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# Airworthiness engineering and practices of COMAC C919 airplane

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ABSTRACT

This paper systematically summarizes the basic philosophy and principles of airworthiness that COMAC follows in the process of developing C919 large passenger aircraft. It carries out type certification along with the aircraft development process, and plans and implements compliance activities for airplane design features. Targeting the airworthiness requirements, COMAC has also established an airworthiness management system, including design assurance system and continuing airworthiness system, to ensure that aircraft are designed in accordance with airworthiness requirements, to show compliance with airworthiness requirements and to continuously ensure the airworthiness of airplane by dealing with continuing airworthiness events in service.

## 1. Philosophy and principles of airworthiness

Commercial Aircraft Corporation of China, Ltd. (COMAC) was established in Shanghai China in 2008. COMAC functions as the main force in implementing large passenger aircraft programs in China. It also responsible for the overall planning of developing trunk liner and regional jet programs and realizing the industrialization of civil aircraft in China. The vision of COMAC is to deliver safer, more cost-effective, more comfortable, and more environment-friendly commercial aircraft.

Safety is always the priority when COMAC develops and produces airplanes. Therefore, airworthiness management is the key element of COMAC's management system, and COMAC allocates all necessary resources to establish the organizational architecture, responsibilities and company manual, policy, and procedures to ensure the airworthiness.

Airworthiness means the inherent nature of aircraft for safe flight (including take-off and landing) in expected environments, and this inherent nature can be reserved by appropriate maintenance [1]. The applicant/holder of type certificate must design and manufacture the aircraft in accordance with the airworthiness standards. These standards set the minimum safety limits recognized by the public and published by the authority, ensuring that the aircraft's design and manufacture meet the airworthiness standards and demonstrating to the authority that the aircraft designed and manufactured meet the airworthiness standards. That is, the applicant/holder of type certificate must take full responsibility for the airworthiness of the aircraft [2–4].

Therefore, COMAC cherishes the value of airworthiness standards and regards them as the common wealth of global aviation safety activities, valuable knowledge without intellectual property restrictions, and the cornerstone of sustainable development of civil aircraft aviation industry. COMAC always follows the airworthiness standard evolution, understands the intend of the airworthiness standard and transfers the practical experiences into COMAC's know-how. In COMAC airworthiness management, we focus on safety, share the safety information with all stakeholders, and use the risk management tools.

Aircraft design and manufacture is a highly complex program. It takes more than ten years and involves more than ten thousand managers, engineers and workers. Aircraft manufacturer, suppliers, authority, airlines are different stakeholders. Conflicts of interest, arguments and difficulties are inevitable, while delivering a successful product to the market is the common goal. Therefore, integrity and putting people first are the basic values and culture in COMAC airworthiness management. Integrity requires an open, honest, and constructive communication, fulfilling a commitment to airworthiness and safety, taking responsibility for decisions and actions, clearly sharing information and ideas, solving problems at their root cause and actively participating in the decision-making process and advancing toward the common goal. Putting people first requires treating others as oneselves with justice and mutual respect, open to different opinions, constantly progressing, maximizing the talents of people with different backgrounds and perspectives, striving to improving your own and other people's abilities, as well as appreciating each other's accomplishments in public and share problems in private.

## 2. Development and certification process of C919 airplane

COMAC has delivered two airplane types to service, one is ARJ21–700, a regional jet, and the other is C919, a trunk liner. C919 airplane is a 150-seat transport airplane with a maximum takeoff

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weight of 78.9 tons and a design range of 5555 kilometers. The C919 airplane has a conventional layout with a swept and low wing, a high-aspect-ratio supercritical wing, and two LEAP-1 C high-bypass-ratio turbofan engine installed under the left and right wings respectively. C919 meets ICAO four-stage noise and CAEP6 emission requirements, and is suitable for airports with ICAO flight area level above 4 C.

COMAC follows the civil aircraft development process and obtains type certification by Civil Aviation Administration of China (CAAC).

### *2.1. Seamless integration of the certification process with the airplane development process*

Civil aircraft development follows the aviation industry standard “Development Process for Civil Aircraft” (HB8525–2017). Normally it includes 5 phases: (1) Requirements and Concept Definition; (2) Preliminary Design; (3) Detailed Design; (4) Trial Production and Verification; (5) Batch Production [5].

