**NATIONAL TRANSPORTATION SAFETY BOARD**
**OFFICE OF AVIATION SAFETY**
**WASHINGTON, D.C. 20594**

**February 27, 2015**

# SYSTEM SAFETY AND CERTIFICATION GROUP CHAIRMAN'S FACTUAL REPORT

**NTSB ID No.: ERA14MA271**

## A. ACCIDENT:

| | |
|---|---|
| Location: | Laurence G. Hanscom Field (BED), Bedford, Massachusetts |
| Date: | May 31, 2014 |
| Time: | About 2140 Eastern Daylight Time (EDT) |
| Aircraft: | Gulfstream G-IV, N121JN, S/N 1399 |

## B. GROUP MEMBERS:


Chairman: Mike Hauf
National Transportation Safety Board

Member: Pedro Carleial
Gulfstream Aerospace Corporation

Member: Gideon Jose
Federal Aviation Administration


## C. SUMMARY:


On May 31, 2014, about 2140 eastern daylight time, a Gulfstream Aerospace Corporation G-IV, N121JM, operated by Arizin Ventures, LLC, crashed after a rejected takeoff and runway excursion at Laurence G. Hanscom Field (BED), Bedford, Massachusetts. The two pilots, a flight attendant, and four passengers were fatally injured. The airplane was destroyed by impact forces and a postcrash fire. The personal flight, which was destined for Atlantic City International Airport (ACY), Atlantic City, New Jersey, was conducted under the provisions of 14 *Code of Federal Regulations Part 91*. An instrument flight rules flight plan was filed. Night visual meteorological conditions prevailed at the time of the accident.

## D. DETAILS OF THE INVESTIGATION:

### D.1 Purpose:

This report factually documents the type certification activities performed by Gulfstream Aerospace Corporation (GAC) for demonstrating how the G-IV gust lock system met the applicable Federal Aviation Administration (FAA's) requirements.

### D.2 Type Certification Process and Overview:

The FAA is responsible for prescribing minimum standards required in the interest of safety for the design, material, construction, quality of work, and performance of aircraft, aircraft engines, and propellers (Ref. 49USC44701). Product certification is a regulatory process administered by the FAA to ensure that aircraft manufacturer's products comply with Federal Aviation Regulations (FAR). Successful completion of the certification process enables the FAA to issue a type certificate (TC). To obtain a TC, the manufacturer must demonstrate to the FAA that the aircraft or product being submitted for approval complies with all applicable regulations. The FAA determines whether or not the applicant has met its responsibility to show compliance to the applicable regulations. According to 14 Code of Federal Regulations (CFR) 21.21 (Amendment 21-27, Effective 12/1/69), an applicant is entitled to a type certificate for an aircraft in the normal, utility, acrobatic, or transport category, if:

(a) The product qualifies under Sec. 21.27; or

(b) The applicant submits the type design, test reports, and computations necessary to show that the product to be certificated meets the applicable airworthiness requirements and aircraft noise requirements of the Federal Aviation Regulations and any special conditions prescribed by the Administrator, and the Administrator finds that:

  (1) Upon examination of the type design, and after completing all tests and inspections, that the type design and the product meet the applicable aircraft noise requirements of the Federal Aviation Regulations, and further finds that they meet the applicable airworthiness requirements of the Federal Aviation Regulations or that any airworthiness provisions not complied with are compensated for by factors that provide an equivalent level of safety;

  (2) For an aircraft, that no feature or characteristic makes it unsafe for the category in which certification is requested.

The Federal regulations that apply to type certification of transport-category aircraft are 14 CFR Part 21, 25, 26, 33, 34, and 36. The Part 25 regulations are those concerned with the airworthiness standards for transport-category airplanes and are organized into subparts A through G. According to 14 CFR 21.21[1], the Federal regulations that apply to a specific transport-category airplane are contained in the type certification basis that is established by the FAA effective on the date of application per 14 CFR 21.17 a(1). These regulations represent the minimum standards for airworthiness; an applicant's design may exceed these standards and the applicant's tests and analyses may be more extensive than required by regulation. The specific applicable regulatory requirements and how compliance will be demonstrated is documented in an FAA approved certification plan.

[1] In June of 2010, this guidance was moved to Order 8110.112.

## D.3 Certification Basis for the Gulfstream G-IV:

The FAA has 10 aircraft certification offices (ACO) which are responsible for approving the design certification of aircraft, aircraft engines, propellers, and replacement parts for those products. The FAA's ACO in Atlanta, Georgia, was responsible for the certification oversight and approval for the G-IV.

On February 29, 1983, Gulfstream applied for a transport category type certificate for the Gulfstream G-IV airplane. According to Type Certificate Data Sheet[2] (TCDS) A12EA, revision 22, dated April 30, 1997, type certificate approval for the Gulfstream G-IV was granted on April 22, 1987, under 14 CFR Part 25 (the airworthiness standards for transport-category airplanes). The Gulfstream G-IV was added as the most recent model in a series of derivative models (or "changed aeronautical products") that were approved and added to Gulfstream type certificate (TC), originally issued for the Gulfstream II on October 19, 1967.

The applicable certification basis for the Gulfstream G-IV was the FAA's 14 CFR Part 25 Airworthiness Standards, effective February 1, 1965, including Amendments 25-1 through 25-56 with some exceptions as listed in table 1.

**Table 1 Exceptions**

| Section | Description | Amendment |
|---|---|---|
| 25.109 | Accelerate-stop distance | FAR 25, dated February 1, 1965 |
| 25.571 | Fatigue evaluation of flight structure | 25-22 (as applies to fuselage and empennage) |
| 25.671 | General | FAR 25, dated February 1, 1965 |
| 25.807(c)(2) | Passenger emergency exits | 25-15 |
| 25.813(d) | Emergency exit access | FAR 25, dated February 1, 1965 |

## D.4 CERTIFICATION BASIS FOR CHANGED AVIATION PRODUCTS:

The certification basis for changed aeronautical products allows an aircraft manufacturer to introduce a derivative model as a design update on a previously certificated aircraft and add the changed product onto an existing TC. The FAA approves such changes if it finds that the changes are not significant enough to warrant application for a new TC. This process enables a manufacturer to introduce derivative aircraft models without having to resubmit the entire aircraft design for certification review. The manufacturer can use the results of some of the analyses and testing from the original type certification to demonstrate compliance, in which case the regulations that were in effect on the date of the original TC apply.

