The Research of Integrated Modular Avionics Airworthiness Verification Technology for Part 23 Aircraft

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Abstract. In order to research the airworthiness verification technology of Integrated Modular Avionics for Part 23 aircraft. This paper provides the guidance and reference for the airworthiness verification work of Integrated Modular Avionics for Part 23 aircraft from four main aspects based on the summary of the airworthiness verification work of Integrated Modular Avionics for the Y12F aircraft. The Y12F aircraft is the first Part 23 aircraft in China to complete the airworthiness review of Integrated Modular Avionics by CAAC and FAA. These are the four main aspects. First, the airworthiness verification flow of Integrated Modular Avionics for Part 23 aircraft is confirmed. Second, the airworthiness verification elements of Integrated Modular Avionics for Part 23 aircraft are given. Third, the CAAC essentials for reviewing of Integrated Modular Avionics for Part 23 aircraft are summarized. Finally, the FAA issues for special attention and applicant’s solutions of Integrated Modular Avionics for Part 23 aircraft are extracted.

Keywords: airworthiness; flow; elements; essentials; issues

1. Introduction
The advanced nature of the Integrated Modular Avionics lies in the fact that its universal core system has a standardized universality in function and technology, and has the diversified expansion. For different types and uses of aircraft, it can be expanded on the basis of a universal core system to meet the needs of different users and aircrafts. The installation of the Integrated Modular Avionics can not only improve the performance of the aircraft, reduce operating costs, but also greatly reduce the work burden of pilot; But at the same time, it also faces great challenges, because this advanced Integrated Modular Avionics is not only different from the traditional avionics system in the system structure, but also differs greatly from the traditional avionics system in terms of development, manufacturing and airworthiness certification. Most of the traditional avionics systems can be designed and verified directly against the requirements of the relevant airworthiness regulations, while the Integrated Modular Avionics have adopted advanced hardware and software technologies, many major functions are achieved through software, and using data bus to realize data sharing. All these changes have brought new airworthiness problems.

The installation of Integrated Modular Avionics has become the development trend of Part 23 aircraft, but the airworthiness verification technology in China still stays on the airworthiness verification of traditional avionics systems, and lacks the method and experience of airworthiness
verification of Integrated Modular Avionics. Therefore, it is necessary to research the airworthiness verification technology of Integrated Modular Avionics for Part 23 aircraft.

The Y12F aircraft is an 8-ton multi-purpose transport aircraft designed in accordance with the CCAR 23 of the China Civil Aviation Regulations and the FAR 23 of the Federal Aviation Special Regulations. It obtained CAAC and FAA type certification in December 2015 and February 2016, respectively. The aircraft is equipped with Integrated Modular Avionics. It is the first Part 23 commuter aircraft in China to complete the airworthiness verification of Integrated Modular Avionics. Based on the summary of the airworthiness verification work of Integrated Modular Avionics for Y12F aircraft, this paper provides the guidance and reference for the airworthiness verification work of Integrated Modular Avionics for Part 23 aircraft.

2. The airworthiness verification flow of Integrated Modular Avionics for Part 23 aircraft

2.1. Validation of the compliance plan
First of all, the applicant submits an application for a type certification to the Bureau, and the Bureau accepts the application. The Bureau responsibility validation organization and the applicant jointly determine the validation basis applicable for the Integrated Modular Avionics, and the applicant prepares a draft compliance plan (CP). The content of the compliance plan mainly includes: system overview, detailed description of system function, principle, configuration, supplier evaluation, system conformity verification basis, system cross-reference compliance plan, system conformity method, conformity verification ideas, equipment forensics methods, system compliance checklist, system verification test project situation, system man-machine factors evaluation and other related content. The compliance plan is a dynamic document that will be refined and improved as the project progresses. Each perfect version needs to communicate with the review representative first, and then both parties sign and confirm.

