Gulfstream Aerospace Corporation

Party Submission

Accident involving

Arizin Ventures LLC – SK Travel LLC – Operated Aircraft N121JM

May 31, 2014

Laurence G. Hanscom Field

Bedford, Massachusetts

ERA14MA271

May 11, 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF QUOTATIONS

1.0 INTRODUCTION

On May 31, 2014, at about 21:40 eastern daylight time[1], a Gulfstream Aerospace Corporation (“Gulfstream”) G-IV, N121JM, operated by Arizin Ventures, LLC, crashed after a rejected takeoff and runway excursion at Laurence G. Hanscom Field (“KBED”), Bedford, Massachusetts. The two pilots, a flight attendant, and four passengers were fatally injured. The airplane was destroyed by impact forces and a post-crash fire. The personal flight, which was destined for Atlantic City International Airport (“KACY”), Atlantic City, New Jersey, was conducted under the provisions of 14 CFR Part 91. An instrument flight rules flight plan was filed. Night visual meteorological conditions prevailed at the time of the accident.

2.0 PROBABLE CAUSES

This accident occurred because the flight crew deviated from approved procedures and training that left the gust lock engaged, and attempted to continue takeoff with a recognized flight control anomaly, rather than promptly executing a coordinated abort procedure.

Gulfstream believes that the following were the causal factors[2] leading to the accident:

- Failure of the flight crew to follow Airplane Flight Manual (“AFM”) procedures at three critical points before rotation speed (“Vr”):
    - Not disengaging the gust lock before engine start;
    - Not checking for freedom of control surface movement following engine start; and
    - Not confirming elevator freedom of movement at 60 knots during takeoff roll.
- Failure of the flight crew to follow flight crew training procedures on four occasions:
    - Not disengaging the gust lock prior to engine start;
    - Not checking for freedom of control surface movement following engine start;
    - Failing to abort takeoff at 80 knots when elevator movement did not occur; and
    - Failing to use appropriate corrective action upon determining that the gust lock was inadvertently left on following engine start.
- Failure of the flight crew to conduct a timely and coordinated abort procedure upon recognition that the gust “lock is on”.

Gulfstream believes that the following were contributory factors[3] leading to the accident:

- Failure of the flight crew to use proper Crew Resource Management (“CRM”) techniques:
    - The occurrence of the [**RUDDER LIMIT**] crew advisory system (“CAS”) message was discussed for 10 seconds, but no effective troubleshooting was performed to understand the issue;
    - No verbalization of the abnormal gust lock handle position nor any discussion to resolve it prior to Vr;
    - A loss of situational awareness as the throttles and engine power are reduced and remain reduced for 13 seconds before Vr;

---

[1] All time reference in this party submission are eastern daylight time (“EDT”), unless specifically noted otherwise.

[2] Gulfstream defines a “causal factor” as any action, behavior, omission, or deficiency that if corrected, eliminated, or avoided probably would have prevented the accident.

[3] Gulfstream defines a “contributory factor” as any action, behavior, omission, or deficiency that set the stage for the accident, or increased the severity of the outcome.

- Following the pilot flying's ("PF")[4] initial ***"lock is on"*** statement and the next 10 seconds to brake application, there is no crew discussion on the situation or corrective action options;
- No announcement of intent to pull the flight power shutoff valve ("FPSOV") or discussion on how it would affect the aircraft;
- The PNF does not verbally respond to any of the PF's seven ***"lock is on"*** callouts;
- Neither the PF or PNF announced a clear decision to abort the takeoff, resulting in an uncoordinated rejected takeoff ("RTO") and delayed power reduction; and
- The more experienced PNF is silent after Vr and throughout the entire RTO providing no feedback, guidance or recommendations on how to address the situation

Gulfstream also believes the following regarding the loss of the aircraft's crew and passengers:

- Based upon the NTSB Survival Factors Report, the initial and secondary accident impacts were survivable;
- The aircraft fuel tanks were ruptured after the aircraft left the runway and impacted ground structures, fueling a severe fire; and
- The smoke, fire and extreme temperatures in the cabin rapidly overcame the crew and passengers prior to opening any emergency exit.

Following the accident, Gulfstream discovered that the gust lock interlock system, designed and manufactured by predecessors to Rockwell Collins for Gulfstream for the G-IV model aircraft, while limiting throttle movement when engaged, did not achieve its stated 6 degree throttle movement limitation, and that this remained undiscovered on more than 500 aircraft, over 25 years and more than 2 million takeoffs. Extensive data collected from the accident aircraft, and the company's and the NTSB's post-accident testing, demonstrate that the interlock as it existed on the accident aircraft achieved its safety intent of limiting the operation of the aircraft, which was recognized by the flight crew early in the takeoff roll. However, the flight crew improperly responded to this recognition by attempting to disengage the gust lock while continuing with the takeoff instead of immediately aborting the takeoff and following proper unlock and engine start procedures.

3.0 SUMMARY OF EVENTS

Based upon the extensive factual record developed during the NTSB investigation and our own experiences, Gulfstream believes the relevant events leading to this tragic accident can best be summarized as follows. Supporting data can be found in the subsequent sections of this party submission. For ease of reference, Appendix A provides a consolidated visual overview of the sequence of events on the active runway.

The events leading to the accident preflight were unremarkable. The highly experienced, qualified and professional crew, knowledgeable and extremely comfortable with the aircraft and each other, flew their principal, a flight attendant and three guests from New Castle Airport in Wilmington, Delaware ("KILG") to KBED. They arrived at KBED's fixed base operator ("FBO") at 15:44 after a 48-minute flight. The principal and guests departed the aircraft for a philanthropic meeting. The crew stayed with the parked aircraft, only leaving to order a pizza at the FBO and returned to the aircraft for their supper. As a part of

---

[4] Gulfstream uses the identifiers Pilot Flying ("PF") and Pilot Not Flying ("PNF") in this party submission. The PF was the more junior of the two pilots, is identified as the pilot-in-command ("PIC") in the NTSB factual reports, is listed as the PIC on the flight plan filed with the FAA and was recovered from the left cockpit pilot seat. The PNF was the more senior of the two pilots, was the chief pilot and director of maintenance for the aircraft, is identified as the second-in-command ("SIC") in the NTSB factual reports and was recovered from the right cockpit pilot seat.

post-flight operations, the aircraft's mechanical gust lock system was engaged by pulling the gust lock handle on the cockpit pedestal to its engaged/ON, up and locked detent position. The crew waited on the aircraft for the return of the passengers and the subsequent flight.

The return flight plan was filed at 15:59, with a proposed departure time of 18:30. The flight plan was later updated with the control tower at 19:53 with passengers expected to arrive at 20:45. The passengers arrived at the aircraft at 21:28 and immediately boarded the aircraft. They were greeted at the aircraft by the more senior of the two pilots, who would be the PNF during this takeoff attempt, and the door was promptly closed. Based on the cockpit voice recorder ("CVR"), it is assumed that the crew began a silent pre-flight check of the aircraft at this time. The right engine was started at 21:30 and quickly followed by the left engine start. The gust lock was not released prior to engine start as required by Gulfstream's AFM. The aircraft powered away from its parked position at 21:32 and began taxiing to the start of Runway 11. During the process of embarking the passengers, preparing the aircraft for departure, departing parking position, and taxiing to the beginning of the runway at 21:39, there was no recorded verbal communications or crew coordination between the pilots related to any aircraft pre-flight or checklist activity. Recorded data shows that, as was their custom, the crew did not perform the required and aviation industry-standard control sweeps to confirm that the aircraft flight controls were unimpeded and free to move, at any time prior to attempted takeoff at Vr. This control column sweep is required and typically performed after both engines are started and prior to an aircraft's movement from parked position.

Using the aircraft's nose wheel steering ("NWS") tiller, the crew taxied the aircraft down taxiways Sierra, Tango and Echo and then turned onto Runway 11, all while discussing only taxi operations. During the taxi, the gust lock system remained engaged with the gust lock handle in the up/ON position. There was no crew discussion regarding takeoff speeds or briefing regarding emergency procedures during takeoff.

As the PF turned the aircraft onto the active Runway 11, briefly braking to make the right-hand turn, the aircraft's crew advisory system displayed a blue "advisory message" [**RUDDER LIMIT**]. The PF noticed the message, stating ***"it says rudder limit light is on"***, and the PNF asked if he was using the aircraft rudder, which could explain the blue CAS message. The [**RUDDER LIMIT**] CAS message may have extinguished shortly thereafter as the aircraft concluded its line-up turn, and the PF removed brake pressure by removing his feet from the brake pedals located on top of the rudder pedals. Neither crew member commented on the [**RUDDER LIMIT**] CAS message again, and significantly, given this is an unusual occurrence during ground operations; neither checked the rudder pedals for freedom of movement. Had they, they would have discovered that the pedals were locked by the gust lock system.

Instead of checking the flight control system and halting the takeoff until the gust lock system was properly stowed, the PF immediately continued with the takeoff roll with the gust lock system still engaged where upon the PF encountered another unexpected indication from the aircraft. The throttles were unable to reach the crew's typical high power setting before engaging the autothrottle ("AT") system. For more than 5 seconds, throttle advancement was impeded by the gust lock/throttle interlock. Undeterred by the throttle restriction, and after achieving 41 knots ("kts") of speed, the crew simultaneously engaged the AT system and was able to bypass the interlock.

The AT system reached its 'HOLD' mode 3 to 4 seconds later at 60 kts. During these few seconds of the takeoff roll, the gust lock handle moved from the up and locked position to an intermediate[5] position (i.e. not fully stowed). The handle moved to this intermediate position either through pilot awareness and deliberate movement, or through a gust lock detent pin failure within the handle. In either case, the throttle system was able to reach a higher than expected power level with the gust lock hooks engaged, due to the abnormal handle position. The PF then commented, ***"couldn't get * * * *",*** acknowledging an unusual condition had just occurred. At the same time that the aircraft reached 60 kts, the PNF noticed that the gust lock handle was not fully stowed and attempted to release the handle by pulling it aft and

---

[5] The NTSB Airworthiness Factual report states that the intermediate handle condition can occur if the gust lock handle transitions from the up position toward the down position but the gust lock hooks remain engaged due to contact forces at the gust lock hook/roller interface. Contact forces at this interface can be caused by hydraulic loading from a flight control actuator, manual loading from pilot input, or aerodynamic loading on a flight control surface.

letting it fall forward. This manipulation of the gust lock handle position had the effect of reducing throttle lever position and engine power, as recorded by a "bump" on the power lever angle ("PLA") and engine pressure ratio ("EPR") time histories in the flight data recorder ("FDR"). It is likely that the PF was aware of the PNF's manipulation of the gust lock handle. The gust lock handle remained in an intermediate position and the system hooks still engaged, due to the hydraulic preload. Instead of manipulating the gust lock handle, the takeoff should have been aborted at this time. The aircraft continued to accelerate up to 90 knots, when the PNF made the ***"80"*** knot call.

During this same period, the PF should have, as per training and flight manual guidance on a normal takeoff, confirmed that the control column relaxed into a neutral position from its full forward static condition, as the aerodynamic forces created by the takeoff roll and increasing speeds lifted the aircraft's elevator from its at rest "down" position to a neutral flight condition. Previous takeoff data for this aircraft showed that the elevator regularly began to move toward an aerodynamically neutral position between 60-80 kts. The crew should have aborted upon failure of control column movement.

Instead, having incorrectly assumed they had resolved the gust lock issue, the crew continued the takeoff roll, without comment, through decision speed ("V1") (119 kts) and then Vr (125 kts). At this speed, and with the rudder trim hydraulic preload, the aerodynamic forces acting on the elevator surface were now contributing to the preload on the gust lock hooks, preventing full disengagement. At Vr, the first time the PF attempted to move the control column by pulling it back to achieve rotation, the physical restriction in the flight control system was obvious. The PF quickly attributed the inability to rotate to the gust lock system being still engaged. He stated ***"(steer) lock is on"***, a total of seven times over the next 12 seconds. Still fixated on accomplishing an immediate takeoff, the crew's initial reaction to this unexpected condition was for the PNF to continue troubleshooting the gust lock system instead of immediately beginning an RTO. Within 6 seconds, and four repetitions by the PF that the flight controls remained locked, the PNF pulled the FPSOV handle. This emergency procedure is only appropriate following confirmed freedom of flight control motion checks and is only effective at disengaging a hydraulically-induced flight control issue, as it allows the crew to manually manipulate the flight controls without the assistance (or suspected interference) of the hydraulic system. The FPSOV removed the rudder trim hydraulic actuator input, which had earlier impeded gust lock hook release, but by this time high aerodynamic and pilot input loads (from the pilot pulling aft on the column trying to rotate) prevented the gust lock hooks from releasing.

Following confirmation from the PF that the gust lock remained engaged, the crew began an uncoordinated RTO by first engaging brakes at 11 seconds after Vr and then, an additional 4 seconds later, retarding the aircraft's throttles and deploying the thrust reversers[6]. The aircraft continued beyond the runway where it impacted the unpaved ground below. The impact caused the landing gear to collapse, with the nose and left main gear being ripped away in the soft ground. The fuel tank remained intact without evidence of fuel spillage as the aircraft continued across the unpaved ground where it then contacted runway lights and an antenna array approximately 700 feet from the end of the paved overrun area. This final collision with the concrete-encased antennas compromised the integrity of the fuel tanks. Shortly thereafter, the aircraft crossed an approximately 15- to 20-foot deep ravine, coming to rest spanning a ravine that is over 50-feet wide. The fuel continued to escape and fueled an external fire.

These dynamic crash events allowed significant smoke to enter the cabin causing those passengers and crew not already rendered unconscious by the impact of the crash to be overcome and rendered unconscious by smoke and fumes. The over-wing emergency exits were likely engulfed in external fire when the aircraft finally came to rest, and would not have provided safe egress, as the wings were suspended above the ravine at that time. The forward main entrance door ("MED") mechanism was still functional, as rescue workers were able to operate and unlatch the handle. The MED would have been operable and able to open fully, if not impeded by the surrounding foliage on the far bank of the ravine. Evidence suggests that some passengers and crew were headed to the MED for egress, but were overcome by smoke and fumes before attempting to open the door. The crash resulted in the loss of all passengers and crew, and the destruction of the aircraft by fire, which led to the fuselage collapsing into

---

[6] Analysis indicates that if at the moment the gust lock engagement was first announced by the PF (or even 2.5 seconds after his sixth callout), the RTO had been accomplished in a coordinated manner (that is to say full brakes and power levers to idle simultaneously), the aircraft would have stopped on the paved runway.

the ravine. The cockpit area and part of the tail, which remained on the edges of the ravine and partially shielded from the ensuing fire, remained largely intact with significant smoke and thermal damage.

4.0 GUST LOCK SYSTEM

Gulfstream has provided detailed system descriptions of the gust lock system, which can be found in the NTSB Airworthiness and Certification Factual Reports (References 1 and 2). The sections below are intended to summarize key aspects of the gust lock system and provide additional information for supporting analysis.

4.1 Gust Lock System Description

The gust lock system is designed to lock the primary flight control surfaces on the ground when the aircraft is parked to protect against damage from wind gusts up to 60 mph. The gust lock system is designed such that when it is engaged, all actuator input forces and wind-gust air loads are reacted by the gust lock hooks and supporting structure. The loads are not transmitted back into the other components of the gust lock system.

The gust lock system is mechanically-driven using pushrods, cables, cranks, pulleys, springs and latches[7]. When the gust lock system is engaged, the ailerons and rudder are locked in the neutral (0°) position and the elevators are locked 13° trailing edge down. Springs are integrated that bias the system toward the unlocked position.

The gust lock system is controlled by a two-position red painted gust lock handle located on the copilot's side of the cockpit center control pedestal (see Figures 1 & 2). When the gust lock handle is rotated aft and up to the ON position, the motion moves latching hooks into position to engage and lock the flight control mechanisms. Moving the gust lock handle forward and down to the OFF position releases the gust lock hooks and unlocks the control mechanisms.

The gust lock system also incorporates a gust lock throttle interlock. The throttle interlock limits throttle movement with the gust lock engaged. The interlock stops are incorporated into the power lever sectors and gust lock sector. When the gust lock handle is placed in the locked position, the interlock stops of the power lever sectors and gust lock sector are in close proximity. Placing the rigging pin through the rig pin slot places the interlock stops within 6° ± 1° of each other. Thus when the power levers are advanced the gust lock sector interlock stop restricts power lever movement.

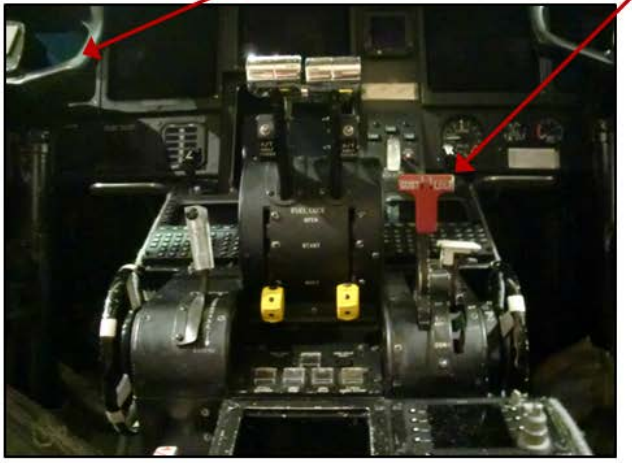


FIGURE 1 – COCKPIT LAYOUT (LOOKING FORWARD)

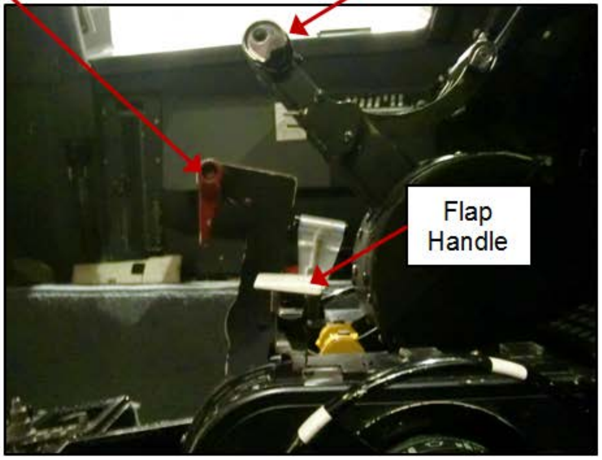


FIGURE 2 – COCKPIT LAYOUT (LOOKING LEFT)

---

[7] The gust lock latches are comprised of hooks that engage rollers on the respective control surface bellcranks.

The gust lock handle is actuated by lifting up on the actuating lever which moves the detent pin out of the link unlock slot position. The handle assembly is rotated at its pivot until the detent pin can be engaged into the slot corresponding to the locked position (see Figure 3).

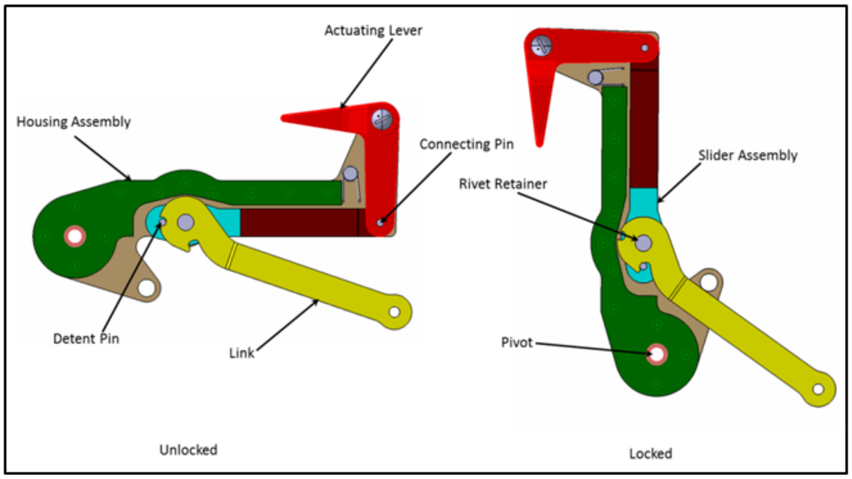


FIGURE 3 – GUST LOCK HANDLE ASSEMBLY

A cable loop system is used to engage the hooks. The cables transmit motion from the forward gust lock handle and sheave in the pedestal to the respective latches in the aircraft fuselage. The cables run throughout the aircraft, engaging and disengaging the aileron, elevator, and rudder gust lock latches (see Figure 4).