Title 14 CFR 21.101, Subpart D, specifies the requirements for demonstrating airworthiness compliance for changed aeronautical products. When Gulfstream submitted its TC application for the G-IV, Title 14 CFR 21.101, amendment 21-42, which became effective on February 7, 1975, was in effect. According to 14 CFR 21.101, the certification basis for the Gulfstream G-IV required, at the discretion of the FAA, compliance with either the regulations cited in the original TC (issued in 1967) or applicable regulations in effect on the date of the application, plus any other amendments the Administrator finds to be directly related.

The current revision of 14 CFR 21.101, amendment 21.92, which became effective on April 16, 2011, differs from the one that applied to the certification of the Gulfstream G-IV. This revision states that an application for a changed aeronautical product to be added to a TC "must show that the changed product complies with the airworthiness requirements applicable to the category of the product in effect on the date of the application."

[2] A Type Certificate Data Sheet (TCDS) is a formal description of the aircraft, engine or propeller. It lists limitations and information required for type certification including airspeed limits, weight limits, thrust limitations, etc.

This regulation is more specific than previous revisions regarding what can be used from the original certification basis in an application for a derivative model involving a major change.

On April 25, 2003, the FAA issued FAA Order 8110.48, *How to Establish the Certification Basis for Changed Aeronautical Products*, which provides the procedures that the FAA and its designees utilizes for determining the certification basis for changes to type certificated products including changes made through an amended Type Certificate which is the method utilized for the GIV. The handbook refers to FAA Advisory Circular 21.101-1, e*stablishing the Certification Basis of Changed Aeronautical Products,* which contains an acceptable means, but not the only means, to comply with 14 CFR 21.101.

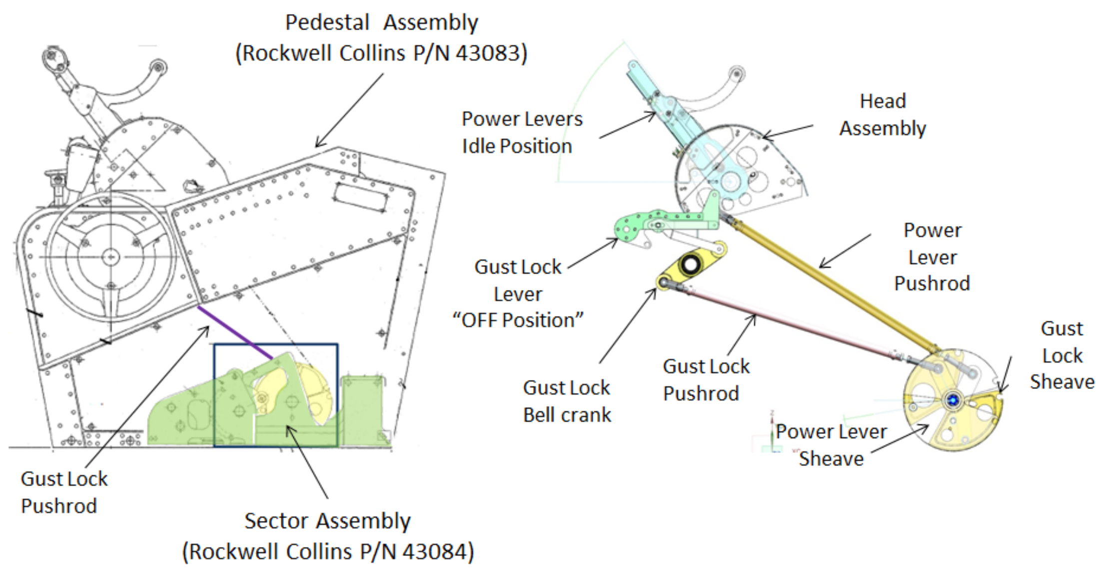
## D.5 Gust Lock System – G-IV:

The Gulfstream GII, GIIB, GIII, and G-IV model airplanes have a mechanical gust lock control system that when engaged, secures the airplane's primary flight control surfaces (ailerons, elevator and rudder) to prevent damage to the surfaces and attached control linkages from wind gusts up to 60 mph.

The gust lock system is controlled by a two-position red painted gust lock handle (labeled "lever" in the figures) located on the copilot's side of the cockpit center control pedestal (Figure 1). When in the aft/ON position, the red gust lock handle provides a visual cue, indicating the gust lock system is ON. The gust lock handle is adjacent to the flap handle, and hand interference with the gust lock handle would likely occur if the flap handle was moved while the gust lock handle was ON. Testing showed that while hand interference may be likely, depending on crew technique, it would be possible for a person sitting in the left seat to move the flaps handle without interfering with the gust lock handle in the ON position.

When the gust lock handle is rotated aft and up, the motion is translated by bellcranks, rods and sheaves to the cable loop. The motion of the cable loop rotates locking mechanisms that in turn move latching hooks into position to engage and lock the flight controls mechanisms. Moving the gust lock handle forward and down to the OFF position releases the gust lock hooks and unlocks the control surfaces.

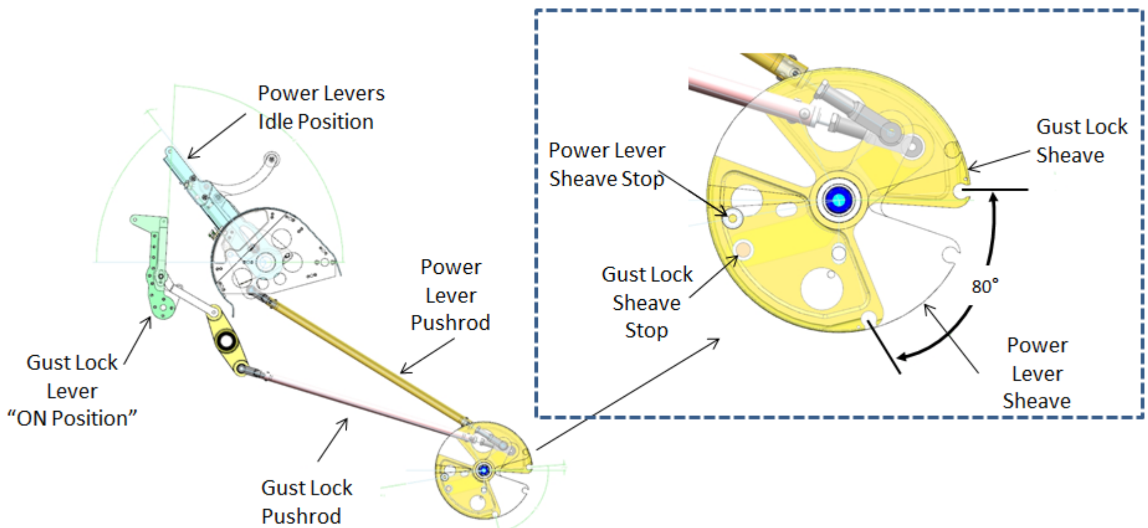
**Figure 1 Diagram of Pedestal Assembly**



