Part 133 or 135 that are not equipped with DFDRs install crash-survivable (or crash-resistant) cockpit video recording devices.

   STATUS: OPEN. Action – NTSB

Other Planned Actions:

Sikorsky Aircraft Corporation and Carson Helicopters Inc. recently announced the S-61T ***Triton***, a joint venture modernization program for the S-61 model aircraft. As part of this program, Sikorsky Aircraft plans further actions to document the actual strength and flight performance of the Composite Main Rotor Blade, to include tension-torsion fatigue substantiation of the improved interleaved back-wall spar configuration, as well as a Performance and Handling Qualities engineering flight test on an S-61N (long fuselage) airframe. These tests are planned for completion by mid-2011.

Additionally, Sikorsky Aircraft plans to conduct leading edge contamination tests on the Composite Main Rotor Blades to assess the effect of contamination as compared to the legacy Aluminum Main Rotor Blades.

APPENDICES

APPENDIX I: Acronyms and Abbreviations

14 CFR Part 91	Code of Federal Regulations (CFR); General Operating and Flight Rules
14 CFR Part 133	CFR; Operating Requirements: External Lift Operations
14 CFR Part 135	CFR; Operating Requirements: Commercial Flight Operations
AD	Airworthiness Directive
AMOC	Alternate Method of Compliance
ARFF	Airport Rescue and Fire Fighting
BS	Blade Station (measured in inches from the blade cuff)
CFR	Code of Federal Regulations
CG	Center of Gravity
CHI	Carson Helicopters Incorporated (for the purposes of this report, this includes CHSI)
CMRB	Composite Main Rotor Blade (Carson Design/Ducommun Manufactured)
CVR/DFDR	Cockpit Voice Recorder/Digital Flight Data Recorder
FAA	Federal Aviation Administration
FCU	Fuel Control Unit
GEAE	General Electric Aircraft Engines
GPS	Global Positioning System
Hd	Height (Density) – Density Altitude
Hp	Height (Pressure) – Pressure Altitude
HFACS	Human Factors Analysis and Classification System
HOGE	Hover Out of Ground Effect
HSI	Horizontal Situation Indicator *also* Helicopter Support Incorporated
HUMS	Helicopter Usage Monitoring System
IGB	Intermediate Gearbox
IFWU	Input Freewheel Unit
IIC	Investigator in Charge
IMC	Instrument Meteorological Conditions
LH	Left Hand
M&P	Material and Processes
MGB	Main Gearbox
MLG	Main Landing Gear
MRB	Main Rotor Blade (Sikorsky Design/Manufacture)
MRH	Main Rotor Head
MSL	Mean Sea Level
N_G	Gas Generator Turbine Speed
N_P	Free (Power) Turbine Speed
N_R	Rotor (Main) Speed
NACA	National Advisory Committee for Aeronautics – series of airfoil designs
NLG	Nose Landing Gear
NTSB	National Transportation Safety Board
NVRAM	Non-Volatile Random Access Memory
OEI	One Engine Inoperative
PAC	Pilot at the Controls
PCR	Pitch Change Rod
PIC	Pilot in Command
PNAC	Pilot Not at the Controls
PT	Power Turbine
RFMS	Rotorcraft Flight Manual Supplement
RH	Right Hand
SAC	Sikorsky Aircraft Corporation
SHP	Shaft Horsepower
SIC	Second in Command
STA	Fuselage Station in inches aft of datum
STC	Supplemental Type Certificate
TBD	To Be Determined
TBO	Time Between Overhaul
TGB	Tail Gearbox
TOGW	Takeoff Gross Weight
TRB	Tail Rotor Blade
USN	United States Navy
USFS	United States Forest Service (a division of the US Department of Agriculture)
$V_{b_{roc}}$	Velocity (best rate of climb)
VMC	Visual Meteorological Conditions

APPENDIX II: Component Serial Numbers

ITEM	PART NUMBER	SERIAL NUMBER	LOGBOOK or PHYSICAL VERIFICATION
Main Gearbox	S6135-20600-046	A14-B-22-77-1057	Logbook
Intermediate Gearbox	S6135-66300-2	A15-801	Physical & Logbook
Tail Rotor Gearbox	S6135-66600-043	A16-958	Logbook
Main Rotor Head	S6110-20003-045	A9-692	Logbook
Main Rotor Swashplate	S6110-24013-3	S460	Logbook
Primary Servo (Fore & Aft)	61650-20300-041	R339	Logbook
Primary Servo (Right Lat)	61650-20300-042	A087	Logbook
Primary Servo (Left Lat)	61650-20300-043	A203	Logbook
Auxiliary Servo	S6165-61500-061	153	Logbook
Main Rotor Blade – Red	163-101-1 Rev O	CHI-0144 *or* 0138	Logbook
Main Rotor Blade – Blue	163-101-1 Rev N	CHI-0018	Physical & Logbook
Main Rotor Blade – Yellow	163-101-1 Rev O	CHI-0138 *or* 0144	Logbook
Main Rotor Blade – White	163-101-1 Rev O	CHI-0133	Physical & Logbook
Main Rotor Blade – Black	163-101-1 Rev O	CHI-0140	Physical & Logbook
Tail Rotor Head	S6110-31400-3	A12-193	Logbook
Tail Rotor Blade – Red	S6117-30101-045	61VR-2347-2298	Physical & Logbook
Tail Rotor Blade – Blue	S6117-30101-045	61VR-2600-2548	Physical (Log = -2546)[51]
Tail Rotor Blade – Yellow	S6117-30101-045	61VR-1412-1381	Physical & Logbook
Tail Rotor Blade – White	S6117-30101-045	61VR-1788-1757	Physical & Logbook
Tail Rotor Blade – Black	S6117-30101-045	61VR-4622-4599	Physical (Log = -4588)[52]
Engine #1 GEAE CT58	CT58-140-1 [53]	295-120	Logbook 22319.8/234.5
Engine #2 GEAE CT58	CT58-140-1	296-024D	Logbook 32435.1/234.5
			Also physical inspection
Engine #1 H-S FCU	JFC26	72835BR	Logbook (118.3 hrs)
Engine #2 H-S FCU	JFC26	49882	Logbook (189.4 hrs)
ELT Artex 406 MHz	C406-N HM	02413	Logbook

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[51] The last digit of the serial number did not match, likely a reading or transcription error. '8' vs. '6'

[52] The last two digits of the serial number did not match, likely a reading or transcription error. '99' vs. '88'

[53] The GEAE CT58-140 engines can be converted between -1 and -2 configurations by changing fuel control and topping settings. The engine dataplates disagreed with the configuration as indicated on the engine log cards.