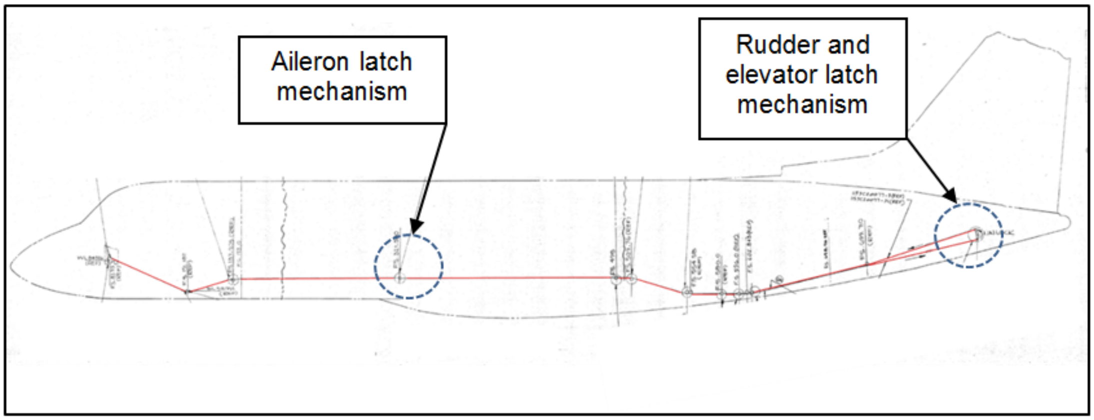


FIGURE 4 – GUST LOCK SYSTEM CABLE LOOP

4.2 Gust Lock System Operation

The gust lock system is intended for ground use only, and due to the mechanical nature of the design, the system requires that the control surface latches only be engaged or disengaged in the absence of hydraulic power. If hydraulic power is present during operation of the gust lock system, small pilot inputs to the control system can command the hydraulically boosted actuators to attempt to move the control surfaces, and as the gust lock latches are trying to restrain the surface, the forces applied to the gust lock control surface latches could be high, and excessive force could result in the inability to engage or disengage the system and/or cause damage to the support structure of the gust lock system. The only approved method for releasing the gust lock system is when the engines are OFF. Further details regarding proper gust lock system operation are provided in Flight Safety International ("FSI") training materials, discussed in Section 6 below.

5.0 AIRCRAFT & CREW BACKGROUND

The accident aircraft was flown by a very experienced crew, current and qualified in the G-IV. Both crewmembers had attended G-IV Refresher training at FSI within the previous year.

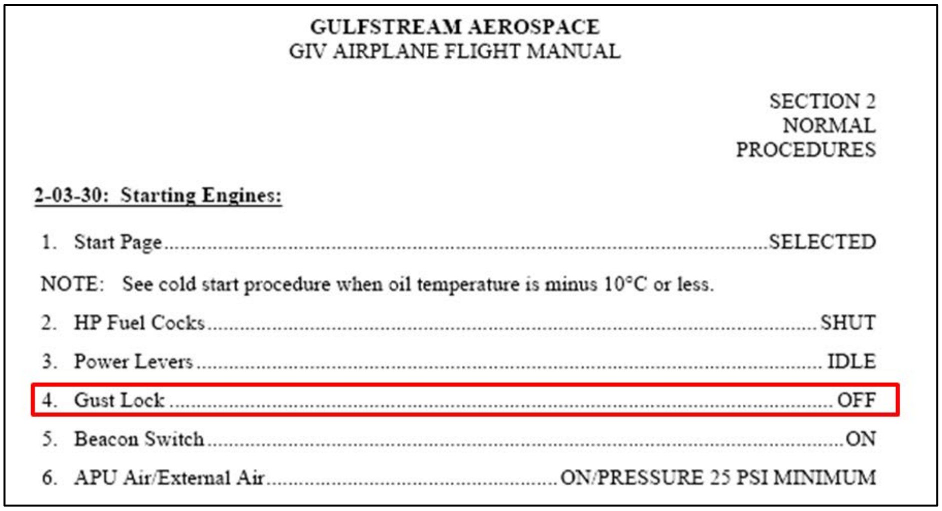
On the accident flight, the PNF, age 61, had 18,530 total flight hours, with 2,800 hours in G-IV airplanes and 4,700 hours in Gulfstream GII & GIII airplanes reported at the time of his recurrent training at FSI, and also functioned as the chief pilot and director of maintenance for the company. The PNF hired the PF, age 44, as a contract pilot who reported at the time of his recurrent training at FSI having 8,275 hours total flight time as pilot-in-command, with 1,400 hours in G-IV airplanes. The PF did not report any second-in-command time. They had been flying together as the main crew in the accident aircraft for the last eight years.

6.0 BEFORE FLIGHT OPERATIONS

The following sections provide a limited discussion of the required flight crew procedures related to the gust lock and flight control systems.

6.1 Gust Lock System Operational Checks

The AFM includes specific instructions for disengaging the gust lock system as part of the engine starting checklist (see Figure 5).



GULFSTREAM AEROSPACE
GIV AIRPLANE FLIGHT MANUAL

SECTION 2
NORMAL
PROCEDURES

2-03-30: Starting Engines:

1. Start Page.......................................SELECTED

NOTE: See cold start procedure when oil temperature is minus 10°C or less.

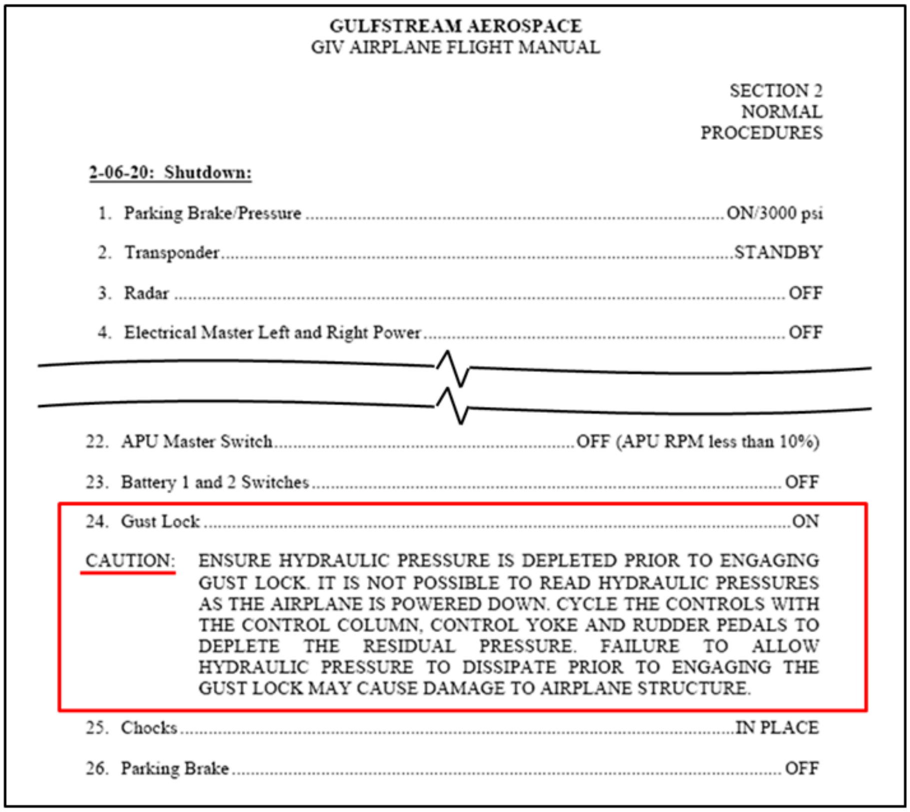
2. HP Fuel Cocks.......................................SHUT
3. Power Levers.......................................IDLE
4. Gust Lock.......................................OFF
5. Beacon Switch.......................................ON
6. APU Air/External Air.......................................ON/PRESSURE 25 PSI MINIMUM

FIGURE 5 – AFM ENGINE STARTING PROCEDURES

The accident scenario demonstrates that the gust lock was never selected OFF and there is no discussion on the CVR that the crew ever attempted to disengage the gust lock system prior to engine start or at any time prior to taxi.

In addition to the flight manual checklist requirement to have the gust lock off prior to engine start, multiple references in Gulfstream literature and FSI literature emphasize the incompatibility of having the gust lock ON and engaged and hydraulic pressure to the flight controls at the same time.

The G-IV AFM, Section 2-06-20: Shutdown: has the following "CAUTION" in association with Step 24. "Gust Lock ……..ON" (see Figure 6):



GULFSTREAM AEROSPACE
GIV AIRPLANE FLIGHT MANUAL

SECTION 2
NORMAL
PROCEDURES

2-06-20: Shutdown:

1. Parking Brake/Pressure .... ON/3000 psi
2. Transponder .... STANDBY
3. Radar .... OFF
4. Electrical Master Left and Right Power .... OFF

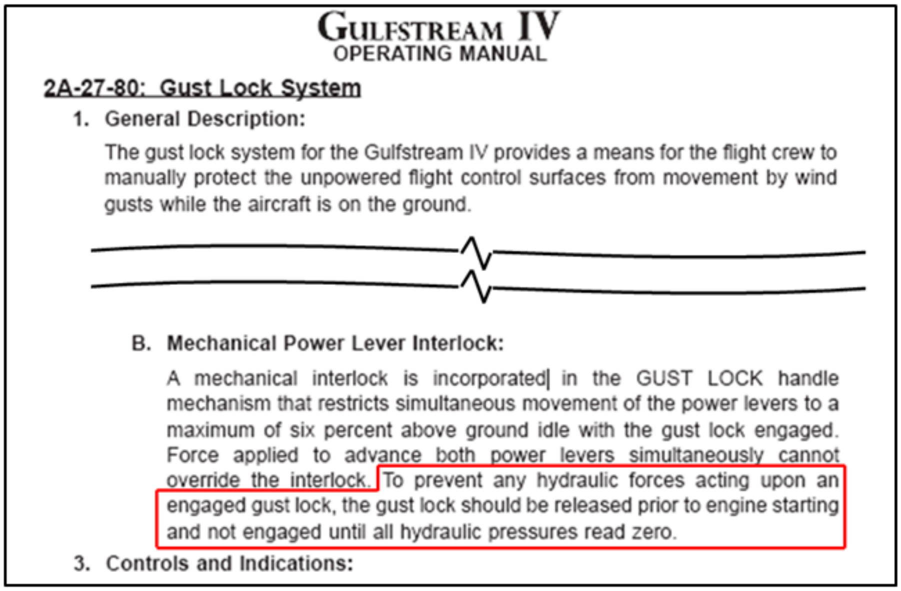
22. APU Master Switch .... OFF (APU RPM less than 10%)
23. Battery 1 and 2 Switches .... OFF
24. Gust Lock .... ON

CAUTION: ENSURE HYDRAULIC PRESSURE IS DEPLETED PRIOR TO ENGAGING GUST LOCK. IT IS NOT POSSIBLE TO READ HYDRAULIC PRESSURES AS THE AIRPLANE IS POWERED DOWN. CYCLE THE CONTROLS WITH THE CONTROL COLUMN, CONTROL YOKE AND RUDDER PEDALS TO DEPLETE THE RESIDUAL PRESSURE. FAILURE TO ALLOW HYDRAULIC PRESSURE TO DISSIPATE PRIOR TO ENGAGING THE GUST LOCK MAY CAUSE DAMAGE TO AIRPLANE STRUCTURE.

25. Chocks .... IN PLACE
26. Parking Brake .... OFF

FIGURE 6 – AFM SHUTDOWN PROCEDURES

The G-IV Airplane Operating Manual (“AOM”), states the following (see Figure 7):



GULFSTREAM IV
OPERATING MANUAL

2A-27-80: Gust Lock System

1. **General Description:**

The gust lock system for the Gulfstream IV provides a means for the flight crew to manually protect the unpowered flight control surfaces from movement by wind gusts while the aircraft is on the ground.

B. **Mechanical Power Lever Interlock:**

A mechanical interlock is incorporated in the GUST LOCK handle mechanism that restricts simultaneous movement of the power levers to a maximum of six percent above ground idle with the gust lock engaged. Force applied to advance both power levers simultaneously cannot override the interlock. To prevent any hydraulic forces acting upon an engaged gust lock, the gust lock should be released prior to engine starting and not engaged until all hydraulic pressures read zero.

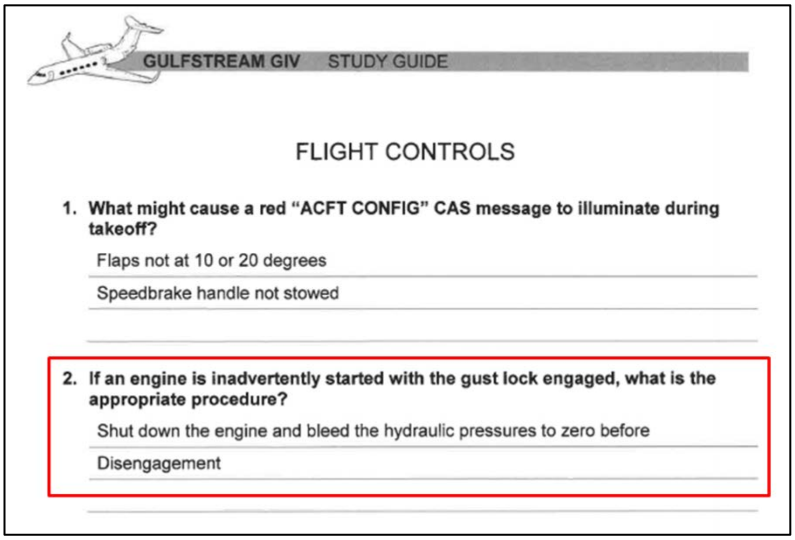
3. **Controls and Indications:**

FIGURE 7 – AOM GUST LOCK OPERATION[8]

---

[8] This AOM reference to “percent” is a manuscript error which should be stated in “degrees”.

FSI training literature also addresses the gust lock. The FSI Gulfstream GIV Study Guide has the following study question (see Figure 8):



GULFSTREAM GIV STUDY GUIDE

FLIGHT CONTROLS

1. **What might cause a red "ACFT CONFIG" CAS message to illuminate during takeoff?**

Flaps not at 10 or 20 degrees

Speedbrake handle not stowed

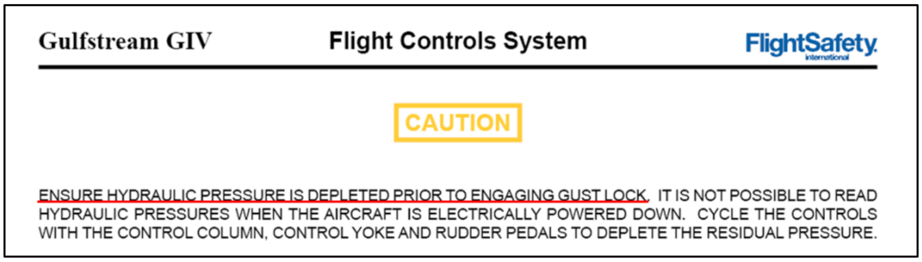
2. **If an engine is inadvertently started with the gust lock engaged, what is the appropriate procedure?**

Shut down the engine and bleed the hydraulic pressures to zero before

Disengagement

FIGURE 8 – FSI GUST LOCK STUDY GUIDE

Also, on the FSI GIV Pilot Training Handbook the following "CAUTION" can be found (see Figure 9):



Gulfstream GIV **Flight Controls System** FlightSafety international

CAUTION

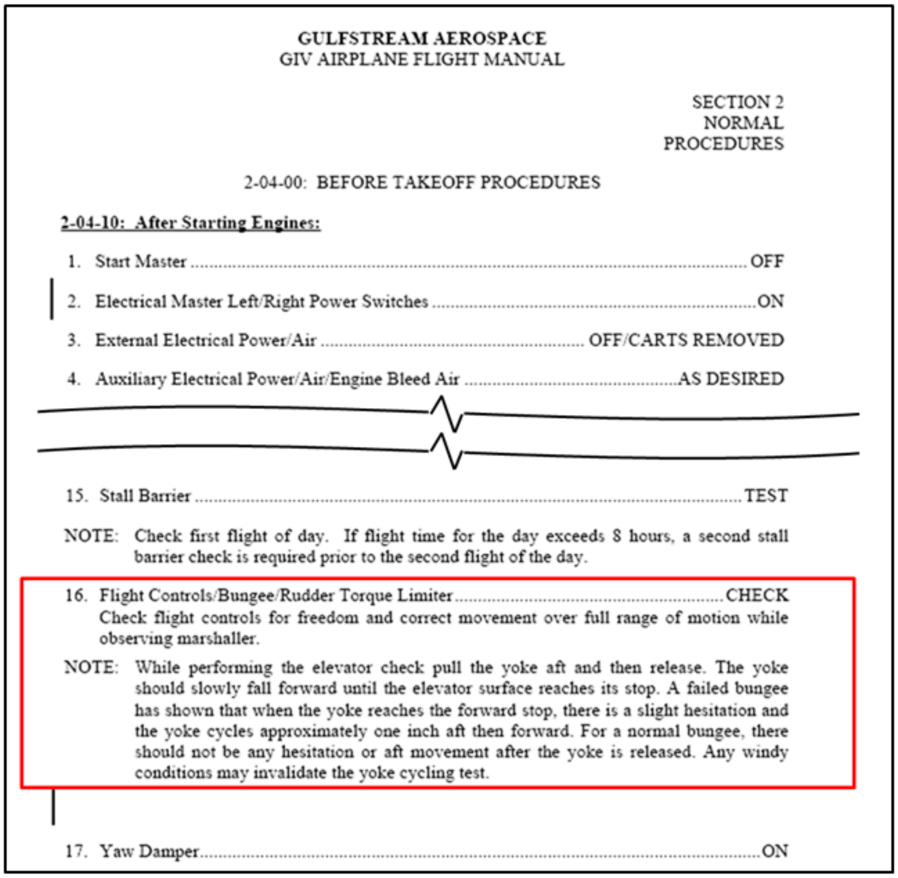
ENSURE HYDRAULIC PRESSURE IS DEPLETED PRIOR TO ENGAGING GUST LOCK. IT IS NOT POSSIBLE TO READ HYDRAULIC PRESSURES WHEN THE AIRCRAFT IS ELECTRICALLY POWERED DOWN. CYCLE THE CONTROLS WITH THE CONTROL COLUMN, CONTROL YOKE AND RUDDER PEDALS TO DEPLETE THE RESIDUAL PRESSURE.

FIGURE 9 – FSI GUST LOCK OPERATION

6.2 Flight Control System Operational Checks

Due to the criticality of the flight control system for takeoff, continued flight and landing, it is essential to verify that the flight control systems are functioning normally following engine start. There are numerous checks defined within the AFM and in the training material, some of which are discussed below.

The AFM includes specific instructions for the flight control system as part of the engine starting checklist. Section 2-04-10, Step 16 reads (see Figure 10):



GULFSTREAM AEROSPACE
GIV AIRPLANE FLIGHT MANUAL

SECTION 2
NORMAL
PROCEDURES

2-04-00: BEFORE TAKEOFF PROCEDURES

2-04-10: After Starting Engines:

1. Start Master .... OFF
2. Electrical Master Left/Right Power Switches .... ON
3. External Electrical Power/Air .... OFF/CARTS REMOVED
4. Auxiliary Electrical Power/Air/Engine Bleed Air .... AS DESIRED

15. Stall Barrier .... TEST

NOTE: Check first flight of day. If flight time for the day exceeds 8 hours, a second stall barrier check is required prior to the second flight of the day.

16. Flight Controls/Bungee/Rudder Torque Limiter .... CHECK
Check flight controls for freedom and correct movement over full range of motion while observing marshaller.

NOTE: While performing the elevator check pull the yoke aft and then release. The yoke should slowly fall forward until the elevator surface reaches its stop. A failed bungee has shown that when the yoke reaches the forward stop, there is a slight hesitation and the yoke cycles approximately one inch aft then forward. For a normal bungee, there should not be any hesitation or aft movement after the yoke is released. Any windy conditions may invalidate the yoke cycling test.

17. Yaw Damper .... ON

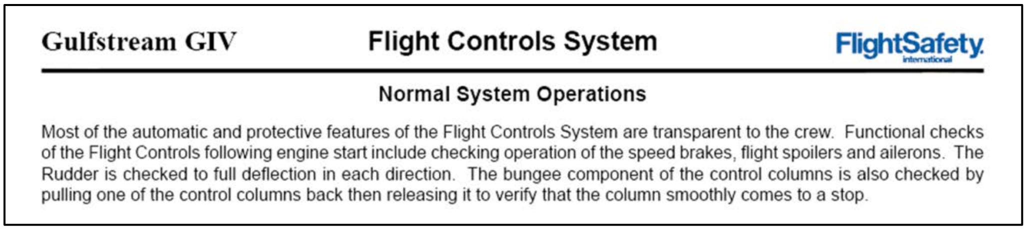
FIGURE 10 – AFM FLIGHT CONTROL CHECK

Although Step 16 is normally performed as a single check, the pilot is actually inspecting multiple systems and observing each control for different results. The rudder torque limiter check is described in the AOM as follows:

> **“WHEN ON THE GROUND WITH THE COMBINED HYDRAULIC SYSTEM OPERATING, RUDDER ACTUATOR LOAD LIMITING CAN BE CHECKED BY APPLYING GRADUAL INPUT FORCE TO THE RUDDER PEDALS UNTIL THE RUDDER SURFACE IS BOTTOMED AGAINST ITS STOPS (LEFT OR RIGHT). THE RUDDER LIMIT ADVISORY CAS MESSAGE WILL BE DISPLAYED AT THE INSTANT OF PRESSURE LIMITING WITHIN THE ACTUATOR. FLIGHT CREWS ARE CAUTIONED THAT BOTH THE GUST LOCK AND NOSE WHEEL STEERING MUST BE OFF BEFORE PERFORMING THIS TEST.”**

These notes clearly explain how the checks are to be performed and what the results of a passing check include. Unlike other checks involving the movement of the flight controls, like the ground spoilers check and the stall barrier check, which are called on in the checklist to be performed as “check first flight of the day,” the flight controls freedom-of-motion check is a mandatory check for each and every flight.

The FSI Pilot Training Handbook also describes what a functional check of the flight controls following engine start should be (see Figure 11).



