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Studies on Historical Evolution of FAR Part 33 Associated with Development of Civil High Bypass Ratio Turbofan Engine

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Abstract

Federal Aviation Regulations (FAR) Part 33 is airworthiness standard of aircraft engine and it is under constant changing to adapt the new safety demands of airworthiness certification. In this paper, starting from the historical amendments, the evolution of Part 33 is studied with development of civil high bypass ratio turbofan engine by statistics analysis and the revised reason is summarized by investigation the proposals of amendments. For analysis, a conception of restriction boundary of regulation is introduced and the influence produced by each revised reason is researched between restriction boundary and safety boundary. Results show that the changed of Part 33 has four cycles, with significant revision every 10-12 years. And interestingly, the civil high bypass ratio turbofan engine has the same development stages and good corresponding relationship with significant revision period of Part 33. Under the contradiction between safety demand of FAA and technology demand of manufacturer, the revised reason of regulation is generalized into five aspects: the development of technology, the hazardous accident, the overly strict rules or vice versa, the unclear definition or explanation, the international uniformity. Therefore, the appeared new aircraft engine can promote the update of regulations and the revised regulations guide the development of next generation engine. Basing on these obtained laws, the next significance amendment of airworthiness regulation Part 33 can be predicated.

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keywords: Historical evolution; FAR Part 33; Civil high bypass ratio turbofan engine; Amendment; Revised reason;

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1. Introduction

The Federal Aviation Regulations, or FARs, are rules prescribed by the Federal Aviation Administration (FAA) governing all aviation activities in the United States. FARs is organized into sections, called parts due to their organization within the Code of Federal Regulations (CFR). Each part deals with a specific type of activity. Among them, Part 33 contains rules for aircraft engine and the rules are designed to promote safe aviation. Thus, the effect of Part 33 can be reflected in two aspects: 1) based on the request of rules, FAA examines the aeroengine products from manufacturer. And if all of the rules are satisfied, the airworthiness certification is passed and this product can be used in commercial. 2) in design stage of an aeroengine, the rules of Part 33 are important reference to be considered during design phase. And before the products enter the market, the airworthiness certification of an aeroengine must be obtained.

Since the publication of Part 33 in 1965, it is under constant changing in last 50 years and is explained that the old rules might not applicable to the new designs or products. That is, the inappropriate rules are revised after the negotiation between FAA and aeroengine manufacturer to update and improve the airworthiness standards applicable to the type certification of aircraft engines, and this process is recorded in Amendment.

In general, the study of Part 33 in airworthiness field mainly concentrates on a single rule or the associated rules of a single aeroengine component, and the research content usually involves the historical origin, development, technological connotation and industry impact of rules itself. From these studies, the manufacturer better understands the requests of rule and takes corresponding technology action to satisfy the rules. However, although there are lots of studies about the single rules or single components at present, it is rare to study Part 33 as a whole. The reason is that Part 33 covers all aspects of aeroengine airworthiness certification and the large number of analysis object and the associated information cause the difficult to study. Filippo De Florio’s book Airworthiness: An Introduction to Aircraft Certification presented a global study of Part 33 [1], but the object of this book concentrated on the whole aircraft and the descriptions of Part 33 were simple. In addition, although the close connection between aeroengine industry and Part 33 is well known, the relationship study and interaction effect of above two have been almost absent in this field.

In this paper, facing the whole FAR Part 33 and starting from its historical amendments, the evolution of Part 33 is researched with development of civil high bypass ratio turbofan engine. The object of this study is firstly to use statistics analysis to reveal the revision laws of regulation, and basing on this, the relationship and interaction effect between civil high bypass ratio turbofan engine development and Part 33 changing is investigated. Then, the revised reason of Part 33 is summarized. Thus, this study is not focused and limited to technical details of rules, but carried out with a higher angle of view to understand the effect of Part 33. The conclusions provide another insight of the airworthiness certification and the next generation engine development for FAA and manufacturer respectively.