The gust lock system also incorporates a mechanical interlock as a safety feature that was intended to provide crew awareness that the gust lock system is still ON, preventing attempted takeoff with locked flight controls.

A sector assembly is located inside the pedestal housing assembly and is mounted to the cockpit floor. The sector assembly contains a gust lock sheave (Reference figure 2), two power lever sheaves, a speedbrake sheave and two fuel cock sheaves. The gust lock sheave, which is connected to the gust lock handle via linkages, contains a mechanical stop which interfaces with corresponding stops on the left and right power lever sheaves. These stops are positioned on the sheaves to allow full power lever movement with the gust lock handle OFF, and were intended to limit power lever movement to 6 degrees of rotation above idle at the throttle sectors with gust lock handle ON, thus preventing the airplane's ability to achieve a takeoff power setting.

**Figure 2 Diagram of the Gust Lock Sheave with Gust Lock lever ON**




The GII, GIII, and the GIIB share the same pedestal assembly, which includes the gust lock handle, linkage to floor sheaves, throttle control head, and throttle linkage to floor sheaves. However, the design of the pedestal assembly was modified for the G-IV.

One of the changes to the G-IV pedestal assembly included the repositioning (down and aft) of the gust lock handle. This change necessitated the following geometric design changes to the gust lock control system:

- The length of the gust lock bellcrank arm was decreased from 2.75 inches to 2.0 inches,
- The range of motion for the gust lock handle (stowed position to its up and locked position) increased from 60° to 87°.
- The position of the detent in the gust lock handle link, which connects the gust lock handle to the bell crank arm, was modified.
- The floor sheaves were modified to accommodate the new kinematics of the system.

When the detent position in the gust lock handle link was modified for the G-IV, the design neutral reference point for the ON detent position also changed. These changes to the gust lock control system did not affect the angular displacement of the gust lock sheave or power lever sheaves in the floor sector assembly. For all models, the rotation of the gust lock handle results in the gust lock sheave rotating a total of 80º.

**Table 2**

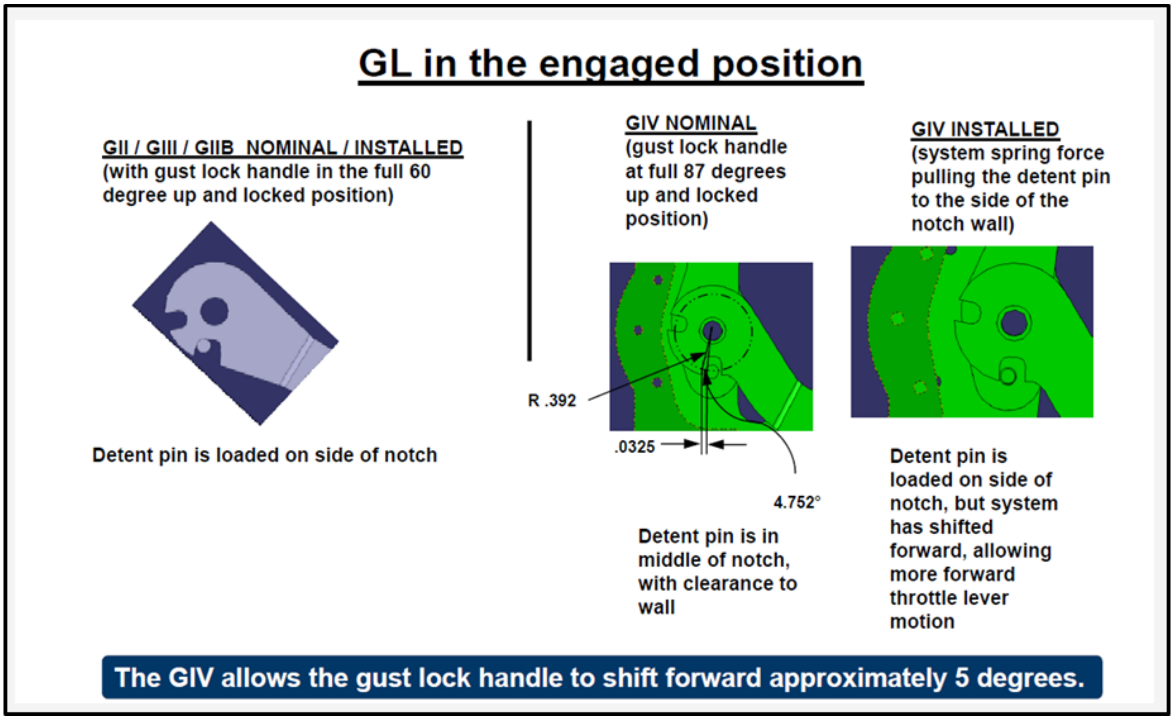
| | G-1159 (GII)<br>G-1159A (GIII)<br>G-1159B (GIIB) | G-IV |
|---|---|---|
| Power lever rotation from idle to maximum power (degrees) | 60 | 58 |
| Power lever sheave rotation (degrees) | 60 | 60 |
| Gust lock lever rotation (degrees) | 60 | 87 |
| Gust lock sheave rotation (degrees) | 80 | 80 |

On the GII, GIII, and the GIIB handle, the ON position reference point for the detent pin is resting against the detent slot wall. On the G-IV handle, the ON position reference point is centered in the detent slot, resulting in clearance between the detent pin and the detent slot walls. As stated in the Airworthiness Group chairman's factual report, the gust lock system contains two return springs (located on the aileron mechanism) and two return springs (located on the elevator and rudder mechanism). When the gust lock system in engaged (ON), these return springs provide a constant force acting to unlock each flight control gust lock mechanism. This spring force is transmitted through the system control cables, gust lock sector, pushrod, gust lock bellcrank, to the gust lock handle link acting on the detent pin to rotate the handle in the down direction.

