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An Engineering Method of Civil Jet Requirements Validation Based on Requirements Project Principle

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Abstract. A method of requirements validation is developed and defined to meet the needs of civil jet requirements validation in product development. Based on requirements project principle, this method will not affect the conventional design elements, and can effectively connect the requirements with design. It realizes the modern civil jet development concept, which is “requirement is the origin, design is the basis”. So far, the method has been successfully applied in civil jet aircraft development in China. Taking takeoff field length as an example, the validation process and the validation method of the requirements are detailed introduced in the study, with the hope of providing the experiences to other civil jet product design.

1. Introduction

With more and more advanced technologies applied in the advanced civil jet development, the system integration plays more and more important role in the industry. Due to this, a new design principle, called Requirements Project, is formed and studied, and finally achieves great development. The core concept of it is Requirements and Requirements Management, which makes it different from the conventional design principle.

The civil jet of China developed bumpily and discontinuously, and many design principles are transplanted from military aircraft design system. The gap still exists between China and other countries in civil jet manufacture, especially in the design concept.

After more than twenty years' efforts and development, the advanced design principles are introduced into Chinese design working, especially in the regional civil jet and single aisle large civil jet. Based on advanced requirements project design principle, a civil jet requirements validation method and process for aircraft concept design phase are defined. They have been applied successfully in design working, and the application prospect is wide in the future.

2. The advanced civil jet requirements project principle

The core factors of requirements project principle are requirements and their management. The requirements are identifiable design elements, which can be validated and verified with the method of simulations and experiments. In the whole product lifecycle, requirements management shall identify, transfer, break down, manage and control the requirements. In the management process, the requirements are traceable, complete, unique and coincident [1], see figure 1.

Requirements are the basis of the aircraft and its systems design working, giving the design working direction. If the requirements are not complete, correct or coincident, the product will not reach the design requirements and objects. Therefore, the definition of top level requirements is important, which is the origin of the product, see figure 1 with red dashed zone. This paper would focus on this part, and propose a new method of requirements validation.



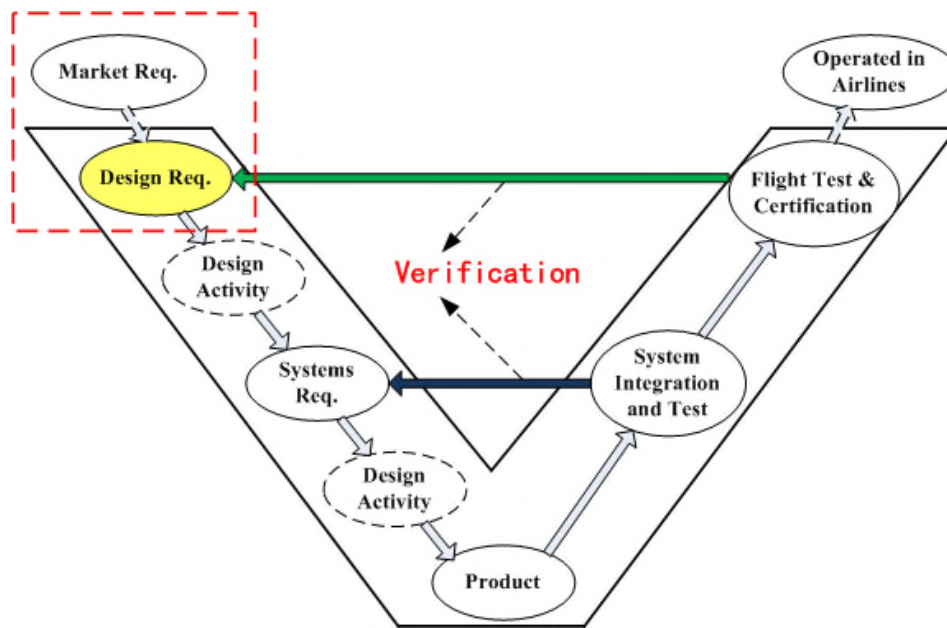


Figure 1. Requirements and Management Frame [1].

