NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

April 26, 2017

Interview Summaries

OPERATIONS / HUMAN PERFORMANCE

DCA16FA199

Contents

A. INTERVIEW SUMMARIES

1.0 Initial On-Scene Bell Helicopter Interviews

1.1 Interviewee: B.J. Thomas, Aerodynamics Handling Qualities Engineer
Represented by: (waived)
Date: July 8, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 1158 CDT
Present: Van McKenny – NTSB; Jon Johnson – FAA; James Harris, Troy Caudill – Bell

During the interview, Mr. Thomas stated the following:

Mr. Thomas works on the Bell 525 as an aerodynamics handling qualities specialist. He has been employed by Bell for over 10 years. He has been with the Bell 525 flight test team for 6 months, but has been involved for the last 10 months. He does not have a pilot certificate, and no flying experience.

Mr. Thomas proceeded to describe the events of July 6 starting with the test team briefing. During the preflight briefing, they went through recent maintenance, the test card. The helicopter was configured in the heavy forward CG configuration. GE (engines) loads data was to be gathered at 0.9Vh at 4,000 feet density altitude (HD), then angle of bank turns up to 60° in a buildup fashion, side slip up to ±10° max. Simulated engine failures were tested to expand the envelope, and explore that portion of the envelope. They were 2-to-1 failures, going from twin engine operation to single, in level flight, from 70% max cruise speed out max cruise speed. OEI testing was followed by expanding out to Vne airspeeds by using a descent to achieve max air speed, out to the target airspeed of 185 kts true (TAS). Just after the brief, he discussed with the pilots, the required delay times after the engine out event. The certification requirements stipulate that the greater of one second or normal pilot reaction delay before reacting to the condition. Due to the nature of the aircraft having the augmentation system that it does, the delay time up to Vh they should be doing the delay on all controls. Typically delay time is for collective only, but if there is a lot of stability in the aircraft the AC actually stipulates that consideration should be given to performing the delay on multiple controls. The pilot did not have any concerns about the delay on all controls up to Vh, but beyond the Vh point the delay would be on collective only.

After the briefing, there was a weather hold due to low ceilings.

Once the weather had improved they went to the TM Room (telemetry room). Mr. Thomas set up his computer to the configuration he desired for this test, specifically viewing delay times, states of control laws where he could see it was deflecting to a certain value indicating the pilot was on the stick out of the detent or if he was on the FTR (force trim release) button. He could determine from those data points when the pilot comes on the controls after the simulated engine failure.

On start-up, the tail rotor balance looked good. There had been some tail rotor harness work done prior to flight. Right after takeoff the pilot noted that the aircraft was AUG ON, meaning to inner loop and outer loop of the control laws were engaged. When approaching the higher speeds, they have seen some low-grade pitch oscillations in the aircraft due to the system "hunting" in the hold mode, attempting to hold a certain altitude.

After takeoff, they established a Vh point for the loads data, 148 kts. The crew performed the side slips first. Airspeed did drop off a bit, so they repeated the right sideslip. Angle of bank turns were next, building up from 45° to 60°. These points were established using Vh of 100% torque, where normally the aircraft is set up such that 90% engine torque is considered 100% maximum continuous power (MCP). The net effect is that the Vh is a higher value than at the lower 90% power setting. They performed angle of bank (AOB) turns at 0.9Vh.

After the AOB turns they set up for the simulated engine failures. To simulate the engine failures, they go into OEI (one engine inoperative) training mode. In order to set the training mode power, the helicopter establishes Vy, and power is "beeped" in based on a calculation done real-time based on pressure altitude test conditions, which was determined to be [redacted] shp[1], and the pilots "beeped" that value in to training mode, and then exit training mode. That power will be what is provided as the set OEI power at 103% Nr. Vh point was established at 90% power MCP[2].

The first OEI point was 102 kts boom CAS[3]. The copilot would it the OEI engage button for training, then fly to a stabilized OEI condition, and then exit training. This was performed at 102 kts, 131 kts, and again at Vh. All through those points the pilot was holding the FTR button on both collective and cyclic, which was their prerogative. Pilots sometimes hold in the FTR while flying to provide a steadier point. Next was the first build up point to Vne targeting 155 kts TAS, the Vh point was 145 kts. The pilot stated that he was going to do the first point with very little delay, and that's what was observed, about 0.5 second delay by looking at the stick position and actuator command. During that point, Nr drooped to 94%.

He was asked at what value of Nr would he call "knock-it-off?" He stated that the lower Nr limit was 86% for this flight and Mid 90% was something that was expected.

The pilot repeated the 155 kt point in order to get a longer delay, however the delay was 0.5 sec and that info was relayed to the crew. The 155 kt point was repeated in record 47, which the delay time met the requirement (he did not record the time) and Nr drooped to 90%. Delay times were for collective only. Proceeded to 165 kt point, delay was 1.3 seconds, Nr droop was 90%.

Record 48 was a void record - the pilot had probably double tapped the button, starting & stopping the record inadvertently.

He was asked about the "air quality" note that was hand written on his test card notes. He stated that note was referring to the set up for the 175 kt point. Pilots were working to get on condition in the descent. There was a "knock-it-off" call because pitch link loads were near or at warning.

[1] Shaft horse power
[2] Maximum continuous power
[3] Calibrated airspeed

So the crew did not actually initiate the engine failure for that run. The pilot stated that he had hit a thermal and saw a slight torque spike and had corrected for it in the descent. The TM Team concluded that was likely the cause of the high loads that they saw. Pilot stated that air quality was pretty "bumpy" or "rough" then said "moderate at best." The setup for the 175 kt point was recorded as "Record 49 - courtesy record."

The TM Team reviewed the 165 kt data point and determined that it had actually been performed at 168 kts TAS, and that the next reasonable step was to move to the 175 kt point. The 175 kt point was performed and the delay time was 1.1 seconds, Nr droop was 90%.

He was asked about a hand-written note about a comment from rotor dynamics - "looked like rotor stall." Mr. Thomas stated that discussion occurred during the courtesy record when they were discussing continuing to the 175 kt point. Rotor dynamics had stated that they had the margin to proceed as long as the air wasn't too bumpy. Some things had gotten to warning. They had seen this before and it wasn't unexpected. There is a region where things onset before it develops into a full stall (retreating blade stall). "Alerts" are higher than "Warnings" and typically Warnings are set about 20% Alert level. Rotor stall on-set is usually indicated by a slight vibration.

Record 51 was targeting Vne, 185 kts. He was fixated on Nr, it looked typical to the other maneuvers. The Nr may have gone level or even come up some, but then dropped rather suddenly. From there he couldn't understand if he was seeing the right thing. He had his Nr scales set between 80% and 120%. He did see it go off the scale, and he heard a "knock-it-off" call. He recalls seeing a digital number of 76%, but by that time he had heard two "knock-it-off" calls. There were two transmissions, one from chase and the other from the test ship. Chase reported "we've had a major accident." From the test ship, he heard "I have the controls", he thought it could have been Boyce's voice. Boyce was in the right seat and Grogan in the left.

When in OEI training mode, the right-side cockpit display is a student display of the simulated parameters for the pilot, and on the left cockpit displayed real aircraft parameters.

Mr. Thomas does not recall who initiated the "knock-it-off" call but it was not himself.

Throughout the test, everything appeared normal. Even the beginning of the 185 kt test looked normal until the Nr dropped off.

He was asked if this was the first test in this CG configuration, and he replied that it was. He recalled that they had done this test at mid gross weight and mid CG, and light gross weight and aft CG. This was the first time for heavy and forward CG. He was in the TM room for the midpoint test, he was not in the TM room for the light aft testing. The light aft testing was performed at 4,000 feet, 8,000 feet, and 12,000 feet all with a build up to 185 kts.

He was asked if he viewed the engine trim files. He responded that they briefed them as being version PJ for this flight. He could not recall seeing that on the configuration list.

He was asked about notes on record 38, that there was a 5,000 foot per minute rate of descent at 59° angle of bank. He responded that it was a bit higher than expected but they had seen numbers like that but it was something that looked odd to him.

He was asked how his IADS[4] station was set up. He had airspeed (IAS) for all 3 air data computers (ADC) and boom system CAS, TAS[5] from ADC's, rate of climb (boom and ship system), total engine torque (%), pressure altitudes (boom and ship systems), total engine power (shp), OEI training parameter what was set by the pilots ([redacted] shp @ 103% Nr) and gets scaled with turbine efficiencies.

[4] Interactive analysis display system
[5] True airspeed

1.2 Interviewee: Nick Flores, Test Director
Represented by: (waived)
Date: July 8, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 1730 CDT
Present: Van McKenny – NTSB; Jon Johnson – FAA; James Harris, Troy Caudill – Bell

During the interview, Mr. Flores stated the following:

Mr. Flores is a flight test engineer as the test director. He communicates with the pilots and is responsible for the conduct of the test. He is the lead flight test engineer for Aircraft 1. He's been employed by Bell for the last 6.5 years, and has his private pilot license with about 70 hours of flight time.

Mr. Flores proceeded to describe the events of July 6. The briefing started at 06:45, where they went through the briefing package, which included GE loads and vibe test, briefed engine failure test, lateral roll oscillation test, and some run-on landings. They reviewed the previous test flight, briefed any squawks that came out of that test. Briefed maintenance, any configuration changes, instrumentation, weight and balance information, limits, and any hazards.

He was asked to describe what hazards were briefed. A typical limit that was briefed was the APU[6] on, APU generator on, an awareness of sideslip at higher airspeeds, limits regarding Ng, Nt, Nr, & Ngt. New awareness items on flight controls, & control laws. The two hazards that were briefed were rotor drooping below safe controllability speed and use of OEI training, and a sudden increase in power available that could lead to over torques, over speeds, & over temps. They mentioned weather, but the weather information in the briefing package was actually for the day before (July 5), they briefed the latest METAR/TAF. They briefed the radio frequency that will be used, and the chase aircraft and crew. They talked about having maintenance look at tire tread after some of the tests. Then they went through the test card. He made a few red lines on line 50, 54, 62, 68 to correct for different power settings. There were altitude changes on line 106 & 108 change 12,000 to 8,000 HD. Redlined 128 and 130, instead of 4,000 they needed to be at 12,000. Redlines for engine failures to show which controls were to be delayed and which were not (lines 82, 84, 104, 106, 126, 128). The 8,000 foot points were not going to be required. Briefed a couple of buildup run on landings at 30 kts and 40 kts. Nothing seemed unusual about the crew's demeanor, the crew didn’t have any questions or concerns about this flight.

The test was on hold for weather. The pilots were watching the weather, and they'd let the team know when the weather was good. Mr. Flores went back to his desk to work on the next day’s test card. Around 10:00 pilots informed him that weather was good enough to go.

The aircraft departed and proceeded to the test area. The crew performed a R3 (R-cubed, repeatable, reliable, record) enroute. The crew noted that the air quality was a little bumpy. They proceeded on to the GE loads Vh point, at 100%. A couple of Warnings were VF1655, 02BC14, 30FA11, 30FS02, transient in nature. No Alerts were displayed. A low-grade porpoise (referred

[6] Auxiliary power unit

as a "Bothwell" by the team) was also evident, which is currently a side effect of the outer loop control laws, and is experienced as a 3-4 kt variation. The porpoise tends to go away when the pilots use the FTR.

The helicopter climbed to 5,000 feet to see if there was smoother air, but it was at the base of the clouds and deemed unusable. Left and right sideslips were performed. Max angle of bank turns were performed. All of these maneuvers were performed at 4,000 HD[7].

They proceeded into engine failures in OEI training mode.

The question was asked about a hand-written notation on his test card about "lots of alerts." Mr. Flores stated that these Alerts were not actually Alerts because they didn't meet the duration criteria to qualify it as a legitimate Alert even though the actual parameter value had met or exceeded the Alert value. Also, a lower value can be set and a certain amount of time above this lower value can trigger an Alert. Although the Alerts were being displayed on his monitor, he did not consider the Alerts valid, because they had hit a vibratory limit but did not exceed a vibratory Alert. The pilots do not see any of these Alerts. The telemetry team was not concerned and were comfortable proceeding with the tests.

They proceeded with the engine failures and set the shaft horsepower while the aircraft maneuvered to Vy. They got another Vh point at a lower total torque value (90%), 145 CAS. First OEI at 0.7Vh, delay was good, then 0.9Vh, delay was good, continued building out in airspeed to Vh (90% torque) where the Nr drooped to 86.9%. This Nr droop wasn't unexpected, delay time might have been longer than desired. They proceeded to 155 TAS, and did this one three times, building up delay times. He noted a 30FS02 oscillatory limit exceedance. The discussion within the control room was that on the third 155 kt point the delay time was met or exceeded and there was sufficient margin to continue the tests. They proceeded to the 165 TAS point, and the delay time was greater than 1 sec. The control room discussed the VF1655 Alert, 11FA41 Warning, and 10BB12 Warning limits, and determined that there was enough margin to continue to the next test point. In the set up for 175 TAS point he made a call to the crew to discontinue the entry because they saw loads coming up and he didn't want to enter the maneuver that way. Main rotor pitch link and pylon loads were touching Warnings. Record 49 was entered as a courtesy record. There was discussion in the control room about the higher loads as well as communication with the crew. It was concluded that the higher loads were a result of air quality. They decided to repeat the point, but not to initiate the maneuver if they were in bumpy air. They performed that point, record 50, and no limits were observed. Control room discussion concluded that there was enough margin to continue to the Vne point. He relayed to the pilots to not enter the maneuver if the air quality was poor.

The aircrew set up for the Vne point. Mr. Flores did not have any additional notations on his test card for the Vne point. He recalls that the crew was established on condition, airspeed was 185 TAS, focused on Nr, once OEI was engaged, Nr drooped to 95% and stabilized, someone called "knock-it-off, knock-it-off." He relayed the "knock-it-off" call to the crew, and received no response. The chase aircraft radioed "we've had a major accident, aircraft going down." He

[7] Density altitude

initiated the flight incident/mishap checklist and went through the checklist noting times tasks were completed. He did not recall who made the initial "knock-it-off" call.

Leading up to the last setup, he had airspeed and Nr on his display, and was monitoring. He was calling out airspeed to the control room as the aircraft hit each airspeed, "155, 165, 175, 185…."

He was asked if he was the test director for either of the other two OEI tests? He was test director for the initial mid-mid OEI test. KC was test director for the light-aft OEI test.

He was asked if he'd been test director for this crew before? He said the he had been test director for each of the pilots but could not recall without going into the database to see if he'd worked with this combination of pilot/copilot. He said that this crew's performance and ability to achieve their test points was consistent with other crews he's work with.

1.3 Interviewee: Prateek Sharma, Mechanical Analysis Engineer
Represented by: (waived)
Date: July 9, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 0830 CST
Present: Van McKenny – NTSB; Jon Johnson – FAA; James Harris, Troy Caudill – Bell

During the interview, Mr. Sharma stated the following:

Mr. Sharma stated that he's been with Bell for 5 years, mechanical analysis and flight test support engineer. He has been with the Bell 525 Test Team since February 2016. He holds a private pilot license, with about 100 hours.

Mr. Sharma proceeded to describe the events of July 6. They had a 06:30 brief. The flight before that occurred on Friday, and some instrumentation catch up that needed to be done had been completed on Wednesday. They were briefing for the flight which was GE Loads and engine failures. Nick Flores was the Test Director and he went through the briefing packet, reviewed the CG, test cards and test points. Did the instrumentation review. They discussed an Alert exceedance that occurred on the previous flight regarding the horizontal stabilizer, which required no action. The horizontal stabilizer exceedance was related to the 02BC14 parameter that measures chord bending that experienced a 12% exceedance during cyclic stir test (exceeded the Alert value by 12%) airspeed was 1.7Vh at the time. Airframes stress group's disposition was that no further action was required because this exceedance had been placed in secondary status. The primary indication of an exceedance should be taken from the envelope plot. Some tail rotor green blade instrument work had been done.

There was a short weather delay. He got the "go" text for test 184.