2.2. Submission and approval of the compliance document
Secondly, the applicant submits to the Bureau responsibility validation organization the compliance document for each airworthiness clause listed in the Integrated Modular Avionics compliance plan, and the Bureau responsibility verification organization approves these documents. The compliance document for the clauses mainly includes the method of conformity of the Integrated Modular Avionics to each of the requirements of the clauses, the brief description of conformity and the list of conformity document. The compliance document is also a dynamic document and is refined as the project progresses. The review representative only needs to approve the final version of the compliance document.

2.3. Submission and approval of the compliance verification documents
Then, the applicant submits the compliance verification documents of the Integrated Modular Avionics to the Bureau responsibility verification organization, and the Bureau responsibility verification organization approves these verification documents. The types of compliance verification documents correspond to the compliance methods. The types of compliance verification documents corresponding to different compliance methods are shown in Table 1.
Table 1. Corresponding Table of Compliance Method and Verification Documents Type

| compliance method       | verification documents type                                                                 |
|-------------------------|---------------------------------------------------------------------------------------------|
| MC0- compliance declaration | ——                                                                                          |
| MC1-illustrative documents | drawings, top-level design documents, requirements documents, compliance document, description document of equipment which is verified along with the aircraft, system document, etc. |
| MC2- analysis /          | analysis report, calculation report                                                          |
| MC3- security analysis   | security analysis report                                                                    |
| MC4- laboratory test     | laboratory test outline and report                                                           |
| MC5-ground test          | on-vehicle ground test outline and report                                                    |
| MC6-flight test          | flight test outline and report                                                               |
| MC7-aircraft inspection  | aircraft inspection outline and report                                                       |
| MC8-simulatortest        | cockpit inspection outline and report                                                        |
| MC9-                     | simulator test outline and report                                                             |

If all the compliance verification documents for a clause are approved, the compliance document for the clause can be approved and the clause can also be approved. After all the clauses are approved, the applicant submits the compliance checklist to the Bureau's responsibility verification organization, and the Bureau's responsibility verification organization approves the compliance checklist. The compliance checklist is mainly a summary of the compliance of each clause, including the airworthiness requirements of each clause, the compliance method, the compliance document, the compliance verification documents and the date of their approval.

2.4. Submission and approval of the documents along with the aircraft

Finally, the applicant consummates the contents of the Integrated Modular Avionics in the documents along with the aircraft. Documents along with the aircraft mainly include: flight manual, maintenance manual, fault isolation manual, wiring manual, system description, illustrated parts catalogue, components (airborne) maintenance manuals and other related documents. The process version and final version of these documents are submitted to the Bureau's responsibility validation organization for approval.

3. The airworthiness verification elements of Integrated Modular Avionics for Part 23 aircraft

The development of Integrated Modular Avionics for civil aircraft is based on the guidelines and methods for conducting safety assessment process on airborne systems and equipment to design the highly integrated or complex aircraft systems, and then to design the hardware and software according to the functions and requirements of the system. At present, the safety assessment of airborne systems and equipment uses US industry standard SAE-ARP4761 [1]. The certification consideration for highly integrated or complex aircraft systems uses US industry standard SAE-ARP4754 [2].

The airworthiness verification of Integrated Modular Avionics for Part 23 aircraft has four elements: hardware airworthiness verification, software airworthiness verification, man-machine factor airworthiness verification and verification test airworthiness verification.

3.1. Hardware airworthiness verification

More and more complex electronic hardware, especially client-based programmable logic devices, are used in Integrated Modular Avionics, which poses challenges to airworthiness design and conformity verification. The safety level of airborne electronic hardware is guaranteed by the DO-254 [3] standard...
of the American Aviation Radio Technical Committee (RTCA). FAA endorses this standard through advisory circular AC20-152. Applicants can use this standard as the compliance for the airworthiness requirements of the client-based programmable logic devices. Although CAAC has not promulgated relevant advisory circular or procedures at present, generally, the Bureau will reach an agreement with the applicant to use explicitly DO-254 as one of the compliance methods for clauses 1301 and 1309 in the newly developed aircraft project.

