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Aircraft Cruise Performance Design Integration Based On System Engineering

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Abstract

This paper summary the lesson learn from certain civil Aircraft practical cruise design and taking certain aircraft as example, Integration for aircraft cruise performance based on system engineering process is proposed: need-function-requirement-proposal. The stakeholder needs for aircraft cruise performance are captured in this paper. The aircraft cruise performance integration function list is summarized and the critical functions are identified as cruise thrust rating, anti-icing bleed, engine thrust limits, RVSM requirements, Cost, pilot work load. Considering the core internal and external constraints for cruise performance Integration, the operational scenario is further analyzed. The integration design requirements are allocated therefore. Three optional proposals are compared based on the cruise performance requirements. The final cruise performance proposal shall balance the cost, performance, human factors, schedule and choose best proposal, which suits itself under the aircraft safety premise.

Keywords: Cruise, Performance, Integration, System Engineering

1. System Engineering Analysis Process

Aircraft Cruise Performance integration follow needs capture–Function Analysis–Requirement Analysis–Design Integration process as shown in figure 1 below.

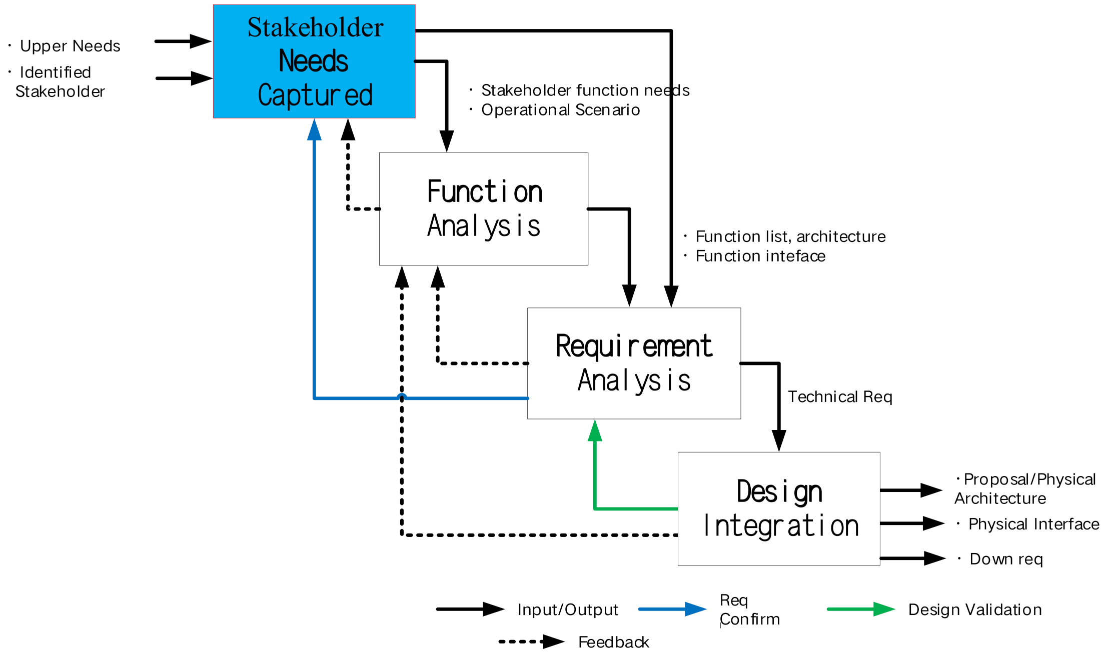

Figure 1 System Engineering Analysis Process

2. The Stakeholder Needs Captured

2.1 Stakeholder Identified

The aircraft cruise performance design Integration stakeholders are identified as shown in figure 2 below.