Type certification follows CAAC procedure “Aircraft Type Certification Procedure” (AP 21-AA-2011–03-R4) and includes 5 phases: (1) Concept Definition; (2) Regulation Requirement Definition; (3) Compliance Planning; (4) Implementation; (5) Post Certification [6].

Type certification is a kind of process control, which is carried out concurrent with the development of aircraft. Seamless integration of the certification process with the airplane development process is cricital to efficience. During C919 development and certification, COMAC integrates these two processes by gate control and phase evaluation. See Fig. 1.

COMAC completed the Preliminary Design Review (PDR) for the C919 airplane in 2011, and submitted the TC application in 2010. The C919 airplane showed its first roll-out in 2015 and fulfilled the first flight in 2017. In 2020, the C919 airplane underwent the authority flight test and obtained CAAC TC on September 29, 2022. The first airplane was delivered to the pioneer customer, China Eastern and entered into service (EIS) in 2023. The C919 airplane development and type certification milestones are concluded in Figs. 2 and 3.

### *2.2. Methodology of showing compliance by system and closing certification basis by regulation section*

According to the CCAR 21.17 of “Certification Rules for Civil Aviation Products and Articles” (CCAR 21 R4), the certification basis of C919 airplane includes 4 parts [7]: (1) the applicable regulations, including CCAR 21, 25, 26, 34, and 36; (2) special conditions; (3) equivalent level of safety findings; (4) exemptions.

The requirements of certification basis have been considered and determined since the concept definition phase and they are the important input for the airplane development. The development of C919 airplanes follows the top-down process by using the idea of system engineering and starting from the requirement capture. The management, validation and verification of airplane requirements run through the aircraft level, system level and equipment level. That means, different Means of Compliance for each section of certification basis are used at aircraft level, system level and equipment level. Since one system is always applied to many sections of certification basis, one aircraft level certification plan, so called Project Specific Certification Plan (PSCP), and 65 system level certification plans are created to record the applicant’s intended means and reach an agreement with the authority. This is to demonstrate that the airplane and its systems comply with the certification basis. From this information, if the plan was successfully executed, its results would show compliance [8].

Regulatory requirements have their own integrity and complexity. Each section of certification basis imposes requirements on various systems and compliance activities are spread across various systems. At a later stage of the implementation phase of the certification process and before the compliance statement is provided, it is necessary to carry out compliance check section by section and record all compliance evidences in the Compliance Check List (CCL). If all sections of certification basis are complied, the integrity and completion are ensured. See Fig. 4.

## 3. Design features and critical compliance technology

The development of C919 airplanes uses mature technology. However, in order to achieve better economic operation and enhance the market competitiveness, some advanced technologies have also been applied.

### *3.1. Performance and control stability verification for fly-by-wire airplane*

C919 aircraft adopts the full time, full authority fly-by-wire system and the active control technology. It has full authority augmentation control in three-axis and flight envelope protection functions. By using fly-by-wire technology, The C919 airplane has flight envelope protection functions, including high incidence protection, alpha floor function and auto throttle speed protection, normal load factor (g) limiting, pitch limiting, roll limiting, high-speed limiting etc.

To verify those functions, according to the CCAR 21.16 [7], several special conditions were prescribed. Performance and control stability flight tests were carefully implemented to demonstrate compliance [9]. See Table 1.

### *3.2. Building block approach for composite structure*

The horizontal and vertical stabilizer, and tail cone after bulkhead are made of composites. In comparison, for ARJ21–700, the composite structure is used for bearing, elevator, wingtip, spoilers, etc. It is the first time for COMAC to use composite in the main structures which are essential in maintaining the overall flight safety of the airplane.

According to FAA Advisory Circular AC 20–107B “Composite Aircraft Structure”, the “building block” approach is used. The strength of the composite structure of C919 is reliably established gradually through a program of analysis and a series of tests conducted using specimens of varying levels of complexity. These tests and analyses at