Paper is divided into five sections. Based on the historical amendments of Part 33, the revised regulation is summarized by using statistics analysis in Section 2. And the relationship and interaction regulation between civil high bypass ratio turbofan engine development and Part 33 are obtained by General Electric Company (GE) as an example in Section 3. Based on the above mentioned analysis, in Section 4, the revised reason is generalized and classification. At last, the principal conclusions are given in Section 5.
2. Summary the regulation amendment of FAR Part 33

With fast development of civil aircraft, especially the appeared turbofan engine, the old Civil Aeronautics Regulations (CAR) cannot suitable the needs of the times. Thus, in order to adapt the demand of airworthiness certification, the old CAR is instead of Federal Aviation Regulation (FAR) and the new Part 33 “Civil Aircraft Airworthiness Standards: Aircraft Engines” is republished by FAA. By May of 2013, Part 33 is under constant changing by thirty-three times of amendments and consists of almost all the rules. It should be noted that the rules of Part 33 from Sec. 33.31 to Sec 33.57 are only associated with aviation piston engine. Therefore, these rules are ignored in the following analysis because the turbofan engine is only concentrated in this paper.

In general, it is well know that the purpose of the amendments of Part 33 is to update and improve the airworthiness standards applicable to the type certification of aircraft engines. However, in the past fifty years, the evolution of Part 33 exists some regularly changing in this process. Using statistics analysis method and according to the implementation time of each amendment [2], the revisions can be divided with the number of involved rules of Part 33 as given in Table 1. It can be seen that the scale and degree of revision in each amendments and years are not same. That is, the number of times amendment is different in one year and the number of revised rules associated civil bypass ratio turbofan engine in every amendment is different. Fig.1 presents this phenomenon more clearly. Since the publication in 1965, Part 33 experiences large scale of revision five times (it also has been emphasized in Table 1 by using italics), which is in 1964, 1974, 1983, 1996 and 2007-2008. Among them, some small scale of revisions is carried out. That is, it is important to reveal that the changed of Part 33 has four cycles, with significant revision every 10-12 years.

To explain this regularly changing, it should be connected with the development of civil aeroengine, especially the relationship and interaction effect between airworthiness regulation and aviation industry, in the past fifty years.

Table 1 Number of amendments with involved rules in each year

| Years | Number of amendments | Number of involved rules |
|-------|----------------------|--------------------------|
| 1965  | Amendment No. 33-0, Amendment No. 33-1 | 30+1=31 |
| 1966  | Amendment No. 33-2 | 1 |
| 1967  | Amendment No. 33-3 | 8 |
| 1971  | Amendment No. 33-4 | 2 |
| 1974  | Amendment No. 33-5, Amendment No. 33-6 | 1+31=32 |
| 1977  | Amendment No. 33-7, Amendment No. 33-8 | 1+2=3 |
| 1980  | Amendment No. 33-9 | 9 |
| 1984  | Amendment No. 33-10 | 23 |
| 1986  | Amendment No. 33-11 | 2 |
| 1988  | Amendment No. 33-12 | 2 |
| 1990  | Amendment No. 33-13, Amendment No. 33-14 | 1+1=2 |
| 1993  | Amendment No. 33-15 | 1 |
| 1995  | Amendment No. 33-16 | 1 |
| 1996  | Amendment No. 33-17, Amendment No.33-18 | 4+7=11 |
| 1998  | Amendment No. 33-19 | 3 |


| Year   | Amendment No.                        | Revised Rules |
|--------|--------------------------------------|---------------|
| 2000   | Amendment No. 33-20                  | 3             |
| 2007   | Amendment No. 33-21, Amendment No. 33-22, Amendment No. 33-23, Amendment No. 33-24 | 5+3+1+4=13    |
| 2008   | Amendment No. 33-25, Amendment No. 33-26, Amendment No. 33-27, Amendment No. 33-28 | 5+8+3+1=17    |
| 2009   | Amendment No. 33-29, Amendment No. 33-30 | 1+4=5         |
| 2011   | Amendment No. 33-31                  | 1             |
| 2012   | Amendment No. 33-32, Amendment No. 33-33 | 1+1=2         |

![Graph](image.png)