3.2. Software airworthiness verification
The function of Integrated Modular Avionics is more and more dependent on software. Therefore, more and more attention is paid to the conformity verification of airborne equipment software. Similar to the conformity verification of hardware, the safety level of airborne equipment software is guaranteed by the DO-178B [4] standard of the American Aviation Radio Technical Committee (RTCA). FAA endorsed this standard through advisory circular AC20-115B. Applicants can use this standard as the compliance for the airworthiness requirements of airborne equipment software. CAAC also endorsed this standard through advisory circular AC-21-02. Therefore, in the newly developed aircraft project, the applicant uses DO-178B as one of the compliance methods for clauses 1301 and 1309.

3.3. Airworthiness verification of human-machine factors
Human-machine factors are very important in the design of Integrated Modular Avionics. The comprehensive consideration and good use of human-machine factors will greatly improve the ergonomics and reduce the driver's work burden. Therefore, the Bureau attaches great importance to the compliance of the human-machine factors in the Integrated Modular Avionics design. Based on the importance of human in flight, FAA has developed a guide for the evaluation of Part 23 small aircraft human-machine factors compliance plans, which requires applicant to formulate a human-machine factors compliance plan (HFCP) to ensure that human-machine factors are fully considered and evaluated during the verification procedure. The applicant and the reviewing representative shall carry out the human-machine factors verification work based on the approved human-machine factors compliance plan. The design of the Integrated Modular Avionics should carry out the work of the human-machine requirements, verification, analysis, etc. from the protocol stage and run through the entire procedure of the Integrated Modular Avionics design. Through repeated iterations, the airworthiness requirements are met.

3.4. Airworthiness verification of verification test
As one of the methods of compliance for airworthiness clauses, the test is also suitable for Integrated Modular Avionics. Tests contain laboratory test, ground test, flight test and simulator test. Ground test and flight test are commonly used. The FAA advisory circular AC23-8B provides relevant guidance on the flight test of Part 23 aircraft.

4. The CAAC essentials for reviewing of Integrated Modular Avionics for Part 23 aircraft
Y12F is the first Part 23 aircraft in China to complete the airworthiness review by CAAC of Integrated Modular Avionics. During the procedure of the airworthiness review by CAAC of the Integrated Modular Avionics for Part 23 aircraft, the essentials for reviewing have four aspects as follows.

4.1. Hardware airworthiness review
For foreign equipment, applicant generally requires the development manufacturer to obtain TSO approval. Therefore, a large part of the work on the airworthiness review of the Integrated Modular Avionics hardware is completed by FAA, which is conducive to the acquisition of FAA type certification for Part 23 aircraft. CAAC's reviews of hardware airworthiness are mainly the verification of design approval for the equipment that has obtained TSOA, namely VDA, and the review of that equipment which is verified along with the aircraft. When the applicant applies for a FAA type certification, FAA and CAAC will sign a bilateral agreement. For FAA-approved TSO equipment, CAAC can perform VDA
only. However, for other equipment approved by the Civil Aviation Security Bureau that has not signed a bilateral agreement with CAAC, CAAC does not recognize it and it still needs to be verified along with the aircraft. For that equipment which is verified along with the aircraft, the applicant is required to provide all relevant materials as required by the reviewing representative.

For the equipment that the third party coordinates to the system development manufacturer, the applicant must also strictly check the requirements, and can't be excluded from the matter. The requirements for airworthiness review should be communicated with the Bureau's review representative in advance.

4.2. Software airworthiness review
CAAC's review of software airworthiness is mainly the review of non-TSO functions of Integrated Modular Avionics. The division of labor and responsibilities of CAAC, FAA, applicant and system manufacturer in the non-TSO functions airworthiness review are as follows:

The system manufacturer clarifies the non-TSO functional items and verification methods and the performance requirements of non-TSO function items, and submits all TSO-related materials to the FAA airworthiness review department. The applicant's verification of non-TSO functions is part of the TSO-related materials;

The applicant is responsible for the verification of non-TSO functional items, and the preparation of non-TSO function items verification procedures and results, submits to CAAC, and coordinates CAAC to evaluate and accept the non-TSO function items verification procedures and results;

CAAC is responsible for reviewing, evaluating and accepting the non-TSO function items verification procedures and results submitted by the applicant, and then providing the verification procedures and results to the FAA Small Aircraft Office;

FAA small aircraft office as the liaison of CAAC and FAA airworthiness review department, receives the verification procedures and results for non-TSO function items from CAAC and reviews them, then submits them to the FAA airworthiness review department.

