NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

March 5, 2012

HUMAN PERFORMANCE

GROUP CHAIRMAN'S FACTUAL REPORT

DCA11MA076

A. ACCIDENT

Operator:	Gulfstream Aerospace Corporation
Location:	Roswell, New Mexico
Date:	April 2, 2011
Time:	0934 mountain daylight time[1]
Aircraft:	Gulfstream G650, N652GD

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

D. DETAILS OF THE INVESTIGATION

The operations / human performance group, initially consisting of only National Transportation Safety Board (NTSB) staff, first convened at the law offices of Tony Center in

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[1] All times listed in the report below are local, unless specified otherwise.

[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.

Savannah, Georgia, on June 1, 2011 to interview the spouses of three fatally-injured crewmembers. On June 7, 2011, the group convened at GAC headquarters in Savannah, Georgia, for a briefing from GAC. From June 16-17, 2011, the group, joined for the first time by GAC and Federal Aviation Administration (FAA) group members, convened at GAC headquarters to interview eight GAC employees who were involved in the G650 flight test program. From July 7-8, 2011, the group, joined by a different FAA group member, convened at the FAA Atlanta Aircraft Certification Office (Atlanta ACO) to interview several FAA personnel who were involved in the oversight of GAC aircraft certification programs. From July 11-12 and August 8-12, 2011 the group convened at NTSB's recorder laboratory to review the cockpit voice and video recordings for the accident flight and video recordings from certain earlier G650 test flights. Between September 12 and October 17, the group participated in intermittent telephone discussions about industry flight test safety practices with several aircraft manufacturers. From October 24-28, 2011, the group convened at GAC headquarters in Savannah, Georgia to interview 18 employees who were involved in the G650 flight test program, five of whom had been interviewed previously. In addition to these activities, the group conducted various telephone interviews and reviewed numerous documents.

1.0. FACTUAL INFORMATION

1.5. PERSONNEL INFORMATION

The airplane's crew consisted of two pilots (a PIC and SIC) and two flight test engineers (FTE1 and FTE2). The pilots sat in the cockpit. The PIC was in the left seat and he served as the pilot flying. The SIC sat in the right seat and he served as the pilot monitoring. FTE1 and FTE2 sat at computerized workstations in the main cabin. According to G650 flight test personnel, one FTE normally served as the on-board test conductor and the other FTE normally monitored the flight control system. Members of the on-site flight test team provided conflicting statements regarding which FTE was performing which duty during the accident flight. A third FTE (FTE3), who was located in the telemetry trailer, said that FTE2 was monitoring the flight control system, whereas the airplane performance group head (APG1), who was also located in the telemetry trailer, said FTE1 was monitoring the flight control system.

1.5.1. The PIC

The PIC, age 64, was married and lived with his wife in Savannah, Georgia. His leisure activities included exercising and flying and maintaining a single-engine piston airplane that he owned. His colleagues said positive things about his knowledge, skills, and teamwork. He was regarded as a very knowledgeable and experienced test pilot.[3] His colleagues described him as friendly, upbeat, open to input, and appropriately assertive. They said that his decision making was analytical, conservative, and safety-oriented. His wife said that he needed 8 hours of sleep per night to feel rested and that, on a typical workday in Savannah, he woke at 0600 and went to bed by 2200. He carried a company cell phone, and cell phone records were used to help document his recent activities.

[3] In 2010, he had, at the request of his supervisor, drafted a company manual titled *Aeronautics for Gulfstream Aviators* that was distributed to all GAC pilots.

1.5.1.1. Activity look-back / 72-hour history

On March 25, 2011, the PIC traveled to Roswell to participate in field performance testing. He served as PIC on that day and on each subsequent day until the date of the accident. During this period, he averaged 6 hours of duty time (range: 2.5 - 10 hours) and 3 hours of flight time (range: 1 - 5 hours) per day. The PIC joined colleagues for breakfast in the hotel about 0530 each morning, and was seen making regular use of the hotel fitness center in the afternoons. An SIC from the prior week's testing who flew with him and shared a car with him in Roswell from March 28 to April 1, 2011, said that they finished dinner by 2000 and headed to their rooms by 2100 every night. That SIC, and other colleagues, described the PIC as acting normally and seeming upbeat in the days before the accident.

On Wednesday, March 30, 2011, the PIC made a 1-minute call at 0508. Between 0701 and 0833, he acquired 1.5 hours of block time, performing landing performance, braking performance, and thrust reverser effectiveness tests. The G650 project pilot spoke with him that morning and the PIC said that the testing was going well. The last activity on the PIC's cell phone that day was an outgoing text message at 2201.

On Thursday, March 31, 2011, at 0531, the PIC made a 1-minute call. Between 0707 and 0948, he acquired 2.7 hours of block time, performing landing performance, braking performance, and thrust reverser effectiveness tests. Between 1225 and 1447 he acquired 2.4 additional hours of block time, flying landing performance tests. The last activity on his cell phone was a 2-minute outgoing call at 1658.

On Friday, April 1, 2011, the PIC made a 1-minute call at 0559. Between 0744 and 0842, he acquired 1 hour of block time in the accident airplane flying braking performance, landing performance, and rejected takeoff tests. After the SIC, FTE1 and FTE2 arrived, the PIC participated in two afternoon briefings. The PIC's wife spoke with him by phone and recalled that he was in a good mood. The PIC went to dinner with colleagues in the evening and returned to the hotel about 2000. The last activity on his cell phone was a 1-minute voice mail retrieval call at 1959.

On Saturday, April 2, the PIC's colleagues recalled seeing him in the hotel lobby at the usual time (about 0530). Flight test video showed him entering the cockpit at 0541. The crew performed their first takeoff at 0617. At 0857, after 9 takeoffs, the PIC parked the airplane near the telemetry trailer, visited the restroom, and went into the telemetry trailer. Subsequent comments made by the PIC and captured on cockpit audio recordings indicate that he had a discussion with APG1 about how the tests were going. Both pilots entered the cockpit and the PIC began to taxi the airplane at 0908. The crew performed 3 more takeoffs, the last of which was the accident takeoff.

1.5.2. The SIC

The SIC was 51 years old, married, and lived with his wife and children (ages 7 through 11) in Savannah, Georgia. His leisure activities included exercising and spending time with his family. His colleagues described him as well qualified, but new to large-cabin GAC airplanes. They said he was good-natured, positive, appropriately assertive, and open to criticism. His wife said that he normally woke at 0600 and went to bed between 2100 and 2200, and his sleeping activities were very regular. He carried a company cell phone, and records from that phone were used to help reconstruct his recent activities.

1.5.2.1. Activity look-back / 72-hour history

Saturday and Sunday, March 26 and 27, 2011, were the SIC's scheduled days off. He took an additional day of on Monday, March 28, 2011, in anticipation of his upcoming trip to Roswell. He resumed work on March 29, 2011. His wife said that in Savannah he normally left home for work between 0730 and 0800 and returned home between 1730 and 1800. She reported that his mood seemed fine and his behavior seemed normal in the days before the accident.

On Wednesday, March 30, 2011, the SIC went to work between 0730 and 0800. Company records and witnesses indicated that he spent an hour in the G650 Integrated Test Facility (ITF), between 1700 and 1800, practicing takeoffs with FTE1 (see Attachment 6). His wife could not specifically recall what time he went to bed. Cell phone records revealed no early morning or late evening activity.

On Thursday, March 31, 2011, the SIC went to work in Savannah between 0730 and 0800. Company records indicate that he spent time executing failure hazard analysis validation test points in the ITF with an engineer from the GAC Flight Sciences Organization from 0800 to 1200. After work, he went out to dinner with his family and engaged in routine activities at home. Cell phone records showed no early morning calls and the last activity on his cell phone was a 1-minute voice mail retrieval call at 2141. His wife recalled that he fell asleep a little after 2200.

On Friday, April 1, 2011, the SIC woke about 0600, left for work in Savannah about 0840 (EDT), and traveled on a company airplane to Roswell, arriving about noon. He participated in two afternoon preflight briefings, went to dinner with colleagues in the early evening, and returned to the hotel about 2000. The last activity on his cell phone was a 1-minute voice mail retrieval call at 2042.