3. A method of civil jet requirements validation based on requirements project principle

The design principle based on requirements project has been applied successfully in many industries, such as auto industry. However, due to the development state of the civil jet industry and the limited cognitive of the principle in China, it is lately that the principle is introduced into the civil jet industry of China.

Comparing with the conventional design principle, the requirements project has its own advantages, for instance, the design is requirement-based, the design input and output is clear, and the design flow management can be easily controlled. Although the new principle is applied, the conventional design principles should not be abandoned completely. It is necessary to combine two principles effectively to achieve “1+1 $\geq$ 2” effect.

Base on the study on the design principle put up by the foreign advanced civil jet manufacturers and the analysis of the design principle of China, three rules for building new design system are proposed as follows:

- (1) The origin design elements which are the basis of product should not be abandoned;
- (2) Increasing the design elements facing customer's requirements to direct and lead the design work;
- (3) Defining the input and output of every design element to make management easier.

A new design method is drawn from the experience and summed up, which concentrates on top level design requirements validation phase. See figure 2 for details.

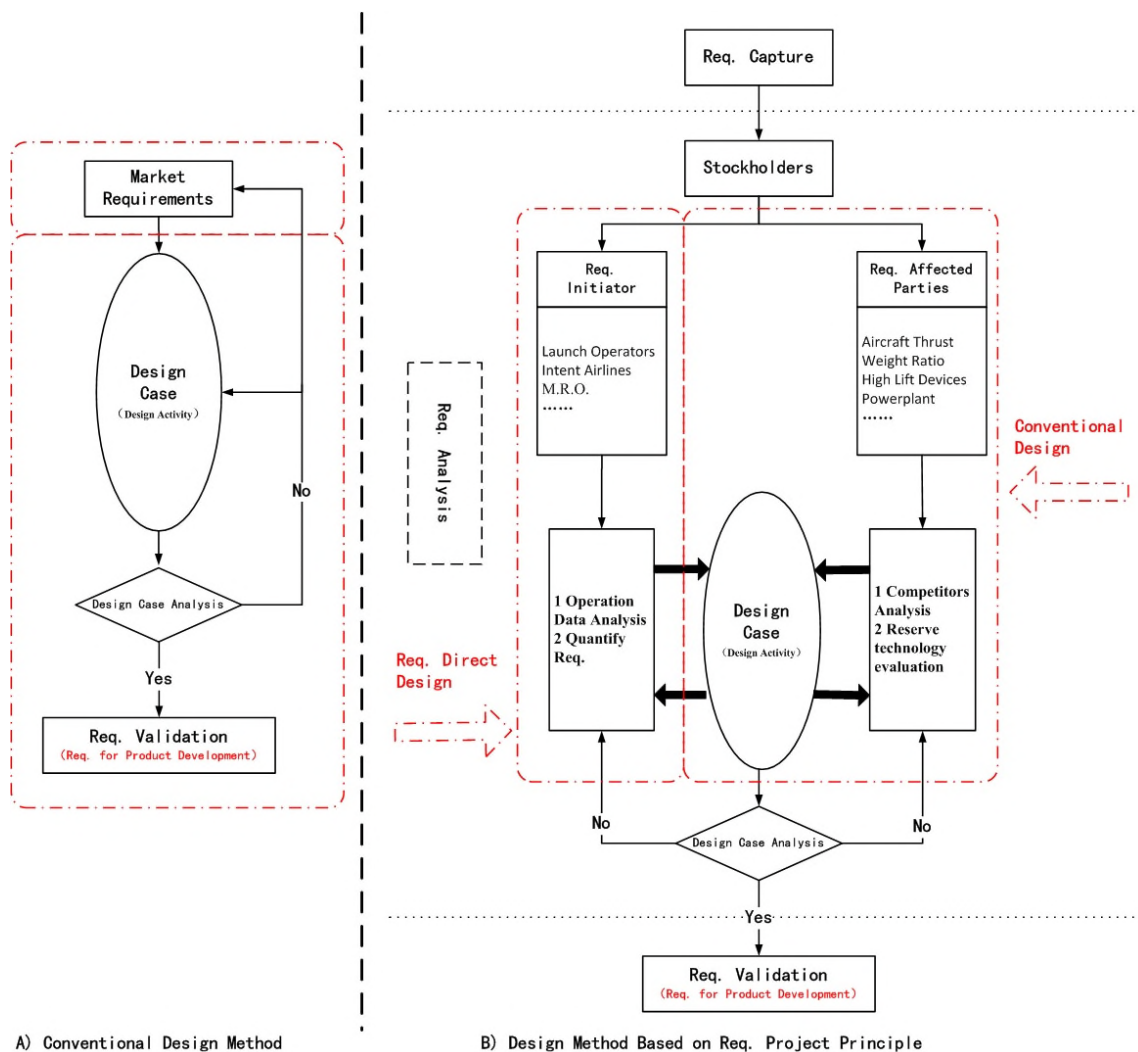


Figure 2. Design Methods Frame.

Figure 2 shows the primary difference between the two design principles is that the design elements facing customers is now sinking into design level. On one hand the importance of market has not decreased, on the other hand the design elements have been completed, and the design work meets the requirements of market directly.

There are three steps in the whole requirements validation process, which are requirements capture, requirements analysis and requirements validation.

Requirements capture is the origin of product development, which directly facing customers, designers, manufacturers, customer service staff, and salesmen.etc. Because of the characteristics of market, more attentions are usually paid to the external characteristics and performances of the product, and the internal characteristics are usually ignored, such as product construction and work principle. So the requirements in the requirements capture phase are not the real requirements. These requirements are need to be confirmed. They just reflect a trend lack of completeness, correctness and feasibility. A key phase of product development, called “Requirements Analysis”, is necessary to convert and transmit these requirements.

