Research on Risk Assessment with Uncontrollable High Thrust for Civil Airplane

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Abstract. Not all single failures and probable combinations of failures that can cause UHT malfunction can be eliminated for the civil airplanes, a petition for a partial exemption from FAR25.901(c)/CCAR25.901(c) related to UHT is usually requested. The risks associated with exempting the UHT from FAR25.901(c)/CCAR25.901(c) should not be greater than those currently known and accepted for comparable existing transport category airplanes. Based on the development of a high horizontal tail airplane with 2 rear-mounted engines, this paper proposes a method for UHT malfunction risk assessment from handling qualities aspect by simulation analysis and simulator tests.

Keyword: Uncontrollable high thrust (UHT), Exemption, Simulator test.

1 Introduction

For transport category airplanes, the flight crew normally control engine thrust/power directly by means of a thrust/power/throttle lever or indirectly by means of an auto-throttle. Within traditional engine control systems, there are numerous single and anticipated combinations of failures that will result in losing these normal means of control. A subset of the resulting failure conditions may include actual thrust/power either increasing to significantly higher than commanded and/or remaining high when low thrust/power is commanded (or would have been had the failure not made that problematic, such as in the case of a stuck throttle). This subset of failure conditions is referred to herein as “uncontrollable high engine thrust/power” or “UHT” failure conditions. In other words, if the flight crew are unable to reduce excessive engine thrust/power through the normal means, that is a “UHT” failure condition.

These failures, and the hazards they pose, have long been inherent in transport airplane designs. In fact, the “fail-safe” states for engine controls have traditionally been chosen to protect high thrust capability and allow the flight crew to decide when an engine shut down is appropriate. Compliance with the relevant airworthiness regulations within parts 21, 25 and 39 have traditionally been based in part on accepting an assertion that the flight crew can recognize and safely accommodate these “uncontrollable high thrust (power)” conditions, including shutting down the affected engine via an independent fuel shutoff as required, before such a failure can pose an unacceptable hazard to the airplane. Over the last 20 years, the average rate of occurrence for the uncontrollable high thrust failure condition on turbosfan-powered large transport category airplanes has remained, as reported by industry, relatively constant at about one every 2.5 million flight hours. This would indicate that to date an “Uncontrollable high thrust failure condition” has occurred hundreds of times without...
resulting in a single reported serious injury. Nevertheless, in recent years, several factors have raised the risks and authority concerns associated with these types of failure conditions:

1) In recent years, engineering studies and service experience, including a 1997 Saudi Arabian Airlines Boeing 737-200 accident[1], indicate that the traditional assertion that flight crews will recognize and safely accommodate loss of the normal means to control engine thrust (power) is not always valid.

2) The fact that some trends, both in design and operation, are tending to increase the risks associated with uncontrollable high thrust failures.

There are numerous regulations which may limit allowable UHT failure modes, effects and/or rates. The most limiting regulation is usually FAR25.901(c)[2]/CCAR25.901(c)[3], which states in part that: “no single failure or malfunction or probable combinations of failures will jeopardize the safe operation of the airplane”. Certain aircraft manufacturers has been unable to eliminate all single failures and probable combinations of failures that can cause an engine to produce high thrust while not responding to the thrust levers. If the applicant cannot show compliance to 25.901(c), they may request a finding of equivalent safety or a petition for a partial exemption from 25.901(c) related to engine uncontrollable high thrust.

All practicable actions should be taken to minimize the adverse effects on safety associated with requesting this petition. These will include, but are not limited to, practical actions to eliminate or further reduce the risks by improving designs, procedures, training and instructions for continued airworthiness, and the risks associated with the partial exemption are no greater for the proposed type designs than those currently known and accepted for comparable existing transport category airplanes. Acceptable risk for this provision can be characterized as:

1) The airplane complies with all applicable regulations for any foreseeable uncontrollable high thrust failure conditions in flight, except possibly during approach below 400 feet.

2) The expected overall frequency of occurrence of uncontrollable high thrust failure conditions is less than once per ten million airplane operating hours.

The following of this paper will offer an example for confirming whether the aircraft is under acceptable risk level, base on the handling qualities analysis and simulator tests of a high horizontal tail airplane with 2 rear-mounted engines.