The FAA airworthiness review department accepts the verification procedures and results for non-TSO function items submitted by the FAA small aircraft office after CAAC evaluating before TSO approval, and eventually issued FTSOA to the system manufacturer. Then the FAA airworthiness review department forwards the system manufacturer's FTSO VDA application to CAAC which reviews and approves it.

Many of the main functions of the Integrated Modular Avionics are implemented through software. In order to reduce the modifications proposed by the software during the airworthiness review, the relevant personnel of the airworthiness review may be invited to participate in the detailed design review of the Integrated Modular Avionics as appropriate.

4.3. Human-machine factors airworthiness review
The applicant should prepare a compliance plan of human-machine factors to elaborate detailed the airworthiness verification of Integrated Modular Avionics. The airworthiness clauses involved in Integrated Modular Avionics for Part 23 aircraft are mainly 23.1311, 23.1321, 23.1322, 23.1367 and 23.1381 [5] [6]. The airworthiness verification can integrated use the conformity instructions, aircraft inspection and flight test methods. CAAC first evaluates the materials provided by the applicant, such as drawings, compliance document, configuration descriptions and similarity statements, and then evaluates the human-machine factors of Integrated Modular Avionics through the aircraft inspection and cockpit evaluation. Finally, the human-machine factors of Integrated Modular Avionics are evaluated by witnessing flight test and flighting in person.

4.4. Verification test airworthiness review
CAAC's verification tests airworthiness review of Integrated Modular Avionics for Part 23 aircraft is mainly to review and approve the ground test outline and flight test outline of the Integrated Modular
Avionics, witness important ground tests and/or flight tests, and flight in person, review and approve ground test reports and flight test reports.

5. The FAA focus on issues of Integrated Modular Avionics for Part 23 aircraft

Y12F is the first Part 23 aircraft in China to complete the FAA airworthiness review of the Integrated Modular Avionics. During the FAA airworthiness review of Integrated Modular Avionics for Part 23 aircraft, the following issues were highlighted:

5.1. Circuit protection of Integrated Modular Avionics

FAA proposes the problem of the Integrated Modular Avionics circuit protection. The applicant provides the equivalent security of the Integrated Modular Avionics circuit protection. The content of equivalent security first elaborates detailed the internal module structure of the core processing unit of the Integrated Modular Avionics, and then focuses on describing the detailed external and internal power supply wirings, the circuit protection measures of various parts and the impact of various power supply failures. Finally, the security analysis of the whole core processing unit shows that the circuit protection and airworthiness clause 23.1357 [5] [6] of the Integrated Modular Avionics can achieve the equivalent safety level.

5.2. Compliance of the Integrated Modular Avionics with the airworthiness clauses 1301 and 1309

The FAA raises questions about the conformity of the Integrated Modular Avionics to the 1301 and 1309 airworthiness clauses. The applicant first requires that the Integrated Modular Avionics development manufacturer must carry out the Integrated Modular Avionics design according to the requirements of SAE-ARP4761, SAE-ARP4754, DO254 and DO178, obtain the TSO approval, and submit to CAAC for the verification of design approval VDA, then submit the Integrated Modular Avionics compliance plan, installed compliance related documents, Integrated Modular Avionics security analysis report and some related illustrative documents, and finally submit the 1301 and 1309 compliance of Integrated Modular Avionics.