On Saturday, April 2, the SIC's colleagues recalled seeing him in the hotel lobby area at the usual time (about 0530) and phone records showed no earlier activity. Flight test video showed the SIC entering the cockpit at 0541 and the crew performed their first takeoff at 0617. At 0857, after 9 takeoffs, the PIC parked the airplane near the telemetry trailer and both pilots left the cockpit. Subsequent comments made by the SIC and captured on cockpit audio recordings indicate that he had a discussion with FTE1 about how the tests were progressing while the airplane was parked. The pilots entered the cockpit, and the PIC began to taxi the airplane at 0908. The crew performed 3 more takeoffs, the last of which was the accident takeoff.

1.5.3. The lead FTE (FTE1)

FTE1 was 48 years old, married, and lived in Savannah, Georgia with his wife and children (ages 7 through 12). His leisure activities included yard work, church activities, and spending time with family. He was not a pilot. His wife said that working as a lead flight test engineer was his dream job. His colleagues described him as skilled, experienced, good natured, collaborative, and appropriately assertive. They said that his decision making was safety-oriented, and they cited his efforts to improve test airplane external safety markings and brief local airport rescue and fire fighting personnel about the test airplane. His normal work schedule consisted of four ten-hour days (Monday through Thursday), but his wife said he often worked Fridays and sometimes Saturdays as well. She said that in Savannah he normally woke at 0500 and went to bed about 2200 and he needed just seven hours of sleep per night to feel rested. When working in Savannah, he normally left home for work about 0615 and returned about 1800. He carried a company cell phone and a personal cell phone. Records from these phones were used to help reconstruct his recent activities.

1.5.3.1. Activity look-back / 72-hour history

Company records indicate that FTE1 was off duty March 26-27, 2011, and he worked 12 hours on March 28, 2011, and 11.5 hours on March 29, 2011.

On Wednesday, March 30, 2011, he left for work about 0615. On or about this day, he showed a video and plots of the roll-off event that occurred during flight 132 (on March 14, 2011) to the manager, flight test engineering. At the suggestion of the manager, flight test engineering, FTE1 then briefed the director of flight test. Company records and witnesses indicated that, between 1700 and 1800, FTE1 spent an hour in the ITF practicing takeoffs with the SIC. Company records indicate that he worked 12 hours that day. His wife recalled that he went to bed about 2200. His cell phone records contained no early morning or late night calls.

On Thursday, March 31, 2011, FTE1 took the day off from work. He woke at 0500, drove his children to school, ran errands, and worked in the yard. In the afternoon, he picked his children up from school and ran more errands. At 1448, he received a call on his cell phone from a G650 flight controls and handling qualities engineer. According to his wife, FTE1 then drove home to participate in a work-related conference call. The engineer who called him and participated in the subsequent conference call told investigators that a decision was made during this call that field performance testing in Roswell was going to end on Wednesday, April 6, 2011, a few days earlier than planned.[4] Company records indicated that FTE1 recorded no work hours on March 31, 2011. His wife recalled that he went to bed about 2200. His phone records contained no early morning or late evening activity.

On Friday April 1, 2011, FTE1 woke at 0445, according to his wife. He drove his children to school, went to work, and traveled from Savannah to Roswell on a company airplane with the SIC and FTE2. After arriving in Roswell around noon, he met the FTE group head, his direct supervisor, who had been serving as test conductor for the previous two weeks. FTE1 subsequently conducted two afternoon briefings with flight test team members who would be working with him the next day. During the first, he explained his intention to use a decreased target pitch of 9 degrees for the flaps 10 condition. During the second, he reviewed flight 153 test cards in detail. He had a telephone conversation with his wife at 1800, went to dinner with

[4] The G650 flight controls and handling qualities engineer told investigators that the current round of testing in Roswell was ending early because it had been determined that some of the maximum gross weight tests needed to be performed at sea level. According to the FTE group head, some of the tests had to be deferred because of aircraft configuration issues.

colleagues, and returned to the hotel about 2000. Company records indicate that he worked 10 hours that day. His phone records contained no early morning or late evening activity.

On Saturday, April 2, 2011, FTE1's phone records showed an outgoing call to FTE2 at 0350 with an elapsed time of zero minutes. At 0406, he received an incoming call from his wife that lasted 18 minutes. His wife recalled speaking with him and she said that this conversation was routine. Colleagues reported seeing FTE1 in the hotel lobby area about 0530. Cockpit audio indicated that he boarded the airplane by 0547. After 9 takeoffs, FTE1 experienced problems with his computer workstation and he asked the flight crew to park the airplane so that he could reboot his computer. The airplane was parked next to the telemetry trailer at 0857. Subsequent comments made by the SIC and captured on cockpit audio recordings indicate that FTE1 had a discussion with the SIC about how the tests were progressing. Taxiing resumed at 0908, and the crew performed 3 more takeoffs, the last of which was the accident takeoff.

1.5.4. The second FTE (FTE2)

FTE2 was 47 years old, unmarried and lived alone in Savannah, Georgia. He had formerly worked as a GAC production test pilot. His leisure activities included working on cars, hang gliding, woodworking, and hunting. He was a pilot. His colleagues regarded him as highly competent. He was in charge of airspeed calibration testing, which they regarded as a very difficult assignment. The day of the accident was the first time he had participated in field performance testing on the G650. He was filling in for another FTE who was unable to make the trip due to a scheduling conflict. FTE2's colleagues described him as friendly, outgoing, and willing to do what it took to complete a job. A few days before the accident, he had accepted an offer of employment from a different airplane manufacturer and he planned to begin his new job as soon as GAC could train his replacement. Friends and family said he was looking forward to the new job because he was going to be working as a test pilot again. FTE2 carried a company cell phone and records from that phone were used to help reconstruct his recent activities.

1.5.4.1. Activity look-back / 72-hour history

Company records indicate that FTE2 was off duty March 25-27, 2011. He spent the weekend visiting friends in Atlanta, GA. Company records indicate that he worked 10 hours on March 28, 2011, and 12 hours on March 29, 2011.

Friends, relatives, and colleagues were unable to provide detailed information about his activities in the 72 hours before the accident.

On Wednesday, March 30, 2011, company records indicate that he worked 12 hours. His phone records showed no early morning or late evening activity.

On Thursday, March 31, 2011, company records indicate that he worked 10 hours. His phone records showed no early morning or late evening activity.

On Friday, April 1, 2011, FTE2 traveled to Roswell on a company airplane with the SIC and FTE1, arriving about noon. His supervisor, who was already in Roswell, met him at the airport when he arrived and recalled that he was in a good mood. Company records indicate that he worked 10 hours that day. His phone records showed no early morning or late evening activity.

On Saturday morning, April 2, 2011, FTE2's colleagues saw him in the hotel breakfast area at the usual time (about 0530). His phone records listed no early morning activity. Cockpit audio recordings indicate that he boarded the accident airplane by 0547. After 9 takeoffs, the crew parked the airplane by the telemetry trailer at 0857. FTE2's activities during the break are unknown. Taxiing resumed at 0908 and the crew performed 3 more takeoffs, the last of which was the accident takeoff.

1.5.5. Other personnel

Personnel in the telemetry trailer at the time of the accident consisted of FTE3, APG1, two additional engineers who had been temporarily assigned to the airplane performance group (APG2 and APG3), and a telemetry engineer. FTE3 was monitoring test results in real time and communicating with the on-board crew. APG1 was verifying test conditions and comparing results to performance objectives. APG2 was placing markers in the flight test data stream to facilitate later analysis. APG3 was observing operations in the trailer. The telemetry engineer was monitoring data-link connections between the trailer and the airplane and adjusting a roof-mounted antenna as needed to maintain this connection.

1.5.6. Flight crew familiarity and interpersonal dynamics

The pilots' spouses said that the PIC and SIC had a positive professional relationship. The engineers in the telemetry trailer reported that all on-board crewmembers were getting along on the morning of the accident. All flight test team members were well-acquainted, with the exception of APG3, who was new to the company and was observing field performance testing for the first time. APG1 said that the flight test team was "re-energized" by the recent change-out of some team members.

1.13. MEDICAL AND PATHOLOGICAL INFORMATION

1.13.1. The PIC

According to his wife, the PIC was physically fit and in excellent health. He had not experienced any significant recent changes in his health, sleeping, eating, or leisure activities. His wife said he had not displayed any recent signs of illness. She stated that he did not use tobacco products and he normally consumed about one alcoholic beverage (a beer) per week. According to FAA records, he was taking coltracine (a prescription anti-inflammatory medication used to treat and prevent gout) and atorvastatin (a prescription lipid-lowering agent used to treat lipid disorders and elevated cholesterol). His wife and colleagues reported having no knowledge of his use of any other medications. His most recent FAA first class airman medical certificate, dated January 18, 2011, bore the limitation, "holder shall wear corrective lenses."

