NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Washington, D.C. 20594

April 13, 2010

Hover Study Addendum #1

by John O'Callaghan

A. ACCIDENT

Location: Weaverville, CA
Date: August 5, 2008
Time: 19:41 Pacific Daylight Time (PDT)[1]
Aircraft: Sikorsky S-61N helicopter, registration N612AZ
NTSB#: LAX08PA259

B. GROUP

Not Applicable

C. HISTORY OF FLIGHT

On August 5, 2008, about 1941 Pacific daylight time, a Sikorsky S-61N helicopter, N612AZ, impacted trees and terrain during the initial climb after takeoff from Helispot 44, located at an elevation of about 6,000 feet in mountainous terrain near Weaverville, California. The airline transport pilot, the safety crewmember and seven firefighters were killed; the commercial copilot and three firefighters were seriously injured.[2] Impact forces and a postcrash fire destroyed the helicopter. The helicopter was being operated by the United States Forest Service (USFS) as a public flight to transport the firefighters from Helispot 44 to another location. The helicopter was registered to Carson Helicopters, Inc. (CHI) of Grants Pass, Oregon, and leased to Carson Helicopter Services, Inc. (CHSI) of Grants Pass. The USFS had contracted with CHI for the services of the helicopter.[3] Visual meteorological conditions prevailed at the time of the accident, and a company visual flight rules flight plan had been filed.

The Hover Study for this accident (Reference 1) presents the results of computing the maximum weight at which the helicopter could hover out-of-ground-effect (HOGE) as a function of time for the seven takeoffs recorded on the helicopter's Cockpit Voice Recorder (CVR). The calculations are based on:

[1] Local time at Weaverville on the day of the accident was Pacific Daylight Time (PDT). PDT = UTC - 7 hours. Times in this Study are in PDT unless otherwise noted.
[2] The safety crewmember was a USFS Inspector Pilot.
[3] Initially, the NTSB was informed that the contract was between the USFS and CHSI. For further information refer to the Operations Factual Report.

- The gas-generator speed (N_g) of the two engines obtained from a sound-spectrum analysis of the engine sounds recorded on the CVR.
- The shaft horsepower required to HOGE as a function of helicopter weight and atmospheric conditions, as provided by the appropriate performance chart in the Rotorcraft Flight Manual (RFM).
- The shaft horsepower (SHP) provided by each engine as a function of N_g, as generated by General Electric (GE) (the engine manufacturer) using mathematical models of the engines' performance.
- Helicopter gross weight values provided by the Operations Group.

The results of the calculations indicate that on the accident takeoff from Helispot 44 (H44), the helicopter was operating within 100 lb. of the HOGE weight corresponding to the shaft horsepower generated by the engines at their maximum ("topping") N_g. The results also indicate that the helicopter was operating under similar but slightly less critical conditions during two previous (successful) takeoffs from H44.

This Addendum to the Hover Study presents calculations of the torque developed by the engines during the accident takeoff, based on:

- The main rotor speed (N_R) obtained from a sound-spectrum analysis of the planetary mesh sounds recorded on the CVR, as described in the *Sound Spectrum Study Cockpit Voice Recorder* (Reference 2) and presented in the Hover Study.
- The gas-generator speed (N_g) of the two engines obtained from a sound-spectrum analysis of the engine sounds recorded on the CVR, as described in Reference 2 and presented in the Hover Study.
- The shaft horsepower (SHP) provided by each engine as a function of N_g, as generated by General Electric (GE) (the engine manufacturer) using mathematical models of the engines' performance and presented in the Hover Study.
- The physical relationship between power, torque, and main rotor speed, by which torque can be computed from shaft horsepower and N_R.

The calculations are presented as plots of N_R and torque vs. time, with relevant comments from the CVR indicated on the plots at positions corresponding to the times at which they were recorded. The plots indicate that the torque and N_R callouts by the crew during the accident takeoff are consistent with the N_R values based on the CVR sound spectrum analysis, and with the torque calculations presented in this Addendum. This in turn indicates that the power developed by the engines during the accident takeoff matched the power expected based on the N_g values determined from the sound spectrum analysis, and the mathematical models of the engines' performance provided by GE.