**Fig. 1** Revised frequency of amendments with involved rules in the past fifty years.

### 3. Evolution laws of airworthiness regulation with development of civil high bypass ratio turbofan engine

In the above section, it is known that the changed of Part 33 experiences four cycles, with significant revision every 10-12 years. Interestingly, based on the overall pressure ratio and bypass ratio, the development of civil high bypass ratio turbofan engine from 1960s to now also can be divided into four stages and have a good corresponding relationship with significant revision period of Part 33. Table 2 presents these four stages with the typical characteristics and using technologies [3-6]. It can be seen that, for the civil high bypass ratio turbofan engine, the interval of two stages is about 10 years. Thus, the evolution of airworthiness regulation can be comparative studied with the development of civil high bypass ratio turbofan engine to reveal the relationship and interaction effect between FAA and aeroengine manufacturer. In this paper, the civil high bypass ratio turbofan engine produced by General Electric Company (GE) is as an example [5] and the other aeroengine company has the similar results.
Table 2 Development stages of civil high bypass ratio turbofan engine with the typical characteristics and technologies

| Years | Pressure ratio | Bypass ratio | Typical characteristics and technologies |
|-------|----------------|--------------|-------------------------------------------|
| 1970s | 22–30          | 4.2–5.0      | Conventional design, material and manufacture technology |
| 1980s | 28–34          | 5.0–6.0      | Quasi-3-D or 3-D blade design; Directionally solidified and Single-crystal material turbine blade; Overall welding compressor rotor; Powder metallurgy (PM) turbine disk; Full Authority Digital Electronic Control (FADEC); |
| 1990s | 34–40          | 6.0–8.0      | 3-D design of fan, high compressor and turbine blade; Wide chord and composite material fan blade; Diffusion Bonding and Superplastic forming manufacturing method; Brush seal structure in air and oil seal; High temperature resistance material and coating; New generation FADEC; |
| 2000s | 40–52          | 8.0–11.0     | New generation 3-D blade design; Skewed design fan blade; Composite material box of fan; Lower emissions combustors; Low noise design; High efficient cooling technology in turbine blade; Intelligent condition monitoring system; |

3.1 Development of GE aeroengine with airworthiness regulation evolution

According to the development time, Fig. 2 arranges the most typical GE aeroengine with the evolution of airworthiness regulation in the past fifty years. It can be seen that there are six engines to investigate.

A. TF39 and CF6

GE TF39 is the first high-power, high-bypass jet engine available [4]. After the successful utilized in the 1960s of the TF39 for the C-5 galaxy, GE offered a more powerful development for civilian use as the CF6 and the first run of CF6 was in 1971. During this time, the airworthiness regulation experienced two large revisions: the Amendment No. 33-0 in 1965 [8] and the Amendment No. 33-6 in 1974 [9]. For Amendment No. 33-0, the revised reason can be believed that the power of civil aviation is transferred from turbojet to turbofan, and the old airworthiness regulation based on turbojet engine is not able to meet the demand of situation and is bounded to amend. Conversely, the successful development of one generation turbofan engine by manufacturer, like CF6, applies many new technologies and consequently the old regulation gradually fall behind the demand of airworthiness certification. Thus, based on the suggestion from industry and the negotiation result between FAA and manufacturer, the Amendment No. 33-6 is published and sought to accommodate the increasing complexity of airframes and engines and their interfaces and even the further impact of supersonic flight.
B. CFM56

For the demand situation of international civil aviation market, the next generation engine, high bypass ratio turbofans in the "10-ton" (20,000 lbf; 89 kN) thrust class, was introduced to research by French government in the late 1960s [10]. After the investigation and analysis, SNECMA, who had mostly built military engines until then, decided to mainly cooperate with GE and to develop this engine in 1971. Then, the CFM international was established in 1974 and the new engine was named CFM56. CFM56 applies the F101 core technology of GE [11] and can satisfy the future demand of low fuel consumption, low noise and low pollution. In June 1979, CFM56 finished the first run and then obtained the airworthiness certification of FAA and French. Therefore, the development time of CFM56 is between two large revisions, the Amendment No. 33-6 in 1974 [9] and the Amendment No. 33-10 [12] in 1983. During the development of two generation engine, like CFM 56, the industry becomes even more complex and specialized. Thus, the need for clarification and elimination of redundancies in test and design requirements becomes evident in regulation. Responding to these needs, the FAA in mid-1977 announced an Aircraft Engine Regulatory Review Program, solicited rule change proposals from the aviation and general community, and held a week-long Regulatory Review Conference in January 1978 [13], attended by over 100 industry and public representatives. In the basis of these conferences and negotiations, the regulation was revised and the Amendment No. 33-10 was published to adapt the existed situation or used new technology in aviation industry.

