EMBRAER S.A. SUBMISSION Re- 505-0089
[C-GJOL] / RUDDER GUST LOCK ACTUATOR FAILURE at PALM SPRINGS AIRPORT NOVEMBER 23, 2014

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1 ABSTRACT

This document is the l Submission of Embraer SA (Embraer) pursuant to 49 C.F.R §831.14, which summarizes Embraer's technical assessment of the incident with aircraft 505-0089, Canadian Registration C-GJOL at Palm Springs Airport on November 23, 2014.

2 SCOPE

This document presents a description of the EMB-505 Gust Lock System, and a technical analysis of the event with aircraft 505-0089 in Palm Springs, on November 23, 2014. This document also presents the actions taken by Embraer to reduce the possibilty of similar events.

DEFINITIONS, ACRONYMS AND ABBREVIATIONS

AFM	Airplane Flight Manual
CAS	Crew Alerting System
PN	Part Number
RGLA	Rudder Gust Lock Actuator
TLA	Throttle Lever Angle
TOGA	Takeoff / Go Around

3 DEVELOPMENT

3.1 Electrical Architecture

The rudder gust lock electrical architecture is shown below:

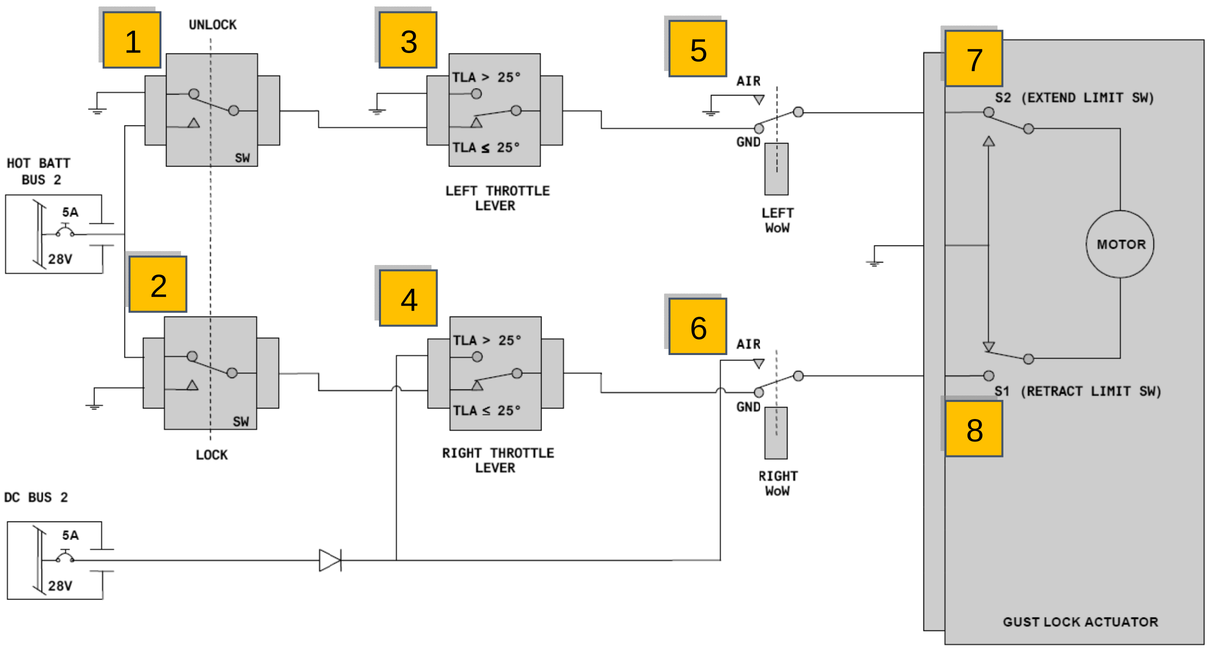


Figure 1: Electrical Architecture

Components description:

1. Cockpit switch #1 located in pilot yoke
2. Cockpit switch #2 located in pilot yoke
3. Throttle lever angle interlock switch (Left)
4. Throttle lever angle interlock switch (Right)
5. Weight on wheels interlock sensor (Left)
6. Weight on wheels interlock sensor (Right)
7. Actuator extend limit switch
8. Actuator retract limit switch

3.2 Mechanical Architecture

The mechanism and its interfaces are shown in the schematic drawing below.