Proceeded with the normal startup sequence and transitioned out to the test area. They established Vh at 148 boom CAS. Right pedal and left pedal side slips, at 100% engine torque, 4,000 density altitude (HD). Proceeded into the level max angle of bank turns, 45°, 55°, then max usually around 60°.

Next were the simulated engine failures. Set the shaft horsepower of [redacted] into the OEI training mode. Proceeded level flight at Vh at 90% engine torque. Started the 2-1 engine fails, 0.7Vh, 0.9Vh, Vh at MCP. Then they proceeded to the Vne build up points, started with 155 TAS at 4,000 ft, 165 TAS, and 175 TAS. During the 175 kt engine chop point they had to take two records. The first time, pilots got set up on condition at 175 kts but the flight crew had called "knock-it-off" because they hit a thermal. The second attempt at 175 kt engine chop went as planned. At this point, a few Warnings showed up on his screen, primarily on the rotor system, main rotor lead/lag damper loads, blade bending warnings, and green pitch link on the main rotor had a Warning (30FA10, 30FA11, 30FA12, 30BB5, 11FA61, 11FA41). On the tail rotor, the green pitch link (11FA62) was over Warning. During the buildup, he was looking at the worst performing parameters and doing step calculations to see how far away they were from Alert. The primary concern was the lead/lag damper loads and pitch link loads. After each point, he was in communications with the Test Director to review the numbers to see if there was enough margin to perform the next test point. At the 175 kt test point they took a slightly longer time to get ready for the final Vne point. The Test Director had explicit discussion with the flight crew to call "knock-it-off" if anything unsafe occurred. Pilots got set up on condition and hit the button (OEI training mode). Shortly afterwards many Alerts had popped and almost simultaneously he called "knock-it-off" with Matt Hendricks. The Test Director notified the crew to "knock-it-off" but got no response. The last notification he heard was "we've had a major accident, aircraft is going down." A second or two after he received all the Alerts he lost telemetry.

Test Director initiated the incident/mishap protocol, secured the TM room and wrote down observations in a journal entry. All data was secured.The question was asked about the discussion in the control room after the 175 kt test if any one of the team members expressed reservations about continuing the test. Mr. Sharma said that he did not observe anything specific, everyone was doing due diligence. There was nothing out of the ordinary. All parameters that did show exceedances, were expected.

The question was asked how he determined the worst load parameters? He said that some loads were inching closest to the Alerts and his primary concern was the lead/lag dampers and the pitch link loads on the main rotor (30FA's and 11FA's). Using the peaks from the 175 kt test, he did step calculations taking a percentage off the Alert value to determine the available margins. They would be close to Alerts. The load trends from 155 thru 175 were linear in nature, and he determined for example on the lead/lag damper loads that he had 14% margin before the Alert limit was reached. Alert loads, if reached, would require the aircraft to return to base for inspection. Alert loads are not the engineering ultimate loads, but are prudent stopping points.

He was asked if he felt he had enough time to do his calculations and if he felt pressure to proceed with the test. He stated that he did not feel pressured to proceed with the test, and he had time to all his calculations.

He was asked about the atmosphere in the control room, and if there was any resistance to speak out? The control room was very calm, and sterile. Anyone is free to discuss anything, it is a very open atmosphere. Anyone can call "knock-it-off", there is no retribution for calling "knock-it-off."

He was asked if the loads he observed were highest at the initiation of OEI or at low Nr? Peak loads occur in the torque transient, during initiation of OEI.

He was not involved in either of other two OEI test flights.

He was asked what area he'd look at if he could? He stated that historically the parameters that end up initiating a RTB has been typically tail boom parameters. Those parameters have been expanded recently, and it is interesting that none of those warning were being tripped. Recent tail boom strengthening and pull tests on the structure has resulted in new numbers for expanded Warnings. Aircraft modification occurred in June (2016).

He was asked if he felt he was adequately trained to do this job in the TM room. He responded that he felt very comfortable, and has no hesitation in working in the TM room. He felt trained and qualified. His training mostly consisted of shadowing an experienced test engineer and performing on-job-training (OJT). The OJT is individually tailored, but usually lasts a number of months before they sit a console alone.

He was asked if there was any simulator or scenario training for the TM engineers? They do review previous test flights, but there is no simulation or scenario training per-se.

1.4 Interviewee: Matt Hendricks, Structural Dynamics Engineer
Represented by: (waived)
Date: July 9, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 1000 CST
Present: Van McKenny – NTSB; Jon Johnson – FAA; James Harris, Troy Caudill – Bell

During the interview, Mr. Hendricks stated the following:

Mr. Hendricks is a Structural Dynamics Engineer and has worked for Bell Helicopters for the last 8 years. He has been in flight test for 1 year, and the Bell 525 is the first program he has worked on. He is not a pilot. His primary duties in the telemetry room are to monitor engine vibrations, main rotor and tail rotor balance, torsional stability, and to understand the vibration environment of the helicopter.

Mr. Hendricks proceeded to discuss the events from July 6. During the preflight briefing, they went over the GE Loads plan, which was his main focus on this test flight. The OEI training were also presented. He was mainly monitoring the torsional stability and clutch/declutching of the rotor at different speeds, engine to drive system. Monitoring the damping response for those points. He stated that he was not expert on the OEI testing or OEI training mode and what the goals of the test were, however, he was monitoring the engine performance & interface with the main rotor gear box. In the previous test a wire harness had come loose and that was discussed during the briefing. The wire harness from the tail rotor green blade was the harness in question, and they were satisfied that for this flight test the problem was sufficiently resolved. They reviewed the test risks. There is a standard review of the rotor speed risks and mitigations when performing the OEI tests. Control laws gain parameters had been set incorrectly, high speed side slip was an issue, and became an awareness item for the crew.

During the startup, rotor dynamics noted something odd going on with the green damper (tail rotor). Discussed if that was indicative of a wire harness failure. One of the maintainers went out and spot checked the rotor while it was turning, and nothing unusual was noted. Anytime the tail rotor had work done on it he is especially cognizant of tail rotor dynamics and monitor the balance on the radial tail rotor gearbox accelerometer. Last time it was 0.3 ips[8] at 103% rpm. At single engine idle it looked ok, at 2 engine idle it looked ok, and at flight idle it was consistent with signatures observed before the tail rotor area had been worked on, so he was comfortable with the data. Main rotor balance was good, no issues with that. Both the main rotor and tail rotor vibrations should be below 0.5 ips.

During takeoff, hover, and transit nothing was noted.

Once in the test area, Vh was established. Vh was at 100% takeoff power. Steady heading side slips (right pedal) at 0.9 Vh was performed, right side slip (left pedal), repeated left side slip. The last set of points for the GE Loads was max angle of bank turns, wings level-45°-wings level left turn was good, level - 58° - level left turn was good. One of the engine accelerometers (VF1655)

[8] Inches per second

went over the Alert limit but it was less than 5 seconds. The VF1655 is located on the right engine, right hand side, fore-aft accelerometer. That vibe is typically due to a 5 per rev from the main rotor. There is an engine fore-aft mode around 28 Hz, where as the main rotor 5 per rev is around 21.3 Hz. The engine fore-aft response can increase due to airframe modes. This has been seen before with different pylon down stops where the engine fore-aft vibes would increase, which were attributed to fuselage second vertical bending mode that would get excited. Normally engine fore-aft vibration limits are the first ones to trip because they are so low 2.5 ips, where the other engine accelerometers limits are at 5 ips. GE limits are set up in such a way as it is acceptable to exceed that steady limit as long as it is less than 5 seconds and doesn't go up to some max transient allowable. For the fore-aft accelerometers the transient max allowable is 5 ips. What was seen was less than 5 seconds and less than 5 ips. Moved on to the right turns angle of bank, 45°, 55°, followed by a telemetry momentary drop out. Once telemetry was regained, the aircraft was recovering from 60° angle of bank turn, which is where the engine vibrations are the worst, they were over some limits on the engine vibes but they were less than 5 seconds and below the transient allowable. Nothing odd in the data was observed.

They then moved on to the OEI training. Shaft horsepower was set to [redacted] at Vy. Went to Vh at MCP 90% torque (3 knots slower than 100% torque). First one was done at 0.7Vh, 0.9Vh, and at Vh, nothing noted. At 155 kt TAS, response time was 0.5 seconds, and was repeated 2 more times. At one point Nr drooped to 87%. Below 86% is an RTB[9]. This brought the awareness of Nr to the forefront. Next point was record 48, 165 kts TAS. Courtesy record was taken, pilots reported "air quality moderate at best." 175 kt TAS, nothing noted. Went out to Vne, 185 kts TAS. For each of these points, he is switching between the torsional stability page and the engine vibration page. There was a torque oscillation during the event, he paused the time and went into the IADS screen to check the damping of the system. Then switch to engine vibes. Typically for these points he saw a very momentary increase in engine vibrations, but nothing sustained. He was watching the tail rotor balance which remained normal. He also was monitoring tail rotor drive shaft misalignments and it appeared normal.

On record 51 he was looking at torsional stability which looked ok, then looked at the engine page and noticed increased vibrations. The engine data looked abnormal, it went over the Alert limit and he called "knock-it-off." Nick Flores called to the aircraft to "knock-it-off." On his IADS screen all the vibration readings were "blowing up." Chase radioed that a major event had occurred. They then lost the telemetry signal.

He was asked that when the crew went to OEI if he recalled the engine response on Record 51? He stated that he did not because he was flipping back and forth on his screens, and he has no reference as to when the crew enters OEI mode. He was watching the torsional stability page when the OEI was executed.

He was asked about the discussion in the control room after the 175 kt test point. Mr. Hendricks stated that someone had seen something odd in the rotor system. There was some discussion whether to continue or back off. The conclusion was that the bumpy air was the issue during the set up.

[9] Return to base

He said he had never felt pressure to proceed when he had concerns. There was no perceived pressure to get the points done.

He was asked if he felt if wad adequately trained. He said that he felt confident and was interpreting the data the way he was supposed to. Most of his training was done via OJT/shadowing. OJT look several months to complete.

He said he'd really like to take a look at the crew accel's, the rotor stuff, & Nr droop data.

1.5 Interviewee: Thomas Jeffrey Newman, Rotor Dynamics Engineer
Represented by: (waived)
Date: July 9, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 1100 CST
Present: Van McKenny – NTSB; Jon Johnson – FAA; James Harris, Troy Caudill – Bell

Mr. Newman has been employed at Bell Helicopter for 23 years. He works as an Engineering Flight Test Unit Member. He has been working flight test since 2007. Other programs he has work on are AFLEX, QARTR, 214ST Demo, wind tunnel 0.2 scale V-22, and 412 testing. His role on the 525 program is rotor dynamics which involves stability of the rotor system, motions, aero-servo elastic stability (interaction of the control laws with structure).

Mr. Newman proceeded to state that they came in at 06:30 for the brief. The brief was typical, addressing safety related items, configuration, instrumentation, and talked through the test points. The aircrew had no concerns or questions relating to his area. The aircrew did state that they had performed these tests in the RASIL[10] (engineering simulator). After the briefing, he returned to his desk until he was called for test, sometime around 10:00.

The aircraft was started, and there were two gauges that have alternative data sources. One was the tail rotor green damper (87DA12) reading zero. In this case, there are 3 other sources of the same information (the other tail rotor dampers). The other was 35FA12, green damper axial load was on "band edge" showing a flat value. The startup sequence up to arrival to the test area was uneventful. They set up at 4,000 feet, performed side slips, then performed maneuvers at 0.9Vh (132kt CAS) turns at different bank angles. Was observing the main rotor damper temperature, noting the temperature rise; this was information he intended to use in future hot weather testing. On Record 38, at the highest angle of bank turns, he noted that the main rotor pitch link loads and actuator loads reached Warning level, which was typical. It was an indication that they were reaching the performance limits of the rotor. He wasn't sure which main rotor pitch links were instrumented, but he was pretty sure the red and green pitch links were. He uses stability and motions. He does use pitch link and damper loads as a secondary data source. Other engineers are monitoring those items for limits.

The one engine maneuver was next. The pilots set up on condition and then push a button (OEI training mode) to simulate that one engine is not working. This usually drops the engine power going to the rotors, rpm will drop off and increase back to the normal operating rpm. All the blades will move in a leading direction all together in response to the reduction in power, after which the blades come to stabilized point. Depending on what rpm the rotor is at, it can affect the loads, the motions in the rotor, effect stability. There was nothing unusual in any of these maneuvers.

When they reached Record 50, 175 kt point, he saw high pitch link and actuator loads, indicating that they were at the performance limit of the rotor. They were at the Warning level but not over the Warning level. There was a discussion within the telemetry room about moving on to the Vne

[10] Relentless Advanced Systems Integration Lab

point. There was no indication that there was an issue, and the test team agreed to proceed with the test.

They set up for the flight condition for Record 51, 4,000 feet density altitude, 185 kts TAS. He looked at the control loads data, stability and motions appeared normal. The pilots initiated OEI training, power came off, rpm dropped down. Everything looked normal. It wasn't until later in to the record that things seemed to be different. What he saw after several seconds into the record was the damper motion on the main rotor showed more amplitude than he had seen before, the frequency of the lead/lag motion had become larger than he had seen before. He was just about to call "knock-it-off" when the guy beside him called "knock-it-off" for what he was seeing. The pilots got through the OEI maneuver and were in the recovery portion of the maneuver when the unusual motion of the lead/lag damper occurred. Telemetry data stopped a few seconds after that. He noticed that mast torque had gotten to very high oscillatory levels. Tail boom bending in the vertical direction moment was very large. The (Nr) rpm had dipped down as normal, began to climb up, but then went down again. Matt Hendricks had called the "knock-it-off" first.

He was asked if there had been any pressure in the control room to continue the test? Mr. Newman said that pausing to consider the data before proceeding was a very common occurrence. This was done per the normal procedures by the Test Director. No one appeared uncomfortable with the decision to proceed with the Vne test point.

The chase aircraft radioed that "we've had a major accident." He thought he heard chase come back on and one pilot say to the other pilot "take the controls." He wasn't certain it was the chase, it might have been the 525.

In an overall statement, it looked like everything was normal until all of a sudden it wasn't normal.

He was asked what data he would like to look at at this time? He stated that he'd like to look at displacements, damper loads, divergent signatures, look at main rotor phasing, shear and torque in the mast.

He said he felt fully trained and qualified to be at his station. He felt no pressure to continue on, and he is confident that he would have called off the test if he felt it was not safe to proceed.

He said that the helicopter had been at this flight condition before. The thing that was different during this event was the OEI training at that condition. Turbulence probably had an influence in the loads that they were seeing, but it wasn't at an inappropriate level. Gusts can affect the response to the rotor, damping is what damps out the response. He didn't see any issues with the weather conditions during the test.

The have tested for degraded dampers, where its damping capability was very low, and they found no issues in that condition, but they also were not done at these airspeeds.

He was asked what could cause one of the blades to suddenly be flying out of plane? Mr. Newman said that when the Nr is low, behavior of the rotor is unpredictable. If a pitch link failed he expected it to go flat and not out of track, but that would be something to investigate in that case. The biggest contributor is rpm, he would expect a lot of motion in the out of plane position. Anything below 86% rpm would be dangerously low.

1.6 Interviewee: Nicholas Cooper, Data Reduction
Represented by: (waived)
Date: July 9, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 1300 CST
Present: Van McKenny – NTSB; Jon Johnson – FAA; James Harris, Troy Caudill – Bell

During the interview, Mr. Cooper stated the following:

Mr. Cooper has been employed by Bell Helicopters for 10 years, he is a data reduction engineer, and has been part of the 525 test team since the fall of 2014. His primary duties are to prepare the telemetry room for the test, and monitor aircraft limits. He checks and monitors all limits on the aircraft and calls out if any limits are exceeded. He has worked on the following test programs: 412 EPI, OH-58D upgrade, ARH, H-1, Eagle Eye UAV, & Fire Scout. He has 12 years of test experience.

Mr. Cooper proceeded to recall the events of July 6. The briefing was normal and he did not recall any specific topics that were discussed. After the briefing, he went upstairs to set up the TM room, and then waited for weather conditions to improve.

