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Consideration and validation of flight control requirements under all engine failure conditions for MEA

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Abstract: Since the lower carbon emission and lower direct operating cost, MEA has drawn great attention worldwide. Considering and validating the flight control requirements under all engine failure conditions for MEA is the minimum design requirement, which is widely associated with aircraft characteristics, controllability and manoeuvrability, and system specialities such as electrical system, power plant system, hydraulic system, and avionics. Therefore, taking this topic as an example to illustrate a requirement validation process will be great interest to the aircraft design and integration, where the correctness and completeness of the requirements would be satisfied, the method and evidences of validation would be proposed, the requirement assumption validation and management should be presented, and scenario analysis and typical timeline analysis would be analysed. This paper presents the above processes from configuration, requirement definition and validation, to scenario analysis in compliance with SAE 4754A, which will be a fundamental process to the further verification and integration tasks.

1 Introduction

For a civil aircraft, the controllability and manoeuvrability of the flight control system under all engine failure conditions is a complicated topic, which has drawn great attention for a new aircraft design process. Part 25.671(d) of China Civil Aviation Regulation (CCAR) [1] has clearly defined this function, which is also the minimum design requirement. For a new aircraft architecture, especially when part of the hydraulic power of is replaced by electrical power, consideration and validation of flight control requirements under all engine failure conditions is meaningful and significant for the MEA architecture design, comparing with traditional aircraft requirements, characteristics and configuration change.

In civil aircraft operation history, some incidents happened during flying across volcano clouds or thunder clouds, and ice inhalation or birds impact have occurred occasionally. Therefore, in the design process, the flight control requirements under all engine failure conditions should be considered, and even should be selected as an important subject for requirement definition and validation. All engine failure scenarios during each flight phase should be considered for the flight control system analysis, and finally, the ability from cruising to approaching with reasonable velocity to landing is fundamental for civil aircraft safety operation in rigorous conditions (Figs. 1 and 2).

2 Aircraft configuration description

For a civil aircraft, studies on the controllability and manoeuvrability of the flight control system under all engine failure conditions should be limited to a particular configuration, so that the flight control requirement definition and validation can be confirmed in a specific configuration. Generally speaking, there are three types of flight control operation under all engine failure conditions:

(i) For flight control system simply driven by a mechanical system, the function of flight control system may irrelevant to the engines. As a result, when all engines fail, the flight control system depends on the mechanical controllability.

(ii) For flight control system featured by power driving, which also has a manual switch that can change to mechanical driving, if the power is generated by hydraulic pumps, pneumatic pumps, or generators driven by engines, the power driving system will fail under all engine failure conditions. So the controllability and manoeuvrability depends on manual controllability with conditions changing from power driving to mechanical driving, and the detaching mechanism, manual mechanical controllability is obviously of great importance.

(iii) For flight control system featured by the power driving flight control system, which does not have a manual switch to mechanical driving function, it should be equipped with a backup power source. The power source should be independent of engines, such as redundant power plant, RAT, backup batteries and so on.

Based on the above classification, given the conventional aircraft configuration for this study is shown in Fig. 3, and the MEA configuration is shown in Fig. 4.

It can be seen from Fig. 3 that the traditional aircraft ascribed to the third type of aircraft configuration, with the power driving flight control system which does not have a manual switch to mechanical driving function, and double-engine configuration. The energy supply architecture of aircraft operating system is 3H + 1E type, i.e. three sets of the hydraulic system, and the RAT, which acts as a backup power source. The engines and RAT are independent of each other, and the flight control actuation system is driven by hydraulic pumps. Assuming that the MEA is the third type of aircraft configuration, with the power driving flight control system which does not have a manual switch. The energy supply architecture is 2H + 2E type, i.e. two sets of hydraulic systems and two sets of emergency power supply systems provided by the RAT energy, which is independent of the engines. The layout of more electrical aircraft actuation system is shown in Fig. 4.

