NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

February 24, 2012

Group Chairman's Factual Report

OPERATIONAL FACTORS

DCA11MA076

ACRONYMS / DEFINITION OF TERMS

AAL	Above Airport Level
ACO	Aircraft Certification Office [FAA]
ACO 1	Atlanta Aircraft Certification Office, Flight Test Branch Manager
ACS	Aircraft Certification Service [FAA]
AEO	All Engines Operating
AERO 1	G650 Aerodynamicist
AFM	Aircraft Flight Manual
AOA	Angle-of-Attack
AOM	Aircraft Operating Manual
APG	Airplane Performance Group
APG 1	Flight Sciences Group Head
APG 2	Flight Sciences Preliminary Design Specialist, Environmental/Performance
APG 3	Flight Sciences Personnel [Flight 153]
APG 4	Flight Sciences Principal Engineer
APU	Auxiliary Power Unit
ATP	Airline Transport Pilot
CG	Center of Gravity
CFR	Code of Federal Regulations
C_L	Coefficient of Lift
C_{Lalpha}	Coefficient of Lift versus angle-of-attack
C_{LMAX}	Coefficient of Maximum Lift
CTO	Continued Takeoff
CVR	Cockpit Voice Recorder
EGPWS	Electronic Ground Proximity Warning System
EPR	Engine Pressure Ratio
ETP	Experimental Test Pilot, Field Performance Testing
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCC	Flight Control Computers
FDR	Flight Data Recorder
Flight 153	Accident Flight
FLTOPS 1	Vice President of Flight Operations
FTE	Flight Test Engineer
FTECS	Flight Test Engineering Chief Scientist
FTEFC	Flight Test Engineer for Flight Controls
FTEGH	Flight Test Engineering Group Head
FTIE	Flight Test Instrumentation Engineer
GAC	Gulfstream Aerospace Corporation
HIPF	High Incidence Protection Function
HIRF	High Intensity Radiated Fields
IDEM	Internal Data Examination and Monitoring
IGE	In Ground Effect

ITF	Integrated Test Facility
KBHM	Birmingham-Shuttlesworth International Airport
KIAS	Knots Indicated Airspeed
KROW	Roswell International Air Center Airport, Roswell
NTSB	National Transportation Safety Board
PFD	Primary Flight Display
GIV	Gulfstream G450
GV	Gulfstream G550
GVI	Gulfstream G650
MAID	Modification Access of Internal Data
MTO	Maximum Takeoff Power
MTOW	Maximum Takeoff Weight
NAOA	Normalized Angle-of-Attack
NTSB	National Transportation Safety Board
NWS	Nosewheel Steering
OEI	One Engine Inoperative
OEO	One Engine Operating
PF	Pilot Flying
PFD	Primary Flight Display
PIC	Pilot in Command [Flight 153]
PJP	Project Pilot [G650 Program]
PLI	Pitch Limit Indicator
PM	Pilot Monitoring
PR	Problem Report
RAT	Ram Air Turbine
RTO	Rejected Takeoffs
RVSM	Reduced Vertical Separation Minima
SETP	Society of Experimental Test Pilots
SFTE	Society of Flight Test Engineers
SIC	Second in Command [Flight 153]
SOP	Standard Operating Procedures
SRB	Safety Review Board [GAC]
TC	Type Certificate
TCAS	Terrain and Collision Avoidance System
TIA	Type Inspection Authorization
TM	Telemetry
TOLD	Takeoff and Landing Data
TPS	Test Pilot School
TSHA	Test Safety Hazard Analysis
T/W	Thrust-to-weight ratio
USAF	United States Air Force
VFR	Visual Flight Rules
V_{EF}	Engine Failure Speed
V_{MCA}	Minimum control speed, air
V_{MCG}	Minimum control speed, ground
V_1	Takeoff Decision Speed

V_2	Takeoff Safety
V_{35}	Screen Height Speed
V_{LOF}	Liftoff Speed
V_{MU}	Minimum Unstick Speed
V_R	Rotation Speed
V_S	Stall Speed
V_{SR}	Reference Stall Speed

A. ACCIDENT

Operator:	Gulfstream Aerospace Corporation
Location:	Roswell, New Mexico
Date:	April 2, 2011
Time:	0934 Mountain Daylight Time[1]
Airplane:	Gulfstream GVI (G650), Registration Number: N652GD, Serial Number: 6002

B. OPERATIONS GROUP

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C. SUMMARY

On April 2, 2011, about 0934 mountain daylight time, an experimental Gulfstream Aerospace Corporation (GAC) GVI (G650)[2], registration N652GD, serial number 6002, crashed during takeoff from runway 21 at Roswell International Air Center Airport (KROW), Roswell, New Mexico. The flight was being operated by the manufacturer as part of its G650 developmental field performance flight test program. The two pilots and the two flight test engineers were fatally injured, and the airplane was substantially damaged. The flight was being conducted

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[1] All times are Mountain Daylight Time (MDT) based on a 24-hour clock, unless otherwise noted. Actual time of accident is approximate.

[2] Gulfstream uses the Roman numeral designation "GVI" for aircraft certification purposes and the designation "G650" for marketing purposes. These designations mean the same aircraft model for purposes of this report and are used interchangeably.

under 14 Code of Federal Regulations (CFR) Part 91, and visual meteorological conditions prevailed at the time of the accident.

D. HISTORY OF FLIGHT

On the day of the accident, the test team was performing test cards associated with flight 153, which was part of the developmental takeoff field performance testing. The purpose of the testing associated with flight 153, as described by the GAC Flight Sciences Group Head (APG 1), was to develop future speed schedules by using the data with other continued takeoff test data that had been collected to determine and finalize those speeds that would be used for the airplane’s certification. Flight 153 was about 02:42 hours in duration, during which time the test team completed three test cards with a total of 9 test runs. The accident occurred during the second run of the last test card, Card 7, while performing a one engine inoperative (OEI) takeoff. Test assets to support the test were a telemetry station/trailer (TM) and a GAC portable weather station.

The PIC used the pitch limit indicator (PLI) as a maximum pitch reference for all of flight 153 test runs. APG 1 thought that the column pull forces used were the result of testing that had been performed by the second-in-command (SIC) and the lead on-board flight test engineer (FTE 1) in the Integrated Test Facility (ITF) and were based on pilot feedback. The column forces to be used for flight 153 were briefed as 60-65 pounds. The Flight Sciences Group Head (APG 1) stated that a control column ramp input that was used solely for flight 153 was to pull the column force over a short period of time. That input had lengthened from the instantaneous pull (step inputs) with 60-70 pounds used on prior tests. A step input was an incremental and very quick pull from no column force to 70 pounds. The intent of the new technique for flight 153, a ramp control input, was to allow the pilot to have a sense of the airplane’s response rate to pull forces and to afford the pilot better judgment to meet pitch targets and fly the maneuver. The use of the ramp input was to allow the takeoff technique to be repeatable and predictable. APG 1 thought that the step and ramp inputs were conceptualized from coordination between the pilots and Flight Test Engineering. APG 1 stated the she was not involved in the discussion relating to the establishment of the target pitch that would allow a repeatable test technique and one that would not result in a pitch overshoot. The discussion involved performance engineers, including the Flight Sciences Principal Engineer; FTE 1; and, she thought, the Flight Test Engineering Chief Scientist (FTECS). She heard of the pitch target being discussed during the afternoon briefing prior to flight 153’s preflight briefing. APG 1 stated that the data analysis for flight 153 was going to be a combined effort between Flight Test and Flight Sciences engineers.

On the day before the accident, the test team held two briefings for the accident flight. The pitch target for flaps 10 was changed from 10 to 9 degrees (+/-) 1 degree. This target was used during all test runs, including those with flaps 20 (which was already planned to be performed with a pitch target of 9 degrees). The maximum pitch was 20 degrees for all engines operating (AEO) takeoffs with flaps 20.

On the day of the accident, about 0645, both pilots entered the cockpit. The PIC sat in the left pilot seat, and the SIC sat in the right pilot seat. According to an onboard video recorder, the pilots’ respective seat positions did not change throughout the flight; the left seat pilot was the flying pilot, who manipulated the flight controls; and the right seat pilot was the nonflying pilot. FTE 1 and 2 were already onboard upon the flight crew's arrival. The on-board test team began their preflight checks for flight 153.

About 0652, the airplane engines were started and the airplane was then taxied to runway 21. Runway 21 was chosen by the PIC for the day's test because it avoided flight over a residential area. The residential areas were located at the departure end of runway 3.

The PIC set his primary flight display's flight path angle to 9 degrees. He practiced pulling on the control column several times targeting a column force of 60-65 lbs. The PIC said that a column force of 60-65 lbs was what he had used previously and found it to be "bobble free," a term used within the program to describe an overshoot of the pitch target that had occurred on previous field performance takeoff flights. FTE 2 asked FTE 1 where he could find center of gravity (CG) information on the performance screens, to which FTE 1 said that the information located on the secondary performance screens.

About 0708, the PIC briefed the takeoff, and the SIC performed the taxi/before takeoff checklist and confirmed that the flight controls were in First Flight Mode. The PIC centered the Flight Path Marker (FPA) on the heads up display (HUD) on the Standby Multifunction Controller (SMC). The PIC also checked with FTE 3 that the wind station was operational.

About 0710, FTE 3 announced that the test team would begin the test with Card 2C, an AEO takeoff at maximum takeoff weight (MTOW), maximum takeoff (MTO) power, and flaps 20 degrees. The PIC looked at Card 2, which had the following information highlighted: “9-degree pitch target” and "do not exceed 20 degrees pitch attitude." Card 2 was briefed by the SIC, who confirmed with FTE 1 the target speed for the takeoff. FTE 1 asked the flight crew to hold short for takeoff while he configured the FCC because he was “a little behind the power curve” because he was a “neophyte at doin’ this FCC stuff.” The PIC stated that he would target 12-14 degrees of pitch for V2 depending on the acceleration rate after rotation. The PIC stated not to wait for the gear up call but to raise the landing gear as soon as weight on wheels in Air Mode was displayed on the Flight Control Page of Display Unit 3 with a positive [climb] rate. The flight crew and FTE 1 later agreed to wait about one second after the Air Mode indication so that the landing gear would be down in the event that the airplane was not positively airborne, which would result in the airplane repeatedly contacting the runway. At the beginning of the test run, the SIC asked if the test run would be aborted if an 11 degree pitch target was encountered; the PIC said that it would. During the test run, the PIC applied a column force of 63 lbs and achieved about a 9-10 degree pitch, then 15 degrees during the initial climb, followed by 20 degrees pitch to maintain V2+10 knots. During the climb, the SIC raised the landing gear about 600 feet above ground level after he was questioned about its position by the FTE 1.

The PIC said that the PLI is “in the way of everything,” and that it is distracting and obscures the pitch attitude. The pilot chose to disable to FPA Mode Flight Director Display for subsequent runs.

About 0723, a second test run of Card 2C was performed. Following the test run, FTE 2 reported that the PIC achieved a column force of 71 pounds, there was no bobble, and the initial pitch was a little short. The peak pitch rate was 6.5 degrees/second. The PIC then indicated that he would try to use “slightly less” column force and use “more of a ramp” for the next test run. The PIC said that a pitch attitude of 20-22 degrees would be needed to maintain V2+10 knots. The PIC then asked what the reason was for a 20 degree pitch limit. FTE 1 said that a 20 degree pitch would be enough and agreed to limit it during climb to 20 degrees. The PIC asked what VR was, and FTE 1 deferred the question to FTE 3 who provided those values.

About 0741, the airplane was stopped on the taxiway to allow FTE 1 to discuss his flight test workstation screens with the primary FTE for flight controls via telephone. Meanwhile, FTE 3 confirmed V-speeds with the PIC. The PIC stated that almost 20 degrees of pitch would be needed to the maintain V2+10 knots. The SIC stated that he remembered “it was like you got to the pitch limit and you (didn't't/couldn't) pull fast enough.” and “it’s really kind of a different animal.” The PIC said “you don’t want to pull too much. I think the [PLI] is gonna have to be set higher because it comes on too early.” The PIC then discusses the PLI settings in terms of normalized angle-of-attack (NAOA) for landing. The SIC said “or like you just said just set it where the shaker – where the limit is and use it as a cue for the limit. Not sure – you know the way we’re using it is a holdover from the stick shaker/pusher concept instead of here's your limit maybe with this one, I don’t know.” FTE 1 then said that the team would perform another AEO test run to see if they could achieve a [9 degree pitch]. The PIC said that he would need a pitch attitude of 18 or 19 degrees and was going to “pull it up” to capture V2+10 knots.

About 0747, a third test run of Card 2C was performed, after which the PIC stated that there was a “bobble.” FTE 1 agreed and reported that the column force was 64 pounds and that the pitch attitude reached 9.8 degrees and then decreased to 8.4 degrees. The PIC said “well darn, let me keep working on it guys, sorry” and further stated, “just keep doing it. I…should have practiced more last week.” The PIC stated, “the only thing I can say is you’re not gonna be at 9 degrees very long if you want to catch V2.” FTE 1 replied that he agreed with the PIC’s statement. The PIC stated that “It’s like okay we’re there and let’s move on ‘cause it’s coming up, here it comes ready or not, and I’m still overshooting it."

About 0752, a fourth test run of Card 2C was being performed when about 7 seconds after rotation, the PIC noted the activation of the stick shaker about 18 degrees. The SIC then said "there’s twenty" and the PIC said "yeah there’s no way you’re gonna maintain it [V2+10 knots] within two knots…I mean we’re up at 20 right now. That's what it is.” FTE 1 stated that he thought the pitch was good, the column force was 57 pounds, and the control input was more of a ramp input. The PIC stated, “well that works to get rid of the bobble, but that may not be what [APG 1] wants.” Following landing, the airplane was taxied off the runway for a tire/brake check. During that time, APG 1 reviewed the test run data, which FTE 3 provided to the onboard test team. The pitch rate was about 5.5 degrees/second, and APG 1 was looking for 6 or 7 degrees/second. The rotation was good, the column force was 55 pounds, and the pitch was 8.7 degrees. The PIC said that he liked the lower column pull force and that he believed that it made the technique more repeatable. There was no “bobble” during the test run. The SIC stated that it was not a set procedure, and the PIC stated that they were trying to develop what they wanted to tell the “feds to use” to achieve V2 + 10 knots with AEO. The PIC added that more than 20 degrees of pitch was needed and then asked if they want to “knock it off at 20.” FTE said “yeah, I’m not all that concerned about gettin’…” and was interrupted by the PIC who stated, “I think that's more of an engine out event anyway...you're not at 9 degrees very long if you want to capture that rascal." FTE 1 confirmed that a 55-60 pound column pull force was effective.

About 0803, the PIC briefed the first test run for Card 3A, which was an OEI takeoff at MTOW, with MTO power on the left engine, MTO power to a throttle chop on the right engine, a forward CG, and flaps 20 degrees. The flight crew discussed the use of the HUD, but the PIC stated that he was not going to use it because he did not think the HUD was useful for maneuvers involving nose-high attitudes. He considered using synthetic vision but decided that it would not be appropriate for the test. He stated that he wanted a nice solid pitch attitude and an acceleration cue but that he could not have both on the same display. He briefed the maneuver again and said the 12 degrees of pitch might work to maintain V2. The PIC told the SIC to "make real sure" to raise the landing gear. The SIC said that he had been looking for the three "As" on the Flight Controls Display Page and then was waiting one second before raising the landing gear. The PIC added "a little positive rate on the radar altimeter." About 0808, Card 3A was performed after which the PIC stated that it took about 16 degrees of pitch to maintain V2 during the climb and FTE 1 noted that it took about 15 pounds of column force to maintain it. The PIC stated that he was using a nice smooth ramp input and that "I'm not doing that jerk stuff, because it just doesn't work." He added, "that's not the way they're going to fly the airplane, and I don't think the FAA's gonna like it either...it's such a great flying airplane, you shouldn't have to abuse it to get the damn thing flying." FTE 2 reported that the control column force was 60 pounds to which the PIC responded that it was comfortable. The SIC said "so a ramp [input] to 60 [pounds] worked pretty good."

About 0816, FTE 3 stated that APG 1 asked if the flight crew could release the input on the control column a little slower for the second test run for Card 3A. The flight crew asked if she meant when capturing 9 degrees, and FTE 1 said to do the same thing over again. After the test run, the PIC stated that he was trying to find a good pitch angle to maintain a stabilized V2 and that it took 12.5-13 degrees of pitch. He added, "but it's pretty dynamic, I mean you're going to overshoot it and then it comes back."

FTE 1 asked if it took a while to accelerate to V2 because the PIC had to hold pitch for a couple of seconds. The PIC said "no…it was pretty expeditious" and that they were exceeding V2 again, even with OEI. He said that he was trying to find the pitch to target and that it was "like 13, 14 [degrees]." The PIC said that he previously spoken with ETP 1 about what technique he used, which sounded "pretty jerky. I mean he'd come back with it and jerk it forward...you are setting yourself up for bobble city with that one." FTE 2 reported that the column force for the test run was 61.1 pounds. The PIC said that it was good and that is all that they needed. He said they did not need column forces of about 70 pounds anymore.

FTE 1 said that the only thing that he was seeing was that, "when you pause at the pitch I guess you're staying there a little while." The PIC said "yeah, I need to just keep going with it. I mean that's the thing. I mean we're so intent on capturing that I'm blowing through V2." The PIC said "it's almost like a continuous maneuver." The PIC said "so, I think the idea is though, to get the pitch to get the airplane airborne." FTE 1 agreed. The PIC said "but it's still blowing through V2 and it's just barely getting off the ground. I think it's just what it is, apparently, the only thing we can fix that, we had a lot of conversations about that is...we talked about an earlier rotation or earlier liftoff, but I think we're about as slow as we want to go on that I think, unless we're doing VMU testing." FTE 3 asked if they were going to perform the test run again, and the PIC responded that they were. FTE 3 said that they were about 2 knots below VR and 3.5 knots above V2. The PIC said "we're not going to hang out long at 9, we're going to hit nine and then we're gonna go for the 13 to 14 [degrees] for V2." FTE 1 agreed. The PIC repeated, "it's almost a continuous maneuver." He added that 3 knots above V2 was not bad because 2 knots was the criteria. The speed at 35 feet was critical. He said "nine degrees, based on that is a pretty good target...because that's how they're determining their distance."

About 0827, the third test run of Card 3A was performed. After the test run, FTE 1 said "I think that's it." The PIC said "we're done, I think we caught it there." FTE 1 agreed. The PIC said "we must be onto something there." FTE 1 said the airplane was still heavy and he thought that they would perform a maneuver with flaps 10 degrees and "tomorrow we'll go for score on it." The PIC said he was happy with the ramp input and 50-55 pounds of column force. The PIC added that the airplane was drifting a little bit but that he was not inputting roll.

The flight crew stopped the airplane in the hold short area and discussed the next test run, which was Card 6. The flight crew commented that the V-speeds did not change much for the change to flaps 10, except that V2 increased. The PIC said that he would rotate the airplane until a pitch of 9 degrees, wait for a positive rate of climb, and then capture V2. He also said that more than 20 degrees of pitch would be required to maintain V2 with both engines, but he liked the 9 degree pitch target and the rotation technique.