C. GE90

In the 80s, the major aeroengine manufacturer realized that it faced high cost (> 2 billion dollars of today’s value) and risk in the development of new engine even if the various manufacturing and experimental equipments were obtained conditions [14]. And it was the typical characteristic of the three generation engine. Thus, for sharing the development resources, opening the market and gathering the technology, the international cooperation was the trend of engine development. In this context, developed from the 1970s NASA Energy Efficient Engine, GE90 was launched in 1990 GE Aviation associated with SNECMA (France), IHI (Japan) and Avio (Italy) [15]. And the first run was in 1995. Therefore, in historical, the development of GE90 is located between the published large Amendment No. 33-10 in 1983 [13] and Amendment No. 33-17 in 1996 [16]. During this time, the revision of airworthiness mainly reflects the characteristic of international uniformity, especially in Amendment No. 33-17. That is, Part 33 of title 14 of the Code of Federal Regulations (14 CFR part 33) prescribes certification standards for the issuance of original and amended type certificates for aircraft engines. Part- E of the Joint Aviation Requirements (JAR-E) prescribes the corresponding certification standards of the JAA. While part 33 and JAR-E are similar, they differ in several respects. Non-uniform standards impose a regulatory burden on applicants seeking certification under both sets of standards in the form of additional costs and delays in the time required for certification.

D. GEnx and LEAP-X

From 1990s to 2000s, GE Aviation developed their next generation engine GEnx and the major application was in Boeing 747-8 and Boeing 787 Dreamliner. The major structure design of GEnx was originated from GE90 and thus it had low risk of research due to the applied mature technology [17]. The first run time was in 2006. So, the development of GEnx is between two large revisions, the amendment in 1996 and 2007-2008. It should be noted that although FAA published many amendments (from Amendment No. 33-21 [18] to Amendment No. 33-28 [19]) in 2007-2008, the major revised content of
these amendments is related to the international uniformity because the increasing international cooperation and the established EASA require improving efficiency and saving cost in airworthiness certification.

In addition, during the airworthiness regulation large revised in 2007-2008, GE Aviation and SNECMA were developing a new engine and it was officially launched as "LEAP-X" on 13 July 2008 [20]. The LEAP ("Leading Edge Aviation Propulsion") incorporates technologies that CFM developed as part of the LEAP56 technology acquisition program, which CFM has been launched in 2005. It is intended to be a successor to the CFM56-5Band CFM56-7B. Currently proposed for the LEAP is a greater use of composite materials, a bypass ratio around 10-11:1 and 16% lower fuel consumption [21].

Fig. 2 The comparative relationship between historical evolution of Part 33 and development of civil high bypass ratio turbofan engine produced by GE Company

3.2 Summary

Although the civil high bypass ratio turbofan engine of GE Aviation has the same development stage and good corresponding relationship with significant revision period of Part 33 from the above discussion, the airworthiness regulation amendment reflects hysteresis quality. That is, the new generation aeroengine is bound to use new design technology and to seek high international cooperation because of the progress in science and increased cost respectively, and it impels the regulation to adapt new situation when the new aeroengine appeared. However, on the contrary, the amended and new published regulation restricts the new generation aeroengine development in legal, i.e. the mandatory design standard, method, and experimental et.al, to guarantee safety. Therefore, the FAA and manufacturer are supplementary to each other in the development of civil aviation.

Basing on these obtained laws, it can bold predicted that the next significance amendment of airworthiness regulation Part 33 will be in 2017-2020 and the content must be related to the developing
engines, like LEAP-X, by major manufacturer. And it is benefit for manufacturer to improve efficiency and save cost in airworthiness certification.