2. Risk assessment method

According to the FAA memorandum[4], close attention should be paid to the following potentially Hazardous or Catastrophic single failure scenarios when confirming whether the aircraft is under acceptable risk.

Takeoff Abort Scenario #1: An uncontrollable high thrust failure condition occurs during the takeoff roll between power set and V1; an abort is initiated; thrust on the normally operating engine retards normally while thrust on the failed engine remains high; and the resulting asymmetric thrust causes the airplane to depart the side of the active runway.

Takeoff Abort Scenario #2: Same as Takeoff Abort Scenario #1 except the resulting net excess thrust causes the airplane to overrun the end of the active runway.

Cruise Scenario #1: An uncontrollable high thrust failure condition occurs during some minimum control margin condition and the airplane becomes uncontrollable or suffers critical structural damage.

Go-Around Scenario #1: An uncontrollable high thrust failure condition occurs on approach/flare; the pilot can’t hold runway center-line and initiates a go-around; however, the airplane sink-rate cannot be overcome in time and the airplane touches down off to the side of the runway.

Go-Around Scenario #2: Same as Go-Around Scenario #1 except the airplane attitude is such that the wing tip contacts the ground on (or off) the runway.

Go-Around Scenario #3: An uncontrollable high thrust failure condition occurs on final approach; the pilot attempts to compensate with significant rudder input but can not hold runway center-line and initiates a go-around; as the normally operating engine accelerates to go-around thrust the failed engine hits its over-speed trip and cuts back to minimize flow effectively resulting in loss of the failed
engine; exceptional pilot skill is required to perform the rudder reversal required to maintain control; the pilot loses control of the airplane and there is insufficient altitude for recovery.

Landing Scenario #1: An uncontrollable high thrust failure condition occurs during final approach; the pilot attempts to hold runway center-line and continues landing and the airplane touches down off to the side of the runway.

Landing Scenario #2: Same as Landing Scenario #1 except wing tip contacts the ground on (or off) the runway.

Landing Scenario #3: An uncontrollable high thrust failure condition occurs during final approach or landing; thrust on the normally operating engine retards normally while thrust on the failed engine remains high; the resulting asymmetric thrust causes the airplane to depart from the active runway.

Landing Scenario #4: An uncontrollable high thrust failure condition occurs during the final approach; thrust on the normally operating engine retards normally while thrust on the failed engine remains high; the crew compensates for the thrust asymmetry, lands long and eventually shuts down the failed engine; however, the landing performance impacts of landing long and carrying high thrust for the extra time causes the airplane to overrun the end of the active runway.

Landing Scenario #5: An uncontrollable high thrust failure condition occurs during the application of reverse thrust on landing; reverse thrust on the failed engine increases; the flight crew, concluding the lateral control problem is due to deploying the reversers, restows the reversers; the thrust on the normally operating engine retards and the reverser stows as commanded; the thrust on the failed engine remains high and the reverser is incapable of restowing due to the excessive gas path pressures; the resulting asymmetric thrust causes the airplane to depart from the side of the active runway.

The method used in risk assessment for the 11 failure scenarios from handling qualities aspect is shown in Table 1.

**Table 1. The risk assessment method and condition**

| Scenario          | Method            | Criterion (should not)                        | Configurations and Conditions                      |
|-------------------|-------------------|-----------------------------------------------|---------------------------------------------------|
| Takeoff Abort #1  | Simulator test    | Depart from the side of the active runway     | Takeoff configuration, after CG, low pressure altitude runway |
| Takeoff Abort #2  | Simulator test    | Overrun the end of the active runway          | Takeoff configuration, forward CG, high pressure altitude runway |
| Cruise #1         | Simulation calculation | Become uncontrollable or suffers from critical structural damage | Cruise configuration, after CG, high altitude/MMO, low altitude/VMO |
| Go-Around #1      | Simulator test    | Touch down off to the side of the runway      | Landing configuration, after CG, low pressure altitude runway |
| Go-Around #2      | Simulator test    | The wing tip contact the ground on (or off) the runway | Landing configuration, after CG, low pressure altitude runway |
| Go-Around #3      | Simulator test    | Lose control of the airplane and there is insufficient altitude for recovery | Landing configuration, after CG, low pressure altitude runway |
| Landing #1        | Simulator test    | Touch down off to the side of the runway      | Landing configuration, after CG, low pressure altitude runway |
| Landing #2        | Simulator test    | The wing tip contact the ground on (or off) the runway | Landing configuration, after CG, low pressure altitude runway |
| Landing #3        | Simulator test    | Depart from the active runway                 | Landing configuration, after CG, low pressure altitude runway |
| Landing #4        | Simulator test    | Overrun the end of the active runway          | Landing configuration, forward CG, high pressure altitude runway |
| Landing #5        | Simulator test    | Depart from the side of the active runway     | Landing configuration, after CG, low pressure altitude runway |
3. Simulation calculation method and results
Simulation models, including the airplane dynamic model and pilot model, should be built up first, and general view of pilot in loop simulation is shown in Figure 1.

