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Analysis of an alternative actuator for primary control surfaces

Abstract

Background: Aviation Industry has adverse effects on the environment since past few years. Despite these effects, industry is expected to grow more than 10% strategically in many regions across the globe in a near future. Accordingly, several global aerospace Original Equipment Manufacturers (OEM) and Research organisations are focusing on this trend to develop eco-friendly aircraft which aim to use the renewable sources of energy. Output of that research is to Design, Develop, Manufacture and Qualify the All-Electric Aircraft (AEA) and release into the market within the near future. When it comes to the electrification of the aircraft, every single conventional system on the aircraft is driven using electric energy rather than hydraulics or pneumatics. Control surfaces and other secondary systems on the conventional aircraft operates using hydraulic or pneumatic driven actuators and they have direct or indirect effect on the environment. To begin with, this research has mainly focused on design and development of Jam-Tolerant Electromechanical or Electro-Mechanical Actuator (EMA) concepts.

Scope: Comparatively, with its Hydraulic and Pneumatic actuator counterparts, EMA's have potential benefits in the power efficiency, weight, and envelope sizes. However, EMA's has the lower reliability and one of the main parameters affecting the reliability factor is as they are not jam tolerant. This research addresses this issue and focused on developing jam tolerant or anti jam EMA concepts.

Methodology: Concepts for jam tolerant or anti jam EMA are proposed, then the desirable solution is developed.

Conclusion: The developed solution has achieved the aim of jamming problem by designing the "jam tolerant/anti jam EMA" that can be used in Primary Control Surfaces of the aircraft. However, with the modifications to the interfaces, it has potential to use in others such as Secondary Control Surfaces.

Keywords: aviation industry, alternative actuators, primary control surfaces, jam tolerant/anti jam EMA

Volume 6 Issue 4 - 2022

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Received: September 03, 2022 | **Published:** September 14, 2022

Introduction

Aviation Industry has adverse effects on the environment during its life. However, the industry is expected to grow more than 10% strategically in many regions across the globe in a near future.[1] According to a leading international body established by the United Nations Environment Program (UNEP) and the World Meteorological Organisation (WMO), air transport contributes to 4.9 per cent of human-caused climate change, including emissions of carbon dioxide and other greenhouse gases. In the year 2019, 9 billion passengers are flown across the globe and within the next 10 years is expected to be doubled. Also it is confirmed by UNEP and WMO that the major contributor of rise in these numbers is Kerosene and its chemical constituents which tend to emit the CO_2.[2]

Also, as per European Aviation Safety Agency (EASA) aerospace industry is one of the major contributors for raise in the current global temperature to 1.5°C above previous average. And it has taken the measures to reduce CO_2 emissions 45% by 2030 and go with net carbon zero by 2050. A snapshot of the aviation emissions and climatic impact is shown in Figure 1.[3] The strong growth rates in China, India, and other Asian economies are expected to continue over the next 20 years, elevating millions to middle class economic status. According to estimates by Oxford Economics, as cited in Airbus forecasts, the middle class could rise from 40 percent of the world's population in 2017 to 57 percent by 2037, so the air travelers increase to 8.2 billion.

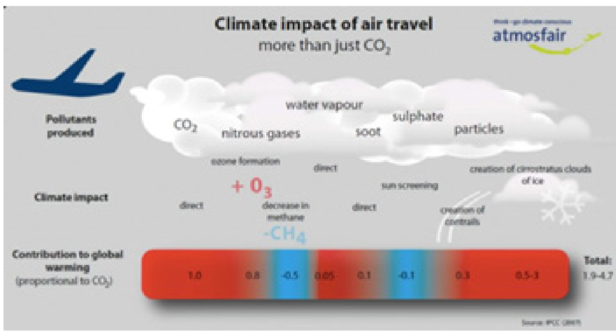
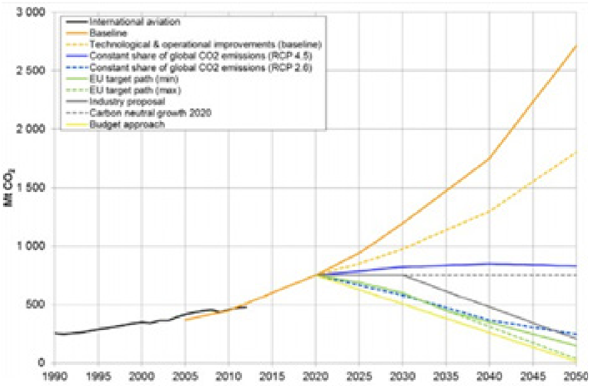
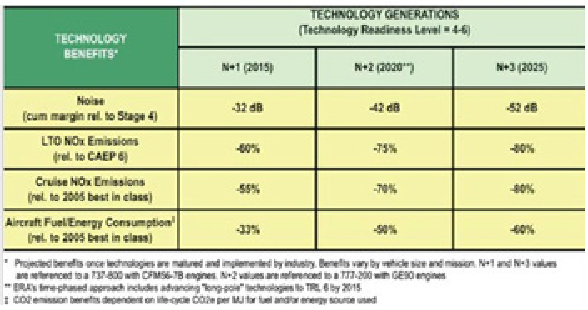