1.13.1.1. Toxicological test results

Toxicological testing was performed by the University of New Mexico Health Sciences Center Office of the Medical Investigator on biological specimens obtained post-mortem from the PIC. This testing detected brompheniramine (an over the counter antihistamine medication with side effects that are potentially performance impairing, 31 ng/mL), caffeine, and theobromine (a stimulant compound found in tea and chocolate) in the pilot's blood. Toxicological testing performed by the FAA Forensic Toxicology Research Team, Civil Aerospace Medical Institute (CAMI) detected no ethanol in the pilot's vitreous fluid. CAMI also tested the PIC's specimens for a variety of drugs.[5] These tests revealed atorvastatin in liver and heart blood and brompheniramine (0.098 ug/ml) in liver and heart blood (see Attachment 2).

1.13.2. The SIC

According to the SIC's wife, the SIC was physically fit and in good general health. She said he had not experienced any significant recent changes in his health or personal life, aside from starting his job as a test pilot at GAC. His leisure activities included spending time with his children and exercising, and there had been no recent changes in these activities. He did not normally use tobacco products or drink alcohol. The SIC's wife and colleagues reported that he did not display signs of illness in the days before the accident. According to FAA records, he was taking the prescription medications warfarin (an anticoagulant) and esomeprazole (a proton pump inhibitor used to treat heartburn and acid reflux disease). His most recent first class medical certificate, dated October 12, 2010, bore the following limitations: "holder shall wear corrective lenses" and "not valid for any class after April 30, 2011."

FAA medical records indicated that the SIC had a history of deep vein thrombosis and hypercoagulopathy resulting from a genetic condition (Factor V Leiden deficiency) that required anti-coagulation therapy, and that the condition was well controlled by his ongoing use of anticoagulant medication. In a May 12, 2010 letter, the manager of the FAA Aerospace Medical Certification Division granted the SIC a 6-year authorization for special issuance of a first class medical certificate, with the condition that his treating physician would provide the FAA a yearly status report, the SIC's aviation medical examiner would recertify him on an annual basis, and the SIC would promptly report any adverse changes in his condition.

1.13.2.1. Toxicological test results

The University of New Mexico Health Sciences Center Office of the Medical Investigator performed toxicological testing on biological specimens obtained post-mortem from the SIC. This testing revealed the presence of caffeine in the SIC's blood. Testing of the SIC's specimens at CAMI found warfarin in liver and blood specimens. No ethanol was detected in vitreous fluid (see Attachment 3).

[5] CAMI's drug screening process is designed to detect the following drugs: amphetamines, opiates, marihuana, cocaine, phencyclidine, benzodiazepines, barbiturates, antidepressants, and antihistamines. For comprehensive information concerning all drugs detected by the laboratory, see the CAMI Drug Information Web Site, http://jag.cami.jccbi.gov/toxicology/.

1.13.3. The lead FTE (FTE1)

According to his wife, FTE1 was physically fit and in good health. There had been no significant changes in his health or fitness in the last year. He was not taking any prescription medications. His wife said that he did not use tobacco products and he normally drank one alcoholic beverage per day (a beer) when he returned from work. His wife and colleagues said he displayed no signs of illness in the days before the accident. He held a third class FAA airman medical certificate. His most recent certificate, dated September 28, 2009, bore no limitations.

1.13.3.1. Toxicological test results

CAMI performed toxicological testing on biological specimens obtained post-mortem from FTE1 (see Attachment 4). These tests revealed the presence of fexofenadine (an over-the-counter antihistamine that is not reported to have performance-impairing side effects).

1.13.4. The second FTE (FTE2)

FTE2's next of kin (his father) described his general health and fitness as good and said there had been no significant recent changes in his leisure activities. FTE2's next of kin said that he did not have any significant medical conditions. He did not use tobacco products and he drank alcohol in moderation. According to colleagues, he showed no signs of illness in the days before the accident. According to FAA records, he was taking the prescription medication pravastatin to control hyperlipidemia. He held a first class FAA airman medical certificate, and his most recent certificate, dated January 17, 2011, bore no limitations.

1.13.4.1. Toxicological test results

CAMI performed toxicological testing on biological specimens obtained post-mortem from FTE2. These tests revealed the presence of salicylate (an over-the-counter analgesic used for the treatment of mild pain) in urine. No ethanol was detected in vitreous fluid (see Attachment 5).

1.17. Organizational and Management Information

1.17.1 Program Management

The purpose of the G650 experimental flight test program was to support type certification of the GAC G650. Field performance testing was one of many components of this broader program. The purpose of field performance testing was to gather data to support type certification and the development of takeoff and landing speed schedules and distances in the airplane flight manual. The *GVI Field Performance Certification Flight Test Plan* "Table of Contents" listed the following field performance test maneuver categories: [6]

- V_{MU} speeds
- Takeoff performance

[6] Gulfstream Aerospace Corporation. (October 7, 2010). *GVI Field Performance Certification Flight Test Plan, GVI-FT-082, Revision A*. Savannah, Georgia.

- Abused takeoff assessment
- Rejected takeoff / accelerate-stop demonstrations
- Thrust reverser effectiveness
- Landing performance
- Aero coefficient determination free-rolls

Prerequisite testing not included in the field performance test plan included in-ground effect air data calibrations, stall speeds, minimum control speeds and climb performance.

The G650 program was led by a company vice president, the G650 program manager, who reported to the senior vice president, programs, engineering, and test, who reported, in turn, to the president of the company. Below the G650 program manager, the organizational structure was a matrix, with G650 program personnel appearing on organizational charts for the G650 program and on charts for "core" departments. Key groups involved in the G650 flight test program that are discussed in this report include flight test, G650 flight sciences, and flight operations. The director of flight test reported to the vice president of engineering, who reported to the senior vice president, programs, engineering, and test. G650 flight sciences was also led by a director. The director of G650 flight sciences reported to the director and chief engineer, G650, who reported to the G650 program manager. Flight operations was led by a vice president. The vice president, flight operations, reported to the senior vice president, programs, engineering and test. Generally speaking, directors supervised managers, managers supervised group heads, and group heads supervised non-supervisory employees (see Attachment 8).

A review of company records indicated that incentive compensation goals for the G650 program manager and the senior vice president, programs, engineering and test included five major categories of goals. For both managers, the first category contained goals associated with safety, the second included goals associated with budgets, and the third included goals associated with program schedules. The fourth and fifth goals reflected their differing responsibilities.

1.17.1.1. Scheduling

According to GAC and FAA personnel, the G650's first flight was in November 2009, flight testing was scheduled to begin in June 2010. GAC was publicly committed to obtaining type certification and delivering the first "green" G650 airplanes to customers by the end of 2011,[7] but an internal company schedule dated July 6, 2009, projected type certification would be completed by March 23, 2011, and an internal schedule dated April 6, 2010 projected that type certification would be completed by May 16, 2011.

According to FAA personnel, GAC had a 5-year window, ending September 28, 2011, in which to complete the activities necessary for type certification.[8] If certification was completed within this window, GAC would be required to implement the safety requirements of 14 CFR Part 25 through Amendment 119 (effective May 11, 2006). If certification could not be completed within this window, the deadline could be extended, but GAC would have to

[7] A "green" airplane is one that has gone through the production line, but has not yet been outfitted with a cabin interior to meet the final specifications established by the purchaser. Outfitting is accomplished by Gulfstream.
[8] 14 CFR Part 21.17 (c)

incorporate new certification / safety requirements imposed between the beginning of the previous 5-year window and the beginning of the new 5-year window.[9] If the airplane could not be certified until the spring of 2012, for example, GAC would have to incorporate new safety requirements contained in 14 CFR Part 25 Amendment 120 (effective February 15, 2007). If the airplane could not be certified until the fall of 2012, GAC would have to incorporate safety requirements through 14 CFR Part 25 Amendment 121 (effective October 9, 2007). According to the FAA project manager, new requirements imposed by Amendment 120 were relatively minor because they addressed extended operations (ETOPS) requirements that were "almost moot" for the G650, but Amendment 121 imposed extensive new requirements involving in-flight icing.