He then moved on to describe the test flight. He said that everything was normal during start up and transit to the test area. Winds at the airport were gusty, tower called out the wind as 200 at 13 gusting to 23 kts. Once in the test area the aircraft performed side slips and turns. There was nothing unusual about those events. They started doing the single engine throttle chops at a lower speed, 0.7Vh and slowly increased speed. One of the points had a longer delay than necessary. Once at the higher speeds the pilot was reacting more quickly, and then build up to the longer delay. They set up for the OEI throttle chops, and one test point had to be called off because there were a few Warnings during set up. The pilot indicated it was getting choppy (turbulence). There was discussion in the telemetry room whether to proceed and the decision was made to continue and to have the pilots knock-it-off if they encountered thermals. During the actual maneuvers there were no Alerts, there were some Warnings for engine vibrations. There were some oscillatory Warnings on the main rotor. The Warnings that were being seen were due to the being in a dive and air being choppy, not really related to the test point.

On Record 50 there were some Warnings. Engine vibes have time limits and those had not been exceeded. No one in the telemetry room was uncomfortable with the decision to proceed, and that the margins were available. Jeff Newman asked if they've done these before (Vne at forward CG) and Nick Flores answered "yes."

On Record 51, everything seemed the same. He refreshes his screen that shows the Warnings and Alerts (for all system parameters) every few seconds. His screen went from normal readings to a flow of Warnings and Alters after his last refresh. Engine vibe warnings covered the whole screen. He could not tell which Warning or Alert came first. He could see on Matt's (Matt Hendricks - engines) that he had vibes reading that covered the whole screen. Matt said "knock-it-off" and then Nick called it to the crew. After a few seconds, he heard a radio call "I'm on the controls, something happened, aircraft going down" (possibly Erik Boyce's voice). Then the telemetry link was lost. Tower called out the last known radar location.

Mr. Cooper said that he did not perceive any pressure to complete this test. They were at the bottom of the fuel band, so the aircraft would need to return to base and refuel before the 12,000 foot tests could be performed.

He felt that he is well trained and was prepared for this test. He had an engineer shadowing him for this test. It usually takes a few weeks of OJT before someone was allowed to sit at his console. It depends on how quickly someone learns to use the limits monitoring tool. The station that the engineers use is CAFTA (computer aided flight test analysis tool) and IADS. His screen only shows exceedances (Warnings or Alerts). If there are no exceedances then his screen will remain blank.

The majority of the Warning/Alerts that he has seen during past flight tests are oscillatory and engine vibrations.

1.7 Interviewee: David Adjei, Flight Controls Engineer
Represented by: (waived)
Date: July 9, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 1400 CST
Present: Van McKenny – NTSB; Jon Johnson – FAA; James Harris, Troy Caudill – Bell

During the interview, Mr. Adjei stated the following:

Mr. Adjei stated that he has been employed by Bell Helicopters for 13 to 14 years. He is a flight controls engineer and has been working in flight controls the entire time. He has been involved with the 525 for the last 2 years. He has worked in test for the last 10 years, and he worked on the 609 program.

His duties during the flight is to monitor all the FCC (flight control computer) data; actuators, AHR sensors[11], NVM[12] data, fault data from the flight. His primary job in the TM is to monitor the health of the flight control system. He does not have to sign off anything for the preflight, but does squawk resolution post flight.

The briefing for July 6 was at 0630. They went through the test cards and then there was a weather delay.

He went to the telemetry room about 10:00. The startup was normal, the preflight BIT [13]check was normal, and the helicopter proceeded to the test area. They started going through the maneuvers, side slips, and turns. Proceeded to throttle chops at increasing speed. On the last one everything was looking fine, then it wasn't, then they got the call that the aircraft was going down. When he heard "knock-it-off" he saw the AHRS 3 (attitude heading reference system) fault and SFD (standby flight display) fault. AHRS faults are mostly due to comparison failure between the 3 computers. The SFD usually fails at 1.5g's or during high vibes.

His screen displayed parameters (Warnings/Alerts) that he was monitoring on the left side. On the right screen, he had strip charts showing control stick positions, actuator positions, airspeed, bank angles. The screen on the left is the main screen he watches. After the event, he started scrolling through the tabs on the right screen just to review the data up to the point where the telemetry data was lost.

He'd like to look at the sets of AHRS data bits in the accident data to see where the data diverges.

After every test point they would stop and discuss the data to see if they had the margin to proceed. This was a pretty standard procedure after each point and he did not recall any specific discussion about not going to the next test point.

---

[11] Attitude heading reference sensor
[12] Nonvolatile memory
[13] Buit in test

1.8 Mr. Adjei felt really comfortable in his training and preparation for this work. He would be very comfortable in making a knock-it-off call if there was any CAS (crew alert system) message, AHRS-3 fault, or actuator fault.Interviewee: Barbara J. Lewis, Chase Aircraft Pilot and Patrick J. Twomey, Chase Aircraft Co-pilot
Represented by: (waived)
Date: July 11, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 0730 CST
Present: Van McKenny – NTSB; Jon Johnson – FAA; James Harris, Troy Caudill – Bell

During the interview, Ms. Lewis and Mr. Twomey stated the following:

Ms. Lewis and Mr. Twomey were the pilots in the chase aircraft, a Bell 429.

Ms. Lewis has been employed by Bell Helicopters for 10 years as a pilot. She is new to the test group, and helping in safety and training. She is training some of the new pilots in the chase aircraft. She holds an ATP certificate for rotorcraft and airplane multiengine. She holds a certified flight instructor certificate with ratings for rotorcraft and instruments. She has 8,000 hours of flight time.

Mr. Twomey has been employed by Bell Helicopters for 4 months as an experimental test pilot and conducts test flights in the 525. He holds a ATP certificate with a multiengine land rating, a commercial pilot certificate with ratings in rotorcraft and instruments. He holds a certified flight instructor certificate with ratings for rotorcraft and instruments. He has 3,200 hours of flight time, and he is a graduate of Naval Test Pilot School (NTPS)

Ms. Lewis stated that they were scheduled to brief at 0630 but it slid to 0645. There wasn't anything extraordinary in the brief. They had to replace some sensors on the green tail rotor blade, there was some discussion about how they were going to ensure those did not come loose again. The standard weight and balance was briefed as well as the standard duties for chase. The duties for chase include area clearing for traffic, and safety issues. When flying chase she usually flies with test aircraft on her side of her aircraft in order to have the best view, and will move to the other side as necessary, or if the other pilot has the controls they will keep the test aircraft on their side. The chase joins up with the test aircraft during takeoff.

Weather cleared up around 10:00. Ms. Lewis usually gets in the chase aircraft and flies a couple of circuits around the pattern for currency. She was in the right seat and Mr. Twomey was in the left seat. They did 4 turns in the pattern and by that time N525TA was ready to go. She positioned her aircraft in a hover behind the test aircraft and they departed as a flight of two.

Once in the operating area she noted that the weather had cleared up, winds were 15-20 kts making things a bit choppy. They started with the card, point by point. When she was flying Mr. Twomey had the cards and when he was flying she had the cards, and was following along with the test points. At one point, they hit a Warning on the red pitch link. There was discussion in the TM room about what the limit was, why was it set, what were they doing when they hit the limit, and then decide to continue or cut some points out of the card or come back to base. The decision was to continue.

The test aircraft started doing the 2-1 OEI test on the card starting at 155 kts (not sure exactly what airspeed the tests were started at), but airspeeds were being bumped up 10 kts at a time, 155, 165, 175.

Ms. Lewis was asked if they were able to keep up as the airspeed increased? She said that generally they fall behind, but at the end of each point the test aircraft would pull up and slow down at which time she was able to close back the distance. The 429 is the best thing they have for chase, but 145 or 150 kts is about as much as she can get out of it straight and level. The test aircraft was using true airspeed so that makes the speeds a bit different.

The test aircraft was doing the last point, Vne, and nosed over to get the required airspeed. They then heard "knock-it-off, knock-it-off" form the TM. Ms. Lewis saw the nose come up just a bit as if they were trying to knock-it-off and execute a decel. She never heard a radio call from the test aircraft. The rotor system started to look like it was out of phase with the cabin, one blade appeared to be flying significantly higher than the others, she saw the tail get a little wave through it go down and come up. The tail then folded up and drifted away. Pieces flying everywhere, she was maneuvering to stay clear of the debris.

Ms. Lewis was asked about a radio call "I have controls" that the TM had heard? She stated that it was probably her that made that transmission. Mr. Twomey didn't think that comment went external to the aircraft, but did confirm that they exchanged controls at that point.

Mr. Twomey stated that he was at the controls during the test point, and they were positioned on the right side of the test aircraft. After the knock-it-off call, he waited a couple of seconds to see if there were going to be any more radio transmissions. He saw one of the blades flying high, and he made the radio call to the test aircraft "Hey, you're flapping pretty good." There was no radio response from the test aircraft. The rotor looked wobbly and slow. Chase position was on the right side, in an extended chase position 3-4 rotor distance and 100 foot step up. The test aircraft was at 185 TAS which equates to around 155 kias, and they were flying at 145 kias, so they had been able to stay in position throughout the maneuver. Ms. Lewis made the radio call "We've had a major accident." After the accident they circled, landed, shut down, and went to see if they could assist the crew.

The question was asked to describe the trajectory of the aircraft. Ms. Lewis said it rotated and pieces just flew all over the place with the larger pieces continuing on the flight path forward. Mr. Twomey recalled that the tail and main fuselage jack-knifed and the nose came to the left. While in their decent, the nose kind of pitched up and the tail broke away to the right side forward and fell away. The aircraft was still pitching up and then rolled to the left a little bit. After the aircraft yawed left, the trajectory became more vertical. The aircraft appeared to be left wing down when it impacted the terrain.

They were asked if they could recall any of the similar airframe flexing or shuttering on previous flights. Both said no.

They were asking about previous drooping trends. Mr. Twomey stated that on one of the points there was some discussion between the aircrew and TM about the length of their delay, because they were shooting for a 1 second delay. There was one point at the time they got the Warning on the red rotor blade where they got down to 86.9% Nr and the discussion revolved around not getting down to 86%. When at 86%, they could not really see the rotor change much, and were not observing the expected yaw kick. The fact that the Nr drooped to 86.9% did not concern them but appeared to be a valid data test point.

Ms. Lewis expanded on her observations regarding the airframe wave she had mentioned. She said it looked like the tail rotor went down and came back up in the vertical plane, but more like a flex of the airframe.

Mr. Twomey said that a main rotor blade coming out of plane was not unusual when performing a track and balance for example. This aircraft normally had a pretty flat track. The recovery from the OEI did not seem as pronounced as compared to the recovery at the other (lower) airspeeds.

Mr. Twomey said that he did not perceive any unusual test schedule pressure and the test were appropriate for the maturity of the program. The test team seems to be fairly insulated from external pressures on the program.

The question was asked to describe the current crew limit practices. Ms. Lewis said that the crew limits were based on the commercial flight operations base on single pilot or dual piloted. Generally, it is based on a 12-hour crew day but can be extended on a case by case basis. There are limits to how many consecutive days the pilots can be scheduled, and dwell time between being schedule. Mr. Twomey said that as a general rule they adhere to an 8-hour day.

The question was asked whether either one of the flight crew expressed concerns about the tests or the program? Mr. Twomey said that they had not expressed concerns to him. That before the flight they were discussing normal life stuff. Ms. Lewis said that she had had a lot of discussions with the pilot about testing this aircraft and he never expressed any misgivings or concerns.

They were asked to describe the air quality during their flight. Both pilots said that it was a bit choppy but were not experiencing thermals. Air speed during the dives were really steady. Mr. Twomey thought the air quality was fairly stable. Ms. Lewis said it was light chop. If air quality was poor then they would expect a lot of verticals/thermals.

1.9 Interviewee: Stephanie Baynham, Control Laws Engineer
Represented by: (waived)
Date: July 11, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 0830 CST
Present: Van McKenny – NTSB; Jon Johnson – FAA; James Harris, Troy Caudill – Bell

During the interview, Ms. Baynham stated the following:

Ms. Baynham has been an employed by Bell Helicopter for 4.5 years, as an engineer on the 525 control laws team. She has been with the 525 program for 3 years. She is not a pilot.

They met early at 0630 for the brief. They went thru the normal briefing format to include any configuration changes on the aircraft, weight and balance, limitation, and then reviewed the flight test card. From the control laws perspective, there had been a recent software drop 2 weeks prior to the test. One of the limitations discussed was one of the gains in the control laws, a high gain in the roll axis and pedal responsiveness on the ground.

There were a few hours between when the brief ended and when the flight took place.

When they did start the testing, It was a normal start up sequence of the helicopter. The aircraft transitioned out to the flight area, performed some steady heading side slips and constant angle of bank turns. Everything on her monitor screens looked normal. The test proceeded to establish Vh for the next set of test points. Started at 0.7Vh for the OEI maneuvers and they were using the OEI training mode, which includes control laws and engine software that work together. For the OEI points, she was looking at pilot stick positions, main and tail rotor actuator movements, and watching the aircraft lateral acceleration, pitch and roll. Additionally, she monitored the simulated engine parameters, Ng, Np, Ngt. They did 0.7Vh and 0.9Vh, and then out to Vne in 10 kt increments. At one of the speeds, 145 kts, they got a rotor droop down to 86.9%. Discussion in the TM room was that 86.9% was low, and they definitely didn't want to go below 86%. That information was relayed to the pilots. The pilots had delayed a bit longer, around 2 seconds, on that records. The decision was to use shorter delay times on the next points. The next point was 155 kts, with a much shorter delay, Nr got down to 94.5%. The aircraft did a couple of points at 155 kts, then they went up to 165 kts, and the Nr droop looked fine. At the 165 kts point they had a few Warnings on either the main or tail rotor. She recalls that there was a 12% margin on one parameter and an 8% margin on the other so they decided to proceed to the next test point.

Moving on to the record where everything happened (185 kt). The pilots were instructed to set up on the Vne speed and if the air felt smooth and calm to do the OEI point, if TM saw any exceedances or the air was not good, then they would call knock-it-off. The aircraft got set up at Vne, there were a couple parameters that had Warnings, but those Warnings were cleared because they had enough margin from the Alert limits. The pilots engaged OEI mode. She could see the engine parameters, the collective dropped, she looked away from her monitor to record the rpm droop when she heard multiple "knock-it-off" calls. At that point, she observed the pilot stick positions "going crazy" oscillating back and forth, both cyclic and collective. The main rotor and tail rotor actuators were vibrating quite quickly. The pitch and roll rates were oscillating quite a bit. The pitch and roll attitudes were fairly good within the ±11° limit that she had set her display for those parameters. There were 6-8 seconds of crazy data where everything was just shaking, and then they lost telemetry. The pilots never responded to the knock-it-off calls. The chase aircraft radioed that there had been a major accident. About 2 minutes passed in the TM room where it was silent. Nick instructed everyone to make their journal entries.

Ms. Baynham was asked to elaborate on the control law change that had been part of the pretest brief. The Flight Test Interface Panel (FTIP) had multifunction's, containing 25 parameters with in the software that can be modified for flight. 24 of them were gains within the control laws, the remaining parameter is a threshold monitor. They are able to adjust gains, and also input stim (stimulated) commands in the main rotor and tail rotor, so they can input dwells, and stirs of the swashplate. The build release was a FTIP update for control laws tuning. There was a preflight bit change (PF Bit). The FTIP gains were slightly different than the nominal setting, so response in the roll axis in high bank turns would be more sensitive, and on the ground taxiing pedal response was going to be quicker than it had been. There were a few max angle of bank turns on this test which might create some oscillations.

She was asked about monitoring the OEI training mode. She said that at no time did she observe the disengagement of the OEI training mode. It remains engaged the whole time. On the prior dives, she observed the OEI training mode disengaged a few seconds after the rpm (Nr) was recovering. Normally about the time the rpm droop would be called out and the rpm was recovering is when the OEI training mode would have disengaged.

