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AN INVESTIGATION OF EFFECTS OF FLIGHT MANEUVERS ON A SUPERSONIC AIRCRAFT WITH HORIZONTAL TAIL ACTUATOR FAILURE

Seyool Oh*, Inje Cho*, Craig McLaughlin**
***Korea Aerospace Industries, ltd, **The University of Kansas**

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Abstract

Modern aircraft with fly-by-wire systems have high performance, precision control systems that are different from conventional aircraft with manual control systems. Without precise actuator functions, supersonic aircraft can be unstable or have limited performance. To reduce the operational risk from actuator damage or failure, safeguards can be implemented by designing a reconfigurable control system. This reconfigurable control system is therefore capable of improving the safety and survivability of supersonic aircraft. This paper examines the effects of flight maneuvers on a supersonic aircraft with actuator failure using a reconfigurable control system.

1. Introduction

Modern military aircraft in particular have statically unstable characteristics to improve maneuvering and performance. As a result, these aircraft in subsonic or supersonic cruise flight rely on a flight control computer to stabilize these unstable characteristics by commanding actuators to deflect control surfaces thereby reducing the workload of the pilot [1],[2].

There are some papers which show the effects of flight in a subsonic flight condition under actuator failure. However, there are few papers that provide the effects of maneuvers in the supersonic regime with a modern military aircraft. This research presents the simulation results for the design of a control system with an optimized actuator and supports to verify actuator hinge moments on a prototype "Iron Bird" in the dynamic test facility for the new military aircraft.

After the changes of hinge moments are discussed in asymmetric conditions about horizontal tails, the limits of maneuverability in the aircraft's flight envelope are discussed. In addition, the hinge moment is calculated for the forward and aft C.G. locations of the supersonic aircraft and analyzed from the perspective of actuator failure. The effects of flight maneuvers on loading a variety of weapons with actuator failure are analyzed.

2. Aircraft Model

The T-50 Golden Eagle supersonic trainer was selected to investigate the current methodology used in a six degrees of freedom (6DOF) simulation for this research (Figure 1). The T-50 has a single engine producing 18,000 lb of thrust. It was manufactured by Korea Aerospace Industries (KAI) for the Republic of Korea Air Force (ROKAF). The length is 43.1 ft (13.14 m). The wing span is 30.0 ft (9.45 m). The height is 15.8 ft (4.82 m). The maximum takeoff weight is around 27,000 lbs. The aircraft is capable of Mach 1.5. Maximum thrust to weight is 1.0 [3], [4].

Fig. 1. Aircraft Model: T-50 aircraft

3. Simulation Results of Actuator Failure and No Failure

The aircraft's actuators for the primary control surfaces include flaperons (combination flaps and ailerons), rudders, and horizontal tails. This paper investigates the failure of horizontal tail actuation because its loss represents a direct threat to longitudinal stability and is therefore a driving factor in the aircraft's operational safety and maneuverability

3.1 Subsonic Maneuver without Store Loading at 20,000 ft

Figs. 2 and 3 show the simulation of T-50 without store loading in subsonic flight at 20,000 ft and a control stick input with ±10 lbs to a 360° roll.

One of the most important combat maneuvers is commanding a roll rate (p_b). Maximum roll rate without actuator failure is ~114 deg/sec while the loss of control to the left horizontal failure reduces this to ~70 deg/sec. In the bank angle (ϕ) of the left horizontal tail failure, it takes 7 seconds to perform a 360° roll. In the bank angle (ϕ) of no failure (normal), it takes 5.4 seconds to perform a 360° roll. The side slip angle (β) is a difference of less than one degree.

As shown in Figure 3, when the actuator of the left horizontal tail (HT_L) failed, it automatically changed to a damped bypass mode. Both flaperons' deflection in the left horizontal tail failure is less than the normal right horizontal tail. In the left horizontal tail failure, the hinge moment of the left horizontal tail ($HM\ HT_L$) moves to zero.