For the GII, GIII, and the GIIB gust lock handle, the designed ON position reference point for the detent pin is such that the pin would be resting against the detent slot wall of the gust lock handle link. This is representative of the actual handle position because the system return springs will bring the detent flush with the lock pin. For the G-IV gust lock handle, the designed ON position reference point for the detent pin is such that the pin is centered within the detent slot, resulting in a clearance between the detent pin and the detent slot wall of the gust lock handle link. This is not representative of the actual handle position because the system return springs will bring the detent flush with the lock pin. The difference between the design position (center of detent) and the actual position (flush with detent) results in unintended gust lock lever travel and therefore allowing extra forward movement of the power levers (up to approximately 5 degrees) when the gust lock is engaged.

Since the mechanism is spring loaded, the pin is pulled against the slot wall instead of resting in its centered design reference position when the G-IV mechanism is commanded ON (See Figure 3).

**Figure 3 Gust Lock Handle - Detent Clearance**




## D.6 Certification G-IV Control System Gust Locks:

### D.6.1 Requirements - Control System Gust Locks (GII – G-IV):

The applicable certification basis for the Gulfstream G-II aircraft was Civil Air Regulations (CAR) 4b dated December 31, 1953, including Amendments 4b-1 thru 4b-14. According to TCDS A12EA, revision 22, dated April 30, 1997, the date of application for the Gulfstream G-II type certificate was June 24, 1964 and type certificate approval was granted on October 19, 1967.

Paragraph 4b.326 "*Control system locks*" required that provision shall be made to prevent damage to the control surfaces (including tabs) and the control system which might result from gusts striking the airplane while it is on the ground or water (reference 4b.226). If a device provided for this purpose, when engaged, prevents normal operation of the control surfaces by the pilot, it shall comply with the following provisions.

(a) The device shall either automatically disengage when the pilot operates the primary flight controls in a normal manner, or it shall limit the operation of the airplane in such a manner that the pilot receives unmistakable warning at the start of take-off.

(b) Means shall be provided to preclude the possibility of the device becoming inadvertently engaged in flight.

On December 24, 1964, the FAA issued a final rule (70 Federal Register 18289) that adds Part 25 [NEW] to the Federal Aviation Regulations to replace Part 4b of the Civil Air Regulations, and was a part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 F.R. 10698). This rule became effective on February 1, 1965. As part of the change, Paragraph 4b.326 "*Control system locks*" became 14 CFR 25.679, "Control System Gust Locks."

Requirement 14 CFR 25.679, "Control System Gust Locks" states:

(a) There must be a device to prevent damage to the control surfaces (including tabs), and to the control system, from gusts striking the airplane while it is on the ground or water. If the device, when engaged, prevents normal operation of the control surfaces by the pilot, it must:
   (1) Automatically disengage when the pilot operates the primary flight controls in a normal manner; or
   (2) limit the operation of the airplane so that the pilot receives unmistakable warning at the start of takeoff.

(b) The device must have means to preclude the possibility of it becoming inadvertently engaged in flight.

### D.6.2 14 CFR 25.679, "Control System Gust Locks" - Interpretation:

As requested by the NTSB, the FAA provided its formal interpretation of 14 CFR 25.679(a)(2) "Limit the operation of the airplane so that the pilot receives unmistakable warning at the start of takeoff." In a letter dated August 29, 2014, the FAA stated the following: With respect to gust lock engagement, "Limit the operation of the airplane so that the pilot receives unmistakable warning at the start of takeoff." This is a performance based requirement and an applicant can use any means at their disposal, so long as it shows compliance with the rule. To comply with this paragraph applicants use various means to limit the operation. Examples include gust locks that when they are engaged, also prevent throttle lever/actuator advance. Some airplanes incorporate gust locks that hold the nose wheel offset such that if throttles are advanced the airplane will tend to circle on the ground. Both of these means of compliance limit the operation of the airplane. The FAA emphasizes the rule language that states, "must—(2) Limit the operation of the airplane" to prevent pilots from ignoring or mistaking visual and aural take off warnings. The FAA considers the examples given above as unmistakable warnings in that they limit the operation of the airplane. With respect to 25.679, the FAA considers an "unmistakable warning" to be a warning that physically limits the operation of the airplane to prevent an unsafe takeoff.

According to Gulfstream, the following features of the gust lock system limit the operation of the G-IV airplane when the gust lock system is engaged and would provide an unmistakable warning to the flight crew:

1. It restricts the operation of the pilot controls (i.e. yoke, column, rudder pedals) during the AFM required control checks.
2. It limits the operation of the throttle levers.
3. As an additional warning feature, the gust lock handle is painted red and located prominently adjacent to the flap handle such that there is physical contact with the co-pilot's hand during operation of the flap handle.

### D.6.3 14 CFR 25.679, "Control System Gust Locks" – Certification:

As previously stated, the mechanical stops on the gust lock sheave are intended to allow full power lever movement with the gust lock handle OFF, and, according to the requirements contained within Gulfstream's certification documents, the G-IV pedestal design requirement was intended to limit power lever movement to no greater than 6° +/- 1° from the idle position during operation with gust lock engaged, including system design tolerances. Force applied to advance either or both throttle levers cannot override the interlocks.

### D.6.3.1 Compliance Checklist for Gust Lock System:

A compliance checklist is a document created by an applicant for the purpose of documenting that all applicable regulations for a project have been shown and found compliant, to support the FAA's grant of a type certificate. It is completed at the end of the certification effort, once all of the findings of compliance have been accomplished. The G-IV compliance checklist (1159C-GER-107), dated 3-19-1987 and Revision A dated 4-22-1987, each had a "Recommend Approval" 8110-3 form signed by Gulfstream DERs[3]. This indicates that both compliance checklists were submitted to the FAA for findings of compliance.