D. DETAILS OF THE INVESTIGATION

I. Physical relationship between torque, N_R, and power

Power is the rate of doing work, or the vector dot-product of force with a differential element of distance, divided by a differential element of time:

$$P = \frac{\vec{F} \cdot d\vec{x}}{dt} \qquad [1]$$

In a linear reference frame, Equation [1] is equivalent to the vector dot-product of force with velocity. In a rotating reference frame, the differential vector element of distance ($d\vec{x}$) becomes the vector cross-product of the differential angle of rotation with the radius of rotation:

$$d\vec{x} = \vec{r} \times d\vec{\theta} \qquad [2]$$

Substituting Equation [2] into Equation [1] gives

$$P = \frac{\vec{F} \cdot \vec{r} \times d\vec{\theta}}{dt} = \vec{F} \cdot \vec{r} \times \vec{\omega} = \vec{F} \times \vec{r} \cdot \vec{\omega} = \vec{Q} \cdot \vec{\omega} \qquad [3]$$

Where $\vec{Q}$ is the torque about the center of rotation, and $\vec{\omega}$ is the angular velocity of rotation. For each of the S-61N helicopter's two engines, torque is measured at the engine inputs to the Main Gear Box (MGB) of the transmission, and the angular velocity at those inputs is each engine's free turbine rotation speed (N_F). The resulting power is that required to rotate the turbine at N_F, and is equal to the power output of the engine. The British engineering units for the quantities in Equation [3] are:

- Power in lb*ft/sec;
- Torque in lb*ft,
- Angular velocity in radians/sec.

From Equation [3] the magnitude of the torque $\vec{Q}$ is given by

$$Q = \frac{P}{\omega} = \frac{P}{N_F} \qquad [4]$$

Since the N_F and N_R are mechanically linked through the transmission, they are proportional to one another:

$$N_R = kN_F \qquad [5]$$

Where k is a constant scale factor. Substituting Equation [5] into Equation [4] gives

$$Q = \frac{P}{kN_R} \qquad [6]$$

Or,

$$kQ = \frac{P}{N_R} \qquad [7]$$

Which gives the torque Q scaled by the constant k.

In operational practice, power is measured in horsepower, and torque and N_R are measured as a percentage of a nominal, 100% value. For the S-61N, the 100% values of N_R and the quantity kQ defined in Equation [7] are:

- 100% NR = 21.24 radians / sec = 202.8 RPM
- 100% kQ = 31,332 ft*lb

The torque displayed on the cockpit instruments is kQ, expressed as a percentage of the 100% kQ value. The displayed torque can be computed from the engine output in horsepower, and the rotor N_R expressed as a percentage of the 100% N_R value, as follows:

$$Q_G = \left(\frac{100\%}{31{,}332\ ft * lb}\right)\left\{\frac{P\left(550\ \frac{lb * ft/sec}{HP}\right)}{\left(\frac{N_R}{100\%}\right) 21.24\ rad/sec}\right\} = 8.2646\left(\frac{P}{N_R}\right) \qquad [8]$$

Where Q_G is the torque value displayed on the cockpit gauge (in %), P is the engine power in horsepower, and N_R is the main rotor RPM (in %).

II. Computation of engine torque for the accident takeoff

The torque for each engine corresponding to the computed power presented in the Hover Study can be determined from the main rotor N_R derived from the CVR sound spectrum analysis, and Equation [8].

The computed power for each engine is shown in Figure 10a of the Hover Study, duplicated here as Figure 1. The results of the torque computations, using the engine power and N_R shown in Figure 1 and Equation [8], are shown in Figure 2. The torques for each engine corresponding to an OAT of both 23° and 20° are shown as a function of time.

III. Crew callouts of torque and N_R as recorded on the CVR

Selected crew comments that were recorded on the CVR are shown in Figure 2 as text centered on vertical lines. The vertical lines intersect the time axis at the times corresponding to the initiation of each comment, as recorded on the CVR. The comments were selected based on their relevance to the conduct of the takeoff, and on the likelihood that the comment contained callouts of the first officer's readings of the torque and / or N_R gauges. The selected comments are also listed in Table 1. See Reference 3 for the complete CVR transcript.

Assuming that the following statements by the co-pilot refer to torque, these torque callouts coincide relatively closely with the computed values of torque shown in Figure 2:

19:41:02.90	INT-2	okay there's seventy five - there's eighty
19:41:06.40	INT-2	there's eighty five
19:41:10.50	INT-2	there's ninety …

At the time of the "there's ninety" callout, the computed torque is about 92% for engine "A" and 93.5% for engine "B",[4] using an OAT of 23° C, and about 1% higher than these values for an OAT of 20° C.