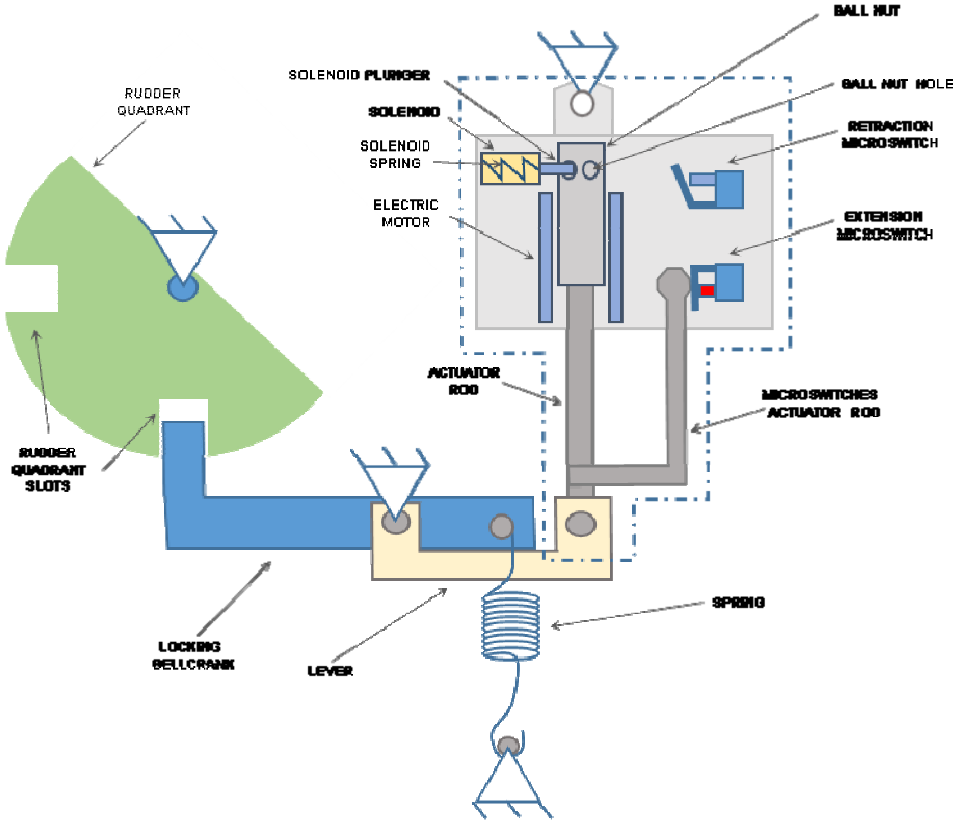


Figure 2: Mechanical Architecture

RGLA main components:

1) **BALL NUT:** Component responsible for transforming rotational motion into linear motion.
2) **BALL NUT HOLE:** Holds the solenoid plunger tip resulting in the ball nut lock.
3) **SOLENOID:** Responsible for actuator irreversibility feature.
4) **SOLENOID SPRING:** Keeps potential energy when solenoid is energized. Releases the potential energy when solenoid is de-energized in order to lock the ballnut.
5) **SOLENOID PLUNGER:** Locks the ball nut through ball nut hole.
6) **ELECTRIC MOTOR:** Provides energy to rotate the ball nut.
7) **ACTUATOR ROD:** Attached to aircraft mechanism to arm/disarm the system.
8) **MICROSWITCHES ACTUATOR ROD:** Responsible for microswitches activation.
9) **EXTENSION MICROSWITCH:** Responsible for actuator shutdown after extension movement.
10) **RETRACTION MICROSWITCH:** Responsible for actuator shutdown after retraction movement.

Aircraft mechanism main components:

11) **LEVER:** Releases locking bellcrank from rudder quadrant slot when actuator retracts.
12) **LOCKING BELLCRANK:** Locks the rudder quadrant.
13) **RUDDER QUADRANT:** Locks rudder surface when locking bellcrank is in the slot.
14) **SPRING:** Keeps residual energy to ensure locking movement towards rudder quadrant slot when rudder surface is commanded.

3.3 System Operation

The actuator is vertically mounted and connected to the aircraft through the upper fitting and its rod is attached to the mechanism lever. The aircraft must be on ground for rudder gust lock system operation.