Gulfstream GIV Flight Controls System FlightSafety International

Normal System Operations

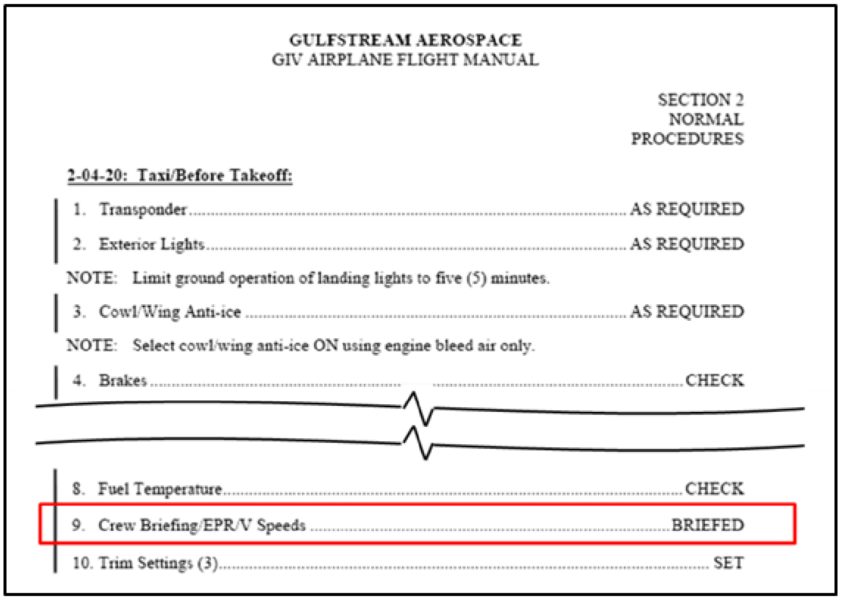
Most of the automatic and protective features of the Flight Controls System are transparent to the crew. Functional checks of the Flight Controls following engine start include checking operation of the speed brakes, flight spoilers and ailerons. The Rudder is checked to full deflection in each direction. The bungee component of the control columns is also checked by pulling one of the control columns back then releasing it to verify that the column smoothly comes to a stop.

FIGURE 11 – FSI FLIGHT CONTROL CHECK

There is direct evidence, recorded in the FDR and quick access recorder ("QAR") data for the accident, that the flight crew did not perform the flight control system check at any time prior to the accident takeoff attempt. Furthermore, evidence from the QAR confirms, that on a regular basis, this crew habitually failed to perform this critical flight control check, as mandated by aircraft manuals and training, to be performed before every flight. Because of this failure to perform this critical flight control check, the crew failed to recognize that their flight control system was locked during taxi and early in the takeoff attempt.

6.3 Takeoff Briefing

The CVR Factual Report (Reference 3) transcript does not show evidence of any kind of a flight or takeoff brief being performed by the crew. A takeoff brief is called for in Step 9 of the AFM (see Figure 12).



GULFSTREAM AEROSPACE
GIV AIRPLANE FLIGHT MANUAL

SECTION 2
NORMAL
PROCEDURES

2-04-20: Taxi/Before Takeoff:

1. Transponder .... AS REQUIRED
2. Exterior Lights .... AS REQUIRED

NOTE: Limit ground operation of landing lights to five (5) minutes.

3. Cowl/Wing Anti-ice .... AS REQUIRED

NOTE: Select cowl/wing anti-ice ON using engine bleed air only.

4. Brakes .... CHECK

8. Fuel Temperature .... CHECK
9. Crew Briefing/EPR/V Speeds .... BRIEFED
10. Trim Settings (3) .... SET

FIGURE 12 – AFM BRIEFING INSTRUCTIONS

This briefing is considered an industry standard practice and expected to be performed even in the most abbreviated form prior to each takeoff. In addition to Step 9 of the AFM briefing instruction, a crew brief typically involves a discussion of normal procedures, abnormal procedures, departure procedures, obstacle clearance/minimum safe altitude, emergency return, and intentions.

Also during this time, the crew normally reviews the performance tables in the AFM to determine required engine power, takeoff speeds, and required runway lengths. As discussed throughout this document, engine power is calculated and represented as a function of the EPR parameter. While the AFM performance tables define the minimum required EPR targets for each takeoff, in the G-IV aircraft, the crew typically uses the performance computer to calculate the takeoff EPR which in turn is used by the AT system to control throttle advancement when selected.

7.0 TAXI

The airplane was taxied via taxiway Sierra, Tango and Echo from the FBO ramp at 21:32, and there were discussions between the flight crew and the control tower with regards to the taxi route, as particular sections of the airfield's taxi routes were closed for maintenance. The exact taxi route and time details provided in the NTSB Aircraft Performance Study (Reference 4) can be seen in Figure 13 below.

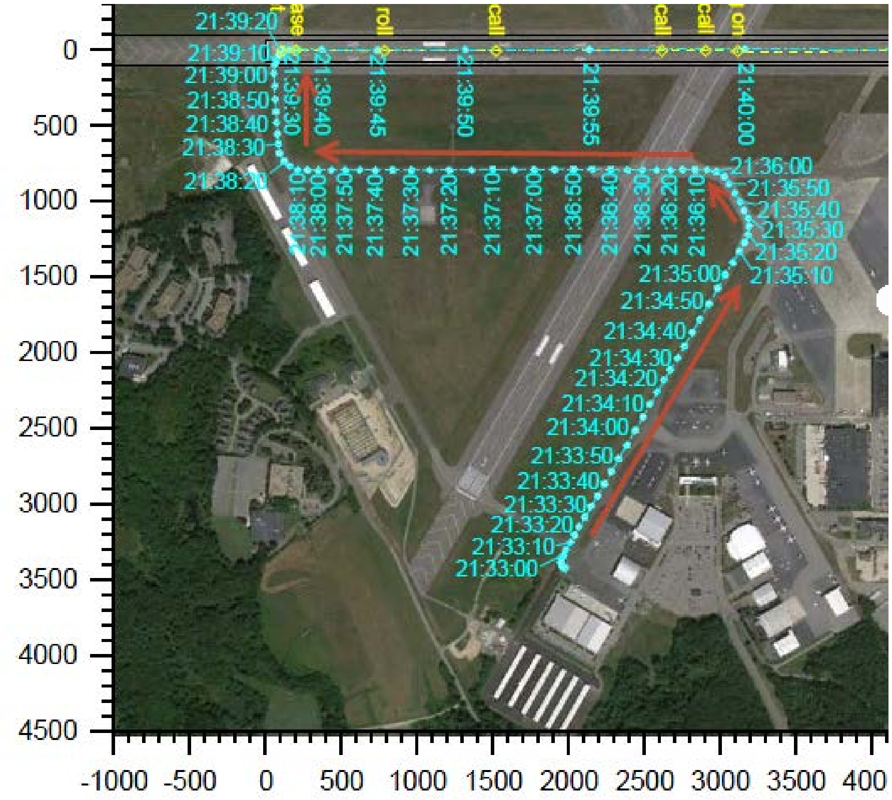


FIGURE 13 – TAXI ROUTE

The following sections review the status of the aircraft systems during taxi and correlate accident data to the aircraft operation.

7.1 Gust Lock System/Handle Status During Taxi

Based on the NTSB FDR Factual Report (Reference 5), Gulfstream has concluded that the gust lock handle was in the up and latched position during taxi, resulting in the gust lock system control surface hooks being locked and the flight control surfaces being restricted in movement.

To verify the gust lock system characteristics during taxi, Gulfstream performed numerous taxi tests on exemplar G-IV aircraft to demonstrate the behavior of the flight control system with:

1) the gust lock system OFF,
2) the gust lock system ON, and
3) the gust lock handle and throttle interlock moved to an intermediate position but with the gust lock control surface hooks remaining locked.

The FDR data from the various tests were compared to the accident FDR data.

Testing with the gust lock system OFF was performed to baseline the flight control system characteristics. These baseline test results showed the normal movement of rudder surface positions during taxi. The FDR rudder surface position data for N121JM, during a previous takeoff attempt, were consistent with these baseline, gust lock system OFF, surface movements.

With the gust lock system ON, testing repeatedly demonstrated that an up/latched gust lock handle would always maintain the flight control surfaces in a locked state during taxi as would be expected from its design.

Gulfstream ground taxi tests also demonstrated that positioning the gust lock handle to an intermediate position, while maintaining the control surfaces in a locked state, required a constant input to one or more of the flight controls, or by the use of the rudder trim function to provide a preloading force into the rudder gust lock control surface hook. The gust lock handle, preloaded in an intermediate position via the flight control system, would always release to the fully down (control surfaces unlocked) condition during low speed taxi operations with turns, due to rudder/yaw damper inputs.

These findings demonstrate that the gust lock was in the fully ON position during taxi.

7.2 Limited Rudder Movement during Taxi

With the gust lock handle in the up and latched position, the gust lock system control surface latches would be locked, and the rudder control surface would be mechanically limited to prevent gusts from moving the surface. The G-IV directional control system is designed to allow up to 22.5 degrees of left or right rudder under normal operations; however, with the gust lock system engaged, the rudder motion would be restricted to a 2 degree band of movement. Gulfstream performed ground and taxi tests with exemplar G-IV aircraft to validate rudder freedom of motion with gust locks engaged (see References 6 and 7).

During normal taxi operations, the crew can use manual inputs to the NWS tiller, mounted on the LH side console, to steer the aircraft. Even while using the NWS system, rudder movements during taxi are expected from random aircraft vibrations and from the yaw damper. The yaw damper system attempts to compensate for changes in aircraft yaw attitude by commanding rudder deflections in the opposite direction (to maintain intended flight path). Even with the gust lock system engaged, Gulfstream taxi testing showed that rudder movement is possible, although with a very limited range (see Figure 14).

Based on the NTSB FDR Factual Report, the accident aircraft utilized rudder travels that range from a 4 degree total band during the previous taxi, to a 7 degree band during the previous successful takeoff (see Figure 15). However, during the accident aircraft's attempted takeoff, the rudder travel was within a 2 degree total band during taxi, attempted takeoff, and during the rejected takeoff (see Figure 16). This limited rudder movement is additional evidence that the gust lock was engaged during this timeframe.

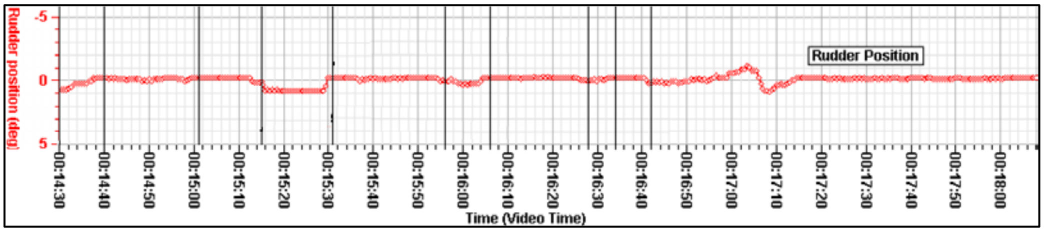


Figure 14 – Rudder Position (Gust Lock ON Taxi Test)

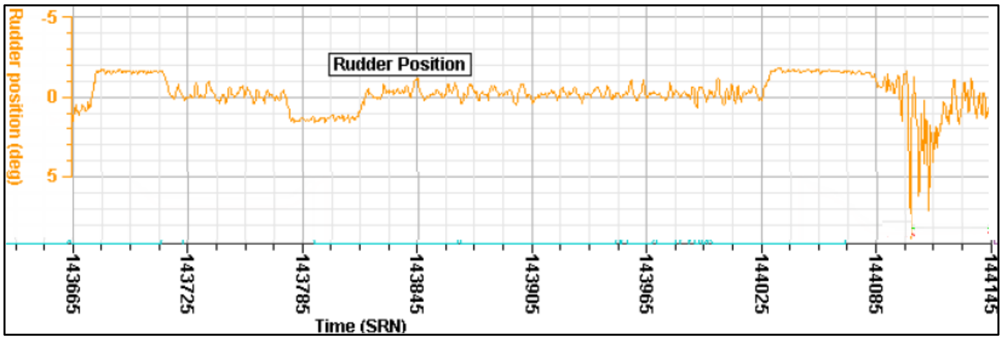


Figure 15 – Rudder Position (Previous Takeoff Cycle)

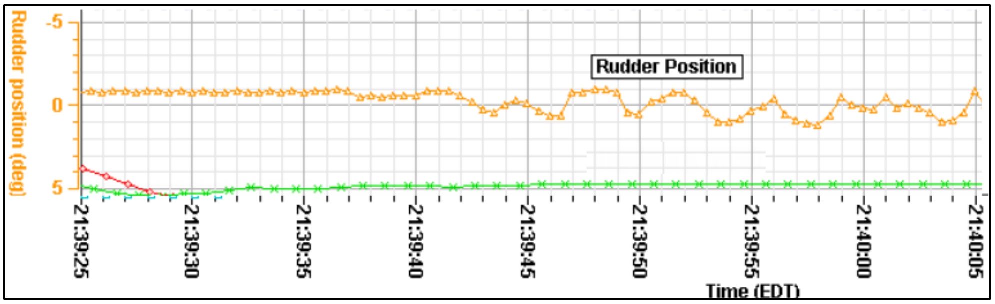


Figure 16 – Rudder Position (Accident Takeoff Cycle)

7.3 Rudder Limit CAS Message

As the aircraft transited through the final taxiway, it made its final turn onto Runway 11. In order to control their speed for the ~90 degree turn, the crew applied brake pressure. The right brake pressure was noted in the accident FDR as being higher than the left. Coincident with the right turn and the differential brake pressure, the crew received a blue advisory [**RUDDER LIMIT**] CAS message, as documented in the CVR Factual Report.

[21:39:21.1] PF: "It says the rudder limit light is on."
[21:39:23.9] PNF: "What's that?"
[21:39:24.7] PF: "The rudder limit light is on."
[21:39:26.4] PNF: "Are you using your rudders?"
[21:39:27.8] Unknown: "No * *."
[21:39:31.1] Unknown: "Huh."

Quotation 1 – Rudder Limit Message Discussion (CVR Transcript[9])

---

[9] Per the NTSB CVR Factual Report, asterisks (" * ") represent an "unintelligible word".

To limit the output force from the rudder actuator, and protect the structure from excessive loads, the G-IV rudder control system includes devices to limit the output force capability. For crew awareness of any rudder actuator output force limiting activity, the rudder limiting devices annunciate this as a blue [**RUDDER LIMIT**] CAS message.

On the ground, the [**RUDDER LIMIT**] CAS message would normally only be displayed if the flight crew were commanding maximum rudder surface displacement (approximately 4 inches of pedal movement), such that the control surface has reached its mechanical stop (22.5 degrees left or right). The AFM requires crews to exercise the rudder system to its full mechanical displacement during preflight and to look for the blue CAS message once the stops are reached.

Since the gust lock system remained engaged throughout taxi, slight rudder input command had the potential to increase rudder actuator cylinder pressure high enough to activate the [**RUDDER LIMIT**] CAS message. Rudder input commands could have been generated from yaw damper system activity or inadvertent rudder pedal application. During the 7-minute long taxi route, the aircraft made several left- and right-hand turns, which could have resulted in a yaw damper input and subsequent CAS message activation at any point during the taxi. However, the data is inconclusive to determine if the CAS message displayed prior to the final turn. The crew discussion on the CVR is the only indication that the message activated.

As documented in Gulfstream test reports (References 6 and 7), Gulfstream performed multiple taxi tests with the gust lock engaged. In addition to direct rudder pedal input commands, the tests repeatedly confirmed that the yaw damper system alone is capable of activating the CAS message. With the gust lock engaged, and only using NWS, the tests made several left and right 90-degree turns, up to a maximum speed of 30 kts. Upon entering a turn, the yaw damper system would sense the difference in aircraft acceleration and heading versus rudder position and command a new rudder position to compensate. This rudder command, being opposed by the gust lock, would increase rudder actuator pressure and cause the CAS message to be displayed.

The brake and rudder pedals in the G-IV aircraft are attached to the same mechanism and both are manipulated by the pilot’s feet. During N121JM’s final 90-degree turn onto the active runway, the differential pressure between the left and right brakes was roughly 300 psi (see Figure 17). Gulfstream has concluded that either: 1) the uneven pedal position during brake pressure application resulted in inadvertent rudder pedal input or 2) yaw damper activation during the turn caused some amount of rudder input. With the gust lock engaged, only minimal rudder input is required before the rudder actuator reaches its internal pressure limit and the [**RUDDER LIMIT**] CAS message is displayed. While the PNF asked the PF if he was on the rudder as the first sign of troubleshooting, no further actions appear to have been taken and the crew did not perform a rudder control check. A simple check of the rudder control pedals in response to this CAS message would have demonstrated that the gust lock was engaged and the flight controls were locked, and the takeoff should have been abandoned. This discussion on the blue advisory message over a 10-second period indicates that the crew understood this was an abnormal message at this phase of airplane operation, and the crew’s failure to follow up demonstrates poor CRM.

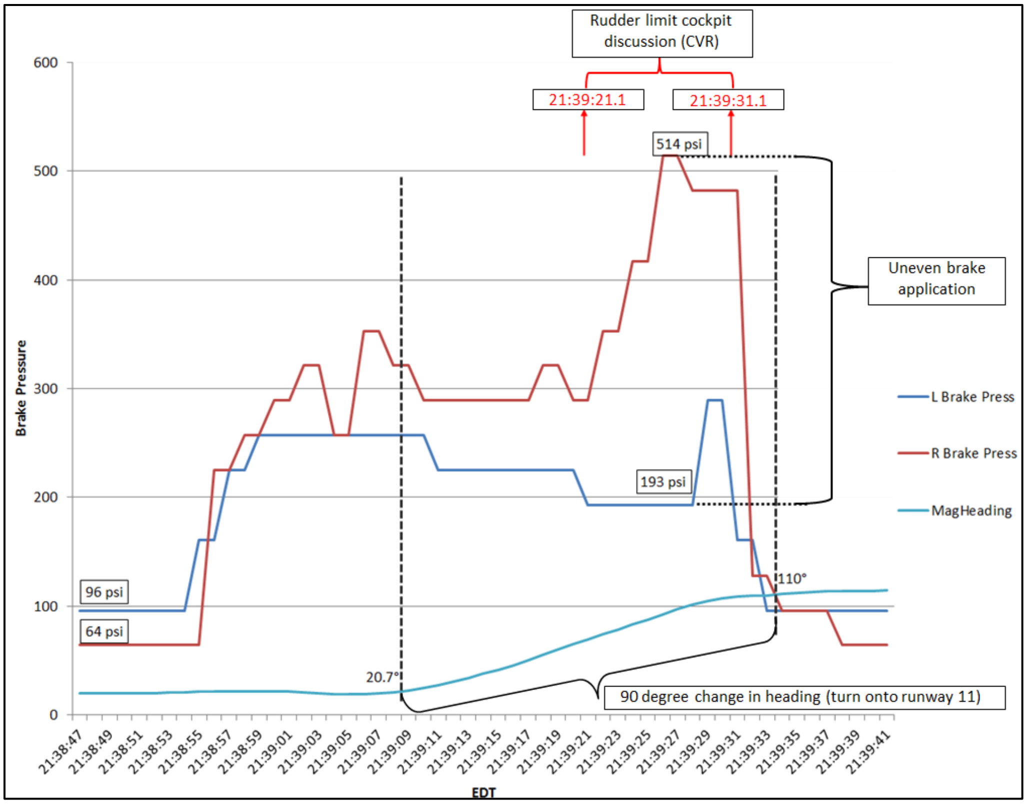


FIGURE 17 – ACCIDENT BRAKE PRESSURE RISE WITH RUDDER LIMIT CAS MESSAGE

8.0 TAKEOFF ROLL – PRE Vr

Other than one statement by the PF that he ***"Couldn't get * * * *"***, the CVR provides little insight into the crew's actions from the beginning of the takeoff roll until the PF unsuccessfully attempted to rotate the aircraft at Vr. The FDR plot of the PLA and EPR, parameters provide the most insight into the status of the gust lock system and the crew's awareness of that status (see Figure 18). The following sections discuss the most probable explanation of the pertinent FDR parameters based upon extensive testing and analysis.

The accident FDR data are split into different segments in an effort to explain the activity occurring in the cockpit during this critical phase of takeoff. The segments are chronologically organized as follows:

- Initial PLA/EPR Plateau: An initial period of constant PLA and EPR, between brake release and AT engagement, during manual throttle command.
- Peak PLA/EPR: The PLA and EPR parameters reach a momentary peak.
- Reduction in PLA/EPR: The PLA and EPR suddenly reduce when power should be increasing.
- Low EPR thru Vr: The reduced PLA and EPR remain in their reduced state thru Vr. The 80 kt call occurs during this segment.