Fig. 1 *Schematic map for aircraft crossing volcano clouds*

Fig. 2 *Schematic map for aircraft passing thunder clouds*

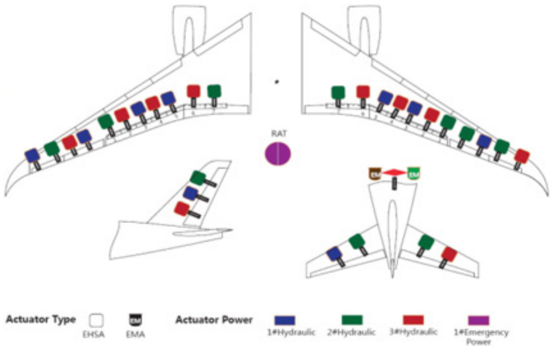

Fig. 3 *Energy supply of a traditional aircraft actuation system*

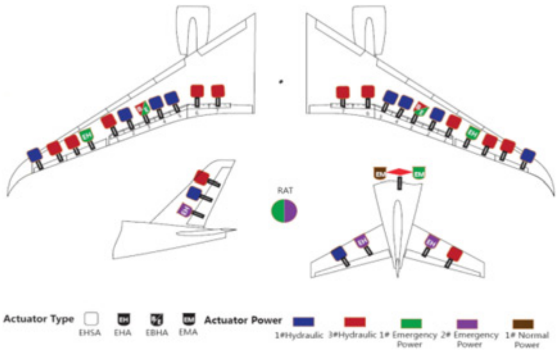

Fig. 4 *Energy supply of an MEA actuation system*

3 Requirement definition

Illustrating requirements definition of the flight control system under all engine failure conditions is to analyse working conditions of the flight control system, engine system, power system, hydraulic system, landing gear system, avionics system and other systems, as well as the impact of the relevant systems' working conditions on the operation of the flight control system. In order to facilitate the development of the definition, the requirements definition object is limited to those which have a direct relationship with the flight control system. In compliance with the requirements validation in SAE 4754A, the initial defined requirements are as follows:

(i) *Minimum acceptance control (MAC) design of the flight control system:* According to the aircraft's safe flight and landing request, MAC is the technical bottom line of the flight control system design. Therefore, the operation control of the flight control system under all engine failure conditions should meet the MAC design requirements.

(ii) *Loading and execution requirement of secondary mode control law and direct mode control law:* According to different flight control electronics architecture, it can be divided into normal mode control law, secondary mode control law, and direct mode control law. In normal flight condition, it will execute the normal mode control law. Under all engine fail conditions, it will downgrade to secondary mode control law, and even to direct mode control law. Since secondary mode control law and the direct mode control law may execute on different hardware devices, it is necessary to consider conversion time of the control law change, the validity of the control law execution, the correctness and completeness of sensors required by direct mode control law, as well as the control law design requirements under condition of different heights and attitudes.

(iii) *The correctness of control surface actuator command input and output:* Although under all engine failure conditions the flight control actuators that can be used to control three axes of the aircraft are not plentiful, yet they are very important. Conventional aircraft is powered by RAT-driven backup hydraulic sources to provide the power for actuation system, while MEA is powered by RAT or batteries for electrical actuation system. At this point, the control surface actuator command calculated by secondary mode control law or direct mode control law must be effectively communicated in the right place, and the input and output transmissions and commands should be correctly carried out.

(iv) *The automatic retracting function of multi-function spoiler and other control surfaces:* Some control surfaces that have an impact on aircraft aerodynamic characteristics and are abandoned by MAC under all engine failure conditions, should have an automatic retracting function, and cannot perform non-command opening actions.

(v) *Hydraulic flow requirement under all engine failure conditions:* In the moment of all engine failure, if the actuators of the primary flight control system maintain an acceptable working condition, it needs to maintain a certain hydraulic flow, which should be calculated by the deflection rate of the flight control actuation user, deflection rate of the actuator with maximum load, peak flow of the actuator with load, and the amount of leakage of the actuator and so on.