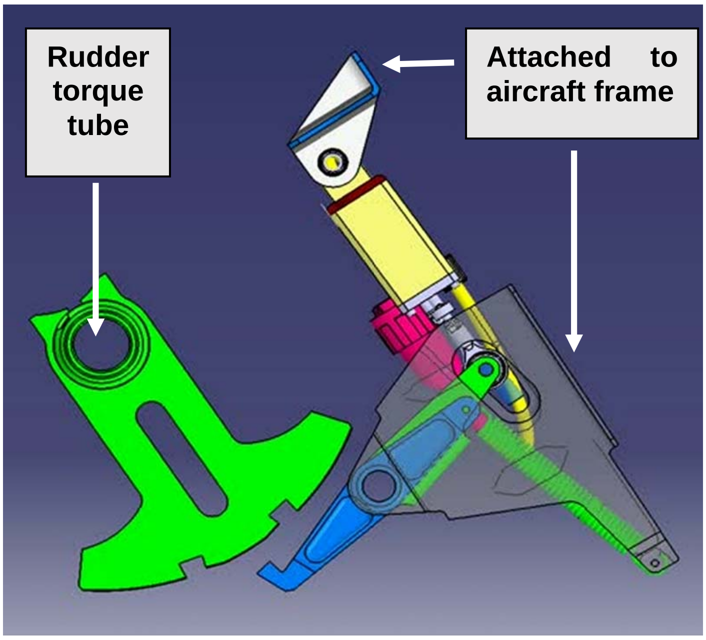
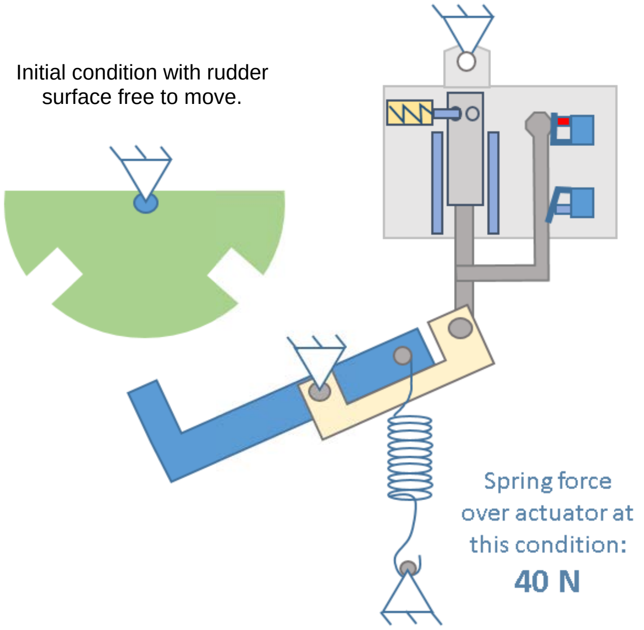


Figure 3: Actuator Installation

A step-by-step description is presented in the following sections to illustrate operation of the rudder gust lock.

3.3.1 Locking Movement

3.3.1.1 **First Stage**



1st) Pilot inserts yoke gust lock pin to activate the system

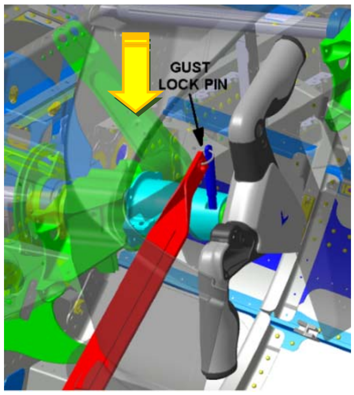
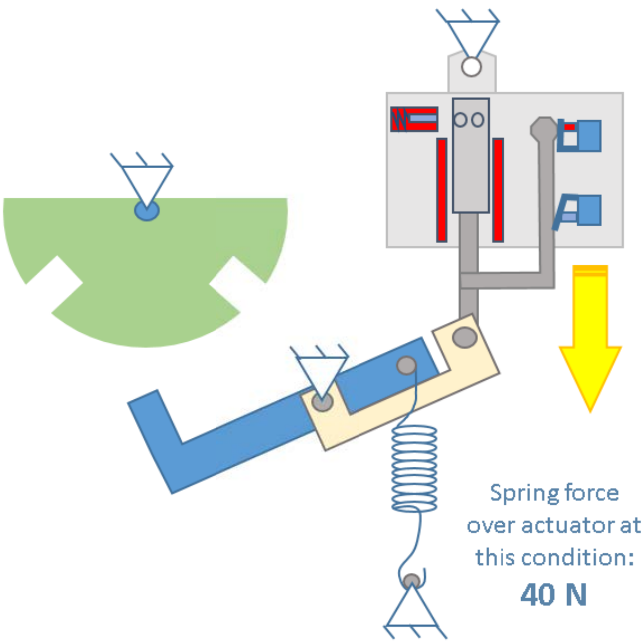