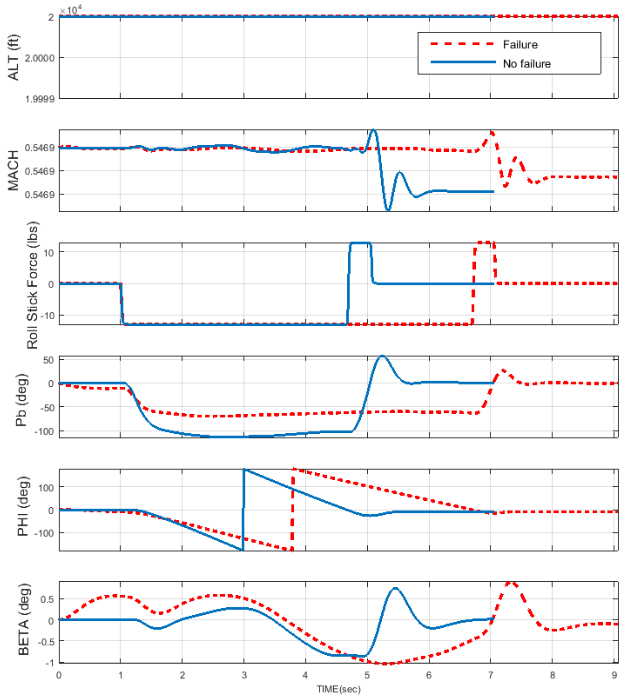


Fig. 2. Simulation results without store loading: altitude (20,000 ft), Mach number (0.547), roll stick force, Pb, ϕ, and β between no failure and failure

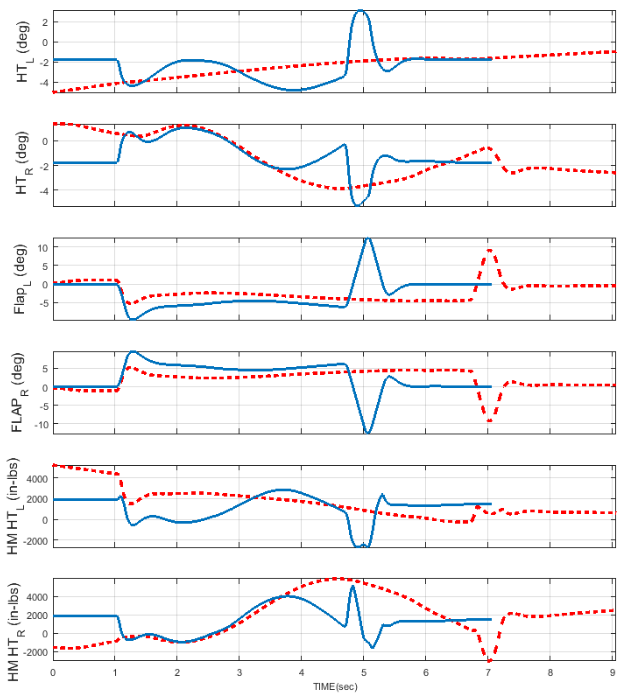


Fig. 3. Simulation results (20,000 ft, Mach 0.547) without store loading: HTL, HTR, FlapL, FlapR, HM HTL (Hinge Moment of the left Horizontal Tail), and HM HTR (Hinge Moment of the right Horizontal Tail) between no failure and failure

3.2 Subsonic Maneuver with Store Loading at 20,000 ft

Figs. 4 and 5 show the simulation of T-50 with store loading in subsonic flight at 20,000 ft and a control stick input with ±10 lbs to a 360° roll.

The aircraft roll rate (p_b) response with and without the store loading are similar to the roll rates without store loading. The nominal roll rate including stores is ~116.6 deg/sec which reduces to ~72.18 deg/sec in the event of actuation failure. In the bank angle (ϕ) of the left horizontal tail failure, it takes 7.4 seconds to perform a 360° roll. In the bank angle (ϕ) of no failure (normal), it takes 6.5 seconds to perform a 360° roll. The side slip angle (β) is a difference of less than one degree.