Figure 1 Climate impact on air travel.

As the middle class expands in developing nations, so will the demand for air travel. The International Air Travel Association (IATA) predicts 44 percent of the world's additional passenger trips will originate in China and India over the next 20 years. China will become the world's largest passenger market, overtaking the United States in 2025. India will move from number seven in the world to number three, and Indonesia from tenth to fourth by 2031.[4] From the studies conducted by the various institutions and organisations, aerospace industry has the global impact on the environment and many strict goals have been assigned to reduce the carbon foot- print, NOx and the noise levels as shown below in Figure 2.





TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines. N+2 values are referenced to a 777-200 with GE90 engines.
** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015
‡ CO2 emission benefits dependent on life-cycle CO2e per MJ for fuel and/or energy source used

Figure 2 Potential CO_2 emission, NOx, and noise reduction targets in aviation industry.

Future of aviation: aircraft electrification

Electric solutions offer better solutions towards cleaner and green environment than its counterparts non-renewable energy sources. Certainly, to reduce the footprints of CO_2, NOx & Noise levels and achieve the targets as shown in Figure 2, aerospace industry is moving towards all electric aircraft design, development, and qualification/certification strategies.

On one hand, aircraft electrification has advantages over reducing the environmental impact, on the other hand, it has several issues in meeting the design challenges as discussed below. In all-electric aircraft section, full propulsion is electric which will probably increase the mass of the airframes, because all the batteries or energy storage devices are additional to the actuation systems which are already installed on the airframe structures. Furthermore, as the aircraft is no longer shedding mass via fuel burn during the flight, the landing weight of aircraft to be higher than current. To compensate these effects, reduction of airframe mass is required and possible option to achieve the weight reduction on the same mission profile is the applying of electromechanical systems.

Electromechanical actuation system

Electromechanical actuators do not use hydraulic fluid, eliminating the presence of the toxic and flammable liquid and its associated piping, power sources and potential for leaks. Electromechanical actuators convert electrical energy to mechanical energy. An electric motor drives linear or rotary actuators. The rotary motion of the servo motor is coupled mechanically through a gearbox to an acme lead screw, ball screw or planetary roller screw for conversion to linear motion. Direct-drive versions are also possible in which the motor is directly coupled to the screw mechanism without a gearbox. A primary benefit of electromechanical actuators compared to conventional electrohydraulic actuators is their elimination of hydraulic fluid. The absence of this liquid and the pipes needed to carry it results in increased safety, reduced weight, saved space, higher energy efficiency and lower environmental impact. Easier maintenance is facilitated by no risk of leaks and a lack of fluid conditioning tasks like filling, charging, purging, and filtering.[5]

As per the study conducted on aircraft actuation technologies,[5] electromechanical actuators may appear to be an optimal solution for more electric and all-electric aircraft since they eliminate the need for hydraulic fluid. Current electromechanical actuator technology, however, runs into limitations for applications. For example, the downsides of electromechanical actuators include backlash, jamming and thermal management issues. Backlash can occur due to gaps between interlocking gear teeth or screw threads and results in positional inaccuracies. Backlash can increase as repeated wear cycles cause surface degradation. Jamming is a risk for electromechanical actuators due to potential failures involving screw components interfering or seizing up, preventing motion of the actuator. Electromechanical actuators are not yet considered mature enough as actuation solutions for primary flight controls that continuously perform safety-critical aircraft flight trajectory corrections (e.g., the rudder adjusts yaw, the ailerons control roll, and the elevator changes pitch). Electromechanical actuators, however, are entering service in less critical roles onboard aircraft. They are used on the Boeing 787 for trimming the horizontal stabilizer, actuating the mid-board spoilers and activating the landing gear brakes.[6] An example of EMA layout is shown in Figure 3.