About 0842, the first test run of Card 6C was performed, which was an AEO takeoff at MTOW, MTO power, and a flap setting of 10 degrees. After the test run was completed, the PIC said "you just can't do it within 20 degrees." He asked what the pitch was and said that he must of have pulled a little bit more on the control column because he overshot the target a little bit. FTE 1 reported that the pitch was 10.5 degrees (the target pitch was 9 degrees). The airplane was stopped the ramp after FTE 1's display had malfunctioned. The airplane then taxied to the TM trailer to obtain assistance from technicians about 0857. The PIC left the airplane for a break about 0859. The SIC had a conversation with someone in the doorway of the airplane about the desired takeoff rotation technique, describing it as a pull to 9 degrees, a hesitation, and then an additional pull. The PIC then returned to the cockpit and said "so APG 1 is saying we don't want to hang out at 9 degrees very long. Engine-out we gotta just keep it coming." The SIC said "we were just talking about it with FTE 1. It's almost like it's just like a goal to go towards, but sometimes you get to it you gotta keep pulling again to keep the speed down." The PIC agreed. The SIC said "it's like the aggressive pull." The PIC agreed. The SIC said "and then the rest of it."

About 0912, the second test run of Card 6C was performed. During the test run, the PIC said that V2 could not be captured but that the test run looked good. FTE 1 reported that the pitch was "nailed" and that the column force was 56 pounds. After landing, FTE 1 said that the airplane was "pretty fast" at 35 feet. The PIC said "yeah…there's very little time at 9 [degrees], you just gotta keep going, you wanna try one more and I'll just pause at 9 [degrees] and just keep going?" FTE 1 concurred. The PIC said "I'll capture it and boom we're back into it. It's kinda what [APG 1] was saying. Let's try another one...based on what I looked at with [APG 1], it's almost a continual rotation. You can target 9 [degrees], but you don't want to hang out there very long, because it's gonna blow right through it. Now we're into kind of a technique thing in how we're gonna do this." FTE 1 said "okay...that's what I was hoping, just spend today just to get something we like."

About 0919, the third test turn of Card 6C was performed. At rotation, the PIC said "I'm going up, got 9 [degrees], I'm going up, didn't stay there very long that time." FTE 1 agreed. The PIC said "see what that does for us." FTE 1 said "okay that's good." The PIC said "did you like that one?" FTE-1 said "well you didn't stay long, that was better on pitch." The PIC said "got nine [degrees] and just continued up." FTE 1 said "you're six knots fast instead of ten, so that was a lot better. I think that's probably as good as it gets for that." The PIC said "could be, if you want any pause at nine [degrees]." FTE 3 said "speeds were better this time, pitch is a little high." The PIC said to FTE 3, "we didn't pause very long as 9 [percent]. We're trying to capture that V2 at 35 [feet], so we're just, it's just not there very long. I think that's what you were seeing." FTE 1 said "that helps." The SIC said "it's really just becoming, especially when it's all engines, a 50 pound pull just to try to get the speed, to get the rate." The PIC said "yeah I don't even have to think about it anymore, we don't have to be jerking it off the runway or anything." During the maneuver, the SIC attempted to raise the landing gear twice before the gear was in Air Mode. The SIC raised the gear successfully on the third attempt.

The test team then performed the first of two runs of last test card, which was Card 7, an OEI takeoff at MTOW, MTO power on the left engine, MTO power to a throttle chop on the right engine, and a flap setting of 10 degrees. During the first test run, the airplane was rotated to the 9 or 10 degrees of pitch, held for a few seconds, and then climbed at about 15 degrees of pitch. The pitch attitude remained very close to the PLI, tracking just under it. After landing, the PIC said that they could try the same test run again using less of a pause while at the target pitch value. He said "it's almost a continual maneuver then...I can try that, target nine [degrees] and just keep on going. I don't know how else we're gonna do it." FTE 1 said "it seems like we are kinda hangin' there for a little bit." The PIC said "well we're pausing, because we're tryin' to do this capture, and I think we're getting too focused on that…I think it's a target, and then uh 'cause you have a real engine failure, the guys aren't gonna be looking at nine degrees, they're gonna be lookin' at tryin' to get to V2, they're not gonna be payin' any attention to that. so that's what I'm thinkin'. It's an abnormal."

About 0933, the test team began the accident run. The PIC advanced the throttles with his right hand while his left hand was on the control wheel He moved his right hand onto the control wheel about 32 seconds later. At a speed of about 100 knots, the SIC retarded the right throttle to idle, and at a speed of about 127 knots, the PIC pulled back on the control column with both hands to rotate the airplane. After the pitch attitude reached about 10 degrees, the PLI appeared. The pitch attitude was at or near the PLI. The wings were level, and the slip indicator was displaced slightly to the left. The primary flight display showed a change in bank angle, and the PIC began made a left control wheel input. About 51 seconds after the test run began, the onboard video recording ended. At that time, the recording showed that the landing gear was extended.

The cockpit voice recorder (CVR) showed that, after the first officer called for rotation, the PIC stated, "[unintelligible] going on," which was followed by "whoa" by both pilots. The cockpit area microphone recorded increased background noise, and the audio panel electronic voice annunciated, “bank angle.” The PIC stated, “power power power,” and the SIC stated, “power power, power’s up.” The SIC stated “no no no no” as the bank angle annunciation continued. The PIC stated, “ah sorry guys,” which was the last transmission from the flight crew.

E. DETAILS OF THE INVESTIGATION

1.0 Operations Group Investigative Activities

The National Transportation Safety Board’s (NTSB) Operations / Human Performance Group Chairman initially attended a GAC Return to Flight presentation on May 19, 2011, with Federal Aviation Administration (FAA) Atlanta Aircraft Certification Office (ATL ACO) personnel at the offices of the ATL ACO, Atlanta, Georgia.

The Operations/Human Performance Group, initially consisting of only the NTSB members, first convened at the law offices of Tony Center in Savannah, Georgia, on June 1, 2011, and interviewed the spouses of three of the four fatally-injured crewmembers. On June 7, 2011, the group convened at GAC headquarters in Savannah, Georgia, for a briefing by GAC’s Safety Review Board (SRB). On June 16-17, 2011, the group, joined for the first time by the GAC Party Representative to the Operations/Human Performance Group, and an FAA Party Representative, convened at GAC headquarters, and interviewed eight GAC employees who were involved in the G650 flight test program. On July 7-8, 2011, the group, joined by a different FAA Party Representative, convened at the ATL ACO, and interviewed several FAA personnel who were involved with the oversight of GAC aircraft certification programs. On July 11-12 and August 8-12, 2011, the group convened at the NTSB Recorders Laboratory and reviewed the G650 accident flight (flight 153) cockpit voice recorder (CVR) recording and video recording from an on-board cockpit video recorder. In addition, the group reviewed flight test video recordings from certain earlier G650 program test flights.

Between September 12 and October 17, 2011, the group participated by telephone in informational discussions with four aircraft manufacturers to learn about industry flight test safety practices. On October 24-28, 2011, the group convened at GAC headquarters in Savannah, Georgia, and interviewed 18 employees involved in the G650 flight test program, 5 of whom had been interviewed previously.

In addition to these activities, the group conducted various telephone interviews and reviewed numerous documents.

2.0 History of Gulfstream’s G650 Field Performance Testing

Field performance developmental testing, which included landing and takeoff performance testing, was being performed in preparation for subsequent certification testing under 14 CFR Part 25, Airworthiness Standards for Transport Category Airplanes. The development flight was using company processes for flight operations and safety. This testing was performed by the accident airplane, which was also referred to by its serial number, 6002, and began with an initial deployment with flight 065 on October 19, 2010[3]. The initial takeoff performance tests were followed by 14 additional flights, which included the accident flight, flight 153.

The takeoff performance test flights were considered high risk tests and each flight was flown by two of four GAC experimental test pilots. The flights were conducted without the use of the airplane's angle-of-attack (AOA) limiter, which was part of the airplane's original design specifications. The development of the G650 AOA limiter software had not yet been completed at the time of the field performance testing. However, it was planned that the stick shaker, which was also part of the airplane's original design specifications, was to be used to provide tactile stall warning. The G650 design incorporated an AOA limiter in lieu of a traditional stick pusher.

During the second half of 2010 and the first quarter of 2011, other tests relating to various airplane systems were also performed on Gulfstream's fleet of 5 test aircraft, including flight tests on 6002 not related to field performance testing. The takeoff field performance developmental test flights (which are a subpart of field performance developmental testing), objectives, and test durations, flight crews, and locations are summarized in the following table:

Date	Flight	Objective	Flight Time (hours)	Pilots	Location
10/19/2010	065	V_{MCG} 1[4]	4.4	PJP[5], PIC[6]	KVQQ[7]
10/20/2010	067	V_{MCG} 2	3.4	PJP, PIC	KVQQ
11/10/2010	081	V_{MU}[8] at Heavy[9] Airplane Weight	2.1	PJP, PIC	KROW
11/11/2010	083	V_{MU} at Light Airplane Weight	0.9	PJP, PIC	KROW
11/14/2010	086	Takeoff Performance – AEO[10] and OEI[11]	4.5	PJP, PIC	KROW
11/15/2010	087	V_{MU}, Takeoff Performance, APU[12] starts, and RAT[13] Deployment	1.3	PJP, PIC	KROW
11/16/2010	088	V_{MU}, Takeoff and Landing Performance	1.9	PJP, PIC	KROW

[3] Gulfstream tracks test flight activity by flight number within each specific aircraft developmental flight test program
[4] V_{MCG} is the Minimum control speed on the ground - the minimum airspeed at which the aircraft is directionally controllable during acceleration along the runway with one engine inoperative, takeoff power on the operative engine(s), and with nose wheel steering assumed inoperative.
[5] PJP designates the GAC G650 Project Test Pilot.
[6] PIC designates the pilot-in-command of the accident flight, flight 153.
[7] KVQQ is Cecil Airport, Jacksonville, Florida.
[8] Section 3.2 of this report discusses V_{MU} definition and associated tests for its determination.
[9] GAC defined aircraft weight ranges into categories of light, medium, and heavy.
[10] All engines operating.
[11] One engine inoperative.
[12] Auxiliary power unit.
[13] Ram air turbine.

11/17/2010	089	Normal and Abused Takeoff Performance	1.3	PJP, PIC	KROW
11/18/2010	091	V_{MU}, Abused Takeoff, Out-of-Trim Takeoff	2.0	PJP, PIC	KROW
02/13/2011	111	Takeoff Technique Development	4.1	PJP, SIC[14]	KBHM[15]
03/11/2011	129	Takeoff Performance	4.5	PJP, SIC	KROW
03/12/2011	130	Takeoff Performance and Braking Performance	4.5	ETP[16], SIC	KROW
03/13/2011	131	Takeoff Performance and Performance Braking	1.4	ETPETP, SIC	KROW
03/14/2011	132	Takeoff Performance, Performance Braking	4.6	SIC, ETPETP	KROW
04/2/2011	153	Takeoff Performance	2.7	PIC, SIC	KROW

Table 1: Takeoff Field Performance Developmental Test Flights in Aircraft 6002

The initial series of field performance flights conducted at KROW in November 2010 prior to flight 111 was designated by GAC as "Roswell I.[17]" Roswell I included aircraft 6002 experimental test flights 080 through 093.

For each flight, the flight crew was tasked with multiple test runs.[18] During flight 088, the airplane experienced a right wing drop/rolloff immediately after liftoff during a V_{MU} test run with flaps 20 and a medium airplane weight. The flight test crew recovered the airplane, continued a climb out, and returned for landing without further incident. The airplane did not contact the ground and was not damaged during the run. The incident test run was flown by the pilot-in-command of flight 153 (PIC) who was accompanied by the G650 project pilot (PJP) in the right seat. Following the incident, GAC personnel attributed the wing drop/rolloff to an over rotation by the PIC. GAC at that time did not analyze whether a stall had occurred prior to the predicted in-ground effect (IGE) stall angle (See Section 10.0 for further elaboration on flight 088).

In January 2011, the Flight Sciences Principal Engineer (APG 4), FTE 1, the Chief FTE – Staff Scientist (FTECS), and APG 1 met together to discuss the fact that they were experiencing excess desired speeds if a constant pitch was held following V_R. They suggested that if the technique was adjusted to increase pitch, then the resulting slower speeds and additional climb may result in a better V_2 speed.

[14] SIC designates the second-in-command of the accident flight, flight 153.
[15] KBHM is Birmingham-Shuttlesworth International Airport.
[16] ETP designates an Experimental Test Pilot assigned to field performance testing
[17] Other field performance developmental tests relating to landing performance and the like were performed during Roswell I that are not set out on the table above.
[18] A test run is one test card completion. There may be multiple times a test card is performed; therefore, multiple runs which are tracked incrementally.

Between Roswell I and KBHM, on February 11, 2011, at one of several weekly meetings held with a group of about 50 people comprised of the G650 development program team, the GAC Senior Vice President of Programs, Engineering and Test and the Vice President G650 Program, Flight Sciences discussed initial field test performance issues, including that the speeds were high and the takeoff field lengths were longer than the G650's 6,000-foot takeoff field length (+/-8%) guarantee target. The guarantee was based on an aircraft takeoff configuration with flaps 20. A portion of the calculation required one engine inoperative (OEI) data. There was no performance guarantee for an aircraft takeoff configuration with flaps 10. The flaps 10 and OEI test data was to be used for competitive based performance takeoffs at high airport elevations. Flight Sciences told the group that they could improve on Roswell I results with technique improvements intended to be tested at KVQQ, but eventually were tested at KBHM.

The PIC and the second-in-command of flight 153 (SIC) did not attend the Certification Issues weekly meetings, which was usually attended by PJP.

Flight 111 was flown at KBHM by the PJP with the accident flight SIC seated in the right seat. That testing further convinced APG 1, APG 4, FTE Group Head (FTEGH) and FTE 1 that they were coming very close to the GAC guarantee target for takeoff performance. Testing continued, and after flight 125, in preparation for flight 132, the stick shaker onset AOA setting was increased, but was still determined to provide margin to IGE stall AOA using revised estimates based on V_{MU} test results (See Section 11.0 for further elaboration on stick shaker setting).

Flight 132 was then conducted during the second deployment to Roswell ("Roswell II"), and during the second test run, the airplane encountered a wing drop/rolloff. Flight 132 was a simulated (OEI) takeoff with flaps 20 and a light airplane weight. The pilot-in-command for flight 132 was the SIC for the accident flight. The second-in-command for flight 132, who was also an experimental test pilot for field performance testing (ETP), originally attributed the wing drop/rolloff to a stall due to over rotation, the wing drop/rolloff was later attributed to an inoperative yaw damper and loss of directional control following a post flight review. (See Section 12.0 for further elaboration on flight 132).

The accident flight, flight 153, was a field performance developmental test flight performing heavy and medium weight all engines operating (AEO) and OEI continued takeoff (CTO) tests. The accident occurred during the second run of an OEI test with flaps 10 and a heavy takeoff weight. The accident occurred after the previous run of the test card had not met the test criteria for capturing and maintaining V_2 (See Section 13.0 for further elaboration on flight 153).

3.0 Flight Test Crew and Support Team Information

There were 22 GAC personnel and 3 GAC supplier personnel at KROW on the morning of the accident. The test team for flight 153 was comprised of four GAC personnel onboard the airplane and five GAC personnel in a telemetry (TM) trailer. The four personnel onboard, which made up the "minimum" flight test crew, were two Flight Operations Experimental Test Pilots, the lead flight test engineer for field performance testing (FTE 1) and another Flight Test Engineer (FTE 2). According to a March 29, 2011, email, FTE 1 stated that he would monitor the flight control system and delegate other duties to FTE 2 for the upcoming testing at KROW.

The GAC personnel within the telemetry (TM) trailer were a Flight Sciences Airplane Performance Group Head (APG 1), a Flight Test Engineering Technical Specialist, Aerodynamics (FTE 3), a Flight Sciences Preliminary Design Specialist, Environmental/Performance (APG 2), another Flight Sciences engineer (APG 3), and a Flight Test Instrumentation Engineer (FTIE).

According to the APG 1, Flight Sciences personnel other than herself and APG 4 attended various field performance tests to gain experience in flight test for future programs. APG 2 had participated in all field performance testing during Roswell I. APG 3 did not have in experience in GAC field performance testing prior to flight 153.

According to the Vice President of Flight Operations, company records indicated that the G650 CTO test experience of the four pilots who had been performing field performance testing was as follows:

Pilot	Total V_{MU}	Total CTOs
PJP	21	67
PIC	21	59
SIC	0	50
ETP	0	20

Table 2: Test Pilot Experience in Continued Takeoff Flight Testing

In addition, the PIC had performed numerous CTOs on other GAC aircraft models as well as several military aircraft (See Section 3.1 for further information on the PIC's experience). The Vice President of Flight Operations (FLTOPS 1) also stated that the PIC and SIC had extensive experience performing CTOs.

PJP and ETP had performed a series of aerodynamic stalls in the G650 during previous flight testing. In addition to the direct experience noted in the previous wing drop/rolloff events of flights 088 and 132, the PIC had previously performed at least one G650 aerodynamic stall, and the SIC had performed none during previous testing. Both the PIC and SIC had experience with aerodynamic stalls as part of their military backgrounds.

According to the FLTOPS 1, who was also a flight test pilot and graduate of the United States Air Force USAF Test Pilot School with 30 years of flight test experience, a test pilot is differentiated from an operational pilot by a test pilot's expertise in the flight test discipline. What differentiates flight test pilots first and foremost is their training on how to conduct flight test operations safely and their experience in flight test. In his view, excellent flying skills alone are not enough to be a successful flight test pilot. He added that the complete skill set necessary to successfully perform the precise test maneuvers needed in a flight test program were usually based upon not just an extensive aviation background, but also on having some education in an engineering field so the pilot could understand the underlying theory of the test maneuvers. FLTOPS 1 also stated that test pilots are not often going to perform the theoretical calculations pertaining to a particular flight test or set of flight tests; however, they know the theory and bring prior experience from other test programs with which to judge the information they are provided.

Test pilots rely on information that is provided by engineers, but he believes that a flight test pilot must still question the data. He added that in the course of testing, a flight test pilot has to make sure it passes the common sense test.

According to the Senior Vice President, Programs, Engineering and Tests, GAC will now pair the most senior design engineering talent with the flight test engineering group to support subsequent high risk tests.

3.1 PIC Information

Age: 64
Date of Hire: August 25, 1997
FAA Certificates: **Airline Transport Pilot (ATP)**
Airplane Multi-Engine Land
B-707 (VFR only), B-720 (VFR only), G-1159 (GII/GIII), GIV, GV, and LR-JET
Commercial Privileges
Airplane Single-Engine Land, Glider
Flight Instructor
Airplane Single-Engine Land, Airplane Multi-Engine Land, Glider

The PIC received a Bachelor of Science degree in General Engineering from The United States Military Academy in 1969. He received a Master of Science degree in Aeronautical Engineering from the Air Force Institute of Technology in 1976. He was a Distinguished Graduate of the USAF Test Pilot School (TPS) in 1981.

From 1977 – 1980, he was assigned to the USAF TPS and from 1981 – 1983, he was reassigned to the USAF Academy, Department of Aeronautics, as Professor where he was the test director/project pilot on the Schweizer TG-7A Motorglider. From 1983 – 1985, he was a USAF TPS flight and academic instructor where he also served as Chief of Academics. He was an instructor pilot in the Northrop T-38 Talon, deHavilland U-6 Beaver and UV-18 Twin Otter, and glider airplanes.