The requirements analysis is a bridge connecting the requirements origin with the product development. Therefore, the analysis to the “Requirements Initiator” is important, see figure 2. On one hand it could reflect the requirements project principle, on the other hand it is the key phase to translate these requirements in a proper way. Besides, in this phase, conventional design elements are the basis of the requirements analysis, the analysis and evaluation of competitors and technical reserve are also the basis of design case drawing-up.

The last step is “Requirements Validation”. To connect “Requirements Initiator” with “Requirements Affected Party” effectively, an appropriate platform, the design case of the product, is needed. With the design case, all the design elements can be handled and leveraged on the same platform. The product requirements are defined, and the relationship between the requirements origin and product development is established in the phase.

4. Applications in product development

Requirements are the basis of the product development, and their quantities are huge. For easily understood, the requirement of “take off field length” would be introduced as an example.

4.1. Take off field length

According to CCAR Part 25, take off field length is defined as follow:

4.1.1. *Take off distance [2]*. For given operational conditions (temperature, pressure altitude, weight, etc.):

a) The takeoff distance on a dry runway is the greater of the following values:

$TOD_{N-1 \text{ dry}}$ = Distance covered from the brake release to a point at which the aircraft is at 35 feet above the takeoff surface, assuming the failure of the critical engine at V_{EF} and recognized at V_1 .

$1.15TOD_{N \text{ dry}}$ = 115% of the distance covered from brake release to a point at which the aircraft is at 35 feet above the takeoff surface, assuming all engines operating.

b) The takeoff distance on a wet runway is the greater of the following values:

TOD_{dry} = Takeoff distance on a dry runway (see above).

$TOD_{N-1 \text{ wet}}$ = Distance covered from brake release to a point at which the aircraft is at 15 feet above the takeoff surface, ensuring the V_2 speed to be achieved before the airplane is 35 feet above the takeoff surface, assuming failure of the critical engine at V_{EF} and recognized at V_1 .