As shown in Figure 5, when the actuator of the left horizontal tail (HT_L) failed, it automatically changed to damped bypass mode and the hinge moment of the left horizontal tail (HM HT_L) moves to zero. Both flaperons' deflection in the case of a left horizontal tail failure is less than nominal.

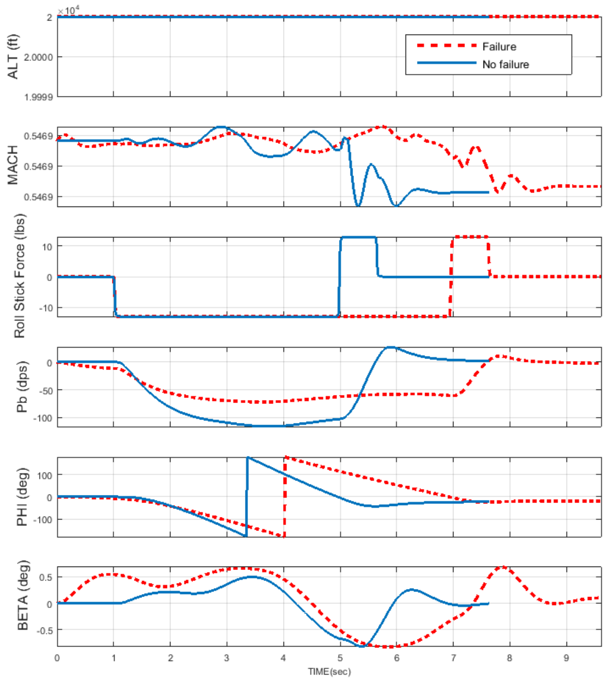


Fig. 4. Simulation results with store loading: altitude (20,000 ft), Mach number (0.547), roll stick force, pb, ϕ, and β

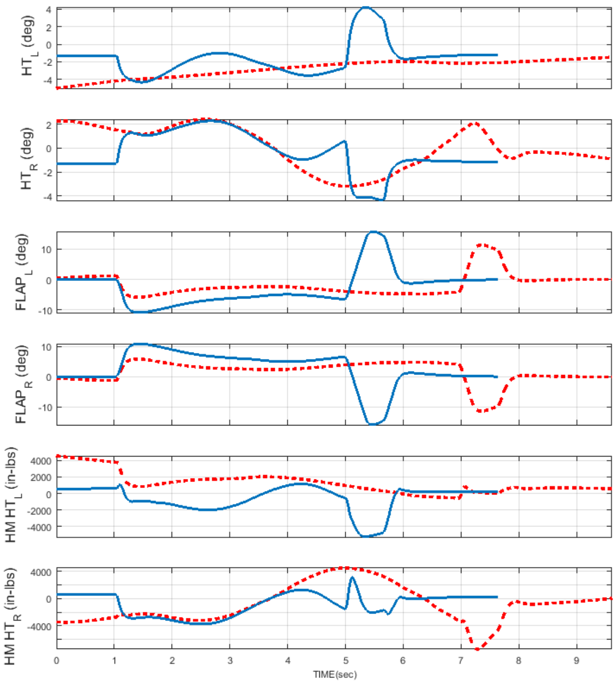


Fig. 5. Simulation results with store loading (20,000 ft, Mach 0.547): HT_L, HT_R, $Flap_L$, $Flap_R$, HM HT_L, and HM HT_R between no failure and failure

3.3 Transonic Maneuver without Store Loading at 20,000 ft

Figs. 6 and 7 show the simulation of T-50 without store loading in transonic flight at 20,000 ft and a control stick input with ±10 lbs to a 360° roll.