![Diagram of pilot in loop simulation](image)

**Figure 1.** General view of pilot in loop simulation

The liner pilot model is adopted[5], $Y_H(s) = \frac{K}{1 + t_n s} e^{-\tau s}$, where $K$ means the gain of pilot, $t_n$ means delay component of the pilot with the time constant of 0.1~0.2s, $\tau$ means pilot’s reaction delay time that usually is 0.15s. $\tau$ is set as 1.5s conservatively considering the total pilot’s reaction delay and the control system delay when simulating the airplane responses after UHT failure. The free responses after UHT failure without pilot in loop is also computed.

Thrust on the failed engine remains high as shown in Figure 2, and airplane responses after UHT failure with or without pilot in loop are shown in Figure 3. Without pilot in loop, roll angle of the airplane changes 20 degrees, yaw angle changes 13 degrees while CAS increases 10 knots and altitude descends 400 feet after 30 seconds. But roll angle remains within about 6 degrees, yaw angle changes about 4 degrees, CAS increases 5 knots and altitude descends less than 100 feet when the “pilot” attempts to maintain wing level after UHT failure using the ailerons and rudder, that indicate that the airplane is totally controllable.

![Graph of thrust comparison](image)

**Figure 2.** Thrust of the failed engine and normal engine
Figure 3. The airplane responses after UHT failure with or without pilot in loop

4. Simulator test method and results

Simulator tests for takeoff, go-around and landing scenarios were conducted by 2 flight crews on the flight simulator approved by the airworthiness authority and with specific UHT malfunction models. Test results consist of the airplane response and movement data and the pilot’s comment on the UHT failure have impacts on handling qualities using the Cooper-Harper rating scale.

For Takeoff Abort Scenarios, tests are started with UHT failure occur at V1, and then a lower speed, until Vmcg - 30 knots. Also, 3 thrust control procedures in Takeoff Abort Scenarios are tested:
1) Not use reverse and shut down the affected engine via an independent fuel shutoff
2) Use maximum reverse, then shut down the affected engine via an independent fuel shutoff
3) Shut down the affected engine via an independent fuel shutoff, then use maximum reverse

The maximum lateral departure from the runway center-line is about 50ft and the airplane is controllable in all test points of Takeoff Abort Scenario #1 and Takeoff Abort Scenario #2. The pilots rate C-H 2~4 and recommend the third procedure. Takeoff length increase obviously in Takeoff Abort Scenario #2, but still within the runway length of the most critical anticipated operation airport.

For Go-Around Scenario #1, tests are started with UHT failure occur at altitude of 400ft above the runway until 100ft. The maximum altitude change during go-around is less than 150ft, all controllable and without touching down off to the side of the runway, but the airplane touches down on the runway when UHT occur at altitude of 100ft. The pilots rate C-H 3~4 and suggest shutting down the affected engine after go-around to the safe altitude, then land with one engine inoperative.

For Go-Around Scenario #2, tests are started with UHT failure occur at altitude of 400ft above the runway until 100ft. The maximum altitude change during go-around is less than 170ft, lateral departure is less than 100ft, and the wing tip do not contact the ground on (or off) the runway, but the airplane touch down on the runway when UHT occur at altitude of 100ft. The pilots rate C-H 2~5 and suggest shutting down the affected engine after go-around to the safe altitude, then land with one engine inoperative.

