D5.1: REPORT ON ATM AVIONIC SYSTEM ARCHITECTURE DEVELOPMENT

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EXECUTIVE SUMMARY

Addressing environmental challenges, especially global warming, is more than ever an issue for the community. This matter is becoming an increasing priority at regional and global level. Commitments have been made to reduce the aviation's environmental footprint. Global air traffic is contributing to climate change, influencing local air quality and, consequently, affecting the health and quality of life of all citizens. The air traffic is growing and is expected to continue growing significantly in the future to cope with the increasing demand for mobility and connectivity. A long-term effect on the environment from aviation sector, mainly caused by aircraft noise and exhaust gases (especially CO_2, nitrogen oxides NO_x and methane), make it a clear target for mitigation efforts. The future growth of aviation shall go hand in hand with environment sustainability policies. Therefore, studies and research are being conducted worldwide exploring possible optimization of the aircraft technologies as well as Air Traffic Management (ATM) operations. Given the close interdependency between several flight parameters, including the route of flight, and environmental impact, optimization in flight trajectory design and air traffic control (ATC) operations are an appropriate means to reduce the emissions in short- and medium-term time frames.

The international project "Greener Air Traffic Operations" (GreAT) has been launched in line with this objective. This Horizon 2020 project is conducted in cooperation between 6 Chinese and 7 European partners.

This document takes the avionics system as the research object. According to the concept of greener operation, it extracts the functions undertaken by the aircraft during flight. Based on these functions, this document deduces the functional architecture supporting greener cruise operation, which provides the direction for the development of avionics system in the future.

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GLOSSARY

Acronym	Signification
AAS	Aircraft Application System
ABAS	Aircraft Based Augmentation System
ACARS	Aircraft Communications Addressing and Reporting System
ADS-B	Automatic Dependent Surveillance-Broadcast
AFDX	Avionics Full Duplex Switched Ethernet
AOC	Airline Operation Center
ASBU	Aviation System Block Upgrades
ASSAP	Airborne Surveillance and Separation Assurance Processing
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATN	Aeronautical Telecommunication Network
ATSU	Air Traffic Service Unit
AMAN	Arrival management
ARINC	Aeronautical Radio Inc
ATFMC	Air Traffic Flow Management Center
CDTI	Cockpit Display of Traffic Information
CDO	Continuous Descent Operation
CMU	Communication Management Unit
CTA	Controlled Time of Arrival
CPDLC	Controller Pilot Data Link Communication
DME	Distance Measuring Equipment
DSP	Data Service Processor
EASA	European Aviation Safety Agency
EICAS	Engine Indication and Crew Alerting System
ELDT	Estimated landing time
EPP	Extended Projected Profile
ES	Extended Squitter

ETA	Estimated Time of Arrival
EVS	enhanced vision system
FMS	flight management system
GAS	Ground Application System
GBAS	Ground Based Augment System
GES	Ground Earth Station
GLS	GBAS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GS	Ground Station
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IRS	Inertial Reference System
ITP	In-Trail Procedure in Oceanic Airspace
LAAS	Local Area Augment Systems
LNAV	Lateral Navigation
PBN	Performance Based Navigation
RDC	Remote Data Concentrator
RNP	Required Navigation Performance
SATCOM	Satellite Communication
SESAR	Single European Sky ATM Research
SMAN	Surface Management
SDU	Satellite Data Unit
SVS	Synthetic Visual System
TAWS	Terrain Awareness Warning System
TCAS	Traffic Alert and Collision Avoidance System
TIS-B	Traffic Information Service-Broadcast
TOBT	Target off block time
TOD	Top of Descent
TCAS	Traffic Alert and Collision Avoidance System

UDC	Up/Down Converter
UPT	User Preferred Trajectory
VDLPS	VDL Power Supply
VDR	VHF Data Radio
VNAV	Vertical Navigation
VOR	Very High Frequency Omnidirectional Range
WAAS	Wide Area Augmentation System

1. INTRODUCTION

Global warming and the climate change are one of today's most serious crisis, that will constitute a significant danger for future generations [Matthews 2017]. This is even amplified by the fact that the climate change is a relatively slow process, which is caused by the accumulation of greenhouse gases over years and decades [Rahmstorf 2007]. When thinking only for the next couple of years in advance, the changes are hardly measurable; therefore, economic interests have always been prioritized in the past. The further emission of greenhouse gases by daily traffic, energy production with coal or an outdated technology used in a factory was seen as acceptable, as the individual case is always only a very small contribution to worldwide climate change. In addition, trying to save emissions here would not noticeably change the situation and would not make a big difference within the near future.

In the last few years, this attitude started to change, as the consequences of the climate change are more and more recognizable to the public. In the same way, also the awareness increases that every emission of greenhouse gases – no matter how small it is – contributes over the years and decades and indeed makes a difference. The Intergovernmental Panel on Climate Change (IPCC) considers carbon dioxide (CO_2) as the principal greenhouse gas [IPCC 2014]. Aviation represents approximately 2 to 3% of the total annual global CO_2 emissions from human activities, and in addition to CO_2, has impacts on climate from its non-CO_2 emissions (e.g. NO_X, particles) [McCollum 2010]. Uncertainties still exist in the assessment of the impact of the aviation emissions on the environment, especially regarding effects associated with non-CO_2. Nonetheless, non-CO_2 impacts cannot be ignored as they potentially represent approximately 60% of total climate impacts that are important in the shorter term[1]. Regarding the Radiative Force (RF) of all aircraft emissions, studies estimate the aviation impact to be within the range 2% to 8% [Jungbluth 2018]. The CO_2 and non-CO_2 emissions from aviation are increasing continuously. Nevertheless, CO_2 emissions are becoming of high priority considering the long-term effect. As a conclusion, it is also worth thinking about how even small gas emissions can be reduced or avoided. Although aviation only contributes to global CO_2 emissions with a very low percentage, emissions savings that can be achieved there – even if they are small – are important.

1.1. PURPOSE OF THE DOCUMENT

Greener avionics technology refers to the generic term of airborne communication, navigation, monitoring, flight management, display control, and other technologies in support of greener air traffic operation, which is the key supporting technology that implements and gives play to the effectiveness of the greener air traffic management strategy. As the main provider for aircraft airborne-side capabilities, the avionics system contains flight management, communication, navigation, monitoring and display control subsystems, with a series of functions of coordinating and managing aircraft operation and interacting with the outside. The organization and application of greener traffic-oriented avionics system capabilities mainly utilize the existing technical conditions to establish the corresponding flight environment perception, comprehensive information analysis and decision-making capabilities in the face of different flight missions and flight application scenarios. Through the collaboration of various avionics subsystems, greener avionics technology meets the capability requirements of four-dimensional flight trajectory optimization, key information acquisition and processing, intelligent human machine interaction, high-precision positioning and guidance, efficient air-ground cooperation, etc. presented by greener long and short route operation. Based on

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[1] https://www.easa.europa.eu/eaer/climate-change/aviation-environmental-impacts

analyzing the longand short route aircraft operation process, this document constructs an operation scenario model based on the system engineering modeling tool, extracts the relevant requirements of stakeholders, and lays a foundation for follow-up further research.

This document has the purpose to describe and derive greener airborne avionics system architecture, based on greener air traffic management (ATM) fundamental concepts which are proposed by MWP2; and finally, for validation activities (MWP6), and the environmental impact assessment (MWP7). The architecture will have a more appropriate functional organization form to provide airborne capability support for greener ATM concept to realize.

1.2. SCOPE

This document presents an airborne avionics system architecture in support of greener aircraft cruising operation. It builds an aircraft operation scenario focusing on analyzing the characteristics of aircraft operation in the cruise stage. The scenario maintains the most fuel-efficient trajectory through a series of activities such as upper wind detection, fuel-efficiency level identification, level change, meteorological detection and conflict resolution, reflecting the greener concept and forms an application architecture model.

Then, based on the application architecture, it extracts the aircraft level requirements and avionics system level requirements for the flight level change, conflict detection and alarm functions that intensively reflect the avionics system functions, completes function allocation in combination with the functional composition of the avionics system, and forms the functional architecture of the avionics system.

Finally, concept elements will be derived that can serve as building blocks for constructing greener ATM concepts for a detailed use case. Several examples how these building blocks can be assembled to a whole concept will be provided, which are the foundation for later activities in the project.

1.3. INTENDED READERSHIP

This section describes the intended audience for this document. In general, readers of this document can be:

1) Readers internal to the project, using this document as input for their own activities;
2) Readers from the GreAT sister projects (ACACIA, CLIMOP and ALTERNATE), to follow latest developments and approaches, and to drive scientific exchange between the sister projects. This is for the purpose of aligning the activities of all four projects and to identify synergy effects. Finally, this document can also serve as reference for scientific publications.
3) Readers from the GreAT Advisory board, to provide input and to follow the developments from a stakeholder point of view.
4) Readers involved in current and future projects dealing with reducing the impact of aviation on climate change, especially to build upon the approaches described in this document; and to align other developments (e.g. modifications to aircraft propulsion and airframe) with it.
5) Readers from air navigation service providers (ANSPs) or other stakeholders not involved in the project but effected from its improvements (especially airports, airlines and air traffic control (ATC) equipment providers).

6) Standardization bodies and regulating authorities / organizations, such as ICAO, European Union Aviation Safety Agency (EASA), EUROCONTROL or Civil Aviation Administration of China (CAAC).
7) All other interested members of aviation community.

1.4. STRUCTURE OF THE DOCUMENT

This document contains the following sections:

Chapter 1 Introduction – describes the purpose and scope of the document, the intended audience and the document structure.

Chapter 2 Baseline Situation – outlines the avionics system technical status and development trend to support greener global transportation operation. Some development planning in Europe and China are mentioned.

Chapter 3 Application Architecture Solution for Airborne Avionics System in Support of Greener Aircraft Cruising Operation – builds an aircraft operation scenario in support of greener cruising operation, focusing on analyzing the characteristics of aircraft operation in the cruise stage. The most fuel-efficient trajectory is maintained through a series of activities such as upper wind detection, fuel-efficient level identification, level change, meteorological detection and conflict resolution, reflecting the greener concept and forms an application architecture model.

Chapter 4 Functional Architecture Solution for Airborne Avionics System in Support of Greener Aircraft Cruising Operation – extracts the aircraft level requirements and avionics system level requirements for the flight level change, conflict detection and alarm functions that intensively reflect the avionics system functions, completes function allocation in combination with the functional composition of the avionics system, and forms the functional architecture of the avionics system.

Chapter 5 References – contains the references.

2. BASELINE SITUATION

Global air traffic activities maintain sustained fast growth, and air transportation has produced serious impacts on the global, and regional environments while facilitating public travel, mainly in terms of carbon dioxide emitted during aircraft flight and noise effect around the airport in takeoff and landing stages. Statistics show that the carbon emissions generated by civil air transportation flights account for about 2% of the total carbon emissions from human activities, and civil air transportation flights become the fastest-growing greenhouse gas emitters. As the number of flights further increases, there is still a trend of further increase in the total greenhouse gas emissions.

Currently, the earth ecosystem and climate system may have reached or even broken through important critical points, which may lead to irreversible changes, and extreme weather such as high temperature, heavy fog and strong thunderstorms will occur more frequently. Moreover, these extreme weather will cause extensive flight cancellations and delays, which will in turn affect and restrict the development of air transportation industry.

Facing the increase in air transportation demands in the future, major international research institutions such as International Civil Aviation Organization (ICAO), Federal Aviation Administration (FAA) of United States and European Aviation Safety Agency (EASA) all believe that the enhancement in the efficiency of air transportation in the future requires simultaneous improvement in the level of air traffic management and airborne avionics system. On requirements of greener traffic in the future, the research of avionics system mainly focuses on the following two aspects:

(a) Research on how avionics system participate in the organization and management of operation activities as well as the organization and application of greener-traffic-oriented avionics system capabilities more effectively in the greener traffic operation environment;
(b) Improvements in the function, performance of avionics, and research on the capabilities of avionics;

The research on the capabilities of avionics mainly focuses on avionics system architecture, sensor device and other technologies. The avionics system of the Boeing 787 aircraft is taken as an example, and its display system uses a large-screen liquid crystal display technology to comprehensively show primary flight information, navigation information and electronic checklist; the communication system contains a VHF digital link, a satellite communication system and a crew wireless LAN device that can be used in combination with the wireless LAN infrastructure in the airline terminal area; the navigation system includes an inertial reference system, an air data system, a DME, a radio altimeter, an emergency locator transmitter and an integrated navigation receiver, which can show the actual navigation performance and required navigation performance demands, support the flight requirement for RNP 0.1nmi, and fulfill landing at airports with harsh climates and poor facilities. The reconfigurable automatic integrated surveillance system consists of TCAS,TAWS, meteorological radar and mode S transponder; the common core system connects external sensor signals to the AFDX network by RDC, providing centralized computing resources, and integrating dozens of avionics/non-avionics hosted functions.

The organization and application of greener traffic-oriented avionics system capabilities mainly utilize the existing technical conditions to establish the corresponding flight environment perception, comprehensive information analysis, and decision-making capabilities in the face of different flight missions and flight application scenarios, which is also one of the most effective means for improving aircraft operating effectiveness and one of the main research directions of greener traffic.

Combined with its concrete domestic situation, the United States presents in the NextGen program the technical fields in which operational improvement is to be supported by the avionics system. See Table 1 for details.

Table 1. Technical fields in which operational improvement is to be supported by the avionics system as presented in the NextGen program

S/N	Technical Field in Which Operational Improvement is Supported	Detailed Improvement Supported
(1)	Improve aircraft operation efficiency of airports	(a) Optimize the taxi path (b) Reduce the taxi time (c) Improve the taxi safety capability
(2)	Reduce the influence of meteorological factors	(a) Optimize the approach envelope (b) Enhance the visual monitoring capability (c) Improve the guidance capability
(3)	Improve the utilization of airport airspace and resources	(a) Establish the takeoff and landing procedures for parallel runways (b) Establish the high-precision navigation capability of PBN (c) Improve the flight interval, wake and wind force monitoring capability
(4)	Improve the efficiency of takeoff	(a) Improve the process and efficiency

S/N	Technical Field in Which Operational Improvement is Supported	Detailed Improvement Supported
	and landing	of RNAVSIDs and STARs (b) Improve the capability and efficiency of authorized approach (AR) process (c) Improve the navigation reinforcing capability
(5)	Improve the airspace utilization and flow management	(a) Improve the airspace measurement capability (b) Improve the current traffic flow management capability (c) Improve the arrival, scene and takeoff flow management capabilities
(6)	Improve the UPT and dynamic collaborative trajectory management	(a) Enhance the collaborative trajectory selection capability (b) Enhance the collaborative management of airspace UPT (c) Enhance the decision support capability in traffic management
(7)	Improve the safety and effectiveness management in complex environments	(a) Improve the trajectory climb and descent capabilities in ocean areas (b) Improve the wake vortex separation classification and organization capabilities (c) Improve the automatic alarm in terminal areas
(8)	Improve the full flight and airspace information management capability	(a) Establish the airspace flight information system (b) Improve the specific airspace management capability (c) Improve the airspace utilization and safety

In combination with the specific domestic situations, Europe presents in the SESAR program the technical fields in which operational improvement is to be supported by the avionics system. See **Erreur ! Source du renvoi introuvable.** for details.