The transonic roll rate during normal operation increases to ~131.2 deg/sec, this reduces to ~68.13 deg/sec in the case of actuation loss on the left horizontal tail. In the bank angle (ϕ) of the left horizontal tail failure, it takes about 7.5 seconds to perform a 360° roll. In the bank angle (ϕ) of no failure (normal), it takes about 4.7 seconds to perform a 360° roll. The side slip angle (β) is a difference of less than one degree.

As shown in Figure 7, when the actuator of the left horizontal tail (HT_L) failed, it again automatically changed to a damped bypass mode and the hinge moment of the left horizontal tail again moves to zero. Both flaperons' deflection in the case of actuator failure is less than nominal.

The effect of actuator failure on the case without a store loading increased the maximum hinge-moment from approximately 10,000 in-lbs (nominal operation) to 15,410 in-lbs (failed actuation). The effect of the store loading results in a nearly four-fold increase in the maximum horizontal tail hinge moment (from approximately 4,000 in-lbs without stores to 15,410 in-lbs with stores) during the worst case of actuator failure.

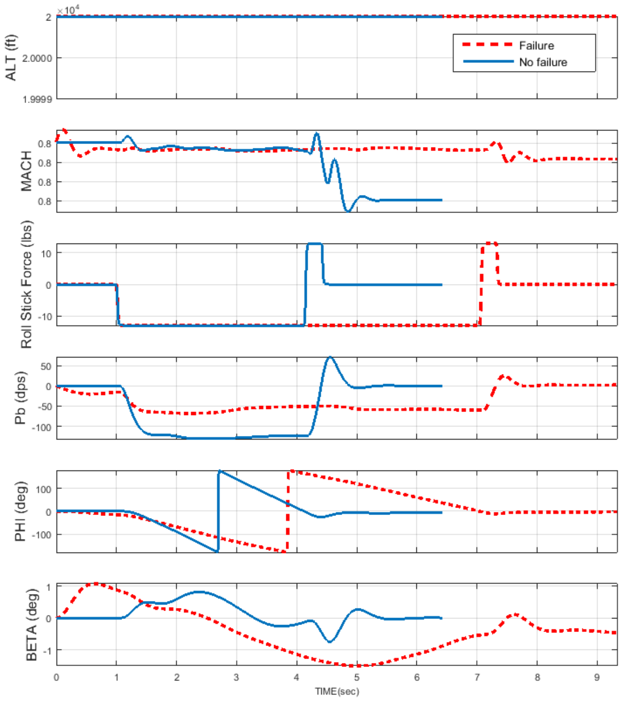
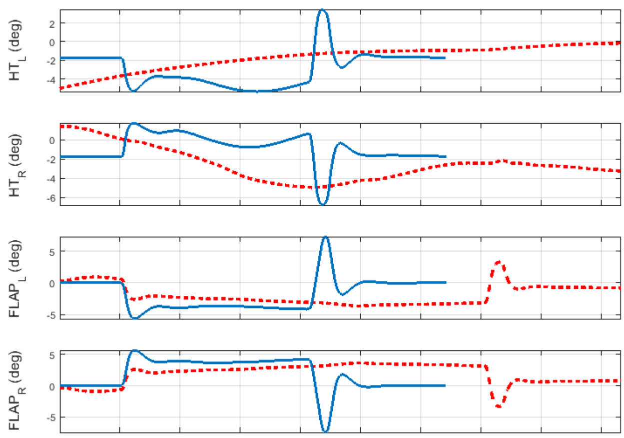


Fig. 6. Simulation results without store loading: altitude (20,000 ft), Mach number (0.8), roll stick force, Pb, ϕ, and β between no failure and failure



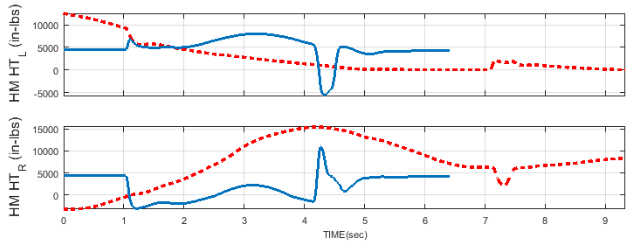


Fig. 7. Simulation results without store loading (20,000 ft, Mach 0.8): HT_L, HT_R, $Flap_L$, $Flap_R$, HM HT_L, and HM HT_R between no failure and failure

3.4 Transonic Maneuver with Store Loading at 20,000 ft

Figs. 8 and 9 show the simulation of T-50 with store loading in transonic flight at 20,000 ft and a control stick input with ±10 lbs to a 360° roll.