For Go-Around Scenario #3, tests are started with UHT failure occur at altitude of 400ft above the runway until 100ft. The maximum altitude change during go-around is less than 160ft, all are controllable without wing tip contacting the ground on (or off) the runway. When UHT occurs at 100ft, the airplane succeed the go-around with touching down on the runway. The 1st pilot rate C-H 4~6 and the 2nd pilot rate C-H 7~9, that means exceptional pilot skill and more workload is required to perform the rudder reversal required to maintain control due to the failed engine thrust changes. Result of one test with UHT occurs at 100ft is shown in Figure 4.

Test configuration and condition of Landing Scenario #1, Landing Scenario #2 and Landing Scenario #3 are similar, and it is not so hard for the flight crew to hold runway center-line and continue landing. Tests are started with UHT failure occurs at altitude of 400ft above the runway until 100ft. Both flight crews land the airplane safely for all test points with lateral departure less than 170ft.
except that UHT occurs at 100ft (the wing tip touch down the ground). The pilots rate C-H 3~5 (9 for the test point UHT occurring at 100ft) and suggest conducting go-around when UHT appear near ground or shutting down the affected engine as soon as possible if continuing landing is necessary.

Landing Scenario #4 test are conducted at high altitude airport, and the compensation for the thrust asymmetry increase the landing length a lot but still within the runway length of the most critical anticipated operation airport. The pilots rate C-H 3~6 and suggest conducting go-around when UHT appears near ground or shutting down the affected engine as soon as possible if continuing landing is necessary, but compensation for the thrust asymmetry is not recommended.

The reverse thrust on the failed engine do not affect the taxing control a lot and the airplane is completely controllable until completely stop without departing the side of the active runway (the maximum lateral departure less than 30ft) in Landing Scenario #5. The pilots rate C-H 2~3 and suggest shutting down the affected engine as soon as possible and using the reverse thrust of the normal engine normally.
5. Conclusion
FAR25.901(c)/CCAR25.901(c) require in part that: “no single failure or malfunction or probable combinations of failures will jeopardize the safe operation of the airplane”, but not all single failures and probable combinations of failures that can cause UHT malfunction can be eliminated, a petition for a partial exemption from 25.901(c) related to UHT is usually requested. This paper offers an example for risk evaluation for 11 potentially Hazardous or Catastrophic single failure scenarios specified in the FAA memorandum[4] by analysis and simulator tests, and the results indicating:
1) Cruise Scenario: based on the simulation calculation results, there are sufficient control capacity and altitude margin following the UHT failure at cruise condition;

2) Takeoff Abort Scenario: the maximum lateral departure from the runway center-line is about 50ft and the airplane is controllable without departing from the side of the active runway or overrunning to the end of the active runway during simulator tests.

3) Go-Around Scenario: The airplane go-around successfully for all tests points without touching down off to the side of the runway or without wing tip contacting the ground on (or off) the runway, but the airplane touch down on the runway for some test points that UHT occurs at low altitude. It is more critical for Go-Around Scenario #3 and requesting exceptional pilot skill and more workload.

4) Landing Scenario: Both flight crews land the airplane safely for all test points except one test point with UHT occurring at 100ft (the wing tip touch down the ground), and recommend conducting go-around when UHT appears near ground or shutting down the affected engine as soon as possible if continuing landing is necessary for Landing Scenario 1#, 2#, 3# and 4#. Results of Landing Scenario #5 show that the reverse thrust on the failed engine does not affect the taxiing control a lot.

References
[1] NTSB, Safety Recommendation A98-70 [Z], 1998
[2] FAA, Part 25-Airworthiness Standards: Transport Category Airplanes. R4 [S], 2009
[3] Civil Aviation Regulation of China (CCAR), Part 25-Airworthiness Standards: Transport Category Airplanes. R4 [S], 2011
[4] FAA, Policy Statement on the Thrust Control Malfunction Airworthiness Program - Uncontrollable High Engine Thrust/Power Failures [Z], 2003
[5] Qu Xiangju, Pilot-aircraft system and flight qualities [M], Beijing: Beihang University Press, 1994