Revision A of the compliance checklist[4] report listed all the applicable FAR Part 25 airworthiness requirements. For each requirement, the checklist included the FAR number and title, method of compliance (ground test, flight test, analysis, similarity, inspection or design review), a document reference containing the compliance data, and the evidence of FAA approval (such as a form 8110-3 reference number).

For requirement 14 CFR 25.679, the compliance checklist report listed three Gulfstream drawings as the compliance data within the "method of compliance" section of the checklist. The FAA approval section indicated "accepted", and for each drawing listed, the checklist indicated that an FAA 8110-3 form was submitted. Reference table number 3 for a list of the compliance drawings associated with 14 CFR 25.679 and attachment number 1 for a copy of the checklist. According to Gulfstream, compliance with 14 CFR 25.679 (a)(2), which requires that the gust lock system limit the operation of the airplane so that the pilot receives unmistakable warning at the start of takeoff, was found by review of the drawings.

**Table 3 Method of Compliance**

| FAR Number | FAR Title | Indicated Method of Compliance |
|---|---|---|
| 25.679(a) | Control System Gust Locks | GAC Drawing 1159C20005 "Control Installation – Flight Controls Gust lock" |
| | | GAC Drawing 1159SCF450 "Control Pedestal ASSY- Cockpit" |
| | | GAC Drawing 1159SCF451 "Controls Sectors & Support ASSY" |
| | | |
| 25.679(b) | Control System Gust Locks | GAC Drawing 1159C20005 "Control Installation – Flight Controls Gust lock" |
| | | GAC Drawing 1159SCF450 "Control Pedestal ASSY- Cockpit" |
| | | GAC Drawing 1159SCF451 "Controls Sectors & Support ASSY" |

An NTSB review of the three drawings associated with the certification of the gust locks system found that the design requirements pertaining to the flight control systems were contained within specification control drawing1159C20005, and the design requirements pertaining to the pedestal interlocking mechanism were contained within drawings 1159SCF450 and 1159SCF451.

### D.6.3.2 Findings of Compliance to 14 CFR 25.679:

Historically, the FAA has relied on a variety of organizational or individual designee programs to meet its responsibility to hold the aviation industry accountable to its safety standards. The FAA utilizes designees

[3] A DER may approve or recommend approval of engineering technical data within the limits of their authority by means of FAA Form 8110-3, Statement of Compliance with the Federal Aviation Regulations.

[4] Compliance checklist titled, "Gulfstream IV compliance checklist for FAA part 25", dated April 22, 1987

across its scope of responsibilities, such as pilot licensing, mechanic certification, pilot medical examinations and aircraft design certification.

When Congress created the FAA in 1958 to promote the safety of civil aviation, it recognized the practical necessity of FAA utilizing private sector expertise to keep pace with the growing aviation industry and explicitly gave the agency the authority to delegate certain certification activities, as the agency deems necessary, to qualified persons. The designee program itself has roots as far back as 1927, and the Federal Aviation Act continued and allowed for the expansion of delegations of authority.

Typical individual designees involved in aircraft design, certification and manufacturing include Designated Engineering Representatives (DERs), Designated Manufacturing Inspection Representatives (DMIRs), and Designated Airworthiness Representatives (DARs). Delegation Option Authorization (DOA), Organizational Designated Airworthiness Representative (ODAR) and Designated Alteration Stations (DAS) are examples of organizational delegation programs that have been utilized for many years-, or in the case of DOA, for several decades.

As previously stated, an 8110-3 form was submitted to the FAA along with each of the three drawings listed in table 4. (Reference attachment 2) An NTSB review of the three 8110-3 forms found that a Gulfstream-employed DER approved the compliance data as a finding of compliance.

**Table 4 8110-3 Forms**

| Drawing Number | 8110-3 Form | Documentation |
|---|---|---|
| Drawing 1159C20005, Rev F | Form dated 7-8-84 | Documented that FAR 25.679 was an applicable regulation. |
| Drawing 1159SCF450, Rev K | Form dated 1-13-87 | Documented that the purpose of the revision to the drawing was to revise pedestal markings and that 14 CFR 25.1301(b) was the applicable regulation. |
| Drawing 1159SCF451, Rev B | Form dated 3-4-85 | Documented that the purpose of the revision to the drawing was to provide G-IV specifications for control sectors similar to the GIII design and that 14 CFR 25.1141, 1143, 1351-1359 were the applicable regulations. |

### D.6.4 Gust Lock Lever to Flight Control Surfaces:

Drawing, 1159C20005 “Control Installation – Flight Controls Gust lock”, contained the design specification requirements for the interaction between the primary flight controls and their respective gust lock mechanism. According to the document, with the gust lock system engaged, the flight control surfaces should be positioned as follows:

1) Elevator -13.0 +0/- 1°
2) Rudder[5] 0.0 +/- 1.5°
3) Aileron 0.0 +/- 1.5°

[5] Drawing 1159C20005 EO H9 changed this to 0.0 +/- 0.25° on 8/28/2002.

### D.6.5 Gust Lock Lever to Power Lever Interlock Mechanism:

The G-IV control pedestal is mounted to the aircraft cockpit floor structure and is located between the pilot and copilot seats. The control pedestal consists of two major assemblies: the pedestal assembly (Gulfstream 1159SCF450, Rockwell Collins 43083), and the floor sector assembly (Gulfstream 1159SCF451, Rockwell Collins 43084). Gulfstream's design requirements pertaining to the pedestal interlocking mechanism were contained within these two specification control drawings 1159SCF450 and 1159SCF451.

The control pedestal contains a large portion of the cockpit controls such as the longitudinal trim wheels, flap control lever, gust lock lever, speedbrake control lever, etc. The pedestal assembly also contains the throttle control head assembly (Kaiser/Rockwell 43087), which contains the engine controls (power levers, reverse thrust levers, and fuel cocks). The floor sector assembly is mounted to the cockpit floor, underneath the pedestal housing. This assembly consists of control cable sheaves mounted on common axes, which transmit incoming motion of the power levers, fuel cocks, gust lock, and speed brake controls via pushrods to the appropriate control system cables. The sheaves connected to the power levers and gust lock lever contain the mechanical stops which make up the gust lock/throttle interlock by limiting motion of the power lever sheaves with the gust lock sheave rotated to the Gust Lock Engaged position.