For traditional aircraft under all engine failure conditions, even in extreme cases that generators and APU are failed, and the No.1 and No.2 hydraulic systems are failed. As a result, the No.3 hydraulic system should maintain at least the above calculation of the hydraulic flow in order to ensure working requirement of the actuators. It is also necessary to consider the supply of backup hydraulic energy before RAT releasing.

For MEA under all engine failure conditions and No.1 and No.2 hydraulic systems are failed, the corresponding two sets of emergency power supply systems should provide power and energy to maintain the force and deflection rate similar to the hydraulic flow in traditional aircraft. It is also necessary to consider the energy supply of emergency power supply system before RAT releasing.

(vi) *Power consumption curve under all engine failure conditions:* For MEA, in addition to ensure the power supply in the moment of all engine failure, it also needs to provide the power consumption curve of the flight control system, which can be used to confirm whether the power and quality of the energy powered by RAT and batteries meet the requirements of the flight control system or not. And the curve needs to be exported to batteries for estimating the power supply time in this case.

(vii) *Release time of RAT under all engine failure conditions:* For traditional aircraft under all engine failure conditions with the No.1 and No.2 hydraulic system failures, the hydraulic energy for aircraft users can only be provided by the No.3 hydraulic system accumulator. The general accumulator can only provide energy for a short period of time, and sequentially RAT system needs to follow up the energy supply. At this point, the release time of RAT is an important parameter to provide input of the No. 3 hydraulic system.

For MEA under all engine failure conditions with the No. 1 and No. 2 hydraulic system failures, there is no No.3 hydraulic system and RAT has not yet released, at this point, batteries are needed to supply the power to the flight control actuation system. In this case, the battery capacity is limited, therefore, the RAT release time will be the design parameter input of the battery system.

(viii) *RAT working speed:* In general, RAT has the following parameter for normal work. When the speed of aircraft is greater than a certain speed (assuming V_{rat1}), RAT can support the DC component load and AC component load. When the speed of the aircraft is less than V_{rat1} and greater than V_{rat2}, RAT can only support the AC component load, and the DC component of the RAT will be powered by batteries. When the speed of the aircraft is less than V_{rat2}, RAT will not generate power supply.

Under all engine failure conditions with different heights, speeds, and weights, RAT working speed will affect the opening time of flats/slats and the time for seeking landing point. The two parameters, V_{rat1} and V_{rat2}, are key parameters that constrain aircraft's return and safe landing.

(ix) *Gliding speed for maximum horizontal distance:* Regardless of traditional aircraft or MEA, it can calculate a series of gliding speeds for different weight parameters, of which there is a suitable gliding speed, with which the maximum horizontal distance is obtained. Therefore, it can save more time to change the attitude and heading of aircraft, and provide the pilot more opportunities to find a suitable landing point.

(x) *The time required for the aircraft to drift down at a favourable speed under all engine failure conditions:* Under different heights and weights, the time required for the aircraft to drift down without the power can be calculated with the favourable speed, which provides expectable time for flight to reach a suitable landing location, and provides the pilot more opportunities to find a suitable landing point.

(xi) *Flutter suppression under all engine failure conditions:* In the flutter suppression analysis, for conventional aircraft, the stiffness characteristics of aileron, elevator, rudder and spoiler in a typical pressure state (full pressure, half pressure) should be analysed, such as the probability that aileron, elevator, rudder, spoiler actuators into the damping mode, the probability that one side of aileron, elevator, rudder, spoiler actuators loss damping, at the same time the other actuators maintain damping state, and the damping characteristics of aileron, elevator, rudder, spoiler actuators (frequency characteristic analysis for specific control surface and a particular damping configuration).

For MEA, except the above needs, it also needs to provide the stiffness curve of the electric-liquid mixed control surface in a typical working condition (normal state, backup state). The probability that actuators of electric-liquid mixed control surface into the damping mode should be analysed; the probability that the electric actuators loss damping and the other hydraulic actuators maintain damping state, or the hydraulic actuators loss damping while other electric actuators maintain damping state should be analysed.