The transonic roll rate (p_b) responses with and without actuation failure and including a store loading are similar to the roll rates without the store loading. The nominal, transonic roll rate is ~129 deg/sec while the case with actuator failure reduced the roll rate to ~63.2 deg/sec. In the bank angle (ϕ) of the left horizontal tail failure, it takes about 9.1 seconds to perform a 360° roll. In the bank angle (ϕ) of no failure (normal), it takes about 5.9 seconds to perform a 360° roll. The side slip angle (β) is a small difference of less than one degree.

As shown in Figure 9, when the actuator of the left horizontal tail (HT_L) fails, it automatically changes to a damped bypass mode and the hinge moment of the left horizontal tail moves to zero. Both flaperons' deflections in the actuation failure case is less than the unaffected right horizontal tail.

The maximum hinge moment of the left horizontal tail under failure with a store loading is about twice the hinge moment of the same left horizontal tail failure case without a store loading. The maximum hinge moment of the left horizontal tail failure with store loading is about 7,000 in-lbs.

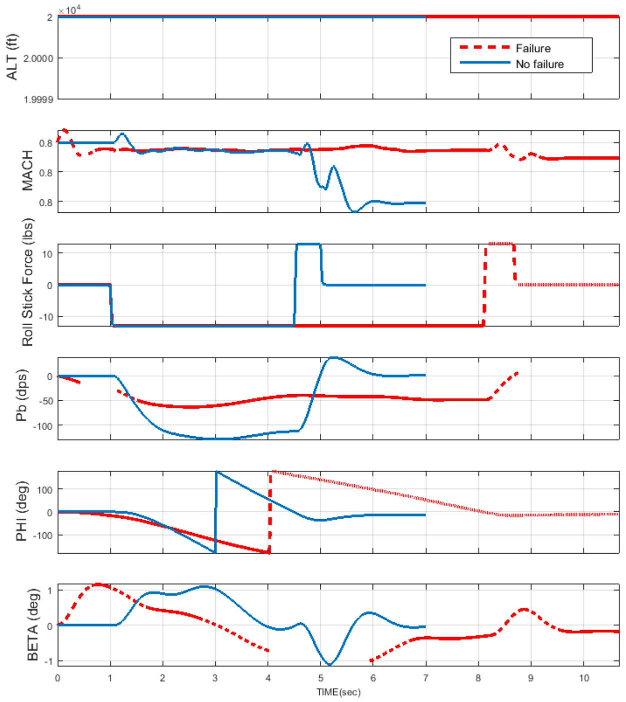


Fig. 8. Simulation results with store loading: altitude, Mach number (0.8), roll stick force, Pb, ϕ, and β