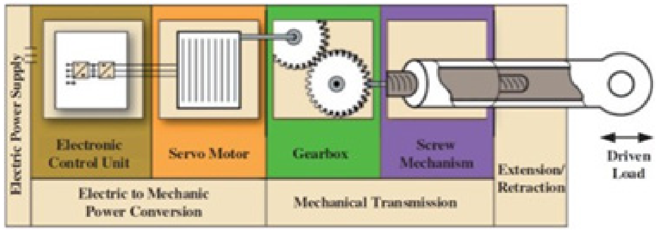


Figure 3 Electromechanical actuator layout.

Overview of EMA operation

As per the study conducted, EMA Jam prone areas are shown in Table 1. Majority of research is already conducted in Electric Motor Jam and Gearbox Jam and potential solutions are already in-service in the aerospace market. However, solutions concerned with Bearing, Gear Box, Ball screw or Roller screw jam are very limited, and it has decided to mainly focus on this area and propose the potential solution. Hierarchical design process for addressing the ball screw or roller screw jamming issue in the EMA is as follows also shown in Figure 4.

Table 1 EMA jamming design philosophy

Jam prone areas in EMA	Mitigation
Prime mover (electric motor)	Solutions pertaining to integral dual redundant motor configuration already exists in the market
Gear Box	Clutches can be used. (Which are already proven in commercial aerospace market) Current study also focuses in this area
Bearing/ Ball/ Roller Screw	Limited solutions are available. Current study shall focus on this area

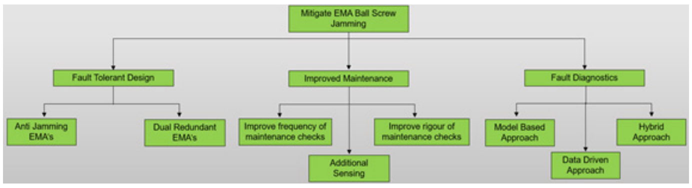


Figure 4 Hierarchical process model_design of jam tolerant EMA_ballcrew or roller screw jamming.

Conceptual proposal: jam tolerant EMA (Rotating screw & translating nut configuration)

EMA configuration general layout

Note: Conceptual development of Jam tolerant actuator shall focus only on proposing and analysing the anti-jamming features. It means; bearings, electric motors and other miscellaneous items are not considered and analysed as part of this study (Figure 5).

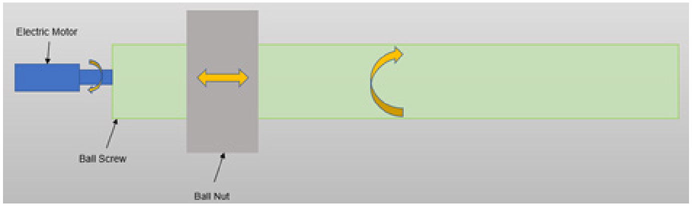


Figure 5 EMA, rotating screw & translating ball nut configuration.

Concept definition

(Figures 6–11), (Table 2).

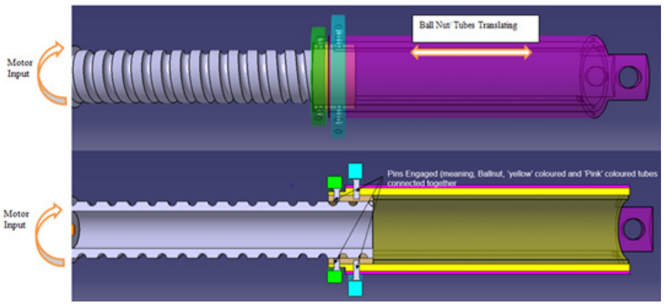


Figure 6 Jam tolerant EMA concept _ overview (100% stroke _ Normal Operation).