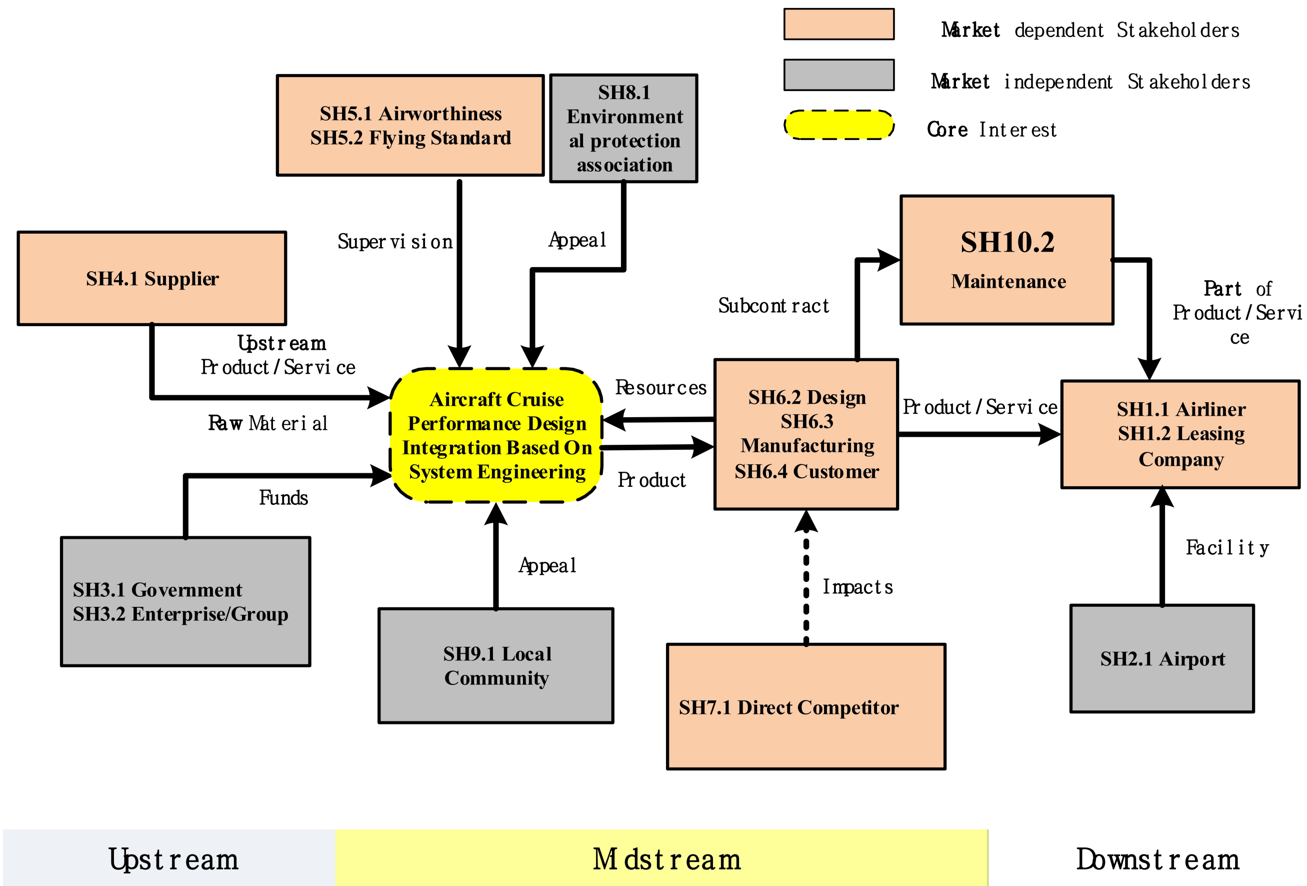

Figure 2 stakeholder identified

2.2 Needs Captured For Aircraft Cruise Performance Design Integration

The needs for aircraft cruise performance design integration are captured and the core interest is concluded by the importance level as shown in table 1 below.

Table 1 Summaries for The needs for aircraft cruise performance design Integration

Stakeholder Type	**Stakeholder**	**Needed Captured**	**Importance**
SH1.Customer	SH1.1 Airliner	1.Aircraft continues safety flight in specified flight envelope	☆☆☆☆☆☆
		2.Faster, Higher, Better Fuel Efficient	
		3.Less Aircraft Auto Cruise Operation Constraint is	
	SH1.2 Leasing Company	1.Better Aircraft Auto Cruise performance, fuel efficient, Competitiveness	☆☆☆☆
	SH1.3 Pilot	1.Less Pilot Concern	☆☆☆☆☆
		2.Lower Work Load, Better Human Factors	
	SH1.4 Maintenance Crew	1.Low System Failure and Better Maintenance	☆☆
		2.Easy Procurement for Aviation Material	
	SH1.5 Flight Attendant	1.Safety Flight and Comfortable	☆☆☆
SH2.Airport	SH2.1 Air Traffic Control	1.Flight Altitude Level Resource Allocated Easily	☆☆☆☆☆
		2. Stable Horizontal Vertical Separation	
SH4.Supplier	SH4.1 Design Supplier	1.Low Risk and Easy Implemented	☆☆
		2.Low Proposal Development Cost	
		3.Short Program Schedule	