Table 2. Technical fields in which operational improvement is to be supported by the avionics system as presented in the SESAR program

S/N	Technical Field in Which Operational Improvement is Supported	Detailed Improvement Supported
(1)	Improve the flight trajectory capability and efficiency	(a) Improve the flight envelope organization and flight trajectory performance oriented ATM planning capability
(2)	Improve the capability of collaborative organization for flight	(a) Establish a three-party coordination mode of planning,

S/N	Technical Field in Which Operational Improvement is Supported	Detailed Improvement Supported
	planning	flight and management through the latest flight and related information in the global airspace network (b) Improve the flight management capability of ATM through the trajectory information obtained by ATSUs of ATM network
(3)	Improve the dynamic flight route organization capability	(a) Plan the route independently by defining midway waypoints (b) Provide a direct route of UPT to improve flight efficiency (c) Increase the flight frequency and enhance the airspace utilization
(4)	Improve the descent and approach capabilities and efficiency	(a) Improve the runway throughput through effective queuing and deviation monitoring (b) Improve the landing and approach efficiency through continuous descent operation (CDO) and controlled time of arrival (CTA) management
(5)	Improve the takeoff and landing efficiency	(a) Optimize the terminal airspace usability and runway availability, and improve the takeoff and landing capabilities (b) Reduce the hold-up time on the ground and in the air with less delay and improve the takeoff and landing efficiency
(6)	Improve the flight plan and airspace flow organization	(a) Enhance the airspace utilization through collaborative planning and decision-making (b) Improve trajectory optimization through ATM estimation and enhance flight predictability (c) Enhance the collaborative planning capability over network
(7)	Improve the flight and airspace information support capability	(a) Improve the ATM capability for information sharing (b) Improve the flight, technical and management information services (c) Establish the user's independent information management capability (d) Establish a standard common information model
(8)	Improve the operational efficiency of the airport and terminal airspace	(a) Establish a severe meteorological condition oriented integrated airport operation mode of arrival, takeoff and scene management. (b) Enhanced the ground taxi

S/N	Technical Field in Which Operational Improvement is Supported	Detailed Improvement Supported
		planning, guidance and takeoff
(9)	Improve the operational safety of the airport scene and runway	(a) Establish runway incursion detection and potential conflict prediction alarm (b) Establish monitoring and guidance of scene taxiing conflict (c) Establish the scene monitoring scenario situation and provide air traffic controller cautions
(10)	Improve the flight route optimization and decision-making capability	(a) Establish the route selection capability and reduce potential main route and intersection congestion (b) Provide the flexibility of flight plane spacing (c) Support the user-willed trajectory

Combined with its concrete domestic situation, China presents in the ASBU the technical fields in which operational improvement is to be supported by the avionics system. See Table 3.

Table 3. Technical fields in which operational improvement is to be supported by the avionics system as presented in the ASBU program

S/N	Avionics related technology	Detailed Improvement requirement
(1)	Communication and monitoring	(a) Gradually introduce FANS 2 / B to support ATN based data link (b) Installation of air collision avoidance system (TCAS) (c) FFans 3/C will be ready to provide integrated communication and monitoring capabilities by connecting fans equipment and flight management system (FMS).
(2)	Navigation	(a) FMS supports PBN (b) FMS will integrate airport navigation function and support initial 4D trajectory capability (c) The deployment of multi constellation and multi frequency global satellite navigation system will support the improvement aircraft based augmentation system (ABAS) (d) FMS will support full 4D trajectory capabilities
(3)	Airborne safety network	(a) Electronic flight packages will be popularized (b) Airport map and traffic information display will be realized

S/N	Avionics related technology	Detailed Improvement requirement
		(c) The enhanced vision system (EVS) and integrated Synthetic Visual System (SVS) in the cockpit for the airport will be ready

3. APPLICATION ARCHITECTURE SOLUTION FOR AIRBORNE AVIONICS SYSTEM IN SUPPORT OF GREENER AIRCRAFT CRUISING OPERATION

This section will analyze the stakeholders, activities involved and responsibilities of all parties from the operation scenarios. On this basis, a scenario analysis model is established based on the system engineering modeling tool to extract the functional requirements of all parties.

3.1. OPERATION SCENARIO ANALYSIS

The whole flight service process of an aircraft mainly includes three stages: pre-cruise, cruise, and post-cruise, each of which involves relevant activities and information interaction between the aircraft and operation nodes such as ground control center, airport, airline and another aircraft. This chapter establishes the operation scenarios in support of greener aircraft cruising operation from the above three stages.

3.1.1. PRE-CRUISE STAGE

3.1.1.1 SCENARIO OVERVIEW

Flight preparations are implemented in this stage:

1. The airline applies for and approves the route; the ATC Center issues airspace status and use restrictions to the airline. The airline and ATC party make collaborative planning of conflict-free plan trajectories, then the aircraft establishes data link connection with the ATC system, and control departments including the Tower, Approach and Area Control Center, airport and aircraft negotiate to determine conflict-free reference flight trajectories.
2. The aircraft confirms its own status, applies for the release and push-back permission, and taxis to the target runway according to the designated taxi path. During this period, the aircraft needs to ensure its own operation safety without conflict with other aircrafts.
3. When arriving at the target runway, the aircraft applies for the runway entry and take-off permit. After obtaining the permit, it starts to take-off, and then the Tower transfers the control to the Approach Control Center. After the transfer is completed, the aircraft joins the departure flight flow and starts to climb.
4. The Approach Control Center monitors the climb operation; in case of aircraft conflict, the aircraft gives a climb conflict alarm to the Approach Control Center,

waits for the Approach Control Center to issue a release instruction and confirms the execution of the control instruction; the Approach Control Center updates the reference trajectory and sends the updated reference trajectory to the Area Control Center and ATFMC, and relevant centers evaluate and update the trajectory and continue to monitor the climb operation; when the aircraft is about to reach the cruise altitude, the Approach Control Center transfer control to the Area Control Center. After confirmation by the aircraft, the aircraft reaches the cruise altitude and enters the cruise stage.

3.1.1.2 STAKEHOLDERS INVOLVED

This document mainly analyzes the application architecture, functional architecture and physical architecture of the avionics system, regards ATC as a whole, and no longer distinguishes different ATC departments. The stakeholders are as follows:

1. Aircraft;
2. ATC department;
3. Airport;
4. Airline.

3.1.1.3 ACTIVITY ANALYSIS

Table 4. Pre-cruise Stage

Activity Name: Pre-cruise stage	Simple Event Procedure
Trigger Condition	
Case 1	From about one week before flight operation to before cruise starts
Exit Condition	
Condition 1	The aircraft reaches the cruise altitude
Procedure Overview: From about one week before flight operation to one day before flight operation, the airline, airport, flow management department, airspace management department, etc. cooperate based on the flight schedule, continuously adjust the flight trajectory in the planning stage in accordance with the latest operating limitations, and finally determine a feasible flight trajectory before flight takeoff. On the day of flight operation, the flight crew applies for taxi permission, ATC issues taxi permit, and the aircraft taxis to the waiting area outside the runway according to the designated route. During this period, the Tower control center continuously monitors the consistency of aircraft operation in the taxing stage, the National Air Traffic Flow Monitoring Center monitors the capacity-flow balance at the airport scene, and the aircraft maintains the conflict detection and release, etc. in	

Activity Name: Pre-cruise stage	Simple Event Procedure

operation during the taxiing stage to finally ensure that the aircraft successfully reaches the designated runway entrance and has to wait there.

The controller confirms that the runway status is available, issues the take-off permit, and allows the aircraft to enter the runway and take-off. The pilot confirms the take-off permit and controls the aircraft to complete the process of entering the runway and take-off. Then, the Tower control center transfers the control to the Approach Control Center, and the aircraft confirms the transfer of control, joins the departure flight flow and starts entering the climb stage.

The aircraft climbs to the cruise altitude according to the reference flight path, and the ATC monitors the consistency of flight operation and flight conflict. In case of aircraft conflict, the Approach Control Center will confirm the conflict, execute tactical interval management, issue a new control instruction and updates the reference flight path. After the Approach Control Center confirms the route altitude, the control is transferred to the Area Control Center, and the aircraft will confirm the control transfer with the Area Control Center.

Stakeholder Analysis

Stakeholder	**Responsibility**
Airline	1. Submit the ideal planned trajectory; 2. Submit the Target Off-Block Time (TOBT) to the Tower Control Center.
ATC	1. Provide intelligence services; 2. Update and release of planned trajectory; 3. Departure taxiing route allocation; 4. Communicate with aircraft about route; 5. Negotiate, confirm and store departure trajectory; 6. Issue the ATC permit; 7. Issue the launch permit; 8. Monitor the aircraft operation path;

Activity Name: Pre-cruise stage	Simple Event Procedure
	9. Update the taxiing path in the case of aircraft conflict; 10. Monitor the consistency of flight operation; 11. Monitor the flight conflict; 12. Execute the tactical interval management; 13. Update the reference flight trajectory; 14. Transfer of control.
Airport	1. Evaluation, feedback, confirmation and storage of departure trajectory;
Aircraft	1. Receive, calculate, upload and negotiate the departure trajectory; 2. Check the trajectory and aircraft status; 3. Apply for control permit; 4. Confirm and execute the trajectory; 5. Perform conflict alarm and detection, and send the control; 6. Execute the conflict resolution instruction; 7. Update the trajectory according to the control instruction; 8. Execute the reference flight trajectory; 9. Confirm the transfer of control.
Procedure	
Procedure Description: 1. The ATC department provides intelligence services; 2. The airline submits the ideal planned trajectory; 3. The ATC department updates and issues the planned trajectory; 4. The airline submits TOBT to the Tower Control Center; 5. The Tower control center allocates the taxi route and uploads the departure trajectory information to the aircraft;	

Activity Name: Pre-cruise stage	Simple Event Procedure
6. The aircraft calculates the departure trajectory and downloads it to the Tower Control Center; 7. The Tower Control Center sends the received departure trajectory to ATFMC, airport, Area Control Center and Approach for joint participation in the negotiation; 8. The ATFMC, airport, Area Control Center and Approach Control Center feed back the trajectory evaluation results to the Tower Control Center respectively; 9. The Tower Control Center updates the negotiated departure trajectory and uploads it to the aircraft; 10. The Tower Control Center, ATFMC, airport, Area Control Center and Approach Control Center update, confirm and store the departure trajectory; 11. The aircraft checks the trajectory and the aircraft status; 12. The aircraft sends a release permit request to the Tower Control Center; 13. The Tower Control Center issues a release permit to the aircraft; 14. The aircraft sends a launch permit request to the Tower Control Center; 15. The Tower Control Center issues the launch permit to the aircraft, and the aircraft confirms the permit; 16. The aircraft executes taxiing; 17. The Tower Control Center monitors the consistency in the aircraft taxiing stage (consistency between planned and actual taxi routes); 18. The ATFMC predicts and monitors the capacity-flow balance in the terminal area, and there is capacity-flow balance in the terminal area at this time; 19. The aircraft continues to perform the taxiing task, detects a conflict with the routes of other aircraft during taxiing, and sends a conflict alarm to the Tower Control Center immediately; 20. The Tower Control Center immediately updates the taxi route and sends the new route to the aircraft; 21. The aircraft continues to taxi to the runway entrance according to the new taxi route; 22. The aircraft waits at the holding point and enters the runway when receiving	

Activity Name: Pre-cruise stage	Simple Event Procedure
clearance from the Tower Control Center ; 23. The aircraft starts to take off when receiving take-off clearance from the Tower Control Center ; 24. The Tower Control Center delivers control to the Approach Control Center when the aircraft enters climbing phase ; 22. The Approach Control Center continuously monitors the aircraft climb process; 23. The aircraft immediately issues a conflict alarm to the Approach Control Center in case of conflict during climb; 24. The Approach Control Center issues a release instruction; 25. The aircraft executes the control instruction; 26. The Approach Control Center updates the reference trajectory and sends the updated reference trajectory to the aircraft, Area Control Center and ATFMC; 27. The Area Control Center and ATFMC evaluate, update and confirm the trajectory; 28. The Approach Control Center continues to monitor the aircraft climb operation and executes the control transfer after confirming the flight altitude; 29. The Area Control Center takes over the control; 30. The aircraft confirms the transfer of control and enters the cruise stage after reaching the cruise altitude.	

3.1.2. CRUISE STAGE

3.1.2.1 SCENARIO OVERVIEW

The following processes are mainly implemented in the cruise stage:

1. When the aircraft identifies a more fuel-efficient level, the aircraft requests the Area Control Center to change to this level. After analyzing the airspace operation situation and judging that the conditions permit, the Area Control Center issues a level change permit to the aircraft, and the aircraft executes and completes the level change, and downloads the latest EPP data.
2. The Area Control Center updates the ground reference flight trajectory and issues the updated reference trajectory to the aircraft and the National Air Traffic Flow Monitoring Center. The Intelligence Service Department sends meteorological information to the Area Control Center, and the Area Control Center broadcasts meteorological information to the aircraft.

3. After the aircraft judges that there is a meteorological conflict in the subsequent trajectory, the aircraft generates the initial diversion trajectory and submits it to the airline, and the airline submits the initial diversion trajectory to the National Air Traffic Flow Monitoring Center. The diversion trajectory is confirmed and issued to the Area Control Center and the airline after being received and evaluated by the National Air Traffic Flow Monitoring Center, then the airline sends the diversion trajectory to the aircraft, and the aircraft applies for a new release permit to the Area Control Center after receiving the diversion trajectory. After the Area Control Center receives and downloads the permit, the aircraft will recalculate the trajectory and download it to EPP and cruise in accordance with the updated reference trajectory.

The scenario contains three subevents: upper wind detection, level change procedure and diversion.