(xii) *The force-fighting requirement of the control surface in the moment of all engine failures:* When an aircraft performs control surface movement, from surface strength analysis, it should consider the force-fighting monitoring and equalisation strategy of actuators. However, under all engine failures, the design requirements for force-fighting of actuators are different.

For conventional aircraft, because of the same type of actuators, the fault frequency characteristic curves of actuators are relatively similar. The change of force-fighting state can be expected more accurately, so the controller monitoring and alleviating the force-fighting is rather simple.

For MEA, due to different types of actuators, the force-fighting monitoring and equalisation algorithm is more complex. Consider one actuator fails (damping or loss of damping), two actuators fail (damping or loss of damping) and others, it is more complex to monitor and balance the changes in force-fighting of the electric actuation system for different types of actuators.

(xiii) *Half speed condition for flaps/slats:* In the normal working state of flaps/slats, two hydraulic motors simultaneously drive the control surface movement. When a hydraulic motor fails, the system enters the half-speed mode, and the power distribution unit (PDU) outputs all the torque, but the speed is half of the normal value.

For conventional aircraft, RAT provides the power to the No.3 hydraulic system and drives the PDU of the high lift system part under all engine failure conditions. According to the different design of the PDU, the control surface may be half-speed state or 1/4 normal speed state, providing time calculation parameters for approaching and landing configuration.

For MEA, RAT provides the power to the flats/slats actuators of the high-lift system. It is also necessary to consider the velocity state of flats/slats and to provide the calculation parameters for the opening time of approaching and landing configuration.

4 Requirement validation

Fig. 5 shows the requirement validation process model of SAE 4754A. In order to facilitate consideration and scenario analysis, it is assumed that the aircraft has completed the requirements validation's work at aircraft level, system level and component level, this paper only describes requirements that need to consider from scene perspective.

4.1 Correctness and completeness analysis

The correctness analysis of flight control requirements validation under all engine failure conditions follows the procedures (Tables 1 and 2):

(A) First, determine whether the requirements have been expressed correctly.
(B) Second, determine whether the requirements are necessary requirements for the completeness check.
(C) Third, determine whether it's appropriate to merge some requirement with another single requirement.
(D) Finally, determine whether settings of requirements reflect the demand of safety analysis correctly.