Figure 4: Locking Movement: First Stage

3.3.1.2 **Second Stage**



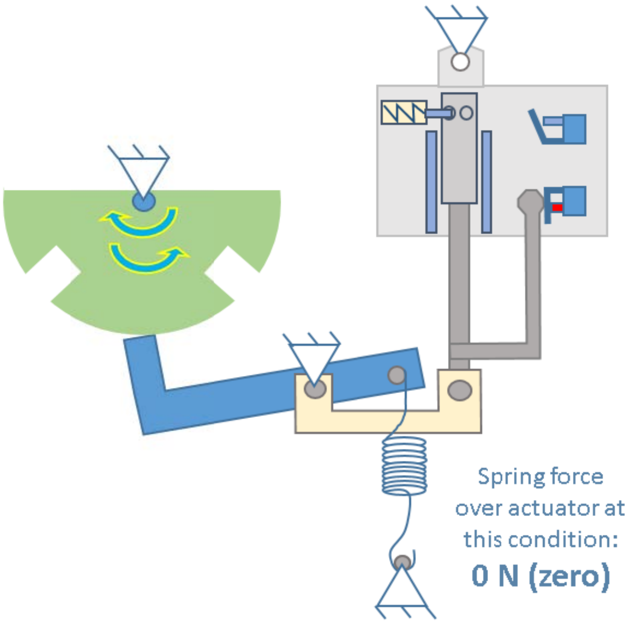
2nd) Power is supplied to the electric motor and solenoid simultaneously

3rd) Solenoid plunger tip releases the ball nut

4th) Actuator rod starts its extension movement

Figure 5: Locking Movement: Second Stage

3.3.1.3 **Third Stage**



5th) Microswitches actuator rod reaches the extension microswitch

6th) Power applied to motor and solenoid is interrupted

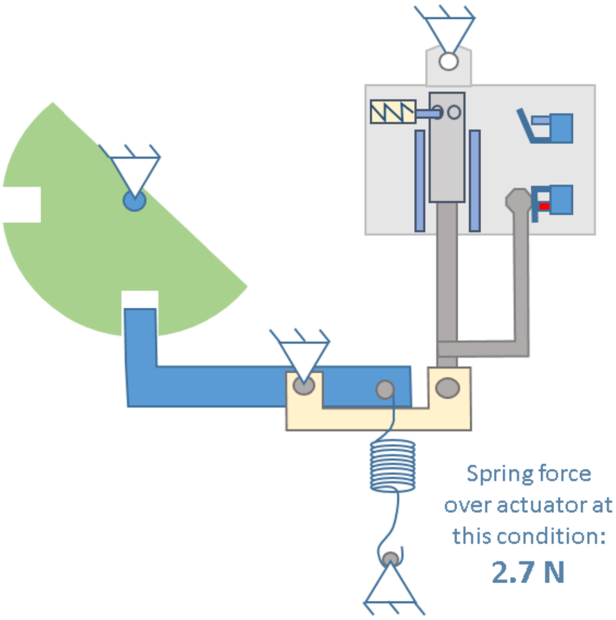
7th) Solenoid plunger tip locks the ballnut through ball nut holes

8th) Locking bellcrank touches rudder quadrant

9th) Pilot is required to command pedals to lock the rudder surface.