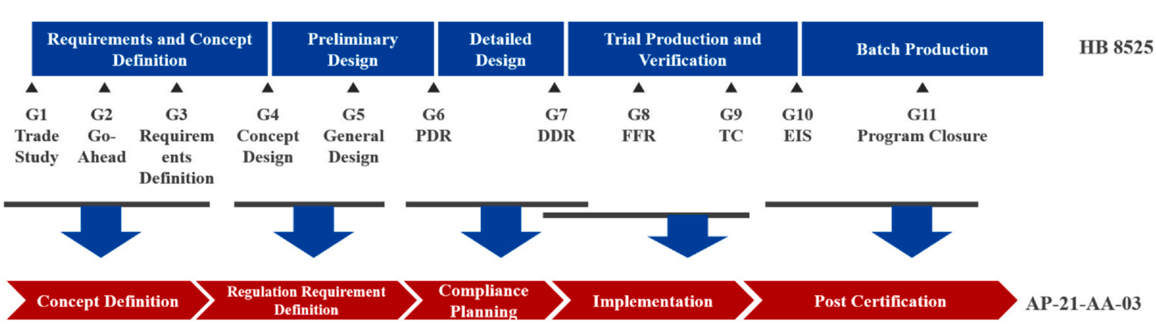


**Fig. 1.** Seamless integration of the certification process with the airplane development process.


**Fig. 2.** C919 airplane development milestones.

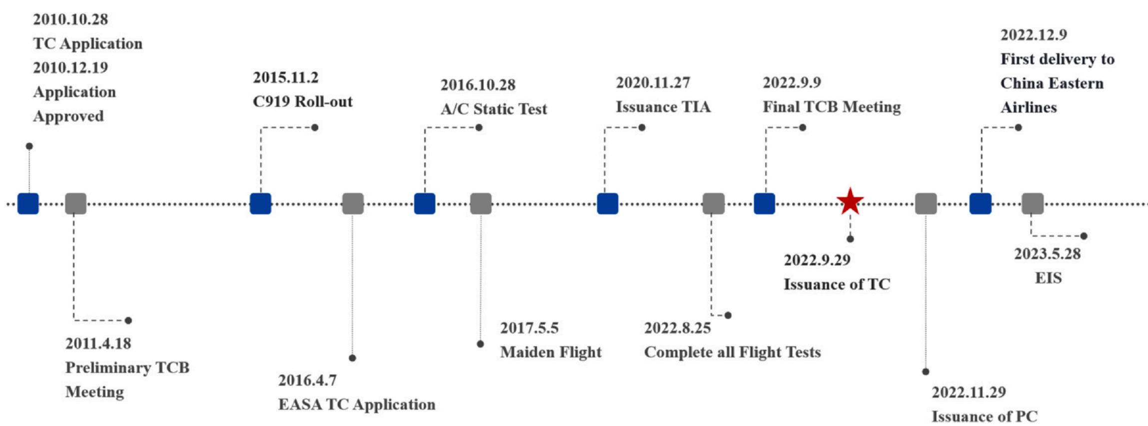


**Fig. 3.** C919 airplane type certification milestones.

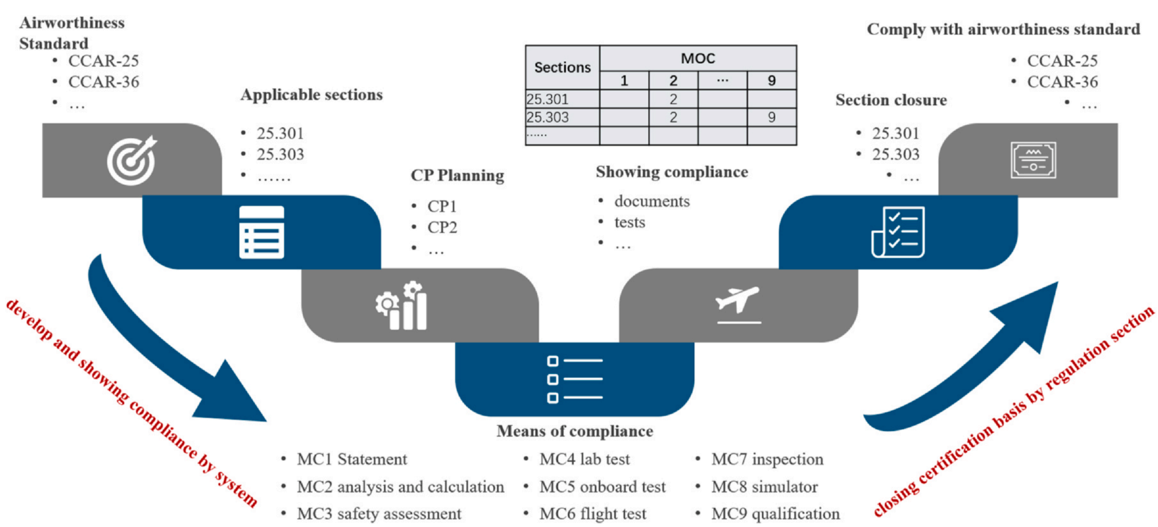


**Fig. 4.** Methodology of showing compliance by system and closing certification basis by regulation section.

**Table 1**
Performance and control stability flight tests.

| No | Test | No | Test |
|---|---|---|---|
| 1 | Stall Speed | 1 | Longitudinal control |
| 2 | Minimum Unstick Speed | | Directional and lateral |
| 3 | Abused Takeoff | | control |
| 4 | Take-off | | |
| 5 | Maximum Practicable Rate Rotation | 2 | Minimum control speed |
| 6 | Accelerate-stop Distance | | |
| 7 | Climb | 3 | Stalls |
| 8 | En-route Flight Paths | 4 | Vibration and Buffeting |
| 9 | Landing | 5 | Stability |
| 10 | Contaminated Runway Flight Performance | 6 | Maneuvering Capabilities |
| 11 | Calibrated Airspeed | 7 | High speed characteristics |
| | …… | | …… |

the coupon, element, details, and subcomponent levels are used to address the issues of variability, environment, structural discontinuity (e.g., joints, cut-outs or other stress risers), damage, manufacturing defects, and design or process-specific details [10]. See Fig. 5.

### *3.3. Certification considerations of airplane, system and airborne software and hardware by applying development assurance technology*

According to CCAR 25.1309 (b) of "Transport Category Airplanes Airworthiness Standard" (CCAR 25 R4), the airplane systems and associated components, considered separately and in relation to other systems, must be designed so that catastrophic occurrence of any failure condition is extremely improbable and hazardous occurrence is improbable [11]. For airplanes containing many complex or integrated systems, it is likely that a plan is required to describe the intended safety process. This plan should determine the detailed means of compliance, which may include the use of Development Assurance techniques [12].