3.1.2.2 STAKEHOLDERS INVOLVED

The stakeholders are as follows:

1. ATC department;
2. Aircraft;

3.1.2.3 ACTIVITY ANALYSIS

Table 5.Cruise Stage

Activity Name: Cruise stage	Complex Event Procedure
Trigger Condition	
Case 1	The aircraft reaches the cruise altitude
Exit Condition	
Condition 1	The aircraft enters the approach sequencing management area
Procedure Overview: The aircraft cruises according to the reference flight path, and the ATC monitors the consistency of flight operation and flight conflict. The aircraft may apply to the Area Control Center for more fuel-efficient level flight according to actual needs, and the Area Control Center judges whether to issue the level change permit according to the airspace status after receiving the request for flight path level change; if the permit is issued, the aircraft acquires the position information of aircraft around through ADS-B IN and executes the level change procedure after receiving the level change permit.	
Shareholder analysis	

Activity Name: Cruise stage		Complex Event Procedure
Shareholder	**Responsibility**	
ATC	1. Monitor the aircraft operation situation; 2. Evaluate whether the airspace operation situation can meet the flight level change; 3. Issue the control permit; 4. Update the reference flight trajectory; 5. Transfer the control.	
Aircraft	1. Upper wind detection; 2. Fuel-efficient level identification; 3. Perception of surrounding aircraft; 4. Meteorological conflict detection; 5. Diversion.	
Procedure		
Procedure Description: 1. The Area Control Center monitors the aircraft operation; 2. The airborne system of the aircraft identifies the planned level upper wind variation; 3. The aircraft identifies a more fuel-efficient level and applies for level change; 4. The aircraft negotiates with the Area Control Center and executes the level change; 5. The Area Control Center updates and issues the ground reference flight trajectory; 6. The aircraft cruises according to the updated reference trajectory; 7. The Intelligence Service Department releases meteorological information to the Area Control Center; 8. The Area Control Center sends the meteorological information to the aircraft; 9. After receiving the meteorological information, the aircraft evaluates that there is meteorological conflict or traffic conflict in the follow-up trajectory, and starts the		

Activity Name: Cruise stage	Complex Event Procedure
diversion procedure.	

3.1.2.4 SCENARIO ANALYSIS MODEL IN THE CRUISE STAGE BASED ON SYSTEM ENGINEERING MODELING TOOL

ACTIVITYCOMPOSITION IN THE CRUISE STAGE

The cruise stage is a complex event including three subevents: upper wind detection, level change and diversion. The activity composition in the cruise stage is as follows.

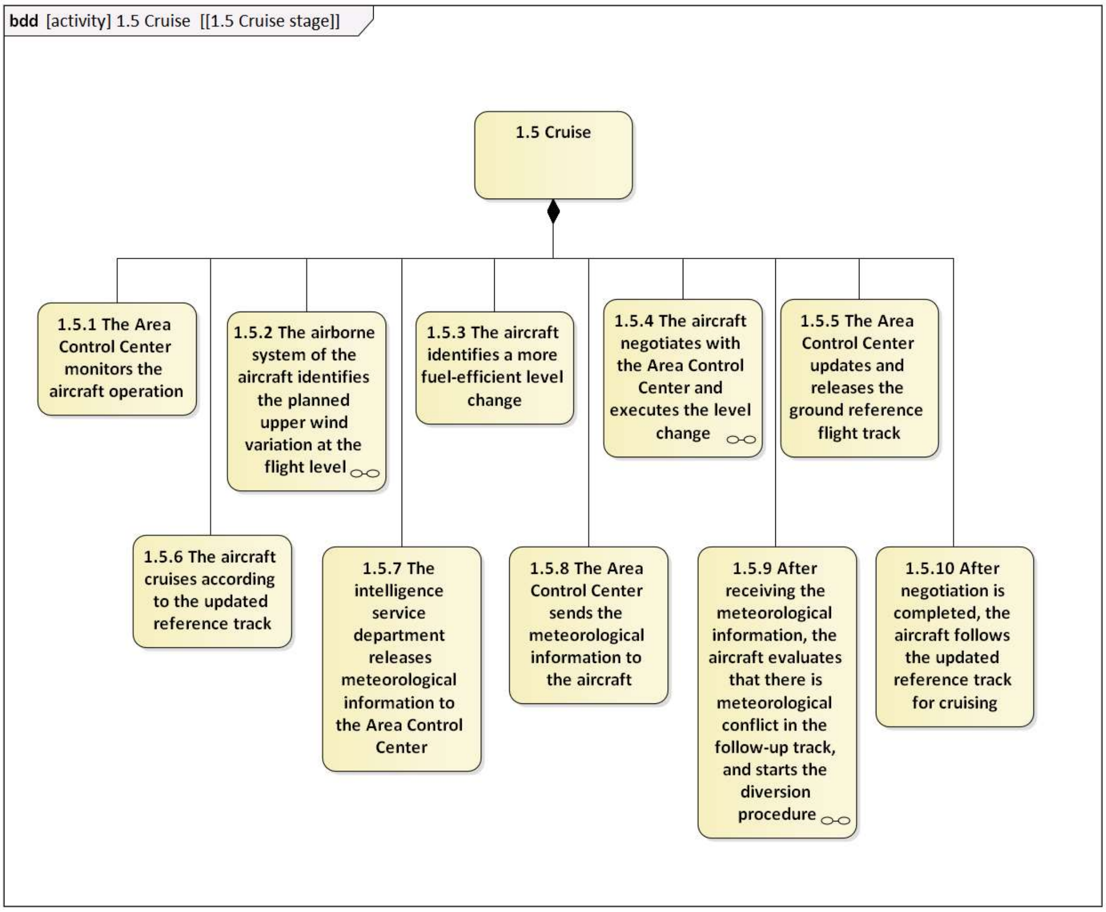


Figure 1: Activity Composition in the Cruise Stage

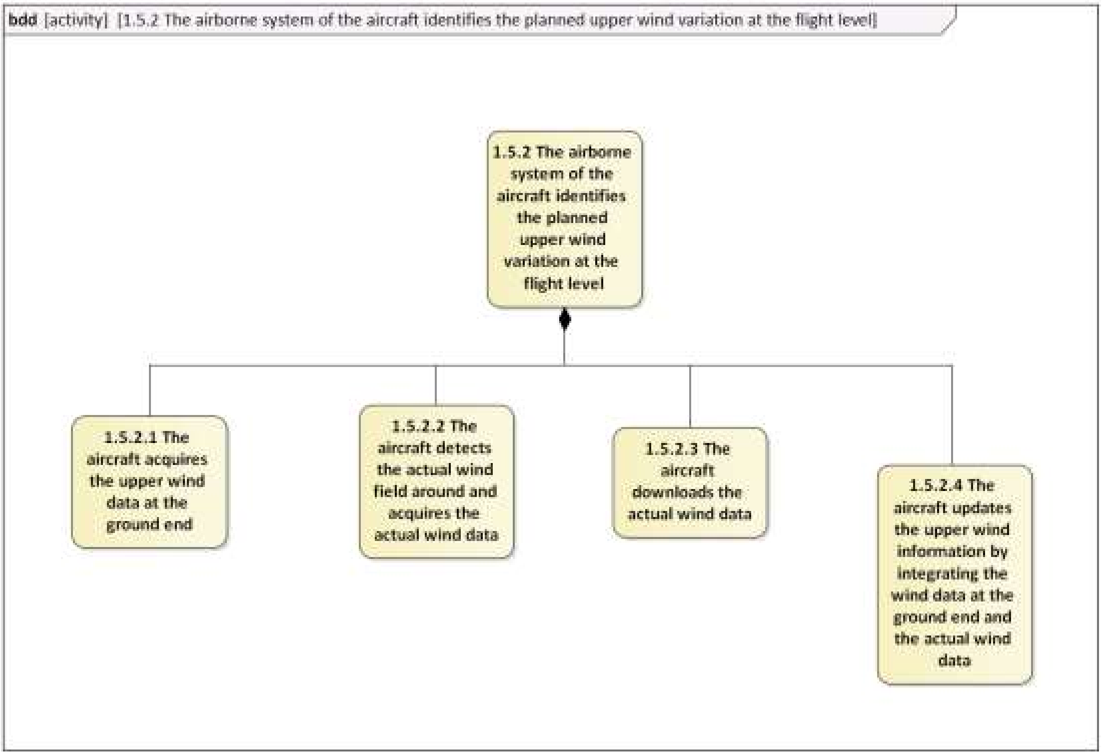


Figure 2: Composition of Upper Wind Detection Activity

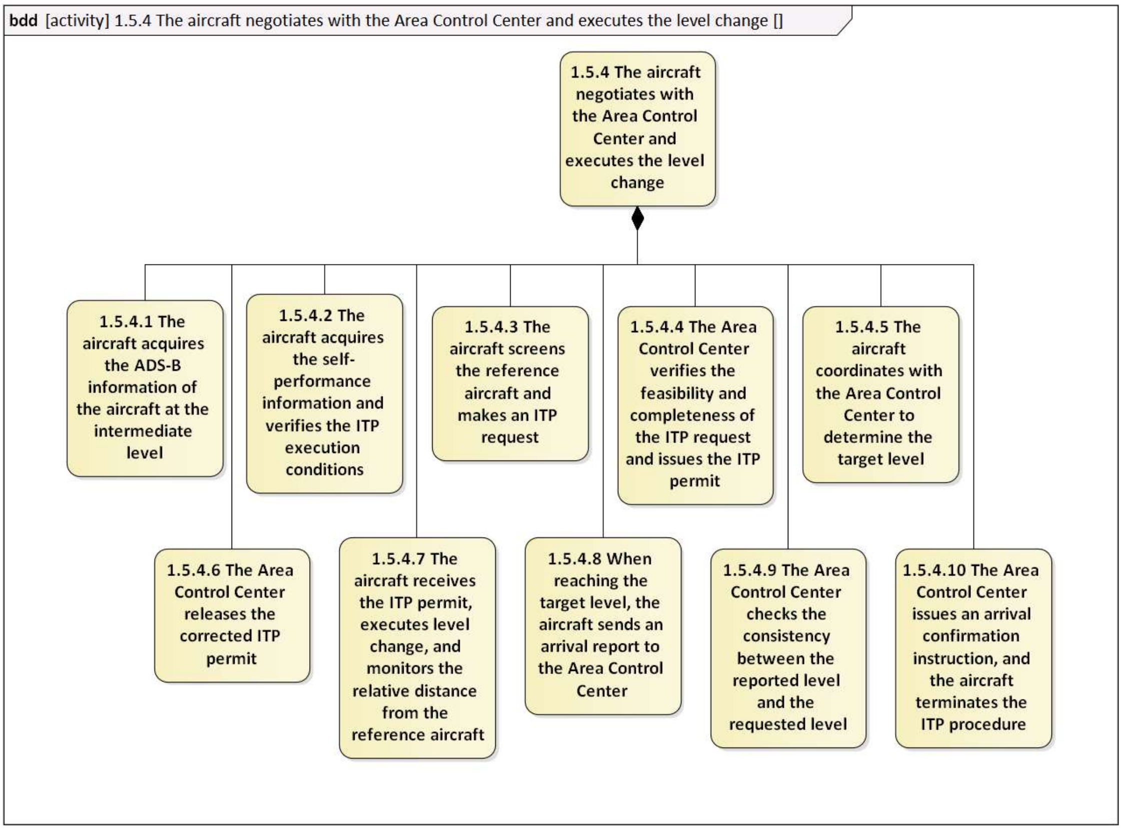


Figure 3: Composition of Level Change Activity

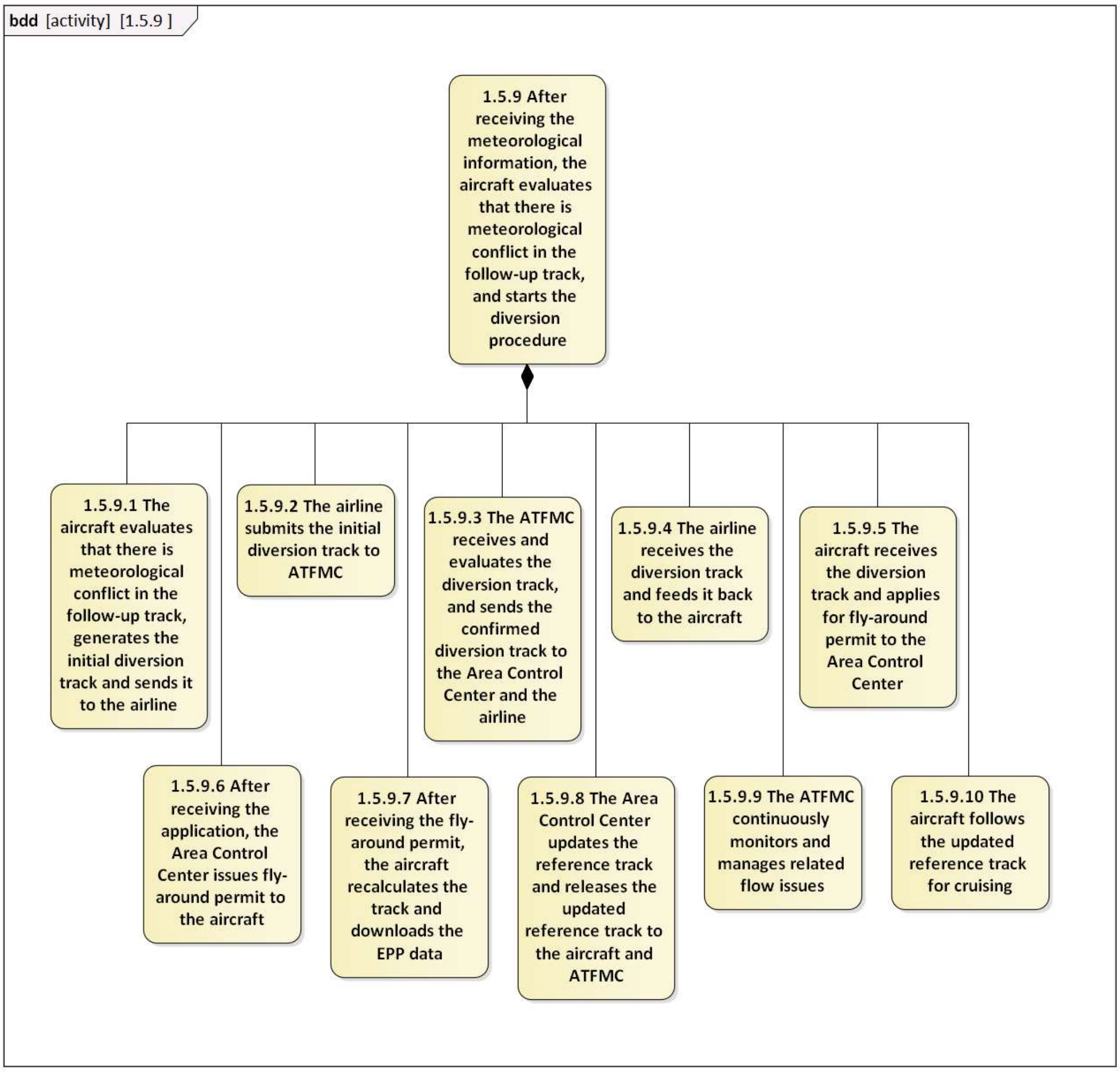


Figure 4: Composition of Diversion Activity

ACTIVITY PROCESS IN THE CRUISE STAGE

The corresponding activity process in the cruise stage is as follows.