Figure 6: Locking Movement: Third Stage

3.3.1.4 **Fourth Stage**

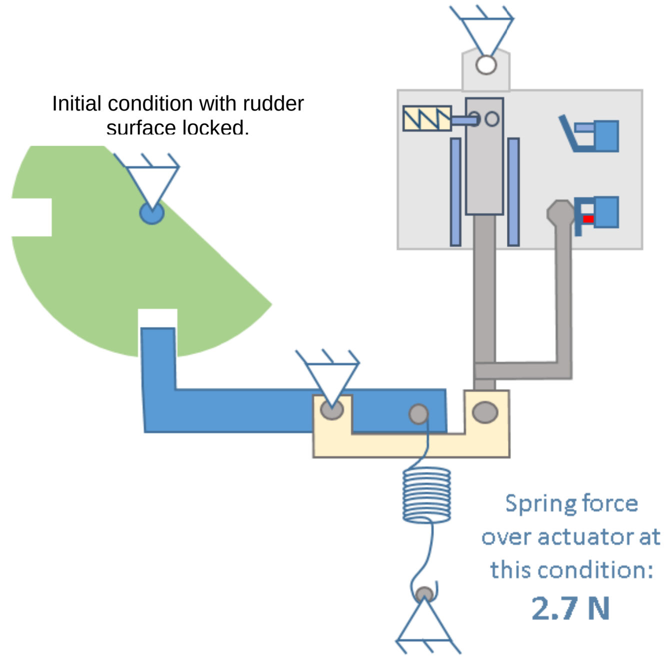


10th) Rudder quadrant locks by pilot action over rudder pedals

Figure 7: Locking Movement: Fourth Stage

3.3.2 Unlocking Movement

3.3.2.1 **First Stage**



1[st]) Pilot removes yoke gust lock pin to activate the system

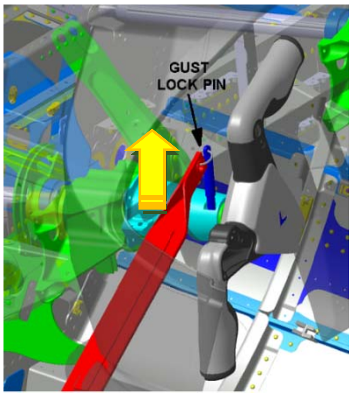
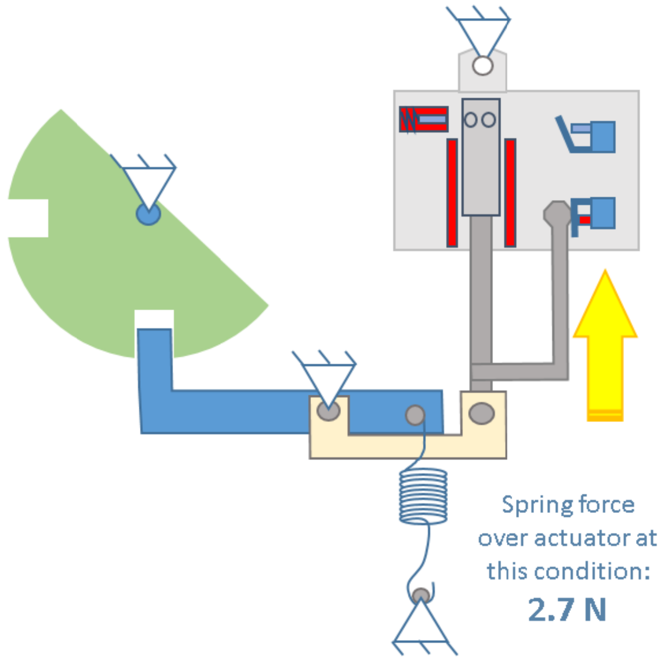