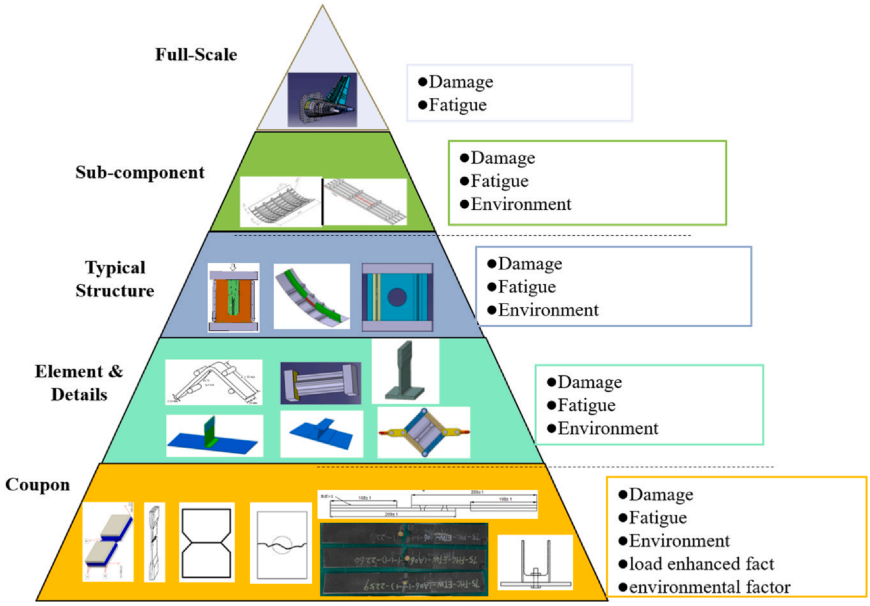


**Fig. 5.** Building block approach for composite structure.

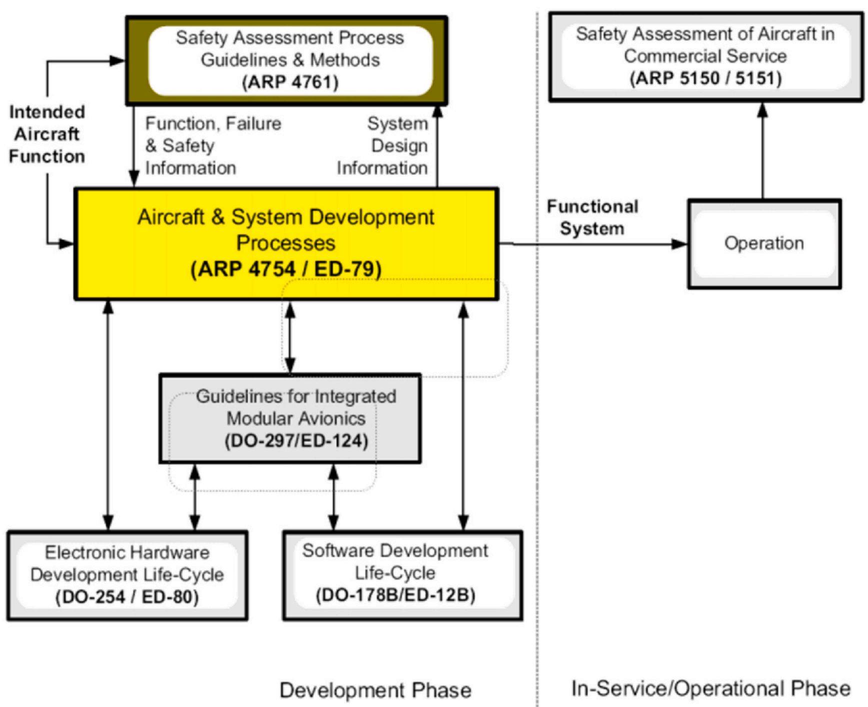


**Fig. 6.** Design assurance technology.

Refer to "Development of Civil Aircraft and Systems" (AC 20–174) [13] and the principles of "Guidelines for Development of Civil Aircraft and Systems" (SAE ARP 4754 A) [14], COMAC builds its system, manual, policy, and procedures to apply development assurance techniques, as the means of compliance with CCAR 25.1309.

The C919 aircraft level and complex or integrated systems, such as primary flight control system, integrated modular avionics (IMA), strictly implement the objectives and requirements of development assurance process. The C919 aircraft level and all the systems strictly implement the requirements of the safety assessment process. And functional requirements are strictly controlled according to the Functional Development Assurance Level (FDAL) generated from the safety assessment process. Issues identified in the process are assessed for acceptability. For IMA development and certification, "Integrated Modular Avionics (IMA) Development Guidance and Certification Considerations (RTCA DO-297)" is adopted [15].

At software and hardware level, COMAC also builds its policy and procedures to ensure the Development assurance for software and hardware development and certification, "Software Considerations in Airborne Systems and Equipment Certification" (RTCA DO-178B) [16] and "Design Assurance Guidance for Airborne Electronic Hardware" (RTCA DO-254) [17] are adopted. See Fig. 6.

### *3.4. Structured system safety assessment*

The safety assessment follows "Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment" (SAE ARP 4761) and is to evaluate whether the implemented system/