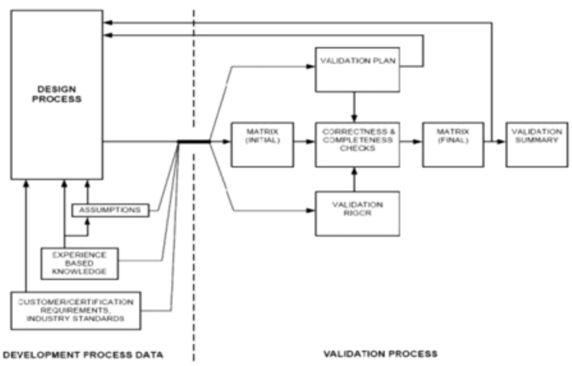

Fig. 5 *Validation process model [2]*

Table 1 Requirement correctness analysis and severity classification

No.	Requirement	Correctness analysis	Function design assurance level (FDAL)
1	MAC design of the flight control system	Changed to: The flight control system of MEA should meet MAC requirements of the aircraft under all engine failure conditions.	A
2	Loading and execution requirement of secondary mode control law and direct mode control law	Changed to: Secondary mode control law and direct mode control law can be loaded to execute and the mode switch does not affect the flight control system minimum safety guarantee.	A
3	Correctness of control surface actuator command input and output	Changed to: The command is given by the control surface actuator controller and the feedback command of the actuator should be correct.	A
4	Automatic retracting function of multi-function spoiler and other control surfaces	Changed to: The spoiler with no control function (except jamming) should be automatically retracted under all engine failure conditions.	B
5	Hydraulic flow requirement under all engine failure conditions	Changed to: the Hydraulic flow of the flight control system should meet the MAC requirements and the hydraulic flow demand curve should be provided under all engine failure conditions.	A
6	Power consumption curve under all engine failure conditions	Changed to: The power of the flight control system should ensure the MAC requirements and the energy consumption curve should be provided under all engine failure conditions.	A
7	Release time of RAT under all engine failure conditions	Changed to: The time required for RAT release to reach normal operation needs to be provided.	A
8	RAT working speed	Changed to: The speed when RAT works normally need to be provided.	C
9	Gliding speed for maximum horizontal distance	Changed to: The gliding speed for the maximum horizontal distance needs to be displayed or indicated.	D
10	The time required for the aircraft to drift down at a favourable speed under all engine failure conditions	Changed to: The time required to drift down at a favourable speed needs to be displayed or indicated.	D
11	Flutter suppression under all engine failure conditions	Changed to: Under all engine failure conditions, in the event of a fault condition with various combinations of actuators and control surfaces, the requirement of aircraft flutter suppression should be met.	A
12	Force-fighting requirement of control surface in the moment of all engine failure	Changed to: Under all engine failure conditions, in the event of a fault condition with various combinations of actuators and control surfaces, the aircraft force-fighting design requirement should be met.	A
13	Half-speed condition for flaps/slats	Changed to: Under all engine failure conditions, the design requirement of the working conditions (half speed, 1/4 speed) of flaps/slats should be met, and the current status should be displayed or indicated.	D

Table 2 Requirement completeness validation

Requirement	Parent requirements	Interface and processing	Other
No.	Satisfied or not	Procedure expressed or not	Aspect
1–13	satisfied	expressed	satisfied

The completeness check for the flight control system under all engine failure conditions can be demonstrated from the following aspects:

(A) Determine whether this requirement clearly meets its parent requirements from the point of traceability and supporting theory.
(B) Determine whether the requirement interface systems and the processing procedures are expressed in the requirement set (high-

Table 3 Requirement validation methods and evidences [2]

Methods and evidences	Development assurance level – A and B	Development assurance level – C	Development assurance level – D	Development assurance level – E
PASA/PSSA	R	R	A	N
validation plan	R	R	A	N
validation matrix	R	R	A	N
validation summary	R	R	A	N
requirements traceability (non-derived requirements)	R	R	A	N
requirements rationale (derived requirements)	R	R	A	N
analysis, modelling, or test	R	one recommended	A	N
similarity (service experience)	A	one recommended	A	N
engineering review	R	one recommended	A	N

Note: R – recommended for certification, A – as negotiated for certification, N – not required for certification.

level functions fully covered, safety requirements, airworthiness regulations and recommendations, industrial and enterprise design standards, flight operations and aircraft maintenance scenarios).
(C) Determine whether the interface with other systems, personnel and processing procedures are prescribed.
(D) Determine whether each defined interface constraint is sufficient for implementation.
(E) Determine whether the system, personnel and processing procedures of the interface are consistent with the requirement obtained by both parties.
(F) For a necessary action, whether a corresponding restricted action would be generated. If yes, whether this restricted action is defined.
(G) Determine whether the functional requirements can be traced back to the system architecture, and can fully cover the system architecture.
(H) Determine whether the functional requirements clearly correspond to the electronic hardware and software in the system architecture.
(I) Determine whether the assumptions are adequately defined and stated.

4.2 Requirement validation methods and validation evidence

According to the process of 4754A, with different development assurance level, the requirements validation methods and validation evidence are not same. From the perspective of airworthiness, the requirements are shown in Table 3.

According to the updated requirements in Table 1, the requirements validation methods and evidence type can be listed, as shown in Table 4.

4.3 Requirement assumptions validation and management

See Table 5.