4. Analysis the revised reason of airworthiness regulation

From the above sections, it is known that the civil high bypass ratio turbofan engine has the similar development stage and good corresponding relationship with significant revision period of Part 33. In the following, the revised reason of airworthiness regulation is introduced in details.

In general, for each revision of Part 33, it is the result of negotiation between FAA and aeroengine industry. And before the final rule implement, the content of negotiation, i.e. the exposed problems, the suggestion or requirement of manufacturer, the clarification for doubtful text, et.al, is recorded in Notice of Proposed Rulemaking. It should be noted that the essence of regulation revision is to set aviation industry standard in safety, reliability, and durability. Thus, under the instruction of this thought, the revised reason of airworthiness regulation can be summarized and classified into five aspects through review and analysis the information provided by Notice of Proposed Rulemaking:

1) The fast development of technology causes that the current situation exceeds the restriction scale of old regulation, or the old regulation cannot guarantee the effective airworthiness certification.
2) The appeared hazardous accident exposes the problem, mistake and unconsidered situation existed in old regulation.
3) Because of the unclear safety demand of aeroengine, the overly strict rules cause high manufacturing cost in aeroengine industry.
4) The unclear definition or explanation in some regulations produces misunderstanding and confusion for manufacturer.
5) The enlarged international cooperation in civil aviation, especially the established European Aviation Safety Agency (EASA), requires the uniformity of regulation between FAA and EASA to reduce the difficult and period of airworthiness certification.

Fig.3 Five amended reasons of Part 33 and the corresponding variation between restriction boundary of regulation and safety boundary
For the above five revised reasons, in this paper, it is presented by concept of logical boundary in detail. That is, in design stage of an aeroengine, the safety must be guaranteed and the relevant measures for manufacturer can be defined by safety boundary. Actually, the airworthiness regulation should play this significant role to restrict the manufacturer, and this restriction effect can be reflected by a conception of restriction boundary in this paper.

In logical, the restriction boundary should be larger than the safety boundary to guarantee safety aviation. And the most ideal situation is that the restriction boundary is close with safety boundary because it not only satisfies the demand of FAA but also not wastes the resource for manufacturer. However, it is difficult. In reality, the dissatisfactory situation is that the restriction boundary exceeds the safety boundary and the obviously result is the increased cost. But the most unideal situation is that the restriction boundary is smaller than safety boundary in some region, and consequently some hidden risks, even hazardous accident, are left to safety operation in design or manufacture stage.

Therefore, each revised reasons mentioned above can be presented and investigated by the variation between restriction boundary and safety boundary as shown in Fig. 3.

4.1 Development of technology

In general, the typical development of technology is directly reflected in material, machining, technological process and analysis theory, et.al. Definitely, these technologies are quickly applied in the product development of aeroengine because the manufacturer constant pursues high-performance engine and low product cost. Therefore, the safety boundary is enlarged when new technologies are constant used in aeroengine industry. Correspondingly, the old restriction boundary gradually losses its safeguard effect and even limits the development of aeroengine, thus the airworthiness regulation should be simultaneously enlarged with expand safety boundary to include these new technologies as shown in Fig. 4.

![Development of technology](image)

Fig. 4 The variation of safety and restriction boundary caused by development of technology

As an example of airworthiness regulation revision caused by technology development, in 1974, Amendment No. 33-6 [9] added the requirement of life limited parts in regulation Sec. 33.14 “Start-stop Cyclic Stress” in order to solve the safety risk of critical parts induced by low cycle failure problem. Actually, the study of fatigue failure problem has a long history. Wohler researched the failure problem in locomotive axle and introduced the conception of metal fatigue in 1850s [22]. It was believed the basis of fatigue research. In 1945, based on the large experimental studies about fatigue problem, Miner formulized the linear cumulative damage law introduced by Palmgren and built the criterion of the linear
cumulative damage [23]. Then, Manson and Coffin put forward the Manson-Coeffin Equation to reflect the relationship between plastic strain and fatigue life and presented the study method of low-cycle fatigue problem [24]. On the basis of the above mentioned studies, the local stress-strain method is acquired and used in the aviation fatigue life calculation. Therefore, aeroengine manufacturer develops many life management methods to prevent life limited parts of encountering pre-mature failure. In this situation, FAA adds the regulation Sec. 33.14 to guide the design of life limited part and to avoid existed risk caused by fatigue failure problem.