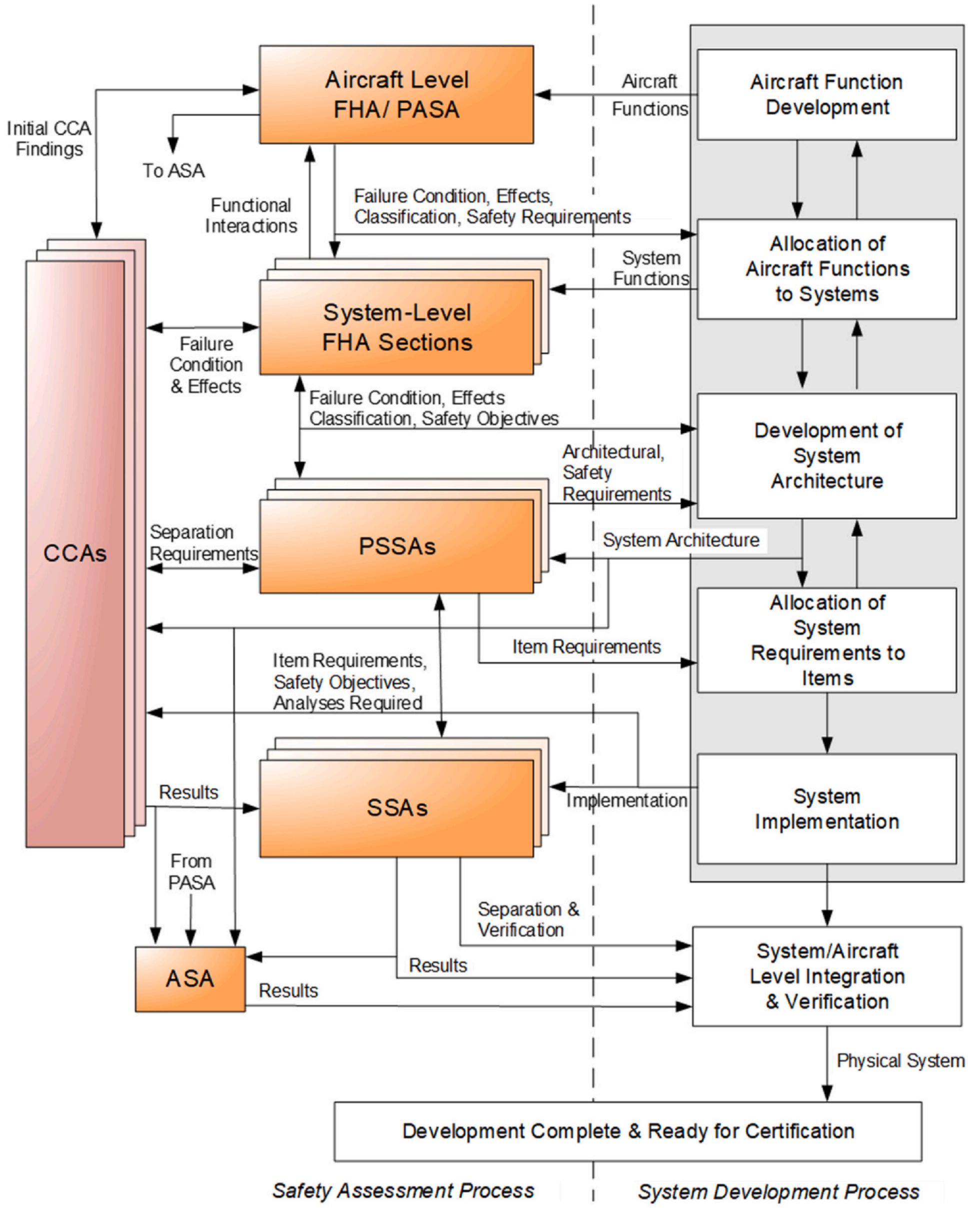


**Fig. 7.** System safety assessment.

aircraft meets the applicable safety requirements [18]. The steps of safety assessment include: (1) determine system safety objective and requirement; (2) issue aircraft safety plan; (3) conduct safety assessment.

At aircraft level, Aircraft Function Hazard Assessment (AFHA), Preliminary Aircraft Safety Assessment (PASA), Common Cause Analysis (CCA), Cascading Effect Analysis (CEA), Aircraft Safety Assessment (ASA) are implemented and documented. At system level, System FHAs, Preliminary System Safety Assessments (PSSAs), SSAs, CCA (including Particular Risk Analysis (PRAs), Common Mode Analysis (CMAs), Zonal Safety Analysis (ZSAs))are implemented and documented. See Fig. 7.

### 3.5. System verification capacity-building

Besides the design assurance technology and structured system safety assessment, laboratory tests and simulator tests are important to verify the system design requirements and the compliance with airworthiness regulations. Compared the analysis and calculation, laboratory tests and simulator tests can better reflect the real condition of the systems. Compared the flight test, laboratory tests and simulator tests are more flexible, comprehensive and able to traverse system functions. Furthermore, they are more feasible and less risky than flight tests for simulating various failure conditions. Therefore, with the development of C919 airplanes, COMAC has established a complete system verification capability and built various system test facilities including various electromagnetic laboratories, iron bird test bench and engineering simulators. See Fig. 8.

## 4. Airworthiness management system

Type certification is a kind of product certification that determines whether the airplane meets airworthiness requirements. To ensure that the TC applicant/holder has the necessary knowledge and means to develop certification demonstration to be confident in their statements of compliance, a robust airworthiness management system is needed to demonstrate the capability.