5 Scenario analysis

Since in-service aircraft has several phases for a whole flying range, so the engine failure scenarios should not only cover the possible operating environments and operating modes but also cover anomalous operation conditions as well, such as stall warning boundary in which the aircraft can change the current status to normal condition.

Therefore, take state diagram and timeline diagram analysis as examples, all possibilities that all engine failure conditions occurred for effect analysis of flight crew, passengers and emergency operations are described.

5.1. State diagram analysis

Take state diagram as an example, the flight phase definition is shown as below (see Fig. 6 and Table 6):

(A) Ground phase: including periods from power-on to taxi-out, and from taxi-in to power-off:
G1: the period from power-on of aircraft to stopping at the starting position of the runway.
G2: the period from the end of taxing to power-off of aircraft.

(B) Take-off phase:
T1: the period from brakes-off to reaching the speed V_1.
T2: the period from reaching the speed V_1 to take-off.
T3: the period from take-off to reaching safe altitude 35 ft.

(C) In-flight phase:
F1: Climb:
F1-1: the period from safe altitude 35 ft to altitude 1500 ft.

Table 4 Flight control requirement validation plan

Requirement no.	Validation method	Evidence level	Evidence type
1	traceability	R	Parent requirements, design decisions, data derived from the requirements
	analysis	R	FHA, PSSA
	modelling	R	models of the system
	test	R	*ad-hoc* test result, system test result
2	analysis	R	FHA, PSSA
	test	R	*ad-hoc* test result, system test result
3-4	test	R	*ad-hoc* test result, system test result
5	analysis	R	FHA, PSSA
	modelling	R	hydraulic model, energy equivalent model
	test	R	*ad-hoc* test result, system test result
6	analysis	R	FHA, PSSA
	modelling	R	electrical model, energy consumption model
	test	R	*ad-hoc* test result, system test result
7	analysis	R	FHA, PSSA
	modelling	R	RAT release model, energy consumption model
	test	R	*ad-hoc* test result, system test result
8	analysis	R	FHA, PSSA
	modelling	R	RAT function model
	test	R	*ad-hoc* test result, system test result
9-10	analysis	R	FHA, PSSA
	modelling	R	aircraft performance model
11	analysis	R	FHA, PSSA
	modelling	R	actuators and surfaces stiffness model
	test	R	*ad-hoc* test result, system test result
	similarity	A	equivalent environment, Same failure condition classification
12	analysis	R	FHA, PSSA
	modelling	R	actuators and surfaces stress model
	test	R	*ad-hoc* test result, system test result
	similarity	A	equivalent environment, same failure condition classification
13	analysis	R	FHA, PSSA
	modelling	R	flaps and slats function model
	test	R	*ad-hoc* test result, system test result

Note: R – recommended for certification, A – as negotiated for certification.

F1-2: the period from altitude 1500 ft to cruise altitude.

F2: Cruise: the period from climbing to the cruise altitude to the descent starting altitude, including accelerating to cruise Mach number, cruising, and decelerating before descent.
F3: Descend: the period from reaching cruise altitude to approach altitude 1500 ft.