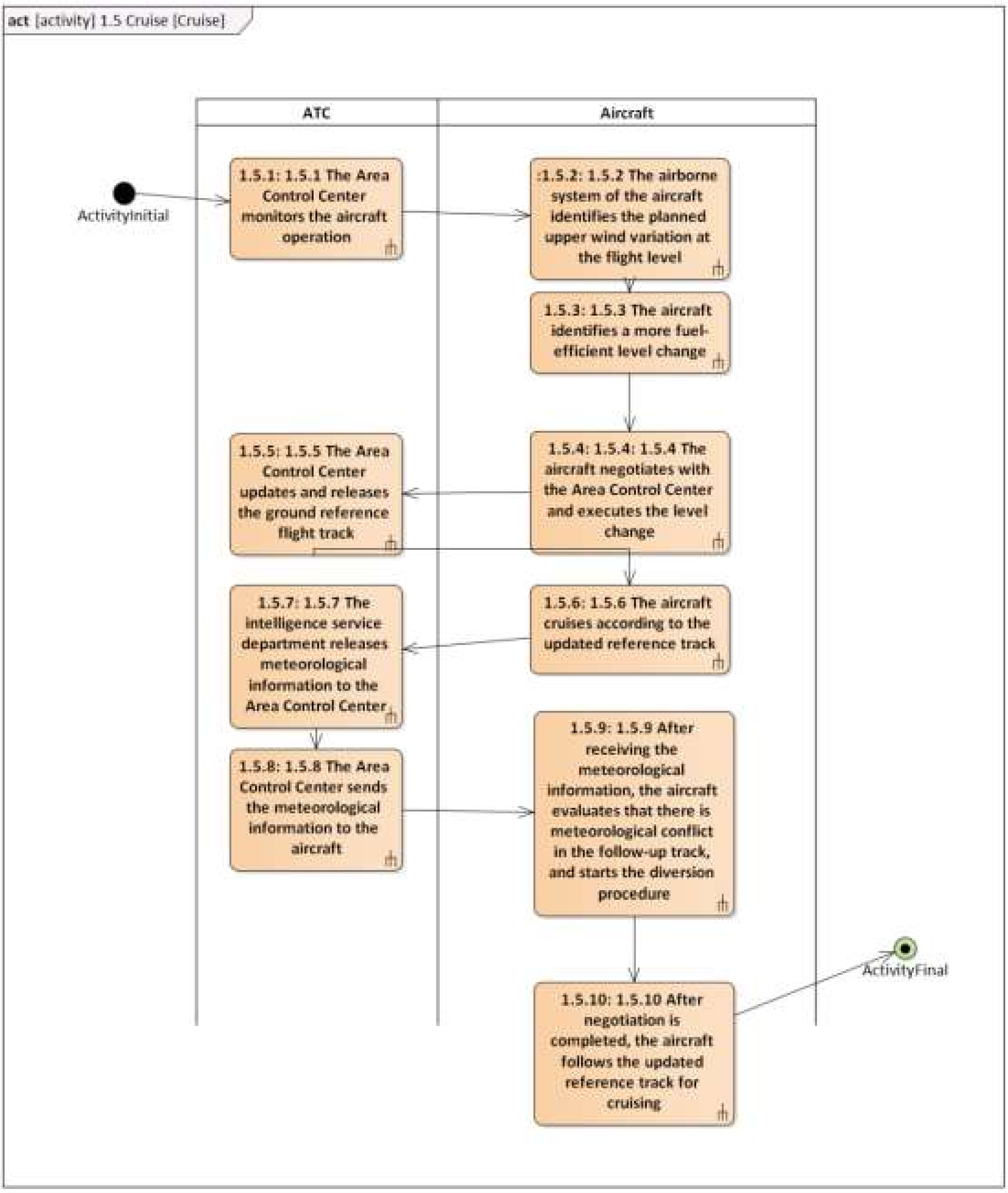


Figure 5: Activity Process in the Cruise Stage

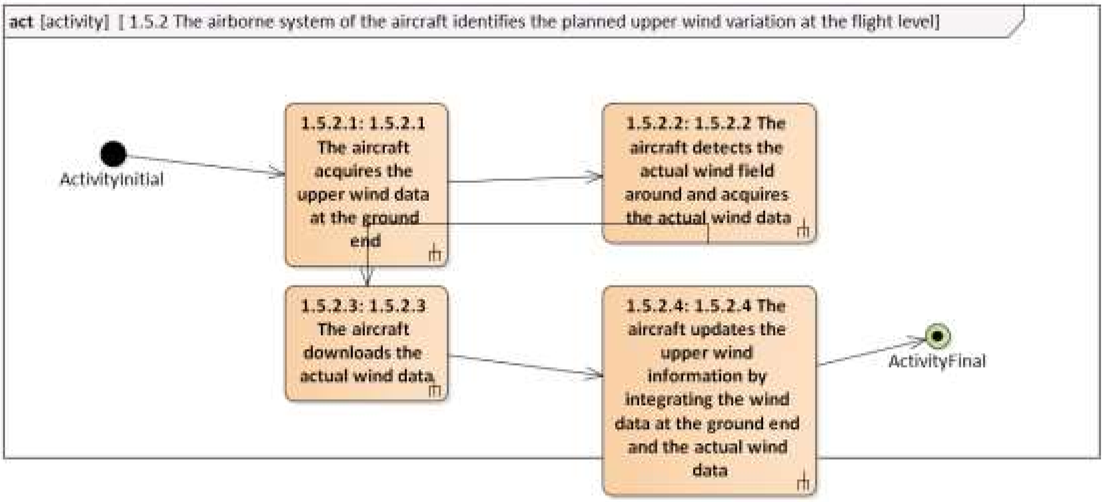


Figure 6: Upper Wind Detection Activity Process

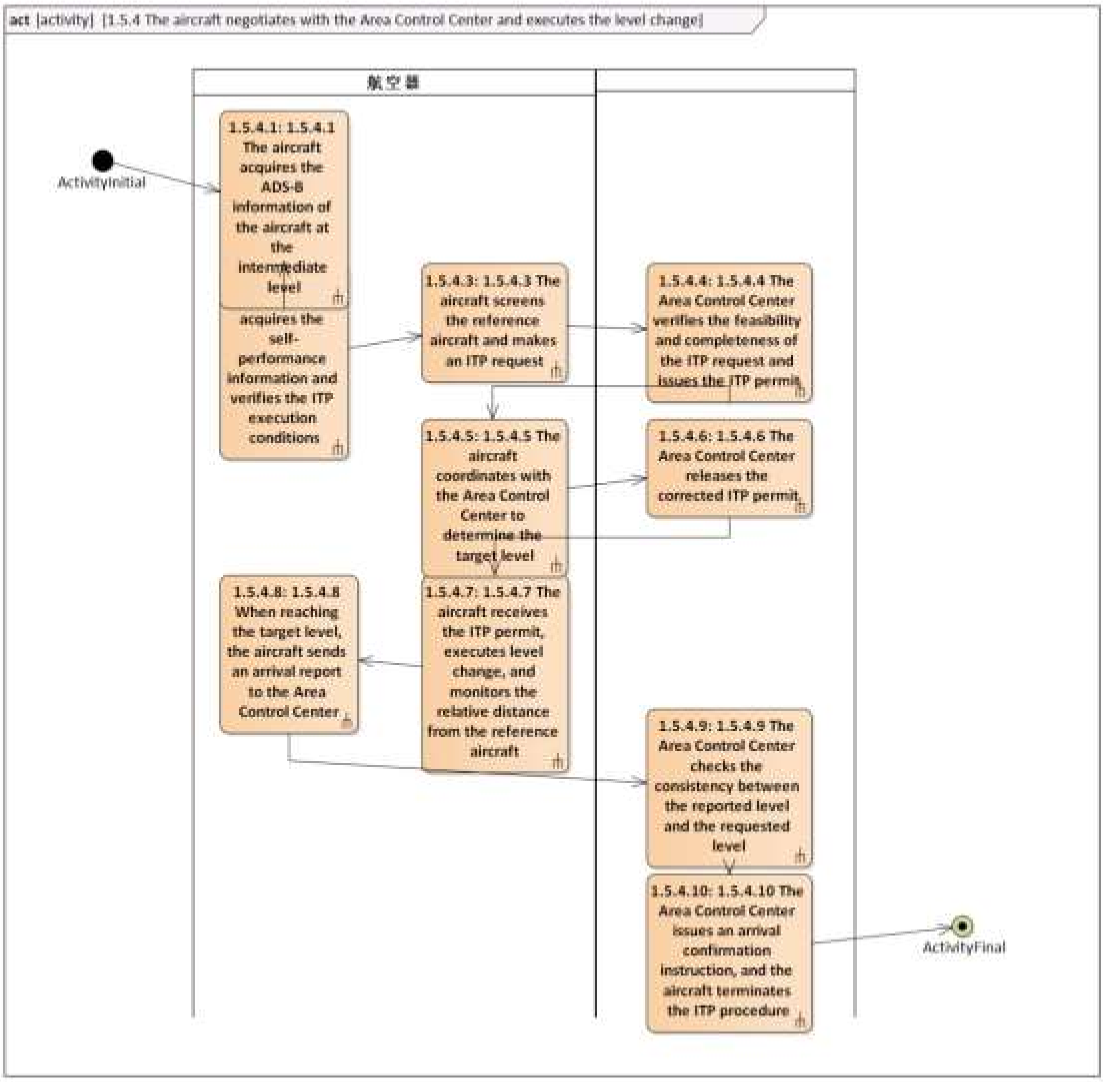


Figure 7: Level Change Activity Process

3.1.3. POST-CRUISE STAGE

3.1.3.1 SCENARIO OVERVIEW

The following processes are mainly implemented in the post-cruise descent stage:

1. The aircraft enters the approach sequencing management area and makes a request for meteorological and operation information from the intelligence service department. The AMAN of the Approach Control Center calculates the approach trajectory, and the Area Control Center shares the approach trajectory with the aircraft.
2. The aircraft receives the meteorological and operation information, negotiates and formulates the approach trajectory, and downloads it to the Approach Control Center through the ETA window. The Approach Control Center, Tower Control Center and ATFM negotiate the CTA with the Area Control Center respectively, the Area Control Center combines and uploads the negotiated CTA to the aircraft for confirmation and

updates the approach trajectory with the Area Control Center; the ATFM shares the ELDT time, the airport allocates the parking bays, the tower SMAN plans the approach taxiing trajectory, and the Area Control Center uploads the approach taxi route to the aircraft.

3. The aircraft receives the scene taxiing information, arrives at TOD, and receives the descent permit issued by the Area Control Center and descends for operation. When judging that there is a descent conflict alarm, the Area Control Center issues a conflict resolution instruction to the aircraft and updates the descent reference trajectory. The ATFM performs evaluation and update of the descent trajectory.
4. When descending to the control transfer altitude, the Area Control Center transfers the control to the Approach Control Center, and the aircraft confirms the control transfer.

The following processes are mainly implemented in the post-cruise approach stage:

1. The Approach Control Center monitors the initial approach point, and the aircraft evaluates CTA; when the aircraft judges that the CTA is unavailable, it negotiates the CTA with the Approach Control Center.
2. The aircraft adjusts the speed according to the CTA, the Approach Control Center performs sequence approach, issues the approach permit, and authorizes the aircraft to maintain the airborne interval; the airport updates the parking bays to the Tower Control Center, the tower SMAN updates the approach taxi route to the Approach Control Center, the Approach Control Center uploads the updated taxi route to the aircraft and notifies the runway meteorology and monitoring.
3. The aircraft executes the final approach, the Approach Control Center transfer the control to the Tower Control Center, and the aircraft confirms the control transfer.

The following processes are mainly implemented in the post-cruise landing stage:

1. The Tower Control Center monitors the aircraft operation; when the runway is unavailable, the Tower Control Center reallocates the runway, and the aircraft makes a request for landing permit after receiving the updated runway information.
2. After the Tower Control Center issues the landing permit and it is confirmed by the aircraft, the aircraft lands and reaches the runway end.

The following processes are mainly implemented in the post-cruise taxi-in stage:

1. The aircraft exits the runway, the Tower Control Center issues the taxi-in permit which is confirmed by the aircraft, and the aircraft slides in; the Tower Control Center performs taxi monitoring and issues the parking permit which is confirmed by the aircraft, and the aircraft enters the apron.

3.1.3.2 SHAREHOLDERS INVOLVED

The shareholders are as follows:

1. ATC department;
2. Aircraft;
3. Airport.

3.1.3.3 ACTIVITY ANALYSIS

Table 6.Post-Cruise Stage

Activity Name: Post-cruise stage	Simple Event Procedure
Trigger Condition	
Case 1	The aircraft enters the approach sequencing management area
Exit Condition	
Condition 1	The aircraft enters the parking bay
Procedure Overview: The aircraft operates by continuously descending according to the reference flight trajectory, and the ATC monitors the consistency of flight operation and flight conflict. Due to uncertainties such as meteorology and aircraft execution, the system detects potential flight conflict, gives an alarm, and automatically generates conflict resolution strategies; the controller executes tactical interval management after confirmation, issues a new control instruction and updates the descent reference trajectory. The aircraft reaches the control transfer altitude, the Area Control Center transfers the control to the Approach Control Center, and the aircraft confirms the control transfer. The aircraft acquires the permit issued by the Approach Control Center to execute the approach procedure, establishes the course and glide path, adjusts the landing attitude and maintains the operation approach procedure through the airborne interval, and the ATC monitors the consistency of flight operation and flight conflict in real time. After the parking bay is updated at the airport, the ATC updates the approach taxi route by SMAN, and the Approach Control Center uploads the updated taxi route to the aircraft; after the Approach Control Center notifies the runway meteorology and monitoring, the aircraft completes the final approach and starts to prepare for landing. The Tower Control Center acquires the control, monitors the aircraft operation and confirms whether the runway is available; if it is available, a landing permit is issued; if it is not available, the airport needs to reallocate the runway, and the aircraft will issue a landing permit after receiving the updated runway information.	