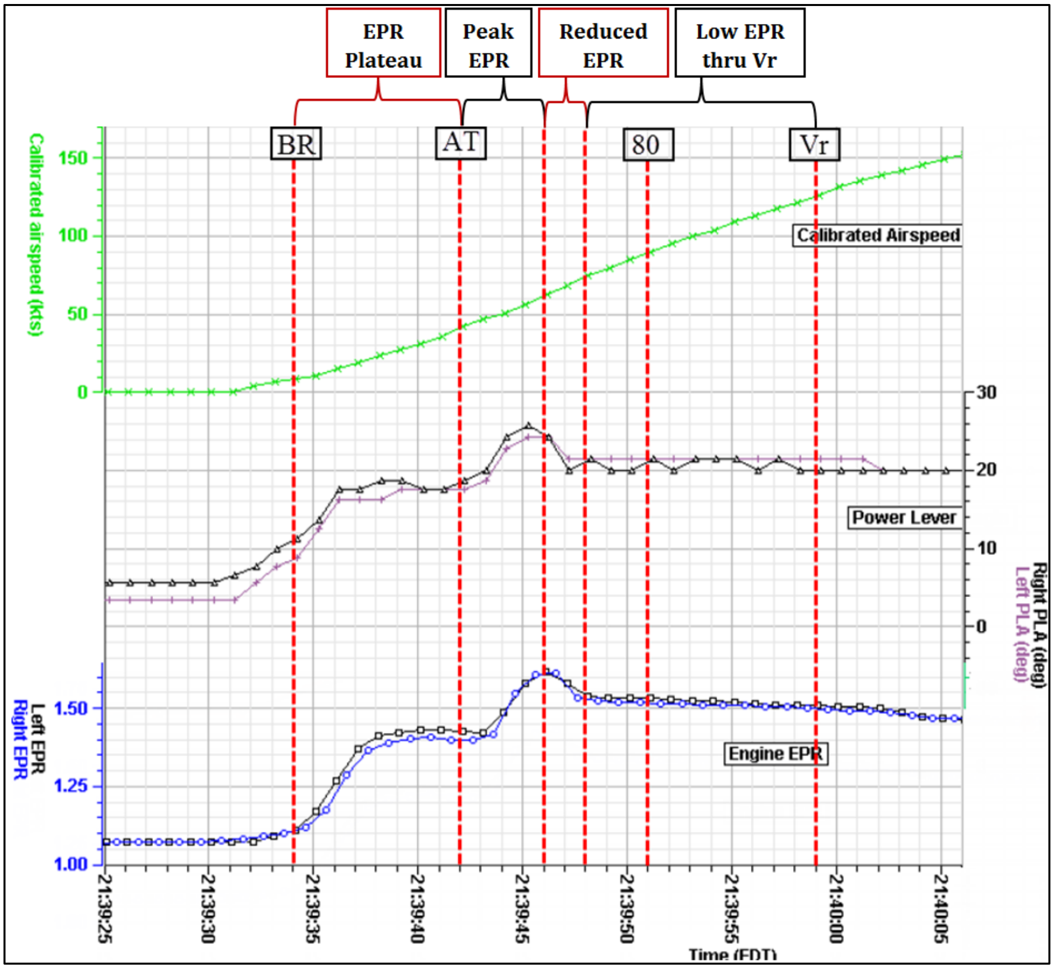


FIGURE 18 – FDR TAKEOFF ROLL (PRE VR)

8.1 Initial PLA/EPR Plateau

Based on the data provided in the NTSB FDR Factual Report, the throttles were advanced manually, achieving an initial EPR of approximately 1.4 about 5 seconds after brake release. The corresponding initial PLA achieved at this time was approximately 17.5 degrees, according to the FDR data.

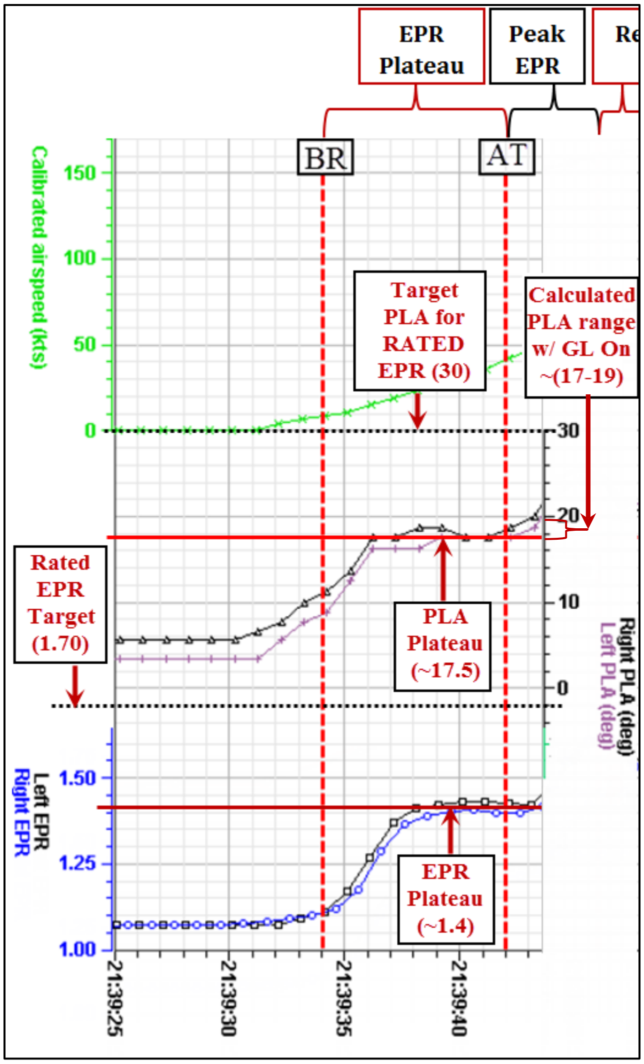


FIGURE 19 – PLA & EPR PLATEAU (PRE-AT ENGAGEMENT)

8.1.1 Calculated Throttle Interlock Position

To assess the accident aircraft's throttle interlock capability, the NTSB performed post-accident testing on N121JM's pedestal using a spare gust lock handle. With the spare handle installed, the maximum throttle movement achieved, with the gust lock handle in the up and latched position, was 22 degrees throttle lever angle ("TLA"). Based on information supplied by AT manufacturer Honeywell, TLA values are larger than PLA values by a nominal factor of 1.159. This nominal conversion factor would result in a theoretical maximum PLA of 18.98 degrees, for the 22-degree TLA mentioned above.

Based on post-accident company testing at Gulfstream, PLA was recorded on an additional four aircraft which demonstrated a PLA to TLA conversion factor varying between 1.148 and 1.413. The lowest conversion factor provides for the maximum possible PLA. Therefore, using the lowest conversion factor that Gulfstream observed (1.148) results in a possible maximum PLA of 19.16 for the fully functional gust lock handle with an intact gust lock handle detent pin, in the up/latched position for the same 22 degrees TLA mentioned above. Alternatively, using the average conversion factor observed (1.280), the possible maximum PLA would be 17.18 degrees.

Hence, the TLA of 22 degrees measured on the accident aircraft can correspond to a PLA ranging from 17-19 degrees, which is consistent with the recorded PLA on the accident aircraft (17.50/18.75 degrees left/right PLA) at the plateau. This demonstrates that it is very likely for the accident aircraft throttles to have been restricted by the gust lock interlock during this phase of flight.

8.1.2 Throttle Advancement Technique

QAR data for the ten previous takeoffs was provided by the NTSB (Reference 20). The prior ten takeoffs demonstrate the crew's[10] typical throttle advancement technique (manual advancement of the throttles to RATED EPR and subsequent AT engagement). Figure 20 overlays the previous takeoffs with the accident takeoff attempt, aligning each graph around the 60 kts calibrated airspeed ("KCAS") line (when the AT 'HOLD" mode activated). The timing and achieved PLA at AT engagement can be compared for each graph.

---

[10] The aircraft flight log (NTSB Operations Factual Report Attachment 8) indicates that the same crew piloted these ten flights in addition to the accident takeoff attempt.

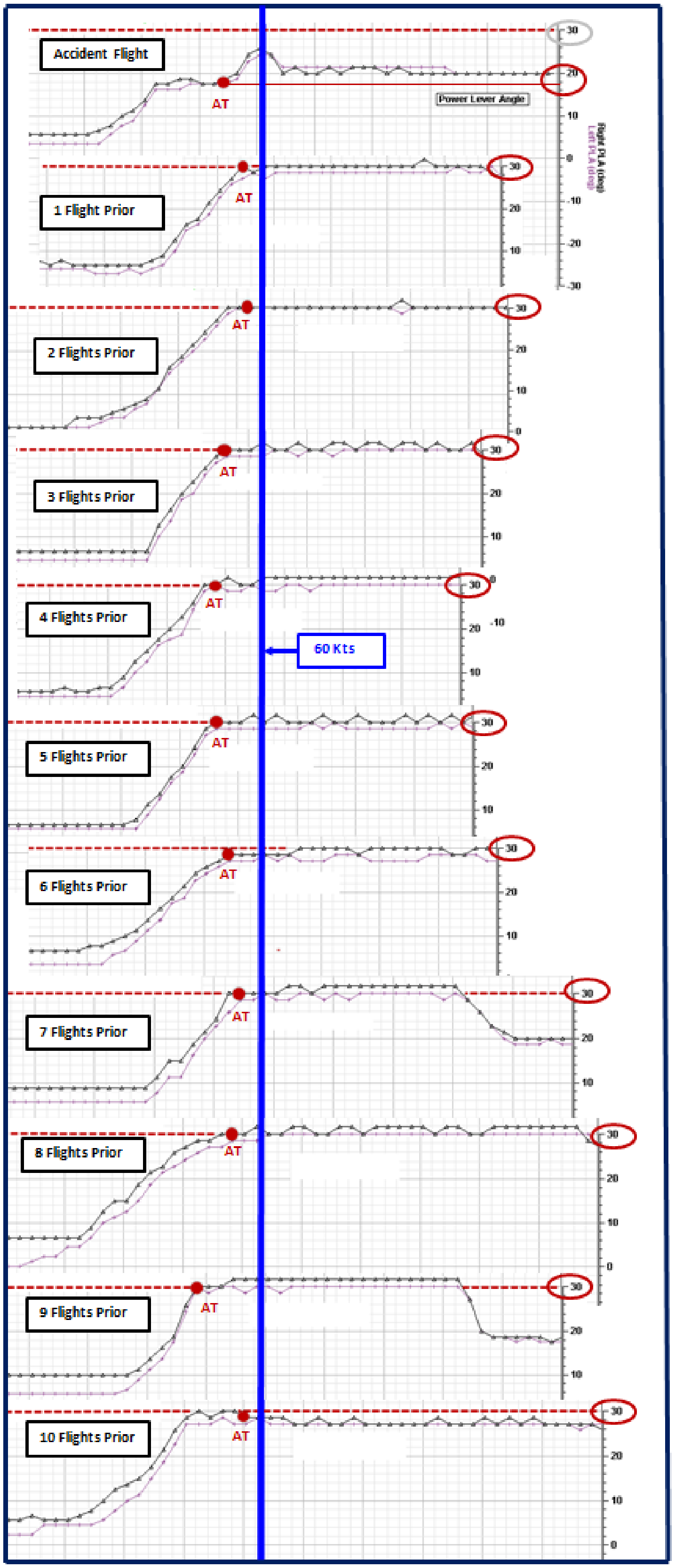


FIGURE 20 – CREW THROTTLE ADVANCE TECHNIQUE-PLA VS. TIME (FDR ADDENDUM #2)

8.1.3 Plateau Analysis

As can be seen in Figure 19 above, the PLA reached 17.5 degrees and the initial EPR value of 1.4 was held for approximately 5 seconds (“PLA/EPR plateau”), after which time the AT was engaged. This PLA value is consistent with the calculated PLA values for an up and locked gust lock handle (17.18 to 18.98), indicating that the throttle levers are being restricted by the gust lock/throttle interlock.

Review of QAR data for the ten previous flights demonstrates that the crew always advanced throttles to achieve RATED EPR (approximately 30 degrees PLA) at a constant rate, without stopping at any intermediate throttle position. On the accident takeoff attempt, they reached the throttle interlock restriction early in their advancement of the throttles. This unexpected and prolonged restriction at a low power setting should have been recognized by the PF as a clear physical warning of limited aircraft capability. Seconds later, the PF stated ***“couldn’t get * * * *”***, strongly suggesting that the PF was aware of the throttle limitation.

It should also be noted that the timing of the AT activation, unlike the previous ten takeoffs, occurred during this period of low PLA/EPR setting. On those previous takeoffs, AT was never engaged until the target PLA/EPR had already been achieved.

8.2 Peak PLA/EPR

As can be seen in Figure 21 below, the initial PLA/EPR plateau was exited at 21:39:43, coincident with the engagement of the AT. The PLA/EPR subsequently reached a peak of 25.71 / 1.62 approximately 4 seconds later. The aircraft reached the peak PLA/EPR at 60 knots, at which time the AT entered ‘HOLD’ mode.

The AT system is designed and has been demonstrated to disengage in the presence of excessive resistance to motion, including contact with the gust lock/throttle interlock when the gust lock handle is in the up and latched position. During testing (Reference 9) with the gust lock engaged, when larger EPR values were targeted by the AT system, the AT would disengage even faster when contacting the interlock. In the accident takeoff attempt, the ATs were engaged at an EPR of 1.4 and targeting a RATED EPR value of 1.70. They did not disengage during this time. With the ‘HOLD’ mode engaged at 60 kts, by design, the AT system removed electrical power to the AT servos while keeping the AT servo clutches engaged.

Gulfstream has concluded that the engagement of the AT was an attempt to achieve the target EPR, and it is at this point that the gust lock handle was released to an intermediate position by either the flight crew manual input, forced by the AT, or a combination of AT and manual throttle advancement. The last two scenarios involving AT or combination of manual and AT engagement, would only be possible if there were further deformation or damage to a previously compromised gust lock handle detent pin (see NTSB Airworthiness Factual Report & Materials Laboratory Factual Report (Reference 8) for further details of the damaged pin).

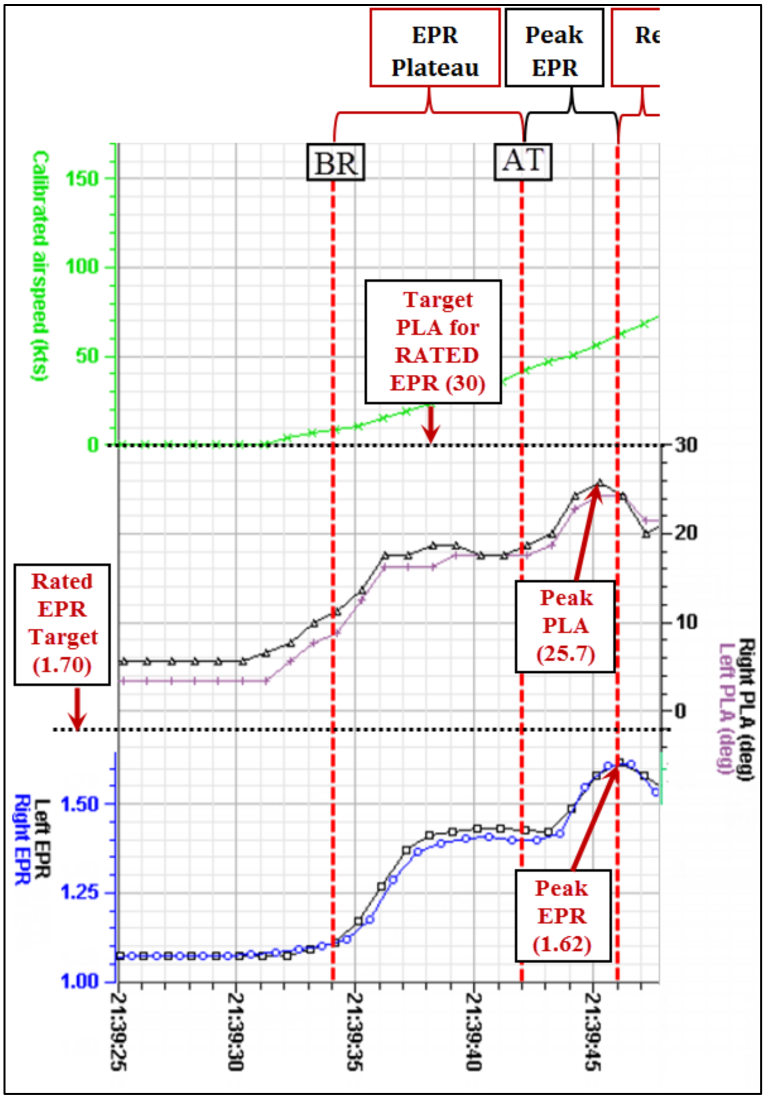


FIGURE 21 – PLA & EPR PEAK (POST-AT ENGAGEMENT)

8.3 Reduction in PLA/EPR

Based on the data provided in the NTSB FDR Factual Report, the AT engagement occurred just 10 to 20 knots short of the required airspeed at which AT 'HOLD' automatically engages. This resulted in the AT system having approximately 4 seconds to advance and achieve the target EPR before 'HOLD'. As can be seen in Figure 22 below, the AT system briefly achieved a PLA/EPR of 25.71/1.62, but then reduced to a stabilized PLA of 21.4 and an EPR of 1.53. An EPR of 1.53 is below the minimum EPR expected for a FLEX or RATED[11] EPR takeoff.

---

[11] Gulfstream literature uses the term 'RATED' and 'MIN' EPR interchangeably to define the EPR required to perform a maximum thrust takeoff, as prescribed in the performance section of the AFM.

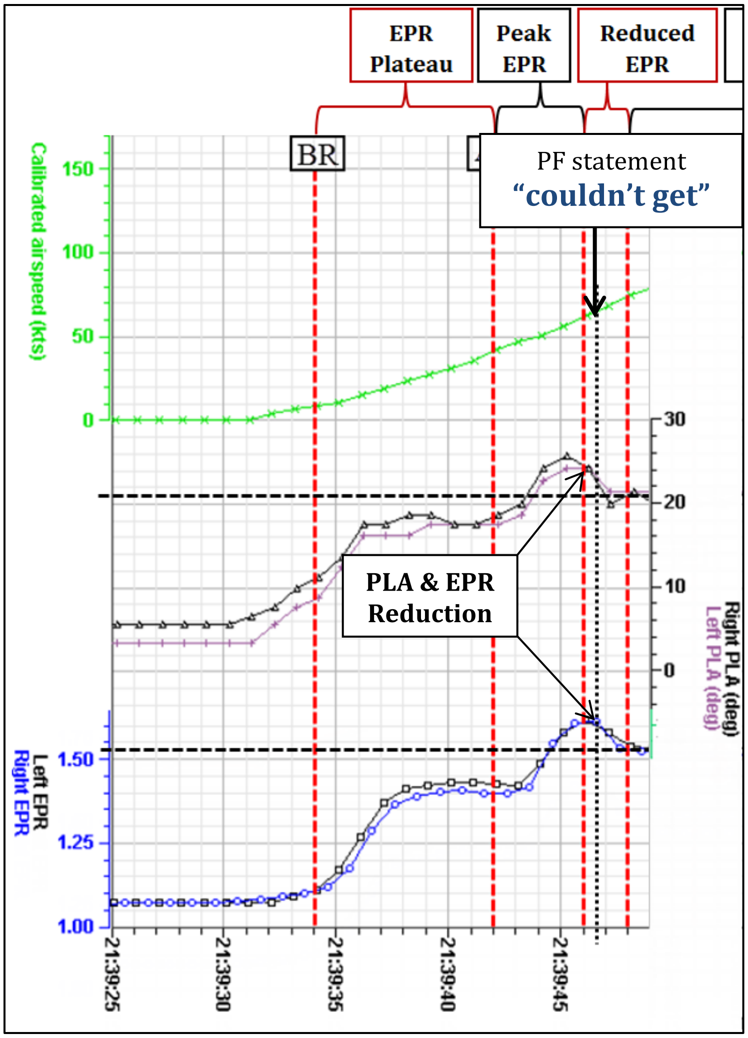


FIGURE 22 – PLA & EPR REDUCTION

Based on the data provided in the NTSB FDR Factual Report, and per its intended function, the AT 'HOLD' mode was engaged at 60 KCAS on the accident aircraft takeoff attempt. At this time, the AT system removed electrical power to the AT servos while keeping the AT servo clutches engaged. Per aircraft design, the AT system maintained the EPR achieved at that time. By design, the AT system does not input any commands that alter the EPR levels at this point, however any physical movement of the throttles, including movement induced by abnormal gust lock handle position and aft manipulation, will change the PLA and EPR.

Gulfstream testing, documented in Reference 9 simulated the accident conditions and was able to achieve a reduction in EPR of this magnitude only by a manual input to the gust lock handle, which due to the throttle interlock would also move the throttles. Direct movement of the throttles would have the same effect, but it is very unlikely that a crew member would reduce throttles at this point in the takeoff. Figure 23 below shows the results of the Gulfstream test (Reference 19), in which the gust lock handle is moved to an unlatched/intermediate position, the autothrottles engaged, and then the gust lock handle pulled aft in an attempt to release the gust lock mechanism. The peak in PLA/EPR can be clearly seen, as well as the subsequent reduction in PLA/EPR. During this test, the gust lock mechanism did not become released until the aircraft was turning onto the taxiway at the end of test.

