

Research on Verification Method for Unusable Fuel Quantity Compliance of Civil Aircraft

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Abstract. In civil transport aircraft, due to the structural characteristics of the fuel tank, fuel pipelines, and fuel pump layout, a certain amount of fuel in the fuel tank cannot be delivered to the engine by the fuel pump. This part of the fuel is known as unusable fuel. This article mainly refers to CCAR25 [1] requirements and the airworthiness certification practices of domestic and foreign models. It analyzes the technical requirements of the airworthiness clause regarding unusable fuel quantity from aspects such as design and verification requirements, the scheduled operation and maneuver flight of the aircraft, the most unfavorable fuel supply conditions, and the criteria for abnormal engine operation. According to the analysis of the requirements of airworthiness regulations, this article also presents the proposed airworthiness compliance verification methods and analyzes the technical key points of MC1, MC2, MC5 and MC6 airworthiness compliance verification methods, providing references for the airworthiness compliance verification of civil aircraft unusable fuel.

Keywords: Civil Aircraft; Unusable Fuel; Compliance Verification.

1. Introduction

Civil transport aircraft has a certain amount of fuel in the fuel tank that cannot be delivered to the engine through the fuel pump due to fuel tank structure characteristics, fuel pipe and fuel pump layout, etc. This part of the fuel is known as unusable fuel. According to AC25-7D, the unusable fuel quantity is the fuel quantity that can be discharged from the fuel tank sediment tank when the aircraft is in a normal horizontal attitude after the fuel tank unavailable fuel test, plus the undrainable fuel quantity in the fuel tank [2].

The unusable fuel quantity is part of the aircraft's empty weight and represents the direct weight loss of the aircraft. The unusable fuel quantity will be used for the determination of aircraft empty weight data, the calibration of fuel gauges, and the verification of fuel flow, etc. Therefore, during the civil aircraft airworthiness certification stage, the unusable fuel quantity must be determined according to the airworthiness clause requirements, and the fuel gauges must be calibrated according to the determined unusable fuel quantity to ensure that the fuel quantity indication provided to the flight crew is accurate and reliable .

Fan Tianhao et al. [3] proposed a method for determining the extreme unusable fuel quantity for a certain type of low-cost expendable unmanned aircraft. Leng Zhongming [4] studied the flight test method of unavailable fuel quantity in combination with the requirements of CCAR25. Zhao Shiyang [5] comprehensively considered the influences of overload, angle of attack, flight path pitch angle, etc. on the oil surface angle to study the determination method of unavailable fuel quantity of commercial aircraft. Chen Zhanbin et al. [6] carried out research on the flight test of unavailable fuel quantity of a certain civil aircraft fuel system. Chen Min et al. [7] studied the flight test method of unavailable fuel quantity of a certain civil helicopter through airworthiness regulations requirements and analysis, and analyzed the unavailable fuel quantity through flight tests. Dou Tengyao et al. [8] analyzed and studied the unusable fuel quantity of the helicopter based on the AMESim model; Song Zhiqiang et al. [9] determined the unusable fuel quantity of the civil aircraft fuel system through the analysis and addition of flight test methods. This article systematically focuses on studying the compliance verification methods for the unusable fuel quantity of civil aircraft, starting from the requirements of airworthiness regulations.

2. Airworthiness Requirements and Analysis

2.1 Airworthiness Requirements

Section 25.959 of the airworthiness standard for transport aircraft (CCAR25 - R4) stipulates that, for each fuel tank and its fuel system accessories, the unusable fuel quantity must be set to be no less than the following amount: for all scheduled operations and maneuvering flights that require supply from the fuel tank, under the most unfavorable fuel supply conditions, when the engine starts to work abnormally, the fuel quantity in the fuel tank need not consider the failure of fuel system components. At the same time, section 25.1337 (b) (1) stipulates that each fuel gauge must be calibrated so that when the remaining fuel quantity in the fuel tank is equal to the unusable fuel quantity determined in accordance with section 25.959 during level flight, its reading is 'zero'. [1]

2.2 Airworthiness clause analysis

The following is the technical analysis carried out for the airworthiness clause of unusable fuel quantity:

2.2.1 Design and Verification Requirements Analysis

During the design process of the aircraft, especially in the design stage of the fuel system and fuel tank, according to the requirements of Clause 25.959, it is necessary to formulate the maximum unusable fuel quantity index, which is a crucial design consideration factor. By accurately determining this index, the design team can carry out the targeted layout work of the fuel tank structure, fuel pipes, fuel pumps, and other equipment. In practical operations, this requires carefully designing and optimizing the shape, layout, and positions of various components of the fuel tank to minimize the amount of unavailable fuel to the greatest extent. For example, rationally planning the space of the fuel tank to avoid areas where fuel cannot flow or be stored smoothly; carefully arranging the fuel pipes to ensure that fuel can be efficiently delivered to each part; and precisely adjusting the installation positions of fuel pumps and related equipment to improve the operating efficiency of the fuel system.