From 1985 – 1989, he was a Boeing B-52G Stratofortress project test pilot and investigated aircraft flutter, performance, and stability and control. From 1988 to 1989, he was Squadron Commander of the 6519th Test Squadron, Edwards Air Force Base, California. In 1989, he retired from active duty as a Lieutenant Colonel.

From February – October 1990, he was employed by a Part 121 air carrier as a DC-9 first officer. He left that position to return to flight test.

From October 1990, he was employed by Northrop Grumman Corporation as a Senior Engineering Test Pilot on the B-2 program where his test experience was in the areas of performance, stability and control, flutter, all weather, aircraft subsystems, and engine out testing. From 1993 – 1995, he was the Chief Test Pilot for the Northrop Joint Primary Aircraft Training System, during which he conducted performance, stability and control, and spin testing of the EMB-312H Super Tucano.

On August 25, 1997, he began employment with GAC as an experimental test pilot. Among other flight test duties, he was the project pilot for HALO, CAEW, SEMA, JCG, and HIAPER Special Missions derivative programs, including field performance test points such as V_{MU}, V_{MCA}, V_{MCL}, and V_{MCG}. He was also involved in field performance certification testing on the GV-SP, including V_{MCG}, V_{MU} and AEO and OEI CTO test points.

3.1.1 Aircraft Flown by PIC

Boeing B-52D,F,G,H
Boeing KC-135 Stratotanker
Cessna A-37 Dragonfly
Cessna T-37 Tweet
Cessna T-41 Mascalero
deHavilland C-7A Caribou
deHavilland U-6 Beaver Learjet
deHavilland UV-18 Twin Otter
EMB-312H Super Tucano
Gliders
Gulfstream IV
Gulfstream V
Gulfstream VI
Learjet 35A
Lockheed C-130 Hercules
Lockheed T-33 Shooting Star
LTV A-7 Corsair
McDonnell Douglas DC-9
McDonnell Douglas F-4 Phantom
Northrop Grumman B-2 Spirit
Northrop T-38 Talon
Schweizer TG-7A Motorglider

3.1.2 The PIC's Certification Record

On April 29, 1981, the he was initially issued a Federal Aviation Administration commercial pilot certificate with airplane single and multi–engine land and B-707 (VFR only) ratings based on military competency. His airman application for the certificate indicated: 1,560 hours pilot-in-command, 600 hours second-in-command, and 230 hours of instruction received. Subsequently, a glider rating was added to his commercial pilot certificate. On January, 18, 1991, he was issued an ATP certificate with a Learjet rating. On October 18, 1997, a Gulfstream GV rating was added to his ATP certificate. On October 16, 1997, B-707 and B-720 ratings were added to his ATP certificate along with a GV rating. On October 30, 1998, he was issued his last airman pilot certificate, which added a G-1159 (GII/GIII) rating on his ATP certificate.

He received his last Part 61.58 Pilot-in-Command Proficiency Checks under for GIV and GV series airplanes after completing flight simulator and ground training at FlightSafety International in Savannah, Georgia. He completed the GIV check on April 23, 2010, and the GV check on February 17, 2011.

FAA records indicate that the pilot had no record of accidents, incidents, or enforcement actions.

3.1.3 The PIC's Flight Times

The left seat pilot's flight times, based on GAC records:

Total pilot flying time	11,237 hours
Total PIC time	9,500 hours
Total GVI flying time	263 hours
Total GVI PIC time	160 hours
Total flying time last 24 hours	2 hours
Total flying time last 7 days	21 hours
Total flying time last 30 days	39 hours
Total flying time last 60 days	63 hours
Total flying time last 90 days	117 hours
Total flying time last 12 months	306 hours

3.2 SIC Information

Age: 51
Date of Hire: July 9, 2007
FAA Certificates: **Airline Transport Pilot (ATP)**
Airplane Multi-Engine Land
B-737, G100, IA-1125, GV
Commercial Privileges
Airplane Single-Engine Land, Glider
Flight Instructor
Airplane Single-Engine Land, Instrument Airplane, Airplane Multi-Engine Land (Limited to Centerline Thrust)

The SIC received a Bachelor of Science degree in Marine Systems Engineering from the U.S. Merchant Marine Academy in December 1999. He received a Masters of Science degree in Aeronautical Engineering from the Naval Postgraduate School. He also was a graduate of the U.S. Naval Test Pilot School.

From January 2000 – August 2002, he was a test pilot in the Naval Strike Test Squadron on X-31, F/A-18, and T-45 airplanes. He was involved in high AOA and Flush Air Data Systems on the X-31 Vector program. He conducted developmental engine surge and ground handling on the T-45 and multi-information distribution systems testing on the F/A-18. From September 2,002 – March 2004, he was a program manager for U.S. Joint Advanced Tactical Missile Systems and AIM-9X.

From March 2004, he was the officer-in-charge at Cecil Field, Defense Contract Management Agency where he oversaw the maintenance and modification of F/A-18 and E-6A airplanes and conducted functional check flights on the F-18/A-F airplanes and the Joint Helmet Mounted Cuing System.

On June 9, 2007, he began employment with GAC in Airborne Product Support as a captain.

On April 12, 2010, he was reassigned to the GAC Experimental Flight Test department.

3.2.1 Aircraft Flown by SIC

McDonnell DouglasF/A-18 A-F Hornet	North American T-2B/C Buckeye
Gulfstream IV	Beechcraft T-34B/C Mentor/Turbo-Mentor
Gulfstream V	Northrop T-38A Talon
Gulfstream VI	McDonnell DouglasT-45A/C Goshawk
Douglas T/A-4J Skyhawk	Rockwell-Messerschmitt-Bölkow-Blohm X-31

3.2.2 The SIC's Certification Record

On July 18, 1990, the right seat pilot was initially issued a commercial pilot certificate with airplane single-engine land, airplane multi-engine (limited to centerline thrust) based on military competency. On November 19, 2006, he was issued an ATP certificate with a B-737 rating. On August 4, 2007, an IA-1125 (G100) rating was added to his ATP certificate. On December 22, 2009, a GV rating was added to his ATP certificate.

He received his last Part 61.58 Pilot-in-Command Proficiency Checks under Part 61.58 for GV series airplanes after completing flight simulator and ground training at FlightSafety International in Savannah, Georgia. He completed the GV check on November 12, 2010.

FAA records indicate that the pilot had no record of accidents, incidents, or enforcement actions.

3.2.3 The SIC's Flight Times

The right seat pilot's flight times, based on GAC employment records:

Total pilot flying time	3,940 hours
Total PIC time	2,637 hours
Total GVI flying time	140 hours
Total GVI PIC time	78 hours
Total flying time last 24 hours	2 hours
Total flying time last 7 days	2 hours
Total flying time last 30 days	44 hours
Total flying time last 60 days	72 hours
Total flying time last 90 days	89 hours
Total flying time last 12 months	151 hours

3.3 FTE 1 Information

Date of Hire: June 8, 2009

FTE 1 received a Bachelor of Science in Aerospace Engineering from Iowa State University, Ames, Iowa, in 1986.

From 1987 – 1995, the lead FTE 1 was a McDonnell Douglas senior flight test and performance engineer on the C-17 program. During that program, he was involved with C-17 takeoff and landing performance flight manual data expansion, airspeed calibrations, and rejected takeoff and landing tests. He was also involved in the MD-11 program with airspeed calibrations and stall speeds analysis, cruise performance, drag reduction, takeoff performance, buffet boundary, minimum control speeds, and V_{MU} speeds.

From 1995 – 1999, he was employed by Lockheed Martin Aeronautical Systems Company where he was a senior specialist flight test analyst engineer. He was a designated engineering representative (DER) flight analyst. He reviewed aircraft conformity issues, pre-type inspection authorization (TIA) test results, and TIA test results for all FAR Subpart B performance and flying qualities. He was involved in the C-27J propulsion, avionics, and data processing coordination and management. He worked on the C-130J airspeed calibrations, stall speeds, stall characteristics, cruise and climb performance, and thrust deck substantiation. He was also a flight manual committee group chairman. He was involved in the C-5 reduced vertical separation Minima (RVSM) airspeed calibrations.

From 1999 – 2002, he was the Flight Sciences section chief at Bombardier Aerospace Flight Test Center. He was the Flight Sciences group lead supervising aircraft performance, flying qualities, and weights tasks. He was a Transport Canada design approval designee for performance and flying qualities. He also prepared ASTOR, BD-100, and RJ-900 airplane performance test definition sheets.

From 2002 - 2009, he was employed by Lockheed Martin Aeronautical Systems Company as a senior specialist in flight test operations on the F-16. He was involved in the planning and integration of tests relating to handling qualities, high AOA, air data development, loads, flutter, data link, electronic warfare, and maximum gross weight takeoff and landing.

From 2009, he was employed as a senior technical specialist within the Flight Test Engineering department. He was involved in aerodynamic performance tests, including natural icing and ice shape testing, and led the G650 takeoff performance test program. On October 1st, 2010, he became a Gulfstream Flight Analyst DER.

3.4 FTE 2 Information

Dates of Hire: November 13, 2006
FAA Certificates: **Airline Transport Pilot (ATP)**
Airplane Multi-Engine Land
G150, G200, CL600
Commercial Privileges

Rotorcraft
Instrument Privileges
Rotorcraft

FTE 2 received a Bachelor of Engineering Science and Mechanics degree from the Georgia Institute of Technology in 1988. From 1983-1997, he served in the United States Army Reserve where he became qualified to pilot CH-47D and UH-1H helicopters and was a maintenance officer and flight platoon leader.

From 1988 – 1993, he was employed at the Douglas Aircraft Company in areas of aircraft performance, flying qualities, structures, propulsion, systems, and avionics tests. He also assisted in the approval and certification of T-45A and MD-11 airplanes.

From 1994 – 1996, he was an FAA contract project engineer in research for differential augmentation technology for the satellite-based precision instrument approach systems where he drafted test plans and evaluated data form flight and laboratory tests.

From 1996 – 1997, he was a contract FTE employed by GAC as an avionics test engineer for the GV certification program. He was involved in testing and data analysis and wrote certification reports. He was also involved in the integration and testing of cockpit displays, radar altimeter, and the maintenance data acquisition unit. He planned and conducted trials for differential global position system (GPS) accuracy, which was used for all GV field performance tests.

From 1997 – 2000, he was employed by Lockheed Martin Aeronautical Systems as a contract FTE and was a Flight Test Analyst on C-130J and C-5M test programs. He was involved in the planning, execution, and reporting of air data, performance, and flying qualities tests that also involved systems tests. In 2000, he began employment with Atlantic Southeast Airlines as a first officer on Canadair Regional Jet CRJ-200 and EMB-120 airplanes and then upgraded to captain on the CRJ-200. During 2004 – 2006, he was simultaneously employed at Lockheed Martin Aeronautical Systems.

From 2006, he was employed at GAC as a senior production test pilot for airworthiness flight on G150 and G200 airplanes and performed maintenance check flights, customer demonstration flights, training flights, and service flights. On April 13, 2009, he became an FTE on the G650 test program during which he was involved in air data calibration, thrust reverser certification testing, and icing flying qualities tests.

3.5 APG 1 Information

Date of Hire: March 3, 2003[19]

APG 1 received a Bachelor of Science in Aerospace Engineering from Pennsylvania State University in 2001.

[19] Date of hire for full-time employment.

Following a GAC internship with the Flight Sciences and Structures Groups, she was hired as an Engineer II and on March 27, 2006, became a Flight Sciences Technical Specialist. She indicated during an interview that she had been working on the G650 since the completion of the preliminary phase and the beginning of the developmental phase.

From 2002-2008, her test experience included, but not limited to: G550 field performance flight testing in 2002, research and development high-speed wind tunnel testing in 2005, and G650 cryogenic wind tunnel testing.

In 2009, APG 1 became an FAA DER.

On July 6, 2010, APG 1 became the Flight Sciences Group Head and during her interview she stated that her role in the G650 program was as lead performance engineer, specifically on aircraft performance which includes takeoff climb, cruise, descent and landing areas. APG 1's managerial functions included supervision of 7 engineers within the Flight Sciences Department, creating program task breakdowns to ensure program schedule and goals, and formulating resource plans and budget requirements.

3.6 APG 2 Information

Date of Hire: October 22, 2007
FAA Certificates: **Private Pilot**
Single-Engine Land

The Flight Sciences Preliminary Design Specialist received a Bachelor of Arts in English in 1995, a Master of Arts in Teaching in 1997, and a Doctorate in Aerospace Engineering with a thesis in volumetric aircraft sizing from Georgia Institute of Technology in 2007.

From October 2007, he was employed by GAC as an Engineer II and on March 29, 2010, as a Technical Specialist I. At the time of the accident, APG 2 was on loan to the Flight Sciences Airplane Performance Group.

3.7 FTE 3 Information

Start of Contract Work: June 2010

FTE 3 received a Bachelor of Science in Aeronautical and Astronautical Engineering from Purdue University in 1981, a Bachelor of Science in Applied Mathematics from Wichita State University in 1995, a, and a Masters Degree in Statistics from Wichita State University in 2002.

From 1995 – March 2009, she was employed at the Cessna Aircraft Company where she held positions as an FTE on the Citation X and as an aerodynamics engineer on the Cessna Columbus, Mustang, Sovereign, and Citation X aircraft. As an FTE, she evaluated the simulated data against flight test data, evaluated takeoff performance data, and prepared technical publications data. As an aerodynamics engineer, she reduced and evaluated wind tunnel data, evaluated takeoff, and landing performance data, and established wind tunnel test requirements for specific airplane configurations in addition to other activities.

From 2010 to present, FTE 3 was a contract FTE for Gulfstream working the field performance test program.

4.0 FAA Flight Test Advisory and Certification Standards Information

Advisory Circular (AC) 25-7A, Flight Test Guide for Certification of Transport Category Airplanes, provides guidance for the flight test evaluation of transport category airplanes. These guidelines provide an acceptable means of demonstrating compliance with the pertinent regulations contained in 14 CFR Part 25. Section 2 of the AC discusses takeoff field performance maneuvers to be used in speed development or V-speeds, which are, in part, defined and explained in the following sections of this report.

Order 4040.26A, Aircraft Certification Service Flight Safety Program, dated March 23, 2001, provides guidance to FAA ACO personnel when conducting certification flight testing with aircraft manufacturers. Additionally, the guidance is also used as part of safety related agreements and standards with the respective aircraft manufacturer with whom they will participate in certification testing. The document, agreements, and Federal Regulations do not give the FAA authority to oversee the conduct of experimental or developmental flight test operations by aircraft manufacturers, beyond what authority the FAA may possess under Part 91 of the FARs.

4.1 Advisory Circular 25-7A, Flight Test Guide for Certification of Transport Category Airplanes

4.1.1 Takeoff Decision Speed (V_1).

The takeoff decision speed, V1, is the maximum speed during the takeoff at which a pilot can safely stop the aircraft without leaving the runway. This is also the minimum speed that allows the pilot to safely continue to the Takeoff Safety Speed, even if a critical engine failure occurs between V_1 and V_2.

V_1 may not be less than V_{EF}[20] plus the speed gained with the critical engine inoperative during the time interval between V_{EF} and the instant at which the pilot takes action after recognizing the engine failure. This is indicated by pilot application of the first deceleration device such as brakes, throttles, spoilers, etc. during accelerate-stop tests, or by the first control input during V_{MCG} testing. The applicant may choose the sequence of events. If it becomes evident in expansion of takeoff data for the aircraft flight manual (AFM) that excessive variation in V_1 exists, resulting from the many performance variables involved (variations of +1.5 knots or +100 feet have been found acceptable), then measures should be taken to ensure that scheduled performance variations are not excessive. Examples of such measures are small field length

[20] V_{EF} is the speed at which the critical engine is assumed to fail during takeoff.

factors, or increments, and multiple web charts (accelerate go/stop, V_1/V_R) for a particular configuration.

4.1.2 Minimum Unstick Speed (V_{MU})

The minimum unstick speed,$V_{MU,}$ is the speed at which the weight of the airplane is completely supported by aerodynamic lift and thrust forces.

V_{MU} tests are performed by rotating the airplane as necessary to achieve the V_{MU} attitude. It is acceptable to use some additional nose-up trim over the normal trim setting during $V_{\mathbf{MU}}$ demonstrations. Determining the liftoff point from gear loads and wheel speeds has been found acceptable in past programs. After liftoff, the airplane should be flown out of ground effect. During liftoff and the subsequent climb out, the airplane should be fully controllable.

V_{MU} testing is a maximum performance flight test maneuver, and liftoff may occur very near the AOA for maximum lift coefficient. Also, even though pitch attitude may be held fairly constant during the maneuver, environmental conditions and transiting through ground effect may result in consequential changes in AOA. It is permissible to lift off at a speed that is below the normal stall warning speed, provided no more than light buffet is encountered.

An artificial stall warning system (e.g., a stick shaker) may be disabled during V_{MU} testing, although doing so will require extreme caution and depend upon a thorough knowledge of the airplane's stall characteristics. If the airplane is equipped with a stick pusher, for flight test safety reasons it should normally be active and set to the minimum AOA side of its rigging tolerance band. However, depending on the airplane's stall characteristics and the stick pusher design, disabling the pusher or delaying activation of the system until a safe altitude is reached may be the safer course. Again, this decision should be made only with a thorough knowledge of the airplane's stall characteristics combined with a complete understanding of the stick pusher design.

4.1.3 Rotation Speed (V_R)

Rotation Speed is the speed at which the airplane's nose wheel leaves the ground.

The rotation speed, V_R, in terms of calibrated airspeed is selected by the type certificate (TC) applicant. V_R has a number of constraints that must be observed in order to comply with Part 25.107(e).

Early rotation, one-engine-inoperative abuse test.

> (1) In showing compliance with Part 25.107(e)(3), some guidance relative to the airspeed attained at the 35-foot height during the associated flight test is necessary. As this requirement dealing with a rotation speed abuse test only specifies an early rotation (V_R-5 knots), it is interpreted that pilot technique is to remain the same as normally used for a OEI condition. With these considerations in mind, it is apparent that the airspeed achieved at the 35-foot point can be somewhat below the normal scheduled V_2 speed.

However, the amount of permissible V_2 speed reduction must be limited to a reasonable amount as described below.

(2) These test criteria are applicable to all unapproved, new, basic model airplanes. They are also applicable to previously approved airplanes when subsequent abuse testing is warranted. However, for those airplanes where the criteria herein are more stringent than that previously applied, consideration will be given to permitting some latitude in the test criteria.

(3) In conducting the flight tests required by Part 25.107(e)(3), the test pilot shall use a normal/natural rotation technique as associated with the use of scheduled takeoff speeds for the airplane being tested. Intentional tail or tailskid contact is not considered acceptable. Further, the airspeed attained at the 35-foot height during this test must not be less than the scheduled V_2 - 5 knots. These speed limits should not be considered or used as target V_2 test speeds, but rather are intended to provide an acceptable range of speed departure below the scheduled V_2 value.

(4) In this abuse test, the simulated engine failure should be accomplished sufficiently in advance of the V_R test speed to allow for engine spin-down, unless this would be below the V_{MCG}, in which case V_{MCG} should govern. The normal one-engine-inoperative takeoff distance may be analytically adjusted to compensate for the effect of the early thrust reduction. Further, in those tests where the airspeed achieved at the 35-foot height is slightly less than the V_2-5 knots limiting value, it will be permissible, in lieu of conducting the tests again, to analytically adjust the test distance to account for the excessive speed decrement.