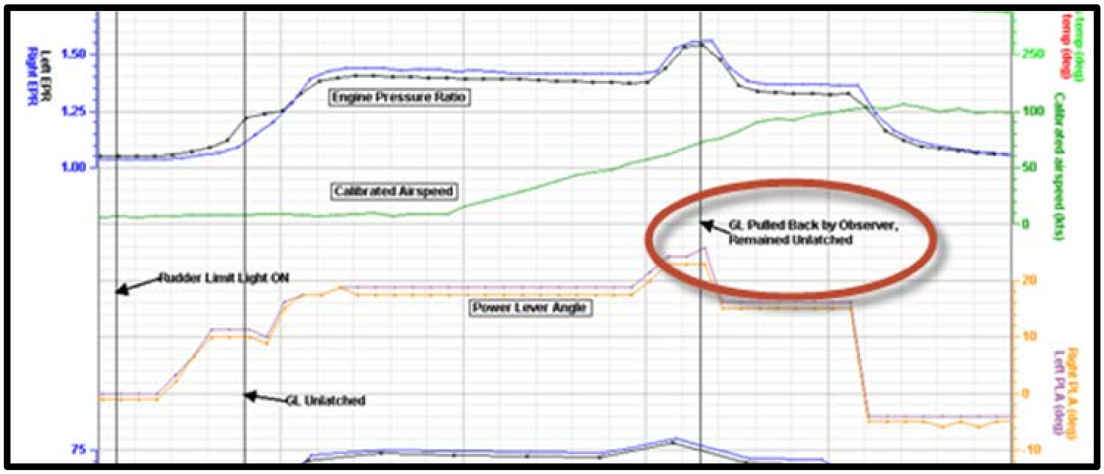


FIGURE 23 – RECREATED PLA/EPR REDUCTION (GUST LOCK PULL BACK TEST)

Gulfstream has concluded that the PNF was likely moving the gust lock handle in the aft direction in an attempt to release it from its position. In tandem with the AT system being in 'HOLD' mode, this aft movement of the gust lock handle resulted in the reduction in throttle position, which due to being in 'HOLD' mode, remained constant until the throttles were reduced when the takeoff was aborted.

8.4 Low EPR through Vr

While Gulfstream does not know with certainty if the crew intended to use a target of FLEX or RATED takeoff EPR (RATED EPR=1.70, FLEX EPR=1.59), an NTSB review of QAR data for previous takeoffs noted that the crew consistently set a RATED EPR target for takeoff. Additionally, at the time of the accident, there were no operational restrictions in place at the airfield requiring FLEX EPR. The NTSB Aircraft Performance Study goes on to discuss the accident target EPR as follows:

> **"THESE SPEEDS DO NOT MATCH THE FDR SPEEDS AT THE TIMES OF THE CVR CALLOUTS AS CLOSELY AS THE "FULL THRUST" TAKEOFF SPEEDS MATCH THE FDR SPEEDS. IN ADDITION, IT SHOULD BE NOTED THAT THE EPR VALUES FROM BOTH ENGINES RECORDED ON THE FDR ARE CONSISTENTLY BELOW BOTH THE MIN EPR AND FLEX EPR VALUES SPECIFIED ABOVE (SEE FIGURES 5 & 6), EXCEPT FOR THE BRIEF PEAK AT 21:39:46, WHERE THE EPR'S MOMENTARILY REACH 1.62."**
>
> **QUOTATION 2 – ACCIDENT EPR TARGET (NTSB PERFORMANCE REPORT)**

Based on this information, it is reasonable to conclude that the crew was targeting a RATED EPR of 1.70 for this takeoff. The FDR data shows that the peak EPR of 1.62 was reached at about 62 knots, but by 70 knots and less than 2 seconds later, it had reduced to 1.53. As previously noted, the crew likely acknowledged the difficulties in achieving EPR, but there is no subsequent evidence in the CVR of the crew either verbalizing or noticing the power reduction. There is also no indication on the FDR of any action being taken to correct the low EPR by disconnecting the AT system and manually increasing power. Figure 24 below shows the data from the FDR and the absence of PLA inputs.

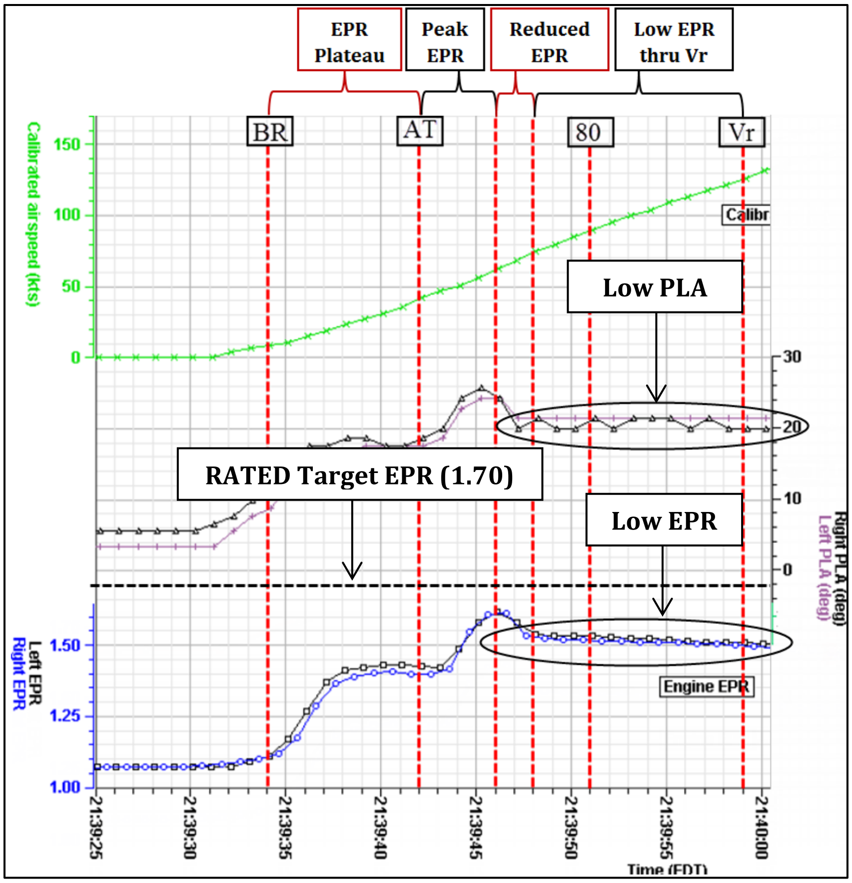


FIGURE 24 – STABILIZED PLA/EPR BELOW MINIMUMS

The following set of pictures show the EPR power setting differences between what the crew should have expected to see for RATED EPR takeoff settings vs. the achieved sustained EPR. The desired value is digitally shown on the engine instrument and crew alerting system (EICAS) display panel as a green number and the actual EPR is shown as a white number.

Figure 25 shows what the EPR thrust indications would look like if the crew had selected RATED EPR as the takeoff power EPR setting and actually achieved it.

Figure 26 shows what the crew would have seen at the momentary peak EPR (1.62) compared to the 1.70 RATED EPR target.

Figure 27 shows what the crew would have seen at stabilized EPR values (1.53) compared to the 1.70 RATED EPR target.

FIGURE 25 – EXAMPLE RATED EPR TARGET BEING ACHIEVED

FIGURE 26 –SIMULATED MOMENTARY ACCIDENT PEAK EPR VALUE BEING ACHIEVED

FIGURE 27 – SIMULATED STABILIZED ACCIDENT EPR VALUE NOT REACHING RATED EPR TARGET

Aircraft performance tables are based on either a FLEX or RATED EPR target for takeoff. Failure to achieve the targeted EPR extends the runway length necessary to attain the required takeoff speeds. This reduces the runway available in the event of an aborted takeoff, making monitoring of the target EPR essential. Per the FSI Pilot Training Handbook, Standard Maneuvers and Callouts, at 60 kts, the PNF is directed to note when actual EPR matches target EPR and the autothrottle mode indicates 'HOLD' and to state "POWER SET".

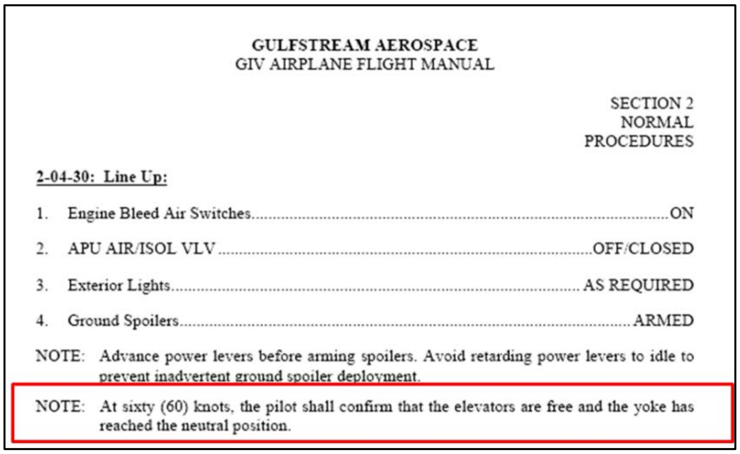
If actual EPR does not match target EPR, the PNF is directed to state "EPR LOW, INCREASE POWER".

The PNF monitoring EPR did not make either of the callouts, although the displays in the figures clearly illustrate that the achieved EPRs are well below a RATED EPR of 1.70. There is no evidence on the CVR of the crew either verbalizing or noticing this power reduction. There is no evidence on the FDR of any action being taken to correct it by disconnecting the autothrottles and manually increasing power.

8.5 Freedom of Motion Check at 60 - 80 kts

8.5.1 AFM Instructions at 60 kts

The AFM contains additional notes following Step 4 in Section 2-04-30 that call for a specific check to be performed by the pilots during the takeoff run (see Figure 28). The FDR shows there is no elevator control surface movement at 60 kts.



GULFSTREAM AEROSPACE
GIV AIRPLANE FLIGHT MANUAL

SECTION 2
NORMAL
PROCEDURES

2-04-30: Line Up:

1. Engine Bleed Air Switches.......ON
2. APU AIR/ISOL VLV.......OFF/CLOSED
3. Exterior Lights.......AS REQUIRED
4. Ground Spoilers.......ARMED

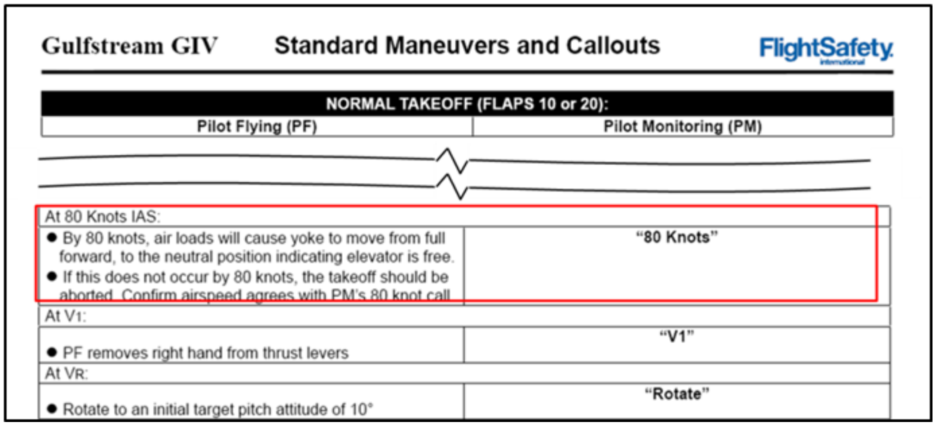
NOTE: Advance power levers before arming spoilers. Avoid retarding power levers to idle to prevent inadvertent ground spoiler deployment.

NOTE: At sixty (60) knots, the pilot shall confirm that the elevators are free and the yoke has reached the neutral position.

FIGURE 28 – AFM 60 KT FCS CHECK

8.5.2 FSI Instructions at 80 kts

On the FSI Pilot Training Handbook, Standard Maneuvers and Callouts, when the Pilot Monitoring (PNF on the accident aircraft) makes the "80 knots" call, the PF has two points of information (see Figure 29):



Gulfstream GIV Standard Maneuvers and Callouts FlightSafety

NORMAL TAKEOFF (FLAPS 10 or 20):

Pilot Flying (PF)	Pilot Monitoring (PM)
At 80 Knots IAS:	
● By 80 knots, air loads will cause yoke to move from full forward, to the neutral position indicating elevator is free. ● If this does not occur by 80 knots, the takeoff should be aborted. Confirm airspeed agrees with PM's 80 knot call.	"80 Knots"
At V1:	
● PF removes right hand from thrust levers	"V1"
At VR:	
● Rotate to an initial target pitch attitude of 10°	"Rotate"

FIGURE 29 – FSI 80 KT FCS CHECK

The FDR recording shows that the elevator control surfaces never moved from the full trailing edge down position which corresponds to the yoke remaining in the full forward position in the cockpit during the attempted takeoff at this and higher speeds.

The CVR transcript shows the pilot in the right seat making the “80 knots” call but there is no indication from either pilot that they are recognizing or responding to the yoke remaining uncharacteristically in the full forward position or that the yoke has failed to “float” to the neutral position. There is no takeoff abort call from either pilot at this point.

FDR data from the prior flight and QAR data from the prior 176 flights as reported by the NTSB, show that on this aircraft, the elevators began moving at 60-80 kts during previous takeoff rolls. Given this data, the crew should have noticed this anomalous condition because the control column would have been 5-6 inches further forward than would have been expected.

The crew should have immediately aborted the takeoff upon recognizing this anomaly in accordance with training.

9.0 TAKEOFF ROLL – POST Vr

9.1 Reference to Lock Being On

As described in the NTSB CVR Factual Report, there were a total of seven callouts by the PF declaring ***“(Steer) Lock is ON”***, with the first callout occurring exactly one second after the Vr call, and the last callout 12.7 seconds after the first (13.7 seconds after Vr). It should be noted that in the NTSB report, the word “Steer” is a “questionable insertion”.

With respect to the flight control system and the words ***“Lock is ON”***, the gust lock system is the only system on the aircraft that is ‘ON/OFF’ selectable by the flight crew to lock the flight controls and is the only ***“lock”*** that would be referred to by the crew in this circumstance. The PF’s choice of words of a lock being on (versus using the word “jam” or the like) and the immediacy with which the callout is made, indicates immediate recognition, and likely prior knowledge, that the gust lock system was restraining the flight controls as opposed to any other cause. As conclusively demonstrated by the accident data, the PF was correct, and the gust lock system was restraining the flight control system.

From the NTSB CVR, FDR and Performance Factual Reports, the sequence of events related to the ***“lock is on”*** callouts is as follows (see Table 1):

TABLE 1 – “LOCK IS ON” TIMELINE

Timeline	Event	Elapsed Time (s)	Data Source
21:39:58.9	Vr Call-out		NTSB (Perf)
	Co-Pilot: “Rotate”	T -1.0	NTSB (CVR)
21:39:59.9	1st Reference to Lock being ON		NTSB (Perf)
	Pilot: “(Steer) Lock is ON”	T = 0	NTSB (CVR)
21:40:02.7	2nd Reference to Lock being ON		NTSB (Perf)
	Pilot: “(Steer) Lock is ON”	T +2.8	NTSB (CVR)
21:40:03.7	3rd Reference to Lock being ON		NTSB (Perf)
	Pilot: “(Steer) Lock is ON”	T +3.8	NTSB (CVR)
21:40:04.4	4th Reference to Lock being ON		NTSB (Perf)
	Pilot: “(Steer) Lock is ON”	T +4.5	NTSB (CVR)
21:40:05.2	*[Sound Similar to Thump and Squeak]*	T +5.3	NTSB (CVR)
21:40:05.7	FCS behavior indicative of a Flight Power Shut-Off Valve operation	T +5.8	NTSB (FDR)
21:40:06.6	5th Reference to Lock being ON		NTSB (Perf)
	Pilot: “(Steer) Lock is ON”	T +6.7	NTSB (CVR)
21:40:07.5	6th Reference to Lock being ON		NTSB (Perf)
	Pilot: “(Steer) Lock is ON”	T +7.6	NTSB (CVR)
21:40:10.0	Brake Pressures start to rise	T+10.1	NTSB (Perf)
	No associated reduction in Engine Thrust		NTSB (FDR)
21:40:10.3	Peak Speed (162.3 kts)	T +10.4	NTSB (Perf)
	Minor reduction in speed seen from this point, but brake anti-lock effectiveness reduced by full engine thrust still being applied.		NTSB (Perf)
21:40:12.6	7th Reference to Lock being ON		NTSB (Perf)
	Pilot: “(Steer) Lock is ON”	T +12.7	NTSB (CVR)
21:40:14.0	Engine Thrust Reduction *No Ground Spoilers due to FPSOV*	T +14.1	NTSB (Perf)

9.2 Flight Power Shutoff Valve Activation

The purpose of the FPSOV is to provide the flight crew with the capability to remove hydraulic power from the flight control system in the event that one or more of the hydraulic actuators is suspected to be responding incorrectly to pilot inputs. The FPSOV handle is mounted on the left hand side of the center console, and when the handle is moved to the vertical positon, the flight controls will revert to manual (mechanical) operation. Hydraulic power will be removed from the following:

- Elevators
- Ailerons
- Rudder
- Flight Spoilers
- Ground Spoilers

9.2.1 FPSOV Activation Evidence

As described in the NTSB Performance and FDR Factual Reports, between 5 and 6 seconds after the initial callout ***“lock is on”***, noises were heard relative to activity in the cockpit, and the position of the aileron and spoiler flight control surfaces was seen to change slightly. Also, the yaw damper system disengaged.

The magnitude and direction of the spoiler and aileron control surface positional change is indicative of the loss of hydraulic power to the actuators controlling the control surfaces, such that aerodynamic loads on the surfaces will result in the surfaces moving (floating) a small distance in the up direction.

For the aileron control surfaces, normal control modes always result in the LH and RH control surfaces moving in an opposing direction. However, in the event of hydraulic loss to the actuators, the aerodynamic loads will result in LH and RH control surfaces floating in the same direction, which is clearly seen in the FDR data at 21:40:06.

The yaw damper system is used to control any in-flight lateral control/directional control coupling (Dutch roll), and requires hydraulic pressure at the rudder actuator to operate. The yaw damper active/inactive state is shown on the accident FDR. It indicates that the yaw damper transitions from the active to inactive state at 21:40:06.

The data for the aileron, spoilers, and yaw damper systems recorded on the accident FDR clearly indicates that the FPSOV was activated to remove hydraulic power from the flight control system at 21:40:06 (see Figure 30) in an inappropriate attempt to release the gust lock system while the aircraft was traveling at 149.6 kts. Following FPSOV activation, the rudder, elevator and aileron continued to exhibit restricted motion consistent with the gust lock control surface hooks remaining engaged.

The FPSOV and the handle were both found in the post-accident wreckage review to be in positions consistent with FPSOV activation.

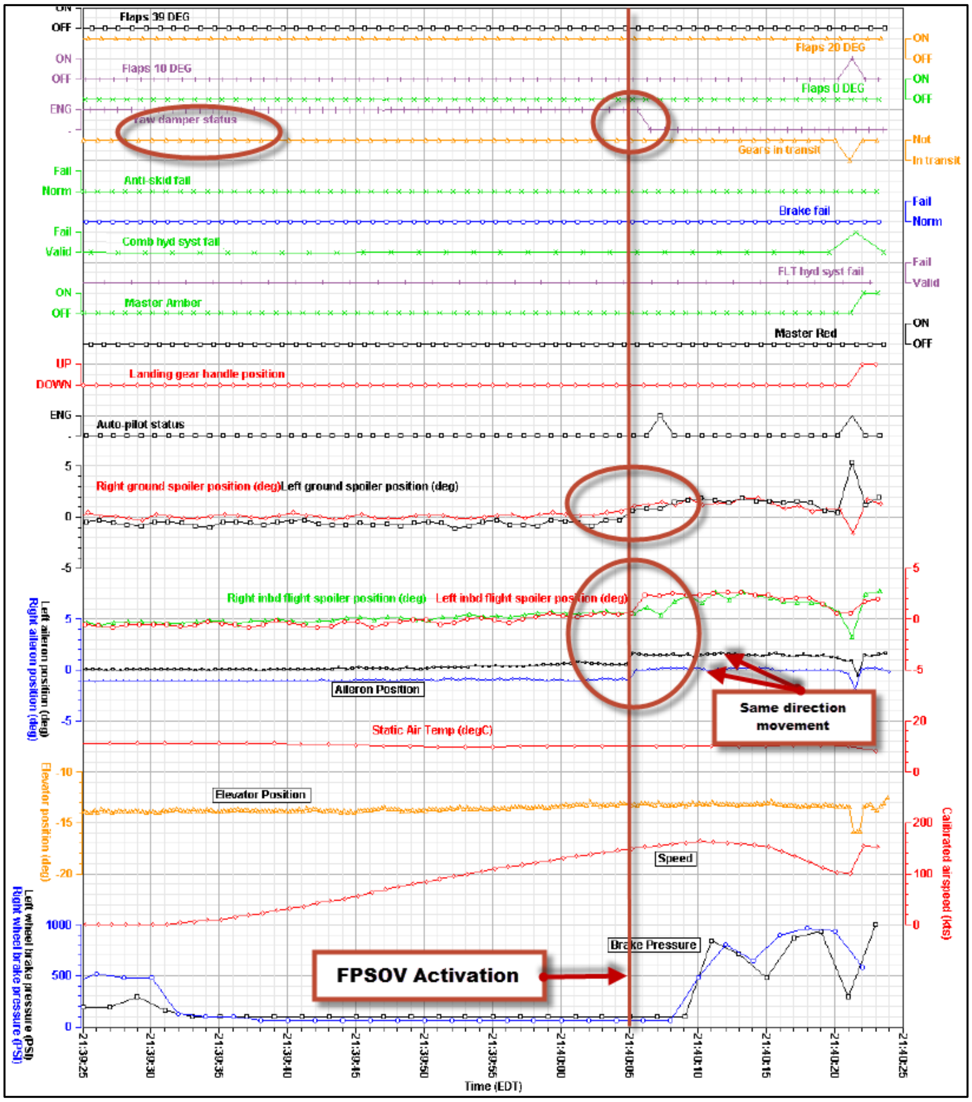
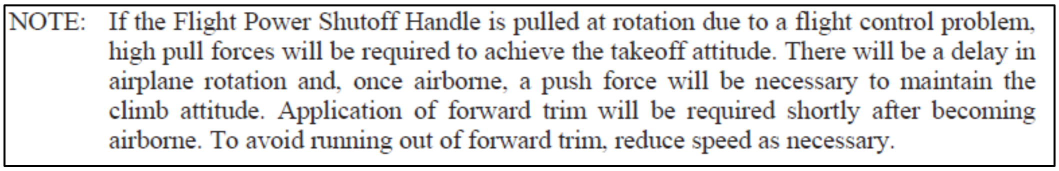


FIGURE 30 – FPSOV ACTIVATION-FDR EVIDENCE

9.2.2 FPSOV Training/Instructions

The G-IV AFM, refers to the FPSOV operation as part of the line-up instructions as shown in Figure 31.