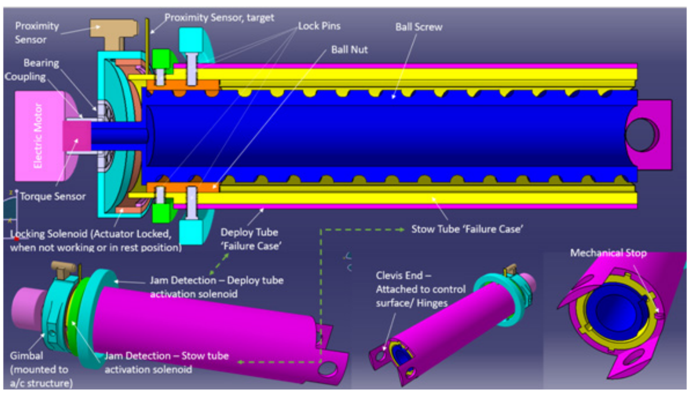


Figure 7 Jam tolerant EMA concept overview (0% stroke normal operation).

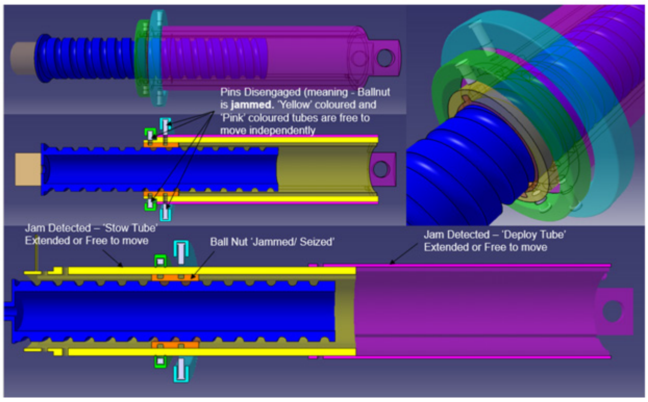


Figure 8 Jam tolerant EMA concept overview (50% stroke _ jammed operation _ pins disengaged).

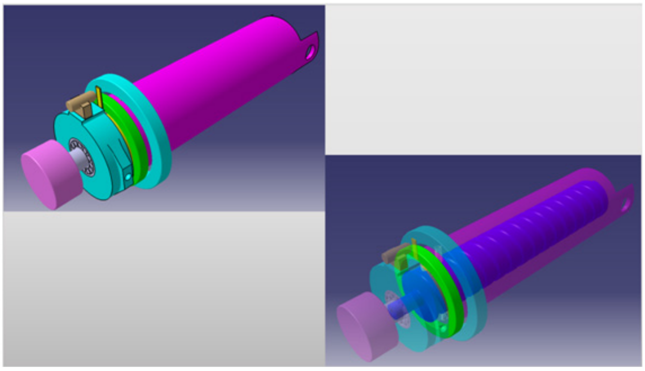


Figure 9 Jam Tolerant EMA concept: isometric overview.

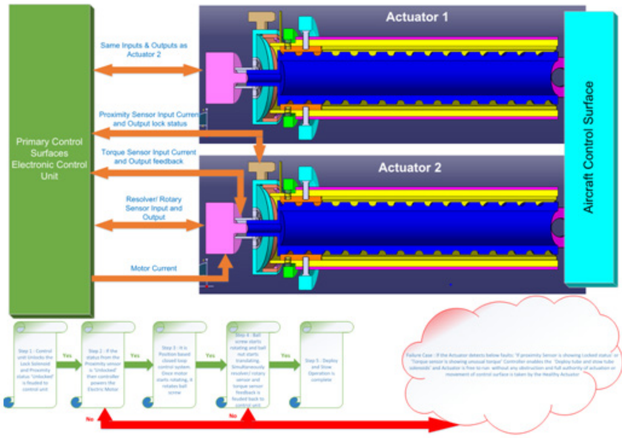


Figure 10 Jam Tolerant EMA concept: system architecture.

Figure 11 Jam Tolerant EMA concept: built prototype parts.