Table 5 Flight control requirement assumptions validation and management

Requirement no.	Assumptions	Validation process	Management and category
1	Assumption 1: All engine failures are a type of aircraft failures. The capacity of flight control after the failure should above the MAC capacity. Assumption 2: The MAC design of the flight control system has considered all the failure conditions.	review analysis test	operational/environmental assumptions design assumptions
2	Assumption: The secondary mode control law, the direct mode control law, as well as the switching process of control law, can guarantee the flight control of the aircraft, and does not reduce the flight safety standards.	review analysis test	operational/environmental assumptions design assumptions
3	Assumption: The actuator controller is capable of accepting commands in a fault condition due to all engine failure, and feedback command correctly.	test	operational/environmental assumptions design assumptions
4	Assumption: The probability of non-command opening of the spoiler is 10^{-9}.	review analysis test	operational/environmental assumptions design assumptions
5	Assumption: Under all engine failure conditions, the hydraulic system still provides energy to the actuation system, the requirement for hydraulic flow can guarantee the manoeuvring action.	review analysis test	operational/environmental assumptions design assumptions
6	Assumption: Under all engine failure conditions, the electrical power provides energy to the actuation system, and the requirement for electrical power can guarantee the manoeuvring action.	review analysis test	operational/environmental assumptions design assumptions
7	Assumption: The current speed of the aircraft can meet the requirement of RAT's normal operation.	analysis test	operational/environmental assumptions design assumptions
8–10	NA	NA	NA
11	Assumption: The design of the flutter suppression of the aircraft actuation system has considered the actuator operating condition under a various combined fault condition, in addition to the normal actuator condition.	analysis test	installation assumptions design assumptions
12	Assumption: The strength design of the aircraft actuation system has considered the actuator operating condition under a various fault condition, in addition to the normal actuator condition.	analysis test	installation assumptions design assumptions
13	Assumption: Under all engine failure conditions, it needs to retain the retracting and extending function of flaps/slats.	test	operational/environmental assumptions

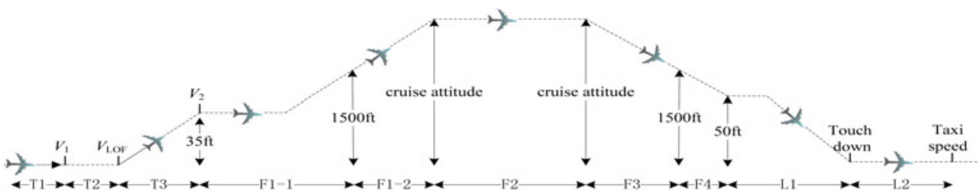

Fig. 6 *Flight state diagram*

F4: Approach: the period from descending to approach altitude 1500 ft to reaching safe landing altitude 50 ft.

(D) Landing phase:
L1: the period from reaching safe landing altitude 50 ft to main gear touchdown.
L2: the period from main gear touchdown to taxi speed.

(E) Others: according to other conditions, such as go-around phase, or RTO.

5.2 *Timeline diagram analysis*

Due to varieties of combination flight tests about single engine failure, two engines idle, icing, rainy weather in the take-off phase and landing phase, therefore in this timeline diagram analysis, it will focus on the flight control system requirements during flight phases under all engine failure conditions.

Engine failures could be divided into two types: sudden failure and general failure. Sudden failure may stem from engine fan, engine structure or control system severe damage and suddenly shutdown, while general failure means the transition from steady working condition to idle condition, and finally to a shutdown condition which may experience 60 s or even more time.

So the requirement scenario analysis should include the above failure conditions. In the timeline diagram scenario, there are several influence factors which should be taken into account, such as altitude, weight, velocity, flight phase, and aircraft attitude.

Suppose the following conditions:

Case 1: All engine failures occur when the flight altitude is above 1500 ft. At this moment, the aircraft needs to make a maximum 180° turn, and flight to 1500 ft using Flap 0 with the drift-down velocity.

First, in this condition, the crew member should acquire the drift-down velocity according to the current weight and related parameters.

Second, according to the drift-down velocity, the RAT working condition can be judged, if the drift-down velocity is smaller than