Assuming that the following statements by the co-pilot refer to N_R, these N_R callouts coincide within 1% with the values of N_R shown in Figure 2:

19:41:10.50	INT-2	… showin' ah hundred and three percent
19:41:18.80	INT-2	nope hundred percent Roark

Figure 3 shows the torque and N_R gauges on the S-61N. Note that the torque gauges are incremented at 5% intervals, and that the N_R gauge is incremented at 2% intervals.

The close correspondence between the computed torque values and the co-pilot's torque callouts recorded on the CVR indicates that the power developed by the engines during the accident takeoff matched the power expected based on the N_g values determined from the sound spectrum analysis, and the mathematical models of the engines' performance provided by GE.

E. CONCLUSIONS

This Addendum to the Hover Study presents calculations of the torque developed by the engines during the accident takeoff. The results are presented in Figure 2 as plots of N_R and torque vs. time, with relevant comments from the CVR indicated on the plots at positions corresponding to the times at which they were recorded.

The plots indicate that the torque and N_R callouts by the crew during the accident takeoff are consistent with the N_R values based on the CVR sound spectrum analysis, and with the torque calculations presented in this Addendum. This in turn indicates that the power developed by the engines during the accident takeoff matched the power expected based on the N_g values determined from the sound spectrum analysis, and the mathematical models of the engines' performance provided by GE.

John O'Callaghan
National Resource Specialist – Aircraft Performance
Office of Research and Engineering

[4] As noted in the Hover Study, while two independent sound signatures for each engine are identifiable on the CVR, it is not possible to identify which signature corresponds to which engine; hence, the N_g speeds (and engine powers, and torques) are associated with "Engine A" and "Engine B," instead of left or right engines, or #1 or #2 engines. Engine A could be either the left or the right engine, and so could Engine B.

F. REFERENCES

1. National Transportation Safety Board, Office of Research and Engineering, *Hover Study, Errata #1, Sikorsky S-61N, Weaverville, CA, August 5, 2008,* NTSB Accident Number LAX08PA259, (Washington, DC: NTSB, March 26, 2010). (Contact NTSB at pubinq@ntsb.gov).

2. National Transportation Safety Board, Office of Research and Engineering, *Sound Spectrum Study Cockpit Voice Recorder, Sikorsky S-61N, Weaverville, CA, August 5, 2008,* NTSB Accident Number LAX08PA259, (Washington, DC: NTSB, May 1, 2009). (Contact NTSB at pubinq@ntsb.gov). See also Errata to the *Sound Spectrum Study Cockpit Voice Recorder,* dated March 25, 2010.

3. National Transportation Safety Board, Office of Research and Engineering, *Cockpit Voice Recorder Group Chairman's Factual Report, Sikorsky S-61N, Weaverville, CA, August 5, 2008,* NTSB Accident Number LAX08PA259, (Washington, DC: NTSB, August 17, 2009). (Contact NTSB at pubinq@ntsb.gov).

TABLES

Time (PDT)	Source	Comment
19:40:31.40	INT-1	throttles comin up
19:40:42.90	INT-1	okay we're pulling pitch Jim
19:40:46.90	INT-1	pullin' pitch
19:41:02.90	INT-2	okay there's seventy five - there's eighty
19:41:06.40	INT-2	there's eighty five
19:41:10.50	INT-2	there's ninety showin' ah hundred and three percent
19:41:18.80	INT-2	nope hundred percent Roark
19:41:22.90	INT-2	no ah droopin' Roark

Table 1. Selected CVR comments. See Reference 3 for complete transcript. INT-1 = Flight crew intercom, voice identified as the pilot. INT-2 = Flight crew intercom, voice identified as the co-pilot.