Meanwhile, in accordance with the requirements of Clause 25.1337(b)(1), the aircraft must be equipped with indicating devices to clearly indicate the available fuel quantity in each fuel tank to the aircraft crew during flight. This requires that during the design stage, the measurement and display methods of the fuel indicator need to be determined, the fuel gauge needs to be strictly calibrated to ensure the accuracy and reliability of its measurement. The design team should consider how to effectively integrate the fuel indicator with the fuel tank structure and other parts of the fuel system. In this way, during the flight, the crew can accurately understand the fuel situation in each fuel tank at any time. This can help the crew rationally arrange flight plans can improve the safety and economy of flight. In short, in the design of the aircraft fuel system and fuel tank, these requirements complement each other and jointly guarantee the safe and efficient operation of the aircraft.

2.2.2 Analysis of aircraft scheduled operations and maneuvering flights

During the type design stage, it is necessary to precisely define the entire flight envelope of the aircraft. The flight envelope is like the "territory" of the aircraft's flight, covering the flight range of the aircraft under various conditions. At the same time, for the flight attitudes of any maneuvering flight that the aircraft may perform within the envelope, such as the special flight state of sideslip, which will affect the aerodynamic performance of the aircraft; the change of pitch attitude determines the degree of the aircraft's raising or lowering its head and has a direct impact on the control of flight altitude; the go-around attitude is the emergency adjustment attitude when the aircraft encounters special situations during the approach; and the roll attitude is related to the lateral stability and maneuverability of the aircraft. Only by clarifying these flight attitudes can a solid foundation be provided for determining the subsequent analysis, calculation, and test contents and methods.

2.2.3 Analysis of the most unusable fuel supply conditions

In the process of determining the most unfavorable fuel supply conditions, a deep and comprehensive consideration needs to be given to the specific layout of the fuel system and fuel tank. At the same time, a comprehensive analysis of the aircraft envelope and all possible maneuvering flights within it should be conducted. This is because the envelope range of the aircraft varies in different flight phases and under various weather conditions. And any maneuvering flight within this range, such as the sharp change in aircraft attitude during go-around pull-up, the special role of aerodynamics during sideslip, and the dynamic maneuvering effect caused by acceleration, etc., may all have a significant impact on the fuel supply. It is necessary to establish the relationship between the unusable fuel quantity and the aircraft attitude, and determine the unusable fuel quantity under the most unfavorable fuel supply condition and flight attitude.

It should be emphasized that this most unfavorable fuel - supply condition is determined based on the more common and possible situations in actual flight, rather than extreme situations that are extremely difficult to occur during the operation of the aircraft. This determination process provides a solid foundation for the safety of aircraft fuel supply, ensuring that the aircraft can have sufficient fuel to support its normal operation in various complex situations.

2.2.4 Analysis of Criteria for Abnormal Engine Operation

During the test process, the continuous consumption of fuel leads to a gradual decrease in fuel flow, which will cause the rotational speed of the test engine to be unstable. The most obvious manifestation of this is the fluctuation of the engine speed. Once this phenomenon of engine speed fluctuation occurs, it can be reasonably regarded as "the engine is not working normally". Therefore, throughout the entire test period, it is essential to always keep an eye on whether the test engine has a flameout phenomenon. Only by ensuring that the engine is always in a working state can the test proceed smoothly.

At the same time, it is necessary to ensure that the fuel flow at the engine inlet is continuous without interruptions or large fluctuations, and the inlet fuel pressure is within the normal range. Only in this way can the engine obtain a stable fuel supply and ensure its normal operation. If there are abnormalities in fuel flow, pressure, etc., timely adjustment and repair measures should be taken to ensure the accuracy and safety of the test.