The FAA project manager stated that personnel from the Atlanta ACO met regularly with GAC for 6 weeks in the spring of 2010 and these meetings culminated in a June 2010 preflight board meeting. The preflight board meeting cleared the way for FAA familiarization flights, training, and type inspection authorizations (TIAs). The FAA project manager said he expected FAA personnel would begin participating in flight tests shortly after the preflight board meeting, but by July and August TIAs had been postponed and the first TIA was not completed until September 2010. Additional delays occurred thereafter. Later that year, the FAA urged GAC to develop a revised schedule showing more realistic dates, and in January 2011, GAC provided one. The revised schedule projected that some TIAs would be completed after the previously-planned spring 2011 certification date. It did not project a new certification date. The FAA project manager told investigators that he initially regarded the January 2011 schedule as "ambitious," but not "overly aggressive." However, TIAs scheduled for completion in February and March 2011 were subsequently delayed, causing a pile-up of TIAs scheduled for completion in the summer of 2011.[10] By March 2011, the FAA project manager felt that there was too much compression and that the schedule had once again become unrealistic.

In a weekly flight test teleconference held on March 25, 2011, GAC asked the Atlanta ACO for permission to deviate from the planned approach to TIA 15a (stall speeds). TIA 15A was behind schedule due to delays in the development of the flight control system. Some parts of TIA 15A were prerequisites for TIA 7 (field performance), so the company proposed dividing TIA 15A into two parts in order to avoid delays to TIA 7. In a March 31, 2011, letter drafted by the FAA project manager and signed by the manager of the Atlanta ACO, the FAA denied this request, citing a reluctance to approve too many "work-arounds" (see Attachment 9) The letter stated, "We also hope that our decision will serve as the impetus for other changes to the schedule that are needed to reflect the true status of the GVI program... For some time now the FAA has expressed our concerns about the overly aggressive schedule, and for some time now you have acknowledged 'unofficially' that things are slipping; however, the company TIA schedule continues to reflect a pace that has proven to be unrealistic."

In the March 31, 2011, letter, the FAA urged GAC to prepare for a possible extension of the 5-year certification window, writing, "given the number of schedule slippages to date, and the number of company and certification tests that have yet to be performed, we feel it would be prudent for GAC to be ready in case there is a need to file for an extension of the original [type

[9] 14 CFR Part 21.17 (d) (2)
[10] An internal company schedule dated March 25, 2011, that was provided to investigators indicated that, by this time, the company expected to complete type certification on August 1, 2011.

certificate] application… Although we do still believe it is possible for the GVI to receive a [type certificate] before the current deadline of September 28, 2011, we also believe it would be wise for GAC to review the requirements of 14 CFR 21.17(d)(2) and have a contingency plan in place." The FAA project manager discussed the letter with GAC's G650 program manager before it was sent, and he recalled coming away from this conversation with the impression that the program manager knew the company would be unable to meet the existing certification deadline but found it difficult to convince higher-level managers to adjust major milestones or the program's end date. GAC's G650 program manager told investigators that he recalled discussing this letter with the FAA project manager, and he recalled believing that the schedule was "aggressive but achievable."

On April 1, 2011, GAC reviewed the latest flight test schedule with the Atlanta ACO during a weekly conference call. Documents shared during this conference call indicated that 10 out of 45 TIAs had been approved thus far and 9 more were schedule for approval in April 2011. TIA 7, Field Performance, was schedule for approval on April 23, 2011. In a post-accident interview, the FTE group head told investigators that by April 1, 2011, the majority of the V_{MU}, rejected takeoff, thrust reverser, and landing tests had been performed and FTE1's report on V_{MU} testing had been drafted and was awaiting review, but there was a lot of work remaining and he did not regard April 23, 2011, as a date that was achievable.

In a post-accident interview, the FAA project manager told investigators the pace of the G650 flight test program had been similar to that of previous GAC flight test programs, and it had been "average" or a "little bit slower" than programs conducted by other manufacturers that were overseen by the Atlanta ACO. He said an average to slightly below-average pace was to be expected because the G650 was GAC's first totally new aircraft in over 40 years. He added that GAC had the luxury of incorporating a lot of new technology in its new airplanes because its customers were willing to pay for it, but new technology imposed additional requirements that could add to development time. By late March 2011, however, the ACO was concerned that if GAC personnel actually worked at the pace that would be required to meet existing deadlines, quality and safety issues could arise. He said he had not heard about any GAC employees losing their jobs because of program delays, so he did not think GAC managers were demanding that the schedule be met "come hell or high water," but he did not have direct knowledge regarding how much pressure was being imposed on GAC personnel.

The FAA's Atlanta ACO flight test branch manager, who participated in G650 flight testing prior to the accident, said the ACO held weekly meetings with GAC during the flight test program. He said GAC typically produced a schedule with an optimistic list of TIA dates and GAC and FAA personnel would smile and say, "this is the schedule management is giving us." He said that those schedules were never successfully executed because they were driven more by management and marketing than by flight test. He told investigators he had worked on major certification programs at two other aircraft manufacturers, and he had never seen a program meet the milestones produced by marketing and management and no GAC employees had approached him to express concerns about the pace of the program. An FAA flight test engineer assigned to the G650 project told investigators that flight test program schedules always "moved to the right," flight test was last, and the end date never changed until it was obvious that a manufacturer could not meet it.

GAC's director, flight test, said G650 flight test schedule delays and schedule compression were similar to "just about every test program" on which he had worked. He said GAC tried to deploy its resources as best it could to complete the work in the shortest time span that was reasonable. The G650 program manager said TIAs had been delayed in every program he had seen and no one had expressed concerns to him about the quality of the work that was being performed in flight test because of the aggressiveness of the schedule. He said that if someone had expressed such concerns he would have addressed them immediately.

The senior vice president, programs, engineering and test, said test programs often fell behind schedule due to unforeseen events, but if a company did not plan for a tight schedule, the program would slip even more. Program schedules "always look like you can't do them," but such schedules were maintained "so that we pay attention to the schedule and do them as effectively as we can." He said that a lot of thought went into the planning of individual TIAs, but the schedules were dynamic because of unforeseen events that arose during testing. The company had to rearrange tests and swap airplanes to keep things moving and every program had been like that in his experience. He said there was a tendency for TIAs to pile up and actually be executed that way during the GV program. He knew that the G650 program was behind schedule and over budget at the time of the accident, and he recognized that the end date for certification was going to have to slide, but he could not say exactly when that would have occurred.

GAC's principal engineer, flight test, who was also the lead FTE for the G650, told investigators he had expressed concerns to senior managers about the pace of the schedule, telling them it did not allow for contingencies, and warning them that everything would have to go perfectly for the program to meet its certification deadline. He was told management was willing to accept the risk and that they would adjust the G650 program schedule as necessary. Asked whether he thought the schedule was feasible at the time of the accident, he said, "Difficult to say. It certainly was feasible." He added that the schedule was still aggressive and "did not account for contingencies that were likely to arise," but he believed it would be modified if certification or safety of flight issues were discovered and that no one would be penalized if delays occurred for such reasons.

The company's chief FTE said the G650 flight test program was originally scheduled as a 14-month project and, by comparison, the GV program had been scheduled to last about 15 months, and took about 18 months to achieve full type certification. He said that the G650 flight test schedule was revised several times before the accident and was "constantly adjusted" to achieve certification by the third quarter of 2011. He stated, "There was always pressure to try to maintain the date" but "the schedule was going to be what the schedule was going to be basically." According to GAC records, the original flight test schedule called for a 21 month flight test program. With the slippage of first flight from June to late November 2009, only 14 months remained on the original schedule. By April 2010, the company's internal schedules reflected an extension of certification to May 16, 2011, providing for a 17.5 month flight test schedule. By March 25, 2011, the planned certification date had slipped farther to August 1, 2011, allowing for a 20 month flight test schedule.

Asked whether he thought pressure to meet the scheduled date affected the ability to analyze flight test data as the program progressed, the chief FTE said “It was some pressure to test if we were not fully analyzing data.” He said there had been discussions about delaying the projected certification date at “low levels” in the company, but as of early March 2011, he did not believe the company would have made a decision to delay the external certification date unless it was absolutely necessary. He believed that the only person who could have provided relief on the certification end date was the senior vice president, programs, engineering, and test. The company’s principal engineer, aircraft performance, said that, in hindsight, the schedule (and available staffing) had not provided enough time for analyzing and sharing V_{MU} data. He believed that essential information, such as safe pitch attitudes and pitch attitudes to avoid at liftoff, had been obtained from the V_{MU} data by flight test before the accident, even though the official report on the V_{MU} testing was not yet completed, but he said that he did not obtain a copy of FTE1’s draft report or discover that the V2 speeds provided to the flight crew on the day of the accident were incorrect until after the accident.