4.1.2. *Accelerate-stop distance [2]*. The accelerate-stop distance on a dry runway is the greater of the following values:

$ASD_{N-1 \text{ dry}}$ = Sum of the distances necessary to:

- Accelerate the airplane with all engines operating to V_{EF}
- Accelerate from V_{EF} to V_1 assuming the critical engine fails at V_{EF} and the pilot takes the first action to reject the takeoff at V_1
- Come to a full stop
- Plus a distance equivalent to 2 seconds at constant V_1 speed

$ASD_{N \text{ dry}}$ = Sum of the distances necessary to:

- Accelerate the airplane with all engines operating to V_1 , assuming the pilot takes the first action to reject the takeoff at V_1
- With all engines still operating come to a full stop
- Plus a distance equivalent to 2 seconds at constant V_1 speed

a) The accelerate-stop distance on a wet runway is the greater of the following values:

ASD_{dry}

$ASD_{N-1 \text{ wet}}$ = same definition as $ASD_{N-1 \text{ dry}}$ except the runway is wet

$ASD_{N \text{ wet}}$ = same definition as $ASD_{N \text{ dry}}$ except the runway is wet

4.1.3. *Balanced field [3-5]*. For a given takeoff weight, any increase in V_1 leads to a reduction in both TOD_{N-1} . The reason is that all engines acceleration phase is longer with a higher V_1 speed, and, consequently, in case of an engine failure occurring at V_{EF} , the same V_2 speed can be achieved at 35 feet at a shorter distance.

As a result, the following graph providing the takeoff/rejected takeoff distances as a function of V_1 can be plotted. This graph clearly shows that a minimum distance is achieved at a particular V_1 speed. This speed is called “balanced V_1 ”, and the corresponding distance is called “balanced field”. See figure 3 for details.

In the design work, balance field is usually chosen for evaluation [3-5].

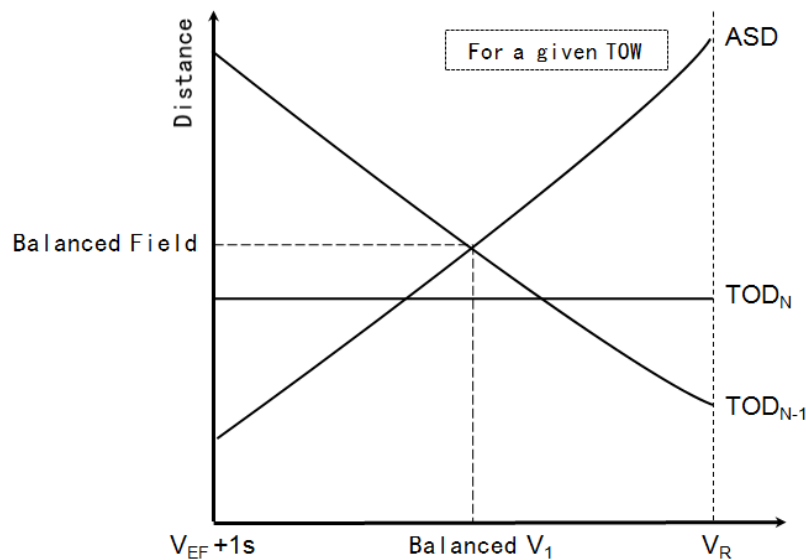


Figure 3. Balanced Field Definition [3-5].

4.2. Requirements Capture

- a) Market investigation: intent airlines, intent leasing aircraft companies
- b) Investigation background: the shorter take off field length is, the wider the market of airlines is.
- c) Initial requirement: take off field length is no more than A m (MTOW, SL, ISA+15 °C).

Note: The initial requirement is a partly prepared requirement with potential problems, especially when it is analyzed with conventional methods, so more time and more resources are needed to refine it. See requirements analysis for details as follow.

4.3. Requirements Analysis

The conventional design method and the new method are both used to analyze the requirements, so it is easy to see the different processes and results between the two methods, and the advantages and benefits of the new method.