Citation: Shahneh A, Pandirolla SKV. Analysis of an alternative actuator for primary control surfaces. *Aeron Aero Open Access J.* 2022;6(4):145–149. DOI: 10.15406/aaoaj.2022.06.00153

Table 2 Jam tolerant EMA concept operation sequence

Serial number	Working operation
Explanation of Figure 6	
1	In this concept ball screw rotates using electric motor power and ball nut translates simultaneously.
2	In Figure 6, it is shown that the ball nut is at 0% stroke and 100% stroke.
3	In general, aircraft control surfaces are directly connected to the actuators or connected through the linkages/ hinges (for the load share and reduce the actuator size).
Explanation of Figure 7	
4	As shown in Figure 7, concept has the below components.
	(a) Ball screw – Electric motor rotary input is provided to the ball screw. Torque sensor is installed between/ at the interface of electric motor shaft and ball screw.
	(b) Ball nut – Rotary input from the ball screw is converted into translation. Aircraft control surface is connected to the ball nut.
	(c) This concept has three solenoids, all are rotary type.
	(d) Rotary solenoid, which is mounted on the gimbal, holds the actuator in locked position at 0% stroke and when it is stationary or not in operation.
	(e) Another rotary type solenoids (X 2) will be operated (installed on the tubes) when jam is detected.
	(f) Lock pins (X 4) basically creates a link between ball nut, deploy tube and stow tube. Pins enables three components to move together.
	(g) Gimbal will be mounted to the aircraft structure.
	(h) Inductive proximity sensor is installed on the gimbal mount is stationary and provide the actuator status to the flight computers.
	(i) Proximity sensor lock target is installed on the tube.
	(j) When actuator is stationary or when not in motion, the lock sensor target is 'near' to the lock position. Represents 'Locked' position. When the actuator target is in the 'far' position, it means it is in 'Un locked' position. Both the status is feuded back to the flight computers.
Concept: Normal Operation shown in Figures 6 & 7	
Step 1	Rotary Lock Solenoid (installed on the left of the actuator) is energised and then it disengages the locking elements of the actuator. Simultaneously, lock feedback (far) from the proximity sensor is feuded back to the control unit.
Step 2	Once the lock status is read as 'far' by the controller, it then energises the electric motor.
Step 3	Once the Electric motor starts rotating, it rotates the ball screw and thus ball nut translates (extends)
Step 4	Once the extension is complete, it retracts back to its zero position. Once the zero position is achieved then proximity sensor target position 'near' is feuded back to the controller. Therefore, controller cuts the electricity to the motor.
Concept: Jam Conditions in Figures 8 to 10	
Step 1	Toque sensor feedback is continually feuded to the control unit. In normal operation torque generated by the motor is let's say 'a' Nm. When the jam is detected, it will be a+1 or a-1 Nm.
Step 2	When the Jam is detected (bearing/ gear box/ ball screw seized), the unusual torque is detected by the controller. In such scenario two rotary solenoids installed on the deploy and stow tubes gets energised.
Step 3	When two rotary solenoids energised, they rotate at certain angle (let's assume 45 degrees).
Step 4	Lock pins (X 4) installed are spring loaded and when the rotary solenoid is energised the spring-loaded lock pins (X 4) pops out and settles in the holes of the lock solenoid.
Step 4	When pins are popped out, the ball nut, deploy tube and stow tube are free to slide independently. It is tried to achieve the free motion independent to the motor rotation.
Step 5	Therefore, when the jam is detected at 0% of the stroke deploy tube slides out or move freely without any restriction. Stow tube cannot slide out because, the mechanical stop installed on the stow tube will only allow to move in one stow direction but not in deploy direction.
Step 6	In the same manner, if the jam is detected at 50% or 100% or any position of the stroke. During deploy/ extend, the deploy tube will side out/ move freely. Also, during stow/ retract only stow tube will slide in/ move freely. Deploy tube cannot move to stow direction as it has mechanical stop which restricts the motion and vice versa with the stow tube.
Step 7	As shown in Figures 9 and 10, the proposed architectures use two actuators per one aircraft control surface.
	In general, when there are no Jam tolerant actuators used on the aircraft control surfaces, when one actuator is jammed the other healthy actuator try to move the control surface. However, the jammed actuator will restrict the motion as it is stuck in between.
	However, in the proposed configuration when the jam is detected or one actuator is seized, the healthy actuator will take over the control surface movement. And jammed actuator will not restrict the movement of the control surface as discussed above, deploy, or stow tubes slides in and out freely.
	Reaction Torque _ Purpose of using two tubes
	As discussed in the Figures 8 to 10, when the jam is detected if ball nut does not have a contact with the deploy and stow tubes. The end torque or load applied on the actuator will tend for misaligning the ball but position. And in that case, ball nut and anti-jam features (deploy and stow stubes) loose contact with each other because of misalignment.