All-engines-operating abuse tests.

(1) Section 25.107(e)(4) states that there must not be a "marked increase" in the scheduled takeoff distance when reasonably expected service variations such as early and excessive rotation and out-of-trim conditions are encountered. This has been interpreted as requiring takeoff tests with all engines operating with:

(a) An abuse on rotation speed, and

(b) Out-of-trim conditions, but with rotation at the scheduled V_R speed.

NOTE: The expression "marked increase" in the takeoff distance is defined as any amount in excess of 1% of the scheduled takeoff distance. Thus, the abuse tests should not result in field lengths more than 101% of the takeoff field lengths calculated in accordance with the applicable requirements of Part 25 for presentation in the airplane flight manual (AFM).

(2) For the early rotation abuse condition with all engines operating, and at a weight as near as practicable to the maximum sea level standard day takeoff weight limit, it should be shown by test that when the airplane is over-rotated at a speed below the scheduled

V_R, no “marked increase” in the scheduled AFM field length will result. For this demonstration, the airplane should be rotated at a speed 7 % or 10 knots, whichever is less, below the scheduled V_R. Tests should be conducted at a rapid rotation rate or should include an over rotation of 2 degrees above normal attitude after liftoff. Tail strikes during this demonstration are acceptable if they are minor and do not result in unsafe conditions.

(3) For reasonably expected out-of-trim conditions with all engines operating and as near as practicable to the maximum weight allowed under sea level standard day conditions, it should be shown that there will not be a “marked increase” in the scheduled AFM takeoff distance when rotation is initiated in a normal manner at the scheduled V_R speed. (See paragraph 21(c)(7)(ii) for additional guidance regarding the evaluation of flight characteristics for out-of-trim conditions.) The amount of mistrim should be the maximum mistrim that would not result in a takeoff configuration warning, including taking into account the takeoff configuration warning system-rigging tolerance. It is permissible to accept an analysis in lieu of actual testing if the analysis shows that the out-of-trim condition would not present unsafe flight characteristics or “marked increase” in the scheduled AFM field lengths.

Stall Warning During Takeoff Speed Abuse Tests

The presumption is that if an operational pilot was to make an error in takeoff speeds that resulted in an encounter with stall warning, the likely response would be to aggressively recover to a safe flight condition rather than making a conscious effort to duplicate the AFM takeoff performance data. Therefore, the activation of any stall warning devices, or the occurrence of airframe buffeting during takeoff speed abuse testing, is unacceptable.

4.1.4 Liftoff Speed (V_{LOF})

The liftoff speed, $V_{LOF,}$ is defined as the calibrated airspeed at which the airplane first becomes airborne (i.e., no contact with the runway). V_{LOF} differs from V_{MU} in that V_{MU} is the minimum possible V_{LOF} speed for a given configuration, and depending upon landing gear design, V_{MU} liftoff is shown to be the point where all of the airplane weight is being supported by airplane lift and thrust forces and not any portion by the landing gear.

4.1.5 Expansion of Takeoff and Landing Data for a Range of Airport Elevations

Guidelines for the expansion of takeoff and landing data for a range of airport elevations apply to expanding AFM takeoff and landing data above and below the altitude at which the airplane takeoff and landing performance tests are conducted. Historically, limits were placed on the extrapolation of takeoff data. In the past, takeoff data could generally be extrapolated 6,000 feet above and 3,000 feet below the test field elevation when proven testing and data reduction methods were used. For extrapolations beyond these limits, a 2% takeoff distance penalty was to be applied for every additional 1,000 feet extrapolation. Such limitations were generally not applied to extrapolation of landing data, provided the effect of the higher true airspeed on landing distance was taken into account.

Since then, considerably more experience has been gained both in terms of modeling airplane and propulsion system (i.e., turbine engines and propellers, where appropriate) performance and in verifying the accuracy of these models for determining high (and low) altitude takeoff and landing performance. This experience has shown that the soundness of the extrapolation is primarily a function of the accuracy of the propulsion system performance model and its integration with the airplane drag model. The basic aerodynamic characteristics of the airplane do not change significantly with altitude or ambient temperature, and any such effects are readily taken into account by standard airplane performance modeling practices.

4.2 Order 4040.26A, Aircraft Certification Service Flight Safety Program

Order 4040.26A, appendix 3, provides direction for risk assessment and risk alleviation. The associated FAA risk hazard levels are defined with examples of tests that would fall into levels of high, medium, and low risk. The Order also states that these definitions are "very subjective and are used the assignment of risk levels." These risk levels are defined as:

> High Risk – Test or activities which present a significant risk to personnel, equipment, or property, even after all precautionary measures have been taken. This necessitates close oversight at all levels.
>
> Medium Risk – Test or activities which present a greater risk to personnel, equipment, or property than normal operations and require more than routine oversight.
>
> Low Risk – Test or activities which present no greater risk to personnel, equipment, or property than normal operations..

The following chart from Order 4040.26 is provided to help visualize the categories. The dark colored area represents High Risk:

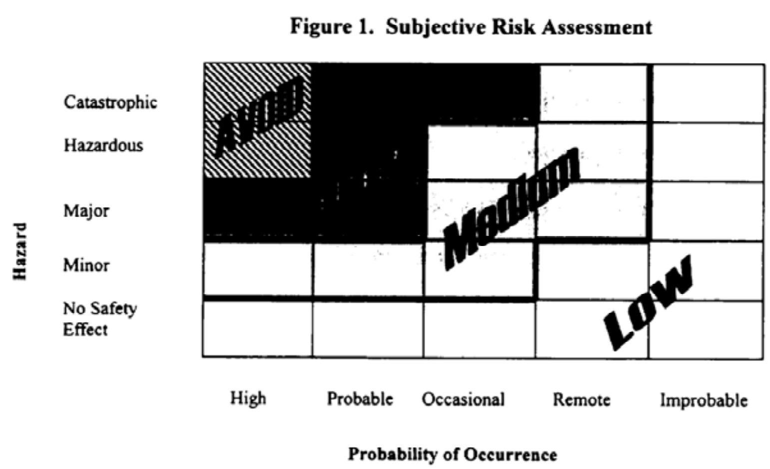

Chart 1: Subjective Risk Assessment

4.3 FAA Regulatory Information

4.3.1 General, Part 25.101

Part 25.101, states in part:

(a) Unless otherwise prescribed, airplanes must meet the applicable performance requirements of this subpart for ambient atmospheric conditions and still air.

(d) Unless otherwise prescribed, the applicant must select the takeoff, en route, approach, and landing configurations for the airplane.

(e) The airplane configurations may vary with weight, altitude, and temperature, to the extent they are compatible with the operating procedures required by paragraph (f) of this section.

(f) Unless otherwise prescribed, in determining the accelerate-stop distances, takeoff flight paths, takeoff distances, and landing distances, changes in the airplane's configuration, speed, power, and thrust, must be made in accordance with procedures established by the applicant for operation in service.

(h) The procedures established under paragraphs (f) and (g) of this section must:

(1) Be able to be consistently executed in service by crews of average skill;
(2) Use methods or devices that are safe and reliable; and
(3) Include allowance for any time delays, in the execution of the procedures that may reasonably be expected in service.

4.3.2 Takeoff, Part 25.105

Part 25.105 states the level of piloting skill needed in the performance of any maneuver required and states in part:

(b) No takeoff made to determine the data required by this section may require exceptional piloting skill or alertness.

4.3.3 Takeoff, Part 25.107

Part 25.107, provides a definition of takeoff speeds, which are also presented in AC 25-7, and states in part:

(a) V_1 must be established in relation to V_{EF} as follows:

(1) V_{EF} is the calibrated airspeed at which the critical engine is assumed to fail. V_{EF} must be selected by the applicant, but may not be less than V_{MCG} determined under Part 25.149(e).

(2) V_1, in terms of calibrated airspeed, is selected by the applicant; however, V_1 may not be less than V_{EF} plus the speed gained with the critical engine inoperative during the time interval between the instant at which the critical engine is failed, and the instant at which the pilot recognizes and reacts to the engine failure, as indicated by the pilot's initiation of the first action (e.g., applying brakes, reducing thrust, deploying speed brakes) to stop the airplane during accelerate-stop tests.

(b) $V_{2\ MIN.}$, in terms of calibrated airspeed, may not be less than—

(1) 1.13 V_{SR} for--

(ii) Turbojet powered airplanes without provisions for obtaining a significant reduction in the one-engine-inoperative power-on stall speed;

(3) 1.10 times V_{MC} established under Part 25.149.

(c) V_2, in terms of calibrated airspeed, must be selected by the applicant to provide at least the gradient of climb required by Part 25.121(b) but may not be less than—

(1) $V_{2\ MIN;}$

(2) V_R plus the speed increment attained (in accordance with Part 25.111(c)(2)) before reaching a height of 35 feet above the takeoff surface; and

(3) A speed that provides the maneuvering capability specified in Part 25.143(h).

(d) V_{MU} is the calibrated airspeed at and above which the airplane can safely lift off the ground, and continue the takeoff. V_{MU} speeds must be selected by the applicant throughout the range of thrust-to-weight ratios to be certificated. These speeds may be established from free air data if these data are verified by ground takeoff tests.

(e) V_R, in terms of calibrated airspeed, must be selected in accordance with the conditions of paragraphs (e)(1) through (4) of this section:

(1) V_R may not be less than—

(i) V_1;

(ii) 105% of V_{MC};

(iii) The speed (determined in accordance with Sec. 25.111(c)(2)) that allows reaching V_2 before reaching a height of 35 feet above the takeoff surface; or

(iv) A speed that, if the airplane is rotated at its maximum practicable rate, will result in a V_{LOF} of not less than 110% of V_{MU} in the AEO condition and not less than 105% of V_{MU} determined at the thrust-to-weight ratio corresponding to the OEI condition.

(2) For any given set of conditions (such as weight, configuration, and temperature), a single value of V_R, obtained in accordance with this paragraph, must be used to show compliance with both the OEI and the AEO takeoff provisions.

(3) It must be shown that the one-engine-inoperative takeoff distance, using a rotation speed of 5 knots less than V_R established in accordance with paragraphs (e)(1) and (2) of this section, does not exceed the corresponding one-engine-inoperative takeoff distance using the established V_R. The takeoff distances must be determined in accordance with Part 25.113(a)(1).

(4) Reasonably expected variations in service from the established takeoff procedures for the operation of the airplane (such as over-rotation of the airplane and out-of-trim conditions) may not result in unsafe flight characteristics or in marked increases in the scheduled takeoff distances established in accordance with Sec. 25.113(a).

(f) V_{LOF} is the calibrated airspeed at which the airplane first becomes airborne.

4.3.4 Controllability and Maneuverability, Part 25.143

Part 25.143 stipulated the controllability and maneuverability of a transport category aircraft in various flight phases and maximum short and long period control forces that a pilot is to experience in pitch, roll, and yaw. Part 25.143 states in part:

(a) The airplane must be safely controllable and maneuverable during:

(1) Takeoff
(2) Climb
(3) Level flight
(4) Descent
(5) Landing

(b) It must be possible to make a smooth transition from one flight condition to any other flight condition without exceptional piloting skill, alertness, or strength, and without danger of exceeding the airplane limit load factor under any probable operating conditions.

(d) The following table prescribes, for conventional wheel type controls, the maximum control forces permitted during the testing required by paragraph (a) through (c) of this section:

Force, in pounds, applied to the control wheel or rudder pedals	Pitch	Roll	Yaw
For short term application for pitch and roll control—two hands available for control	75	50	-
For short term application for pitch and roll control—one hand available for control	50	25	-
For short term application for yaw control	-	-	150
For long term application	10	5	20

Table 3: Maximum Control Forces Permitted During Testing

(e) Approved operating procedures or conventional operating practices must be followed when demonstrating compliance with the control force limitations for short term application that are prescribed in paragraph (d) of this section. The airplane must be in trim, or as near to being in trim as practical, in the preceding steady flight condition. For the takeoff condition, the airplane must be trimmed according to the approved operating procedures.

4.4 Test Articles and Airplane Information

GAC uses an Integrated Test Facility (ITF), which is a fixed simulator for research, development, and evaluation of the aircraft's integrated software. The ITF is a dimensional representation of the aircraft's electrical and computer system and is equipped with a G650 cockpit and video displays to visually simulate the aircraft environment and motion. The ITF was used by the SIC to perform takeoff field performance maneuvers in preparation for actual aircraft field performance flight testing prior to Roswell II.

Following an Operations Group Chairman's request for ITF usage records by flight 153's on board test team, GAC reported that there were no records. The ITF Director stated that on March 21, 2011, the SIC contacted him requesting to use the ITF to practice maneuvers that were going to be flown during Roswell II. The ITF Director said that he told the SIC that the ITF's performance modeling was not necessarily accurate for the maneuvers that he wanted to perform. The SIC stated that he was going to evaluate the lab capability and try the maneuvers anyway. The ITF Director stated that the SIC used the ITF about March 23 and/or March 24, 2011. He was then seen by the ITF Director on March 29 or March 30, 2011, practicing in the ITF. On March 31, 2011, the ITF Director discussed the SIC's experience in using the ITF, during which the SIC stated that the ITF was not fully representative of the maneuvers he practiced but that it provided some capability to practice test technique.

APG 1 stated that the ITF was used by the FTEs and pilots, specifically FTE 1 and the SIC, who had used the ITF to test techniques prior to Roswell II. Following the accident, improvements were made to the ITF aerodynamic model to the takeoff phase. APG 1 also thought that following the accident, the ITF was being used to a greater extent and that it is very useful.

GAC also uses a second simulation device called the "Iron Bird," which is a dimensionally representative, full-scale skeleton of the G650 simulator for research, development, and evaluation of software and hardware systems interfaces. Examples of tests would include the testing of the flight control system, the RAT, and landing gear.

The accident airplane was one of five airplanes used in the test program and the test areas for which they were instrumented and configured were:

6001	6002	6003
Envelope Expansion Air Data Calibration Flutter Inlet Compatibility Flight Controls Hydraulics Stability and Control Ice Shapes Flow Visualization In-flight Performance Autoflight (AP/AT) RVSM	Field Performance Engine Margins Air Data Calibration ECS Cooling and Ventilation Flammable Fluids and Drainage Electrical Power Fuel Ice Protection Landing Gear, NWS Brakes APU Engine Control/Performance Water Ingestion Water/Waste RVSM	Communication Navigation Displays Weather Radar Exterior Lighting FDR CMC SFC Flap/Wing Loads Fly-over Noise RVSM
6004	6005	
Function and Reliability Crew Workload Type Rating EASA Validation Interior Tests CVR TCAS/EGPWS RVSM	HIRF/Lightning RVSM	

Table 4: GAC Aircraft Instrumentation and Configuration for Flight Test

5.0 Flight Test Operations Manuals

Following a request for the company's Flight Test Operations Manuals, GAC provided two manuals pertaining to flight test operations titled Flight Test Standard Practice Manual, GV-

GER-1329, revision F, dated November 2, 1998, and Flight Operations Test Standard Operating Procedures, revision number 3-09, November 11, 2009.

Flight Test Standard Practice Manual, FT-SOP-001 was provided on February 6, 2012, following a request for process documentation relating to the document used to request flight test services, Flight Test Request for Flight Test Services. Flight Test Standard Practice Manual, FT-SOP-001, was prepared/reviewed from October 28 to October 31, 2011, and revised by GAC's Aviation Safety Office on November 7, 2011.

6.0 Test Planning

The summary of field performance test planning that had taken place was based upon company reports obtained from GAC and interviews of GAC personnel in June 2011 and October, 2011. Additional information regarding the circumstances pertaining to relevant flights prior to and including the accident flight is documented in the On-Board Video Recording Group Chairman's Factual Report.

6.1 Field Performance Data Analysis Plan

The GAC document "Model GVI Data Analysis Methods," dated June 25, 2009, presents the data analysis methods and flight test procedures which were to be used during the GVI development, company (pre-TIA) flight test phase and the certification flight test phase. This document was prepared by the Flight Test Department and reviewed by APG 1, the 6002 Lead FTE, and a Powerplant FTE. It also underwent technical approval by the FTECS, and was approved by the: Director of G650 Flight Sciences, the G650 Powerplant Product Development Team Lead, and the then-Manager of Flight Test.

6.1.1 V_{MU} Testing

The GVI Data Analysis Method states in part that there is uncertainty regarding air flow characteristics of the wing in the presence of ground effect, which on the GIV (a prior developmental program), led to an unanticipated premature wing stall (See Section 13.0 for further information). Since V_{MU} is selectable by the applicant, it has been GAC's tradition not to attempt demonstration of absolute minimum V_{MU} speed as definition because of the reasons cited. Instead, demonstrated speeds are selected sufficiently low enough to comply with Part 25.107, but still well above aerodynamic stall.

The demonstrated V_{MU} speeds are normally used as a basis from which normal speed schedules are developed (V_1, V_R, V_2). A matrix of test conditions covering the entire range of thrust/weight (T/W) ratios of each certified takeoff configuration is tested. Then rotation and liftoff increments are added to the V_{MU} baseline speeds to work forward to the operational speeds, and specifically, the V-speeds. During GIV certification testing, V_R and V_{LOF} from V_{MU} based speed schedules resulted in V_2 speeds slightly less than the required 1.2 V_S. This led to a redefinition of the speed schedules based upon the V_2 requirement at 35 feet. Appropriate increments were then subtracted from the V_2 requirement to work backwards to V_{LO} and V_R. The resulting liftoff speeds were then checked against Part 25.107 (e)(1)(iv) requirements to be above 105 and 110% of V_{MU} for single and all-engine cases, respectively.

Only a minimal number of V_{MU} tests were to be used to demonstrate compliance with Part 25.107. As per AC 25-7A Change 1, critical single engine and all-engine T/W ratios will be tested at speeds of 5 and 10% (plus some margin) below anticipated normal liftoff speeds. These demonstrated worst case speeds will then be used as a reference for all T/W conditions during liftoff speed schedule determination.

V_{MU} will be tested for both 10and 20flaps at the critical T/W ratios for both engines operating and one engine inoperative. However, rather than conducting actual single engine takeoff tests, AC 25-7A Change 1 allows all-engine operation at thrust levels consistent with single engine operation. The results of the simulated engine inoperative tests will be analytically adjusted to account for asymmetric trim drag that would have been required to counter asymmetric thrust (See Section 12). Ordinarily, V_{MU} testing is conducted with normal takeoff elevator trim set at forward center of gravity (CG) limit. However, if the airplane has limited pitch authority precluding the demonstration of forward CG V_{MU} at the desired speed, then aft CG or additional nose up trim, or both, will be used as necessary. The resulting speeds will be analytically adjusted to the forward CG/normal trim values as per AC 25-7A guidelines outlined in section 8.2.

> *Note: Initial target rotation speeds and pitch attitudes will be based upon estimated stalling speed in ground effect from wind tunnel results, and limited by estimates of pitch authority, lateral-directional controllability, and minimum climb gradients. Initial V_{MU} tests will require a "build-down" approach to these estimated speeds in order to safely explore the behavior of the wing in ground effect.