<table>
<tr><td>Activity Name: Post-cruise stage</td><td>Simple Event Procedure</td></tr>
<tr><td colspan="2">The aircraft obtains the landing permit, completes the landing process, and reaches the runway end.
The aircraft exits the runway, the Tower Control Center issues the taxi-in permit, the aircraft confirms the permit and enters the taxiing stage until it enters the apron. During this period, the ATC continuously monitors the aircraft taxiing.</td></tr>
<tr><td colspan="2">Shareholder analysis</td></tr>
<tr><td>Shareholder</td><td>Responsibility</td></tr>
<tr><td>ATC</td><td>1. Monitor the aircraft operation situation;
2. Provide meteorological and operational information;
3. Plan the approach trajectory;
4. Negotiate, determine and update the approach trajectory;
5.Share the ELDTtime and CTA;
6.Plan the taxi route;
7. Negotiate the CTA;
8. Issue relevant control instructions, and authorize the maintenance of airborne interval;
9. Monitor the aircraft operation status;
10. Update the taxi route;
11. Notify the aircraft of the runway meteorology information;
12. Transfer the control;
13. Monitor the aircraft operation;
14. Reallocate the runway when the runway is unavailable;
15. Issue the landing permit;
16.Monitor the aircraft operation;
17. Issue control permits for taxi-in, parking, etc.</td></tr>
<tr><td>Aircraft</td><td>1. Formulate the initial approach trajectory;</td></tr>
</table>

Activity Name: Post-cruise stage	Simple Event Procedure
	2. Confirm and update the trajectory; 3. Execute the control instruction; 4. Trajectory based operation; 5. Evaluation and negotiation of CTA; 6. Adjust the speed according to CTA; 7. Execute the airborne interval; 8. Receive the updated runway information; 9. Issue the request for landing permit; 10. Receive the permit and execute landing; 11.Receive and execute the control instruction; 12. Operate based on the reference trajectory.
Airport	1. Allocate the parking bays according to ELDT time. 2. Reallocate the parking bays, and update the information.
Procedure	
Procedure Description: 1. The aircraft enters the approach sequencing management area, and the pilot makes a request for meteorology and operation information from the intelligence service department; 2. The ATC plans the approach trajectory and shares the generated approach trajectory with the aircraft; 3. The intelligence service department uploads the meteorology and operation information to the aircraft; 4. The aircraft formulates the initial approach trajectory and downloads it to the ETA window; 5. The Approach Control Center, Tower Control Center and ATFMC negotiate CTA with the Area Control Center and upload it to aircraft; 6. The aircraft confirms and updates the trajectory;	

Activity Name: Post-cruise stage	Simple Event Procedure
7. The Area Control Center updates and shares the approach trajectory; 8. The ATFMC shares ELDT time with the airport; 9. The airport allocates the parking bays; 10. The ATC plans the taxi route through SMAN and uploads the approach taxi route to the aircraft; 11. The aircraft receives the scene taxiing information, and then reaches TOD; 12. The Area Control Center issues a descent permit to the aircraft; 13. The aircraft executes descent operation after confirming the permit; 14. The aircraft reaches the control transfer altitude; 15. The Approach Control Center takes over the control; 16. The aircraft confirms the transfer of control; 17. The Approach Control Center monitors the initial approach point; 18. The aircraft evaluates the CTA. At this time, the CTA is unavailable, and the aircraft negotiates the CTA with the Approach Control Center; 19. The aircraft adjusts the speed according to CTA; 20. The Approach Control Center controls the aircraft sequence approach and issues the approach permit; 21. The Approach Control Center authorizes the aircraft to maintain the airborne interval; 22. The aircraft starts approaching in accordance with the airborne interval; 23. The Approach Control Center continuously monitors aircraft operation; 24. The airport issues the updated parking bays to the Tower Control Center; 25. The Approach Control Center updates the approach taxi route according to SMAN, and uploads the updated taxi route to the aircraft; 26. The aircraft confirms the updated taxi route with the Approach Control Center; 27. The Approach Control Center notifies the aircraft of the runway meteorology information;	

Activity Name: Post-cruise stage	Simple Event Procedure
28. The aircraft completes the final approach segmentand is ready for landing; 29. The Approach Control Center transfers the control to the Tower; 30. The aircraft confirms the transfer of control. 31. The Tower Control Center continuously monitors the aircraft operation. At this time, the runway is unavailable, and the airport reallocates the runways; 32. The aircraft receives the updated runway information and issues a request for landing permit to the Tower Control Center; 33. The Tower Control Center issues a landing permit to the aircraft; 34. The aircraft confirms the landing permit, executes landing, and then reaches the runway end.	

3.2. REQUIREMENT ANALYSIS

Combined with the general idea and application architecture of the airborne avionics system in support of greener aircraft cruising operation, it can be seen that the critical stage of greener aircraft operation is the cruise stage, and the key requirements for realizing greener operation in the cruise stage lie in two applications: level change and diversion.

In the application of level change, the key to the avionics system is to find the greenest level according to the change of meteorological conditions to perform the level change.

But in the application of diversion, the avionics system must first have the functions of conflict prediction and alarm, that is, when to make the decision of diversion, and then find the greenest diversion solution.

To sum up, the most important functions of the airborne avionics system in support of greener aircraft cruising operation are greener level change detection, conflict detection and alarm functions, respectively.

4. FUNCTIONAL ARCHITECTURE SOLUTION FOR AIRBORNE AVIONICS SYSTEM IN SUPPORT OF GREENER AIRCRAFT CRUISING OPERATION

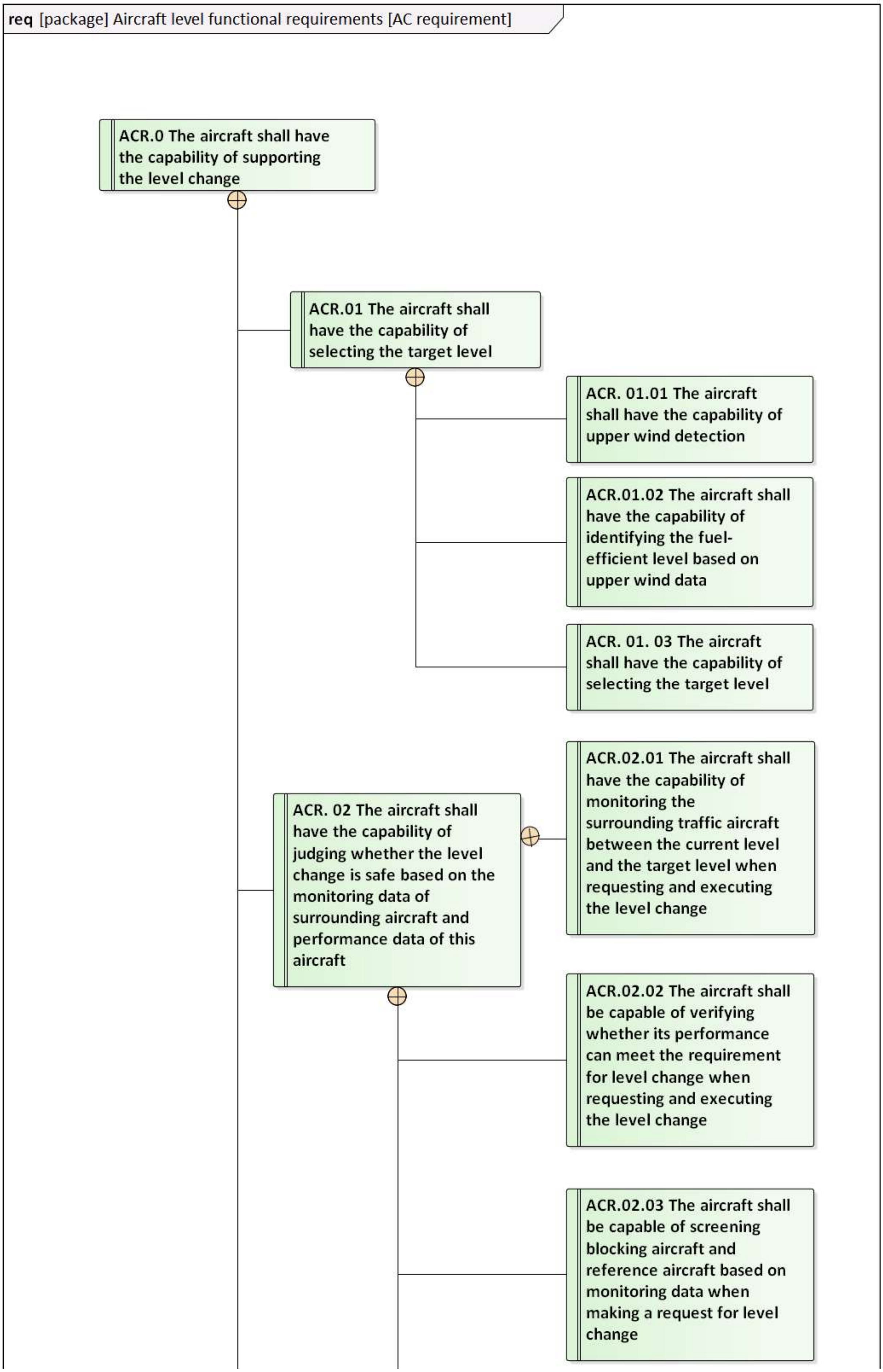
This chapter extracts the aircraft level requirements and avionics system level requirements for the level change, conflict detection and alarm functions that intensively reflect the avionics system functions based on the application architecture, completes function allocation in combination with the functional composition of the avionics system, and finally forms the functional architecture of the avionics system.

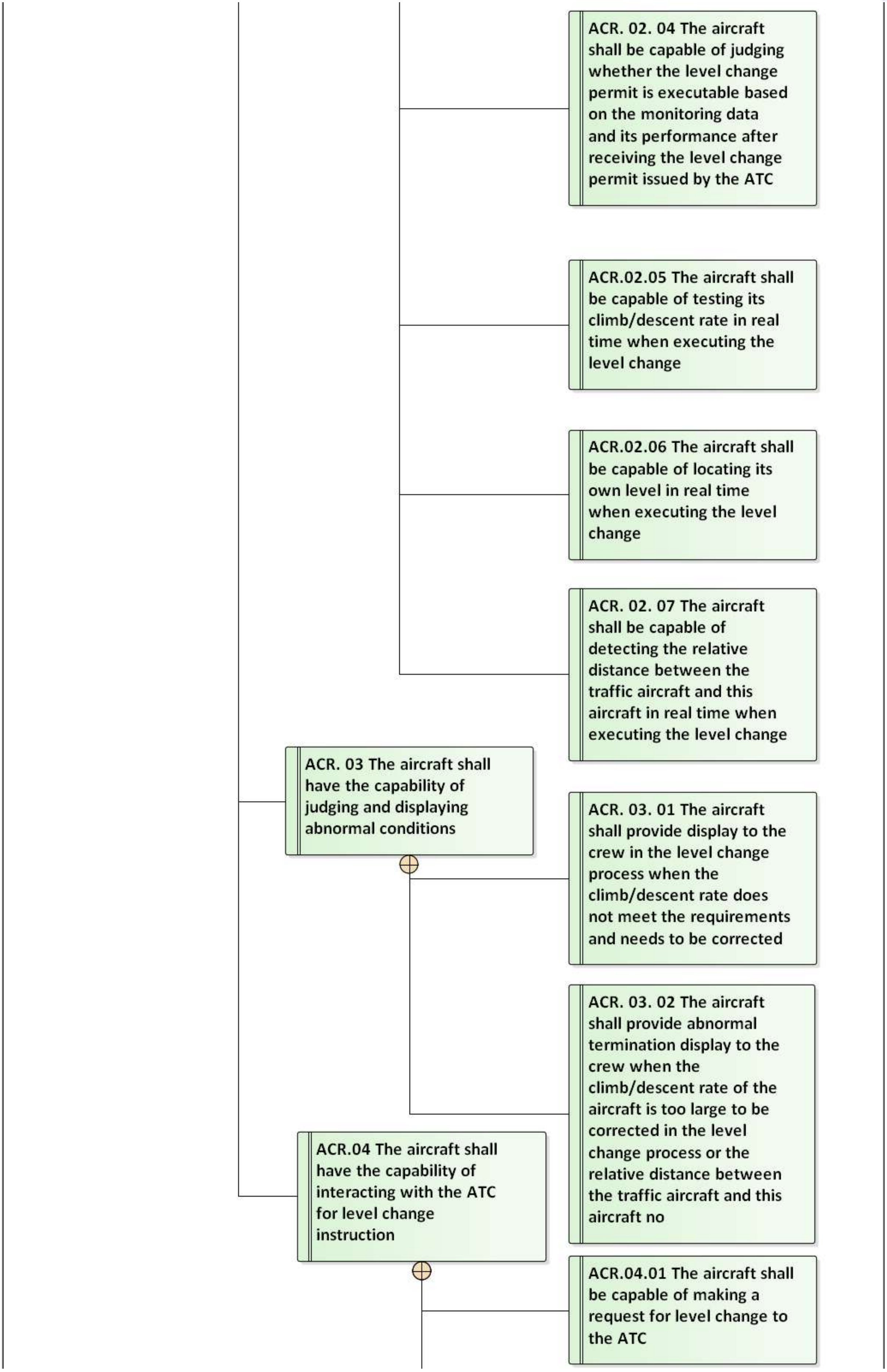
4.1. EXTRACTION OF FUNCTIONAL REQUIREMENTS

4.1.1. EXTRACTION OF FUNCTIONAL REQUIREMENT FOR LEVEL CHANGE

4.1.1.1 EXTRACTION OF AIRCRAFT LEVEL FUNCTIONAL REQUIREMENTS

The aircraft level functional requirements are extracted as follows based on the operation scenario analysis in the cruise stage combined with the sub-activities of upper wind detection and level change.


req [package] Aircraft level functional requirements [AC requirement]
ACR.0 The aircraft shall have the capability of supporting the level change
ACR.01 The aircraft shall have the capability of selecting the target level
ACR. 01.01 The aircraft shall have the capability of upper wind detection
ACR.01.02 The aircraft shall have the capability of identifying the fuel-efficient level based on upper wind data
ACR. 01. 03 The aircraft shall have the capability of selecting the target level
ACR. 02 The aircraft shall have the capability of judging whether the level change is safe based on the monitoring data of surrounding aircraft and performance data of this aircraft
ACR.02.01 The aircraft shall have the capability of monitoring the surrounding traffic aircraft between the current level and the target level when requesting and executing the level change
ACR.02.02 The aircraft shall be capable of verifying whether its performance can meet the requirement for level change when requesting and executing the level change
ACR.02.03 The aircraft shall be capable of screening blocking aircraft and reference aircraft based on monitoring data when making a request for level change



ACR. 02. 04 The aircraft shall be capable of judging whether the level change permit is executable based on the monitoring data and its performance after receiving the level change permit issued by the ATC

ACR.02.05 The aircraft shall be capable of testing its climb/descent rate in real time when executing the level change

ACR.02.06 The aircraft shall be capable of locating its own level in real time when executing the level change

ACR. 02. 07 The aircraft shall be capable of detecting the relative distance between the traffic aircraft and this aircraft in real time when executing the level change