Table 6 Flight control requirement state diagram analysis

Phases		Requirement no.	Effect on aircraft, crew and passengers
ground	G1 G2	2, 3, 12	Aircraft: loss part electrical power, hydraulic power, and pneumatic source. The aircraft safety margin, as well as operation safety margin decreases apparently. Crew: workload increases apparently. Passengers: no apparent effect.
take-off	T1	1, 2, 3, 12	Same as G1, G2
	T2-T3	1–13	Aircraft: loss part electrical power, hydraulic power, and pneumatic source. The aircraft safety margin, as well as operation safety margin decreases apparently. Crew: operate emergency operation procedures according to FCOM, which increases workload apparently. Passengers: possible casualties due to aircraft damages or crashes.
in flight	F1-1 F1-2 F2 F3 F4	1–13 1–13 1–13 1–13 1–13	Aircraft: loss part electrical power, hydraulic power, and pneumatic source. The aircraft safety margin, as well as operation safety margin decreases apparently. Crew: operate emergency operation procedures according to FCOM, which increases workload apparently. Passengers: possibly several injuries.
landing	L1	1–13	same as T2, T3
	L2	1, 2, 3, 12	same as G1, G2
others	RTO	1, 2, 3, 12	same as G1, G2
	go-around	1–13	same as T2, T3

the RAT working velocity, the power of flight control actuation system is driven by batteries. For traditional aircraft configuration, if the drift-down velocity is faster than the RAT working velocity, the power of flight control actuation system is driven by backup hydraulic power accumulator before RAT releasing. Then after RAT releasing, the power is driven by RAT. If the current velocity is slower than the RAT working velocity, the power of flight control actuation system will be driven by batteries. For MEA configuration, it does not equip with backup hydraulic power. As a result, before RAT releasing, the power of flight control actuation system is driven by the batteries. After RAT releasing, the power of flight control actuation system is driven by the RAT. If the current velocity is slower than the RAT working velocity, the power will be provided by batteries again.

In this condition, the power of flight control system will be used for adjusting and maintaining the aircraft's three-axis attitudes,

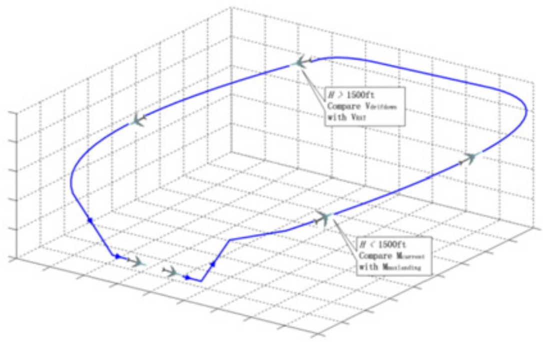

Fig. 7 *Flight timeline diagram*

velocity decreasing, and extending the landing configuration when the aircraft is approaching and landing.

Case 2: All engine failure occurs when the flight altitude is lower than 1500 ft, then the current weight of the aircraft needs to be judged with the maximum landing weight.

If the current weight is heavier than the maximum landing weight, necessary losing weight methods should be adopted. If the current weight is lighter than the maximum landing weight, the procedures will be followed as case 1.

In this condition, the power of flight control system will be used for adjusting and maintaining the aircraft's three-axis attitudes, velocity decreasing, and extending the landing configuration when the aircraft is approaching and landing.

As shown in Fig. 7, the above analysis is related to requirements No. 5–10, No.13, including hydraulic flow rate curves, electrical consumption curves, time for RAT from releasing to normal working condition, aircraft velocity for RAT working, the drift-down velocity, and drift-down time for descending, flaps and slats under all engine failure conditions.

6 Conclusion

The requirements of the flight control system under all engine failure conditions are a complex subject widely associated with civil aircraft characteristics, controllability and manoeuvrability, system specialities such as electrical system, hydraulic system and avionics. For a new aircraft, conducting the flight control requirements definition and validation under this case is meaningful for design, test, verification and safety operation.

This paper illustrates the above process from the configuration, requirement definition and validation, to scenario analysis in compliance with SAE 4754A where requirement correctness and completeness is checked, and validation methods and evidence are proposed, the requirement assumption validation and management and scenario conditions are analysed. The above results and procedures will benefit the aircraft design and integration, which will be a fundamental process to the further verification tasks.

7 References

[1] China Civil Aviation Administration: 'China civil aviation regulations (part 25) transport airline airworthiness standards'. CCAR-25-R4, 2011

[2] SAE ARP4754A: Guidelines for Development of Civil Aircraft and Systems, 2010