4.3.1. Analysis with conventional method. According to the conventional method, the initial requirement is directly transmitted to design team and is used in design. After analysis of design case, which reaches the requirement of take off field length, 5 problems are found out as follows:

- a) The thrust weight ration of aircraft is more than competitors.
- b) The take off field length is shorter than competitors.
- c) The take off thrust is close to the maximum capability of engine for baseline, and the stretched aircraft is limited.
- d) The thrust of engine is bigger than competitors, so its life becomes shorter and the maintenance cost is higher.

- e) For decreasing the thrust, the bigger wing areas and more effective high lift device are applied.

All the problems are the critical for design case. If these problems could not be fixed appropriately, the competitiveness of the product would be affected.

The situation mentioned above is very typical with conventional method. These problems could be found out, and the primary design element causing the problems could be located, but there is no way to solve them effectively. In this condition, the design team can only choose to feed the problems back to the market team. But the market team could not understand the design case, so it is difficult for them to find a right way to solve them. Due to the lack of requirements analysis, large quantity of design time and resources are wasted.

4.3.2. Analysis with the new method. In the new method, when initial requirements have been confirmed, the next important step is to classify and confirm the requirements stakeholders. See table I for details.

Table 1. The Requirements Stakeholders of TOFL.

The Requirements Stakeholders of TOFL	
Requirements Initiators (Primary)	Launch Operators
	Intent Airlines
	Potential Customers
Requirements affected parties (Primary)	Aircraft Thrust Weight Ratio
	High Lift Devices Design
	Powerplant
	Stretched Aircraft Design

After requirements stakeholders classification, the analysis work of requirements initiators and requirements affected parties start in parallel. The analysis work of requirements initiators plays an important role in the requirements analysis period, which is the core of the requirements project, so this chapter would focus on this part, which would help understanding the initial requirements correctly, analyzing the initial requirements in right way, translating the initial requirements into the real requirements for product development, and promoting the product development positively.

a) Analysis of requirements initiators

Main analysis idea is:

- According to the initial requirement of TOFL, the airports have been classified and collected, whose runway length is between A m to A+600 m.
- According to these airports, the airlines with these airports should be classified and collected.
- The airlines should be picked up, which are operated by customers and potential customers. And these airlines characteristics should be analyzed.
- Transmitting this analysis data to requirements affected parties for requirements validation.

After analysis work, the results are that:

- Among the intent customers, there is no airline operating at the airports whose runway length is between A m and A+400 m.
- There are only two potential airlines operating at the airports, but the range of these airlines is relatively short, about a half of design range of aircraft. So there is no limit to aircraft operating in these airlines, because the aircraft take-off weight is lighter than maximum take-off weight.
- The analysis result of requirements initiators is that take off field length is no more than A+400 m (MTOW, SL, ISA+15°C), and the result is transmitted to requirements affected parties.

After above analysis, we can see clearly that the initial requirement is usually not precise, only reflecting the trend of market requirement. It is not proper to be used in product development directly. We should evaluate the initial requirement objectively, dig the data behind the initial requirement deeply, trade off them, and quantify the result.

It is necessary to point out that the conventional design method is lack of analysis of requirements initiators, which induces unsmooth connection between market and design.

b) Analysis of requirements affected parties

The analysis of requirement affected parties is the same as the conventional design work. The primary work is competitor's analysis and reserve technology evaluation. After the analysis of requirements initiators, we could find that the new requirement of TOFL falls into a reasonable range, which is resulted from requirements affected parties. Therefore, design case development turns easier.

4.4. Requirements Validation

After the result of requirements analysis is brought into the preliminary design case, the problems which usually come into in conventional design method is no longer exist. The whole design case is balance and feasible. So the validated requirement of TOFL is no more than A+400 m (MTOW, SL, ISA+15 °C).

5. Conclusions

For meeting the needs of civil jet requirements validation in product development, a method of requirements validation is developed and defined, which is based on requirements project principle. And the following results have also been achieved:

- a) The new method makes the connection more smoothly between market and design.
- b) In the new method, the conventional design elements and requirements elements are reset and recombined effectively, which leads to maximum effectiveness.
- c) This new method has been successfully applied in civil jet aircraft development of China.

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