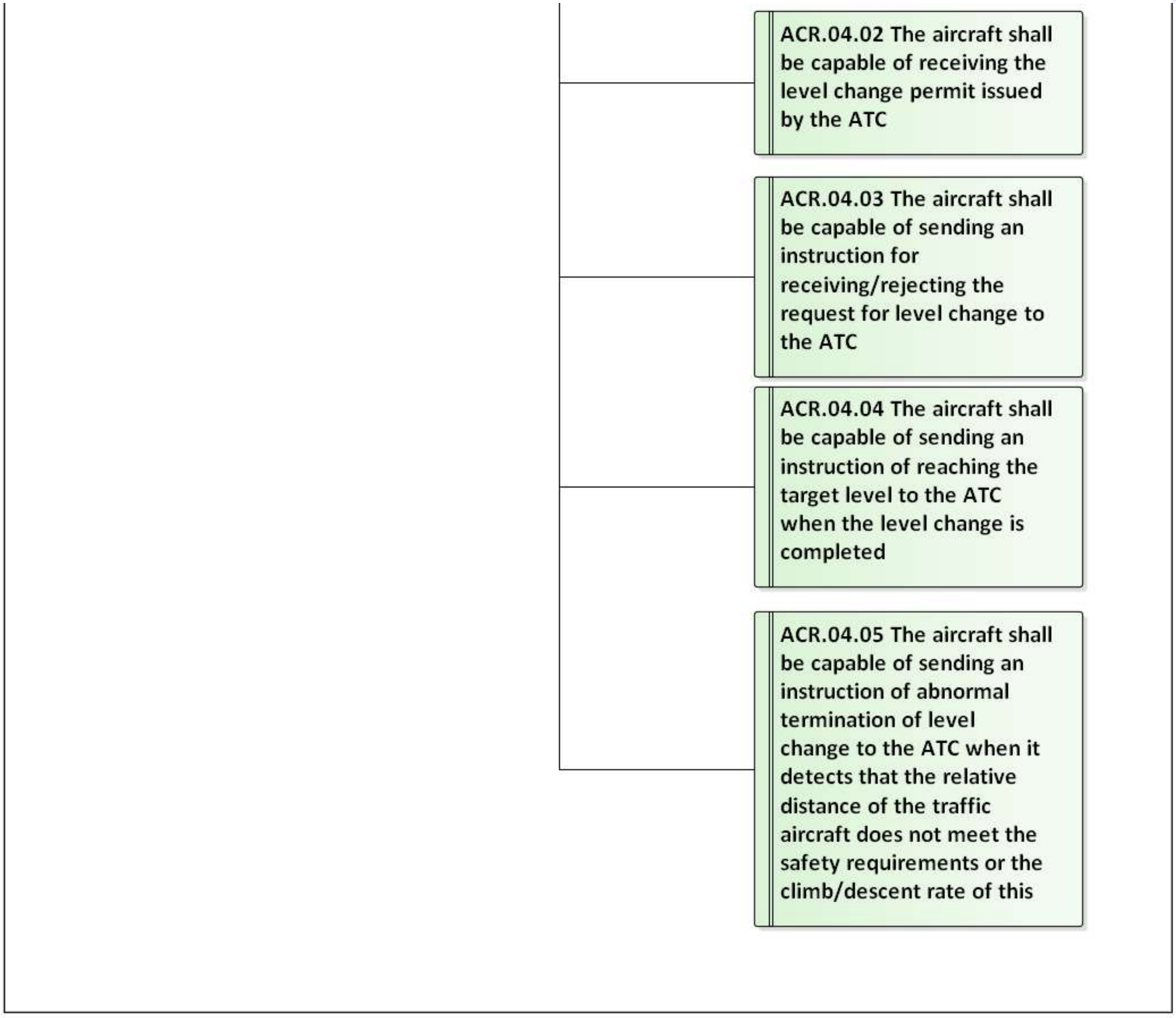
ACR. 03 The aircraft shall have the capability of judging and displaying abnormal conditions

ACR. 03. 01 The aircraft shall provide display to the crew in the level change process when the climb/descent rate does not meet the requirements and needs to be corrected

ACR. 03. 02 The aircraft shall provide abnormal termination display to the crew when the climb/descent rate of the aircraft is too large to be corrected in the level change process or the relative distance between the traffic aircraft and this aircraft no

ACR.04 The aircraft shall have the capability of interacting with the ATC for level change instruction

ACR.04.01 The aircraft shall be capable of making a request for level change to the ATC



ACR.04.02 The aircraft shall be capable of receiving the level change permit issued by the ATC

ACR.04.03 The aircraft shall be capable of sending an instruction for receiving/rejecting the request for level change to the ATC

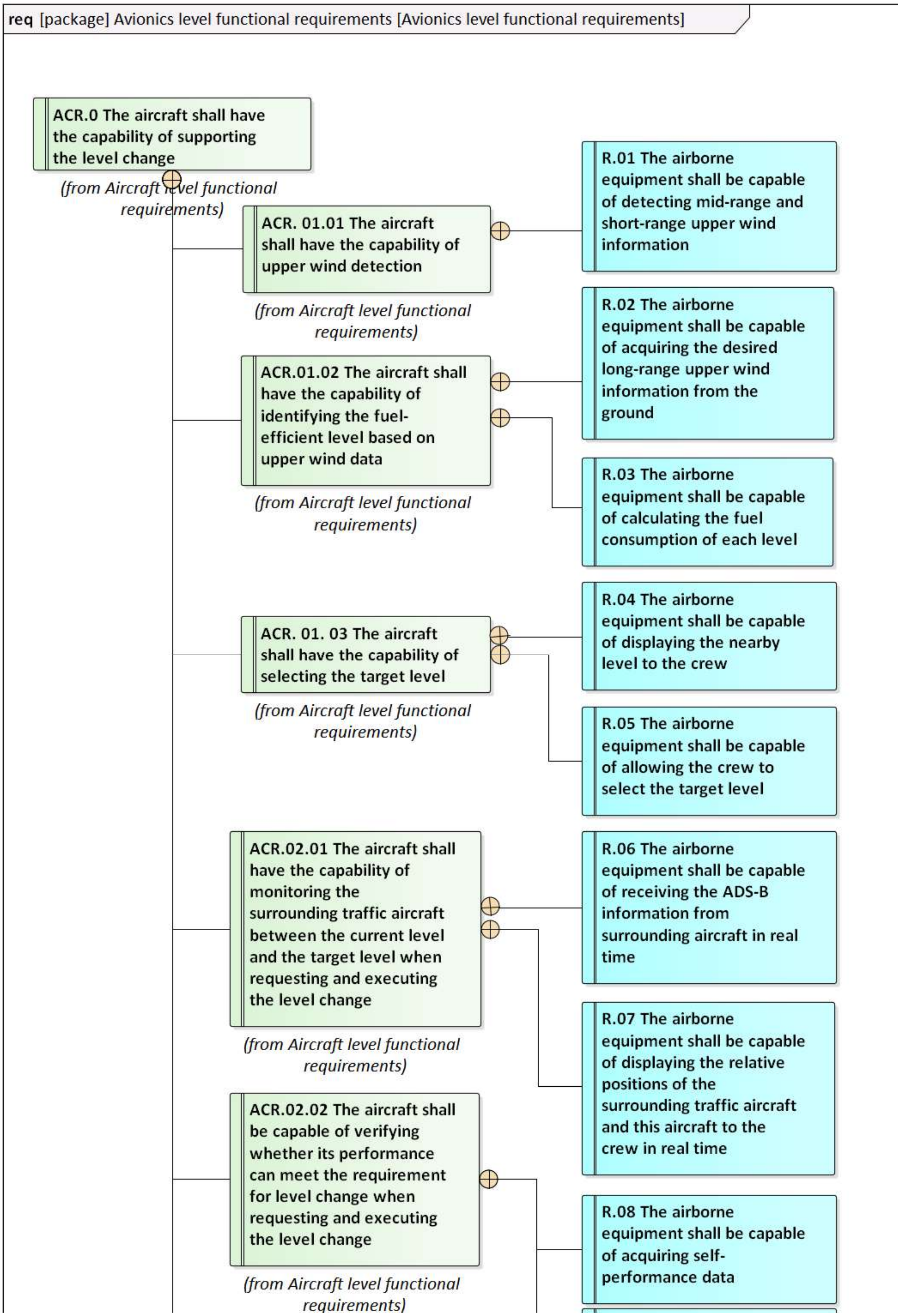
ACR.04.04 The aircraft shall be capable of sending an instruction of reaching the target level to the ATC when the level change is completed

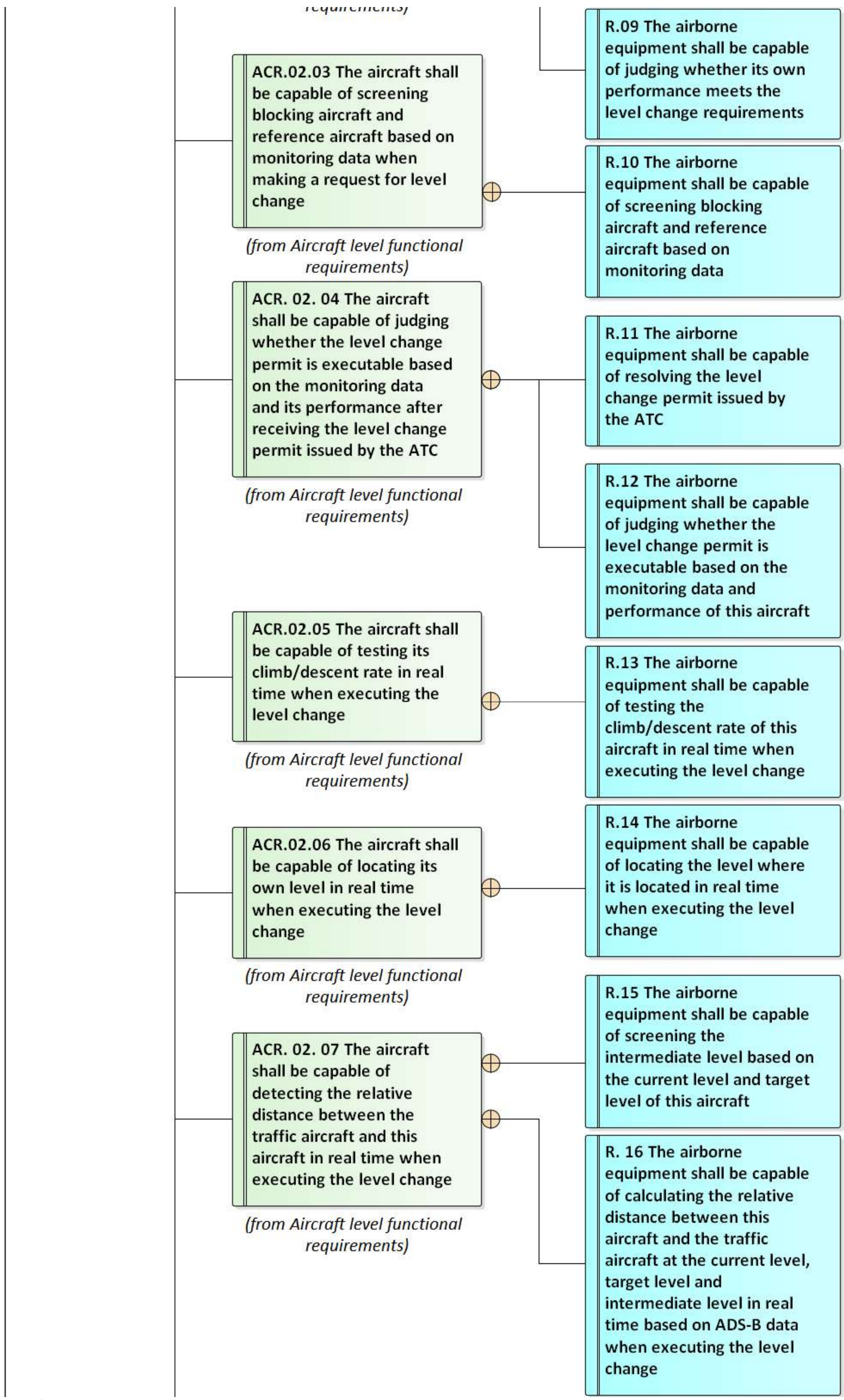
ACR.04.05 The aircraft shall be capable of sending an instruction of abnormal termination of level change to the ATC when it detects that the relative distance of the traffic aircraft does not meet the safety requirements or the climb/descent rate of this

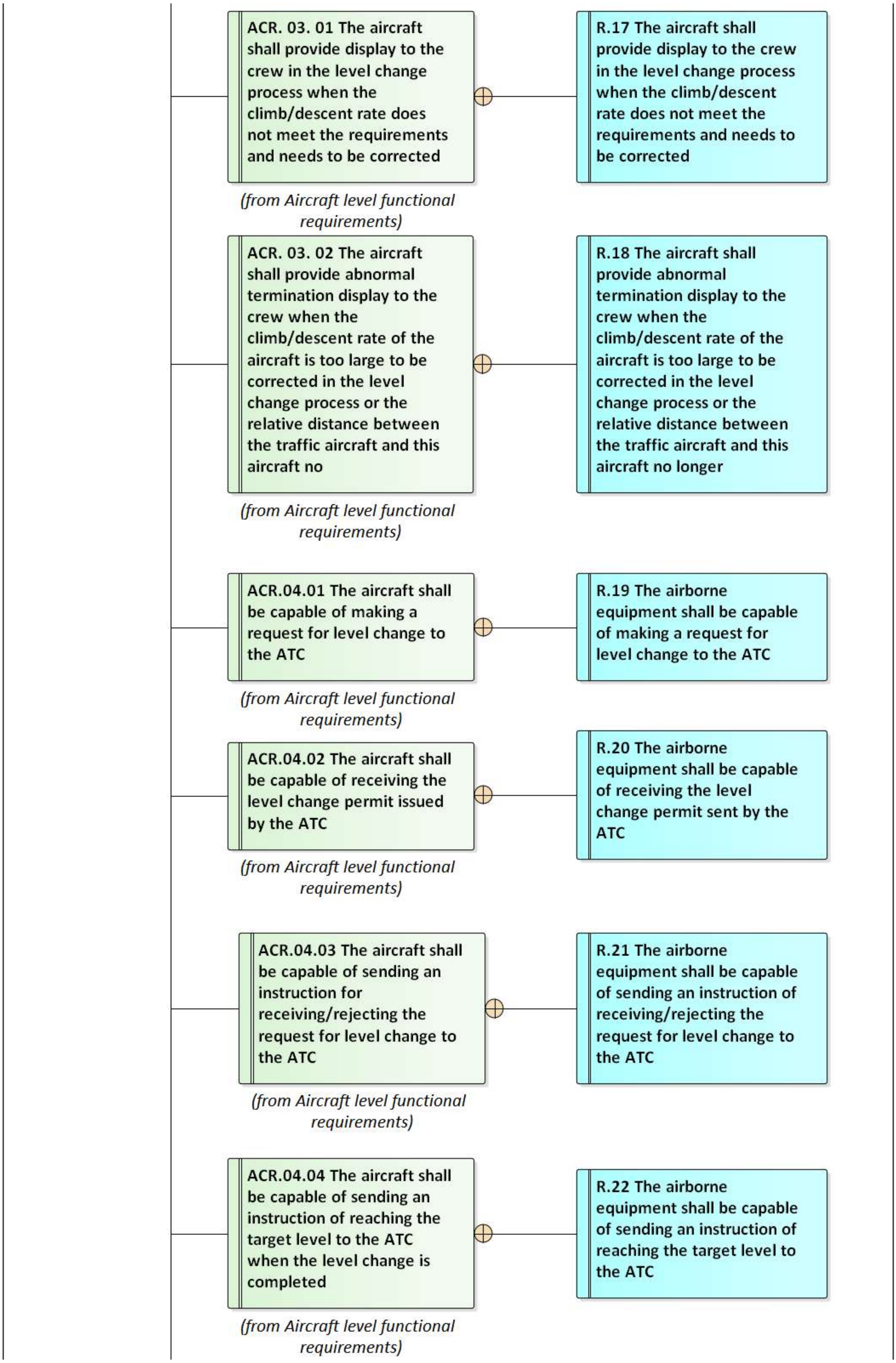
Figure 8: Aircraft Level Functional Requirements of Level Change