Figure 8: Unlocking Movement: First Stage

3.3.2.2 **Second Stage**



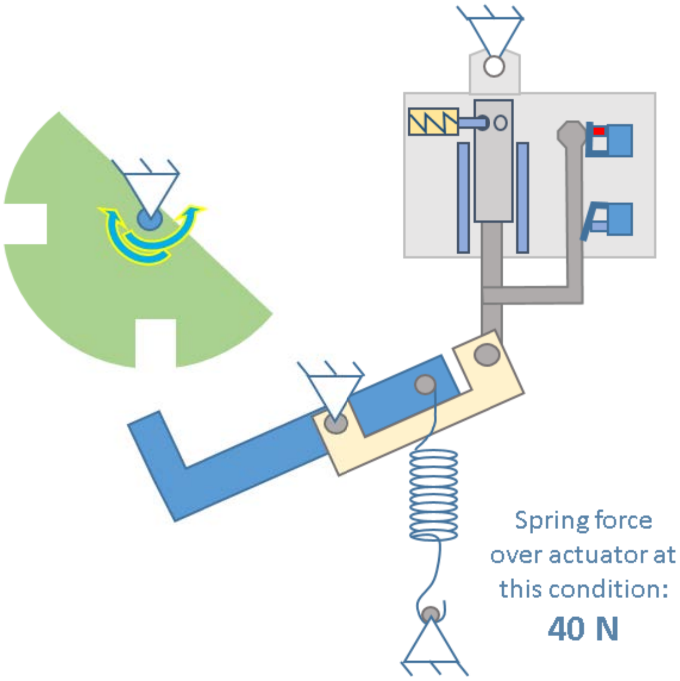
2[nd]) Power is supplied to the electric motor and solenoid simultaneously

3[th]) Solenoid plunger tip releases the ball nut

4[th]) Actuator rod starts its retraction movement

Figure 9: Unlocking Movement: Second Stage

3.3.2.3 **Third Stage**



5th) Microswitches actuator rod reaches the retraction microswitch

6th) Power applied to motor and solenoid is interrupted

7th) Solenoid plunger tip locks the ballnut through ball nut holes

8th) Rudder surface is free to move

Figure 10: Unlocking Movement: Third Stage

3.4 Embraer Actions

The actions taken by Embraer following the event in regard to gust lock system are elaborated below..

3.4.1 Actuator Retrofit

Embraer opted to replace the EMB-505 gust lock actuators through a retrofit campaign. Embraer Service Bulletin 505-27-0017/00 was issued on January 30th, 2014. By September 2016, 95% of EMB-505 fleet had incorporated the new gust lock actuator, which has the same Part Number as the actuator used on the ERJ-145 family and which has a successful operational history and simplified architecture – irreversible jack screw actuation with- out a solenoid/plunger.

3.4.2 Embraer tests to investigate the incident

As part of the investigation of the event and providing assistance to the NTSB, Embraer performed tests as described below to evaluate all possible scenarios.:

- **Test Case 1:** Gust Lock actuator in extended position with Rudder surface locked (as described in section 3.3.1.4)

  The pilot easily identified that pedals were locked, and could not be moved. The rudder and steering movement for both sides were immovable. The Pilot, however, was able to taxi the aircraft using asymmetric thrust and asymmetric braking.

- **Test Case 2:** Gust Lock actuator in extended position with Rudder surface not locked (as described in section 3.3.1.3)

  The pilot was able to perform S-turns and taxi the airplane using small rudder pedal inputs. According to the pilot, operation of the aircraft was possible and included the use of asymmetric thrust and asymmetric braking during taxi.

  Large rudder pedal deflections (greater than 30 degrees of steering), would cause gust lock engagement and would be easily identified by the pilot..

3.4.3 Operational Bulletin

Embraer issued Operational Bulletin No. 505-001/15 on February 6th, 2015. The OB emphasizes the importance of following AFM procedures to ensure the gust lock is not engaged and that rudder is free by exercising full travel of the rudder pedals in both directions.

3.4.4 Manuals

Since certification of EMB-505, the operational manuals require a flight control check after the engines are started by exercising full travel of rudder pedals, control column and control wheel. The successful completion of this task ensures that all controls and control surfaces are free to move without limitation.

As a result of the event and despite the clear check procedures in the AFM, POH ad QRH for freedom of control movements Embraer has revised the procedures in the AFM, POH and QRH for greater emphasis on the importance of freedom of movement verification.

3.4.5 Gust Lock actuator annunciation

During EMB-505 development and certification, a gust lock engaged annunciation was deemed not required due to the fact that it is evident for the pilot that the gust lock is active during the flight control check.

After the incident in Palm Springs, Embraer developed a caution CAS message "RUD GUST LOCKED" to increase the crew situational awareness by indicating that the gust lock is engaged. In normal operation, this CAS message will be displayed whenever the gust lock pin is inserted. When gust lock pin is removed and the gust lock is actually disengaged, the CAS message will go away.

If the gust lock actuator fails in an extended position, the CAS message will remain active. Per the revised MEL the aircraft cannot be dispatched with the CAS message active.