If an aft CG position is required for V_{MU} demonstration, AC 25-7A stipulates that a supplemental tests be performed in order to assure adequate V_{MU} definition. The V_{MU} assurance test is conducted at forward CG position with normal takeoff trim, and holding full aft stick until rotation to the proper liftoff attitude. Both flap configurations will be tested at critical T/W conditions corresponding to maximum takeoff weight and/ or climb limited weight. It is required that the resulting liftoff speed be at least 5 knots below the normally scheduled liftoff speed, but still provide acceptable flight characteristics.

6.1.2 Takeoff Performance Test Procedure

There were to be three types of takeoff field performance tests that were to be conducted:

(1) AEO Takeoff
(2) One Engine Failed Takeoff
(3) Aborted Takeoff - Single Engine

All tests were to be conducted from a smooth, hard surfaced runway and with wind speeds less than 10 knots. Test runs are continuous, but analysis would be conducted on separate and distinct sub-segments of each run. The sub-segments of each run are defined in the following figure:

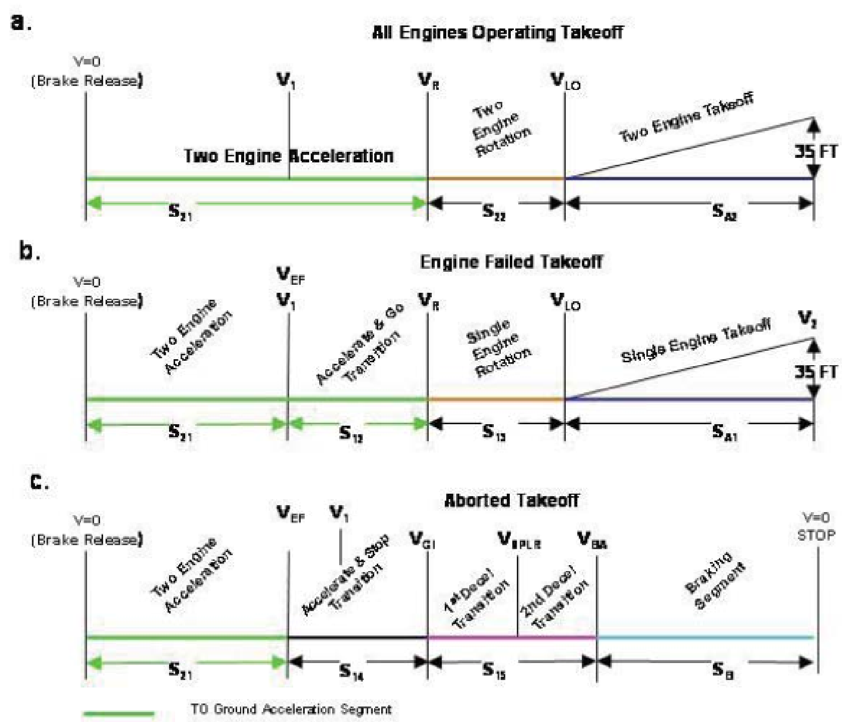

Figure 1: Takeoff Sub-Segments for Each Test Run

6.1.2.1 Takeoff Speed Schedules

Takeoff speed schedules consist of V_R, V_{LO}, V_2, and, V_{35}[21]. The schedules are normally presented in terms of a ratio to stall speed, V/V_S, and are developed from the observations of speed increments experienced during normal one and two engine takeoff test runs. Takeoff speeds are developed in accordance with Part 25.107, which specify a number of requirements that the selected operational speeds must satisfy. As discussed in Section 8.0, the GVI takeoff speeds will be developed under the same theory of takeoff distance optimization as was developed during GIV certification testing. Therefore, rather than using V_{MU} as the basis, the new starting point for speed schedule development will be the establishment of V_2 at 35 feet above the runway (single engine operation). V_2 is specified in Part 25.107 as the higher of 120% of V_S, or 110% of V_{MCA} as defined in Section 2.6. GIV experience has shown that V_{MCA} is sufficiently low as to not affect V_2 determination for any conditions, and it is anticipated that the same situation will exist for the GVI.

The initial target V_R and V_{LO} schedule used for the takeoff testing will be based upon analytical estimates, and updated based on the results of performance stall tests of Section 5.0, and V_{MCA}

[21] Screen height speed, which is the speed at 35 feet above the runway.

and V_{MU} tests if necessary. Testing will be conducted according to procedures developed for GVI operational use, and will be similar to the following procedures used for the GIV certification testing:

All Engines Operating:

1. Set EPR[22] on both engines to maximum allowed values with brakes on.
2. Release brakes and advance throttles, if necessary, to the target takeoff EPR setting before the speed of *TBD*[23] knots is reached.
3. Accelerate to the target rotation speed (V_R), using normal rotation techniques, rotate and climb out at target attitude until 35 feet above ground level (AGL).
4. Initiate gear retraction after 35 feet AGL.
5. Maintain the airspeed (V_{35}) attained at 35 feet and climb out to 200 ft AGL.

One Engine Inoperative:

1. Set EPR on both engines to maximum allowed values with brakes on.
2. Release brakes and advance throttles, if necessary, to the target takeoff EPR setting before the speed of *TBD* knots is reached.
3. Accelerate to the engine failure speed (V_{EF}), then simulate an engine failure by:
   a. Idle Cut -- Abruptly retarding a throttle for one engine to Idle, or...
   b. Fuel Cut -- Shutting fuel off to one engine
4. Continue the takeoff to target rotation speed (V_R), using normal rotation techniques, rotate and climb out at target attitude to 35 feet above ground level (AGL).
5. Initiate gear retraction after 35 AGL.
6. Maintain the airspeed (V_2) attained at 35 feet and climb out to 200 ft AGL.

The V_R/V_S schedule should meet the criteria specified in Part 25.107(e)(ii), which states that rotation speeds must be higher than 105% of V_{MCA}. Paragraph (iv), states that if the airplane is rotated at its maximum practical rate, the airplane should not liftoff at a speed lower than 110% of V_{MU} for all-engines operating, and 105% of V_{MU} for single engine operating. If V_{MU} is conducted at an average rotation rate that is higher than what is used in normal operation, then incremental values of $(V_{LOF} - V_R)/V_S$ can be generated from V_{MU} test results and added to V_R/V_S in order to check V_{LOF}/V_S values. However, experience with GIV V_{MU} testing has shown the airplane to be elevator power limited, and therefore, unable to rotate at a rate that is appreciably higher than operational rates

An additional requirement for two-engine test runs on takeoff speeds is specified in Part 25.107 (e)(2) which states that a single value of rotation speed must be selected to show compliance with both single and all-engine operating takeoff provisions. Compliance is accomplished by selecting the higher of the V_R/V_S schedules determined using the above described procedures for single and all-engine takeoff tests. It is anticipated that the single engine V_R/V_S schedules will be

[22] Engine pressure ratio.
[23] To be determined.

the higher of the two, as was experienced during GIV certification tests. Therefore, the all-engines operating V_R/V_S schedules will be adjusted upward to match the single engine schedules, and then the V_{LOF}/V_S and V_{35}/V_S will also be adjusted on a point-for-point basis. Finally, the adjusted all-engines operating V-speed schedules will be checked against the criterion of Part 25.107 (e) (ii)&(iv), which stipulate that V_R/V_S must be higher than 105% of V_{MCA} and 110% of V_{MU}, respectively.

6.1.2.2 Instrumentation Required

The following parameters that were to be instrumented for testing were:

Angle-of-attack	Pitch and Bank Angle
Brake Pressure and Temperature	Pressure Altitude
Control Surface Deflections	Radar Altitude
Engine Fuel Flow	Spatial Position
Engine Parameters needed for thrust calculations	Strut Pressure
Flight & Run Number	Time
Fuel Quantity	Yaw Rate
Inertial Data (Ground Speed, G's)	

Table 5: Instrumented Parameters for Flight Test

A portable weather station was to be situated alongside the runway and the following parameters were to be manually recorded during each run:

Ambient Pressure	Wet and dry bulb thermometer or other humidity measuring device
Ambient Temperature	Wind speed and direction
Clock	

Table 6: Parameters Recorded by Weather Station

Spatial position measurement was planned to be accomplished with Differential GPS for both vertical and horizontal position. The backup measurement system will be a combination of integrated IRU ground speed for longitudinal position and Radar Altimeter for vertical position. In all cases, spatial position will be time correlated with aircraft parameter measurements. Runway slope will be noted for test location.

7.0 GVI Field Performance Certification Flight Test Plan

The GAC GVI Field Performance Certification Flight Test Plan, dated January 14, 2010, contained the field performance test program required for certification of the GVI. The purpose of these tests were to gather the necessary data required to develop takeoff and landing operating speed schedules and distances for the Airplane Flight Manual (AFM) and to show compliance with the regulations. Test data was to be gathered, reduced and presented in a format consistent with GAC engineering requirements for the construction of aircraft performance charts and incorporation into the AFM Performance Section. The testing was to consist of minimum V_{MU}, takeoff speed schedule development, AEO takeoffs, OEI takeoffs, abused takeoffs, rolling takeoffs, all-engine Rejected Takeoffs (RTO), engine-out RTOs, alternate dispatch case RTOs, the maximum kinetic energy (KE) RTO, free rolls, thrust reverser effectiveness, landing flare development, HUD landing dispersion, full stop landings, and failure case landings.

The test objective stated in part that the testing was to gather data for use in determining performance parameters for AFM takeoff and landing expansion. Initial testing for each type of test was to begin with development testing to develop aircrew techniques and determine aircraft performance characteristics (e.g. speed gains and critical engine). Certification testing was to follow the development testing to gather data required for development of the AFM.

This document was prepared by the FTE 1 and was checked by the FTEGH. The document received technical approval from the APG 4 and the FTECS. It was also reviewed by PJP and approved by the then-Manager of Flight Test.

7.1 Systems Description

The pertinent aircraft systems related to field performance testing discusses the flight control system modes and the afforded control law protections such as AOA limiting.

7.1.1 Flight Control System

The flight control computers (FCCs) host three operational control law modes that provide different levels of flight quality: Normal, Alternate, and Direct. The Backup Flight Control Computer hosts the Backup mode used only when all four FCC channels fail. In addition to Normal mode, a First Flight mode will be made available for flight testing. While field performance testing was to be conducted in Normal control law operating mode, First Flight mode was used as Normal mode had yet to be sufficiently developed when company field performance testing began.

7.1.1.1 Normal Mode

Normal is the default mode when all primary flight control system resources are available. This mode provides augmented pitch control through a speed and maneuver stability control law that requires angular rates, load factor, and air data signals from aircraft systems external to the FCC. When the AOA is trending toward 85% of maximum, AOA limiting is activated. Normal mode roll and yaw control is implemented such that the wheel and rudder inputs result in a gain-scheduled deflection of aileron, spoiler, and rudder surfaces. In addition, a yaw damper function is superimposed on the pilot rudder and aileron/spoiler inputs.

7.1.1.1 AOA Limiting

The control law provides the in-flight AOA limiting or high incidence protection function (HIPF). The HIPF is de-activated on the ground. The HIPF is different from a conventional pusher-shaker stall protection system. The GVI AOA limiter will limit the maximum angle of attack that can be obtained in-flight. AOA will be displayed in the cockpit and normalized by AOA at V_{MIN}. The control column position at the full aft limit will command no more than the scheduled AOA limit. Additionally, the AOA limiter will decrease longitudinal control authority during a dynamic entry to limit AOA rate, and thus limit any AOA overshoots. The final AOA limiter schedule will be determined during stall speeds testing and stall characteristics testing. With regards to field performance, the AOA Limiter will be artificially biased to account for uncertainty in the AOA.

8.0 Flight Test Safety Review Board

The Flight Test Safety Review Board (FTSRB) was convened on October 7, 2010, to discuss the G650 field performance test plan. The Director of Flight Test, who also served as the Co-Chair to the FTSRB, had sent an email to personnel from the various company departments to attend. The approximately 30 attendees included the chief engineer from the G280 program as a management member who was not involved in the G650 program, the four experimental test pilots that performed all the G650 field performance flight testing, and the FTE1 and FTE2 who were on board during the accident flight. The G650 aerodynamicist (AERO 1) did not attend the FTSRB. FTE1 provided a slide presentation during the FTSRB of the test's objectives, ground support, aircraft configuration, TSHAs, test approach, and test conditions and procedures. Slide 29 included documentation of free air and IGE stall AOA as estimated by GAC's G650 low speed wind tunnel data. An FTSRB Action Review was then held on November 1, 2010.

8.1.1 Scope and Schedule

The length of company development and certification testing was planned to be 36 test days and the length of FAA certification testing was planned to be 14 test days. These time periods included other areas of field performance testing. Company testing was to be from November 16 - 23, 2010, and FAA certification testing was to be from January 3 - February 24, 2011.

8.1.2 Objectives

Upon completion of V_{MU} and takeoff rotation development prerequisite testing, the test objectives were to:

(1) Develop pilot techniques and determine aircraft performance characteristics.
(2) Data collection to develop takeoff and landing operating speed schedules and distances for the airplane flight manual (AFM).
(3) Show compliance with regulations.

8.1.3 Ground Support

The ground support for field performance testing was to include side-of-runway video, a telemetry trailer, and weather station. The telemetry trailer was to have 1 TM operator, 2 flight test engineers, and 2 Flight Sciences personnel.

8.1.4 Aircraft 6002 Configuration

The FCC was to be in Normal Mode. It was determined at the FTSRB to conduct Roswell I testing in First Flight Mode with the AOA limiter inoperative and stick shaker available to provide stall warning. The restriction on the use of Normal Mode was later formalized as part of IFR FCS-038A, dated March 23, 2011, which was in place at the time of the accident.

8.1.5 Risk Assessment

The Test Safety Hazard Analysis (TSHA) for V_{MU} (revision A) and OEI (revision B) field performance tests that resulted from the FTSRB were as follows:

ID: TSHA-000083 Field Performance - VMU
Risk: High **Probability:** Low

Test Applicability:
93 - 311 Performance: Field: Vmu Development
93 - 312 Performance: Field: Vmu: Vmu Certificaton
93 - 313 Performance: Field: Vmu: Vmu Assurance

Hazard: Aircraft Departs Runway/Inadvertent Ground Contact

Cause: Excessive rotation force/over rotation at low airspeed, low altitude stall, loss of an engine at low T/W conditions

Effect: Loss of aircraft/loss of crew.

Preventative Actions / Minimizing Procedures:

1. All testing shall be conducted under day VMC conditions on a smooth, hard-surfaced dry runway. Tests shall be conducted at KROW on Runway 3/21 which is 13000'x300' or KVQQ on Runway 18L/36R which is 12503'x197'.
2. Brief local fire and rescue crews on test conditions.
3. Service struts, brakes and tires to recommended limits.
4. Only crewmembers deemed essential for conduct of the test shall be onboard.
5. Testing will be conducted while winds at the runway are below 5 knots from any direction and not gusting.
6. Alpha limiter will remain OFF during the testing.
7. Alternate control law maximum gains will be loaded prior to testing.
8. OEI testing will be conducted by simulating the OEI condition, using the equivalent OEI total thrust divided between both operating engines.
9. VMU testing will be approached in a build-up manner. Testing will begin at AEO high T/W conditions and proceed to the lower T/W conditions required. The number of required build-ups and repeat testing will be determined by the on-site test team. Additionally, the pilot flying shall have recent experience with the test maneuver or perform a build-up maneuver(s) before conducting the test condition.
10. Pitch attitude limit will be based on the build up testing, and will maintain an in-ground-effect AOA margin similar to the free air AOA limiter margin (not less than 1.5 degrees).
11. Do not allow airplane roll angle to exceed 5 degrees. Wing tip TE strike is estimated to occur around 5 degrees of roll attitude for the expected maximum Vmu attitude.
12. Cool brakes as required between test points. Periodically visually inspect brakes and tires and check tire temperatures to maintain below 150 degF.

Corrective Techniques:

1. If the aircraft is airborne and an engine fails, decrease pitch attitude, establish a stable bank angle, and advance the operative engine PLA so the aircraft will accelerate and then climb to desired altitude. Minimize asymmetric thrust if possible. Make turns into the operating engine and climb at no less than V2 to safe altitude.
2. If the aircraft is over-rotated, or rotated early and stalls, decrease pitch attitude, maintain wings level, advance PLA on both engines, accelerate and then climb to desired altitude.

Figure 2: Test Safety Hazard Analysis for V_{MU}

ID:	TSHA-000084	Field Performance - Engine-out Takeoffs (OEI)	
Risk:	High	**Probability:**	Low

Test Applicability:

93 - 321	Performance: Field: Takeoff: Rotation Rate Development
93 - 322	Performance: Field: Takeoff: Pitch Attitude Development
93 - 324	Performance: Field: Takeoff: OEI
93 - 325	Performance: Field: Takeoff: Company Development

Hazard: Aircraft Departs Runway/Inadvertent Ground Contact

Cause: Engine Failure/Loss of Control

Effect: Loss of aircraft/loss of crew.

Preventative Actions / Minimizing Procedures:

1. All testing shall be conducted under day VMC conditions on a smooth, hard-surfaced dry runway. Fuel cut tests shall be conducted at KROW, on Runway 3/21 which is 13000'x300'. Non-fuel cut tests shall be conducted on a runway of at least 12000' in length and at least 150' in width.
2. Brief local fire and rescue crews on test conditions.
3. Service struts, brakes and tires to recommended limits.
4. Brief dual engine-out emergency procedures.
5. Only crewmembers deemed essential for conduct of the test shall be onboard.
6. Winds will be limited to 10 knots total and components of 5 knots cross wind and 2 knots tail wind.
7. Alternate control law maximum gains will be loaded prior to testing.
8. Testing with fuel cuts will be preceded by testing using a throttle chop to idle power. No engine shutdowns will be conducted without conducting a build-up test. The number of required build-ups and repeat testing will be determined by the on-site test team. Additionally, the pilot flying shall have recent experience with the test maneuver or perform a build-up maneuver(s) before conducting the test condition.
9. Cool brakes as required between test points. Periodically visually inspect brakes and tires and check tire temperatures to maintain below 150 degF.

Corrective Techniques:

1. For throttle chops: if the aircraft is airborne and one engine fails, advance PLA as required, decrease pitch attitude, establish a stable bank angle, accelerate and climb to any altitude. Minimize asymmetric thrust if possible.
2. For fuel cuts: if the aircraft is airborne and operative engine fails, restart shutdown engine, if possible, or conduct dual engine-out landing procedures.
3. Make all turns into the operating engine and climb at no less than V2 until 1500 ft AGL.

Figure 3: Test Safety Analysis for OEI

8.1.6 Test Approach

The tests were to be accomplished within the following tolerance criteria to be deemed a valid test for the maneuver outlined in all test cards associated with field performance:

Speed:	+/- 2 knots
Pitch Attitude:	+/- 1 degree
Pitch Rate:	+/- 1 degree/second
Control Forces:	Short and long term limits cited in Part 25.143

8.1.7 FTSRB Action Review

The FTSRB Action Review held on November 1, 2010, determined that the stick shaker for tactile feedback for the AOA limit available to the aircrew was to be in FCC software version 4.22 and build-up testing for control law transition from ground to air with failed engines/hydraulics was needed.