The FTE group head said that the G650 flight test schedule was “the most aggressive” he had seen in 28 years as a flight test engineer working for several aircraft manufacturers. He told investigators that the flight test program fell behind early because G650 test airplanes were delivered to flight test “late, incomplete, and not ready to fly” and they were not in a valid test configuration until well after flight testing began. He attributed this to delays in the development of the airplane’s fly-by-wire flight control system. He said, in addition, that company managers did not pay enough attention to FTE input, and that this complicated the test program and decreased FTE morale.[11] He reported that company managers, such as the director of flight test, frequently re-arranged the TIA schedule, swapping test airplanes and encouraging FTEs to proceed with testing when test airplanes were not yet in their final configuration, even if some tests might have to be repeated later, and it seemed to him as if any time savings realized were outweighed by the time required to prepare the new airplane for testing. He said that he would have preferred to extend the end date of the program. Asked whether he believed that schedule pressure affected the safety of the accident flight, he said no. He said that the FTEs had agreed that they would “take whatever time we needed, regardless of what the schedule said.” If FTE1 needed a day to analyze data, they would talk and FTE1 would “take a day… just to look at data." As a result, he was confident that the FTEs only flew when they were ready to fly, and not simply because they were directed to fly.

The FTE group head said that, in general, FTE workload was “excessive.” He said that the FTEs worked long hours to keep the G650 flight test program moving, often 6 or 7 days per week. He and other GAC employees said flight test team members routinely worked 13 consecutive days during major testing efforts in Roswell before being rotated back to Savannah, and that FTEs “routinely” exceeded company duty time limitation of 12 hours per day when on site in Roswell. A review of overtime records for four FTEs who participated in G650 field performance testing (the FTE group head, FTE1, FTE3, and another FTE) indicated that these FTEs averaged 27 percent overtime during the 9-month period July 1, 2010, to March 31, 2011. They reported between 42 and 60 percent overtime in November 2010 and March 2011, when major field performance testing efforts were under way in Roswell, and about half as much in

[11] FTE1’s wife said her husband had also expressed concerns that management in the G650 flight test program pushed the schedule and did not listen to the FTEs.

other months (see Attachment 7). A review of overtime records for APG1 indicated that she averaged 18 percent overtime during the same 9-month period, and that she reported 39 and 47 percent overtime in November 2010 and March 2011, respectively. Additional data for 34 flight test engineers provided by GAC indicated that 6- and 7-day workweeks were common but not the rule, and the lead FTE, FTE1, FTE2, and FTE3 averaged 5 workdays per week, 10 hours per day in the six months preceding the accident.

FTE2's father said FTE2 had complained to him that GAC was "burning the candle at both ends" and FTE2 wished the company would slow down because it was wearing him out. He also said, however, that FTE2 did not express any concerns to him about the safety of the G650 flight test program. A close personal friend of FTE2's who was an employee at the FAA's Atlanta ACO and worked on GAC certification programs, said FTE2 did not tell her the pace of the G650 program was any different than he had experienced in the past, or that he was being pressured to do things he did not want to do. He just told her that it was a lot of work. FTE3 told investigators that "everyone thought that this schedule was very aggressive," but she had never worked on a flight test program where participants felt that they had adequate time.

APG1 said that the flight test program schedule was "a little aggressive," and there "just seemed to be pressure to continue tests, to continue flying." She said, for example, that when flight test was preparing to resume field performance testing in March 2011, the nosewheel steering was limited above a certain speed. She did not feel this was an appropriate limitation for field performance testing, so she said they were not ready to begin. Afterward, she received feedback that they would have to figure out a way to re-arrange the testing to "make it useful for us to go out a little earlier." She said it would have been "more comfortable" to be able to sequence the tests without having to deal with airplane configuration issues. Asked whether schedule-related pressure had caused her to have any safety concerns, she said her concerns had focused on having enough time to look at data. She recalled having a couple of discussions with the FTEs and APGs in Roswell in March 2011 during which they acknowledged that they did not have enough time to reduce the data and really understand it before the next day's testing. In hindsight, she thought this was a potential safety issue.[12]

1.17.1.2. Staffing

FTE staffing for the G650 field performance flight test program consisted of six FTEs who rotated in and out of Roswell so that only three were present at a time. The FTEs on site always included either FTE1 or the FTE group head, one of whom served as the test conductor.[13] APG staffing consisted of six engineers from flight sciences that also rotated in and out of the testing site so that three were present at a time. The three APGs at the testing site always included either APG1 or the company's principal engineer, aircraft performance, and one of these two served as a liaison with the FTE test conductor (either FTE1 or the FTE group head).[14]

[12] She said, however, that they had made improvements in software scripting and were better able to keep up with the pace of testing in March 2011 than they had been in November 2010.

[13] FTE2 was not among the six FTEs who normally participated in field performance testing and he was participating in G650 field performance testing on the day of the accident because an FTE who was normally assigned to the program had a scheduling conflict.

[14] Numerous additional maintenance and support personnel were also on-site whenever testing was conducted in Roswell. For example, a total of 25 GAC personnel were in Roswell on the day of the accident.

GAC's chief FTE, who had been with the company for over forty years, said that several budget cuts had occurred after the initial G650 budget estimate and before the airplane's first flight in November 2009. As a result, flight test staffing had been reduced and fewer FTEs were assigned to the G650 flight test program than had been assigned to the GIV and GV flight test programs. He said that five FTEs and 3 to 6 APGs were normally on site at a time during the two earlier programs, with three of the FTEs dedicated to the analysis of flight test data. He also stated that the FTEs and APGs worked in shifts to perform post-maneuver analysis and evaluations during the earlier programs. The chief FTE said that during the G650 program, 2 of the 3 FTEs on site were conducting tests aboard the airplane and the third was managing communications in the telemetry trailer. He thought they did not have enough time to reduce and evaluate flight test data, and he believed that the APGs were too few and too inexperienced to accomplish the work.[15] He said that if one or more engineers had been looking at the airplane traces and observed that the liftoff speed for the run before the accident takeoff was "essentially the speed they were trying to target at 35 feet" it would have been "fairly obvious" that they could not achieve the predicted V_2 speed. He said, "I don't think there were enough individuals looking at the data trying to understand what the airplane was doing and, again, the experience level of some of the personnel was really inadequate other than just from a learning standpoint." He said "I think everyone was focused on trying to achieve the target… V2 speeds and they weren't looking at what the airplane was… telling them." GAC's principal scientist for airplane performance also stated that there had been an additional team of engineers dedicated to flight data analysis during past flight test programs.

The chief FTE said he had expressed concern about FTE staffing levels to the director of flight test during the planning stages of the flight test program, and he recalled the director of flight test saying that that was what they had to support the program and that was all they would send.[16] The director of flight test, who had been working in flight test for 24 years and had begun working for GAC in 1997, told investigators that he recalled the chief FTE raising a concern about FTE staffing levels, but the chief FTE's recommendations were "always a little bit more than what we end up with." The director felt it was the test conductor's responsibility to determine how many FTEs were required, and he believed FTE1 and the FTE group head were comfortable with the existing staffing level. Furthermore, he thought advancements in equipment and software and use of the telemetry trailer allowed the engineers to be more productive than they had been during past programs. When investigators asked the FTE group head for his opinion about FTE staffing, he said flight test never felt they had enough people at the beginning of a test program, but they were good at getting things done with the resources they had, so it was difficult to convince management they needed more staffing. He thought having six engineers (FTEs and APGs) on site in Roswell was "more than enough" if their efforts were well coordinated, but he had the impression from conversations with FTE1 that this was not the case. The senior vice president, programs, engineering and test, said that the director of flight test

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[15] Two of the APGs who were present on the day of the accident were new to field performance testing, although APG2 had a PhD in Aerospace Engineering from Georgia Tech and had been with the company since receiving it in 2007. APG3, who received a Masters in Science (Aeronautics) from Purdue in 2006, had worked at Hawker Beechcraft for 4 years prior to joining the company in 2010. The day of the accident was his first time supporting field performance testing.