Load path analysis

After analysis of the tension and compression load paths, it is evident that actuator load axis is in line with the aircraft control surface/ hinge axis. Therefore, offset loading is not seen and all the actuator components subject to the equal load share in this proposed concept. Therefore, with minimal/ no effect on the actuator performance (Figure 12).

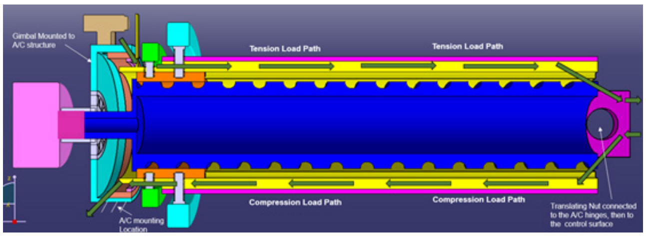


Figure 12 Load path analysis.

Feasibility with aircraft interfaces

In the modern aircraft,[7] actuators are mounted to the panel using the hinges and create a moment in the or guide ways as shown in Figure 13.

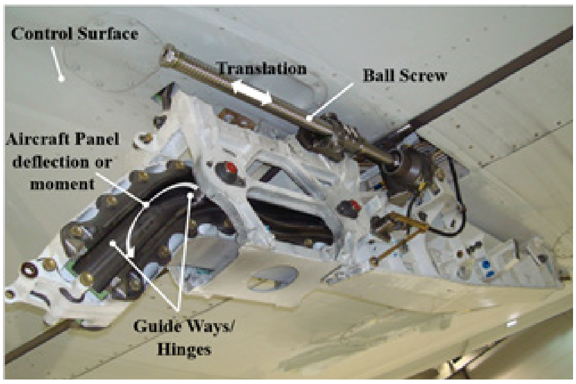


Figure 13 Actuator mounting on the modern aircraft.

In this concept as shown Figure 14, it can be noticed that movement of ball screw and connection of control surface is at minimal distance. This will not have any impact on the aircraft interfaces/ interconnections and thus on the aircraft performance.

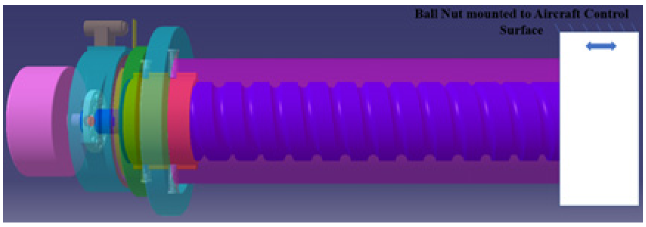


Figure 14 Concept: aircraft interface feasibility.

Discussion & conclusion

Following an extensive study on the conventional aircraft technologies, it is observed that aerospace industry contributes to more than 2.5% of the global emissions and analysed how market is leaning towards the MEA and AEA segments and EMA's will play a critical role in the future of aviation industry. Secondly, study was continued to observe the various technological advancements available in the market about the electromechanical actuation and it was observed that advancements regarding the dual redundant and fault tolerant motors are already in practice and furthermore matured with minimal failures. And performed huge research for identifying the issues with the EMA and it was evident that jamming of EMA is the biggest challenge which aerospace industry is facing and determined how it is creating a barrier to use the EMA onto the primary control surfaces of the aircraft. Many solutions pertaining to the jamming features already exist in the market but most of the solutions have limitations in addressing the jam of actuator throughout the full stroke. Then it is planned to fill that gap and decided to proceed further in designing the Jam tolerant actuator concept, which can be operated without creating any obstructions to the aircraft control surface when one actuator is jammed.

Finally, by following the design process Jam tolerant EMA concept has been proposed. Based on the load path and interface analysis, the proposed concept is analysed and concluded as the potential solution.

Acknowledgements

None.

Conflicts of interest

The Authors declares that there is no Conflict of interest.

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