A question was asked about the different rates observed in FCC 1, 2, & 3 (flight control computers)? She stated that after the loss of telemetry she reviewed the FCC data. The FCC's should all have the same values for their select rates, accels, & attitudes. She normally monitors FCC 1, but post telemetry drop she compared FCC 2 & FCC 3 data screens. She noticed there was an AHRS 3 failure, that would explain why the data on the 3 FCC's were different. At that point one of the air data computers had been lost, so that would be the decision criteria between the remaining two different. AHRS 1 & 2 are located in the back of the aircraft and AHRS 3 is located in the nose, with the FSD which had also failed off. During some ground tests in the past, AHRS 3 has been seen to failed because it is miscomparing with 1 & 2 in the back. It is not surprising that AHRS 3 is the one that fails because it is located in a different part of the aircraft than 1 & 2.

A question was asked for her to go into more detail about the control positions. In general, they have the time history of collective position, the longitudinal & lateral cyclic, and pedal positions. When the OEI maneuver started, the cyclic position was fairly centered longitudinal was slightly forward because the aircraft was in a dive to Vne. They engaged OEI training mode, and the collective came down about 10% after the 1-second delay. Everything remained steady for about 2-3 seconds, then all of a sudden the cyclic starts shaking up & down ± 10-15% in each direction, collective was shaking up and down (± 15-20%) and slowly creeped up higher during the shaking than it had been during the OEI. The collective never got fully up to 100% The control sticks were back and forth, up and down very quickly. The stick traces appeared to be an oscillation on top of a stick movement. This occurred all the way through to telemetry signal loss. It would appear that the pilots were shaking and trying to control the aircraft at the same time.

The question was asked to describe how the OEI training mode is tied into the control laws. They receive flags from the ECU's (engine control units) that indicates that OEI training mode is engaged. Based on that flag indication simulated OEI parameters are calculated to determine whether or not the tactile queuing engages. Tactile queuing is a collective stick force and backdrive that pushes the stick down when engine limits are reached. The pilots can use the FTR to disable the queuing or they can physically pull through it. The engine themselves are well within limits, there would be no actual tactile queuing for them, therefore a simulated tactile queuing signal is generated. As a note, she said that for all the OEI maneuvers the pilots had been using the FTR almost continuously, which essentially means that the pilots would not have experienced the tactile queuing.

A question was asked about the stick position in relation to the actuators. Ms. Baynham said that the stick position and the actuators appeared to be in sync.

She stated that she felt well trained and qualified to be in her position, and has no hesitation to call off the test if necessary.

She stated that her work week averages between 45 and 50 hours per week.

2.0 Follow-up Bell Helicopter Interviews

2.1 Interviewee: Tim Fletcher
Represented by: (waived)
Date: August 3, 2016
Location: Teleconference
Time: 1600 CDT
Present: Sathya Silva, Van McKenny – NTSB; James Harris– Bell

In order to understand the vibration standards described in DO-160G, we talked to Tim Fletcher, a senior engineer in Bell's dynamics group who works with the Organization Delegation Authority (ODA) with the FAA. DO-160G Section 8 specifies the vibration test procedures for airborne equipment. Garmin stated that the GTC and other equipment in the aircraft was certified to comply with DO-160G – 8 – Category U - G. Category U specifies a test for unknown helicopter frequencies and is used by manufacturers when certifying equipment that may install into different aircraft or unknown aircraft.

Mr. Fletcher stated the procedures for the testing as follows and was describing the procedures listed in Section 8.8.1.3 on Page 8-9 of DO-160G. He stated that initially a sweep scan is performed from 10 Hz to 2000 Hz to identify frequencies of resonance. Next, a sino-random performance test is performed. This is followed by a sino-random endurance test which takes a minimum of 2 hours. Section 8.8.2 specifies the test frequencies required. There are three tests with 4 frequencies (±10%) that are excited during each test. The combination of all three tests is designed to encompass the entire endurance range between 10-100 Hz. If resonances were found in the first step, they are to be dwelled on for 30 minutes each in addition to the nominal endurance test. A performance test is repeated following the endurance testing.

When asked why the testing doesn't involve frequencies below 10 Hz, he stated that electro-dynamic shakers do not function below 5 Hz. He stated that typically resonance frequencies for electronic structures range from 150 Hz to 350 Hz and the lowest he had ever seen was 80 Hz. Typically, resonance is not a concern below 10 Hz but display capability may be the limitation there. He stated that to get high g's at lower frequencies, the displacement must be very large.

Mr. Fletcher stated that resonance is the frequency at which a structure naturally wants to vibrate. The goal of the testing is to shake the equipment to a level higher than its natural environment. When asked what resonance would result in inflight, he stated that the item would break (structural failure). He stated not only the external structure, but internal electronic structures such as circuit boards, components on the circuit board, capacitors (for example) all have their own resonant frequencies. In addition to structural failure he stated that experiencing resonance in flight could put inertial loads on other parts which could cause the equipment or nearby equipment to fail. He stated that normally, electronic equipment is not affected by vibration unless the equipment is provided information such as velocity, or attitude. He did agree that it was possible for the equipment structure to resonate and break something inside the box.

He stated that for the testing Table 8-2b specifies the peak g's required for testing each frequency. For performance testing the peak g level for frequencies between 10 Hz and 40 Hz is calculated by multiplying the test frequency by a factor of 0.04. For performance testing of frequencies between 40 Hz and 100 Hz, a peak g level of 1.6 is used. For endurance testing between 10 and 20 Hz, peak g for testing was determined by multiplying the test frequency by 0.2 and subtracting 1.5. between 20 Hz and 100 Hz, a peak g value of 2.5 is used for testing.

When asked what peak g referred to, he responded that it's the peak of the g curve as opposed to the root mean square (RMS) of the g curve. When asked about what they would look for during vibration testing to determine whether the instrumentation performed to standard, he stated that he'd check to see if the display would maintain the image, would not have any color change, wouldn't go black, or wouldn't start smoking. If the screen was blurry, there is a visual acuity standard for displays.

He stated that the endurance testing is the meat of the test which consisted of 2 hours of vibration at loads higher than what they would expect in the environment. The performance tests are done before and after the endurance test for a minimum of 10 minutes.

When probed about Test R compared to Test U, he said that test R would be performed if the equipment was designed for a specific aircraft environment, where Test U would be performed if the equipment is generic and non-specific to a specific aircraft.

When asked what would be the result of large displacements caused by low frequency, high g vibration, he said that you'd see a rattling and contact with other components. He calculated for 6 Hz at 3g's they would have seen plus or minus 8/10ths of an inch displacement on the equipment. He stated that the displacement is proportional to the square of the frequency and gave us the formula: displacement (in) = g*9.78/(test frequency^2).

When asked about specs for connectors, he said that he has done some work with triple 9 connectors under mil spec 38-999 but doubts that the 525 would have had that connector. He said there are connectors that aren't good for vibration environments. He stated that connectors and switches are usually tested in different ways and they are usually tested to conditions worse than expected. The two separate approaches consist of an airframe testing and equipment testing. Airframe testing involves an engineering mathematical model that uses predicted loads to assess natural frequencies. The equipment testing involves standards like DO-160 and experience from other aircraft. He said that at the end of flight testing, they look at the actual vibration seen on the aircraft and see if the testing was encompassed the inflight vibrations. He noted that inflight vibrations are dominated by certain vibration sources such as when blades pass over a fixed point on the aircraft. So, you would expect vibrations that occurred at 5 per rev and 21 Hz or 10 per rev and 42 Hz. Another source of vibration could be the frequency of the drive shaft. If the equipment has resonances at those frequencies of the airframe, they would test further at a 30-minute dwell time. Specifically testing anything to resonance within 10%. They typically know up to 30 Hz that they can identify fundamental fuselage modes such as twist, lateral, vertical modes as well as higher order modes.

2.2 Interviewee: Jeffrey Greenwood, Chief Pilot
Represented by: (waived)
Date: August 4, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 0920 CDT
Present: Sathya Silva, Van McKenny – NTSB; James Harris– Bell

During the interview, Mr. Greenwood stated the following:

He was an aviator in the Marine Corps, deployed twice., was a WTI instructor (Weapons Tactics Instructor Course), and attended Naval Test Pilot School (NTPS). While at NTPS he worked on the UH-1 Y/Z upgrades, and performed ship deck certification for the USCG A-109. After the military, he took a year off and joined bell in 2006. He left Bell in 2007 to work with Eurocopter and rejoined Bell in 2008. At Pax, he flew H-1 Upgrades and the A-109. At Bell, he worked on the armed reconnaissance helicopter (ARH) program, Bell 609 civilian tilt rotor, Bell 412, Bell 210, Bell 525, Bell 505, Bell 427, and the Bell 525. He began working with the Bell 525 since its inception in 2010 or 2011. Troy's the lead on the program and he said that he supports Troy as needed. He was never fully dedicated to the 525 program and does other work such as serving as an Engineering Flight Unit Member (EFUM) which is similar to a DER (designated engineering representative) to the OPA.

He flew the first flights for 525 ships 1 and 2 and the ground runs for the aircraft with Troy. Jason and Erik did the Ship 2 ground testing in December. In January there were multiple tests to get instrumentation ready. These occurred from late January to late February in Amarillo, TX. They also flew the aircraft the 20-30 hours flight time required by the FAA to fly the aircraft to Arlington, TX.

He said that Jason and Erik were in the US Marine Corps Reserve together and recently flew a Cobra cross country together to meet the reserve requirements.
Jeff stated he had about 4,500 hours total time including 500-600 fixed wing time. He has 3,500 hours in Bell products.

He described Erik as a very professional pilot. He and Jason were professional in different ways. Erik was very intellectual and often went to the engineers and CLAW (control laws) guys to understand how certain things worked. He described Erik as, outside of Troy, the most knowledgeable guy on the aircraft and systems. In the aircraft, he was calm and professional. He said that the first time flew the OEI profile, he flew with Erik and let Erik fly it and Jeff served as copilot. He said he had the utmost confidence in both Jason's and Erik's abilities. When asked if Erik ever made rushed decisions, he said that he was cool and level headed, but if a situation required immediate action, he would take it. He stated that neither pilot did anything that made him nervous. He said that Erik was not afraid to push back on management and talk to engineers.

He stated that Erik's concerns were probably more about the company rather than the aircraft. From Jeff's perspective, there was continuous aircraft pressure coming from management He said he'd been asked why each aircraft isn't flown 40 hours every week. Greenwood said that he and Nick Hall managed the pressure and would screen the pilots from this pressure. For the most part, he said the company would listen and if Greenwood said no, they were generally ok with it. They were never pressured to fly if they were not ready. The reasons for delay were typically that something on the helicopter wasn't functional. He was frustrated that the people running the program did not have experience with flight test or helicopters. He said that he never felt consequences of speaking up and wasn't worried about it ramifications because they were already short staffed.

When asked for a time where management didn't respond to pushback he stated an example where they brought up a pilot staffing problem. He said they needed at least 10 test pilots and the management "did not want to hear it." This was the case until after the first flight where they then rushed to hire more test pilots. He said from the pilot perspective he doesn't get a ton of issues with pushback on management pressure and James Harris may have seen more issues.

When assessing fitness for duty he said that they use a risk tool called FRAT[14] analysis. They try to complete it before every flight. The records are kept with Scott Harris. He said that if risk falls within a certain category, the forms get forwarded to him for review. When asked whether he was aware of Erik's recent death in the family, he said that he had talked to Erik about it. He said he told Erik he could take the time off he needed but asked if he wanted to fly. He said Erik said he was lucky to have talked to his grandmother before her death and stated that Erik seemed normal and ok. Mr. Greenwood stated that even after the accident, pilots wanted to fly and may have used it as a way to compartmentalize the grief.

Jason was more gregarious than Erik. In the cockpit, Jason was easy and smooth on the controls. He stated that even under pressure, Jason made calm radio calls. He said even more than Erik, he would express pushback. He did this typically with humor. He said that Jason likely didn't have a concern with the aircraft, but maybe with the program. An example he cited was regarding how the pilots were confident in the control laws in the 525 which were unique and the FAA pushed back on in favor of more nominal control laws. He said that even though the design had good laws, management didn't take the time to explain the laws to the FAA and ended up succumbing to FAA pushback by changing the control laws to a more conventional form.

When asked about training the OEI procedure, he stated that they trained with the RASIL and would check where the Nr would go during the test. He said Erik and himself flew the card together in the RASIL with Erik flying. They briefed it and flew it the next day. They tended to repeat points that were concerning in the RASIL such as points with higher power settings. He did say they reviewed contingencies such as engine failures. The maneuver on Nr, stopping rotor droop, getting control and Nr back. After this, they would get out of OEI training mode. He stated that once that Nr was back, there was no need to be fast on the controls. His rule of thumb for disengaging OEI training mode is 10% below TOP in order to not over torque the engine. When probed he said he was looking for green on the horsepower display. When asked whether in contingency conversation whether they discussed how to exit OEI training mode, he said that they didn't really discuss it. He said that maybe, but other ways to exit aside from pressing the button, such as exiting the OEI training page on the GTC or cycling engine seemed riskier.

The interview was paused at 1000 CDT.

[14] Flight Risk Assessment Tool

The interview was resumed at 1215 CDT.

Mr. Greenwood was asked to describe his typical duties as Chief Pilot. He said that he sends the pilot schedule out to Russell. The calendar he puts together based on his pilots' availability. He said that flight schedules can change daily and he works to cycle crews through. When assigning crews to flights he said that he bases his decision on severity and risk of the flight. He gives maintenance test flights to the "newer guys" in addition to crash rescue and chase flights. The higher risk types of test flights would normally be scheduled with crews consisting of himself, Caudill, Boyce, Grogan, or Lindauer.

The aircraft he manages are the three 525 aircraft, Bell 412, V-22, Bell 407Gx, Bell 427, Bell 429, and Bell 210. He said they use the Bell 429 for chase flights and the Bell 427 and Bell 210 for crash rescue flights. He said he's referring to pilots that were hired before January 2016 as "old pilots" and pilots that were hired after January 2016 as "new pilots." When he sets the schedule, he assigns a PIC for the flight. The PIC typically sits in the right seat and flies the aircraft. There are cases on lower risks flights that the PIC may elect to let the other pilot fly right seat in order to gain experience or if the PIC decides he'd like to be the co-pilot. He sets the PIC role based on qualification and experience of the pilots. For medium/low risk flights the newer pilots may act as a co-pilot and be paired with an experienced PIC. For high risk flights, he typically pairs an experienced pilot with another experienced pilot. When asked what experienced means, he said these are the pilots who at the beginning helped with engineering. The new pilots went through ground school, 14 sim hours that familiarized them with control laws, systems failures, etc, and 6 hours' flight time. They then flew maintenance flights and chase on other flights and chase on the 525. None of the new guys have flown PIC yet. The reason he chose Jason as co-pilot and Erik as PIC was that Jason had been gone for a few weeks and Erik is his most experienced test pilot.

When assigning flights to pilots he said that there is a meeting at 2pm each day to decide the flight schedule for the next day. By 2:30pm, he has the schedule sent to his pilots. They get about a day's notice depending on the flight time. For preparation, the schedule includes the test cards and the pilots typically go talk to the telemetry room engineers. For the flight brief, the TM team, pilots, chase pilots, air instrumentation engineer are required. Occasionally functional specialists maybe requested for the brief as well. Items discussed during the preflight brief typically include a review of the last flight, maintenance, weight and balance, hours on the aircraft, squawks and risks. The pilots get a printout of the brief. They try to schedule the brief within the hour before the flight. Sometimes there may be delays but if they delay more than 3-4 hours they may brief the flight again.

Mr. Greenwood mentioned that they had been trying to complete this particular test for a week. When asked what the delays were, he stated that an access cover came off a week prior and cut some instrumentation, there were 1-2 days of maintenance, and at least one day of weather problems.