4.1.1.2 EXTRACTION OF AVIONICS LEVEL FUNCTIONAL REQUIREMENTS

Based on the aircraft level functional requirements in the avionics level functions are extracted as follows.


req [package] Avionics level functional requirements [Avionics level functional requirements]
ACR.0 The aircraft shall have the capability of supporting the level change
(from Aircraft level functional requirements)
ACR. 01.01 The aircraft shall have the capability of upper wind detection
(from Aircraft level functional requirements)
ACR.01.02 The aircraft shall have the capability of identifying the fuel-efficient level based on upper wind data
(from Aircraft level functional requirements)
ACR. 01. 03 The aircraft shall have the capability of selecting the target level
(from Aircraft level functional requirements)
ACR.02.01 The aircraft shall have the capability of monitoring the surrounding traffic aircraft between the current level and the target level when requesting and executing the level change
(from Aircraft level functional requirements)
ACR.02.02 The aircraft shall be capable of verifying whether its performance can meet the requirement for level change when requesting and executing the level change
(from Aircraft level functional requirements)
R.01 The airborne equipment shall be capable of detecting mid-range and short-range upper wind information
R.02 The airborne equipment shall be capable of acquiring the desired long-range upper wind information from the ground
R.03 The airborne equipment shall be capable of calculating the fuel consumption of each level
R.04 The airborne equipment shall be capable of displaying the nearby level to the crew
R.05 The airborne equipment shall be capable of allowing the crew to select the target level
R.06 The airborne equipment shall be capable of receiving the ADS-B information from surrounding aircraft in real time
R.07 The airborne equipment shall be capable of displaying the relative positions of the surrounding traffic aircraft and this aircraft to the crew in real time
R.08 The airborne equipment shall be capable of acquiring self-performance data


requirements)
R.09 The airborne equipment shall be capable of judging whether its own performance meets the level change requirements
ACR.02.03 The aircraft shall be capable of screening blocking aircraft and reference aircraft based on monitoring data when making a request for level change
(from Aircraft level functional requirements)
R.10 The airborne equipment shall be capable of screening blocking aircraft and reference aircraft based on monitoring data
ACR. 02. 04 The aircraft shall be capable of judging whether the level change permit is executable based on the monitoring data and its performance after receiving the level change permit issued by the ATC
(from Aircraft level functional requirements)
R.11 The airborne equipment shall be capable of resolving the level change permit issued by the ATC
R.12 The airborne equipment shall be capable of judging whether the level change permit is executable based on the monitoring data and performance of this aircraft
ACR.02.05 The aircraft shall be capable of testing its climb/descent rate in real time when executing the level change
(from Aircraft level functional requirements)
R.13 The airborne equipment shall be capable of testing the climb/descent rate of this aircraft in real time when executing the level change
ACR.02.06 The aircraft shall be capable of locating its own level in real time when executing the level change
(from Aircraft level functional requirements)
R.14 The airborne equipment shall be capable of locating the level where it is located in real time when executing the level change
R.15 The airborne equipment shall be capable of screening the intermediate level based on the current level and target level of this aircraft
ACR. 02. 07 The aircraft shall be capable of detecting the relative distance between the traffic aircraft and this aircraft in real time when executing the level change
(from Aircraft level functional requirements)
R. 16 The airborne equipment shall be capable of calculating the relative distance between this aircraft and the traffic aircraft at the current level, target level and intermediate level in real time based on ADS-B data when executing the level change



ACR. 03. 01 The aircraft shall provide display to the crew in the level change process when the climb/descent rate does not meet the requirements and needs to be corrected

(from Aircraft level functional requirements)

R.17 The aircraft shall provide display to the crew in the level change process when the climb/descent rate does not meet the requirements and needs to be corrected

ACR. 03. 02 The aircraft shall provide abnormal termination display to the crew when the climb/descent rate of the aircraft is too large to be corrected in the level change process or the relative distance between the traffic aircraft and this aircraft no

(from Aircraft level functional requirements)

R.18 The aircraft shall provide abnormal termination display to the crew when the climb/descent rate of the aircraft is too large to be corrected in the level change process or the relative distance between the traffic aircraft and this aircraft no longer

ACR.04.01 The aircraft shall be capable of making a request for level change to the ATC

(from Aircraft level functional requirements)

R.19 The airborne equipment shall be capable of making a request for level change to the ATC

ACR.04.02 The aircraft shall be capable of receiving the level change permit issued by the ATC

(from Aircraft level functional requirements)

R.20 The airborne equipment shall be capable of receiving the level change permit sent by the ATC

ACR.04.03 The aircraft shall be capable of sending an instruction for receiving/rejecting the request for level change to the ATC

(from Aircraft level functional requirements)

R.21 The airborne equipment shall be capable of sending an instruction of receiving/rejecting the request for level change to the ATC

ACR.04.04 The aircraft shall be capable of sending an instruction of reaching the target level to the ATC when the level change is completed

(from Aircraft level functional requirements)

R.22 The airborne equipment shall be capable of sending an instruction of reaching the target level to the ATC

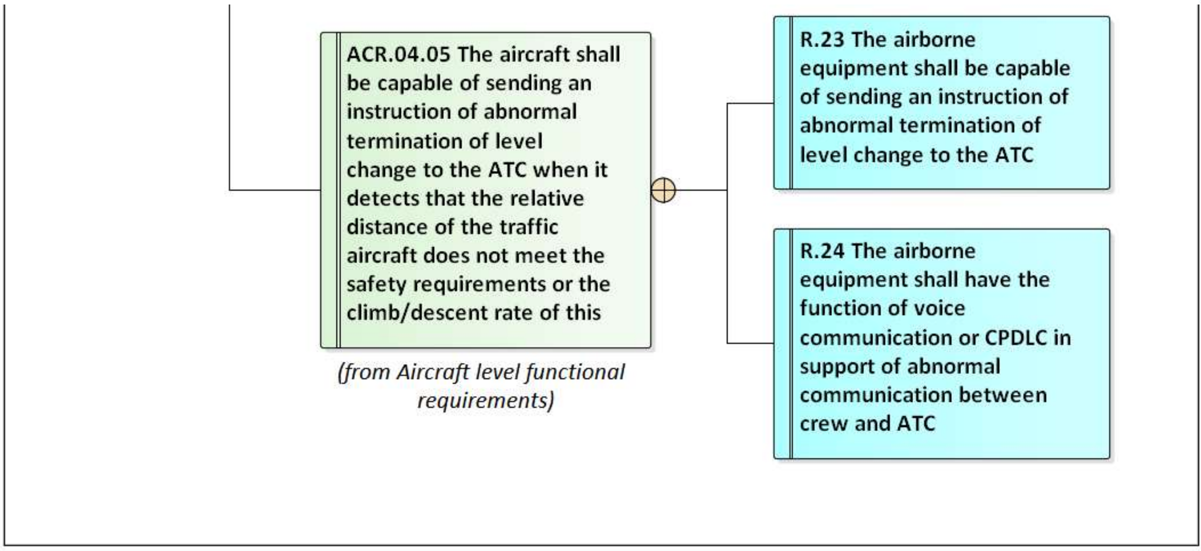
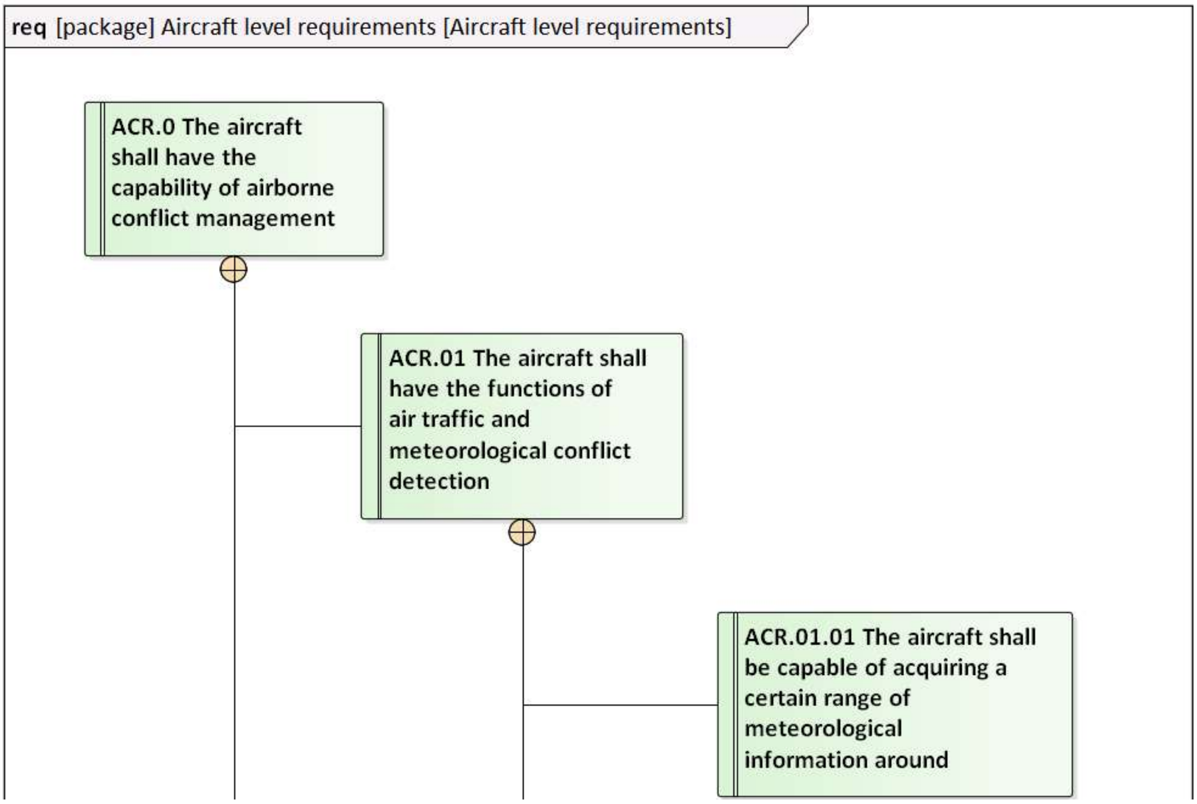


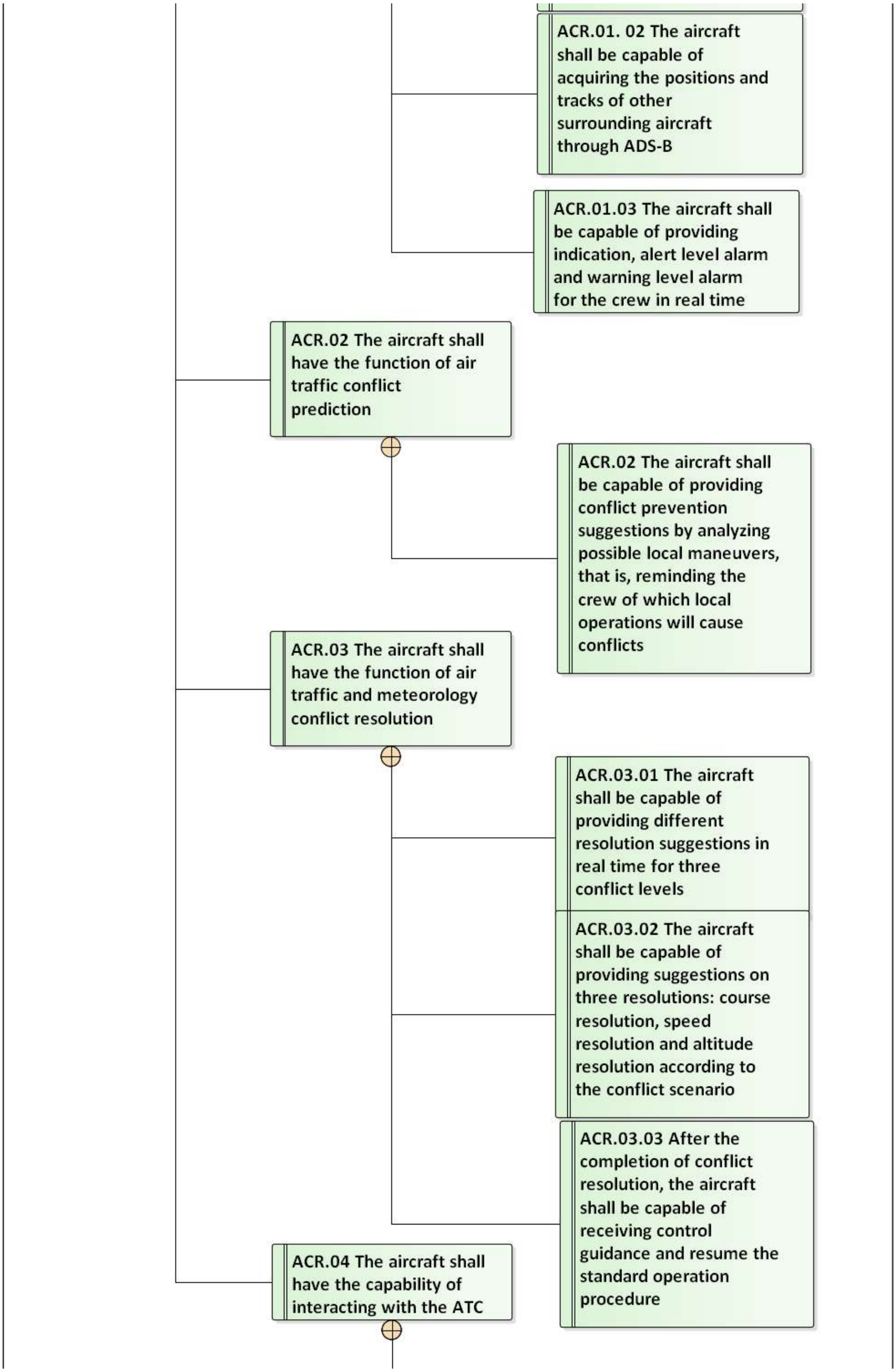
Figure 9: Avionics Level Functional Requirements of Level Change

4.1.2. EXTRACTION OF FUNCTIONAL REQUIREMENTS FOR CONFLICT DETECTION AND ALARM

4.1.2.1 EXTRACTION OF AIRCRAFT LEVEL FUNCTIONAL REQUIREMENTS

The aircraft level functional requirements are extracted as follows based on the operation scenario analysis in the cruise stage in combination with the diversion sub-activities.