### 4.1. Design assurance system

According to CCAR 21.473, the TC applicant/holder must establish the suitable design organization, and demonstrate that the design


**Fig. 8.** System test facilities.

| Possibility | Hazard Severity Categories | | | | |
|---|---|---|---|---|---|
| | No Safety Effect 5 | Minor 4 | Major 3 | Hazardous 2 | Catastrophic 1 |
| A (P > 1E-3) | [GREEN]<15> | [YELLOW]<13> | [ORANGE]<8> | [RED] <3> | [RED] <1> |
| B Probable (1E-5 < P≤1E-3) | [GREEN]<19> | [GREEN]<14> | [ORANGE]<9> | [RED] <5> | [RED] <2> |
| C Remote (1E-7 < P≤1E-5) | [GREEN]<22> | [GREEN]<18> | [YELLOW]<12> | [ORANGE]<7> | [RED] <4> |
| D Extremely remote (1E-9 < P≤1E-7) | [GREEN]<24> | [GREEN]<21> | [GREEN]<17> | [YELLOW] <11> | [ORANGE]<6> |
| E Extremely improbable (P≤1E-9) | [GREEN]<25> | [GREEN]<23> | [GREEN]<20> | [GREEN]<16> | [YELLOW][1]<10> |
| NOTE1: When a single failure / common cause failure occurs, the area shall be orange, or unacceptable risk. | | | | | |

**Fig. 9.** Classification of continuing airworthiness events.

organization has established and is able to maintain a design assurance system for the control and supervision of the design, and of design changes, of civil aviation products and articles covered by the application [7]. This design assurance system must enable the design organization in the ways of: (1) aircraft design and changes in accordance with airworthiness regulations; (2) validating the compliance of type design and modification with airworthiness regulations; (3) demonstrating to the authority the compliance of the type design and its modifications to the airworthiness regulations.

COMAC has integrated the company's design assurance system to fully enssure the independent verification of airworthiness compliance data and obtain the privilege to approve post-certification design minor changes and general repairs. The design assurance system has 3 main functions: (1) design; (2) airworthiness; and (3) independent monitoring.

Airworthiness engineer (AE), compliance verification engineer (CVE), designated airworthiness engineer (DAE) and certifying staff (CS) are assigned for different responsibilities. AE, CVE, DAE, CS are the teams of specialists and managers with professional skills and airworthiness experiences to meet the needs of the company's airworthiness work, and the personnel can be competent for type certification and post-certification management.

### *4.2. Continuing airworthiness system*

According to Annex 8 of the Convention on International Civil Aviation, Airworthiness of Aircraft, continuing airworthiness is paid attention to. That means, a set of processes by which an aircraft, engine, propeller or part complies with the applicable airworthiness requirements and remains in a condition for safe operation throughout its operating life is needed [19].

COMAC has established continuing airworthiness system to collect continuing airworthiness events in service according to "Safety Assessment of Transport Airplanes in Commercial Service (SAE ARP 5150)" [20], to conduct the risk assessment and to provide corrective actions and improvements as necessary. Hazard severity categories and possibility are considered and all continuing airworthiness events are classified into different urgencies. See Fig. 9.

## 5. Future outlook

The technology of aircraft development is constantly updated, and airworthiness regulations are constantly evolving accordingly. COMAC will continue to accumulate experiences in the process of new airplane type development, certification and continuing airworthiness management of aircraft in service. COMAC is open and willing to share its experiences with the industry. In terms of process management, COMAC will pay more attention to risk-based certification policy and pool resources on areas more critical to safety. While improving the efficiency of type certification, it ensures airworthiness and safety.

COMAC's vision is to deliver good airplanes to the aircraft manufacturing industry and the civil aviation transport industry. COMAC is willing to contribute its wisdom to the development of the industry as well. Although product competition is inevitable, it is the common mission and responsibility for every stakeholder in the industry to ensure safety. Achieving airworthiness and safety is a value we all share.

## CRediT authorship contribution statement

**Yuerang Zhao:** Investigation, Visualization, Conceptualization, Methodology, Writing.

## Declaration of Competing Interest

The author declares a potential conflict of interest as follows: The author was once employed by COMAC (Commercial Aircraft Corporation of China, Ltd.).

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