NOTE: If the Flight Power Shutoff Handle is pulled at rotation due to a flight control problem, high pull forces will be required to achieve the takeoff attitude. There will be a delay in airplane rotation and, once airborne, a push force will be necessary to maintain the climb attitude. Application of forward trim will be required shortly after becoming airborne. To avoid running out of forward trim, reduce speed as necessary.

FIGURE 31 – AFM FPSOV REFERENCE

Gulfstream's AFMs are developed to be followed sequentially to ensure safe operation. Prior to reaching rotation speed, the AFM directs the crew to perform a flight controls freedom of motion check and observe the aft movement of the control column at 80 kts. These checks confirm mechanical freedom of motion and a properly functioning hydraulic system at these times. Therefore, with the assumption being that the pilot confirmed freedom of motion just moments before Vr, should the crew experience a flight control problem at Vr, the AFM then directs crews to pull the FPSOV to remove hydraulic power to eliminate the effect of any newly occurring hydraulic flight control issues.

9.2.3 FPSOV Effect on GL Handle/System

The activation of the FPSOV would have no effect on a locked gust lock system under the conditions present at the point of the attempted rotation and would not have an effect on a gust lock system where the gust lock handle is in an intermediate position if the gust lock control surface hooks are already being preloaded by external forces. In the accident scenario, the preloaded forces that prevented the gust lock system from being disengaged by the FPSOV were the aerodynamic forces acting on the elevator surfaces while the aircraft was traveling at 149.6 kts. In addition to these aerodynamic forces, any attempt by the PF to continue to rotate during this time would have added to the preload force on the elevator gust lock hook.

9.3 Uncoordinated Rejected TakeOff

The FDR data and CVR transcript indicate that the attempt to abort the takeoff was a late and uncoordinated effort made in separate steps with significant time delays between steps. These abort actions did not follow established procedure.

The FSI Pilot Training Handbook, Standard Maneuvers and Callouts, in the Aborted Takeoff procedure section, instructs the crew to perform duties as follows:

Pilot in Command (PIC)

- *Annunciate "ABORT"*
- *Simultaneously reduce thrust levers to IDLE and apply maximum wheel braking*
- *Actuate thrust reverse as required to ensure aircraft does not depart end of the runway*

Second in Command (SIC):

- *Verify ground spoilers have deployed. If not, manually deploy Speed Brakes*
- *Notify ATC when possible*

If the SIC (PNF in the accident aircraft) sees a situation that may require an aborted takeoff, the SIC should quickly convey that information to the PIC so that the PIC can decide whether or not to command an "ABORT".

If the PIC decides to allow another crew member the authority to command an "ABORT", the PIC should confirm this during the takeoff briefing.

The Gulfstream IV Operating Manual, in Section 06-02-20, lists the steps to be performed by the pilot in case of a rejected takeoff as follows:

A. Pilot Flying (PF)

1) *Retard power levers to idle and apply maximum braking*
2) *Deploy speed brakes*
3) *Use reverse thrust if desired*

9.3.1 Unannounced Abort

It is considered standard industry practice to use the word "ABORT" to indicate the takeoff is being "aborted" or "rejected" (both terms are used interchangeably). The CVR transcript shows no evidence of either crew member calling for or commanding an abort other than a very late reference at 21:40:14.3 where the PF according to the transcripts said ***"I can't stop it***". This verbal announcement occurred at approximately the same time as throttles are reduced. Also, since the CVR transcript shows no evidence of a takeoff briefing being performed, it cannot be determined if one or both crewmembers had the authority to command an abort.

9.3.2 Brake Application

Brake application as shown on the FDR data commenced 11.1 seconds after the ***"rotate"*** call and 10.1 seconds after the first callout of ***"lock is ON"***. However, no simultaneous power lever reduction is observed as would be expected and required for the proper conduct of a rejected takeoff. At the point of initial brake application, the airplane had reached its peak speed of 162.3 knots. FDR brake pressure indications, tire markings on the runway and tire tread condition were all consistent with normal brake anti-skid operation. Additionally, 2.6 seconds after brake application, the PF makes a final callout to the lock being on, indicating that he may still be attempting to rotate the aircraft and is not fully committed to aborting the takeoff.

9.3.3 Throttle Reduction

Throttle reduction was not commanded immediately upon initial braking but was finally commanded 4 seconds later at time 21:40:14 when the aircraft was traveling at 155.6 kts. Between initial brake application and the reduction in power levers, engine thrust and brakes were working against each other preventing the aircraft from maximum deceleration. A coordinated RTO requires an announced "ABORT" callout followed by simultaneous brake application and throttle reduction. Unfortunately, by the time the crew completed the full abort procedures, the aircraft was unable to remain on the paved overrun area and departed the runway at an excessive speed.

9.3.4 Thrust Reversers

An additional action in a coordinated abort effort is to deploy thrust reversers to assist in stopping the aircraft. According to the FDR, the thrust reversers were commanded and deployed immediately following throttle reduction. By this point, the airplane had just entered the overrun area and was traveling at 149.2 knots with less than 1,000 feet remaining to the end of the overrun area.

9.3.5 Ground Spoilers/Speed Brakes

The takeoff abort procedure calls for the Second in Command (pilot not flying) to:

- *"Verify ground spoilers have deployed. If not, manually deploy Speed Brakes".*

FDR data shows that automatic deployment of the ground spoilers did not take place when the power levers were retarded to idle. Given the fact that the FPSOV was activated at 21:40:06, the automatic deployment of the ground spoilers and the manual deployment of the speed brakes would have been inhibited. Nonetheless, the CVR has no evidence of either pilot vocalizing the need for ground spoilers or speed brakes during the abort.

9.3.6 RTO Analysis

Using aircraft data from the FDR and as discussed in the Performance Factual Reports, Gulfstream performed additional analysis to determine the stopping capability of the aircraft, if the crew had decided to abort the takeoff at different times along the runway. As previously discussed, the crew missed critical checks during the takeoff roll and then attempted to troubleshoot the known gust lock system engagement after Vr for a total time in excess of 14 seconds before fully committing to an abort procedure. At each of these critical checks and throughout the crew's troubleshooting attempts, the crew also had the opportunity to initiate abort procedures and reject the takeoff. The time that elapsed between the uncoordinated RTO efforts proved to be crucial in being able to safely stop the aircraft. Had the crew initiated proper abort procedures at any of the points in time discussed below, the aircraft would have stopped on the paved overrun area.

Gulfstream performed the following analysis using two methods: computer simulations and actual stopping capability (as recorded by N121JM's FDR deceleration rate). Unless otherwise noted, the results of both methods led to the same conclusions, with the computer simulation being more conservative (e.g. N121JM was able to reduce speed more quickly than the simulation predicted).

a) Time 21:39:46.0 (13.9 seconds before first "lock is on" callout)

   This time corresponds to the peak EPR and the commencement in reduction of PLA and EPR, which Gulfstream believes is attributed to the PNF's manipulation of the gust lock handle during the early part of the takeoff roll. The aircraft was traveling at approximately 61 kts with ground spoilers available to perform a full abort. If abort procedures were initiated at this moment, the simulation shows that the aircraft would have stopped with 6,748 ft remaining to the end of the paved surface (including overrun).

b) Time 21:39:59.9 (first "lock is on" callout)

   This time corresponds to the first PF callout of ***"(steer) lock is on"***. The aircraft was traveling at approximately 128 kts with ground spoilers available to perform a full abort. If abort procedures were initiated at this moment, the simulation shows that the aircraft would have stopped with 3,383 ft remaining to the end of the paved surface (including overrun).

c) Time 21:40:05.7 (5.8 seconds after first "lock is on" callout)

   This time corresponds to the activation of the FPSOV. The aircraft was traveling at approximately 149 kts. If the crew opted to abort the takeoff instead of pulling the FPSOV, ground spoilers would have still been available to perform a full abort and the aircraft would have stopped with 1,629 ft remaining to the end of the paved surface (including overrun).

   If the crew had aborted the takeoff immediately after the FPSOV was pulled, ground spoilers would not have been available. If abort procedures were initiated at this moment, the analysis of the actual stopping capability of the aircraft shows that the aircraft would have stopped with 1,557 ft remaining to the end of the paved surface (including overrun).

d) Time 21:40:06.6 (6.7 seconds after first "lock is on" callout)

   This time corresponds to the PF's fifth callout of ***"(steer) lock is on"***. The aircraft was traveling at approximately 152 kts with ground spoilers unavailable to perform a full abort. If abort procedures were initiated at this moment, the analysis of the actual stopping capability of the aircraft shows that the aircraft would have stopped with 1,238 ft remaining to the end of the paved surface (including overrun).

e) Time 21:40:10.0 (10.1 seconds after first "lock is on" callout)

   This time corresponds to the moment brake pressure rises which is also the last possible moment that the crew could have aborted without ground spoilers and been able to stop on the end of the paved surface (including overrun). The aircraft's actual stopping capability was used to determine this value. If the crew had initiated a full abort at this time, or any time before, the aircraft would have come to a complete stop on the paved surface. The speed corresponding to this time was approximately 162 kts, the maximum speed achieved during the attempted takeoff.

9.3.7 Lack of Crew Resource Management during Takeoff Attempt

CRM is defined by FSI as the effective use of all resources to achieve safe and efficient flight operations. CRM training is designed to improve crew coordination, resource allocation, and error management in the cockpit, and encourages all flight crew members to identify and assertively announce potential problems. Although CRM was an element of the FSI training completed by both crew members (see Attachment 1 of the NTSB Operations Factual Report), the following concerns are noted regarding the actions of the crew members during the takeoff attempt:

- The occurrence of the [**RUDDER LIMIT**] CAS message was discussed for 10 seconds, but no effective troubleshooting was performed to understand the issue;
- No verbalization of the abnormal gust lock handle position nor any discussion to resolve it prior to Vr;
- A loss of situational awareness as the throttles and engine power are reduced and remain reduced for 13 seconds before Vr;
- Following the PF's initial ***"lock is on"*** statement and the next 10 seconds to brake application, there is no crew discussion on the situation or corrective action options;
- No announcement of intent to pull the FPSOV or discussion on how it would affect the aircraft;
- The PNF does not verbally respond to any of the PF’s seven ***“lock is on”*** callouts;
- Neither the PF or PNF announced a clear decision to abort the takeoff, resulting in an uncoordinated RTO and delayed power reduction; and
- The more experienced PNF is silent after Vr and throughout the entire RTO providing no feedback, guidance or recommendations on how to address the situation

This lack of CRM resulted in ineffective communication, affected the crew's situational awareness, and unfortunately, led to ambiguity and ineffective troubleshooting to address the situation. If the crew had planned and employed proper CRM techniques throughout the attempted takeoff, a clear decision to abort would have been announced and both crew members would have immediately refocused their full attention on stopping the aircraft. The difference in seniority and roles within the company may have contributed to confusion in the cockpit about who was in charge of the accident flight, leading to a late decision to reject the takeoff.

10.0 RUNWAY DEPARTURE

The aircraft continued beyond the runway and departed the paved overrun area at an approximate speed of 105 knots. Past the runway overrun area, the unpaved ground slopes downward below the level of the main runway surface. At this point the aircraft became briefly airborne as the terrain below it sloped away. As the aircraft departed the paved overrun surface, it arced over the perimeter roadway impacting the soft ground on its landing gear. This is demonstrated by the absence of ground contact marks from aircraft tires past the pavement until they appeared approximately 55 feet past the paved overrun area (see Figure 32).

FIGURE 32 – VIEW FROM RUNWAY SERVICE ROAD

10.1 Initial Impact

The aircraft first impacted the ground on its nose gear followed by the main gears impacting abreast of the initial nose landing gear impact point. At this point, it is seen that the nose landing gear and both main landing gear ("MLG") contacted the ground at nearly the same distance from the runway as all ruts begin at approximately the same point. Upon impact, the three landing gear were partially imbedded in the soft ground as the aircraft continued at high speed toward the airport perimeter.

The ruts formed by the main gear were approximately 40 feet in length and became abruptly shallower as the landing gear began collapsing. The rut from the left main gear measured 16 inches deep in one of its deeper locations. The nose gear rut was approximately 85 feet long (see Figure 33).

As expected, structural failure of the left main landing gear occurred from a combination of the impact and drag load forces as the aircraft first impacted then plowed through the soft ground. In addition to vertical and drag loads, lateral aircraft acceleration was recorded by the flight data recorder. This lateral acceleration affected the failure of the right main landing gear.

A portion of the nose landing gear assembly was found in the grass along the debris field a short distance after the ruts. The nose gear shock strut piston was found having been severed approximately 29 ½ inch above the axle.

The left main gear assembly was located past the nose gear along the debris path. The gear separated from the wing and was still attached to the sponson box. The failure of the left landing gear sponson box was consistent with that predicted by analysis and previously documented landing gear separations.

Ground scarring formed by the right MLG would indicate that the landing gear sponson plates deformed while still being attached to the wing. Initially, the ruts formed by the left and right main landing gear look similar. Later along the path of the right MLG, the appearance of the scarring changes indicating that the right MLG, although collapsed to a degree and at an uncertain angle, was still attached to the aircraft (see Figure 34).

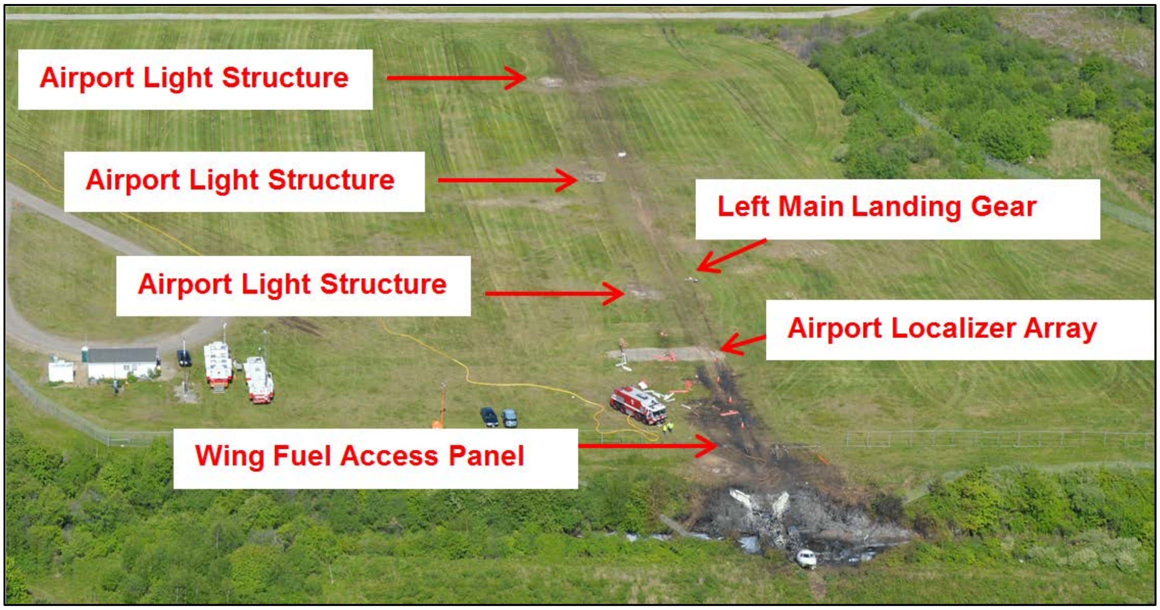


FIGURE 33 – OVERVIEW OF WRECKAGE PATH

FIGURE 34 – RIGHT MLG RUT, AFTER INITIAL IMPACT – VIEW TOWARD RUNWAY

The right MLG assembly was subsequently found partially attached to the airframe located in the ravine underneath the wing root area of the right side of the fuselage. The right MLG sponson plates were found separated consistent with the predicted analysis but otherwise still attached to the wing rear beam and fuselage structure.

From the initial impact location and to the point of impact with the ground localizer antenna array, there is no evidence of fuel spillage (see Figure 33).

10.2 Final Impact

Prior to impacting the ravine, and further down range from the initial ground impact point, three approach lighting structures located along the right side of the track were knocked down and broken. Approximately halfway between the first and second light structures, the grass to the right of the right MLG track began to turn slightly brown. Just prior to the second light structure, the grass to the left of the left MLG track also began to turn slightly brown. The left and right brown trails of grass continued until the airplane hit the localizer antennas approximately 180 feet prior to the ravine. The brown trails of grass are consistent with hydraulic fluid leakage from the damaged wheel well hydraulic connections.

The localizer antennas were in the airplane path and were broken and knocked down. Multiple localizer antenna poles were severed approximately 17 to 18 inches above their base, which is consistent with the compromised landing gear allowing impact of this height to the right wing.

A ruptured wing fuel access panel was found in the charred area a distance past the localizer antenna array (see Figure 35). The fuel tank access panels are mounted inside the wing, covering the openings, and are retained by fasteners to the wing structure. The damage indicates the puncture and separation from the wing occurred from a source external of the wing most probably when the aircraft struck the localizer array. The now open fuel tank allowed fuel to be discharged from the wing. The grass between the localizer antennas and the ravine was blackened and charred from fire. There is no visual evidence of fire spreading backward from the localizer array along the aircraft track. This demonstrates that the first spill of fuel occurred after the localizer array, where the array came in contact with the wing.

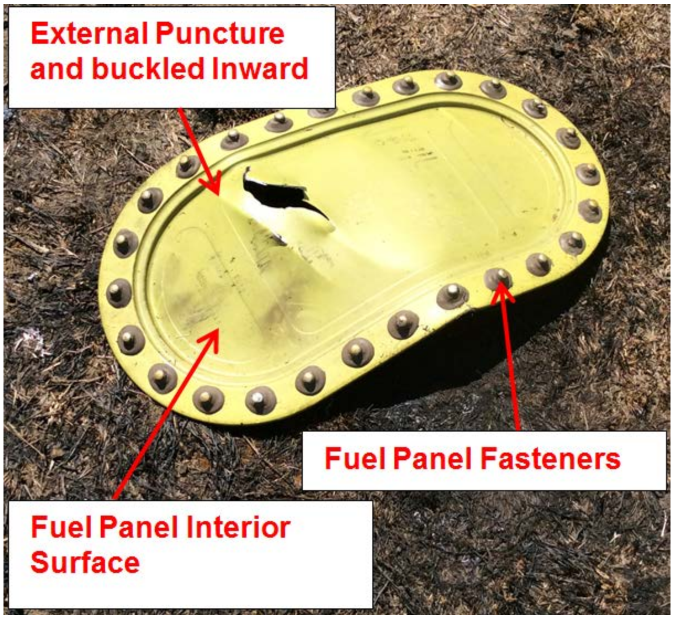


FIGURE 35 – WING FUEL TANK ACCESS COVER

The debris path continued in a straight line, for approximately 850 feet, from the end of the overrun area to the final area where the aircraft came to rest. Along this path the terrain rose in a slight incline toward the Shawsheen River. Just prior to the ravine was a large chain link perimeter fence that was partially knocked down, and a portion of it was carried across the ravine by the aircraft, which was still carrying significant forward velocity at this point.

10.3 Final Aircraft Position

The aircraft forward velocity remained high enough to cause the forward fuselage, including the cockpit, to impact on the far side of the ravine while its tail rested on the near bank. At initial impact, the aircraft was intact and suspended above the Shawsheen River by the nose and tail. As the fire consumed and weakened the structure, the aircraft collapsed into the ravine and river. The airplane wreckage was found spanning the width of the ravine with the tail on the airport side, the engines, wings, and fuselage down in the ravine, and the cockpit on the far side of the ravine. The forward fuselage structure, from the fractured nose cone aft approximately 14 feet, remained mostly intact. The majority of the airplane was destroyed by fire, with the greatest fire damage occurring near the wing root area of the fuselage.

10.4 Egress & Rescue Efforts

The airplane's MED remained closed during the accident sequence and post-crash fire. The MED mechanism was still functional after the accident as rescue workers were able to operate and unlatch the handle. The door would have been operable and able to open fully, if not impeded by the surrounding foliage on the bank of the ravine as stated in the NTSB Survival Factors Factual Report, (Reference 10).

The MED was partially opened by Hanscom Air Force Base Aircraft Rescue & Fire Fighting unit about 2 hours and 11 minutes after the accident. According to firefighters' statements, a Halligan tool was used to depress the secondary latch release on the lower exterior door. Firefighters then pulled the handle open and the door free fell to a partially-opened position, terrain obstructions preventing it from opening further. Later the handrails were removed, and the door and attaching airstair were opened further allowing access inside.

A photograph in the NTSB Survival Factors Factual Report shows that an airstair handle extension was installed and mounted to the forward airstair handrail. The extension is by design a ground use only item, required to be removed before flight as it may impede egress during a gear up landing. It is not known why the extension handle was not removed prior to departure.