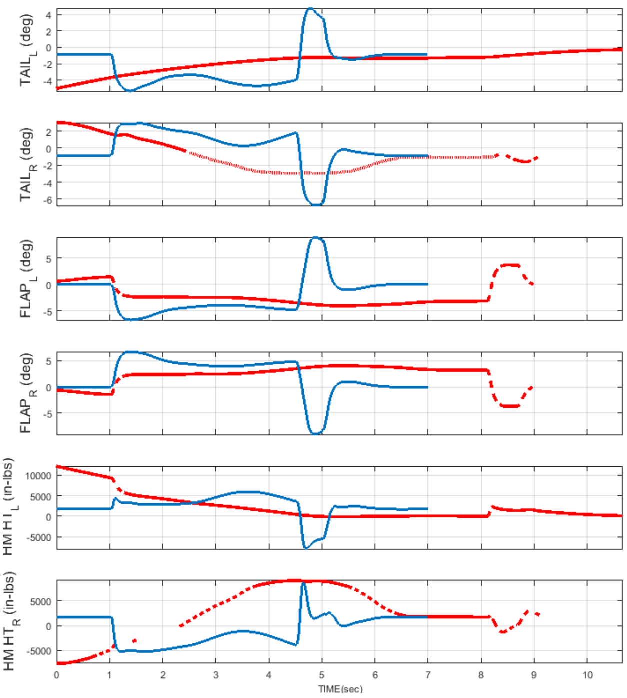


Fig. 9. Simulation results with store loading (20,000 ft, Mach 0.8): HT_L, HT_R, $Flap_L$, $Flap_R$, HM HT_L, and HM HT_R between no failure and failure

3.5 Supersonic Maneuver without Store Loading at 20,000 ft

Figs. 10 and 11 show the simulation of T-50 without store loading in supersonic flight (Mach 1.2) at 20,000 ft and a control stick input with ±10 lbs to a 360° roll.

The supersonic roll rate during normal operation is ~77.77 deg/sec. However, this increases to ~121.2 deg/sec in the case of actuation loss on the left horizontal tail. In the bank angle (ϕ) of the left horizontal tail failure, it takes about 5.1 seconds to perform a 360° roll. In the bank angle (ϕ) of no failure (normal), it takes about 6.7 seconds to perform a 360° roll. In failure condition of supersonic regime, roll rate is bigger than normal operation because the side slip angle (β) during failure is larger than normal operation. The time of performing a 360° roll in failure is faster than normal operation. In supersonic regime, small perturbation of side slip angle (β) makes roll rate and the time of performing a 360 larger and faster.

As shown in Figure 11, when the actuator of the left horizontal tail (HT_L) failed, it again automatically changed to a damped bypass mode and the hinge moment of the left horizontal tail again moves to zero. Both flaperons' deflection in the case of actuator failure is larger than nominal.

The effect of actuator failure on the case with a store loading increased the maximum hinge-moment from approximately 70,000 in-lbs (nominal operation) to 80,000 in-lbs (failed actuation).

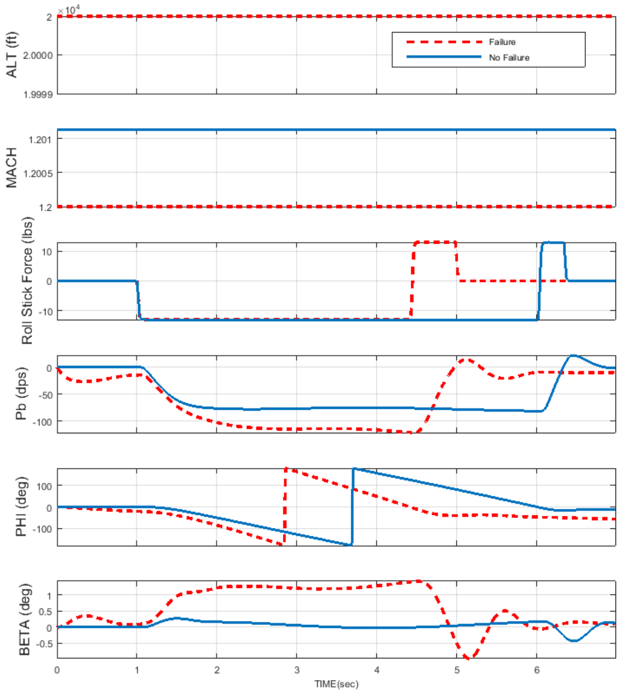


Fig. 10. Simulation results with store loading: altitude, Mach number (1.2), roll stick force, Pb, ϕ, and β