When asked to describe the OEI maneuver, he said that the data point was a given airspeed and the airspeed resulted in a specific power setting. Typically, the co-pilot reads the test card. Then, the pilot accelerates to the specified airspeed. The co-pilot waits for the on-condition call. The pilot states “on-condition” when he reaches the target configuration and states “record ## on” and presses the record button. The co-pilot then scans the PDU (Pilot Display Unit) to verify that an orange light is flashing that indicates that recording is active. He also mentioned that the light flashes at 1 Hz so it’s a good count reference. The co-pilot then states “activating OEI, now, now, now” and on the third now, presses the button on the OEI training page of the GTC (Garmin Touch Controller) that simulates a single engine out condition. At this time, the pilot flying (PF) is watching the Nr. He stated the co-pilot is also watching Nr and he typically has his hand covering over the collective. He said he would be watching for the minimum Nr, and cross checking that the airspeed remains within +/- 2 to 3 knots of the target airspeed.

He stated that the delay specified is a target delay and may not be met always. Typically, the PF is looking at the PSI (power situation indicator) and may have a map on the MFD (multifunction display). For Nr, he said that sometimes it would stabilize without collective input. The co-pilot would then record the minimum Nr, aircraft reaction, any thumps, or yaws. When the PF is ready for the 2nd engine, he would call “Ready for the 2nd engine.” In order to prep for this, he would bring power back and/or put aft input into the cyclic.

When asked if he could conceive a reason why the PF in the accident flight stopped decreasing collective and stopped his recovery of Nr, he stated that if Nr had stabilized, the pilot wouldn’t not have been in a rush and maybe was initiating a slow recovery. He also stated that the reaction is feasible if the saw or felt something he didn’t like. If he was moving the collective and felt something, he said the instinct is to stop moving the collective incase the noise/vibration came from that motion. He said it is also feasible that they could have seen a bird and the response was in reaction to avoid it.

When asked, Mr. Greenwood stated he had not experienced the low Nr warning in the Bell 525. He said that without the PFD (primary flight display), he’d rely on the aural cues of the rotors. If Nr was high, the said that only a light would annunciate. The consequences of a high Nr is a high rate of descent, an inspection that may have to be performed, but the aircraft is still flying.

The interview ended at 1250 CDT.

2.3 Interviewee: Joe Twomey, Test Pilot
Represented by: (waived)
Date: August 4, 2016
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 1410 CDT
Present: Sathya Silva, Van McKenny – NTSB; James Harris– Bell

Mr. Twomey was interviewed at a prior time where background information was gathered and thus not reiterated in this interview. During the interview, Mr. Twomey stated the following:

He received his duties through the Chief Pilot. He'd get a flight schedule, which typically Russell sends out. He said that they typically decide this at a meeting but doesn't typically participate in this meeting. He did say that sometimes before this meeting he may be asked if he's "done xyz before" and based on the answer he may have indication that he may fly the next day or he may be off the schedule.

In order to prepare for the flight, he looks at the time of the flight the next day. The test cards are typically sent out the day prior to the flight. He goes through those and forms an expectation for the flight. If he has questions, he talks to other pilots or engineers. They could conduct the preflight brief the day before, but that's unusual. When asked what he reviews on the card he said that he looks for the flow of actions and tries to visualize the flight. He said he thinks about the techniques used, any control fixtures or other supporting devices and then prepares those as needed. He said he does as much as he can ahead of time.

When asked to describe the pre-flight briefing, he said that they follow a standardized flow but sometimes different people conduct the brief. They typically discuss weather, state of the aircraft, maintenance, outstanding issues, instrumentation, test cards, and test event flight hazards. There is also a question and answer session where he may ask what the team may be looking for, "can we do this instead?", and ask about acceptable augmentation strategies such as using the force trim release (FTR).

After the preflight briefing with the TM, he said that the pilots of the chase and test aircraft have an internal briefing. He stated that they discuss expected altitude bands, speeds, communication expectation, lost sight procedures, and weather. They also discuss emergency procedures such as navigation, traffic, lost communication signals, how to get back to field, and offsite landing procedures.

He said that there was nothing he would really change in the briefing procedures and said that if he did think so, he would speak up during the meeting. He said that the pilots have similar backgrounds. He said that he was taught at test pilot school that if he sees something to say something and he "can't crash just my half of the aircraft." He said he's never in his career felt he couldn't speak up.

He noted that everyone is aware of the schedule, but they balance between safety and production. He said that at his level in the organization they don't really see the production schedule. He said that if there was pressure, you would see everyone working Saturday and Sunday and you don't see that, and the pilots are comfortable going home when their day is over.

Mr. Twomey stated he began with Bell in March of 2016.

When asked to describe Erik, he said that he was professional and prepared. Erik always had a plan, and that was not to say he wasn't flexible. He said that the test pilot group is tight knit and said that when he was hired, Jeff's concern was fit within the group for cohesiveness. When he joined, he said the environment was not "cliquish" and it was warm and open. Erik was thoughtful in his answers, not flippant which to him characterized intelligence. He stated that Erik's strengths were his organization, intelligence, and thoughtfulness. He could not name any weaknesses. The last flight he remembered flying with Erik was in the Bell 427 which was a hospital familiarization flight.

Mr. Twomey had experience performing the OEI maneuver as co-pilot with the chief pilot as PIC. He said he had also performed some of those maneuvers in the simulator and in the RASIL, possibly with Erik. He said he had about 27 hours in the Bell 525 at the time of the interview.

When performing the OEI maneuver, he said the first thing they would do is talk to TM. On the GTC[15], he would select OEI training on the engine page, bring up the instrumentation page, select limitation on horsepower, and set the limits. He stated there are different settings for the HP based on atmospheric conditions.

He said that the copilot would describe what the test is, parameters, hazards, limits, speed altitude, engine simulated out, target delay. He said that he would do a 3 second countdown, "1000, 1, 1000, 2, 1000, 3" where the OEI training mode would be engaged then continue with "1000, 4, 1000, 5" for whatever target delay was expected. The pilot would wait for the target delay or a non-ambiguous cue that something was not ok (indicative of engine failure) and then recover the Nr. He would then set up the aircraft to exit OEI training mode and state that "the point is ceased" or something along those lines and the copilot would disengage the OEI training mode. Other indications of non-ambiguous cues of something not ok, he said, were a yaw or noise in the RPM. He said that in this aircraft you couldn't really hear the engine power reduction due to the location of the engines.

During the maneuver, as the copilot he said that he could focus on hitting the right button to disengage an engine and scan Nr to make sure it didn't droop excessively. He's also watching the pilot to make sure he'd initiate recovery. If recovery was not made and Nr was in the low 80's he said he'd take control with a positive exchange of controls. He said he flies hands off the collective during the maneuver but knows where the collective is without looking and wouldn't take long to take control.

When asked what he would do in the situation the accident pilots were in he said that typically he would reduce collective and bring cyclic back. He also added that flying around at 92-93 Nr isn't necessarily abnormal in an OEI condition. He saw nothing outside from the chase perspective that

[15] Garmin touch controller

he thought would cause the crew reaction that was observed. He also added that Erik and Jason were not the type of people to “freeze” in a situation like that.

He said that Jason was similar to Erik. Externally he was more overt but also intelligent and thoughtful. He said that if Jason had an opinion he had to share it, and was an engaging person. He said that the last time he recalled flying with Jason was during (Rotor Advanced Diagnostic) RADS tuning and CLAWS tuning in the May/June time frame.

During the OEI training, he said that they talked about disengaging the mode, but did not really talk about how to disengage it. He said that pilots were mostly concerned about making sure that the power/collective would not do damage to the aircraft. He stated there were no rules that automatically turned off OEI training mode at an Nr limit. He also said that the only way to disengage OEI training mode was to press the button on the GTC.

He stated that at no point was he ever not looking forward to flying with these two pilots. He learned from them about flying in general and the Bell 525. He stated it was easy to come into the company with the similar structure, discipline, and approaches that he was used to in test flying and there was not really a learning curve. He stated that both pilots were considerate and he never felt any reluctance to talk to them and would have been “totally stoked” to fly with the two of them.

The interview ended at 1507 CDT.

2.4 Interviewee: Thomas Jeffrey Newman, Rotor Dynamics Engineer
Represented by: (waived)
Date: January 17, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 1234 CST
Present: Sathya Silva, Van McKenny, Chihoon Shin, Marie Moler – NTSB; Jon Johnson – FAA

During the interview, Mr. Newman stated the following:

He had been working for Bell for 23 years. His official title was "Engineer 4/ EFM" where EFM stood for Engineering Flight Test Unit Member and acted as a representative of the FAA OEM. His discipline was Rotor Dynamics and Aeromechanics. He had come to Bell immediately after graduating from college. At Bell, he had certification experience on the Bell 412.

He described his responsibilities in the rotor dynamics group in multiple phases. In the development or design phase, his work was analytical, based on code. During flight test, he also did analytics with the flight test data and also monitored the data during test flights. During certification, he worked some time as the EFM and other times supported work for Bell.

He described rotor dynamics to include rotor loads and motions for the main and tail rotor and stability of the rotor and rotor-aircraft system. He specified that stability involved lead lag frequencies and was not referring to handling qualities stability.

Initially, they evaluate ground resonance. This includes looking at the interaction between the main rotor and airframe. They then use a model for hover to test air resonance. Both ground resonance and air resonance are done with only the rotor code not including the aerodynamics of forward flight. They then analyze aeroelastic stability in forward flight and aeroservo elastic stability which includes the control laws.

The design of the rotor first involves receiving specifications for the radius, number of blades, and airfoil shapes. This information also goes into the rotor stress group who provides rotor dynamics with stiffness and mass properties. Rotor dynamics first does analysis using a dynamic model that does not include aerodynamics. They then use the Myklestad program to assess natural frequency. Then, they look into mass balance to ensure that the center of gravity is forward of the aerodynamic center. They then look at classical blade flutter and elastic modes. They use the COPTER model which is a comprehensive code. They use this mostly for loads and performance and not so much for stability analysis. They have codes to analyze ground resonance and also codes incorporating rotor and airframe. The ASAP program incorporates rotor, airframe, and control laws and looks into aero servo elasticity.

The design process can take several years. The Bell 525 design process for rotor dynamics took on the order of years. He did not have experience in the design phase of the Bell 412 and could not provide a comparison of the Bell 525 design process to other bell certification processes.

He interacts with the Bell 525 Flight Technology IPT (Integrated Product Team). The team consisted of approximately a dozen people and included the disciplines of Rotor Dynamics, Loads, and Handling Qualities/Aeromechanics who work together often. There are 2 people who work on Rotor Dynamics. He has a good working relationship with the team. His direct supervisor is in the EFM group but he's not really involved in this phase of the program. He would be more active in the certification phase. His supervisor in flight technology was Eric Carlson who took the position after the incident. Josh O'Neil was the supervisor at the time of the event. He reported having no issues working with either supervisor. He described the strengths of the team to be the analytical expertise and support for flight test. He could not name anything he would improve. He described that it would be nice to have one more person to cover flight test as there are only two full time people that are able to support.

He said that he's felt pressure to get the job done, but wouldn't classify that as "bad" pressure. If there were pressure, he said that they would stop and regroup. He worked overtime during the first year of flight test in Amarillo until February of last year. There were no company incentives to meet schedule deadlines and said that they are wary of people working too much overtime. He described communications to be open between management and engineers.

He described his understanding of safety culture to be a culture of quality and safety and getting that message across. He classified the safety culture at Bell as "good" and said that they have the right policies and people are aware of the policies. They discuss risk and discuss safety often.

During rotor design, they use a limitations document. In this, they put in any limitations that they are aware of from an analytical stand point. The RPM operating arc spans from the RPM required for lift and the RPM that would overspeed the powerplant. While they assess limitations during analytics, but he doesn't assume any of those numbers are good until they flight test. The RPM range is specified as a design requirement and is taken into account in the analytics. The analytical codes are just calculations and not something he relies on.

None of his analysis predicted the event. He described the codes as being limited as ASAP is not great for scissors mode and they rely on the flight test to assess that mode. The codes that are intended to get a systems interaction are not as good.

When asked if there was an opportunity at any point in the design process to identify this issue, he said that they knew the scissors mode could occur as it had occurred in the Bell 429 where they saw a cyclic and collective response first and then the scissors mode. They did not have the opportunity to assess it as thoroughly as they would like as the codes have limitations. This is why they go into flight testing skeptically.

The flight test pilots develop the flight test risk process. Aero-servo-elasticiy did have one of these checklists. He suggested talking to Tom Parham in analytics.

The interview ended at 1329 CST.

2.5 Interviewee: B. J. Thomas, Handling Qualities Engineer
Represented by: (waived)
Date: January 17, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 1332 CST
Present: Sathya Silva, Van McKenny, Chihoon Shin, Marie Moler – NTSB

During the interview, Mr. Thomas stated the following:

He began working at Bell in October of 2005. His current position was an engineer for the Bell 525 program in Handling Qualities. He also serves as an EFM. Other certification programs he has worked on was the Bell 412 STC which he came on during the certification phase and Bell 429 where he came on at the beginning of flight test after the design phase was complete. Prior to Bell, he worked at Lockheed Martin as a flight test instrumentation designer where he would do flight test set up. He had no flight experience.

He described his responsibilities to include writing test plans, reviewing test plans and reports, reviewing data, monitoring all handling quality and aeromechanic telemetry data, building flight manual charts and math model simulations.

He described the Handling Qualities side to involve flight characteristics and the aeromechanics side to involve developing a data base of aerodynamics coefficients and reducing data for performance.

He started on the Bell 525 program full time in 2015 which was immediately after flight testing began. He was not involved with conceptual design of the Bell 525. His work consisted of looking at test plans.

When asked how this program compared to others he's worked, he said he had noted the aggressive schedule of 18 months – 2 years from initial flight to certification. He said he didn't experience any pressure that was more than other programs. He expected to work extra hours and did so often. Early last year, he worked overtime approximately 80% of the time, 10-15 hours per week extra approximately. The company did not provide any incentives for meeting schedule constraints.

His current supervisor is Eric Carlson whom he described he had a good working relationship with. He also said he had a good working relationship with the team and they had open communications. The prior program he worked on included a very small team and he couldn't compare the two teams.

On the Bell 525, he works with Brad, the performance person on the program, often. He also worked with rotor dynamics, structural dynamics, and flight mechanics. They use COPTER for simulations.

He believes the chief engineer sets the program schedule.

When reviewing data, he may discover anomalies. Also, if a pilot comments on something, they will look into the data for an explanation. When reviewing data, they may look at the rotor droop trend and delay time. These are done within the handling qualities team.

They develop the operational test plan checking rotor stability and controllability and then go back on top of that analysis with handling quality analysis. This is always tested during flight test. They assess steady state conditions but hadn't done so for the 92% regime seen during the accident. They don't normally steady state at RPMs. The first time they got a knock it off call, it was for rotor RPM at 86%.

He is not aware of what rotor dynamics does in their analysis of steady states at low RPMs. They had done a power off test at low RPM.

The limitations document specified the rotor limitations. These are different for different programs. They specify governing speeds, transient limitations, and steady state limitations. Steady state limitations existed for the Bell 525 but he could not recall off hand what those were.

For the power off condition, the analysis done by rotor dynamics was the initial bracket for power off Nr. For power on condition, there was some analysis done for OEI within the group.

If he had any concerns, he could report to the IPT lead. He said that the supervisor was receptive, would take the input, and move it up the line if needed. He had not personally elevated any concerns.

The interview ended at 1407 CST.

2.6 Interviewee: Brad Regnier, Performance Engineer
Represented by: (waived)
Date: January 17, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 1429 CST
Present: Sathya Silva, Van McKenny, Chihoon Shin, Marie Moler – NTSB

During the interview, Mr. Regnier stated the following:

He had worked at Bell for 11 years. He was an engineer and reported to the Chief Technology Officer. His former position was as a performance engineer for the Bell 525. Recently he has spent about 70% of his time on the Bell 525, prior to his job change he had spent approximately 90% of his time on Bell 525. He began on the Bell 525 program in June of 2010 at the conceptual design phase. He had not worked at any previous employers prior to Bell. He had sat in on the Bell 412 telemetry room for 1-2 flights.

He described his responsibilities to involve telemetry support primarily. He would also attend preflight briefings to stay plugged into the program. During the design phase, his responsibilities included sizing the main rotor, diameter and chord, sizing the tail rotor. Once the configuration was frozen, they would conduct performance.