4.2 Hazardous accident

In the procedure of establishing airworthiness regulation, it inevitable exists leaks, unconsidered problems and even mistakes because of the restriction of technology development or lack precise safety consciousness for some aspects. The result is that the restriction boundary of regulation cannot cover the whole safety boundary in manufacture as shown in Fig. 4 by using solid line. Thus, the possible risk is produced in engine and consequently leads to the hazardous accident. After the accident happened, based on the exposed problem in old regulation, the related regulations are revised to prevent similar occurrence of accident again. In logical, it is reflected that the restriction boundary is enlarged and includes the safety boundary as seen in Fig. 5.

The typical regulation revision caused by hazardous accident is the crash of United Flight 232 in Sioux City, 1989 [25]. In this accident as shown in Fig. 6, the cause of the engine failure was traced back to a manufacturing defect in the fan disk, which had microscopic cracks due to impurities. Then, the crack grew slightly each time the engine was powered up and brought to operating temperature and eventually the crack grew large enough to cause structural failure of the disk. However, it is noted that the airworthiness regulation Part 33 Sec. 33.14 related to the life limited parts is published in 1974 [26]. Although the low cycle fatigue problem has been introduced in this regulation, people gradually finds that the life management method, based on the conception of safety life, is obviously not enough to deal with the impact problem produced by randomness phenomenon of loads, environment and material in manufacture and working. On one hand, the deterministic approach is used in conventional disk failure analysis. That is, it is assumed that the working environment and loading condition can be completely described. However, in practical application, the material of parts, allowance, working condition and loading condition reflect random characteristic and cannot be completely and correctly described in deterministic analysis. Thus, the conventional analysis method makes large deviation in disk safety analysis. On the other hand, the material and manufacture imperfection are objective and definite, but the existence probability is small and is difficult to reflect in the sampling experiment. Thus, in conventional disk failure analysis method, the imperfection is unconsidered in general. However, the small probability event leads to hazardous accident, i.e. the crash of United Flight 232 in Sioux City.

To overcome the disadvantage of conventional safety management method and promote the safety of life limited part, after the crash of United Fight 232, FAA requires the RISC estimation the application of probabilistic risk assessment based on the investigation of aeroengine uncontained failure problem. And the Southwest Research Institute and four major aeroengine manufacturers are required to study the new parts life management method with failure risk analysis [27]. The purpose of these measures is to control the occurrence rate of risk event and improve the parts safety in whole working life by qualitative analysis the loading randomness and imperfection distribution. On the basis of these studies, for the life limited parts, FAA published the new Amendment No. 33-22 in 2007 [28] and the new regulation Sec. 33.70 “Engine Life-limited Parts” was instead of Sec. 33.14. In this regulation, for the high energy rotor, the airworthiness requirements of design, manufacture and service management are introduced. But most of
all, the damage tolerance assessment is added to form the updated life management system and consequently improve the aeroengine design safety.

**Hazardous accident**

![Diagram of Hazardous accident](image)

*Fig. 5 The variation of restriction and safety boundary caused by hazardous accident*

*Fig. 6 Typical hazardous accident caused by material imperfection: The recovered fan disk from the center engine of UAL 232*

4.3 Overly strict rules

In pursuit of high safety, the airworthiness regulation is naturally inclined to harsh requirement when the real safety demand of aeroengine is unclear. And the restriction of technology development encourages this trend in a certain meaning. Thus, it is easily causes overly strict rules. As shown in Fig. 7, in logical, it is the restriction boundary of regulation over large and the manufacturer should afford unnecessary resource cost to satisfy the regulation requirement. Therefore, shrink the restriction boundary and adjustment the restriction boundary close to the safety boundary, it fits the real demand of manufacturer and can save large cost.