[16] The chief FTE did not specify when this conversation occurred. He said, however, that decisions about FTE staffing were made in 2010.

avoided staffing up too much during a major flight test program because work was cyclical and he would have to find other positions for the FTEs or lay them off when the program was over.

1.17.1.3. Standard operating procedures

Company personnel told investigators that GAC's *Flight Test Standard Practice Manual*[17] was the primary source document governing the company's flight test standard operating procedures. The version of the manual in effect at the time of the accident was Revision F, approved October 28, 1998. The *Flight Test Standard Practice Manual* stated that for any project requiring flight testing a test team would be formed and this team would be composed of the people necessary to conduct the test project from the planning to the final report stage. The manual stated that a team would normally be comprised of the following personnel:

- Manager, Test Coordination
- Test Coordinator
- Test Conductor
- Test Specialist
- Test Analyst
- Instrumentation Engineer
- Configuration Control Engineer
- FAA Coordinator

Specific responsibilities were described in the manual for each of these positions. In post-accident interviews, most of the engineers and pilots working the G650 flight test program said that they had heard of the *Flight Test Standard Practice Manual* but they were not very familiar with it and some, including FTE3 and APG1, said they had never seen it before. Investigators asked the director of flight test if he expected flight test employees to be familiar with the manual, and he said it had been his expectation that the manual would be passed down from senior employees to newer employees, but after the accident he realized that newer employees were not adequately familiar with it.

GAC managers and the lead FTE told investigators that the *Flight Test Standard Practice Manual* was outdated and did not accurately reflect the actual roles and responsibilities of G650 program staff. For example, instrumentation was handled by a group of people, rather than a single person. The duties of the configuration control engineer were also handled by multiple people. The duties of the test specialist had been divided among various members of the on-site test team, and the duties of the test conductor had been expanded to encompass responsibilities that had formerly been divided among the test conductor, test specialist, and test analyst. FTE1, who served as a test conductor, developed field performance test requirements,[18] led test preparation (overseeing the development of test cards and leading pre-flight and post-flight briefings), served as the on-board test facilitator, conducted post-test data analysis, and drafted flight test reports.

[17] Gulfstream Aerospace Corporation. (October 28, 1998). *Flight test standard practice manual, Revision F.* Report No. GV-GER-1329. Savannah, Georgia.

[18] Gulfstream personnel said flight sciences was responsible for defining test requirements through the creation of a Test Requirements Document, but no such a document was generated for field performance flight test program. FTE1 incorporated test requirements into the field performance test plan with help from flight sciences personnel.

The FTE group head was asked whether he felt the combination of responsibilities assigned to FTE1 had created too much workload for one person. He said no, other engineers in flight test and airplane performance were supporting FTE1, and FTE1 had performed a similar range of duties for previous employers. He added that FTE1 had been hired for his ability to perform all of these functions, and he believed that FTE1 enjoyed participating in all stages of the flight testing and analysis process. He said that he himself had assumed similar responsibilities for a subset of field performance tests dealing with landings, and was performing these FTE duties in addition to his supervisory duties. The FTE group head said that he and FTE1 were the most experienced working-level FTEs in flight test, so he had taken responsibility for a portion of the flight test plan to alleviate some of FTE1's workload. He said that he also enjoyed being directly involved in the testing. The principal engineer, aircraft performance, was asked if he thought FTE1 had been assigned too many responsibilities. He replied, "I think a number of us had a number of responsibilities. I was not overly concerned that his plate was too loaded up, possibly in retrospect maybe so. At the time… I did not feel like he had any more responsibility on his plate than a lot of other people."

Field performance flight test team members (FTEs and APGs) said the FTEs were primarily responsible for conducting flight tests and for reducing and analyzing flight test data. They said that the APGs were on site to provide thrust tables and speed schedules, to assist with data reduction and analysis, and to observe how the data were being collected and processed so that they would have a thorough understanding of this process when they subsequently expanded the data to create performance tables in the airplane flight manual. APG1 said that individual roles with respect to data reduction and analysis were loosely defined on site in Roswell. When the on-site test team first began looking at a data set, there was a joint discussion about where the points fell compared to predictions, how they lined up, and how flight sciences was going to expand the data in the airplane flight manual. She added, "It was essentially the on-site teams working out what to look at, what did they want to see, what did they want to reduce between us and, the performance group and the flight test engineers." The FTE group head said that the role the APGs were expected to play on site had been a "long-standing item" between flight test and flight sciences. He said that during past programs, the APGs had been limited to providing thrust settings and speed schedules and reviewing time history data with the FTEs to help decide whether maneuvers were "good or bad," but they had become much more involved in the G650 program. He thought FTE1 was trying to utilize the APGs to "help reduce the data and turn things around quicker," but he believed that the efforts of the FTEs and APGs were not always well coordinated. He cited as an example his observation that the APGs and the FTEs both added marks to live streaming data during flight tests. These marks were combined in a master data file for later use, but the groups used different criteria for positioning the marks. It was difficult to determine who had added which marks, so the FTEs had to subsequently review the data and adjust the marks as necessary to ensure consistency.

Investigators learned that although FTEs were regarded as primarily responsible for performing in-depth analysis of flight test data, APGs also performed in-depth analysis of flight test data. The principal engineer, aircraft performance, for example, performed a detailed analysis of continued takeoff data collected in early March 2011. He told investigators that the APGs had been "taking more and more responsibility for assisting flight test with reducing some of the field performance data" because of the "lack of manpower in flight test." He said that, although he was busy with responsibilities outside the G650 program, he had been able to analyze some continued takeoff data collected in early March 2011 because he and the other APGs who were on site in Roswell at the time had some down time while the FTEs were performing engine lapse rate tests. He said that he briefed FTE1 on his analysis findings during an informal meeting the two of them had on March 27, 2011. FTE1 had performed his own analysis of the continued takeoff data, so they compared notes.

During his March 27, 2011, meeting with FTE1, the principal engineer learned that FTE1 had drafted a report on the November 2010 V_{MU} flight test data. FTE1 had just written this report the week before the accident and that he briefly reviewed it with the principal engineer but he did not give him a copy. The principal engineer said he was not concerned that takeoff testing was continuing before the report was finalized because he believed FTE1 had gleaned from the data the information that was needed to proceed safely. He said that in retrospect, however, a close examination of the V_{MU} test data, considering the reduction in target pitch from 10 degrees to 9 degrees for the flaps 10 one engine inoperative continue takeoff condition, would have indicated that the V-speeds provided to the test team on the day of the accident were not achievable. When the principal engineer was asked why he had performed a detailed analysis of the continued takeoff data from early March but he had not been involved in analyzing older V_{MU} data, he said V_{MU} data had always been a flight test data reduction item but it was understood that the APGs would assist the FTEs with analysis in other areas.

A former GAC employee who served as GAC's director of flight test in the mid-1990s was identified as the creator of the *Flight Test Standard Practice Manual*. He told investigators that when he created the manual, the company was rapidly expanding its flight test staff with a mix of new hires, contract employees, and employees from core engineering departments. The company planned to utilize several test airplanes, which meant that the program was going to be larger and more integrated than past programs. GAC already had procedures in place to conduct test readiness reviews and hold safety review boards but the company lacked detailed guidelines and procedures to create a structure for organizing the new program, so he created some. In preparation for the creation of a new manual, he researched industry best practices, meeting with personnel at Douglas and Boeing, and studying U.S. Navy documents. He also reflected on his experience as chief project pilot during the GIII test program, managed by Grumman. Using the information gained from this effort, he created the first version of the manual which was approved in 1995. He stated that the new manual was generally well-received.

Through the *Flight Test Standard Practice Manual*, the former director tried to align GAC's flight test practices more closely with those of larger manufacturers, separating the duties of test coordination, data analysis and report writing from the duties of test conduct. He said he was convinced that this was the only way to maintain a rapid program pace and ensure that each function would be properly performed. He recalled that some FTEs resisted this change, because they preferred a wider-ranging role, but he tried to ensure the division of labor. He said that the new manual was not followed in every respect during the GV program, but he believed its partial adoption was the first step in a long-term process of cultural change. He recalled that, after the GV received type certification in 1997, GAC down-sized the flight test department. He left the company in 1998. At that time, responsibility for maintaining the *Flight Test Standard Practice*

Manual passed to a new director of flight test, the manager who held that position at the time of the accident. According to the FTE group head, major revisions of the *Flight Test Standard Practice Manual* were initiated in 2000, 2001, and 2009, but were never completed. The senior vice president, programs, engineering, and test, said that although the manual had become outdated, he believed the company's management of the G650 flight test program was consistent with industry norms.