9.0 Flight 088 Wing drop/Rolloff Event

The G650 program encountered its first wing drop/rolloff event on November 16, 2010, during field performance testing with the PIC as the flying pilot and the PJP as the non flying pilot. The PIC had participated in but not performed prior V_{MU} tests in the G650. The 8 degree right wing down wing drop/rolloff occurred during a low thrust-to-weight (T/W) test at an aircraft weight of approximately light weight, a forward CG, flap setting of 20 degrees, and a pitch target of 9-10 degrees. The test point was immediately repeated and completed successfully.

Testing continued and included Card 6, which was an OEI pitch attitude development with a flaps setting of 10 degrees, at a light aircraft weight, and forward cg limit. The test card procedure was to rotate at V_R using a "normal rotation rate (3-5 degs/sec)" to the card's target pitch attitude. The card stated that the target pitch attitude was to be maintained until V_2 was achieved and then adjust pitch attitude to maintain V_2 to landing gear retraction or 400 feet above ground level (AGL). These test points included variations in initial target pitch angles from 7-10 degrees. At the higher target pitch angles, the airplane was exceeding its V_2 target.

The wing drop/rolloff event was attributed by the on-site flight test team to an overrotation by the PIC. The wing drop/rolloff occurred on the PIC's initial V_{MU} run on the G650, and he expressed surprise at the rotation rates obtained, which led to an overshoot of the desired pitch attitude. On the repeat test point, the PIC performed the maneuver successfully.

Following the event, the PIC and on-site flight test team recommended a modification to the V_{MU} TSHA's minimizing procedures to state (additions italicized):

> V_{MU} testing will be approached in a build-up manner. Testing will begin AEO high T/W conditions and proceed to lower T/W conditions required. The number of required build-ups and repeat testing will be determined by the on-site test team. Additionally, the pilot flying shall have recent experience with the test maneuver or perform a build-up maneuver(s) before conducting the test condition.

After return from Roswell, during a Pilot Safety Meeting and at a later time to Flight Test Engineering, the PIC presented a summary of Roswell I testing, including the flight 088 roll-off event. The summary documents the maximum AOA attained during the maneuver, as well as the estimated IGE stall AOA during Roswell I. Following the presentation and before the flight 153 accident, there was no recognition or discussion amongst any of the summary recipients that a stall had occurred prior to the then-estimated IGE stall AOA as documented in the presentation.

10.0 Estimates of Stall Angle-of-Attack In-Ground-Effect

Based on interviews with the FAA and GAC, there were no airplane test techniques to determine stall AOA while an airplane is IGE, the effect of which occurs from the ground level to the wing span height of the subject airplane (G650 wing span is about 100 feet). Wind tunnel testing can provide a prediction of C_{Lalpha} IGE, which was done for the G650. Verification of wind tunnel results can be conducted with aircraft flight testing to verify the predicted C_{Lalpha} such as during V_{MU} tests, but tests should only be used to verify model prediction according to AERO 1.

AERO 1 stated that the Flight Sciences department, that he was a member of, was involved in stall, buffet boundary, lateral stability, and high speed aircraft performance. He was not familiar with FTE 1's range of duties and had not worked with him on field performance testing but worked with him on upcoming artificial ice shapes testing and its test plan. He assumed that as a flight test engineer, FTE 1 would have created the test plans, test cards, and overall conduct of day –to-day testing.

AERO 1 stated that the margin between V_{SR} and free-air stall AOA was originally set at the same margin used on earlier Gulfstream aircraft, except the GV. The estimated decrement for IGE stall AOA, which was carried over from the GIV program and based upon G650 low-speed wind tunnel testing, was about 2 degrees. The decrement also included the effects of aircraft side slip. The 2 degree decrement was provided by his group to Flight Test Engineering and it was a generally accepted value and an agreed upon value. He thought that a 1 degree margin to IGE stall AOA, which would include probe tolerance/error, would be an adequate margin in flight testing; however for normal takeoffs, that margin was expected to be several degrees. AERO 1 did not expect that a refined estimate would result from flight tests because the aircraft would not and should not be flown close enough to stall so that such a value could be ascertained.

During a March 24, 2011, meeting that AERO 1 attended, FTE 1 presented a 1.5 degree decrement for IGE stall from free air stall AOA. FTE 1 did not provide his methodology for decrement determination to the participants at the meeting and had not previously discussed his analysis with AERO 1.

Several weeks following the accident, AERO 1 determined that the decrement presented by FTE 1 during the March 24, 2011 meeting appeared to be derived using a lateral shift of the C_{Lalpha} curve that FTE 1 analyzed, the basis of which was incorrect according to AERO 1.

AERO 1 said that he had heard of flight 088's wing drop/rolloff through a third party sometime before flight 132's wing drop/rolloff event. He did not participate in discussions pertaining to the cause of flight 132's wing drop/rolloff event. He said that had flights 088 and 132 been recognized as stall events, then those events would have provided data points for IGE stall AOA values.

The Director of Flight Test Engineering (FTED) stated that FTE 1 explained to him his (FTE 1) methods for computing the decrement for IGE stall from free air stall AOA and FTED found it "credible." FTED stated that he did not know of an uncertainty value that would have been associated with estimates of IGE stall AOA and that the uncertainty was not addressed during safety planning. He stated that while he was employed at Douglas Aircraft, IGE performance was not an "elevated concern" during field performance testing of two and three engine jet aircraft

FTEGH stated that prior to the accident, he was unaware of FTE 1's work on reducing the IGE stall AOA decrement from the 2.0 degree value from the field performance FTSRB. FTEGH did not know of an uncertainty value that would have been associated with IGE stall AOA estimations.

FLTOPS 1 stated that past GAC aircraft programs used a 2 degree decrement for IGE stall AOA. He did not know the uncertainty or range of values associated with estimated decrements for IGE stall AOA, but later learned of those uncertainty or range values at the time of his October 2011, interview. The Operations Group Chairman provided to GAC, SAE International Technical Paper, 2007-01-3286, "The Effect of Wing Leading Edge Contamination on the Stall Characteristics of Aircraft," (Tanner 2007), that resulted from investigative research. FLTOPS 1 stated that following the accident, he had also performed internet search(s) for the effects of IGE on stall AOA because the information regarding the subject is not comprehensive and/or complete, and the search(s) revealed no further information.

SAE Paper 2007-01-3286, discusses the stall characteristics of swept wings and the effect of IGE and sideslip on wings. The paper states that the stall AOA for all types of aircraft occurs about 2-4 degrees lower with the aircraft on the ground and a sideslip of 20 degrees can reduce stall AOA by up to 3.5 degrees.

FLTOPS 1, who was also a FTSRB Co-Chairman, stated that the FTSRB should have reconvened after flights 088 and 132 to review the wing drop/rolloff events from those flights. He thought that the data from those flights should have been analyzed by Flight Sciences, which would have included the participation of AERO 1. He also said that he did not expect the decrement for IGE stall AOA should have changed from what was briefed during the FTSRB on October 7, 2010. He added that he was not aware of the revised decrement value for IGE stall AOA until after the accident. He said that the FTSRB should have reconvened for the change in stick shaker margins that occurred before flight 132. He was not aware that the stick shaker values had also changed prior to the accident.

11.0 Change in Stick Shaker Margins

According to the Director of Flight Test, following the FTSRB for field performance, the stick shaker was to be set at 0.85 NAOA. However, during takeoff field performance testing, the test flight crew(s) encountered shaker activation, and, because FAA certification requirements for a successful test do not allow for stick shaker activation, a review of stick shaker activation settings was conducted. FTE 1 conducted an analysis of V_{MU} and C_L data, which led to a decrease in the IGE stall AOA decrement from 2.0 degrees to 1.5 degrees. As a result of the resultant increase in predicted IGE stall AOA, a proposal was made to increase the stick shaker activation setting to 0.90 NAOA. The increase was reviewed with and approved by FTECS, and was first used for takeoffs on the aircraft via Modification Access of Internal Data (MAID) on March 11, 2011, prior to flight 129.

The change had been made using GAC's Problem Reporting Process, which was used to record, track, and correct issues detected during development and integration. The problem report (PR) process provided for

1. A database to track issues for various programs.
2. The tracking of systems issues (detected problems, desired upgrades, and design issues.
3. A search capability within the system.
4. Report generation as needed with the capability to customize report for desired details.

The primary FTE for flight controls (FTEFC) said that once a PR is generated, a meeting is conducted to assign someone to authorize the change and before the change is completed, a PR review board consisting of flight operations, flight test, and engineering would review the PR. FLTOPS 1 stated that he did not attend PR Board meetings, which were "mostly" attended by PJP.

FTEFC said that changes to aircraft configuration settings are generally test specific and are made by the person in charge of testing and such changes are documented in test documentation such as the test cards or briefing notes. He added there was a process for management of the airplane configuration.

When asked if the stick shaker change should have prompted a reconvening of the SRB, the primary FTE for flight controls stated that he did not have an opinion if it should have reconvened and such a decision is somewhat up to the test team.

FTEFC stated that following a March 24, 2011, meeting that was attended by control law engineers to change the stick shaker setting, FTE 1 asked and provided an email requesting that FTEFC to create a PR for the stick shaker setting change. He did not remember who all the personnel were that were involved in the decision to change the stick shaker setting but thought that the PTP was one of those personnel. FTEFC programmed the stick shaker change with FTE 1 during the first week at KROW. A verification of the functionality of the stick shaker change was then made in-flight.

FTEFC provided history of the stick shaker schedule throughout the G650 field performance test program. Based on the plots of flaps 10 and flaps 20, the historical approximate predicted margins from stick shaker to IGE stall AOA for the accident takeoff Mach number are presented in the following table:

Location of Test	IGE AOA from Free Air Stall AOA (degrees)	Stick Shaker Setting (NAOA)	Flap Setting (degrees)	Margin Between Stick Shaker and IGE Stall AOA (degrees)
Roswell I and Birmingham	-2.0	0.85	10	1.20
			20	1.20
Roswell II	-1.5	0.90	10	0.60
			20	0.55

Table 7: Predicted Margins for Stick Shaker to IGE Stall AOA

The Director of Flight Test said that it was not unusual to change the stick shaker setting during the program as the takeoff procedure is optimized. The Director of Flight Test added that changes to the stick shaker setting have been made during takeoff performance testing in past Gulfstream programs, and it did not prompt a reconvening of the FTSRB[24].

[24] The Gulfstream Flight Test Standard Practices Manual as published at the time of the accident did not address or

Prior to the accident, the FLTOPS 1 stated that he was unaware that the stick shaker setting had changed from 0.85 to 0.90 NAOA. He said that such a change should have required the FTSRB to reconvene because shaker setting is a safety parameter within the test configuration and that the FTSRB wants to be certain of what the maneuver margins are. He added that he prefers to know what the actual value of the stall setting would be in terms of degrees rather than a relatively normalized value. The FLTOPS 1 also said that his personal comfort level for a margin between stick shaker and IGE [stall] AOA would be a minimum of 1 degree but he would like to have a greater margin of 1 ½ - 2 degrees. When asked whether that margin is one with an active shaker or AOA limiter, he said that he liked to know the value of AOA and that he reacts to a stick shaker and is unable to close the [pilot] loop when using it. In his opinion, the use of the pitch limit indicator (PLI) allows a pilot to close in on a specific AOA and even with the PLI; he would like to know the specific AOA.

The APG 1 and APG 4 both stated that prior to the accident, they did not know what the correlation was between AOA expressed in terms of NAOA and degrees. Also, they did not know that a 0.05 change in NAOA equated to approximately a 50 percent reduction in stall margin.

While advised of the increase in stick shaker activation setting, there is no evidence to suggest that the PIC, SIC or other on-site flight test team members (other than FTE 1) were aware of the resultant reduction in margin to the then-predicted IGE stall AOA.

11.1 Change in FCC Software Versions

Field performance testing was conducted over three phases with four different FCC software versions:

(1) Roswell Phase I (flights 079 – 094) was conducted with FCC 4.22.
(2) Takeoff Development following Roswell I (flight 111) with FCC 5.07.
(3) Roswell II from flight 124 through flight 135 with FCC 5.14.
(4) Roswell II from flight 136-153 with FCC 5.15.

On March 3, 2011, an aborted takeoff was performed during flight 122 with the ATL ACO Flight Test Branch Manager (ACO 1) aboard after the aircraft began to deviate from the runway centerline during takeoff roll. PR 3614 was then generated due to adverse yaw damper filters and an interim flight restriction (IFR), IFR-FCS-034, was issued. The IFR was to monitor and verify a FCC parameter, on the Internal Data Examination and Monitoring (IDEM)[25] on-board tool, was below a certain value prior to takeoff. IFR-FCS-034, revision A, then allowed for the aircraft to be stationary on the runway for 12 seconds before the start of the takeoff roll.

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provide clear criteria for reconvening the FTSRB.

[25] The FCC's flight-test capability includes an IDEM tool that allows the FTE to select parameters from FCC internal memory, and the data values of those parameters are reported in real-time to flight test equipment for display and recording .

On March 10, 2011, IFR-FCS-035 was put into place to account for a known yaw damper software design issue discovered during FCC 5.14 ground testing, which resulted in PR 3623 with a severity 1 classification that was downgraded with the issuance IFR-FCS-035. IFR-FCS-035 required the yaw damper to be disabled in flight while in First Flight and Normal modes and became effective beginning with flight 129 until FCC 5.15 was loaded, which fixed the problem. PTP, SIC, ETP, FTE 1 had all flown CTOs with this IFR in effect during this period.

IFR-FCS-034 and 035 were unrelated.

12.0 Flight 132 Wing Drop/Rolloff Event

The G650 program encountered a second wing drop/rolloff event on March 14, 2011, during field performance testing with the accident SIC as the pilot flying and the ETP as the non-flying pilot. The wing drop/rolloff occurred during a simulated OEI (right engine reduced to idle) CTO test at light weight, a forward CG, flap setting of 20 degrees, and a pitch target of 9 degrees. The test was performed in First Flight Mode, which does not include AOA limiting, and a stick shaker setting of 0.90 NAOA. In addition to the stick shaker, there is a pitch limit indicator (PLI) on the primary flight display which provides NAOA awareness and moves toward the pitch attitude reference as AOA increases. When the pitch reference and PLI coincide the airplane is at shaker AOA and the stick shaker activates. The yaw damper was off for all flying due to IFR-FCS-035.

Immediately following the roll-off, while still in the cockpit and prior to landing, the crew discussed the event and the takeoff technique used. The crew review of the event attributed the wing drop/rolloff to an early rotation occurring at V_1 and prior to the rotate call at V_R as well as an over-rotation in excess of the target pitch angle. After landing, they reviewed the takeoff technique further, including practicing pilot inputs and a discussion of the cg, and then elected to repeat the test point as a training exercise for the SIC. ETP emphasized slowing down the pitch rate to ensure that the target pitch angle was not exceeded. To provide training and build-up for the SIC, the crew decided to perform an AEO test point from a previous test card, after which the OEI test point was repeated successfully by the accident SIC. OEI field performance was then discontinued until the yaw damper issue was corrected and the associated IFR was cancelled. Additional non-takeoff field performance testing followed, all of which is documented in the On-Board Video Recording Group Chairman's Factual Report.

GAC did not perform any additional takeoff field performance test points until the morning of the accident flight.

FTE 1 questioned the flight crew whether or not the shaker activated during the roll-off event. They determined that the shaker did not activate, since the maximum NAOA during the event was 0.86 and the shaker activation setting was 0.90 NAOA (reference Section 12.0 above regarding history of the shaker activation setting). Additionally, post-flight, ETPETP and FTE 1 discussed the predicted IGE stall AOA and decided that since the event AOA had remained 1.5 degrees below the predicted IGE stall AOA, it was determined that it was “not a stall” but was instead attributed to a “C_L Beta event” aggravated by the unavailability of the yaw damper.

12.1 Discussion regarding AOA limiter

The AOA limiter, which was intended to be the primary stall protection system for the G650 production aircraft, was not available and not operational during Roswell I, Birmingham, or Roswell II. For certification planning purposes, a meeting was held on March 24, 2011, to discuss stall protection for the production aircraft. As the aircraft design would not activate the AOA limiter until 10 feet AGL, the meeting participants decided that the stick shaker should be set to 0.90 NAOA through all phases of flight, including 0-10 feet AGL. This was intended to provide stall warning approximately 1 degree below the then-estimated IGE stall AOA.

FTE 1 also requested at this time that the Flight Sciences Control Laws group analyze the planned AOA limiter system to determine if it would have had an impact on the test (i.e., invalidated field performance test points) and whether calibrated speed and AOA rate terms added to later versions of FCC software would have prevented the roll-off event. The determination made by these groups was the AOA limiter would not have activated because the AOA and rate terms never achieved a high enough value during flight 132 to trigger the limiter.

A similar review of flight 088 was requested by FTE 1 to show that the limiter would prevent that aircraft from achieving a pitch attitude of 13 degrees. The review was not performed prior to the accident because the request referenced the incorrect flight number.

13.0 Flight 153

APG 1 provided a written statement regarding the discussions held in the two preflight meetings for flight 153 on April 1, 2011, noted below in Sections 11.1 and 11.2.

13.1 First Preflight Discussion

The first preflight meeting was the CTO Technique Brief held at approximately 1400 on the day prior to the accident. The meeting was attended by the PIC, SIC, FTE 1, FTE 2, FTE 3, and APG1. APG 1's following statement regarding the first preflight briefing follows:

> The purpose of Flight 153 was to perform heavyweight continued takeoffs, and as time permitted to proceed to medium weight CTOs. The takeoff testing was intended to be to practice the small revisions that were made to the takeoff technique to ensure that it was repeatable. It was discussed that each takeoff condition would be completed two or three times to collect a good set of data to compare to previous testing. The takeoff pitch angle to target was 9 degrees for flaps 20 or flaps 10 takeoffs, realizing that there is a tolerance of +/- 1 degree. This target was agreed upon by [FTE 1], [Flight Sciences Principal Engineer] and Chief FTE Staff Scientist, and myself. Further discussion of this target included [FTE 1] and [PIC] reflecting on a previous pitch overshoot during V_{MU} testing, saying comments like "we've already been there, we don't want to go there again" and indicating that if they saw 11 or 12 degrees, it was a knock-it-off and recover maneuver. [The PIC] was particularly concerned about the pitch overshoot, saying that he "didn't like it." The next discussion point was how to fly the maneuver. This was primarily the pilots discussing what reference system to

> use to watch the pitch angle in the cockpit. It was discussed that PJP uses the cross-pointer on the flight director to target pitch on previous flights, that a pilot could use the HUD for flight path only and the scale on synthetic vision is too small, but may work better for speed. It was determined that the cross-pointer on the primary flight display (PFD) was the method to employ. Once we decided how to capture pitch, the discussion moved to discuss the maneuver from liftoff to 35 feet. The intent was for the pilots to capture the pitch of 9 degrees, but not fixate on holding 9 degrees for a period of time. The crew discussed capturing pitch for liftoff, then transitioning to targeting the V_2 speed by the time the aircraft reached 35 feet Above Airport Level (AAL).
>
> Next the discussion moved to pull force and how to apply pressure to the column. We discussed a slightly slower pull (rather than the ramp input that had been employed previously) to a force of about 60-65 pounds. A comment from [the PIC] about the 60 pound target pull force was that it would be more repeatable, and would not be dependent upon jerking the airplane controls around. An objective of slowing the pull technique was to reduce the amount of "bobble" on pitch. This means that the pitch was peaking out, decreasing quite a bit, and then recovering throughout the climb. By slowing the pull technique we hoped to reduce the push that followed liftoff, which consequently reduced the nose attitude, adding time to the liftoff to V_2 portion of the takeoff. [FTE 1] proposed targeting a 6 degree per second pitch rate, and all agreed that sounded reasonable. We also discussed that the target time from rotation to liftoff was 3-4 seconds for a max takeoff weight condition. Other pilot discussion revolved around the pitch limiter coming up on the screen while flying these CTOs. It was discussed that the limiter was set to an arbitrary limit, and should be pushed out of the way for production G650 aircraft so that the customer pilots would not see that during a takeoff if repeating this technique. The pilots also discussed the Normalized Angle of Attack (NAOA) set-up on the legacy aircraft.