5.3. Caution about that the heat switch for the pitot heating of the Integrated Modular Avionics is not turned on

The FAA raises an issue paper about the caution that the "pitot heating switch is not turned on" of the Integrated Modular Avionics. The applicant provides the equivalent safety of the "pitot heating switch is not turned on" caution. The content of the equivalent safety first introduces the background of the question and the requirements of the 23.1326 airworthiness clause, and then details how the applicant to achieve the logic of the two caution messages for "the heating switch is not turned on" and "the failure of the heating transfer". Finally, it shows that this caution logic and the requirements of the 23.1326 [5] [6] airworthiness clause can reach the equivalent safety level.

5.4. Instrument marking for the power instrument and the flap marking of the Integrated Modular Avionics

FAA presents the issue papers about the instrument marking for the power instrument and the flap marking of the Integrated Modular Avionics. The applicant provides equivalent safety. The content of the equivalent safety explains respectively in detail how the Integrated Modular Avionics carries out the instrument marking for the power instrument and the flap marking, and verifies through test that this marking method can achieve respectively the equivalent safety level with the marking method requires by the 23.1549 and 23.1545 [5] [6] airworthiness clauses.

5.5. HIRF protection of Integrated Modular Avionics

FAA presents an issue paper for HIRF protection of Integrated Modular Avionics and electrical systems. CAAC publishes HIRF special condition. The applicant provides the compliance plan of HIRF protection
and compliance statement, and elaborates the conformity of HIRF protection for various equipment of Integrated Modular Avionics and electrical systems.

5.6. The indirect effect of lightning on the Integrated Modular Avionics
FAA presents an issue paper for the indirect effect of lightning on the Integrated Modular Avionics and electrical systems. In addition to require the applicant to satisfy the 23.1309(E) airworthiness clause, CAAC also publishes a special condition for the indirect effect of lightning. The applicant provides a compliance plan and compliance statement for the indirect effect of lightning to elaborate the conformity of the indirect effect of lightning for various equipment of Integrated Modular Avionics and electrical system.

5.7. Key display parameters of Integrated Modular Avionics
During the T5 flight test, FAA proposed that the key parameters of the display system indication are not prominent enough. For example, the slide indicator is white, and the lift speed indication font is small and the color is not easily recognized. The display system of the Integrated Modular Avionics for Part 23 aircraft can be designed with reference to FAA's advisory circular AC23-1311-1B / C, which contains regulations and recommendations on the color and font size of the display parameters.

5.8. Crew alert system messages of Integrated Modular Aviation System
When FAA conducted the T5 flight test, it was proposed that there were always some alert messages which were not real failure when the aircraft was on ground. The applicant can join CAAC type certification censors and AEG censors to convene a review meeting specifically for the crew alert system messages of the Integrated Modular Avionics to determine which crew alert system messages need to be inhibited during which flight phases. The applicant modifies the crew alert system messages based on the results of the evaluation. Modify the alert logic for the alert message whose alert logic can be modified and add conditions for triggering the alert message; Add flight phase inhibit for the alert message whose alert logic can’t be modified conveniently. Then the applicant submits the modification statement to the review representative for reviewing. After the approval by the review representative, the applicant coordinates the system manufacturer to make the modifications.

6. Conclusion
In this paper, the airworthiness verification methods of Integrated Modular Avionics for Part 23 aircraft that meet the airworthiness requirements of CAAC and FAA are given, which can be used for the reference in the airworthiness verification of Integrated Modular Avionics for Part 23 aircraft in the future.

References
[1] Sae-Arp4761-1996 Guidelines And Methods For Conducting The Safety Assessment Process On Civil Airborne Systems And Equipment.
[2] Sae-Arp4754-1996 Certification Considerations For Highly-Integrated Or Complex Aircraft Systems.
[3] Rtca-Do-254-2000 Design Assurance Guidance For Airborne Electronic Hardware.
[4] Rtca-Do-178b-1992 Software Consideration In Airborne Systems And Equipment Certification.
[5] Far23, Part 23- Airworthiness Standards: Normal, Utility, Acrobatic, And Commuter Category Airplanes [S].2011.
[6] Ccar-23-R3, Airworthiness Standards: Normal, Utility, Acrobatic, And Commuter Category Airplanes [S].2004.