The pedestal controls are rigged together with the floor sheaves during installation. Rig pins installed into appropriate rig pin holes in the mechanical components (sheaves and levers) and into structure allow adjustment of the control pushrods to fit the system as fixed by the rig pins. The rigging process is described in the 1159F40300 installation drawing.

At the certificate of airworthiness date for 1399, the production rigging instructions did not contain specific instructions on allowable power lever movement with the gust lock ON.

Gulfstream Quality Assurance Procedure 9.2, "Gulfstream G-IV Acceptance Flight Test", also required a production flight test card to check gust lock operation, but did not contain specific instructions on allowable power lever movement with the gust lock ON.

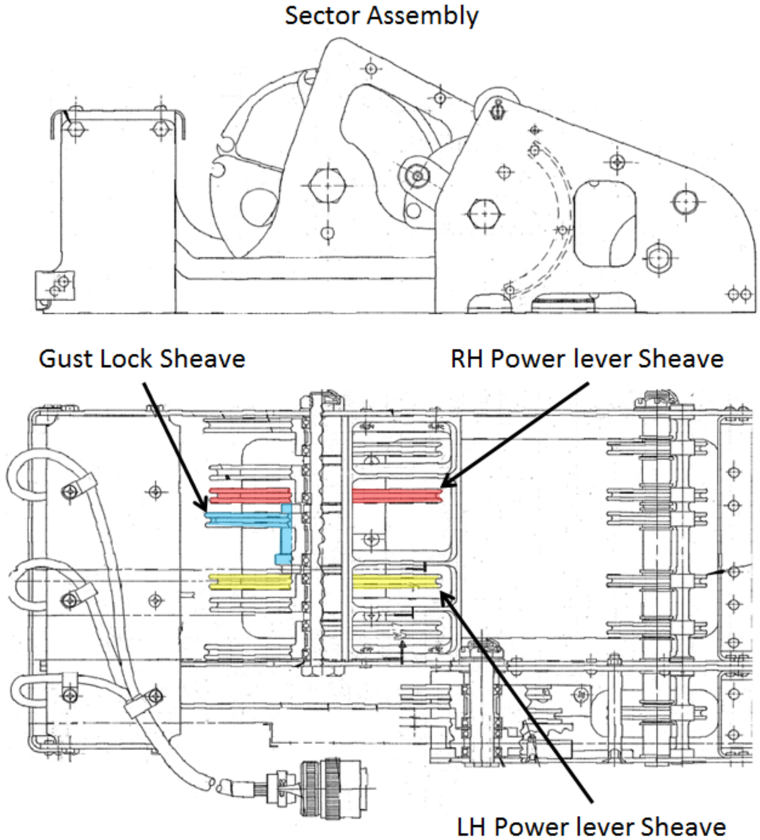
#### D.6.5.1 Drawing 1159SCF451:

GAC Drawing, 1159SCF451 "Controls Sectors & Support ASSY", is a specification control drawing (SCD) which contains design, engineering, performance requirements and standards for the construction of the sector assembly having Rockwell Collins part number 43084[6] (Reference Figure 4). Three of the components of the sector assembly are:

- A left and a right power lever sheave
- A gust lock sheave

[6] The sector assembly was originally designed and manufactured by Sargent Industries, which became Kaiser Electroprecision (manufacturer of the subject assemblies on the accident airplane), which subsequently became Rockwell Collins.

**Figure 4 - Overview of Sector Assembly**




The "design and construction requirements" section of this SCD contained the requirements pertaining to the gust lock sheave. One of the requirements stated: "an interlocking device operated by the gust lock in the locked position shall prevent advancing of either throttle beyond 6° +/- 1° from the idle position." (Reference Attachment 3)

Gulfstream's post-accident review determined that the gust lock and throttle interlock stops on the floor sectors are positioned approximately 6° apart in the neutral position with the rigging pin holes aligned, consistent with the design requirements. However, once the rigging pins are removed, and the system is allowed to translate to its at-rest position under gust lock spring force, additional movement of the throttle levers occurs.

The "quality assurance provisions" section of the SCD contained the production and inspection tests for the sector assembly. Production tests are performed on samples representative of the production equipment to ensure that design and performance are being maintained according to established standards. The SCD states that the vendor shall conduct in-process and final inspection tests on each assembly offered for GAC acceptance under this SCD. Such tests shall be adequate to assure continued compliance with all of the requirements of this specification.

### D.6.5.2 GAC Drawing 1159SCF450:

GAC Drawing, 1159SCF450 "Control Pedestal ASSY- Cockpit", included an SCD containing the design, engineering and performance requirements and standards for the construction of the cockpit control pedestal assembly intended for use on the G-IV. The gust lock lever was one of the pedestal controls included within this specification document. This drawing includes the requirements for the full pedestal assembly, with engine controls installed. It does not include the sector floor assembly, which are covered in 1159SCF451).

The "design and construction" section of the SCD contained the requirements pertaining to controls on the pedestal assembly. Included in the controls were the power levers, fuel cock levers, friction control, speedbrake control lever, gust lock lever and the flap control lever. Two of the requirements for the gust lock lever were: (1) "the gust lock lever shall have a locked position in both the up (ON) and down (OFF) positions. The handle and locking shall be similar to existing Gulfstream III design," (2) "The gust lock lever shall be mechanically connected to its lower sector assembly by means of push rods and a bellcrank."