1.17.2 Safety Management

1.17.2.1. Safety policy

As outlined in Attachment 8, GAC's flight operations organization, headed by the vice president of flight operations (a flight test pilot), consisted of two sub-organizations, a demonstration/transportation organization, and a flight operations test organization. The flight operations test organization was further subdivided into production test pilots and experimental test pilots.[19] According to GAC's vice president, flight operations, GAC began developing a safety management system (SMS) for its flight operations department about five years before the accident. The SMS initially covered demonstration flights, and was subsequently expanded to cover sales and product support flights.[20] The flight operations SMS was based on International Business Aviation Council (IBAC) standards. According to IBAC, these standards were compliant with ICAO Standards and Recommended Practices and the requirements of major aviation regulatory authorities.[21] IBAC standards stressed the importance of management commitment to and responsibility for safety, and they established objectives in the following areas: safety policy, safety risk management, safety assurance, and safety promotion.

The vice president, flight operations, said that flight operations spent about a year aligning its policies and procedures with IBAC standards before undergoing the first of three IBAC audits successfully completed before the accident. The department appointed a flight safety officer, created a flight data monitoring program, and developed ground and airborne safety reporting systems. The vice president, flight operations, told investigators that safety reporting was encouraged and the *Flight Operations Manual* referenced an "internal communication process that allows employees and other personnel to report recognized hazards and incidents without fear of retribution." A safety policy statement incorporated into the *Flight Operations Manual* stated:

> An effective safety management system is the foundation for a successful and well-maintained flight department. Gulfstream Aerospace is dedicated to providing the safest working environment for its employees and customers. In order to achieve this goal, the company and flight department are committed to taking an aggressive role in maintaining the highest level of safety as well as defining and correcting risks that could affect safety. Gulfstream Aerospace maintains in practice that no phase of operation is so urgent that safety and health

[19] A flight operations department organizational chart dated January 4, 2011, indicated that GAC employed 11 experimental test pilots.
[20] According to a flight operations department organizational chart dated January 4, 2011, Gulfstream employed 39 demonstration and product support pilots.
[21] http://www.ibac.org/safety-management/sms-toolkit

> may be comprised. This safety strategy is incorporated into all departmental activities including facilities, maintenance, and flight operations. It is crucial to develop this strategy and mindset not only as a department, but also as individuals. Through individual responsibility, the safety program will be a continued success.[22]

The vice president, flight operations, said that when the flight operations department began developing its SMS, the company asked IBAC if the organization had guidance that was specifically tailored to flight test operations but IBAC did not have such guidance. As a result, the new SMS was not extended to cover flight test operations.

The vice president, flight operations, said, however, that the company's flight test operations were very similar to those he had experienced in his prior military flight test career and in his second career in commercial flight test. He added that the flight test program had a set of safety processes and protocols akin to those in other flight test programs with which he was familiar. A GAC flight operations manual titled *Flight Operations Test Standard Operating Procedures* included the following safety philosophy statement.

> The Vice president of Flight Operations and Chief Test Pilot stress the absolute importance of incorporating safety into all operations. The preventative, proactive posture that has been adopted is designed to indentify associated risk and then mitigate those risks as much as possible. This safety program has been constructed to allow integration within daily flight operations with the overall objective of accomplishing the test efforts in the most efficient and effective manner.[23]

The *Flight Operations Test Standard Operating Procedures* referenced FAA Order 4040.26A, *Aircraft Certification Service Flight Safety Program,* and a July 2008 memorandum of understanding (MOU) between GAC and the Atlanta ACO titled *Flight Test Safety and Risk Assessment*, both of which are described further in Section 1.17.2.2.

Several G650 flight test personnel were asked to identify which executive or manager was responsible for managing the safety of the flight test program and they expressed varying opinions. Some, such as APG2, were not sure which executive was responsible, but they thought that various people probably played some role. The manager, flight test engineering, said that there was not a specific individual who had been assigned that responsibility. The FTE group head and an FTE who was in charge of overseeing the accident airplane, said that no single person was responsible for managing safety, everyone was responsible. Others listed individuals ranging from the director of flight test, to the chief test pilot, to the director of flight operations, to the vice president, flight operations, to the vice president, engineering, to the G650 program manager (also vice president), to the senior vice president, programs, engineering, and test.

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[22] Gulfstream Aerospace Corporation. (March 31, 2010) *Flight Operations Manual, Revision 1-10,* Chapter 2, Safety. Savannah, Georgia.
[23] Gulfstream Aerospace Corporation. (November 1, 2009) *Flight Operations Test Standard Operating Procedures, Revision 3,* Chapter 2, Safety. Savannah, Georgia.

The senior vice president, programs, engineering, and test, was asked how GAC managed the safety of the flight test program and he said that flight test and flight operations had safety-related procedures and that those organizations reported to him. The G650 program manager was asked what role he played in managing the safety of the G650 flight test program and he said that he supported program safety through the director of flight test and attended some FTSRB meetings. The director of flight test was asked how GAC managed the safety of the G650 flight test program, and he referred investigators to the risk assessment / risk alleviation process outlined in section 5.0 of the *Flight Test Standard Practice Manual*. He explained that this process involved identifying risks, performing safety analyses, establishing mitigation strategies, reviewing that with a board, and agreeing that the mitigation strategies were acceptable. He said that he co-chaired flight test safety review boards (FTSRBs), along with the vice president, flight operations, and that he kept higher-level managers, including the vice president, engineering, G650 program manager, and the senior vice president, programs, engineering, and test, apprised of FTSRB activities. He said that multiple FTSRBs had been held to review planned G650 flight tests, and he believed that this risk assessment and alleviation process had served the company well in the past. He stated that his department had conducted between 10,000 and 15,000 hours of experimental test flights over the past 15 years and had not experienced any accidents, aside from a hard landing. Asked to compare GAC's flight test safety management practices to those of two other manufacturers for whom he had worked, the director said GAC's practices were similar except for GAC's lack of an "independent safety function."

1.17.2.2. Safety risk management

A July 2008 memorandum of understanding MOU between GAC and the Atlanta ACO that was titled *Flight Test Safety and Risk Assessment* and was signed by an Atlanta ACO flight test manager, two GAC vice presidents, and GAC's director of flight test, stated that GAC would establish a "jointly agreed upon flight test risk assessment program" (see Attachment 10). GAC agreed to provide a risk assessment section in all certification flight test plans submitted to the FAA that would specify the level of risk involved and identify all test points classified as medium- or high-risk. The FAA stated that it would attend FTSRBs and that it would not participate in certification flight testing or issue TIAs until it had concurred with all proposed risk assessments. The MOU stated that the FAA had reviewed GAC's current processes for flight safety and flight operations and considered them "acceptable to establish an adequate level of safety for FAA flight test program conducted for the purposes of type certification and/or supplemental type certification."

The MOU cited several key references, including GAC's *Flight Test Standard Practice Manual* and *Flight Operations Manual*, as well as FAA Order 4040.26A. FAA Order 4040.26 defined flight test risk management as "the process by which: (1) hazards are identified, (2) an assessment is made of the risks involved, (3) mitigating procedures are established to reduce or eliminate the risks, and (4) a conscious decision is made, at the appropriate level, to accept residual risks." It stated that risk assessment was "normally done by a safety review process in which a flight test plan is reviewed by project and non-project personnel in order to draw out potential hazards and recommend mitigating (or minimizing) procedures." The Order further stated that risk assessment / risk alleviation should occur for "each condition from its earliest definition in the flight cards through its completion in a test," and that the aim of this process was to engage design engineers, FTEs, and pilots in "an ongoing cycle of examination, description and review by a safety review board." Detailed procedures for carrying out risk management were contained within the Order.

FAA Order 4040.26A stated that an AIR risk management process was required to be performed and documented for certification test flights, specifically "TIAs that cover tests flown by FAA flight test crews and also those that are delegated to a Designated Engineering Representative (DER) test pilot."[24] The Order stated that an AIR risk management process was also mandatory for any other flights where FAA aircrews would participate. FAA Order 4040.26 laid out an organizational structure for the FAA Aircraft Certification Service's (AIR's) flight safety program, and detailed AIR's procedures for risk management.[25] The Order stated, however, that FAA flight test crews and DERs could rely on a company's risk management process in lieu of an FAA-managed process if the company's process was well-developed, consistent with Order 4040.26A, and accepted by the FAA.[26] In fact, manufacturers that were "regularly engaged in activities requiring FAA certification flight tests" were encouraged to develop their own FAA-accepted risk assessment process, as GAC had done.