3. Airworthiness Compliance Verification Methods

The airworthiness compliance verification of unusable fuel quantity is mainly based on airworthiness regulations and clauses. The type certificate applicant plans compliance verification methods according to airworthiness regulation clauses and conducts corresponding compliance verification activities. By submitting compliance verification materials, it is indicated that the unusable fuel quantity meets the requirements of Article 25.959 and Article 25.1337(b)(1).

According to AP - 21 - AA - 2023 - 11R1 "Type Certification Procedures" [10], common airworthiness compliance verification methods and codes (MC1 to MC9) are given, which cover four compliance types: engineering evaluation, test, inspection, and equipment qualification. Based on the above technical analysis of airworthiness clauses, the compliance verification method of unusable fuel quantity is presented in Table 1 as follows.

Table 1. Compliance Verification Method for Unusable Fuel Quantity

Clause	Compliance method	Compliance Method Description
25.959	MC1 Compliance Statement	Through fuel system design, describe the system layout and internal structure of the fuel tank. It is necessary to detail information like the composition, function, working description, and key parameters of the fuel system.
	MC2 Analysis/Calculation	Based on the geometric shape of the fuel tank and the layout of the fuel system, analyze and calculate the relationship between the amount of unusable fuel and the aircraft attitude under critical

		conditions. In this process, it is necessary to take into account the specific structure and layout of the fuel system and fuel tank (such as the position of the fuel pump, the shape and size of the fuel tank, etc.) for analysis.
	MC5 Ground test	Conduct ground tests to determine the amount of unusable fuel that cannot be emitted; Measure the amount of unusable fuel in the fuel tank when the aircraft is parked in a normal horizontal attitude on the ground to confirm the accuracy of the analysis/calculation results.
	MC6 flight test	Conduct an unusable fuel quantity flight test to verify the determination of the unusable fuel quantity in the fuel tank under different flight conditions.
25.1337(b)(1)	MC1 Compliance Statement	Provide a description of the fuel system design to demonstrate that the indication and recording of fuel system parameters meet the requirements of the terms.
	MC5 Ground test	Conduct ground tests to verify that the remaining fuel in the fuel tank that cannot be used by the engine is at the zero fuel point of the tank.
	MC6 Flight test	Conduct zero fuel calibration flight tests to verify that under different flight conditions, the fuel gauges of each fuel tank work normally after calibration, and the zero fuel setting meets the requirements of the terms.

4. Analysis of Key Points for Airworthiness Compliance Verification

When using the MC1 verification method, it is necessary to describe in detail information about the fuel system, such as its composition, function, working description, and key parameters. The fuel system consists of key components including various fuel pumps, fuel tanks, and pipelines. Its function is to ensure a stable fuel supply during the aircraft's flight. Moreover, it is essential to clearly explain the operating processes of the fuel system in different flight stages like takeoff, cruise, and landing. At the same time, it is necessary to clearly define the key parameters of the fuel system, such as pressure and flow rate. These parameters are crucial for the normal operation of the fuel system.

Through these parameters, it can be demonstrated that the installation design of the fuel system has minimized the unusable fuel. Moreover, the fuel quantity of each fuel tank and the total fuel quantity can be accurately indicated in the cockpit. The zero scale of the fuel gauge is the unusable fuel quantity during level flight to support the compliance of the clauses related to the indication and recording of unusable fuel quantity and fuel parameters.

When the MC2 verification method is adopted, the specific structure and layout of the fuel system and fuel tank need to be considered. For example, the precise position of the fuel pump directly affects the fuel supply efficiency; the unique shape and size of the fuel tank play an important role in the storage and flow characteristics of the fuel. At the same time, it is necessary to carefully analyze the impacts brought by dynamic maneuvering effects such as possible sideslip, pull-up during go-around, and acceleration. Through these analyses, we can determine the relationship between the unusable fuel quantity in each fuel tank and the aircraft attitude. Also, we can determine the unusable fuel quantity under the most unfavorable fuel supply conditions and specific flight attitudes. This lays a foundation for subsequent ground tests and flight tests.

When using the MC5 verification method, the verification of unusable fuel quantity should take undrainable fuel fuel and unusable fuel into account. Regarding the measurement of undrainable fuel fuel, it is required to add and record the fuel sufficient to fill all the fuel storage spaces in the fuel tank and fuel system, and then discharge and record the volume of the discharged fuel. The difference between the refueling volume and the discharged fuel volume is the undrainable fuel fuel quantity, which is used as the calibration fuel volume of the "zero" oil level of the fuel system.