13.2 Second Preflight Discussion

The second preflight meeting was the Pre-Flight Brief held approximately 1800 of the day prior to the accident to review current aircraft configuration, flight cards, test procedures, and the applicable TSHA. The meeting was attended by the PIC, SIC, FTE 1, FTE 2, FTE 3, APG 1, and APG 2.

APG 1's following statement regarding the first preflight briefing follows:

> Each CTO configuration (both flaps 10 and 20) were to be performed targeting a 9 degree pitch attitude, and [AEO or OEI] , use a 60-65 pound pull force. The previous pitch targets were printed on the cards, but each individual marked up their cards to reflect the 9 degree target for both flaps 10 and 20. Also printed on the cards were procedures for low or medium gradients. These were not performed. All takeoffs were performed at max takeoff thrust settings. It was agreed that each CTO card would be performed about three times. Also printed on

the cards was a procedure to simulate hydraulic failure. During previous Roswell testing, [FTE 1] determined that there was negligible effect on takeoff distance or controllability, so the crew agreed that it was safer to not fail the right hydraulics. This procedure was crossed out on the CTO OEI cards. [PIC] and [SIC] agreed that a takeoff would be called a knock-it-off, and pitch would be corrected by column push if they were to see 11 or 12 degrees. [PIC] again said, “I don’t want to go there.” Once each takeoff procedure card was briefed, the team moved on to brief the TSHA’s. Each entire TSHA was discussed, including the corrective techniques.

The pilots’ discussion about “not wanting to go there” and “I didn’t like it” at the high pitch attitudes can be traced back to previous tests. Each pilot had experienced a pitch overshoot on AC SN 6002 flights with [FTE1] onboard as primary FTE. I was on-site in Roswell for each of these flights, and attended pre-flight briefs and post-test debriefs.

13.3 Flight 153 Test Card 7

According to the APG 1 and the Flight Sciences Principal Engineer, the Roswell II V-speed schedule was not adjusted for the reduced target pitch that was briefed for Flaps 10. Additionally, according to the Flight Sciences Principal Engineer, he did not realize that the V-speeds should have been increased until after the accident when he obtained FTE 1’s draft V_{MU} report from Roswell I testing. He commented that, had the Roswell II Flaps 10 speed schedule been adjusted due to the reduction in pitch angle, the resultant target V_R, V_{LO}, and V_2 speeds would have been approximately four knots higher.

The flight test card, Card 7, as documented by FTE 3, the TM test conductor, for the accident run follows:

Model: C	6002 Flight 153	Card: 7

Performance: Field: Takeoff

OEI

SET UP		NOTES		NOTES	
FLAPS:	10	CG	FWD LIM	FCC:	FIRST FLT
GEAR:	EXT	L PWR	NOTED	SHAKER:	90% NAOA
ALT:	FIELD	R PWR	NOTED	AOA LMTR:	+0.16 DEG
A/S:	0	Bleed	ECS		
Weight	MTOW				

RUN	TEST DESCRIPTION
	25.101, 25.105, 25.107, 25.113
	1. Configure aircraft for takeoff with/except: as specified
	2. Align aircraft on runway and apply brakes
	3. Set L & R PWR: as specified
	4. Release brakes
	5. At target Vef , fail RH engine using a throttle to IDLE.
	a. Use rudder and NWS control as required for directional control
	6. Rotate at Vr+2 using ____ lb pull until rotation begins, reduce force to gradually capture 10° pitch attitude.
	7. Maintain target pitch attitude until V2 is achieved, then transition to speed.
	8. Retract gear after positive Rate-Of-Climb ROC is established.
	9. Adjust pitch attitude to maintain V2 to the lesser of gear retraction complete or 400 ft AGL.
A	93-324.21 HIGH RISK L PWR:MTO ~~R HYD DEPRESS:MAN DEPRESS~~ R PWR: MTO to throttle chop
B	93-324.22 HIGH RISK ~~R HYD DEPRESS:MAN DEPRESS~~ L PWR: Med Gradient, R PWR: Med Gradent to throttle chop
<>	

Figure 4: Flight 153, Test Card 7

As noted previously, for Step 6 of the test card, the pull force had been agreed to as 60-65 pounds.

FLTOPS 1 stated that the G650 was not tail-power or geometry limited in pitch as were previous Gulfstream models. Due to limitations in pitch authority, IGE considerations were not paramount during the GV program. GV pitch rates were limited, resulting in higher liftoff speeds and a transition though IGE “relatively quickly.” For the G650, he said that without these limitations and the lack of flight 153’s test card stating to hold the target pitch attitude until after liftoff, it allowed the PIC to attempt to capture V_2 with a continual increase in pitch..

ACO 1 stated that Card 7 provided a target pitch but not a limit for this test, so there was room for interpretation and that the test card could have been written to specify a limit. In the operational case, what is published in the flight manual is not that specific (GAC notes that the final FAA-approved AFM represents the takeoff procedure that was flown during the certification test).

He was asked if it was reasonable to increase pitch beyond a target pitch, given that the V2 speed exceeded the target speed by 8 knots during previous tests. He responded that the caveat is that the numbers are right in the first place. Even the regulation said that the maneuver must be completed without exceptional skill or alertness. So it needed to be done in an operationally representative manner. It should not require extremely rapid control inputs, barely bouncing off the PLI, or high pitch rates.

He was asked, what if a test pilot decided to keep pitching, does it require writing a new test card, or is it a reasonable interpretation. He stated that the Card 7 was not specific about how long to linger at 9 degrees pitch. The operational procedures in the AFM contain margins for error or technique. In this case, in a test program, the FAA ACO did not know what the margins were yet, and the FAA ACO did not know what technique was being used in the program. The FAA ACO had not done a certification specific to the G650 yet, so the FAA ACO had not compared notes about whether they thought this was a reasonable technique.

ACO 1 also said that the flight 153 pilots had two criteria to meet, 9 degrees of pitch and V_2, and the card was “silent” on how to transition between the two. He was not sure that he had seen the instructions ever be that precise, because the maneuver should not require exceptional precision. He said that by the time they would get to the operational procedure, it should not matter, but as it turns out, it kind of did matter. By the time the FAA ACO reviews a technique that could be accepted for the flight manual, the technique should not require exceptional skill or alertness. At the time that the airplane design is approved with the associated data, there is a margin. He said that the developmental technique is different because the company is determining the limitations during development.

He also said that the takeoff techniques that GAC had been using would probably be more aggressive than what would be expected for an operator to use. When asked if he would have accepted those techniques during the TIA, he said, no, the FAA ACO could not have accepted it.

14.0 Interview of Former GAC Director of Flight Test

The former GAC Director of Flight Test stated that he encountered an IGE stall during V_{MU} field performance takeoff testing of the GIV at KROW with an FAA certification test pilot at the controls. Gulfstream’s Manager of Flight Test Engineering at the time of the test provided the test procedure, which involved holding full aft column until liftoff. He stated that this procedure caused the stall and was promptly changed to hold a constant target pitch attitude due to this event. This revised procedure was used on all further GIV V_{MU} testing and has also been used for all Gulfstream model flight test programs since that time. During liftoff, the airplane pitched “very rapidly” and stalled while the main landing gear wheels might have been a couple of feet off the ground and with the landing gear struts extended. The airplane rolled right and hit the wing tip. He applied flight controls to initiate stall recovery, and the airplane rolled to the left in part due to the impact with the ground. He “jammed in” full rudder and was able to maintain directional control while momentarily airborne above the runway surface. He said the stall was instantaneous and was accompanied by a 20 degree wing drop/rolloff. He said that with the GIV aircraft a pilot could roll wings level and count two seconds to recover because the airflow would reattach itself.

He also said that he was able to recognize the stall because he had performed a lot of stalls in Gulfstream airplanes and was used to them and knew how to respond. The chief aerodynamicist at the time asked him how he knew to apply rudder. He responded that he just did it and he did not know why he applied rudder.

He said that it was revealed later that the designers of the GIV wing had not really looked at IGE because they assumed the wing was the same as the GIII wing. They reviewed the data that they had and determined that the AOA for stick pusher activation should be lowered so that it would activate before IGE stall occurred, in case of an abused takeoff during operational flights, such as applying full aft stick or by pulling too hard, was performed while the airplane was flown operationally. They began testing with a new stick pusher activation setting after having “sort of” a review at KROW with a portion of the review conducted via conference call to GAC headquarters in Savannah. Everyone felt comfortable with the change to the stick pusher and they then flew again. The change seemed to work, but about a week later he encountered another stall at a “little higher” altitude with a wing drop/rolloff but with no wing tip ground contact. The airplane floated down while IGE, but they were able to climb by adding power. He concluded that the change in the pusher setting was not going to work. They then spent a month of testing different leading edge stall configurations, and they became very familiar with the aerodynamics of the stall. He added that they then installed vortilons[26], which worked “real well” and then performed natural stalls off the coast of Georgia as low as 2,500 feet mean sea level to verify they had enough margin beyond the stick pusher for anything that could happen IGE. They finished the program, and they did not have another IGE stall, and it has worked well for 25 years. He said that his impression was that nobody anticipated that the airplane’s characteristics would be that different while IGE. He said that he just attended a Society of Experimental Test Pilots (SETP) symposium where other test pilots and engineers commented that they did not anticipate IGE to be a problem in test programs, and that is what happened in the GIV program.

The former GAC Director of Flight Test also said that the GII, GIII, and GIV airplanes were equipped with a stick shaker and a stick pusher. During a steady state deceleration, the stick shaker would trigger and at the critical AOA, the stick pusher would trigger and lower the AOA by 2 degrees. The airplane had an alpha dot (AOA rate of change) term to compensate for acceleration into the stall. He said that on certain airplanes you could pull fast enough and encounter a stall but not the stick pusher, because the alpha dot term might not be enough, but it would handle most cases. He said that the airplane had to be airborne before the stick pusher would trigger. Occasionally, there were pilots who pulled fast enough and the stick shaker would trigger but not the stick pusher.

During the GIV program, they would pitch the airplane 2 degrees past the stick pusher activation point to ensure that they had built in a little bit of margin to compensate for IGE. In the final GIV configuration with the vortilons installed, they performed aerodynamic stalls in the GIV and past the 2 degree margin where the stick pusher would have triggered. The stick pusher was disabled

[26] Vortilons are fixed devices used to increase lift and reduce stalling at low speeds. They consist of one or more flat plates attached to the underside of the wing near its leading edge, roughly parallel to normal airflow. They function as vortex generators, and these vortices restrict airflow along the length of the wing. The can also be used to improve low speed aileron performance.

for the tests while they tried to create the margin. They first changed the stick pusher AOA trigger point and discussed a "curve" so that the stick pusher would work at a lower AOA IGE up to a certain altitude and beyond that it would return to the schedule that was already in place. Because that did not work, they installed vortilons and used the original stick pusher schedule. One of the concerns was that if they became "too exotic" with IGE regime, then the V-speeds and takeoff performance would have been affected. He said that a manufacturer generally wants to allow the operator to operate from shorter, and thus more, airfields and thus sell more airplanes, which he thought would also be a concern with the GVI. He did not think much was done with IGE analysis for the GIV, and perhaps he was "naive enough to assume that it was done," but it was not done. He said that there was not a program for the GIV to determine the stall AOA IGE; because in the past, it was not a problem and therefore not enough build-up in flight testing was done. He said that, in retrospect, it was a lesson learned.

The incident is presented in a SAE Technical Paper Series, Development of a Stall Improvement Package for the Gulfstream IV (Bruner 1989).

15.0 Interviews of Other Airplane Manufacturers' Test Programs

During the course of the investigation, the flight test departments of four other transport category aircraft manufacturers were interviewed by the Operations, Human Factors, and Performance Group Chairmen. The interviews were information gathering for the investigative team and are protected under 49 CFR Part 831.6(c). Of the four manufacturers interviewed, only two wanted to provide for the summarizations of those interviews.

15.1 Flight Test Department A

15.1.1 Schedule for Type Certification

Flight Test Department A reported that flight test certification test programs typically take about one year to complete for the issuance of a type certificate (TC); however, development issues can increase the time required for issuance of a TC.

There are many factors that dictate the time it takes to complete a certification program. Advanced technologies may affect the program length. This company attempts to complete a new type certificate program in about a year, which is from first flight to the issuance of a TC. The primary metric to track program pace is a flight test schedule that includes a line-by-line item description of the tests to be carried out on flight test aircraft, which is reviewed on a monthly basis and adjusted as necessary. They also have many other metrics, but the line-by-line item is the primary metric for assessing the program's progress. Completion of field performance development and certification testing takes about 4-6 months. Dedicated field performance certification tests, like those conducted at KROW, would take about 2-4 weeks or maybe slightly longer.

15.1.2 Flight Test Staffing

The number of company personnel that support the developmental phase of testing for a new aircraft program consists of: 10 test pilots, 15 FTEs, and 12-15 aerodynamicists. Test team size is based upon the program complexity, the projected volume of work, the length of the program, and the flight rates (hours per month). In an attempt to improve efficiency, historical data is also used, to review and learn from previous programs. The size of the test team would be larger for a new airplane model instead of a variant of an existing model. A small upgrade test program, such as a midlife avionics upgrade, in a 1-airplane program, would consist of 1-2 crews, 1 project pilot, and 1 project FTE. The project FTE would be supported by 2 additional pilots and 2 additional FTEs. A major upgrade test program, such as a new variant or new avionics suite, in a 2-airplane program, would consist of 1 project pilot and 1 project FTE, who would be supported by 8-10 pilots and 10-15 FTEs. Large new development programs with 4-5 airplanes would consist of 4 lead test pilots and 4 lead FTEs who would be supported by 20 test pilots and 20 FTEs. The size of the test team would not necessarily be different if testing involved an airplane with fly-by-wire versus a conventional flight control system. The difference would be that in testing an airplane with a fly-by-wire system, the test team involvement would begin much earlier in the design process. There would be more people who would be working for a longer period of time and involved in simulation efforts prior to flying the airplane.

15.1.3 Flight Test Organizational Structure

The company's organizational structure is formed around functional areas which are: Flight Operations, Flight Test Airplane Support, Flight Test Instrumentation, Flight Test Engineering, and Flight Test Engineering Project and Coordination. Cross functional teams are formed from these groups and each team is collocated to enhance communications. The teams are like small "tiger teams" comprised of all the core disciplines. Flight test pilots and FTEs are formed as a functional group within the team and are responsible for operating the aircraft, scheduling the aircraft, planning, conducting, and reporting. These teams have access to dedicated pilot and FTE resources needed to accomplish the test program. The Flight Sciences group is comprised of aerodynamicists and stability and control engineers and each flight test team had access to dedicated flight science personnel as required for the test.

It is a matrix organization with dedicated resources. The FTEs and test pilots are part of the same functional group, which is Flight Operations, even though they are part of a matrix organization that belongs to individual test programs. Stability and control engineers and aerodynamic performance engineers are in within Flight Sciences and are also assigned to test programs. Each functional department is led by a manager and each flight test team is led by a manager or chief depending on the size of the program.

Small programs may only be led by a chief where as a large scale airplane program would be led by a manager. All chiefs and managers report to the Director of Flight Test. There is no Director of Flight Operations but only a discipline manager. Each discipline manager reports to the Director of Flight Test who has overall responsibility for the Flight Test Center. The Vice President of Flight Test oversees flight test and Flight Operations. Pilot DERs are core members of Flight Operations and are assigned to the flight test team based on program requirements.

Disciplined DERs are assigned to each program but may not be part of a flight test team and are sourced from Core Engineering.

15.1.4 Organizational Groups

The customer-supplier relationships between groups are such that Flight Operations executes test points and Flight Sciences analyzes, reduces, and expands the data.. The FTEs are part of Flight Operations which is responsible for collecting the data, and the core specialists, such as Flight Sciences, reduces the data. Flight Test executes the test and provides the data to Flight Sciences for analysis, which has been structured in that manner for at least the past 15 years. Flight Test and Flight Operations does not perform the actual data expansion but may participate in the data review. A Flight Sciences representative will be present from program inception to define test requirements. The data delivery to Flight Sciences is immediate and continuous throughout the program. The data system that is in place allows engineering to pull data within minutes after the flight. The separation of data analysis by Flight Sciences from Flight Test is due to their respective specializations related to job function. The FTE personnel are highly specialized and educated in flight testing where as Flight Sciences and performance personnel are specialized in analysis of the subject area.

Information flows between groups from data collection, processing, data analysis, and report development, on all medium and high risk field performance testing. Testing is carried out using telemetry, and the data is analyzed real-time as the test is being performed. Additional data reduction and data analysis is done post flight by Flight Sciences. Flight Operations and Flight Sciences debrief the results of each test point either immediately via telemetry to make go and no-go decisions for the next test point or post flight to determine if predicted results match test results. All medium and high-risk field performance testing will always have telemetry, but not all medium and high risk test will have telemetry.

15.1.5 Field Performance Testing

All field performance tests are considered high risk regardless if they are AEO or OEI.

Prior to field performance testing, there is a lot of data already available. Most data, in the center of the envelope, is not analyzed on a test point-by-point basis. The data that is used is for purposes of either build-up or build-down envelope expansion and is analyzed real-time for comparison to predicted results in order to make go and no-go decisions. Envelope expansion is conducted on a test point-by-point basis to ensure nothing unpredicted happens. Post flight debriefing is conducted between Flight Sciences and Flight Test to ensure all data is within acceptable margins. If there is an unpredicted result from a test point then they stop testing and review the prediction model.

An example of an unexpected test result that would stop testing would include a case where an analytically based V_2 with a given configuration did not provide the predicted climb performance. Such testing would begin with AEO tests before OEI tests. In the one case that an unexpected test result occurred, they stopped testing to determine why it did not match the predicted climb performance. They went back and looked at the numbers by reviewing wind tunnel data and their analysis, and it was concluded that they needed to adjust their V_2 higher to match the predicted performance.

Relating to the maturity of the V_{MU} test result analysis, V_{MU} testing is completed as early as possible in the program because it is one of the criteria that is used in establishing takeoff speeds such as V_R, which also becomes the foundation for V-speeds. They typically perform V_{MC} air and ground points and stall speed determination and V_{MU} in a block of testing so that Flight Sciences or Core Engineering has a period of time to reduce the data to determine the appropriate scheduling of field performance. From an operational perspective, it works well because they use KROW because the field elevation is applicable to what will likely be in the airplane flight manuals. The V_{MCG} and V_{MU} testing are done at another location. At the time they deploy to KROW, they have all the V-speeds "very well defined" and they do not have to go back to redefine the basic parameters that affect the runway performance V-speeds. Following V_{MU} testing, a takeoff reduction report is completed, which presents information that will be used in the build-up, prior to subsequent takeoff testing. The data from field performance testing is then reduced, analyzed, and presented in a takeoff certification report containing all the information required under Parts 25.107 and 25.109. It becomes a joint decision by Flight Operations and Flight Sciences whether to continue testing after the data review.