3.5 Incident Analysis

From NTSB preliminary report WPR-15-IA-046: *On November 23, 2014, about 1052 Pacific Standard Time, an Embraer EMB-505 airplane, C-GJOL, experienced an uncommanded severe yaw to the right immediately after takeoff from the Palm Springs International Airport (PSP), Palm Springs, California. Neither the airline transport pilot nor the 4 passengers on board were injured. The airplane, which was owned by a private individual, was operated by Hawkeye Aviation Holdings Ltd, Kelowna, British Columbia. Visual meteorological conditions prevailed for the planned cross-country flight, which was being operated in accordance with 14 Code of Federal Regulations Part 91. An instrument flight rules flight plan was in effect at the time of the event, with Springbank, British Columbia, the reported destination.*

Based on FDR data and analysis of reports , Embraer submits that the following series of events occurred to culminate in the incident, as follows:

1. The gust lock actuator had failed in a position that would lock the rudder surface with a deflection of approximately 12 degrees.
2. The pilot did not exercise a free movement check, which would have engaged the gust lock due to the failed actuator and would therefore have detected the gust lock engagement,
3. The rudder surface locked prior to or during taxi, and the pilot used differential braking and asysmetrical thrust to counter aircraft tendency to the right
4. When TLA was set to TOGA, interlocks commanded actuator retraction with no effect due to actuator failure
5. During Takeoff Run, pilot was able to keep aircraft in centerline by means of diferential brakes, but right after liftoff, the yaw tendency to the right was evident

Below is a detailed discussion of each event:

1. The gust lock actuator had failed in a position that would lock the rudder surface with a deflection of approximately 12 degrees.

   This statement is in accordance with gust lock actuator removed from aircraft 505-00089 after the incident, as it was found almost fully extended.
   Gust lock mechanism condition was most likely as illustrated in **Erro! Fonte de referência não encontrada.**. The actuator had probably failed in one of the two conditions:
   - during actuator extension, when the gust lock was activated after the previous flight; or
   - during actuator retraction, when the locking pin was removed before the flight where the incident occurred.

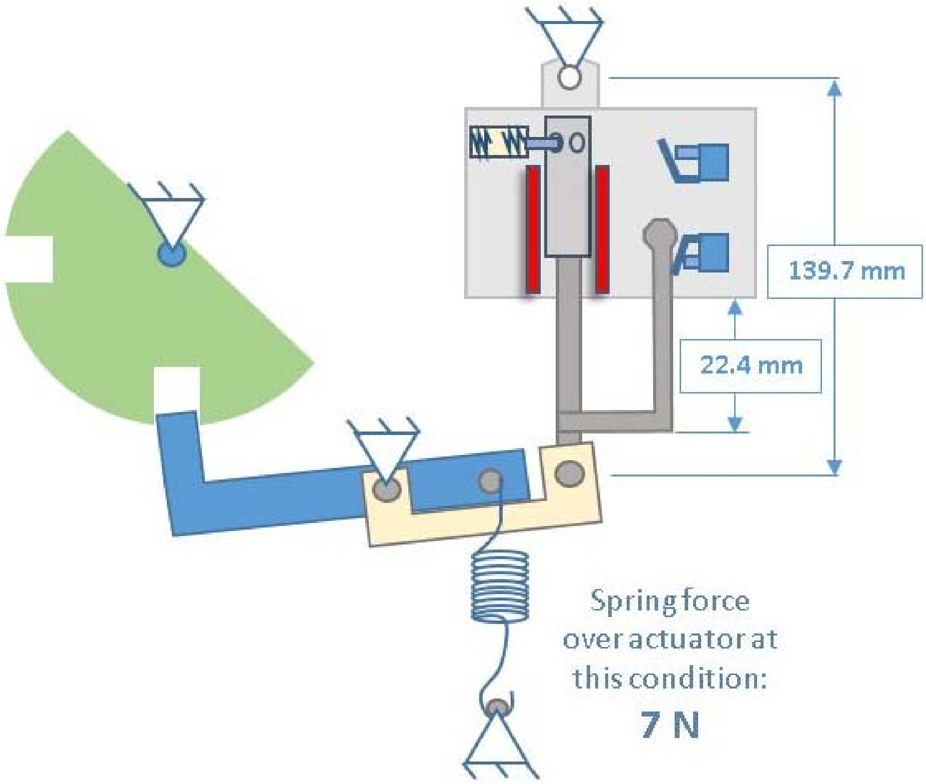


Figure 11: Probable mechanism condition during taxi and flight

2. The pilot did not exercise a free movement check, which would have engaged the gust lock due to the failed actuator and would therefore have detected the gust lock engagement,

According to test carried out by Embraer (Test Case 1), it is evident to the pilot when the gust lock is active. The AFM requires the rudder pedals to have full travel freedom of movement check during pre-flight.