Before conducting the measurement of undrainable fuel fuel quantity, it is necessary to ensure that there is no fuel in the fuel tank. This operation is typically carried out after the aircraft is assembled and the fuel tank has completed the airtight test. For the measurement of unusable fuel

quantity, detailed analysis needs to be carried out. First, it is necessary to determine the parking attitude of the aircraft on the ground. Then, add the fuel amount required for the test into the fuel tank. After that, start the engine and keep it running until the engine shows an abnormal state. During this process, it is necessary to accurately measure and record the fuel mass and density discharged from the fuel tank. These data are crucial for accurately evaluating the unusable fuel quantity.

When applying the MC6 verification method, based on the most unfavorable fuel supply conditions and critical flight attitudes determined by MC2, detailed verification analysis and calculation should be carried out on the unusable fuel quantity data and zero fuel quantity calibration. In the flight test implementation, many factors need to be fully considered. Specifically, in the two key forms of normal approach and landing of the aircraft, the steady - state sideslip situation needs to be predicted. This is because it has a direct impact on the operation of the fuel system and the evaluation of the unusable fuel quantity. For aircraft with high roll and pitch rates, the influence of sudden maneuvering actions needs to be considered. This may cause changes in the distribution and flow of fuel, thereby affecting the accuracy of the unusable fuel quantity. At the same time, the go-around with the maximum acceleration rate and the maximum upward rate of the maximum pitch attitude reached is a test of the fuel system performance of the aircraft in extreme situations. In addition, turbulence also has an impact on the unusable fuel quantity. Only by comprehensively considering and verifying these factors can we ensure the effectiveness and reliability of the MC6 verification method, thus providing a solid guarantee for the safe flight of the aircraft [2].

5. Summary

This paper studies the compliance verification methods of civil aircraft unusable fuel quantity in combination with CCAR25 Part 25.959 and 25.1337(b)(1) clauses. Through in - depth technical analysis of these clauses, it is found that the main compliance verification methods for Clause 25.959 are MC1 compliance statement, MC2 analysis/calculation, MOC5 ground test, and MC6 flight test; for Clause 25.1337(b)(1), they are MC1 compliance statement, MC5 ground test, and MC6 flight test. Furthermore, the key points to note when using MC1, MC2, MC5, and MC6 verification methods are provided, offering airworthiness technical support for the compliance verification of civil aircraft unusable fuel quantity.

References

- [1] Civil Aviation Administration of China: CCAR-25-R4 Airworthiness Standard for Transport Aircraft [S]. 2016.
- [2] The Federal Aviation Administration of the United States Department of Transportation: AC25-7D Flight Test Guide for Certification of Transport Category Airplanes[S] .2018.
- [3] Fan Tianhao, zhang Shiwei, Xue Xiaowei, et al: Research on determination method of limit unavailable fuel quantity for low cost consumable UAV [j]. Aerospace Science and technology, 2024,35 (09): 29-34.
- [4] Leng Zhongming: Unusable fuel for flight test[J]. Large Aircraft, 2021,(04):22-25.
- [5] Zhao Shiyang: Research on the Method for Determining the Unusable Fuel Quantity of Commercial Aircraft [J]. Science and Technology Perspective, 2016, (22): 295-296.
- [6] Chen Zhanbin, Wei Jinzhou, Lv Meiqian: Flight test research on unusable fuel quantity of a civil aircraft fuel system [J]. Engineering and Testing, 2014,54(01):42-44+63.
- [7] Chen Min, Xu Ningxin, Yu Zhongxuan. Study on the Test Flight of a Certain Type of Civil Helicopter with Unavailable Fuel Quantity [J]. Science and Technology World, 2022,(33):98-100.
- [8] Dou Tengyao, zhao Lifei, Huang Kun, et al: Analysis of unusable fuel quantity of helicopter based on AMESim [j]. Science and Technology Horizon, 2022, (14): 57-59.

- [9] Song Zhiqiang, Bian Gang, zhou Yusui: Research on the determination method of unusable fuel quantity in the fuel system of a civil airliner [j]. Science and Technology Information, 2013, (18): 497+499.
- [10] Civil Aviation Administration of China: AP-21-AA-2023-11R1 Type Certification Approval Procedure [S]. 2023.