The other means of egress, baggage compartment external door and over-wing emergency exits, were likely engulfed in external fire when the aircraft finally came to rest and would have been unusable for evacuation, as the wings were suspended above ground at that time.

11.0 EXAMINATION OF OTHER ALTERNATIVE CAUSES

Using a scenario based-analysis, Gulfstream examined eight possible scenarios, including the accident scenario, to confirm that Gulfstream's submission is an accurate and the most likely description of the accident event and its causes. The following sections describe seven alternative scenarios analyzed and eliminated.

11.1 Gust Lock Handle Up and Locked throughout the Takeoff

Testing on multiple exemplar aircraft (References 6 and 7) at Gulfstream has shown that the AT system will disconnect in the presence of an up/latched (locked) gust lock handle. Also, testing and analysis at Gulfstream have shown that the PLA seen during the accident is not achievable with the gust lock handle up/latched. Therefore, this is dismissed as a potential scenario.

11.2 Gust Lock Handle Released during Taxi (Prior to Line-up)

Testing on multiple exemplar aircraft (References 6 and 7) at Gulfstream has shown that if the handle is released to an intermediate position before/during taxi (using hydraulic rudder trim input to preload the gust lock control surface hook), low speed taxi operations with turns will result in the gust lock hooks becoming unlocked due to rudder/yaw damper inputs and the control surfaces becoming free to move. Therefore, this is dismissed as a potential scenario. See Section 12.3 for additional details on this testing.

11.3 Gust Lock Handle Fully Down, but the Gust Lock System Still Engaged

The gust lock handle has a direct mechanical linkage to the gust lock latches that lock the control surfaces. The scenario by which a gust lock handle is fully down, yet the gust lock control surface hooks are still engaged and preloaded, is only possible if the gust lock system return cable fails after line-up, and the gust lock handle moved to the OFF position between line-up and the time at which the engines achieve the commanded EPR. The likelihood of a return cable suddenly failing between the line-up and Vr is improbable, and it is improbable that a handle already in the OFF position would be pulled back (EPR reduction seen) in an attempt to free the gust lock system. Therefore, this is dismissed as a potential scenario.

11.4 Gust Lock Release Prevented by a Pedestal Assembly Jam/Foreign Body Jam

In this scenario, a foreign object or internal component failure would have to result in a gust lock system jam that retains the gust lock handle in an intermediate position following release. Gulfstream testing

(Reference 9) has shown that for the gust lock latches to remain locked at the control surfaces, the gust lock handle movement would have to be limited to a maximum of 15 degrees. As the normal gust lock handle release rotation is 87 degrees, the restriction would have been obvious to the flight crew member releasing the handle prior to engine start.

Additionally, the post-accident investigation found that the pedestal-mounted gust lock components were free to move, with the exception of a potential restriction introduced by a pair of sunglasses that were found in the vicinity of the pedestal mounted gust lock sheave. It is unknown if the sunglasses came to be in this location before or after the final impact of the accident. The NTSB performed a number of evaluations to ascertain if the accident sunglasses and exemplar sunglasses could induce a jam of the gust lock handle. From this testing, Gulfstream concluded that the exact position of the sunglasses was critical to the possibility of restriction, and that with the sunglasses in the same position as found after the accident, the restriction would not have been enough to restrict the gust lock handle sufficiently to maintain a locked gust lock system. It was noted that by careful placement of the sunglasses, the system could theoretically be held in a position such that release of the gust lock handle was impeded at the intermediate position sufficient to allow throttle advancement, while still maintaining the gust lock control surface latches in a locked condition. However, this specific placement was not how the sunglasses were found during the post-accident investigation. Further company testing demonstrated that the sunglasses of the nature found in the accident did not have sufficient strength to prevent further gust lock handle motion to the stowed position. For these reasons, this is dismissed as a potential scenario.

11.5 Elevator Control Surface/Actuator/System Failure/Jam/Foreign Body Jam

Although a mechanical jam within the elevator control system (any element of the system from the control columns to the control surfaces) or the presence of a foreign object within the proximity of elevator control surfaces could result in the elevators becoming locked in a trailing edge down/control column fully forward position, the elevator control system is totally independent from the rudder control system and the aileron control system; therefore, the inability to move the elevator would not have resulted in the locking of those systems. The accident data has affirmatively shown that the rudder and elevator control surfaces were locked and there is no evidence of any aileron movement during the takeoff attempt.

Additionally, due to the system independence noted above, the [**RUDDER LIMIT**] CAS message, seen prior to initiating the takeoff, cannot be as a result of any elevator system activity or malfunction. It can only be seen when the rudder system is utilizing all available hydraulic pressure to move, but is limited from moving beyond its current position. During normal ground operations, the [**RUDDER LIMIT**] CAS message can only be seen if the flight crew are inputting a full rudder pedal input, such that the control system has reached its maximum deflection possible (mechanical stops) and is unable to move further. Therefore, this is dismissed as a potential scenario.

11.6 Elevator Actuator Hydraulic Control Valve Jam

Although a mechanical jam within the elevator actuator control valve could result in the elevators becoming hydraulically powered toward the trailing edge down/control column fully forward position, the elevator control system is totally independent from the rudder control system and the aileron control system; therefore, the inability to move the elevator would not have resulted in the locking of those systems. The accident data has affirmatively shown that the rudder and elevator control surfaces were locked and there is no evidence of any aileron movement during the takeoff attempt.

Additionally, due to the system independence noted above, the [**RUDDER LIMIT**] CAS message, seen prior to initiating the takeoff, cannot be as a result of any elevator system activity or malfunction. It can only be seen when the rudder system is utilizing all available hydraulic pressure to move, but is limited from moving beyond its current position. During normal ground operations, the [**RUDDER LIMIT**] CAS message can only be seen if the flight crew are inputting a full rudder pedal input, such that the control system has reached its maximum deflection possible (mechanical stops) and is unable to move further.

Additionally, operation of the FPSOV would remove hydraulics from the elevator actuator, such that the control valve jam becomes irrelevant, and the actuator reverts to its bypass mode, permitting the pilot-in-command to move the control column and displace the elevator control surfaces manually, rotating the aircraft via the direct mechanical linkages (mechanical reversion mode).

Additionally, post-accident examination of the elevator actuator found no evidence of control valve jams. Therefore, this is dismissed as a potential scenario.

11.7 Stall Barrier Activation

The function of the stall barrier system is to provide an aircraft ‘nose-down’ input to the elevator control system upon the detection of an impending aerodynamic stall. Although this could cause the elevators to become hydraulically powered toward the trailing edge down/control column forward position, the authority of the stall barrier system is limited, such that it does not have the mechanical capability to push the control columns to their full forward position.

Additionally, the elevator control system is totally independent from the rudder control system and the aileron control system; therefore, the inability to move the elevator would not have resulted in the locking of those systems. The accident data has affirmatively shown that the rudder and elevator control surfaces were locked and there is no evidence of any aileron movement during the takeoff attempt.

Additionally, due to the system independence noted above, the [**RUDDER LIMIT**] CAS message, seen prior to initiating the takeoff, cannot be as a result of any elevator system activity or malfunction. It can only be seen when the rudder system is utilizing all available hydraulic pressure to move, but is limited from moving beyond its current position. During normal ground operations, the [**RUDDER LIMIT**] CAS message can only be seen if the flight crew are inputting a full rudder pedal input, such that the control system has reached its maximum deflection possible (mechanical stops) and is unable to move further.

Additionally, operation of the FPSOV would remove hydraulics from the stall barrier actuator, such that the system activation becomes irrelevant, and permits the pilot- in-command to move the control column and displace the elevator control surfaces manually, rotating the aircraft via the direct mechanical linkages (mechanical reversion mode).

Additionally, the stall barrier system can be overridden by the PIC, allowing the elevator surfaces to be rotated with increased column force. Therefore, this is dismissed as a potential scenario.

12.0 POST ACCIDENT INVESTIGATION OF INTERLOCK & IMPROVEMENTS

12.1 Introduction

In support of the NTSB accident investigation, Gulfstream discovered that the gust lock throttle interlock allowed greater throttle movement than originally specified to Gulfstream’s component supplier. This discovery led to a thorough review of certification requirements, evaluation of in-service aircraft, and an impact assessment to the remaining Gulfstream fleet. Throughout this investigation, Gulfstream provided its operators with immediate notification of potential issues related to abnormal gust lock system operations.

12.2 Gust Lock System Certification

The G-IV type certification activities performed by Gulfstream are fully documented in the NTSB System Safety and Certification Factual Report.

12.2.1 Code of Federal Regulation Requirements

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 described in the NTSB Certification Report.

With regard to the gust lock system, requirement 14 CFR 25.679, “Control System Gust Locks” states:

1) 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:
    a. Automatically disengage when the pilot operates the primary flight controls in a normal manner; or

b. Limit the operation of the airplane so that the pilot receives unmistakable warning at the start of takeoff.

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

12.2.2 Gulfstream's Implementation

The G-IV gust lock design prevents damage to the flight control surfaces by mechanically locking the control surfaces and protecting them from wind gusts while the aircraft is on the ground. When the device is engaged, the gust lock system limits the operation of the airplane. Gulfstream design requirements for the system provide unmistakable warning to the flight crew in the following manner:

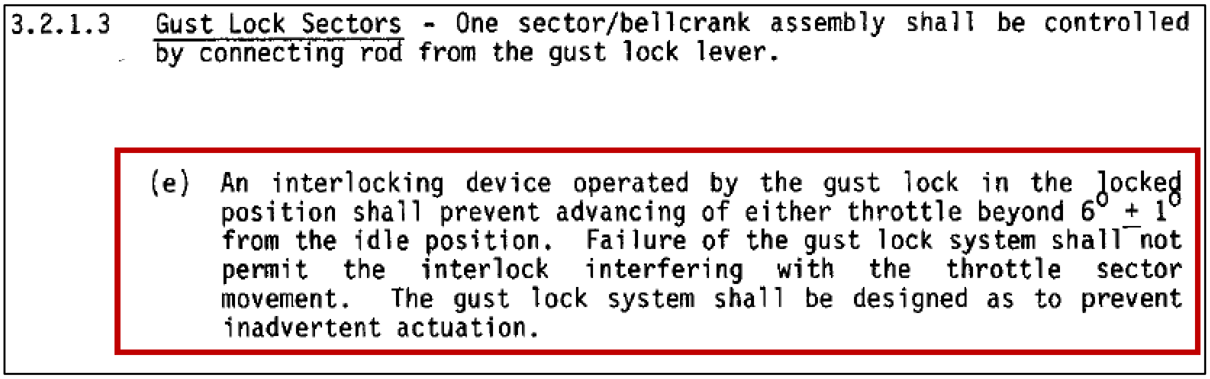
1) It restricts the operation of the pilot controls (i.e. yoke, column, rudder pedals) during the AFM-required control checks.
2) It limits the operation of the throttle levers.
3) As an additional warning feature, the gust lock handle is painted red and located prominently adjacent to the flap handle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

These design features are found in the installation and source control specification drawings; 1159C20005, 1159SCF450, and 1159SCF451.

<u>Installation Drawing 1159C20005 (Reference 11):</u>
Gulfstream drawing, 1159C20005 "Control Instl-Flight Controls Gust Lock", is the top level gust lock system installation drawing. It details the installation of cables, pulleys, bellcranks, and pushrods that connect the cockpit mechanisms (pedestal handle, sheaves, etc.) to the latches at the flight control surfaces (aileron, elevator and rudder). As the G-IV flight control surfaces are directly connected to the pilot controls by mechanical means, locking the flight control surfaces with the gust lock system also locks the pilot controls in the cockpit (column, yoke, and pedals).

<u>Specification Drawing 1159SCF451 (Reference 12):</u>
Gulfstream drawing, 1159SCF451 "Controls Sectors & Support ASSY", is a specification control drawing ("SCD"), provided to the component supplier (Sargent Industries, now Rockwell Collins), that contains design, engineering, performance requirements and standards for the construction of the sector assembly.

The "design and construction requirements" section of this SCD contained a requirement that 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" (see Figure 36).



3.2.1.3 <u>Gust Lock Sectors</u> - One sector/bellcrank assembly shall be controlled by connecting rod from the gust lock lever.

(e) 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. Failure of the gust lock system shall not permit the interlock interfering with the throttle sector movement. The gust lock system shall be designed as to prevent inadvertent actuation.

FIGURE 36 – GUST LOCK SPECIFICATION EXCERPT (1159SCF451)

Specification Drawing 1159SCF450 (Reference 13):

Gulfstream drawing, 1159SCF450 “Control Pedestal ASSY- Cockpit”, is an SCD, provided to the component supplier (Sargent Industries, now Rockwell Collins), that contains the design, engineering, performance requirements and standards for the construction of the cockpit control pedestal assembly for the G-IV. The gust lock handle assembly is one of the pedestal controls included within this specification document.

Drawing 1159SCF450 also contains a diagram defining the operating range requirements of the power lever sheaves with the gust lock handle assembly positioned to its ON and OFF positions. The drawing (see Figure 37) shows the gust lock ON position with an operating range requirement of: “6° max movement from ‘idle’ W/GL on”.

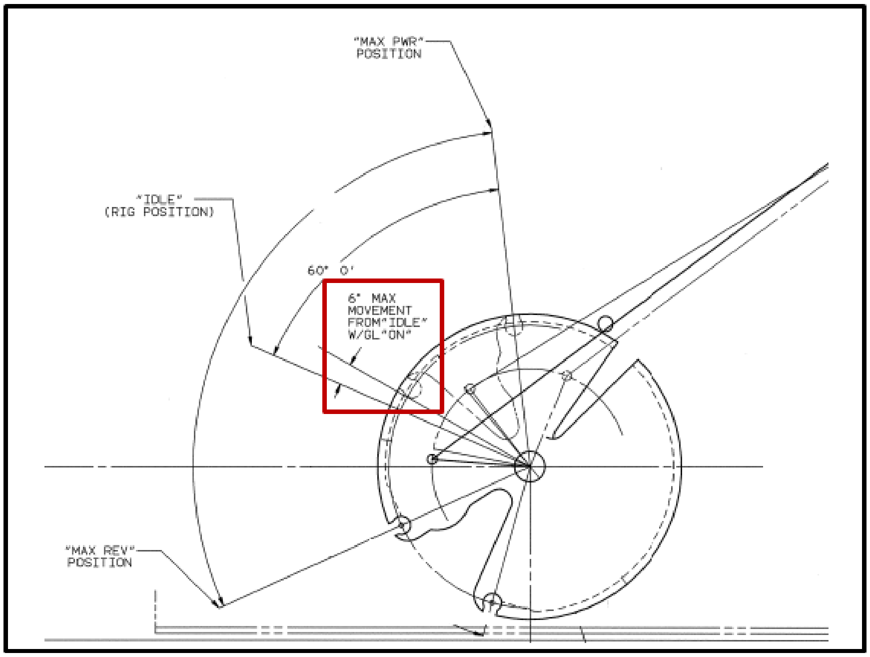


FIGURE 37 - GUST LOCK SPECIFICATION EXCERPT (1159SCF450)

12.2.3 Certification Summary

Sargent Industries Qualification Test Plan 07-43083-1 committed to testing one pedestal, control head, and sector assembly assembled as a unit to verify that the materials, construction, design, workmanship, and performance meet the requirements specified in Gulfstream specification documents 1159SCF450 and 1159SCF451. The Sargent Industries test results report confirmed that the test was conducted and that the pedestal fully conformed to the Gulfstream specifications. However, there was no discussion of the gust lock system in the test report. Further historical documentation has not been located to confirm any additional validation and verification of the 6° requirement beyond the initial compliance finding at the time of certification.

Based on post-accident investigations, Gulfstream has validated that restricting throttle movement to 6° prevents the G-IV aircraft from achieving takeoff EPR for all operating temperatures. These investigations also verified that the current pedestal does not meet the throttle interlock specification requirement. Post-accident analysis and corrective actions are discussed later in Section 12.4.

12.3 In-Service Evaluation & Testing

The G-IV family of aircraft has over 500 aircraft in service, with more than 2 million takeoffs over the past 25 years and, prior to this investigation, Gulfstream had not received any reports of excessive throttle motion with the gust lock engaged. Gulfstream completed an initial technical evaluation of the achievable TLA with the gust lock engaged on nine in-service G-IV aircraft. On four of those nine aircraft, Gulfstream also recorded the PLA. The results of the evaluation can be found in NTSB Memorandum of Record dated March 23, 2015 on the NTSB Accident Docket (Reference 14). Key conclusions from the evaluation were as follows:

- The power levers could be advanced in excess of the 6° +/- 1° design requirement given by Gulfstream to the supplier in document 1159SCF451
- The average achievable TLA was approximately 21.0°, with a standard deviation of approximately 1.7°.
- The average achievable PLA reading was approximately 16.3° with a standard deviation of approximately 2.0°.

Under the direction of the NTSB, Gulfstream conducted a series of aircraft-level tests to characterize normal and abnormal aircraft systems operations (with emphasis on the gust lock and its impact on primary flight control systems) and to simulate conditions present on N121JM on the day of the accident. The results can be found in the NTSB docket and/or referenced in the various NTSB factual reports.

As they relate to the accident sequence of events, the following significant observations were recorded during testing:

- Rudder trim input is capable of preloading the gust lock hook at the rudder such that the gust lock handle can be unlatched and moved to the intermediate position while all flight control surfaces remain locked (Reference 6 and 7).
- In the absence of aerodynamic or pilot control column input forces, activating the FPSOV unloads the rudder trim preload and allows the gust lock handle and system to disengage (Reference 6 and 7).
- When hydraulic systems are pressurized, the blue advisory [**RUDDER LIMIT**] CAS message will illuminate if sufficient rudder trim or rudder pedal is input with the gust lock system engaged (Reference 6 and 7).
- During normal taxi turn operations (using NWS) and with the gust lock system engaged, comparative test conditions demonstrated rudder control surface movements as recorded on the flight data recorder are reduced by approximately half compared to when the gust lock system is OFF (Reference 6 and 7).
- During normal taxi operations and with the gust lock in the intermediate position (due to rudder trim preload), the [**RUDDER LIMIT**] CAS message would illuminate when turning one direction, and the gust lock system would disengage when turning the opposite direction (Reference 7). When traveling straight in calm winds, it was possible to keep the hooks engaged with the handle remaining in this intermediate position (Reference 9).
- When the FPSOV is pulled in flight, the spoilers and ailerons float in the same direction (Reference 6).
- With the gust lock handle in the ON and latched position, the AT system is not capable of reaching FLEX EPR targets at 39 C ambient temperature. The AT system repeatedly disconnects prior to reaching the target (Reference 6).
- With the gust lock handle in the intermediate position, the AT system is capable of reaching both FLEX and RATED EPR targets at 21 C ambient temperature (Reference 9).

As documented in the NTSB FDR Factual Report Addendum 1, specific high speed taxi tests[12] were performed in an attempt to replicate the reduction in PLA/EPR observed on the accident flight (Reference 5). Below are the results of those specific taxi tests:

- With the throttle and gust lock systems in contact at the throttle interlock, there is no observed reduction in PLA/EPR when the AT system enters HOLD mode (Reference 9).
- With the throttle and gust lock systems in contact at the throttle interlock, there is an observed reduction in PLA/EPR when the gust lock handle is pulled aft and unlatched from the up and locked position (Reference 9).
- With the gust lock handle in the intermediate position (due to rudder trim preload) and the AT system in 'HOLD' mode, there is an observed reduction in PLA/EPR when the gust lock handle is pulled aft and allowed to return to the intermediate position (Reference 9).

12.4 Post Accident System Analysis

Portions of the design of the G-IV gust lock and throttle interlock system components were evaluated and analyzed as required to support the accident investigation. The results of these analyses are summarized in the following paragraphs.

12.4.1 Relationship between TLA and PLA

As discussed in the NTSB Airworthiness Factual Report, TLA is defined as the measured differential rotation of the cockpit throttle levers[13] from the rigged idle position. The device used to measure TLA is a mechanical protractor mounted to the throttle control head, and positioned at the throttle lever rigged idle position using the aft surface of the throttle levers as a positional reference. The throttle idle position on the protractor is equal to 48 degrees protractor reading, which is defined as 0 degrees TLA.

PLA is the output value of the engine PLA transducers. The motion of the transducer is controlled by the cockpit throttle levers. For theoretical calculations, a nominal mechanical gain factor of approximately 1.159 should be applied to PLA to convert to theoretical TLA, as specified in report number GAC-CR-0392 (Reference 15). As such, TLA values should be divided by this factor to obtain theoretical PLA values. As discussed in Section 8.1.1 and based upon observed data (four aircraft), the conversion factor between PLA and TLA varies between 1.148 up to 1.413.

12.4.2 Tolerance Analysis

Because the FDR from the accident aircraft showed evidence of the gust lock system being engaged during the accident takeoff attempt, combined with the fact that the engine PLA angles and associated EPRs were higher than would be expected with the gust lock engaged, a mechanical tolerance analysis of the gust lock handle and linkage, engine power lever linkage, and interlock mechanism (see Figure 38) was conducted to determine the maximum TLA achievable, assuming worst-case tolerance conditions. This analysis was conducted by Rockwell Collins to determine whether system tolerances could stack up to achieve the PLA and EPR levels experienced during the accident run with a properly functioning gust lock system installed and erroneously engaged during takeoff. The analysis attempted to include factors that could increase TLA beyond the specified 6° +/- 1° with the gust lock engaged. These factors included, but are not limited to, mechanical design clearances, potential backlash, rigging effects, and structural attachment locational tolerances.