Stakeholder Type	Stakeholder	Needed Captured	Importance
SH5.Supervision	SH5.1 Airworthiness	1.Comply With 25.1309 Regulations	☆☆☆☆☆
		2. Comply With RVSM 300 meters Vertical Separation Requirements(AC-21-3)	
		3.Comply with RVSM Vertical Separation Airspace requirements(AC-91-FS-2018-007R1)	
		4.Comply with CCAR-91 91.80 regulations about airspace operation requirements	
	SH5.2 Flight Standard	1. Air Operator shall meet the operation requirement and provide operation support and guarantee	☆☆☆☆☆
SH6.Aircraft Manufacturer	SH6.2 Design	1.Limits reduction and satisfy the commonality	☆☆☆☆
		2.Less Design Change	
		3.Short Change Schedule	
		4. High Technical Maturity	
	SH6.3 Manufacturing	1.Easy Product Procurement	
		2.Easy Assembly and Test	
	SH6.4 Customer	1. Detailed Design Information and guide the publication update	
	SH6.5 Flight Test	1.Easy Flight Test, less flight and Low Risk	☆☆☆
		2.Avoid special Environment Limit and Instrumentation	
SH7.Competitor	SH7.1 Direct Competitor	1. No Patent interference with Competitors	☆☆

3. Function Analysis For Aircraft Cruise Performance Design Integration

By analysis the need list and the activity sequence diagram below, the stakeholder core functional needs are summarized below:

1) High, faster, better fuel efficiency
2) Fewer Auto cruise constraints
3) Less cross the flight altitude level.

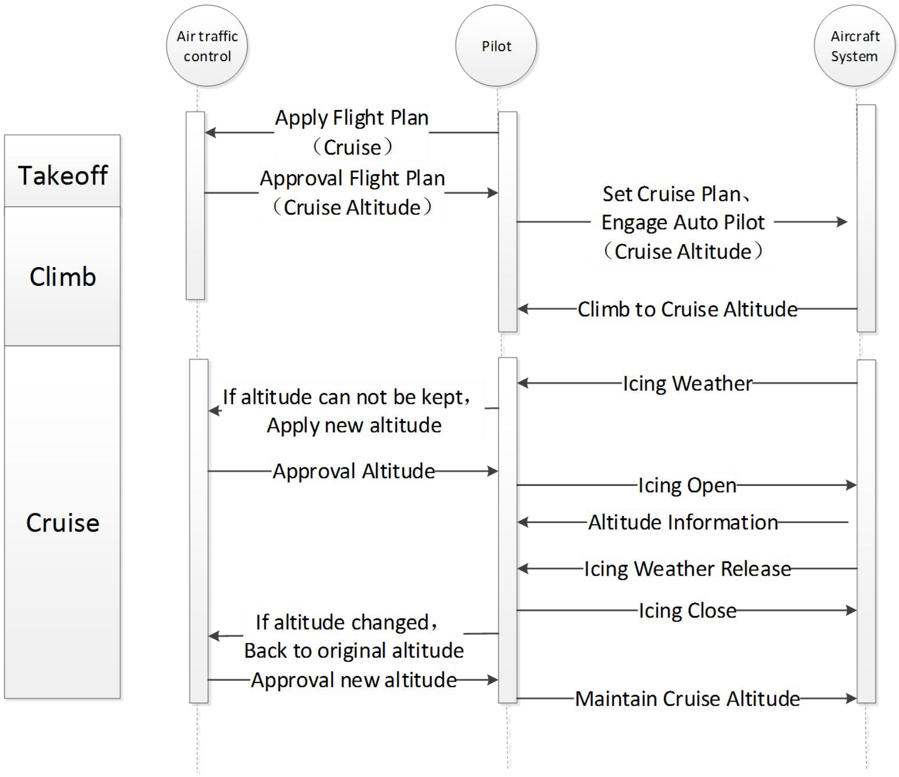

Figure 3 Activity Sequence Diagram For aircraft cruise performance design Integration

The function list related with aircraft cruise performance design Integration is summarized as shown in the picture below : aircraft related Functions, system related functions and related physical systems.