3. The rudder surface locked prior to or during taxi, and the pilot used differential braking and asysmetrical thrust to counter aircraft tendency to the right

Pilot used differential brakes during taxi, mainly left brake pedal, to keep aircraft in a linear path. This indicates that aircraft was tending to the right, which is coherent with aircraft yaw tendency after liftoff. The rudder surface locked prior to or during taxi due to rudder inputs.
The test executed by Embraer (Test Case 1) validated that a pilot is still able to taxi the aircraft using asymmetric thrust and/or braking techniques when the gust lock is active.

4. When TLA was set to TOGA, interlocks commanded actuator retraction with no effect due to actuator failure

When TLA is greater than 25 degrees, interlocks command actuator retraction. But as the actuator had already failed, the interlocks had no effect.

5. During Takeoff Run, pilot was able to keep aircraft in centerline by means of diferential brakes, but right after liftoff, the yaw tendency to the right was evident

   While the aircraft was on the ground, pilot was able to compensate the aircraft tendency to the right, but the means used by the pilot on ground had no effect after liftoff, so the aircraft yawed to the right after liftoff.

3.6 Actuator Failure

During normal operating conditions, the gust lock actuator has the following characteritics:

- It is irreversible, meaning that the actuator does not move due to external traction nor compression forces. Irreversibility of the gust lock actuator is provided by a plunger, which is commanded by a solenoid. If the actuator is not energized, the plunger makes it irreversible.
- The actuator is able to drive forces in the order of 130N (30lbf). For comparison purposes, the force from the spring when it is totally extended is around 40N. Therefore, every time the actuator is energized, it will be able to overpower the force from the spring.

As the actuator was found in an intermediate position, there are two possibilities:

1. The actuator was pulled by the spring to the intermediate position: In Embraer's view this is not the most probable scenario, because it would require that:
   a. The plunger was not effective to provide its irreversibility function; and
   b. The actuator force was not enough to overcome spring force. This is unlikely, as spring force is at its maximum when the actuator is in a retracted position (in the order of 40N), and it decreases linearly to its minimum when actuator is in the extended position (~3N). Considering actuator stroke of 22.4mm, as observed in this event, the spring force would be in the order of 7N, which is much lower than the 130N provided by the actuator.
2. The actuator failed during extension or retraction, stopping at the found position. This scenario requires a single solenoid failure. The solenoid is energized while the actuator is moving; if it fails, the plunger will be released and lock the ball nut.

A solenoid failure during actuator movement seems a more plausible scenario: if during actuator retraction (or extension) the solenoid fails to hold the plunger, it will stop actuator movement. In this scenario, the motor would continue to be energized and trying to move actuator, but with an unexpected high load, causing the motor to overheat. In addition, it is more likely to have a solenoid failure while it is energized, which happens when the actuator is commanded to retract/extend.

Other gust lock actuator failure events have occurred in the field due to solenoid failures confirmed by tear down reports from the manufacturer. Solenoid degradation may happen due to scenarios such as microswitch failures or misadjustment (solenoid would remain energized for long periods).

As the plunger was found engaged exactly in a ballnut hole, it is more likely that it engaged during actuator movement than while the motor was stopped.

Besides its irreversibility characteristics, the actuator was designed and qualified to operate in load conditions provided by the spring.

3.7 Conclusion

After assessment of the incident , Embraer respectfully submits that the actuator failure and the pilot not detecting the subsequent rudder locking before takeoff were major contributing factors to the incident.

Embraer evaluated all scenarios and circumstances surrounding the incident and has taken the actions identified herein to reduce the possibilty of similar events.

Embraer is available to answer any further questions.

Dated: September 22th, 2016

Respectfully submitted,

[redacted]

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EMBRAER S.A.