GAC had not yet transitioned to the certification phase of field performance testing, therefore the company was not yet required to have submitted its risk management planning for field performance testing to the FAA for review and approval.[27] According to GAC personnel and company documents, however, the company's FAA-accepted risk assessment and alleviation process had already been performed for company field performance testing, in accordance with company policy. According to the G650 project pilot, classification decisions for specific test areas were made by referencing definitions and examples in FAA Order 4040.26A and by reviewing classifications assigned in past programs. Test Safety Hazard Analyses (TSHAs) had been prepared for all medium and high-risk tests. The TSHAs listed potential hazards associated with each test area and included risk alleviation statements detailing the steps necessary to remove, minimize, understand, or respond to test risks. According to company records, the results of the field performance risk assessment / alleviation process had been evaluated in an FTSRB meeting co-chaired by the director of flight test and the vice president, flight operations on October 7, 2010, prior to commencement of testing. Flight test personnel reported that TSHAs were also reviewed by flight test team members before medium- and high-risk flights.

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[24] Federal Aviation Administration Order 4040.26A, *Aircraft Certification Service Flight Safety Program*. U.S. Department of Transportation, Federal Aviation Administration. March 23, 2001, p.4.

[25] The AIR flight safety program was headed by a lead flight safety officer and supported by flight safety officers at directorates and geographic offices who received training in safety program management, promoted the use of standard operating procedures, conducted safety meetings, and identified and analyzed trends in safety-significant events, safety issues, and hazards.

[26] Federal Aviation Administration Order 4040.26A, *Aircraft Certification Service Flight Safety Program*. U.S. Department of Transportation, Federal Aviation Administration. March 23, 2001, Appendix 2, page 1.

[27] According to FAA Order 8110.4C, *Type Certification*, Chapter 2, stated, "To comply with 14 CFR§ 21.35(a)(4), the applicant conducts flight tests and inspections before the TIA for research and development. The research and development flight test results are not part of the type certification process. The applicant's flight tests, conducted to satisfy 14 CFR § 21.35(a)(4), are not explicitly part of the FAA's flight test program, unless the FAA agrees to conduct concurrent testing with the applicant and issues a TIA for the test. Official FAA flight testing begins only after the FAA issues a TIA. However, the applicant conducts the tests and inspections to demonstrate that the test article to be submitted for FAA certification ground and flight tests meets the minimum requirements for quality, conforms to the design data, and is safe for the planned tests."

1.17.2.3. Safety assurance

GAC personnel indicated that flight test did not have a formal procedure for reporting safety-related incidents that occurred during flight. GAC had a problem reporting system, but this system was primarily a control mechanism for design issues that served as a method for initiating changes in aircraft systems. It was not generally used to report safety-related concerns or to notify the company about safety-related incidents. Flight test personnel indicated that problems that occurred during flight test that were not perceived as design-related were generally handled through direct communication between appropriate parties. If a problem was serious enough, it could result in the reconvening of an FTSRB, a process that anyone could initiate. The chief FTE said that serious safety issues were likely to be reported up the chain of command fairly quickly. Investigators learned that company managers possessed varying degrees of knowledge about the "wing drop" incidents that had occurred during flight 88 on November 16, 2010, and flight 132 on March 14, 2011. The G650 program manager, senior vice president, programs, engineering and test, and director of G650 flight sciences said they had not been informed about these incidents before the accident, but other managers, such as the manager, flight test engineering, and the director of flight test, said they had been informed.

After the November 16, 2010, wing drop incident that occurred during a V_{MU} takeoff test, informal discussions were held among test participants to determine the cause of the incident. The cause was determined to have been an "over-rotation." The flying pilot (the accident PIC) had not participated in build-up maneuvers for that particular test, and test team members decided that a recurrence could be avoided by modifying TSHAs for medium- and high-risk takeoff testing to more clearly specify that the flying pilot should be involved in build-up maneuvers leading up to the highest risk test condition. A formal FTSRB meeting was not convened because, according to the chief FTE, the incident was considered to be fairly well understood. The PIC, however, took the initiative to formally brief his colleagues and to tell them about the change in test protocol that had resulted from the incident.

On March 3, 2011, a safety-related incident occurred during a field performance test examining thrust lapse rates. An FAA test pilot served as the flying pilot during this test. According to a March 9, 2011, letter sent to GAC by the manager of the Atlanta ACO, the test airplane drifted right during initial takeoff roll and the drift could not be controlled through the use of rudder. The letter stated that the crew aborted the takeoff and found the problem to be repeatable. GAC flight test personnel submitted a problem report to the company's engineering department and the company's flight controls engineers were able to identify an undesirable change in the airplane's fly-by-wire flight control software that had affected the yaw damper system. The company issued a temporary in-flight restriction (IFR) requiring monitoring of residual yaw rates or deactivation of the yaw damper system. Ultimately, a company meeting was held, during which the engineering department presented findings and corrections to personnel from flight test and flight operations, the IFR was lifted, and the problem report was closed. The FAA requested flight data from the incident, which were promptly provided, and directed GAC to perform a review of its change approval process for flight control software, which GAC subsequently presented to the FAA during a June 1, 2011, briefing.

The March 14, 2011, wing drop incident was analyzed shortly after it occurred during an informal meeting between FTE1 and a senior test pilot (the non-flying pilot during the incident flight). According to the senior test pilot, FTE1 expressed concern that the airplane had stalled but FTE1 noted that the wing drop began at approximately 11.5 degrees angle of attack and a stall was not predicted to occur until at least 13 degrees. The senior test pilot told FTE1 he had confidence in the in-ground-effect stall estimate, and he attributed the incident to a sideslip that was not corrected by the yaw damper because the yaw damper had been deactivated as a result of the IFR that resulted from the March 3, 2011, incident. The two agreed that the incident was not caused by a stall and they discontinued further takeoff testing until the yaw damper system could be re-activated. No FTSRB was convened and company personnel subsequently referred to this incident as a "lateral directional event." According to GAC personnel, including the principal engineer, aircraft performance, and a staff scientist, applied aerodynamics, the incident test run was discarded as a bad data point, and the physics of the event were not closely examined.

Prior to the resumption of field performance testing in March 2011, FTE1 decided, in consultation with the chief FTE, to decrease the stall warning margin by increasing the activation threshold for the stick shaker from 85% to 90% normalized angle of attack. According to the chief FTE, this change was made to allow predicted takeoff speeds to be achieved without encountering stick shaker activations that would invalidate tests. According to GAC personnel, the normalized angles of attack at which the November 16, 2010 (flight 88), and March 14, 2011 (flight 132), wing drop incidents occurred were not considered when the stick shaker activation threshold was adjusted to the less conservative setting of 90%. In the days before the accident, FTE1 also decided, in consultation with the principal engineer, aircraft performance, to reduce the target pitch from 10 to 9 degrees (+/- 1 degree) for flaps 10 continued takeoff tests. The principal engineer, aircraft performance, and APG1 said FTE1 made this change to increase maneuver consistency across flap conditions and to ensure that angle of attack would remain well below the range where previous wing drop incidents had occurred. No updated speed schedules were developed as a result of this change. The principal engineer said neither he, nor FTE1, nor anyone else, realized the impact that reduced target pitch would have on the airplane's liftoff speed and its ability to achieve the predicted V_2 speed. According to APG1, FTE1 briefed the test team the day before the accident that they were to discontinue testing if pitch reached 11 to 12 degrees during initial takeoff. APG2 said that FTE1 briefed 11 degrees as a "pitch limit."

LIST OF ATTACHMENTS

1. Interviews with On-Board Crew Next of Kin
2. Toxicological Test Results for the Pilot in Command
3. Toxicological Test Results for the Second in Command
4. Toxicological Test Report for FTE1
5. Toxicological Test Report for FTE2
6. Emails Documenting FTE1 and SIC Use of the ITF
7. Overtime records for nine G650 program employees
8. Charts Depicting GAC's Pre-Accident Organizational Structure
9. Letters from the FAA's Atlanta ACO to GAC
10. July 2008 Memorandum of Understanding between Atlanta ACO and Gulfstream Titled *Flight Test Safety and Risk Assessment*