---

[12] High speed taxi testing was limited to a target maximum velocity of 80 kts and conducted on active runways versus taxiways to ensure the safety of the test.

[13] The cockpit controls that control engine power for the aircraft are interchangeably referred to as either Power Levers or Throttle Levers.

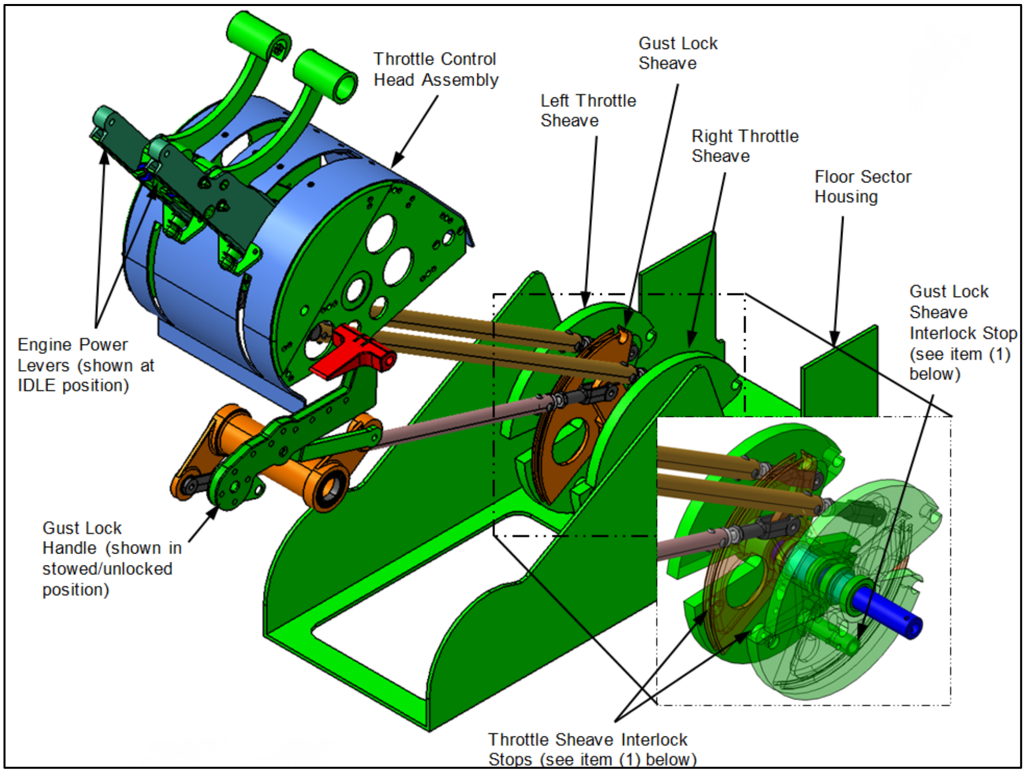


FIGURE 38 – INTERNAL PEDESTAL MECHANISMS (THROTTLES, GUST LOCK, INTERLOCK)

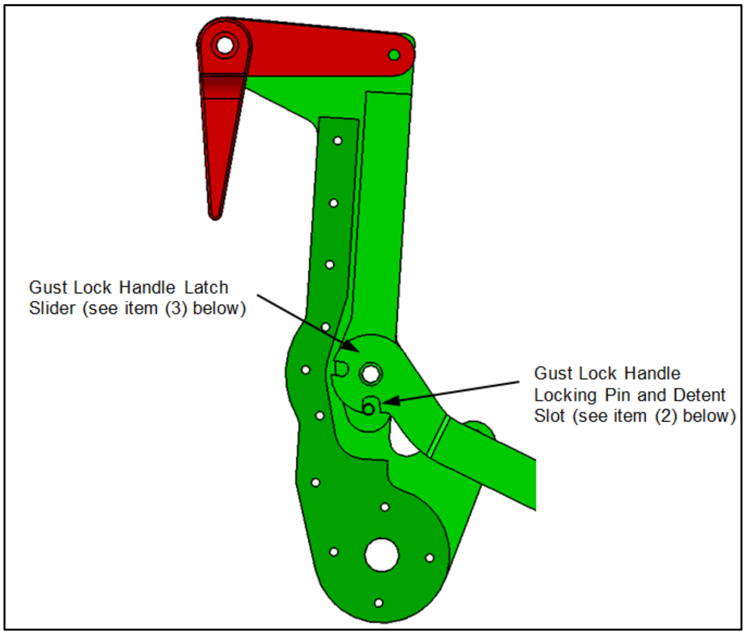


FIGURE 39 – INTERNAL GUST LOCK HANDLE ASSEMBLY (SHOWN IN ENGAGED POSITION)

As documented in the NTSB Airworthiness Factual Report, there is a potential for a maximum of approximately 23 degrees of TLA from the power lever rigged idle position with gust lock in the engaged position for a properly rigged aircraft at the worst-case tolerance conditions (and also including the designed 6° +/-1° gap between the gust lock and throttle interlock stops). This combination of tolerances is highly unlikely, but the analysis was done to demonstrate the maximum possibility.

The interfaces which were shown to be large contributors to additional TLA beyond the rigged idle (0 degrees TLA) position are:

(1) The designed gap of approximately 6° between the gust lock interlock stop and the throttle interlock stop (see Figure 38 above). This feature alone gives a starting TLA of approximately six degrees (design requirement is 6° +/- 1°, given in Gulfstream 1159SCF451) above the rigged idle position. This feature is intentional to allow some throttle motion with gust lock engaged, but not allow enough engine thrust for takeoff before encountering the interlock hard stops.

(2) The design clearance and tolerances between the gust lock handle internal locking pin and the interfacing detent slot wall (see Figure 39 above). This feature can allow in excess of 7° of additional TLA with worst-case tolerances applied.

(3) The tolerances in the gust lock handle internal slider mechanism (see Figure 39 above). This feature can allow approximately 1° of additional TLA.

12.5 Fleet Assessment

Gulfstream conducted design reviews of the gust lock, throttle, and engine systems for the other aircraft models. It was concluded that for each model, the gust lock and throttle system design differed to the extent that no issues are suspected and/or the engine power characteristics are such that the throttle interlock performs its intended function of limiting the operation of the aircraft. The differences are summarized below:

- Gulfstream I
    - The design of the gust lock mechanism is completely different from the G-IV as the Gulfstream I was developed prior to the G-IV and the aircraft is a turboprop design. Unlike the G-IV, the Gulfstream I gust lock handle mechanism interacts with a prop pitch selector such that when engaged, the propellers are locked at a ground pitch, and are not capable of producing takeoff thrust. There is an additional mechanism that prevents the power levers moving together beyond the 30 degree forward (11,000 RPM engine speed) position. Advancing one power lever retards the other power lever in this condition.
- Gulfstream II, Gulfstream III, Gulfstream II-B
    - The gust lock handle detent design is such that when the handle is placed in the locked position, the internal locking pin is immediately resting on the locking detent slot wall, with no forward motion of the handle allowed, thereby not allowing additional throttle rotation as seen on the G-IV (see Section 12.4.2 tolerance analysis above).
    - Additionally, the engine power characteristics of the Rolls Royce Spey engines are such that for lower PLAs, the engine thrust output is significantly lower than that of the G-IV Rolls Royce Tay engines; therefore, these aircraft models both allow less PLA with the gust lock engaged AND develop less engine thrust at these lower PLAs, therefore aircraft operation is sufficiently limited by the interlock..
- Gulfstream V / V-SP and Gulfstream IV-X
    - These aircraft incorporated Full Authority Digital Engine Control (“FADEC”) architecture, which necessitated an electronic Throttle Quadrant Assembly (“TQA”), which incorporates a different gust lock / throttle lever interlock internal mechanism. The design of the TQA is completely different from the G-IV, and the gust lock / throttle interlock mechanically locks the throttle levers at the idle position such that takeoff engine power cannot be developed with the gust lock lever in the engaged position.
- Gulfstream G650
    - This aircraft model does not have a mechanical gust lock system. Instead, it incorporates hydraulic dampening into the flight control actuators which serves the function of a gust lock system. This system is completely different than the mechanical gust lock used on G-IV aircraft and is contained within the flight control actuators.

12.6 Gust Lock Awareness & System Improvements

12.6.1 Awareness to Gulfstream Operators

In response to the accident investigation, Gulfstream immediately released communications to all operators with two separate Maintenance and Operations Letters. The first letter (Reference 17) was issued June 13, 2014, and the second (Reference 18) August 18, 2014. The MOLs emphasized the need to adhere to good airmanship practices and follow the AFM procedures. The procedures are used to confirm flight control integrity and freedom of movement. The MOLs reminded operators of the following AFM procedures:

- Ensure the gust lock is OFF prior to starting engines (not applicable for G650)
- Check flight controls for freedom and correct movement prior to taxi/takeoff
- Confirm the elevators are free during the takeoff roll

Additionally, operators were informed that “while a throttle interlock is incorporated in the design of the gust lock system, if proper procedures are not followed, movement of the throttle to a position capable of providing sufficient engine power for autothrottle engagement and takeoff power may be possible for G-IV models. Throttle movement is not an absolute indicator of the gust lock status for any Gulfstream model. The freedom of flight control movement is the ultimate indicator the gust lock is fully released for all Gulfstream models”.

12.6.2 G-IV Gust Lock System Improvements

Gulfstream is actively working to make the following improvements to the gust lock system and deploy them to the fleet as soon as possible.

- Additional restrictions to throttle movement
- Improved materials in the gust lock handle assembly
- Recurring compliance checks to ensure that the interlock system continues to function as intended

Even with these planned system improvements, the flight controls freedom of motion checks must always be performed to ensure there are no locks, jams or failures in the flight control system prior to takeoff.

13.0 CONCLUSION

This accident occurred because the flight crew deviated from approved procedures and training that left the gust lock engaged and attempted to continue takeoff with a recognized flight control anomaly, rather than promptly executing a coordinated abort procedure.

Gulfstream believes that the following were the causal factors leading to the accident:

- Failure of the flight crew to follow AFM procedures at three critical points before Vr:
    - Not disengaging the gust lock before engine start;
    - Not checking for freedom of control surface movement following engine start; and
    - Not confirming elevator freedom of movement at 60 knots during takeoff roll.
- Failure of the flight crew to follow flight crew training procedures on four occasions:
    - Not disengaging the gust lock prior to engine start;
    - Not checking for freedom of control surface movement following engine start;
    - Failing to abort takeoff at 80 knots when elevator movement did not occur; and
    - Failing to use appropriate corrective action upon determining that the gust lock was inadvertently left on following engine start.

- Failure of the flight crew to conduct a timely and coordinated abort procedure upon recognition that the gust “lock is on”.

Gulfstream believes that the following were contributory factors leading to the accident:

- Failure of the flight crew to use proper CRM techniques:
    - The occurrence of the [**RUDDER LIMIT**] CAS message was discussed for 10 seconds, but no effective troubleshooting was performed to understand the issue;
    - No verbalization of the abnormal gust lock handle position nor any discussion to resolve it prior to Vr;
    - A loss of situational awareness as the throttles and engine power are reduced and remain reduced for 13 seconds before Vr;
    - Following the PF's initial ***"lock is on"*** statement and the next 10 seconds to brake application, there is no crew discussion on the situation or corrective action options;
    - No announcement of intent to pull the FPSOV or discussion on how it would affect the aircraft;
    - The PNF does not verbally respond to any of the PF’s seven ***“lock is on”*** callouts;
    - Neither the PF or PNF announced a clear decision to abort the takeoff, resulting in an uncoordinated RTO and delayed power reduction; and
    - The more experienced PNF is silent after Vr and throughout the entire RTO providing no feedback, guidance or recommendations on how to address the situation.

Gulfstream believes the following regarding the loss of the aircraft’s crew and passengers:

- Based upon the NTSB Survival Factors Report, the initial and secondary accident impacts were survivable;
- The aircraft fuel tanks were ruptured after the aircraft left the runway and impacted ground structures, fueling a severe fire; and
- The smoke, fire and extreme temperatures in the cabin rapidly overcame the crew and passengers prior to opening any emergency exit.

Following the accident, Gulfstream discovered that the gust lock interlock system designed and manufactured by predecessors to Rockwell Collins for Gulfstream for the G-IV model aircraft, while limiting throttle movement when engaged, did not achieve its stated 6 degree throttle movement limitation, and that this remained undiscovered on more than 500 aircraft, over 25 years and more than 2 million takeoffs. As a result of the extensive data collected from the accident aircraft, and the company’s and the NTSB’s post-accident testing, Gulfstream believes that the interlock as it existed on the accident aircraft achieved its safety intent of limiting the operation of the aircraft, which was recognized by the flight crew early in the takeoff roll. However, the flight crew improperly responded to this recognition by attempting to disengage the gust lock while continuing with the takeoff instead of immediately aborting the takeoff.

13.1 Deviation from AFM Procedures & Training

As discussed in the preceding sections, the FAA-approved airplane flight manual and industry-accepted training instructions were not followed during the accident takeoff. Specific guidance and instructions are provided and expected to be followed during the pre-flight and lineup phases of the takeoff. In addition to the safety precautions purposefully designed into the various systems of the aircraft, the flight manual instructions are an essential means of ensuring the safe operation of the aircraft. The AFM instructions and aircraft system operations are established in concert with one another and depend on the reliable performance of both. This coordinated system of safety was violated when the crew repeatedly bypassed important checklist items and standard airmanship practices. This habit of deviating from standard and required practices is seen in their previous 176 takeoffs. The final takeoff attempt continued this habit and resulted in a failure to properly disengage the gust lock system during preflight and an extremely late recognition that the takeoff must be aborted.

13.1.1 Prior to Taxi

Two crucial AFM instructions and training instructions were bypassed prior to taxi: set the gust lock to off prior to engine start and check the flight controls for freedom of motion after engine start. Even if a crew member forgets to release the gust lock, the fight controls check is a mandated AFM check and a standard airmanship practice and would have identified the flight crew's initial error before commencing taxi. The flight control freedom-of-motion check is intended to identify many potential anomalies in the flight control system, not just the gust lock system. By habitually deviating from this critical check, the crew repeatedly exposed the aircraft to unnecessary risks during takeoff.

13.1.2 Takeoff Roll

The crew was alerted to a flight control system issue early at lineup for the takeoff roll. The appearance of the **[RUDDER LIMIT]** CAS message was a highly unusual advisory message at this time and should have been investigated. A quick and simple check of the rudder pedals would have sufficiently identified the engaged gust lock system. Standard procedures require the engine power to be monitored later in the takeoff roll. The AOM and FSI training manuals instruct pilots to closely monitor engine power during this early phase of takeoff. It is not known which of these power settings were selected by the crew, but in either case, the pilot monitoring never verbally confirmed that the aircraft had reached its target EPR. There is a brief statement by the PF that he ***"couldn't get * * * *"***, possibly indicating the he observed an issue with attaining the target EPR. Even so, the PF quickly diverts his attention and fails to notice the subsequent reduction in power. At the same time the crew failed to sustain their target takeoff EPR, the PNF is also purposefully manipulating the gust lock handle at 60 kts, in an attempt to release and stow the handle. This action, to release and stow the handle in the middle of a takeoff attempt, is not recommended or trained in any of the Gulfstream or FSI instruction materials. The only appropriate pilot action to release the gust lock system in this situation is to abort the takeoff, shut down engines, remove hydraulic pressure, and disengage the gust lock system. Failure to do this was a critical error during this takeoff attempt.

After the failure to properly monitor engine power settings and then improperly manipulating the gust lock handle, the crew had one more mandated check for flight controls freedom of motion during the takeoff roll. In a normally configured aircraft, increased aerodynamic loading on the elevator causes it to rise and bring the control column toward a neutral position. Over the 175 previously recorded takeoffs, the elevator on this aircraft consistently started moving toward neutral between 60 and 80 kts. The AFM and FSI training instruct pilots to confirm this control column movement. On this takeoff attempt, the control column did not move and the pilot monitoring did not follow FSI training to abort the takeoff.

The combination of a lack of communication, failure to identify low engine power, the failure to confirm freedom of control column motion at 60-80 kts, the use of inappropriate gust lock disengagement techniques, and failed adherence to abort criteria are all further indicative that the crew were performing their duties in isolation and not employing appropriate crew resource management techniques.

13.2 Gust Lock Engagement & Locked Flight Controls

Because the gust lock system had not been released from its engaged position, the flight control surfaces were locked, and the aircraft was incapable of rotating. Despite the failure to follow prescribed AFM and FSI instructions, the crew were aware of the gust lock handle status early in the takeoff roll. The crew chose to continue with the takeoff roll and address the gust lock system during takeoff operations, in clear contradiction with all AFM and FSI instructions. Despite the early awareness of the gust lock handle status, the crew never checked the flight control system for freedom of motion.

As described in Section 8.3, crew awareness of the gust lock handle status is observed at time 21:39:46:0. The EPR and PLA both suddenly reduce at this time. The most probable, rationale for this reduction in EPR/PLA, as verified by testing, is pilot interaction with the gust lock handle.

All prescribed opportunities to check the flight control systems had come and gone by the time the crew reached 90 kts. More than 30 seconds after the crew first became aware of the [**RUDDER LIMIT**] CAS message, and 15 seconds after a crew member manipulated the gust lock handle, the PF made his first reference to a lock being ON. ***"(Steer) lock is on"*** was uttered immediately when he pulled back to rotate and became aware of the locked flight controls. He would repeat this phrase multiple times as the crew attempted to unlock the control surfaces and preserve the takeoff attempt. As this first callout dismissed all other potential flight control issues and focused directly on the gust lock system, it strongly suggests that the crew immediately became aware that they had not resolved the gust lock system issue prior to Vr. However, the crew continued the takeoff attempt, placing the safety of the aircraft and its occupants solely dependent upon the successful release of the gust lock. Neither the PF nor the more experienced and senior PNF called for an immediate abort.

13.3 Uncoordinated RTO

After 10 seconds of trying to correct a locked flight control issue, the crew began a late and uncoordinated rejected takeoff. Even then, no "ABORT" call was verbalized in the cockpit.

The increase in brake pressure recorded on the FDR is the first indication of an intent to abort the takeoff at a peak velocity of 162 kts. However, it was an additional 4 seconds before a crew member retarded the throttles to complete the RTO actions. During these 4 seconds, the aircraft only decelerated slightly, due to the opposing effects of braking and thrust. By this time, the FPSOV had been pulled and the ground spoilers were not capable of deploying, which further degraded the aircraft's braking performance. The crew's prior attempts to troubleshoot the gust lock issue after Vr consumed significant time and runway such that by the time the crew finally aborted the takeoff effort, there was inadequate remaining runway and overrun to stop the aircraft safely.

If the crew had begun abort procedures at initial gust lock awareness (the reduction in PLA/EPR at 60 kts), or even as late as the sixth callout ***"(Steer) Lock is On"***, the aircraft would have been able to stop safely on the runway or the paved overrun area.

14.0 REFERENCES

1. NTSB Airworthiness Factual Report
2. NTSB System Safety & Certification Factual Report
3. NTSB CVR Factual Report
4. NTSB Aircraft Performance Study
5. NTSB FDR Factual Report
6. Gulfstream Test Report GIV-GER-9978
7. Gulfstream Test Report GIV-GER-9980
8. NTSB Materials Laboratory Factual Report
9. Gulfstream Test Report GIV-GER-0017
10. NTSB Survival Factors Report
11. Control Instl-Flight Controls Gust Lock (1159C20005)
12. Controls Sectors & Support Assy (1159SCF451)
13. Control Pedestal Assy-Cockpit (1159SCF450)
14. NTSB Docket Document: Memorandum of Record dated March 23, 2015
15. Gulfstream Contractor Report GAC-CR-0392
16. NTSB Docket Document: Gulfstream EPR vs PLA Presentation

17. Gulfstream Maintenance & Operations Letter ALL-MOL-14-0015
18. Gulfstream Maintenance & Operations Letter ALL-MOL-14-0024
19. NTSB FDR Factual Report Addendum 1
20. NTSB FDR Factual Report Addendum 2

15.0 ACRONYMS

AFM	Airplane Flight Manual
AOM	Airplane Operating Manual
AT	Auto Throttle
CAS	Crew Advisory System
CFR	Code of Federal Regulations
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
EDT	Eastern Daylight Time
EICAS	Engine Indicating and Crew Alerting System
EPR	Engine Pressure Ratio
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FBO	Fixed Base Operator
FDR	Flight Data Recorder
FPSOV	Flight Power Shutoff Valve
FSI	Flight Safety International Inc.
KACY	Atlantic City International Airport
KBED	Laurence G. Hanscom Field
KCAS	Knots Calibrated Airspeed
KILG	New Castle Airport
kts	Knots
LH	Left Hand
MED	Main Entrance Door
MLG	Main Landing Gear
mph	Miles Per Hour
NTSB	National Transportation Safety Board
NWS	Nose Wheel Steering
PF	Pilot Flying
PIC	Pilot In Command
PLA	Power Lever Angle
PNF	Pilot Not Flying
psi	Pounds Per Square Inch

QAR	Quick Access Recorder
RH	Right Hand
RPM	Revolutions Per Minute
RTO	Rejected Takeoff
SCD	Source Control Drawing
SIC	Second In Command
TLA	Throttle Lever Angle
TQA	Throttle Quadrant Assembly
V1	Decision Speed
Vr	Rotation Speed

APPENDIX A CONSOLIDATED SEQUENCE OF RUNWAY EVENTS