FIGURES

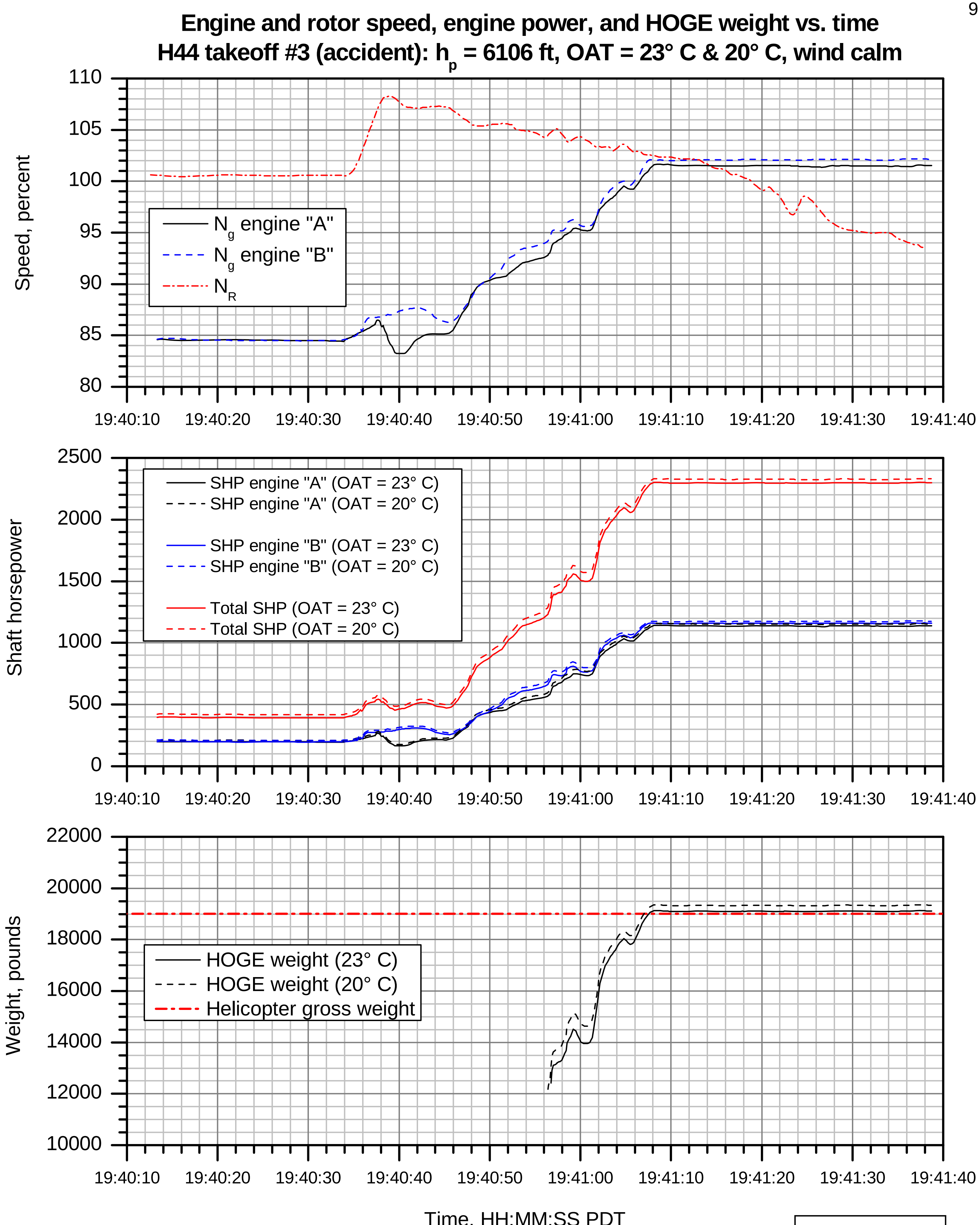
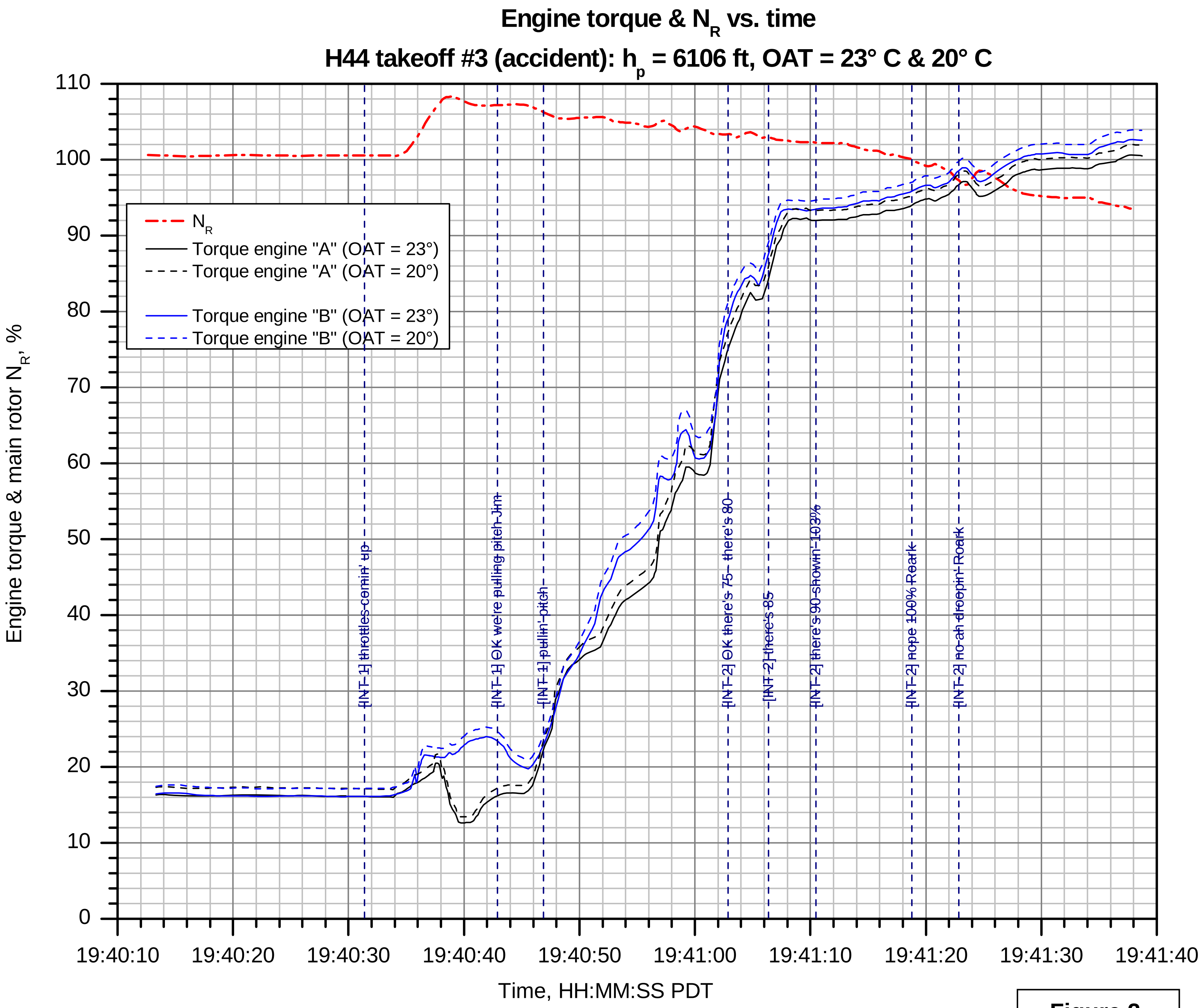