Drawing 1159SCF450 also contained a diagram defining the operating range requirements of the power lever sheaves with the gust lock lever positioned to its ON and OFF position. According to the drawing, when the gust lock is positioned to ON, the operating range requirement should be: "6° max movement from "idle" W/GL on". (Reference figure 5)

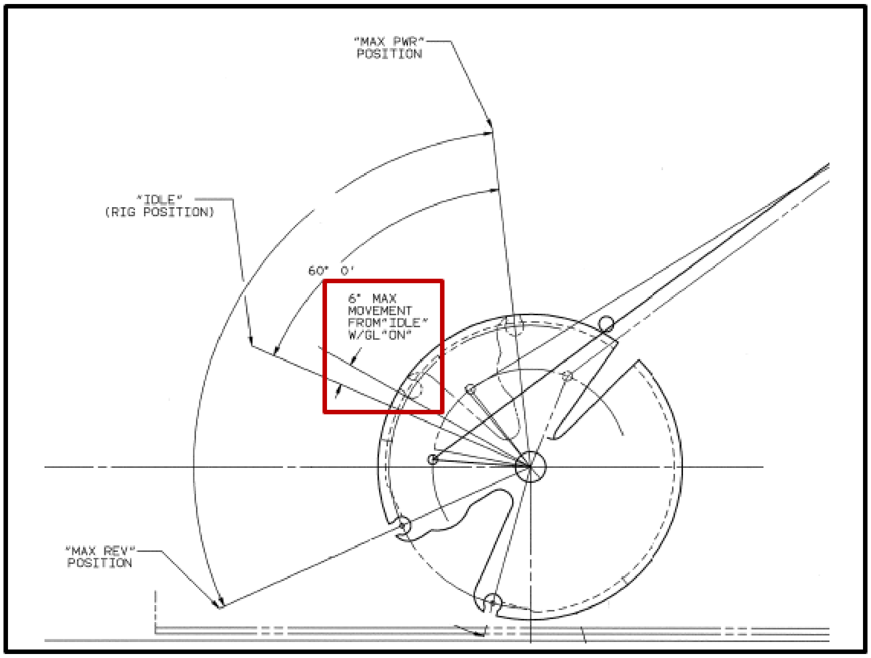
At the request of the NTSB, Gulfstream provided the following information regarding the 6° requirement.

"*According to the requirements in these specification documents (see 1159SCF450 and 1159SCF451), the G-IV pedestal design requires a 6° maximum movement of the throttle sectors from "idle" with gust lock "ON". The interlock is intended to limit throttle movement to less than 6° +/- 1° from the idle position during operation with gust lock engaged, including tolerances (see 1159SCF451 section 3.2.1.3).*

*"Further historical documentation has not been located to confirm any additional validation and verification of the 6° requirement beyond the compliance finding. Based on current 2014 analysis and demonstrations (during the A/C 1399 investigation), GAC has validated that restricting throttle movement to 6° prevents the GIV aircraft from achieving takeoff EPR. This testing verified that the current detailed pedestal design does not meet the 6° throttle interlock specification requirement*."

*"The 6° throttle interlock specification requirement was originally established on the GII model airplane in 1967 in order to limit throttle movement with the gust lock engaged, thereby restricting available engine power. This limits aircraft operation and provides unmistakable warning to the pilot. This requirement was defined on 1159SCP005 ("Power Plant-Control Sectors & Support Assembly, Floor") and remained the same for GIII and GIV aircraft*."

**Figure 5 Drawing Requirements for Gust Lock Sector**




The “quality assurance provisions” section of the SCD defined the three sets of tests to be performed on the pedestal assembly:

1. <u>Qualification tests</u>,
   Qualification tests are tests to be performed on the proposed equipment to establish the adequacy of the design for its intended use.

2. <u>Production tests</u>
   Production tests are tests to be performed on samples representative of the production equipment to insure that the design and performance are being maintained according to the established standards.

3. <u>Inspection tests</u>.
   Inspection tests are tests performed on each assembly submitted for acceptance under contract.

The qualification testing section of the SCD indicated that qualification testing shall be the responsibility of the vendor and shall be performed to Gulfstream’s approved procedures at a Gulfstream approved testing laboratory. The qualification tests included; Examination of the product, Functional tests, Vibration, Mechanical shock test, proof load test, ultimate load test, endurance test, and several environmental tests. An NTSB review of two of the qualification test procedures found the following:

1) Examination of the product:
   The purpose of this procedure was to examine the component (pedestal) for conformance with the drawings of the vendor, GAC drawing 1159SCF450. Any deviations to this SCD incurred by the vendor shall not be acceptable unless GAC approval is received.

2) Functional tests:
   The functional test section specifies tests for the power levers, fuel cock levers and the power friction control. There were no functional tests specified for the gust lock lever, flap lever or the speedbrake lever. Specifically, there was no test requirement to position the gust lock handle in its up and locked

position and ensure that the operating range of the power lever sector met the requirement of: “6° max movement from “idle” W/GL on.”

### D.6.6 Qualification Testing for the G-IV Pedestal Assembly:

In 1985, Sargent Industries prepared and Gulfstream approved a Qualification Test Plan (QTP) for the sector assembly, control head and pedestal assembly that would be installed in the Gulfstream G-IV. The QTP, Gulfstream document number GAC-CR-161, was titled “Qualification Test plan for Gulfstream G-IV sector, control head and pedestal assemblies”, and was dated September 10, 1985. (Reference Attachment 4) The QTP was the overall blueprint for the quality assurance program to be conducted, by Sargent Industries, on the Gulfstream G-IV pedestal, control head and sector assembly to comply with the requirements within Gulfstream’s 1159SCF450 SCD and with paragraph 4, “Quality assurance provisions” of SCD 1159SCF451. An NTSB review of the QTP found that the plan did not include any testing to comply with the design and construction requirements for the sector assembly as detailed within Gulfstream’s 1159SCF451 SCD.

According to the Qualification Test Plan, document GAC-CR-161, Sargent Industries proposed to conduct the qualification tests on one pedestal, control head and sector assembly assembled as a unit.

Section 2 of the Qualification Test Plan was titled “qualification test procedure.” This section of the document stated that a qualification test procedure will be prepared detailing the tests to be performed and referenced by the qualification tests identified in section 4.2 of Gulfstream’s 1159SCF450 SCD. The tests included: Examination of the product, Functional tests, Vibration, Mechanical shock test, proof load test, ultimate load test, endurance test, and several environmental tests.

Section 3.0 of the Qualification Test Plan was titled “Acceptance Test Procedure (ATP).” This section indicated that an ATP will be prepared in accordance with paragraph 4.1(c) of Gulfstream’s 1159SCF450 SCD to individually inspect each pedestal, control head and sector assembly to be shipped.

Section 4.1 of the Qualification Test Plan was titled “Examination of the Product” and had a traceable reference back to the 1159SCF450 SCD, “examination of the product” requirement. This section of the document stated that the pedestal, control head and sector assembly submitted for qualification testing shall each be carefully examined for conformance to Sargent Industries drawings 43083, 43084 and 43087. This procedure did not indicate that the component (pedestal) should be examined for conformance with GAC SCD 1159SCF451 as specified.