For example, FAA revised the regulation Part 33 Sec. 33.83 “Vibration Test” in Amendment No. 33-6, 1974 [9]. In this revision, several commentators recommended that the requirement in Sec. 33.83 for testing to 110 percent of the desired maximum continuous speed rating be deleted because certain high performance turbine engines could not be capable of achieving this overspeed condition [29]. Upon further consideration, the FAA agreed with the commentators' position and the requirement was deleted.
4.4 Unclear definition or explanation

Although the published airworthiness regulation already efforts to pursuit concisely and accurately, it still exists the unclear definition or explanation in some regulations and produces misunderstanding and confusion between regulators and manufacturer. In this situation, based on the suggestions or queries from manufacturer, FAA revised or redefined the wrong or confused text or definition by amendment. Reflected in logical boundary as shown in Fig. 8, the restriction boundary of regulation is transferred from unclear to accurate.

In historical amendments, there are many revisions caused by unclear definition or explanation. The typical is to revise the regulation Part 33 Sec. 33.89 “Operation Test” in Amendment No. 33-6, 1974 [9]. In this amendment, one commentator requested that a better definition be used in Sec. 33.89 (b) for the term "extreme ambient temperature and altitude." The FAA agreed that [29], taken literally, the requirement could be unnecessarily burdensome. Accordingly, the wording was modified to read "maximum and minimum operating ambient temperature" and "maximum operating altitude." In addition, upon further consideration, the last sentence of the proposed requirement was deleted as unnecessary.
4.5 International uniformity

With enlarging international coordination in civil aviation, especially the established European Aviation Safety Agency (EASA) in 2003, the civil aeroengine must be confirmed the airworthiness certification of FAA and EASA before enter the market. However, it should be noted that, in initial stage, FAA carried out the FAR Part 33 regulation but EASA was according to Part 21 regulation [30]. The result is that although the aeroengine produced by Rolls-Royce used in Boing aeroplan or the aeroengine provided by GE already applied in Airbus aeroplane has a long year, it is easily to produce problems and extend the period in the process of airworthiness certification because of the different of airworthiness regulation. To overcome these problems, FAA amends the some regulations to guarantee the international uniformity as shown in Fig. 9.

One example of international uniformity is the revised regulation Part 33 Sec. 33.28 “Engine Control System” [19] and the corresponding regulation in EASA is CS-E AMC-E-50. Before the published Amendment No. 33-26 in 2008 [31], there was difference between Part 33 and CS-E airworthiness regulation. But after this revision, the content was nearly same. The result was that the uniformity of airworthiness regulation between FAA and EASA was benefit to civil aeroengine manufacturer obtain the airworthiness certification more convenient and fast.

![Fig. 9 The international uniformity of airworthiness regulation](image)

5. Conclusion

Federal Aviation Regulations (FAR) Part 33 is airworthiness standard of aircraft engine to promote safe aviation and it is under constant changing by thirty-three times of amendments to update and improve the airworthiness standards applicable to the type certification of aircraft engines in the last fifty years. In this paper, starting from the historical amendments, the evolution of Part 33 is studied with development of civil high bypass ratio turbofan engine by statistics analysis and the revised reason is summarized by investigation the proposals of amendments. During this study, a conception of restriction boundary of regulation is introduced and the influence produced by each revised reason is researched between restriction boundary and safety boundary.

The results show that the changed of Part 33 has four cycles, with significant revision every 10-12 years. And the civil high bypass ratio turbofan engine has the same development stage and good corresponding relationship with significant revision period of Part 33, although the amendments reflect hysteresis quality. Under the contradiction between safety demand of FAA and technology demand of manufacturer, the revised reason of Part 33 can be generalized into five aspects: the development of technology, the hazardous accident, the overly strict rules, the unclear definition or explanation, the
international uniformity. Therefore, the appeared new aircraft engine can promote the update of regulations and the revised regulations guide the development of next generation engine. That is, FAA and manufacturer are supplementary to each other in the development of civil aviation.

Basing on these obtained laws, it can bold predicted that the next significance amendment of airworthiness regulation Part 33 will be in 2017-2020 and the content must be related to the developing engines, like LEAP-X, by major manufacturer. It is benefit for manufacturer to improve efficiency and save cost in airworthiness certification. Thus, the conclusions provide another insight of the airworthiness certification and the next generation engine development for FAA and manufacturer respectively.

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