For RPM operation, the upper limit was defined at low airspeed to be 103% in order to have more energy. During high airspeed flight, the limit was 100% above a specified airspeed (for example 55 knots). They did brainstorm a target of 93% RPM for noise, but did not implement that. All of this was done in the design phase.

He described the operational limitations to include no engines operating, one engine inoperative, and all engines operating. The limitations provide what to expect at the lower limit. The OEI lower limit is generally lower than other conditions. All of these numbers are fed back into the structural design. In the conceptual phase, they went through about 2 revisions of requirements.

When asked what the normal operating regime for RPM meant, he said that he would expect that it would be able to fly within these limits continuously. Transients were defined on either side of the normal operating range. The COPTER model was used by designers to do analysis prior to flight testing. These designers included people doing torsional stability for example, or rotor dynamics. He specified that performance does not have the responsibility of analyzing the RPM regime.

On the ground, they did sweeps of RPM. No steady state testing was done for high Nr or low Nr. He expected that they may have seen the event in a full-scale wind tunnel. In hindsight, he would suggest in flight steady state testing in the future.

Throughout the design, they are constantly changing the model. The design had not been changed after 2 years prior to testing and was only updated if a problem was encountered on flight testing. An example he provided was the expansion of the Vne speed from 165 knots.

Within the Bell 525 team, he had no issues working with any of the members. The schedule was as aggressive as any flight test. The team felt the pressure but there wasn't anybody particularly providing pressure. He did get overtime. The first flight was behind schedule and he was not aware of any direct consequences of the delay. He said in generally people have the desire to get things done.

He described the term "safety culture" as having safety as the top priority. He felt that when the new CEO came in, in possibly 2009, safety was always stressed in meetings. Prior to that, the former CEO did not highlight safety particularly.

If he had a concern, he would report to Josh, but he had never reported a concern. Nowadays he would start with Eric. He said that he felt he could openly speak with them.

When asked about any changes in his discipline after the accident he said that most of the changes would be in rotor dynamics and understanding modes. On the performance side, they were considering RPM changes and going through steady state testing.

When asked how he characterized steady state vs transient, he said that he would consider 5s to not be transient and would classify transient as passing through a certain regime. He did not think the terms were formally defined anywhere.

The interview ended at 1513 CST.

2.7 Interviewee: Cliff Harrell, Manager for Bell 525 Flight Controls, Avionics and Electrical Systems
Represented by: (waived)
Date: January 17, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 1531 CST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Mr. Harrell stated the following:

He had been working for Bell for 30 years. His current position was as a manager for Flight controls, avionics and electrical. He became manager when Chris Cawelti, the chief engineer, came into his position. At the time of the accident, he was the 525 Flight Controls IPT manager. In his current position, he has 40 people below him including engineers and techs. In his prior position, he had 25 people working for him. Bell was his first engineering job.

He has been involved with the Bell 429 certification in the last year and also the Bell 609 certification in 1996 for 3 years. He started on the Bell 525 3 years ago when the system was heavily in development. This was after the initial conceptual design phase.

As a team, their responsibilities include writing requirements for hardware and software, producing software, testing the software, integrating the flight controls in the lab, and supporting flight test. The flight controls are a fly by wire system controlled by FCC's. The computers do inputs, control, and send signals to the actuators. It also does failure monitoring. He had had some experience with FBW in the V22 project in 1988. He described the benefit of FBW as adjustment capability and automation capability. However, it did introduce more redundancy to consider. There were also issues with depth of understanding. The system architecture was similar for the FBW, but the 525 was easier to understand due to the less actuation and engine control.

Design began 6 years ago. They worked toward an aggressive schedule. He did not really feel pressure and was never forced to do anything he didn't feel was safe. He'd expect everyone else to feel that way as well. They have open communication and are not persecuted for delays. He said there was no undue pressure.

He was not a CLAWs person. He looks at the controls. The filters fall into Mike Bothwell's reign. He described the design process as independent and iterative. They have a requirement, develop to that requirement and test. The results of the test feed back into the requirement and the cycle continues. He opens problem reports and sets schedule for software builds. The latest software build has been 1.5 years in work, but they try to release a new build every 6 months.

During the FRR, various IPTs discuss issues. He felt like the 525 FRR was more regimented and had more rigor. The technical specialists would describe where deviations were in the design and describe risks for the deviations. They also went through problem reports. He estimated a half dozen people sign off for the FRR. There was a checklist for the FRR. There were a number of efforts and reviews prior to the FRR as well. There were several iterations of the FRR.

The flight control system is reliant on the hydraulics IPT, cockpit mechanical IPT and the avionics IPT. Mostly, the leads are presenting at the FRR.

He described safety culture to mean developing the FCS for regulations and including primary and secondary independent reviews, using checklists, and looking for safety aspects. Bell's safety culture depends on the disciplines. Management puts safety first.

He wasn't privy to any information on filtering on any axis. He described flight controls vs. control laws as he is on more of the flight control system.

The interview ended at 1614 CST.

2.8 Interviewee: Nick Flores, Test Director
Represented by: (waived)
Date: January 18, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 0811 CST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Mr. Flores stated the following:

He had been working for Bell for 7-8 years. His current position was a flight test engineer. Prior to Bell, he worked for Northrup and Lockheed doing flight testing. He had also worked on the Bell 429 certification testing.

His responsibilities included conducting the flight test, mostly for experimental aircraft. He would configure the controllers which entailed coordinating with engineering for configuration changes, and sequencing when the work happens. He developed work instructions and worked with the shop to do them and worked any issues that came up. He managed the database to track work on each aircraft. They were also in charge of the weight and balance which entailed implementing into the weight and balance spreadsheet, actual weighting of the aircraft, and reducing post-flight numbers for empty weight and center of gravity. He also created test points and test cards based on test plans. He reviewed test plans and reviewed test cards. He conducted test operations in the control rooms or on the aircraft. He worked very closely with instrumentation and engineering personnel. He also did some project management to oversee the complete schedule for the aircraft.

He needed to be familiar overall with all of the limitations. They brief limitations for a particular test. He relies heavily on the specifications by engineering groups. The limitations document is created by engineers and pilots (it is assigned to them) and he can review the limits.

He's never been involved with concept design. He has always become involved after the aircraft has been built or when it is being built. He does the test planning. He is involved with FRR and TRRs. TRRs review overall team readiness. They look at the task instruction. He works with people to decide what needs to be discussed and includes tests, equipment, limits, risk worksheets. They brief the audience. If there are a lot of tests, they would tailor to the test with the highest risk. The test readiness approval is signed by required members. Typically, this include management or senior technical personnel, or if it is higher level risk, the Engineering VP may have to sign. They get action items from TRR. The final approval is given after the action items have been completed.

He classified OEI testing as medium risk. It could be classified as high from the risk worksheet, but that worksheet was based on the risk intended for no engine operation and wasn't specific for OEI. This TRA was signed at a high level. Most of the OEI training is designated as medium risk. The risk worksheets were briefed. The management gives approval for the highest level of risk. The manager of tests and operations signed off on the TRA. The risk worksheet shows high basic risk but mitigated to medium risk with procedures. The pilots are primarily responsible for the risk analysis worksheets, but they get help from engineering to create them. The approval is for the basic risk defined, not mitigated risk. Then, it is reviewed by a committee for each risk level. Severity for risk was critical so probability had to be reduced.

Go/no go decisions have instrumentation requirements. There are also certain parameters that are go/ no go. This does allow flexibility during flight testing. During certification testing, there is no flexibility. The test plan specifies the weather requirement.

He reports to James Harris and has a good working relationship with him. He also has a good working relationship with his team.

He described the pace of the program as high tempo. The hours they flew in 2016 were double what they flew in 2015. He wished he had time to write detailed notes of the flight after each flight. The required items were squawks, preflight briefing, test cards, and summaries for the flights. He always had things to get done, but there wasn't undue pressure. There were no major deadlines missed and no shortcuts would have been needed. They try to set realistic deadlines. He's not sure how comfortable he'd be voicing concerns about schedule as he doesn't want to let management down.

He has seen a CAS[16] warning annunciate for the crew for chip detection. It didn't occur on every flight and occurred once/month approximately.

When asked if he knew of any limitations on the CAS, he said that known issues are communicated from the engineering to flight test group. All are available in the limitations document. He would look it up if he felt he needed the information, but would not have considered it critical to know all the limitations. He found it more important to know where things are.

He described safety culture as the mindset of an organization as it relates to safety. He described the safety culture at Bell as good as they incorporate FRR[17] and TRR[18] plans and foundational processes. They also implemented "safety and quality, above all" slogan. It is important to the company.

The interview ended at 0911 CST.

[16] Crew alerting system
[17] Flight readiness review
[18] Test readiness review

2.9 Interviewee: Casey Johnson, Flight Test Engineer
Represented by: (waived)
Date: January 18, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 0915 CST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Mr. Johnson stated the following:

He had worked for Bell for 12 years. This was his first job out of school outside of internships. His current position was as a Flight Test Engineer. At the time of the accident, he had held that position for 4-5 years. He has been part of the Bell 609 test program in 2005. The Bell 429 had a rotor problem and he was the rotor dynamics telemetry support.

His responsibilities include writing development operations test plan, creating a test matrix of points, creating test cards, reviewing these with the team and pilots, and writing workbook items and instructions for maintenance. On the day of a flight, he would conduct the briefing, discuss weather risks, changes to the aircraft, test card, and team. He would test direct and communicate with the pilot. After a flight, he would write notes and debrief squawks. He also kept a log of flight time for inspections.

James Harris was his supervisor. He said James was a supportive supervisor who would stand up for him. He has 12 younger FTEs to mentor. He has struggled slightly with Flight Technology to share more information. The FTEs would get requirements without adequately explaining why things had to happen that way. It wasn’t resolved and he was directed to do the testing.

There was some strife after the accident during the investigation within the team. He felt that early on there were opinions formed and people had trouble letting go of those opinions when more data came out. There was frustration.

Before the accident, he said that morale was down. They were pushing hard for schedule and it was difficult to maintain a work life balance. After the accident it was down, but its better now. Prior to the accident, he was working 30-40 hours overtime per week. Cessna came to do an audit in the Jan/Feb 2016 time frame and told the program to slow down. Things got better after that.

There was pressure from the chief engineer. It got to the point where he didn’t have to say it anymore and the pressure was ingrained. He was pushing to do things in the short term what would delay in the long term. He was asked to skip steps in procedures. This occurred mostly around first flight. Compared to the other aircraft he’s worked with, the 525 had a different way of getting to the testing. For example, there were debates on pylon pull where in other aircraft there wouldn’t be debates and it would just be done. He didn’t feel like they were ever unsafe. The pressure was verbal. He did not worry about the loss of job, but was worried about admonishment. The FTE’s complained a lot. Sometimes management added people, but it would take more workload to train them and do the job. Some of the FTE’s left or decided not to continue rotation in the department.

After the Cessna audit, there was still overtime, but they implemented rules for rest. James had set up the memo but he said it had probably come from above his level. The flight crew had crew duty hours, but nothing was specified for the engineering support crew so that was debated.

The limitations document was different for testing compared to the production limitations document. He reviewed the document. Sometimes they operate outside of the limitations in order to test the corner of the envelope, for example with Vne, gross weight, and CG.

He has a say if he's concerned about something. Sometimes the engineers evaluate it and he gets a response back saying that its ok. He trusts the designer.

CAS did announce occasionally. The alerts occurred in the TM room often. Advisories came up. There were master warnings that annunciated for chips. This would happen for certain periods of time frequently, and then wouldn't annunciate for a few weeks. Every time it happened they returned to base to address it so it became a hindrance.

There were some setbacks. There were design issues for example with fuel migration. This change was slated for the 4^{th} or 5^{th} ship, however so it wasn't an immediate delay. They also got setback for horizontal stabilizer exceedances or control law builds. There was nothing wildly out of expectation.

He described safety culture as the whole team working together towards a common goal of safety where everyone was held accountable for everyone else. He characterized the safety culture among the flight test team as good. He said that the safety culture was not so good among the Flight Technology team as they may not understand the work. Life cycles were long and there was no one left when a new aircraft was being designed. The knowledge was captured in best practices; however the aircraft was so different, much of the best practice didn't apply. This was the first aircraft with an articular (beam) rotor compared to a flex beam or two bladed teetering system. Articular rotor allowed more movement. When the design started, there were 2-3 FTE's in the company that had worked on a certification program before.

In Amarillo, between May-December 2012, they were working a lot of overtime until the point where they were prepping aircraft 2 for first flight. The rules limited ability to be on flight test team. It was not a rule limiting overtime.

For the Bell 609, he worked on aero-servo-elasticity. The flight control equipment and structure were the same as 525 from FFCs to actuators. The CLAWs between the two would be different.

Prior to the accident, they were aware of these sidebands where you could stir a swashplate and get forces, but they didn't know the airframe impact when there was aerodynamic loading that would cause the blade to get into scissors mode. The aero-servo-elastic code treats the scissors mode as reactionless.

The interview ended at 0915.

2.10 Interviewee: Mert Ozden, Manager for Bell 525 Aircraft Integration, Wiring, and Interiors
Represented by: (waived)
Date: January 18, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 0958 CST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Mr. Ozden stated the following:

He had been working for Bell for 17 years. His current position is the 525 Aircraft integration wiring and interiors manager and has served that for 2 years. He is also an associate technical fellow for wiring. As part of his tech fellow responsibilities he works with all of the programs and provides design review on integrity of installation. Before Bell, he worked as a communications engineer in Turkey. At Bell, he has worked with the Bell 609 project for one year in development, and then worked on a military aircraft.

His responsibilities include leading a group of designers 12-15 people. He works on routing, LRU's and wiring installation on the aircraft. They build harness boards. He also oversees the design changes for the aircraft. His work is all hardware. They do help with the hardware installation of the software, but the software is taken care of by the Avionics group or Flight Control group. His group works with CATIA. He makes sure the wiring is separated and harnesses are in place. He was also a part of the J2 audits for the aircraft.

He expects that the 525 would have held up to the vibration environment of the accident flight. He had had vibration experience with the military program. They did not use a C-clamp and instead used a metallic clamp. They also clamped every 12 inches instead of 18. In the past, there may have been issues with decoupling of the connectors. To alleviate this, he used locking connectors and safety wires.

He reports to Chris Cawelti, the chief engineer. Prior to Chris, he reported to Martin. He had a good working relationship with Martin. Martin had a good overview of the aircraft and was easy to work with. With Chris, he also had a good working relationship, similar to Martin's. Martin had a broader range of experience where Chris was primarily avionics, but Chris built a good team to support him. He described the working relationship within his aircraft integration group as "great" as they had been together for 3 years.

When asked about the pace of the program, he said that his system is the "top of the iceberg." He was relying on other systems in order to get though the integration work. He was pushing his guys to get through CATIA. He said sometimes it was busy but then it would calm down. He said he never pushed too hard. In the past year, they hadn't worked overtime as everything was on schedule. Before the first flight, for 3-4 months, they worked overtime. He has never felt pressure to shortcut due to pressures. He follows the processes and push backs if he needs to.

He described safety culture when "we" keep safety first and don't compromise safety for schedule. He talks to his employees about safety first and puts it into perspective.

When asked if he knew of any failures or issues with any of the MFD, PFD, GTC boxes, he said that it was not in his realm. He would only know if he had to replace a box, and he has not had to replace a box.

The interview ended at 1020 CST.

2.11 Interviewee: Doug Hamelwright, Manager for Bell 525 Airframe Integrated Project Team
Represented by: (waived)
Date: January 18, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 1112 CST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Mr. Hamelwright stated the following:

He had worked for Bell for 12 years. It was his first job out of college. His current position was the Manager for the Airframe IPT. He had worked on four certifications previously at Bell. For the Bell 429, he had done development after the certification of the aircraft. He was in the military and had experience with certification programs. He worked on the ARH and the H1 W model. He had worked 2-3 months also on the VH1.