Section 4.2 of the Qualification Test Plan was titled “Functional tests” with traceable references back to the requirements contained within the 1159SCF450 SCD, functional test section.

### D.6.7 Qualification Test Procedure (QTP) – G-IV Sector and Pedestal Assembly:

In 1986, Sargent Industries prepared and Gulfstream approved the qualification test procedure for the G-IV sector, control head and pedestal assembly. The document was titled “Qualification Test Procedure, GIV Engine Power Control Assembly, Sargent P/N 43083-001, 43084-001, 43087-001” and dated July 28, 1986.

This document defined the qualification tests to be performed on the G-IV engine power control assemblies 43083-001, 43084-001, 43087-001 by Sargent Industries, Huntington Park Division, for

Gulfstream. An NTSB review found that the information regarding the qualification testing was consistent with the information provided in qualification test plan GAC-CR-161.

### D.6.8 Qualification Test Report:

Sargent Industries prepared and Gulfstream approved Qualification Test Report (QTR) titled "Gulfstream IV Sector, control head and pedestal assemblies", dated December 2, 1986. This report provided the qualification test results for the vendor supplied sector, control head and pedestal assembly to be FAA certified as part of Gulfstream G-IV type design. The documentation within the report was intended to support the verification that the sector, control head and pedestal assembly being installed on the G-IV aircraft complied with the FAA FAR 25.1301(a), (b), (c) & (d), and 25.1309(a) requirements.

According to the report, the qualification tests were performed at Wyle Laboratories, El Segundo, California in conformance with Gulfstream control specifications 1159SCF450 and 1159SCF451. The report also states: "from the results of the qualification and post-qualification tests, it is determined that the G-IV control quadrant fully conformed to the requirements of the Gulfstream control specification documents 1159SCF450, rev F and 1159SCF451, rev D.

The testing contained within the QTR was in accordance with information specified in the qualification test procedure document. No information regarding the gust lock lever was contained within the test report or the qualification by similarity report.

### D.7 Certification G-IV Flight Controls:

A review of a Gulfstream G-IV flight control report[7] was performed to gather information on the background and history of how Gulfstream showed FAR 25 compliance with the system design requirements. According to the report, its purpose was to provide the rational for the FAA certification of the flight control systems; it did not include any information pertaining to the gust lock system. According to the report, the G-IV flight control systems certification process began with Gulfstream-FAA engineering discussions at the preliminary type certification board meetings held on 29-30 November 1983. At these meetings, the G-IV flight control systems were discussed and Gulfstream's intent was to certify the control systems based upon previous Gulfstream GII, GIIB and GIII experience and not have to re-certify GIII system/installations carried over to the G-IV aircraft.

According to the report, the G-IV flight control systems were the same as those used on the Gulfstream GII, GIIB and GIII aircraft with some minor changes and therefore were FAA certified by similarity. Gulfstream's G-IV flight control systems certification report, dated, 5-21-1986, documented the changes to the flight control systems; the report was submitted to the FAA via 8110-3 form for compliance to 25.671. The certification basis for the G-IV flight controls was FAR 25.671, dated February 1, 1965.

Far 25.671General (Amendment. 25-23, Effective 5/8/70):

(a) Each control and control system must operate with the ease, smoothness, and positiveness appropriate to its function.

(b) Each element of each flight control system must be designed, or distinctively and permanently marked, to minimize the probability of incorrect assembly that could result in the malfunctioning of the system.

[7] Gulfstream's G-IV flight control report, dated 8-22-1988.

(c) The airplane must be shown by analysis, tests, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag, and feel systems), within the normal flight envelope, without requiring exceptional piloting skill or strength. Probable malfunctions must have only minor effects on control system operation and must be capable of being readily counteracted by the pilot.

(1) Any single failure, excluding jamming (for example, disconnection or failure of mechanical elements, or structural failure of hydraulic components, such as actuators, control spool housing, and valves).

(2) Any combination of failures not shown to be extremely improbable, excluding jamming (for example, dual electrical or hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure).

(3) Any jam in a control position normally encountered during takeoff, climb, cruise, normal turns, descent, and landing unless the jam is shown to be extremely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such runaway and subsequent jamming is not extremely improbable.

(d) The airplane must be designed so that it is controllable if all engines fail. Compliance with this requirement may be shown by analysis where that method has been shown to be reliable.

## D.8 Certification Enhancements since 1983:

As requested by the NTSB, Gulfstream provided the following paragraph to the NTSB describing the changes (enhancements) to the process they use to certify a product (system) since the G-IV was certified.

According to Gulfstream, “since the original G-IV certification efforts in the early eighties, Gulfstream's design and certification practices have evolved significantly as compared to those in use by industry at the time. Advancements in tools, technology, industry standards and regulatory guidance have resulted in a more robust requirements allocation, validation and verification process. Gulfstream has implemented ARP4761 (Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment), resulting in aircraft and system level safety assessments that are more complete, more detailed, and cover many more systems. Gulfstream has also adopted a systems engineering approach to design and verification, implementing ARP4754 Rev A (Guidelines for Development of Civil Aircraft and Systems) into Gulfstream’s design process. Gulfstream uses requirements management tools such as relational databases that provide full requirements traceability and verification from aircraft level to piece part. Advancements in both design tools and Gulfstream's test labs also facilitate more robust integration and verification activities at both system and aircraft levels. The functional requirement of providing a gust lock is an example of how advances in technology and the tools to implement and verify that technology have made designs more robust and reliable. With the introduction of high integrity continuously monitored, fully powered irreversible fly-by-wire designs, ground gust protection can now be provided by natural damping of the control surfaces when there are no hydraulics, eliminating the need for a mechanical lock. Industry's standards and FAA regulations (e.g. 14 CFR 21.101 Changed Product Rule) have evolved significantly since the early eighties, as has Gulfstream’s design tools and methodologies. Gulfstream's certification processes continue to align with FAA Order 8110.4, Type Certification, and tremendous advances in computing capabilities and tools have all contributed to more robust design and certification processes.”

Mike Hauf

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