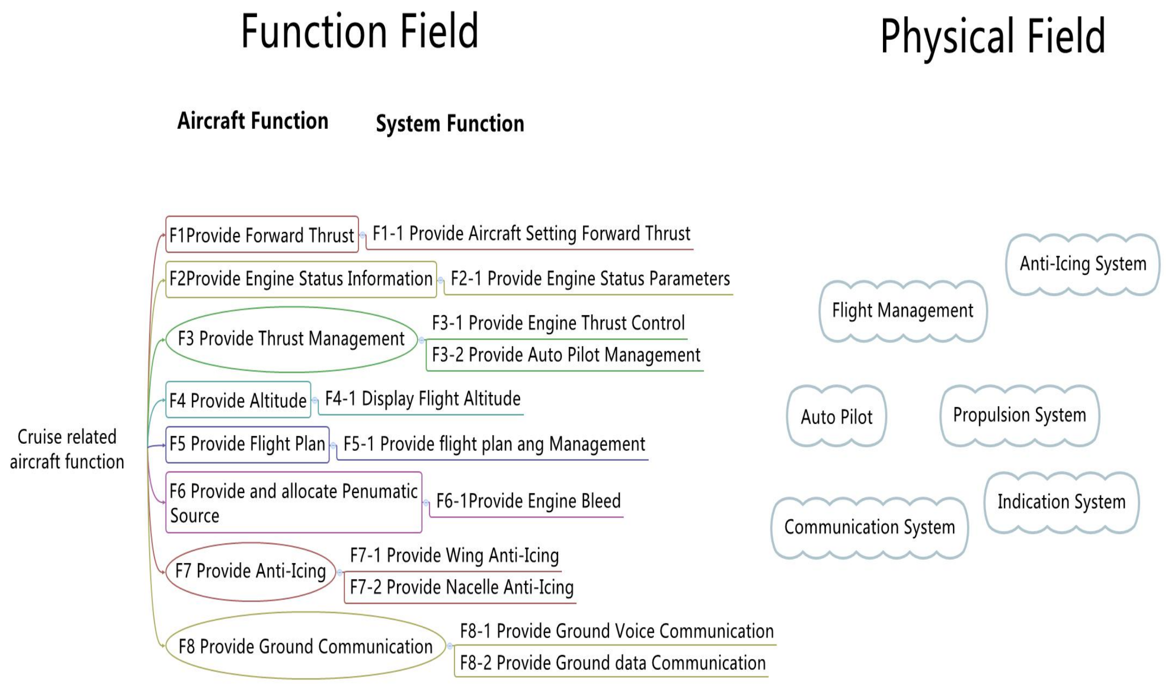

Figure 4 Related Functions and Physical System for Aircraft cruise performance design integration

4. Requirement Definition For Aircraft Cruise Performance Design Integration

4.1 Core Constants Summary

Before the requirement definition for identified functions, the core constraints for cruise performance design Integration are summarized in table 2 below.

Table 2 Core Constraints Summary

Aircraft cruise performance design Integration Constraints Analysis	
Internal Constraints	Outside Constraints
Better Aircraft Auto Cruise Performance	CCAR 121 RVSM requirements
Engine Thrust Limit	CCAR 91 RVSM requirements
Anti-Icing Requirements(impact thrust)	Pilot Concerns and Work Load
Program Schedule and Cost	Less Aircraft Auto Cruise Operation Limits

4.2 Further Study About Aircraft Operational Scenario

Combined with the certain aircraft design parameters and capability, and after the analysis for aircraft operational environment as shown in figure 5 below, the stakeholder needs are transferred into the design object below:

1) During non-icing condition, Aircraft shall able to auto cruise(Ma 0.78, 35000ft) with 42 ton;

2) During Icing condition, Aircraft shall able to maintain cruise altitude

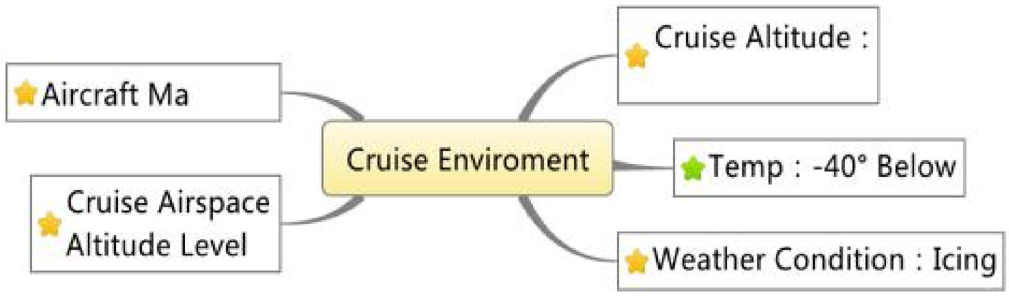

Figure 5 Further Study about aircraft operation scenario

4.3 Requirement Definition

After the further analysis on the aircraft operational scenario, the requirements tailored to aircraft cruise performance Integration are flown down as shown in table below:

Table 3 Requirement Definition following Function Analysis

Functional Requirements		
Functional Requirements	**Requirement Definitions**	**Requirement Allocation**
Provide Forward Thrust	RE1: Engine shall provide enough thrust to maintain Ma 0.78, 35000ft cruise during normal operation	Engine
	RE2: Engine shall provide enough thrust to maintain cruise altitude in RVSM cruise altitude during anti–icing system is opened(>28000ft)	Engine
Provide Engine Status Parameters	RE3: Engine N1 speed shall not exceed Limits	Engine
	RE4: Engine EGT shall not exceed limits	Engine
Provide Thrust Management	RE5: Cruise thrust rating shall be auto selected during Cruise Condition	Flight Management
	RE6: Auto Pilot shall adjust cruise thrust and maintain cruise altitude following cruise target	Auto Pilot
	RE7: Autopilot and auto throttle shall be used to maintain Ma 0.78, 35000ft.	Auto Pilot

Provide Engine Bleed	RE8：Engine shall provide enough Wing Anti Icing Flow during Icing Condition	Engine
	RE9：Engine shall provide enough Nacelle Anti Icing Flow during Icing Condition	Engine
Provide Wing Anti-Icing	RE10：Pilot shall be informed when Icing weather is encountered.	Anti-icing
	RE11：Pilot shall open Wing Anti Icing when receiving Icing alert	Anti-icing
Provide Nacelle Anti-Icing	RE12： Pilot shall open NACELLE Anti Icing when receiving Icing alert	Anti-icing
Non-Functional Requirements		
Factors	Requirement Definitions	
Pilot	RE13:Pilot shall have the highest priority to select thrust rating no matter in any scenario	
Pilot	RE14:The Flight Crew shall select the cruise rating in the specified range of flight performance manual	

5. Integration Proposal

Taking certain aircraft parameters and capability as example, and combined with certain specified requirements to optimize aircraft cruise performance, three different integration proposals comes out. The decision shall consider the balance among Aircraft cruise thrust rating, anti-icing bleed, engine thrust limits, RVSM requirements, Cost, pilot workload.

Optional Proposal:

1) Only highlight pilot need to adjust manually thrust when open anti-icing in high altitude in flight crew manual.
2) Optimize aircraft thrust management logic to make sure crew could select higher thrust than cruise rating in anti-icing condition and avoid the altitude loss by auto throttle
3) Update Engine FADEC thrust management schedule

The tradeoff for 3 proposals are as shown in table 4 below.

Table 4 Tradeoff for 3 proposals

Proposal	Strengths	Weakness
1	Almost no additional change cost, only update the crew manual	1) Crew need to check the performance table during operation, sometimes

		need to do interpolation calculation 2) When Auto throttle is disengaged, the cruise control accuracy would be impacted, risky to meet RVSM requirements 3) It is hard to reach 35000ft, M 0.78 cruise condition when auto throttle is engaged
2	1) No Need to change engine FADEC and anti-icing logic 2) Flight crew is free to select thrust rating and improve the thrust selection flexibility. When cruise thrust is not enough, MCT thrust can be used and the engine performance potential is developed	1) When Cruise thrust is not enough, pilot still need to operate manually to get the higher thrust than cruise. If pilot operation is late, aircraft speed would loss 2) Manually changed the cruise thrust to higher thrust, such as Climb, MCT, aircraft can get the better cruise speed, but may bring worse fuel consumption and engine deterioration.
3	1) No need to update aircraft side thrust logic, only update FADEC thrust schedule 2) Updated Cruise thrust by FADEC can meet almost all scenario 3) No need additional flight crew operation.	Engine would be used in high power in long time, ENGINE EGT in cruise status is reduced and engine life potentially impacted

6. Summary

Taking certain aircraft as example, this paper summary the lessons learn from certain civil aircraft practical cruise design, following the critical process of system engineering, the potential integration proposals are concluded. Aircraft cruise performance design is actually very comprehensive topics, it provide a clear ways for aircraft to choose design Integration proposal, which suits itself under the aircraft safety premise. It is also wished the topics shown in this paper could also provide reference for related engineering field.

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