He leads 20 engineers that do stress, design, liaison, and manufacturing. They design and engineer the airframe which includes the fuselage, tail boom, propulsion structure. He keeps track of program goals and objectives and provides guidance to leadership. He's been a manager for 1 year. He started with the 525 program in 2010 as a stress engineer. Then he was the tech lead for airframe which was the go-to for technical questions from a certification standpoint. For stress analysis, he supported flight test, bench test, and analysis. He has 30 people in Bangalore helping with this initiative. He also manages 8 people in Mirabel, Montreal.

A liaison goes between for supplier and build activities as well as MRB activities. Technical fellows maintain oversight and develop best practices which are lessons learned from other programs. For airframe, the 525 was the first aircraft that was about 50/50 composite and metallic. The lessons learned are revisited as the program goes on.

The program manager, who is the vice president, does the organizational design of the team. The chief engineer also influences this based on his strengths and weaknesses.

He reports to Chris Cawelti. They have a good working relationship. He had a great working relationship with Martin as well. He highly respects them and finds them to be "the smartest guys."

When asked about morale, he said that the program was fast paced but people had gotten used to it. His organization liked the pace. He didn't have any impression of people being worn out. He said that the pace they are at right now, after the accident, makes more sense.

He has faced challenges to figure out a solution faster than they normally would. If it influences safety, they had the leeway to sit down and discuss and reach out to tech fellows.

If anything comes up during a flight test, it is squawked and resolved.

When asked if Bell had an executive that was responsible for safety, he said that they had appointed Keith Dannel after the accident, but couldn't recall anyone before the accident. The 525 program has a safety officer now. People can bring issues to him such as questions on new technology or new load condition. He's not sure if a process exists yet for reporting issues.

He described safety culture as the unwritten governance of the organization where ideas are commonly held across the organization and safety is the top concern, safety concerns are addressed, and there is an understanding of guidelines. He classified Bell's safety culture as 7 out of 10. He had always felt that no one ever downplayed a discussion of safety. He said what is lacking is a known process for bringing concerns forward. The new CEO facilities-wise was safety conscious on the shop floor and in manufacturing. For flight test, there is a known set of controls and the FRR. Across the company the goal is 0 incidents. The new culture has a large team spread out over different areas.

If he had an issue, he'd talk to the technical lead, the lead would discuss with technical fellows, and if it's still not resolved, it would go to the chief engineer. If an issue was found on the flight test side that threated activities for the day, it was considered frustrating by the FTEs and management. Their organization had a lot of moving parts. This kind of issue didn't happen often and the concerns were never dismissed and always addressed.

There were some setbacks to the program due to supplier performance, testing not being completed or requirements not being made and redesign occurring. He felt that normal things that come up in flight testing weren't accounted for in the schedule. Originally, they had targeted Mid 2016 for the type certificate.

The interview ended at 1147 CST.

2.12 Interviewee: Eric Carlson, Handling Qualities Engineer
Represented by: (waived)
Date: January 18, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 1305 CST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Mr. Carlson stated the following:

He had worked for bell for 17.5 years. He came to Bell straight from graduate school. His current position was as the Flight Technology Supervisor on the Bell 525. At the time of the accident, he was the handling qualities engineer. He had supported several other projects as a flight test engineer: H1 upgrade for the Y and Z models, Army Reconnaissance Helicopter, OH58 which was an internal research aircraft, and the Huey 2.

As a supervisor he was managing dynamics, rotor dynamics, loads, handling qualities, and aerodynamics. He was managing tasks and supporting return to flight. When he was a handling qualities engineer, he was more senior in his group. He would derive parameters for instrumentation and help develop the telemetry screen, help support the CAFTA system which is where all of the data is saved and also brings in real time telemetry. He also monitored handling qualities in the telemetry room. He started on the Bell 525 project in March of 2015 when the program was getting ready for ground turning.

In his management position, he has 8 direct reports and 3 others who are not direct reports to him. He reports to Josh O'Neil who is the lead for flight technology and testing. The working relationship is relatively good. They didn't always agree on the value of certain things, like summaries of flights, but usually agreed to disagree. It was never anything major. He described the team to work well together. There were no personality issues and everyone gets along and has the same goals. It was the same situation before he became manager.

If he had any concerns, he would bring it to the boss or whomever was in charge. He had never received any negative consequences from decision makers for speaking up. Prior to the accident, the schedule pace was realistic. James Harris tried to schedule maintenance on Saturdays so that the engineering team didn't have to come in. In Amarillo, they were working Saturdays and logging an extra 8-9 hours' overtime per week. Personally, it was not as bother as he liked his job. He thought morale was fine, but had heard differently from the results of a culture survey. The schedule pressure was nothing new and it didn't seem that bad. It was less at the time of the accident as they were not forced to work Saturdays. He takes vacations and the company works around those. He likes to work.

He described the safety procedures in place for flight testing as the J2 audit after the aircraft is built, FRR, TRR, envelope expansion. They do a first ground run, first flight hover, and then do one lap around the pattern. The flight test engineers manage the safety procedures. The team also does analyses for everything and design with simulations. They monitor control margins and for the FBW, they monitor CLAW full authority.

When asked if Bell had a single executive who was in charge of safety, he said that they had Tony Randall, but he was not an executive. They hired a safety officer recently. He thinks the conversations about that began prior to the accident. They also do safety stand downs and implemented a culture survey.

He described safety culture to be companywide that people were thinking about safety and it was a long-term way to think and behave. He characterized Bell's safety culture as good, but the survey doesn't agree. The company was responding to the survey by implementing safety stand downs. The leadership was shocked by the results and are striving to improve culture. After the accident, Bell brought on a RTF team. They brought the survey in September.

The RPM arc was developed using simulation which would provide RPM ranges that were expected. These would feed a structural design document.

Handling qualities refer to how the aircraft is operating in different axes, airspeed, RPM limits. They make sure there are no undesirable effects. Handling quality work is usually done after the test flight phase of the program. Handling qualities are not a FAA requirement and incorporating it early would increase cost and test time. He thinks the order they do things is fine as they flew all the maneuvers in the RASIL prior to flight test.

The interview ended at 1339 CST.

2.13 Interviewee: Josh O'Neil, Manager for Bell 525 Flight Technology Integrated Project Team
Represented by: (waived)
Date: January 18, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 1359 CST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Mr. O'Neil stated the following:

He had worked for Bell for 12 years. He had no previous employers. His current position was the Manager for Technology and Evaluation for the Bell 525. It was a collection of 4 IPTs. At the time of the accident he was the supervisor for flight technology which he was doing for 4.5 years. He came into the 525 project during conceptual design. He had worked on three prior certification programs at Bell. For the Bell 412 STC, he came on for flight test and analysis following flight test. For the Bell 429 certification, he came on board toward the end of detailed development phase. For the Bell 210, he came on for flight testing. His background was in aerodynamics and handling qualities.

His responsibilities as supervisor of flight technology included management of the technology team who was well into the design work and wind tunnel testing when he came on board. He has close interaction with other IPTs. The team did simulator work, which was all within flight technology. He also worked with the pilots on the simulator work. He participated in PDR, CDR, aircraft build and flight test planning. In Amarillo, in the Early-Mid 2015 timeframe, he worked closely with James Harris for first flight. Then, he helped get aircraft 2 ready for flight test. He feels like the 525 is a tremendous aircraft.

He found the pace of the program appropriately aggressive. At the beginning, there were people always asking about scheduling PDR and CDR. The program was not going too slow. During flight test, he classified the pace as aggressive but manageable. They had the appropriate amount of support. He feels he had the highest performing team that he's ever worked with. They wanted to keep up with more long-term trends.

Some people work regular overtime with a work week of 50 hours. They did put specific guidelines that restrict time when doing flight test operations.

Morale was good. Sometimes his people felt overworked which was typical for flight test. They were doing a good job and the engagement level was high. They had a good working relationship within the team and didn't have challenges out of the ordinary. There was a conflict with the flight test organization when they wanted to be more engaged. The engineering team worked to provide flight test summaries on results to the test team. In the past, the FTE's didn't usually get the engagement they were asking for.

He hasn't had to elevate any concerns to management. Safety concerns were always being discussed. They do preflight and postflight briefings. He has no concern about speaking up. It is a non-issue. He has never witnessed anyone having repercussions for voicing issues. If anything, management would reinforce the concern.

He officially had 10-12 people work for him as supervisor. At the time of the accident he had 9-10 people. There were others that unofficially supported like the technical fellows or Brett Howard.

When asked if there was a single executive responsible for safety at Bell, he said that all of the executives promote safety. The CEO was all about safety. There was nobody with a safety title. Since the accident, they have a safety officer who reports to the chief engineer.

He described safety culture as safety being consistent and pervasive at the company where people are comfortable talking about it and it is not dismissed. Bell was consistent with this description. They have banners about quality and safety. At the CEO level, they are always bringing up safety.

The rotor speed green arc can mean different things for different people, just like the definition of transient. When they look at rotor speed they do an evaluation of how aircraft will perform. They expect steady state, power off, and transients. The model then provides a range which sets the criteria to design the structure. Then they do flight test and certification.

The flight test limitation document has steady state and transient limits. The steady state limits for twin power on for what the engine can be set at. For OEI, the instruction is to droop so they incorporate it into the limits. Usually that limit is between 95% and 100% Nr.

For the display having red, yellow, green. The green means something different for everyone. The team was struggling on definitions. The colors presented in the PSI is a precedent from the Bell 429. He was not in charge of avionics but he talks to the Avionics IPT a lot.

He thinks very highly of his team.

If they wanted to test a steady state condition at 90% Nr, they would do envelop expansion. For power on conditions, they have set points. The minimum continuous is 100%, then they do 103%. There is no step in between. 90-100% is still transient for all engines operating. The FADEC won't let the aircraft get below 100% with all engines operating. You need to be in OEI or no engines to droop. In this case, the minimum continuous Nr is 90%. There had not been any testing at 90% Nr except for no engine case. They are planning to update the table to 95% as minimum continuous, but hasn't expanded the envelop yet. The limitation document as everything. The FTEs managed the envelope expansion.

The interview ended at 1558.

2.14 Interviewee: Brad Linton, Manager for Bell 525 Mechanical Systems
Represented by: (waived)
Date: January 18, 2017
Location: Bell Helicopter Plant 1, Hurst, TX
Time: 1502 CST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Mr. Flores stated the following:

He had worked with Bell for 19 years, 17 of which were officially for Bell. Prior to Bell, he had worked at Vought Aircraft Company/ Northrup from 1987 to 1997 working on military aircraft. At Bell, he had worked on three prior certification programs. On the Bell 427, he came into the project just prior to certification. On the Bell 609, he worked for 4-5 years in the design phase. On the Bell 429, he joined as the aircraft was beginning certification testing. His current position was the Manager of Mechanical Systems which included hydraulics, mechanical controls, and fuel system. Initially he had worked only hydraulics and mechanical controls. His responsibilities included hydraulics, controls, wheel landing gear, fuel system, emergency floats, and hoists. He managed a team of 10-11 people. He was involved with the Bell 525 in the initial design phase and did primarily supplier management (specifying and procuring components).

He reports to Chris Cawelti, the chief engineer. He has a good working relationship with him and has lots of respect for him. His relationship with Martin, the former chief engineer was also good. He also had respect for him. He and Chris were very different people. The working relationship within the group was really good. He has a group with more experienced people who have been working together for a while.

He described the pace of the 525 program as challenging. This was similar to the other programs he had worked on. With commercial programs, there is always schedule pressure. He has had issues come up where he needed more time to get something done right and had never been told to "getterdun." He feels that everyone in his team should feel like they can speak up. If he has asked for more time to do something, he's challenged but he's never gotten a no.

He described safety culture to be when safety is on people's minds all the time. Within his team, there is a very high safety culture because of the components they work with. He could not speak to the safety culture overall at Bell as he works primarily with his group. The program has had setbacks due to design issues that come up weekly/monthly. During preliminary design, there were lots of redesign. He could not think of any specific examples. The schedule targets were always changing. Some things were viewed optimistically in the original schedule, but he feels that they have a realistic schedule now. At the time of the accident, the pace was challenging, but he believed it was possible to get the work done. He has 40-50 major components and it was a challenge to get qualified parts from his suppliers.

He described the Bell 609's mechanical flight controls similar to the Bell 525's conceptually. He did not interface with crew often, but did talk to them for ergonomic assessments for seats.

The interview ended at 1520 CST.

2.15 Interviewee: Melissa Reinch, Avionics Engineer
Represented by: (waived)
Date: January 19, 2017
Location: Bell Helicopter Plant 6, Arlington, TX
Time: 0925 CST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Ms. Reinch stated the following:

She began working at Bell in the summer of 2012 as an intern. She worked part time during her senior year in college and joined Bell full time in June of 2013. Her current position is Avionics Engineer. She had not worked anywhere previously in the aerospace industry prior to Bell. The Bell 525 program was the first certification program she has worked on.

Her duties with the 525-program included base level requirement tracing. She began testing work at the end of 2015 to replace another engineer who was leaving. She also started requirement writing in the last year which included reworking certain requirements for the system.

She came on to the project when the CAS was fully functioning. She took over scripts and wasn't involved with writing CAS messages. She was part of the review of CAS with human factors personnel and pilots. During the Flight Readiness Review, she was a "fly on the wall" and not directly involved.

They use a script to test the CAS activate, inhibit, and deactivate logic. They look for visual and audio annunciation. She mentioned tones were safety of flight and aurals (words) were not safety of flight. An example of an aural was "ENGINE ONE OUT." She classified LO ROTOR RPM as a repetitive tone. The design included 3 bongs plus a unique tone for this warning, but for flight test, they incorporated a continuous 3 bongs for this warning. The continuous bongs were the same indication of a master warning. She mentioned that the software wasn't ready for other tones.

Prior to the readiness review, avionics would develop a spreadsheet of all of the CAS functions and whether they were designated as "safety of flight" critical or not. They would test the safety of flight functions using scripts or a CAS manual test. The results for each function would be "passed," "passed with exception," "failed," or "safe." Failed indicated that the alert did not annunciate or annunciate in time. CAS testing was done standalone for each function, but certain functions also were tested by pilots for certain scenarios. In these cases, the pilots could request changes. All of this testing occurred prior to the FRR. When asked how items were designated as "safety of flight," she mentioned that there was a review process but not sure what it involved.

She was not sure when the Bell 525 program began. It was released to the public in 2012. She was not sure where the CAS design fits within the overall aircraft design.

She has never felt uncomfortable to voice concerns with management. Her concerns were never dismissed and she described her boss as an advocate.

She described the pace of the program as “fast.” She said occasionally deadlines were pushed back, but that she does not have many hard deadlines and most of her deadlines are “as soon as possible.” When she works at Plant 6, she works 50 hour weeks but that does not occur every week. In Amarillo, she worked every day of the week, 10 hour days for 70-hour work weeks. This occurred in September of 2014 and she went to Amarillo for one week at a time.

She likes working for Bell and said that she is constantly challenged. Before the accident, she said that people were tired and overworked. She personally was not, but felt that that was the case at plant 6. That feeling likely started when flight test began and people had to do their normal job, work in the telemetry room, and provide second shift support.

She is not heavily involved with flight test. The avionics group as 6 people. She has a good working relationship with them and they split the work effectively. Her boss is Mike Severson whom she has a good working relationship with. She said that he was always there to listen to her concerns and elevate them if needed.

She did feel pressure to do her job and had several high priority tasks. She never felt at risk of losing her job if she didn’t meet a deadline.

She described the term “safety culture” as the overall work environment and how safe it is, including how safe people feel. When describing Bell’s safety culture, she said that there could be some improvement but overall it was “pretty darn good.” She had heard of others who may not feel like they could speak up with their management. She described possible improvement to be to have a single point for the project. She said there were so many different people on the project and didn’t want any information to get lost in transition. The program is getting a flight safety officer, which in her opinion, she thought they should have had the whole time.

The interview ended at 1014.