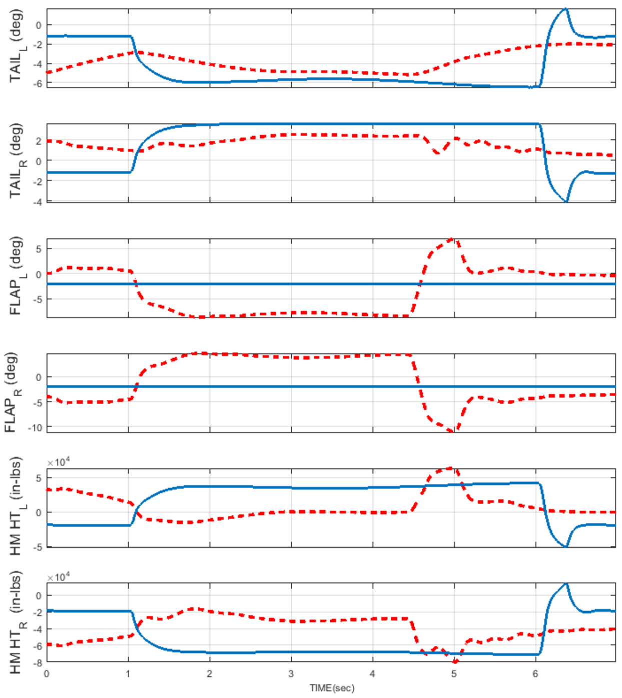


Fig. 11. Simulation results with store loading (20,000 ft, Mach 1.2): HT_L, HT_R, $Flap_L$, $Flap_R$, HM HT_L, and HM HT_R between no failure and failure

3.6 Subsonic Maneuver with most forward CG, nominal CG, and most aft CG at 20,000 ft

Fig. 12 shows the simulation of T-50 without store loading in transonic flight at 20,000 ft and a control stick input with ±10 lbs to a 360° roll. Based on the results below Pb, ϕ, HTR, HM HTL, and HM HTR, are more sensitive to aft CG (center of gravity) compared to forward CG and nominal CG cases.