Prior to first flight, the estimated takeoff performance speeds are set slightly higher than what would be used later so as to converge to the predicted speed for takeoff. The speeds are mostly based upon high lift testing and its derived parameters of C_L and C_{LMAX} to derive the takeoff speeds. They also use past experience but also do the proper confirmation of those derived values in addition to desktop and fixed base simulation modeling combined with certain aircraft characteristics to build down the modeling of the takeoff from V_R to V_2 at 35 feet AGL. In the last large trial of field performance testing which made use of one aircraft, they had 35-40 people at KROW, which involved all disciplines including maintenance and support personnel. There were 10 dedicated flight science engineers for data analysis and shift rotation, 3 or 4 test pilots, 5 FTEs, 2 systems engineers for brake testing, and other disciplines. They had enough people in the TM, in Aircraft Operations, and Flight Sciences so they could have a second shift for data analysis, which was done at KROW. They typically have a single test aircraft dedicated for field performance, which is specialized with instrumentation and egress equipment. If they had been testing more than one airplane the amount of personnel would have increased dramatically. The field performance phase lasted about 2-6 weeks but that time is program-dependent. The data was reduced and analyzed typically for all the tests so that it is completed by the next morning so that the results can be presented to the crew.

They have a standardized program that goes through the data looking at identified parameters of importance. The chosen points of importance are rotation, liftoff, and the 35-foot AGL points. They become the anchor points for the data reduction. They track all the parameters as a function of AOA, C_L, and gradient at 35 feet AGL and compare them to predicted values. They use C_L from free air data and in ground effect. The expectation is that C_{Lalpha} should move up and at some point and at a certain angle there should be a flattening change in C_{Lalpha} which is what they check for in the data reduction by comparing it to free air data. They also do a gradual build up by targeting an incremental increase in angles so as to ensure they move in the right direction. They adjust the C_{LMU} which defines the V_{MU} and from that they derive the rotation speed so they meet the minimum liftoff requirement. This analysis is done at KROW where they use data reduction and expansion programs and as soon as they identify new parameters they can regenerate new takeoff performance speeds.

Hazard mitigation techniques for OEI continued takeoff tests employ a minimum number of engine cuts to define engine out parameters. Throttle reductions are used for the majority of the runs. They try not to perform actual engine cuts by keeping the engine power at an idle power setting. The crew is supposed to wear protective gear such as fire resistant suits and gloves. Airport rescue and firefighting is available for "quick response" and during some tests they are standing by along the runway. Flight Sciences is also required to provide estimated tail bumper strike attitudes. TM is used for each run to provide crew feedback. Flight Sciences provides predicted liftoff speeds and runway distances. The maximum allowable crosswind is 5 knots with a maximum total wind of 10 knots. The minimum runway width is 150 feet. The wing leading edges are cleaned before the test and are periodically checked during testing.

The company defines 6 degrees per second or higher takeoff rotation rate as "aggressive and abused." They do not use anything that approaches abused for a normal takeoff. If the minimum allowable V_R using a rotation rate of 3-4 degrees per second results in exceeding the predicted V_2, and the data review shows that the correct planned procedure was followed, then it would mean that V_2 would have to be adjusted. If the data supports what is being observed during testing then changes cannot be made to rotation rate to improve performance.

Cues that test pilots use to recognize limits and/or AOA so as not to exceed safety limits include: a tail strike wand while on the runway to indicate pitch attitude, a HUD, or the primary flight display (PFD) to indicate pitch targets. Pitch targets are used because it is impossible to actively track an AOA from takeoff rotation to 50 feet AGL because it is a dynamic maneuver.

Safety of test parameters that are monitored include: pitch rate, stick shaker, margin, maximum pitch attitude, etc. If a parameter is exceeded, any test team member may stop the test, and test team members also have the responsibility to stop the test for any parameter exceedance.

If an airplane experienced and recovered from an uncommanded roll during takeoff rotation, then testing of those conditions would cease and a full safety review would be convened. If there was a second occurrence of an uncommanded roll, the safety review would then invite the required departments to investigate the occurrence. Also, such an event would require grounding the airplane until a full safety and data review had been completed.

The company has never experienced an uncommanded roll due to an IGE stall during field performance testing.

The company does not provide takeoff guarantees to customers but provides brochure-level information of performance which is comprised of range, dimensions, takeoff and landing distances.

The company uses cockpit and external video for all field performance testing. The videos are used to review maneuvers to confirm that flight crew and TM observations are in agreement. The videos are also used to review anomalies and for use during safety reviews. The company also has used the videos as a learning tool.

15.1.6 Flight Test Data Analysis

The TM personnel perform the post processing and final analysis because they are the first ones to be looking at the data as the test occurs. The Flight Sciences personnel are divided into three teams: one group looks at the landing segment data, a second team looks at the takeoff segment data, and the third team looks at the briefing data. There are upwards of 10 Flight Sciences personnel involved, of which 1 or 2 personnel would be in TM and 1 or 2 personnel would be analyzing the data. They do not perform all tests simultaneously and they may perform takeoff performance testing for several days and if the data analysis is not completed, then they may perform landing performance testing for several days. Depending on how quickly the data analysis is progressing, Flight Sciences will work with Flight Operations to change the daily schedule, and it is an iterative daily process.

15.1.7 Flight Test Team

The crew in the airplane for field performance testing would typically be 2 pilots and 1 FTE because it is a high risk test. The FTE is responsible for operating the data system and the data log and assisting the test conductor with TM. Additional personnel may be provided for crew relief. The onboard FTEs are typically rotated between the onboard aircraft data station and TM positions. There is always a FTE test conductor present in the TM station who is supported by Flight Sciences. The test conductor is responsible for communication with the aircraft and in charge of the TM.

The selection of flight crews for high risk tests are based upon the pilot-in-command having experience in the particular test and in the aircraft type or of a similar aircraft type if the aircraft to be tested is a new model. The second-in-command must be fully qualified in the aircraft type to be tested. Both pilots must attend or receive a briefing of the safety review applicable to the test, which is mandatory for all high risk tests. The FTE must have experience for the test to be performed; otherwise, a mentor FTE with that experience must accompany that FTE. Crews are rotated only if testing is remote for an extended period or if the crew member becomes unavailable. If crews are replaced, then those crews are briefed on the testing that has been accomplished.

An FTE must to be on board the airplane for testing to include: real time monitoring data, water ballast control, provide target speeds, provide target rates, provide target attitudes, and to monitor real time data. An FTE must also be in the TM station to monitor real time data and to independently determine target speeds, rates, and attitudes. Both the aircraft and TM FTEs must agree on the test parameters prior to performing the test run. TM is a mandatory requirement to be present for all new aircraft model testing or envelope expansion of existing models of aircraft.

The FTE aboard the airplane and the FTE in the TM station will both independently take the performance charts and cross check their performance numbers prior to conducting a test point. They will use two FTEs for purposes of training an FTE during lower risk tests. For envelope expansion, the onboard test team typically consists of three crewmembers. During certification testing, there will be 2 FTEs on board, one of which is from the certifying authority.

Flight crewmembers may not work more than 60 hours per 7-day period and no more than 6 consecutive days. High risk testing may not exceed 12 hours per crew duty day, which is the company safety policy. For any test, there is a potential waiver for lower risk tests, but there is no waiver for high risk tests.

Usually, about 3 or 4 hours of good field performance flight testing is performed, approximately 50-70% of the time at KROW, before the test needs to be stopped due to an increase in the winds or thermal heating as the day progresses. The testing only involves landing, takeoff, and brake testing. There are some days in which they were able to test all day, but that rarely occurs.

There is no safety documentation that stipulates crew rest for engineering personnel, but they have a site manager that is responsible for ensuring that the test team is getting proper rest. They try to have enough personnel on-site, which includes maintenance personnel, so that nobody is overworked.

15.1.8 Test Safety Margins

Safety margins with respect to AOA are established for takeoff performance testing through the use of a stick shaker and experimental instrumentation for AOA, pitch rate, and a tail proximity system for V_{MU} testing. They also have “do not exceed” limits of AOA. The tail proximity system provides a cockpit indication if the aircraft pitch attitude rises above a certain value.

They ensure that the aircraft does not reach the IGE stall AOA through the use of proper speed and pitch rate selection. They want to maximize the excess energy from rotation to 35 feet AGL along the takeoff path. They do not want to pitch the airplane pitch too high because of an increase in drag. There is no advantage to be achieved by a high AOA with the main landing gear wheels on the ground during takeoff.

15.1.9 Stall AOA IGE Determination

The use of true proper takeoff scheduling is how they ensure proper AOA protection IGE. Each aircraft has its own characteristics and the degradation of lift in IGE stall. IGE results in a gain in CL for a given alpha and a reduction in the stall AOA, which is aircraft dependent. The estimation of the degradation is mostly based on previous experience and not on wind tunnel testing. Computational fluid dynamics does give an indication of the degradation but they rely on their previous experience and look for a flattening of the C_{Lalpha} curve during V_{MU} testing. The flattening of the curve is what they use for their limitation. They have not been relying much on IGE wind tunnel testing for their IGE modeling. During flight testing, they cannot go to high enough AOA to really reach the maximum AOA as you would be able to during free-air testing.

15.1.10 Flight Test Manuals

The company has two manuals that govern flight test operations and safety management, which cover crew duty time, defining and recording of aircraft events, and the safety risk management process. The safety risk management process details how to conduct a safety of flight review (SFR) and a TSHA. The SFR is performed prior to any medium or high risk test. The manuals were modeled from best practices from military and civilian programs and from regulations such as FAA Order 4040.26. Version A of the Order is valid but they revised their safety documents to reflect version B. The manuals are disseminated to Flight Operations and Engineering and it is documented electronically that it and any revisions have been read. The crew members are tested on those revisions.

15.1.11 Changes to Flight Test Procedures

A test team that wants to change test procedures in an approved test plan may do it through the company's "red line" process. The process allow changes to be made to test cards so as to correct errors such as typographical errors or minor changes but not a major change to the structure of the test procedure or risk assessment. Changes cannot be made to configurations, airspeeds, limits to test parameters, or risk assessments without a full meeting between all of the participants. The changes then need to be reflected in the original test plan.

15.1.12 Flight Test Cards

The test cards define what and how maneuvers are to be performed and the allowable tolerance of critical parameters such as weight, speed, and center of gravity, depending on the test. The test card must reflect the test parameters on the test definition sheet. Typically, a DER Flight Sciences personnel or a delegate participates in the pre-flight briefing and concurs or modifies the test card. The procedures within a test cards are initially based upon wind tunnel and analytical flight science predictions.

High risk test flights cannot deviate from the parameters and limitations on the test card without a thorough review and re-brief with all parties. If an SFR was performed for the test, then the SFR must be repeated. An SFR review is conducted before any medium or high risk test is conducted. The SFR is also conducted if requested by the flight crew. A change in the margin from stick shaker activation to aerodynamic stall or any change in the stall protection system would require a technical review and an SFR before that system is flown. If there were 5 such changes, then it would be required to have 5 separate technical reviews and SFRs.

15.1.13 Test Safety Review

The company does not use an SRB, which is comprised of a set of individuals, but an SFR. They have held SFRs for low risk tests. The SFR is comprised of the test flight crew, design engineers, Flight Test Engineering, Flight Operations, senior engineering advisor, and the chairman. The chairman can be the Flight Operations Manager or Director of Flight Operations. The chairman must not to be involved in the day to day operations for the test under review. Specialists from the applicable discipline, who are not involved in the program that is under review, also attend the SFR. The specialists are invited but do not always attend. They try to get independent personnel not involved in the program to attend the reviews. They meet about 2-10 days before the test to allow enough time to address the issues resulting from the review. Engineering conducts a preliminary TSHA to identify probable hazards to the crew, aircraft, and facilities. Flight Operations reviews the test request and assists Engineering in performing a more detailed hazard identification. Engineering and the flight crew work together to identify potential hazards based on previous experience, scenario-based thinking, and flight testing archives. They create a TSHA worksheet to define the hazards, causal factors, consequences, and risk mitigation. In general, Engineering is responsible for identifying the technical risks and Flight Operations is responsible for identifying and mitigating operational risk associated with testing. The project FTE leads the hazard identification, the risk mitigation, and completes the TSHA. Updates are done on an as-needed basis, and it is mandatory for any changes in the risk assessment items.

If any unexpected characteristic or deviation from a predicted result occurs during testing, any flight crew member or test team member in the aircraft or TM personnel has the authority to terminate a test until it is determined why the unexpected characteristic or deviation occurred. The company makes it “very clear” that any team member may stop a test until it is determined why there ha been an unexpected occurrence.

There is a lot of regulatory guidance that limits the minimum allowable V_R. V_R cannot be below a certain value. The maximum allowable pitch attitude is chosen to achieve the approximately correct V_2 at 35 feet AGL, using normal rotation rates, which the company defines as 3-4 degrees per second and OEI and weight and temperature (WAT) limited takeoff characteristics, the critical performance condition. The second segment climb limit defines the initial pitch attitude, and upon reaching V_2, pitch is to be increased to maintain V_2.

15.1.14 Safety Management

The company implemented a safety management process for new programs in the late 1998 and early 2002 for sustaining programs. They have not had a major incident or accident under that process. All developmental testing undergoes the safety risk management process. The accountable executive in the company is the Director of Flight Test. The company also has a dedicated Flight Safety Officer.

Safety reporting consists of a safety line to which any employee can make reports to. They also have an aircraft occurrence report that can be submitted by flight crew. Safety line reports are investigated by a Safety Committee and aircraft occurrences are investigated by the Safety Officer.

Investigations of aircraft occurrences are completed within defined time limits and are rated by priority based on the risk assessment of the issue, and it is then addressed according to that priority. The safety line is reviewed and tracked by the Safety Committee, which is comprised of multidisciplinary members who review and track safety line reports. The activities of the Safety Committee and those of the safety officer are dictated by the company safety document.

To prevent future safety related occurrences, recommendations are made, personnel briefings are held, additional training is conducted, changes in procedures are made, or new equipment is procured, all of which are dependent on the particular event. Most of the findings from internal investigations are related to the company processes or products and are not typically shared outside the company. However, pertinent findings would be shared with other organizations and professional societies.

Flight test crews are trained on the flight test safety programs with the use a self-administered test corrected to 100%. The test results are kept in a crew folder. The test is repeated for each revision of the defining documents for the flight test safety program. Revisions to these documents are also briefed. The test would include program items such as crew duty times, the safety process, and various excerpts from the company's safety manual.

Some FTEs belong to the Society of Flight Test Engineers (SFTE) and the company provides funds to employees to be members of up to one professional society. They are encouraged to join such societies. Most of the FTEs, even though they are not members, attend local SFTE chapter events and also SETP events. All of the flight test center test pilots belong to SETP.

16.0 Flight Test Department B

16.1.1 Schedule for Type Certification

Flight test department B has ODA production and TC authority. The industry standard for the time it takes to complete a certification program is 5-20 years. The industry standard for issuance of an aircraft TC from the first flight of the aircraft is about 1 ½ - 2 years.

16.1.2 Field Performance Testing

The first area of performance testing is V_{MU} testing, which provided the opportunity to examine the aircraft's characteristics and behavior at low speeds. Upon completion of V_{MU} testing a specific report of V_{MU} testing is not written, but all the data analyses associated with the test is analyzed and presented, which is completed in several days.

They have not had an aircraft experience an uncommanded roll event during field performance flight test.

Purchase agreements are signed prior to TC issuance and have a spec and description, which contains performance information. The contract says that Company B can change the performance, but that it cannot get worse. If so, the purchaser is entitled to a deposit refund.

16.1.3 Data Analysis

They use both onboard and TM to collect flight test data and the on-site data analysis is primarily through the use of TM. The FTE that is on board the airplane assists the flight crew in looking at the correct test parameters and to conduct the test so that it is set up properly for each run. They want the flight crew to focus on flying the airplane, and not spending a time with their "heads down."

The time that is takes to analyze flight test data is test dependent. The analysis to determine if performance criteria has been met prior is done almost instantaneously and prior to the next test run. During field performance testing, data analysis is performed by a special group within the Flight Test Department. The FTE on board the aircraft is not necessarily the FTE that will be performing the data analysis on-scene prior to the next day's flight.

16.1.4 Flight Test Team

The personnel selected for a test team for any kind of test is based upon their past experience, their demonstrated ability, and on a pilot approval matrix. The test team for flight for field performance testing is comprised of two flight test pilots and 1 FTE. TM is used to allow team members who are not on the airplane to provide additional oversight of items that may have safety implications. The minimum size of the crew aboard the airplane is established by the TSHA. The same test flight crew typically performs the entire performance field testing, but they may have one additional crewmember.

16.1.5 Test Safety Margins

Field performance testing is performed only when all stall speeds and handling characteristics are understood in the approach to stall and at aerodynamic stall.

For OEI CTO tests, they have maximum pitch attitude targets as well as maximum rotation rates, and the target pitch attitude would be identified as not to exceed. In general, pitch attitudes targets, limits, and maximum control forces are specified. The limits are divided into limits IGE and OGE. There is some latitude to adjust to achieve V2 speed. You cannot go from 10 degrees to 20 degrees of pitch to achieve V2, but just a small adjustment to ensure that the scheduled V2 is achieved.

16.1.6 Stall AOA IGE Determination

They were not aware of how other aircraft manufacturers predict and explore the effects of IGE on aircraft characteristics and aircraft speeds. They have used some IGE wind tunnel testing, but there was such a minor difference in IGE that it has not been necessary to modify their aircraft and aircraft configurations. They have not observed unexpected or significantly different behavior between IGE and OGE in a variety of their airplanes.

16.1.7 Changes to Flight Test Procedures

Changes that modify test plans are not permitted without the approval of original team that approved the test plan. A reduction in the stall margin is not allowed without a similar approval. Approval is not needed to perform additional build-up tests. Test crews cannot extrapolate conditions or change procedures because such changes need approval of the team that approved the test plan.

Decisions to continue or discontinue a test are made by those involved in the real-time testing and are based on data collected and the observed conditions, to the extent that they are quantifiably identifiable by the test team.

The number of runs that are attempted depends on the type of test. A benign cruise test point may have several attempts at achieving success test criteria; however a critical test point would not have more than one attempted run. A critical test point is one that would have a significant outcome that damaged the airplane or injured the crew. The nature of a critical test needs to have the team step back and look at what is occurring. Schedule and cost do not drive tests.

16.1.8 Flight Test Cards

Test cards are the "holy grail" of flight testing. They state how each test is to be conducted. The test cards are developed from the approved test plan.

16.1.9 Flight Manuals

They have a policy and procedures manual for engineering flight test operations. It is based upon military flight test best practices and discussions with other manufacturers at SETP flight safety workshops.

F. Attachments

Attachment 1, Flight Crew Company File

Attachment 2, Aircraft 6002 Flight Log (September 10, 2010 – April 1, 2011)

Attachment 3, Gulfstream Flight Test Standard Practice Manual, Revision F

Attachment 4, Excerpt of Safety Review Board Meeting Minutes