2.16 Interviewee: Jillian Alfred, Control Law Engineer
Represented by: (waived)
Date: January 31, 2017
Location: Teleconference
Time: 1259 EST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Ms. Alfred stated the following:

She has worked for Bell 4 years and is currently an Engineer 2 in the Bell 525 control laws team. She's been on the 525 project for 3 years. Previously, she worked on control laws for the Bell 407. It was purely research with modern control laws and was not part of the certification process for the 407.She came straight to Bell following graduate school.

She described her responsibilities as mainly being the "gate keeper of CLAWs. She takes everyone's designs and put them into a configuration system. They put all of the software together and she handles low level reviews and testing. She's familiar with all of the code in the aircraft.

She described low level testing to be testing page functionality - test page by page and testing each function by itself first. They make tests tailoring to high level requirements and they test all of the decision points in the code. They then hand it over to the software team to perform a model level test. The aircraft is fly by wire and has no mechanical linkages between the stick and the actuators. The flight computers take the input signal from the stick and sends it to the actuators. Even if there is no stick motion, the flight controls are constantly inputting signals into the actuator. For testing at the top level, they test different axes for each different mode. In order to test that they are meeting high level requirements (HLR) they do high level testing using documentation. There are HLRs on the entire code and it includes redundancy management. They design scenarios to test HLR. There are 300-400 HLRs. For example, if a HLR states that bank should be limited to a certain angle, they input a signal greater than the angle to see if the aircraft responds the way it was designed to. The HLRs were developed before she started working on the 525. The requirements have evolved and she has helped update them.

In describing how biodynamic feedback is incorporated into the flight control laws, she said that her team gets the filters from rotor dynamics and structural dynamics. These were done "later" in the design about 2 years ago. The filters are developed based on pilot models. Originally (and on accident flight) there were no filters on the collective stick. The cyclic did incorporate filters. They (CLAWs) have a little bit of say regarding filters and are mainly concerned about phase delay in the 1-2Hz range. They make sure that the phase delay in that regime is not hit too much with filters in the higher frequency range. If they are concerned, they will provide feedback to the rotor and structural dynamics people to change the filter. She wasn't sure why there wasn't a filter on the collective. She guessed it was because the pilot model didn't show a need for one.

In order to be ready for flight test, they have to have completed all low-level testing and high level testing with a pass or rationale for not being affected. They "triple lab tie" in failures such as hard-overs and sinusoidal inputs. These are also judged by the pilots and all completed in the RASIL prior to flight. They do CLAWs targeted testing in the RASIL and general cards to see if one thing affects another. They use a board process to review and keep all problem requests in their system called "Dimensions" in order to track issues.

Mike Bothwell is her direct supervisor. She has a good relationship with him. She is his right-hand man so to speak. Bothwell has been her supervisor while on the 525 program. She feels like she can openly voice concerns at Bell. She has never had an urgent concern but has discussed other concerns openly amongst control law team. The conversations are well received, especially within the control laws group. There are 7 members in the CLAWs team and 2 from Flight controls that are involved. When asked if there are any challenges working within the group, she said that it is a normal workplace that has disagreements, but overall, they work pretty well with each other. The group has been together a couple of years and are fairly fine-tuned. Most people are receptive to working things through.

She described the pace of the 525 program as fast. It picked up in 2014 as they flew in 2015. Since then, throughout flight test, the pace has stayed high until the accident. The program was always moving fast and they always wanted to do more. The process was never compromised but she wanted to do more smaller items such as playing with the code and cleaning up some items. There was always pressure to get things done but she didn't feel like there were any negative consequences if they were not on planned schedule. They have delayed releasing software before and management does ask question about what they can do to make the process faster but nothing is usually significantly changed. It is a 3-week process to test quick builds that incorporate a very small change from flight test. This is done with targeted testing. She worked a lot of overtime staring Sept 2014. In flight test, there was a lot of overtime, 10 extra hrs a week. While in Amarillo they worked 60 hour weeks. She described moral within her group as pretty good to average. There were some people who got stressed out during high pace but overall there was good morale

She described safety culture to be a way to look at prioritizing safety and always looking for the safest way to do work and being mindful of safety. She described safety culture to be good at Bell overall. There are lots of checks and balances built within the program. However, they are pushed in flight test to get things done. She'd like to see the program continue with focus on what's best for the pilots and aircraft as opposed to focusing on what gets to certification fastest. She has received some blow back when they delayed a software build.

Since the accident, the pace slowed and priorities changed. They have more time to analyze data and address squawks. She said that the processes are being looked at and the focus will be on making sure everything is ready.

She didn't feel like they could have caught the aircraft response prior to the accident. It was never present in any test records. They are able to tease out biomechanical input and AHRS input and have looked at those inputs following the accident. The biomechanical filters were not brought up in their team as they are mostly concerned with 1-2 Hz. 6Hz is high frequency for them. She did say there were filters in the 5.5 to 6 Hz range on pitch rate, roll rate, yaw rate, and lateral acceleration. The filters are mostly created with other systems and implemented in with CLAWs.

The interview ended at 1344 EST.

2.17 Interviewee: Mike Bothwell, Manager of Bell 525 Control Law Team
Represented by: (waived)
Date: January 31, 2017
Location: Teleconference
Time: 1433 EST
Present: Sathya Silva, Van McKenny – NTSB

During the interview, Mr. Bothwell stated the following:

He has been employed with Bell for 22.5 years. His current position is as manager of the Bell 525 control law team. He came directly from graduate school to Bell. He has worked other certification programs involving the Bell 407 and the Bell 609 aircraft. For the Bell 407 he was in the dynamics group and provided test support and analysis of data. He was not involved in the design phase for the Bell 407. For the Bell 609 project, he was in the simulation group and worked on getting the engineering simulator up and running. He would also support pilot sessions for control law design.

He became chief 5 years ago. 6 months after he started the position, he became involved with the 525 program. He joined before between the PDR and CDR where they were going to freeze the design for flight.

CLAWs are responsible for all 525 control software, development, certification, flight test support, bench test and lab test of software. He described the development/design process. Early on, they developed a desk top program and mode for the Bell 525. They then take the desktop simulator and put it into the engineering simulator. These just include CLAWs. They then get pilot feedback. Eventually, they integrate CLAWs with the rest of the flight control software in the RASIL. After the RASIL, they then move to flight testing. They iterate between the code and requirements throughout this process and flight test to make changes to the software.

He described how requirements are developed in the high level. There are Tier 3 requirements which includes a written description on how the control laws work. There are Tier 4 requirements that includes block diagrams and modelling using Simulink. These are developed in parallel and iteration takes place on both. It is mostly their team that develops the requirements, but they do consult with the subject matter experts and technical fellows.

The IRADS control laws were developed for the 525 program in the 2010-time frame. It was about a year prior to him joining the team. For the other aircraft flight control systems, like the Bell 609, eagle eye UAV, he worked more on the integration side of these programs.

The biodynamic feedback is discussed between flight controls and dynamics groups. They use pilot models to run a linear analysis and create a linear filter. Their pilot model for the cyclic was good and they could set the filter parameters and used stick and rate feedback filters for the cyclic. The model for the collective showed no stability issues in the frequency response. They look for more than 6db margin. The CLAWs team has a code written to address to input the biodynamic feedback, but until they can validate, the code is a pass-through filter and acts as a place holder. Flight data didn't show stability issues on the collective from the dynamics group either. Dynamics is looking on frequency response plot. The window is 6db away from margin. If pitch, roll, yaw, acceleration shows better than 6db margin there is no reason to change filters. Once they ran the analysis, if the response is better than 6 db then the filter is left as is. A filter at high frequency accepts lag at low frequency. If there's too much lag at 1-2 Hz the pilot and ship could get out of phase and cause pilot induced oscillations.

The pilot model used was developed from an older test evaluating a cyclic side stick. They put pilots on the shake table and vibrated them laterally and forward/aft. They did not test vertical vibrations because this test had a traditional collective, as opposed to the side stick collective on the 525. They sweep frequencies and amplitudes at a given RPM. The RPMs were fixed for this test. He couldn't recall whether there was discussion to test a side stick collective for the pilot model. During flight test, they did points where the pilot would provide a pulse input to excite frequencies, but everything was stable. He doesn't remember the vertical axis as being critical. No previous data indicated a need for a filter. The mishap involved different RPM than what had been tested or would have been tested. They did frequency and amplitude sweeps at a fixed rpm (100-103%). Rotor frequency change depending on rpm. He only collected the data for the pilot model, he never did the analysis.

When they develop feedback to filters, they look for no adverse effects for handling qualities. They usually only discuss critical items and he doesn't remember the vertical axis as critical. They will only put a filter in if needed after flight test. If they had built a pilot model for the collective side stick with a shaker mock up, they could get a better transfer function, but they may not have known to add an aerodynamic factor (involving angle of attack and airspeed) to it, so it may not have predicted the behavior seen in the accident flight. Even with an aerodynamic model, they wouldn't have been able to validate it without the mishap data. He suggested for flight testing, they could have tested the lower RPMs at low speed testing and expanded the envelope. This was not something done in the past because previous aircraft couldn't control RPM as precisely as the 525 since the 525 has the fly-by-wire and digital FADEC.

Regarding validating aero models, they have data for steady state and the models are 80-90% accurate for those dynamics, however the highly dynamic flight regimes are harder to model. They typically model those by using a steady state and adding a correlation/correction vector which is derived from flight test data.

The control laws are designed around 1-2 Hz, and they are not typically concerned about 6 Hz frequencies as long as they meet stability analysis requirements. There are many different frequencies and these profiles will have crossings. Their goal is to minimize the crossings by moving them outside of the flight envelope. He would have considered 185 knots at 90% RPM outside of the normal flight envelope. The envelope is defined by development testing. There should be specific RPMs in the envelope for steady state. They had planned to test 93% steady state for noise, but had decided not to pursue that. All the flight tests were done at 100-103% Nr. Tolerance would be above or below 5% of normal Nr range. The design team didn't expect to fly beyond this range. Their idea was that for certain maneuver it was okay to droop when there were other priorities to test. Their expectation was not to fly at 93% Nr when everything healthy.

There are 7 people who report to him. He currently reports to Cliff Harrell. He reported to Martin Peryea (chief engineer) at the time of the accident and had a very good working relationship with

Martin. He felt he was always able to express concerns. He delayed one flight because he wanted to do another simulator session and was supported by Martin and James Harris (Flight T&E IPT Lead).

He described the pace as faster than other programs, aggressive but achievable. He did not find the pace to be unreasonably fast. He did work overtime. The pace was faster when the aircraft were in flight test and when there were multiple aircraft. During this time, he typically worked 50-hour work weeks. He said that morale was good. There was stress but people were excited about the program. In Amarillo, it was tougher and morale was low. It improved when the team got back to plant 6.

There were some setbacks to the 525 program. Early on there was a major weight requirement that required a redesign to meet weight requirements. About 6 months to a year afterwards there were decisions made in control law philosophy. They originally wanted certification in 2016, but he didn't believe that management seriously thought it would be done in 2016. He never got any pushback on control laws. He didn't remember feeling undue pressure, only pressure to get the work done. It was all achievable if everyone did their job.

He described safety culture as being able to freely voice concerns about safety. 4-5 years ago, when Garrison became CEO, there was a push for safety in the shop. Overall it was better than 10-15 years ago. Safety is always mentioned in briefings or presentations.

The interview ended at 1330 EST.

2.18 Interviewee: Troy Caudill, Lead Test Pilot
Represented by: (waived)
Date: January 19, 2017
Location: Bell Plant 6, Arlington, TX
Time: 1100 EST
Present: Sathya Silva, Van McKenny – NTSB

An in-person conversation took place with Bell's lead test pilot, Troy Caudill at Bell Plant 6 on January 19, 2017. Questions were asked regarding the development of the crew alerting system and designation of criticality of messages. During the conversation, Mr. Caudill stated the following:

The criticality of messages is decided based on pilot action. If no pilot action is required, then the alert would be an advisory or would only be available on the maintenance page. If there is pilot action required, they refer to their CAS philosophy. For anything requiring pilot action immediately, it is designated as a warning. If it requires action, but not immediately, it would be a caution, or advisory information if action is required much later. The difference between caution and advisory is a gray area. Landing gear is an example of an advisory.

Safety critical refers to messages for which if nothing is done, it would break the aircraft, cause the aircraft not to be flown right, or it would exceed a limit. All of the warnings count as safety critical and some cautions. The single engine failure is a warning, but depending on where it occurs, an immediate action may not be required, like a caution since they have two engines.

The decision for what is critical comes from the cockpit working group led by Adrian Sullivan. They work with other systems and pilots. The systems present what they think is critical and the pilots provide input about whether they agree. The cockpit working group would work with the systems people, a safety representative, and someone who does design safety analysis. All the decisions are documented. The cockpit working group creates the list of safety critical items. The list is vetted, and then sent to avionics for implementation.

CAS testing is a systems safety analysis. If the loss of an item is critical, they would work to make the probability of it occurring low. The other classification of warnings, cautions, and advisories is iterative. This is done by avionics. Some scenarios of the functional hazard analysis involve pilots. The pilots run conditions in hover, lowspeed, and high speed, corresponding to the hover, takeoff, and cruise phases of flight. They would check that the proper CAS annunciates and provides notice if some change is needed. Hover and lowspeed operations are generally more critical and require more immediate action.

At the time of the decision, they did not have a lot of the aural messages developed. They had picked the tones but hadn't implemented them. The test team determined that having some indication for Lo Rotor RPM was sufficient to continue. Prior to the first flight, there were many nuisance messages. They went through them and sent some to telemetry if they needed them and inhibited others.

If during operation they lose redundancy, they return to base.

During design decisions, they don't go multiple failures deep but do think about it. They are still going through another iteration of CAS.

He said the pilots knew that the Lo Rotor RPM did not have the proper tone and they had flown OEI before. They had done autorotation testing and also had heard the tone in the RASIL.

He mentioned that when he was in a vibration environment similar to the accident, he could not talk due to diaphragm movement.

A loss of display is considered a minor loss as they are independent. There is a 10^-12 probability that they lose all of their displays.

2.19 Interviewee: Tom Parham, Rotor Dynamics Engineer
Date: February 6, 2016
Location: Teleconference
Time: 1433 EST
Present: Marie Moler, Van McKenny, Sathya Silva – NTSB; Tom Parham, Jeff Newman, Gary Miller, Marko Vuga, Eric Carlson, Mike Bothwell, Jillian Alfred – Bell

[redacted]

[redacted] The new collective and cyclic filters will address the biodynamic feedback. In the collective, the feedback is purely biodynamic. Cyclic AHRS pitch and roll rates are filtered by the CLAWs. In the cyclic, the filters address the CLAWs pitch and roll rates in addition to the biodynamic feedback. This existed in the cyclic prior to the accident, however the cyclic numbers are being retuned.

[redacted] The linear model [redacted] shows the control model. It is modeled in Matlab/Simulink. In the new software build 4, the model incorporates correlation factors from the accident flight. The new model shows no vibration growth, aka positive stability throughout the envelope.

Before the mishap, the model didn't use correlation factors, it didn't model scissors mode, and it didn't incorporate collective pilot biomechanical feedback. When they evaluated it with only the physics, it did not correlate – show vibration increase at 8-9s. So, they added a correlation factor which consists of a gain of 50% on the cyclic collective inputs. They placed this 1.5 gain in the model immediately following the actuator block in the forward loop.

[redacted] The pilot is modeled as inches of stick per g of acceleration. In the vertical axis, this translates into how much the control stick is vibrating vs how much the pilot seat is vibrating. In the new model, they have designed for the worst possible pilot case using their shake test data.

In previous programs, they have never shaken anyone vertically. The model prior to the mishap had no filter on the collective. It had not been an issue in previous aircraft and shown stability during flight testing. Previous programs used a traditional collective control, whereas the 525 incorporated a side stick for collective control.

[redacted] The yellow dot shows the gain to correlate to the mishap data. They have designed filters to pilot gain of 0.5 inches of stick deflection per g.

When they run the updated model, they vary airspeed at a particular RPM, then reduce RPM and sweep the airspeed again, essentially doing airspeed sweeps at various rotor RPM. The updated testing includes better damping measuring techniques that includes measuring main rotor scissors mode.