Engine and rotor speed, engine power, and HOGE weight vs. time
H44 takeoff #3 (accident): hp = 6106 ft, OAT = 23° C & 20° C, wind calm
Speed, percent
Ng engine "A"
Ng engine "B"
NR
Shaft horsepower
SHP engine "A" (OAT = 23° C)
SHP engine "A" (OAT = 20° C)
SHP engine "B" (OAT = 23° C)
SHP engine "B" (OAT = 20° C)
Total SHP (OAT = 23° C)
Total SHP (OAT = 20° C)
Weight, pounds
HOGE weight (23° C)
HOGE weight (20° C)
Helicopter gross weight
19:40:10
19:40:20
19:40:30
19:40:40
19:40:50
19:41:00
19:41:10
19:41:20
19:41:30
19:41:40
Time, HH:MM:SS PDT

Figure 1.



Engine torque & N_R vs. time
H44 takeoff #3 (accident): h_p = 6106 ft, OAT = 23° C & 20° C
Engine torque & main rotor N_R, %
Time, HH:MM:SS PDT
N_R
Torque engine "A" (OAT = 23°)
Torque engine "A" (OAT = 20°)
Torque engine "B" (OAT = 23°)
Torque engine "B" (OAT = 20°)
[INT-1] throttles comin' up
[INT-1] OK we're pulling pitch Jim
[INT-1] pullin' pitch
[INT-2] OK there's 75-- there's 80
[INT-2] there's 85
[INT-2] there's 90 showin' 103%
[INT-2] nope 100% Roark
[INT-2] no ah droopin' Roark
0
10
20
30
40
50
60
70
80
90
100
110
19:40:10
19:40:20
19:40:30
19:40:40
19:40:50
19:41:00
19:41:10
19:41:20
19:41:30
19:41:40

Figure 2.

S-61N torque gauge.

S-61N main rotor speed gauge.

Figure 3.