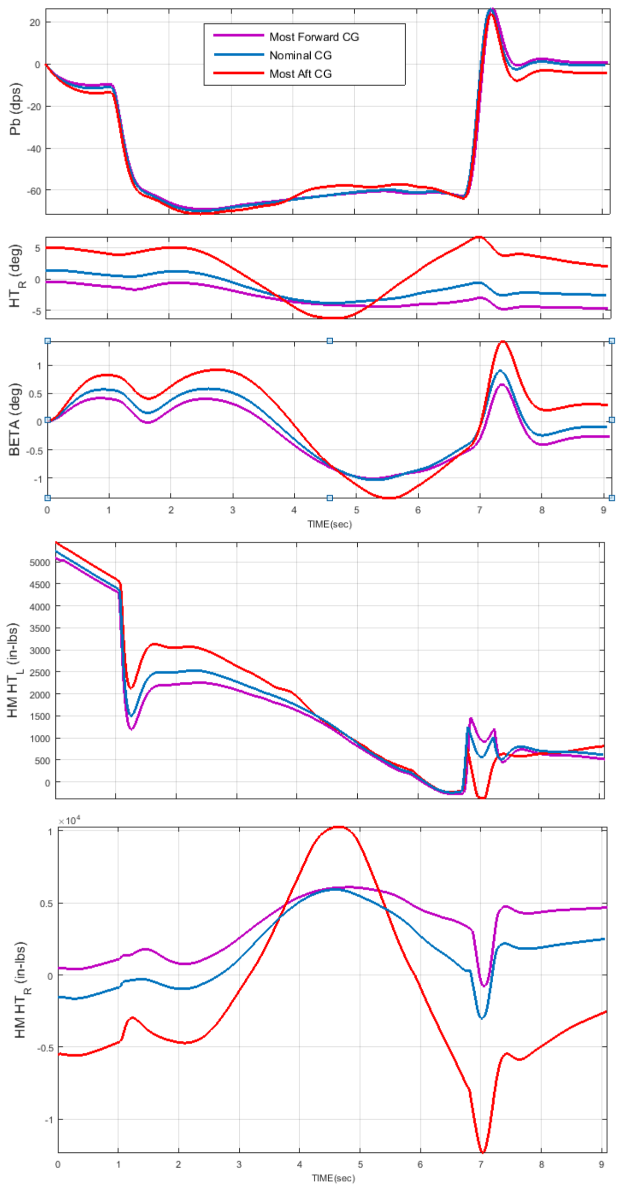


Fig. 12. Simulation results without store loading (20,000 ft, Mach 0.547): pb, ϕ, β, HT_R, HM HT_L, and HM HT_R at Most Forward CG, Nominal CG and Most Aft CG

3.7 Handling Qualities with most forward CG, nominal CG, and most aft CG

Fig. 13 shows the simulation of T-50 without store loading in transonic flight at 20,000 ft and a control stick input with ±10 lbs to a 360° roll. Regarding z-axis acceleration (Nz), handling qualities degrade at the most-aft CG condition. As shown in pitch rate (Qb) of Fig. 13, the actuator failure at the most-aft CG condition also degrades aircraft performance. The degradation of aircraft performance increases the pilot's workload.

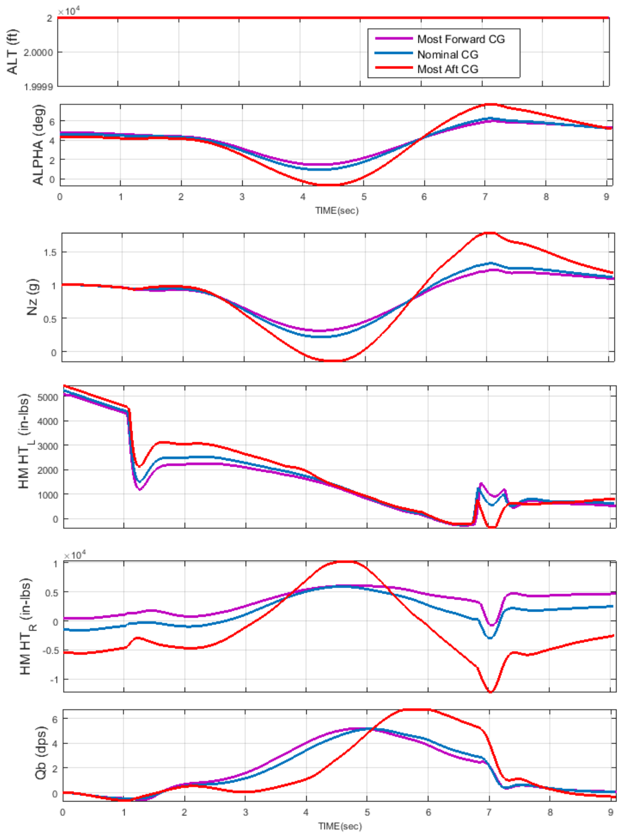


Fig. 13. Simulation results without store loading: Alt, Mach number, α, Nz, HT_R, HM HT_L, and HM HT_R at Most Forward CG, Nominal CG and Most Aft CG

4. Conclusions

This paper has presented the effects of flight maneuvers on a T-50 aircraft with actuator failure. It was ascertained that the failure of the left horizontal tail degrades the roll rate and the simulation results at the most-aft CG condition is significantly degraded more than the most-forward and nominal CG conditions. Even though the roll rate in nominal conditions (no actuation failure) changes with aircraft speed, the roll rate in the actuation failure case does not significantly affect the aircraft Mach number. During a failure condition in the supersonic regime, roll rate is larger than normal operation because small perturbation of side slip angle (β) makes roll rate faster. In regard to the aircraft handling qualities, the actuation failure understandably degrades the aircraft's performance and capability.

Copyright Statement

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