ACR.01. 02 The aircraft shall be capable of acquiring the positions and tracks of other surrounding aircraft through ADS-B

ACR.01.03 The aircraft shall be capable of providing indication, alert level alarm and warning level alarm for the crew in real time

ACR.02 The aircraft shall have the function of air traffic conflict prediction

ACR.02 The aircraft shall be capable of providing conflict prevention suggestions by analyzing possible local maneuvers, that is, reminding the crew of which local operations will cause conflicts

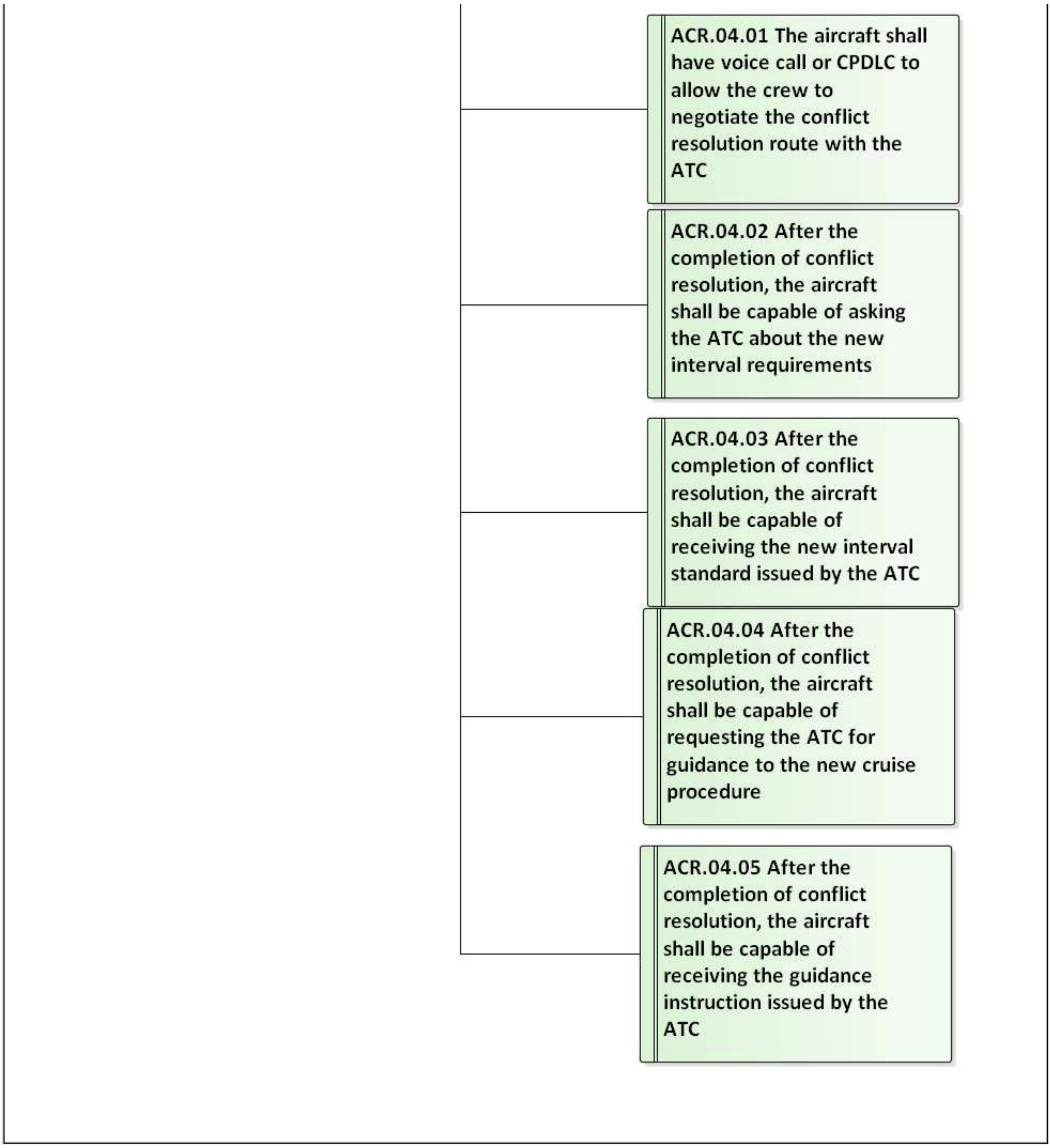
ACR.03 The aircraft shall have the function of air traffic and meteorology conflict resolution

ACR.03.01 The aircraft shall be capable of providing different resolution suggestions in real time for three conflict levels

ACR.03.02 The aircraft shall be capable of providing suggestions on three resolutions: course resolution, speed resolution and altitude resolution according to the conflict scenario

ACR.03.03 After the completion of conflict resolution, the aircraft shall be capable of receiving control guidance and resume the standard operation procedure

ACR.04 The aircraft shall have the capability of interacting with the ATC



ACR.04.01 The aircraft shall have voice call or CPDLC to allow the crew to negotiate the conflict resolution route with the ATC

ACR.04.02 After the completion of conflict resolution, the aircraft shall be capable of asking the ATC about the new interval requirements

ACR.04.03 After the completion of conflict resolution, the aircraft shall be capable of receiving the new interval standard issued by the ATC

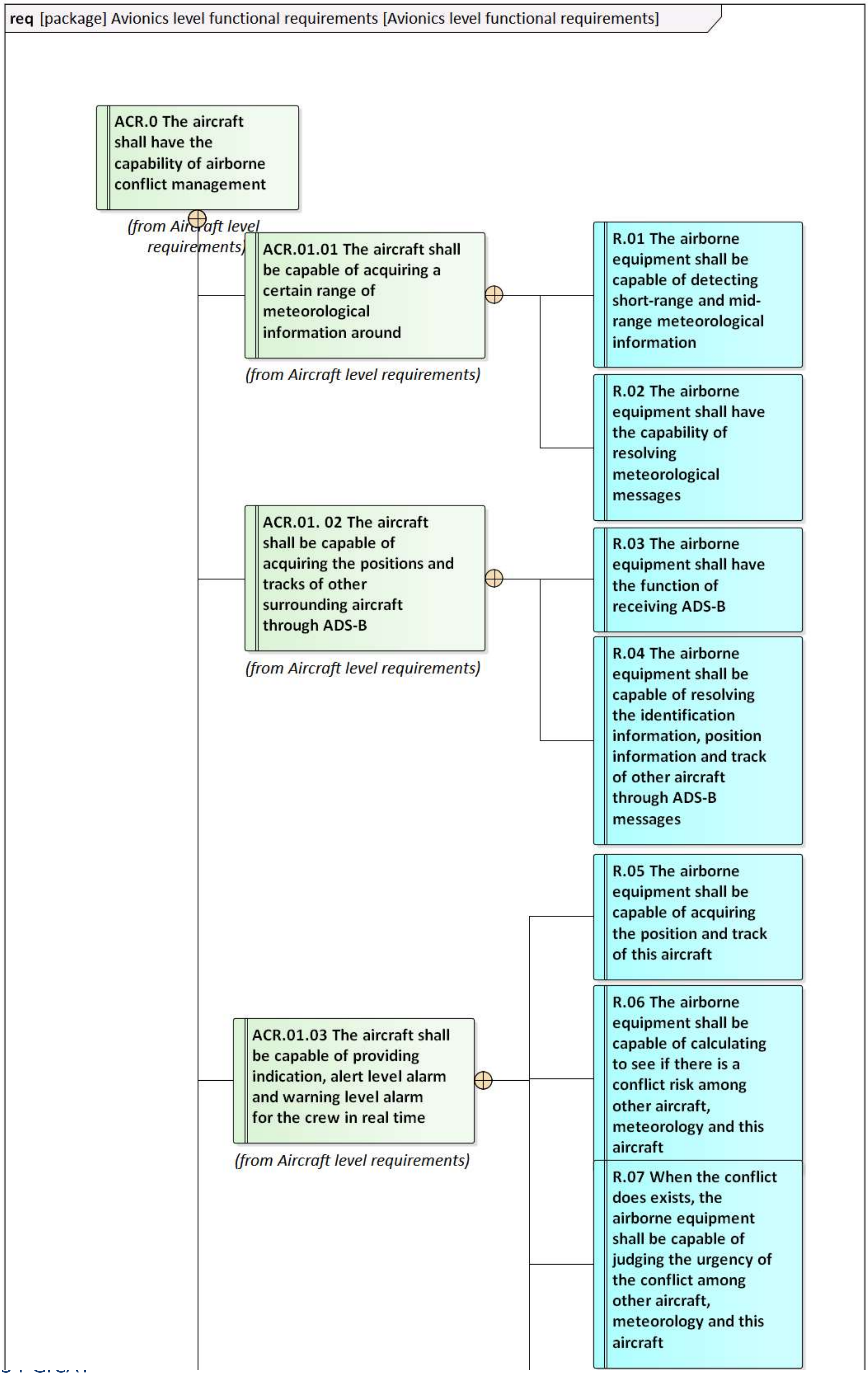
ACR.04.04 After the completion of conflict resolution, the aircraft shall be capable of requesting the ATC for guidance to the new cruise procedure

ACR.04.05 After the completion of conflict resolution, the aircraft shall be capable of receiving the guidance instruction issued by the ATC

Figure 10: Aircraft Level Functional Requirements of Conflict Detection and Alarm

4.1.2.2 EXTRACTION OF AVIONICS LEVEL FUNCTIONAL REQUIREMENTS

The avionics level functional requirements are extracted as follows based on the aircraft level functional requirements in Section4.1.1.



req [package] Avionics level functional requirements [Avionics level functional requirements]

ACR.0 The aircraft shall have the capability of airborne conflict management

(from Aircraft level requirements)

ACR.01.01 The aircraft shall be capable of acquiring a certain range of meteorological information around

(from Aircraft level requirements)

R.01 The airborne equipment shall be capable of detecting short-range and mid-range meteorological information

R.02 The airborne equipment shall have the capability of resolving meteorological messages

ACR.01. 02 The aircraft shall be capable of acquiring the positions and tracks of other surrounding aircraft through ADS-B

(from Aircraft level requirements)

R.03 The airborne equipment shall have the function of receiving ADS-B

R.04 The airborne equipment shall be capable of resolving the identification information, position information and track of other aircraft through ADS-B messages

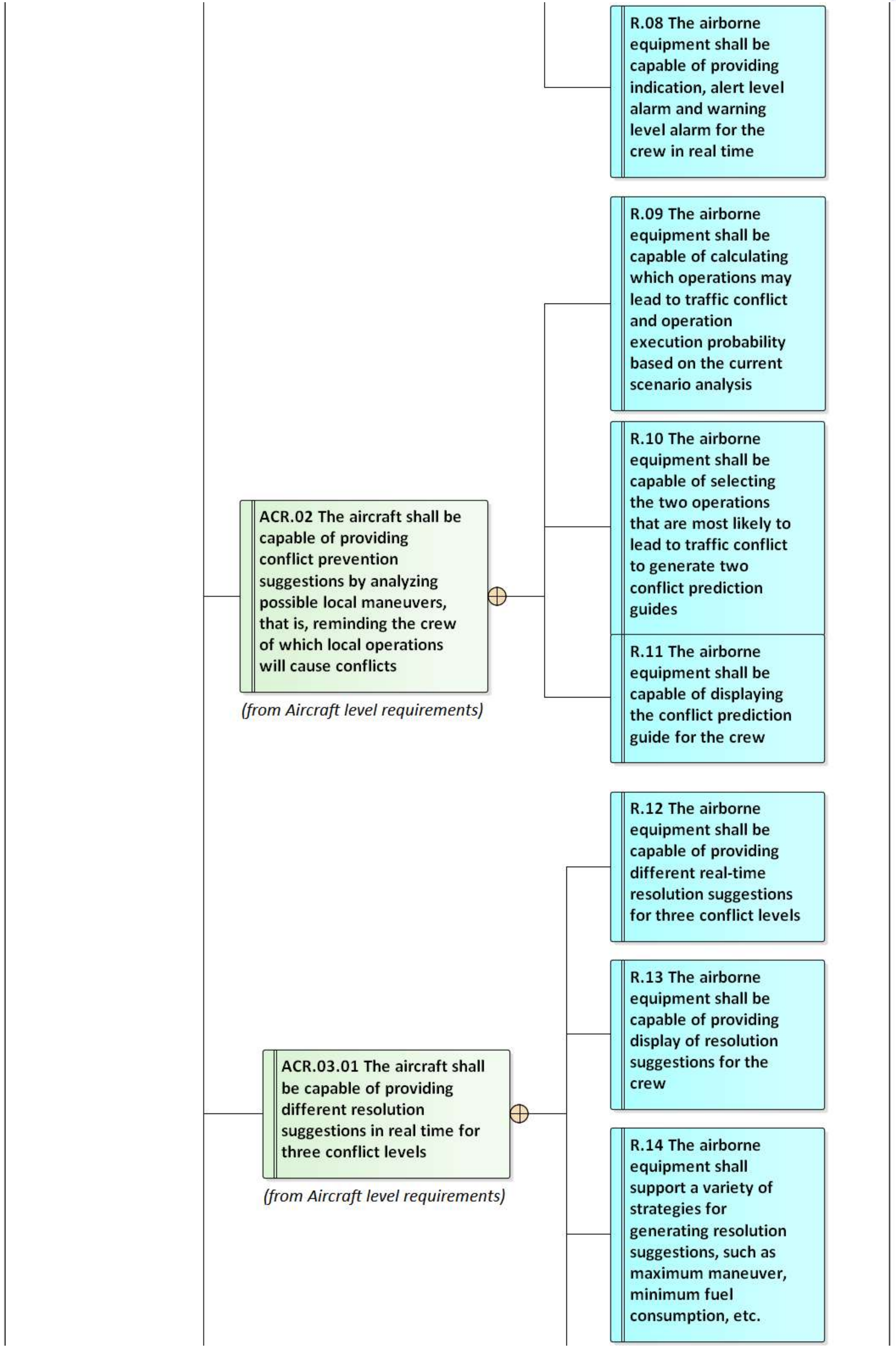
ACR.01.03 The aircraft shall be capable of providing indication, alert level alarm and warning level alarm for the crew in real time

(from Aircraft level requirements)

R.05 The airborne equipment shall be capable of acquiring the position and track of this aircraft

R.06 The airborne equipment shall be capable of calculating to see if there is a conflict risk among other aircraft, meteorology and this aircraft

R.07 When the conflict does exists, the airborne equipment shall be capable of judging the urgency of the conflict among other aircraft, meteorology and this aircraft



R.08 The airborne equipment shall be capable of providing indication, alert level alarm and warning level alarm for the crew in real time

R.09 The airborne equipment shall be capable of calculating which operations may lead to traffic conflict and operation execution probability based on the current scenario analysis

R.10 The airborne equipment shall be capable of selecting the two operations that are most likely to lead to traffic conflict to generate two conflict prediction guides

R.11 The airborne equipment shall be capable of displaying the conflict prediction guide for the crew

ACR.02 The aircraft shall be capable of providing conflict prevention suggestions by analyzing possible local maneuvers, that is, reminding the crew of which local operations will cause conflicts

(from Aircraft level requirements)

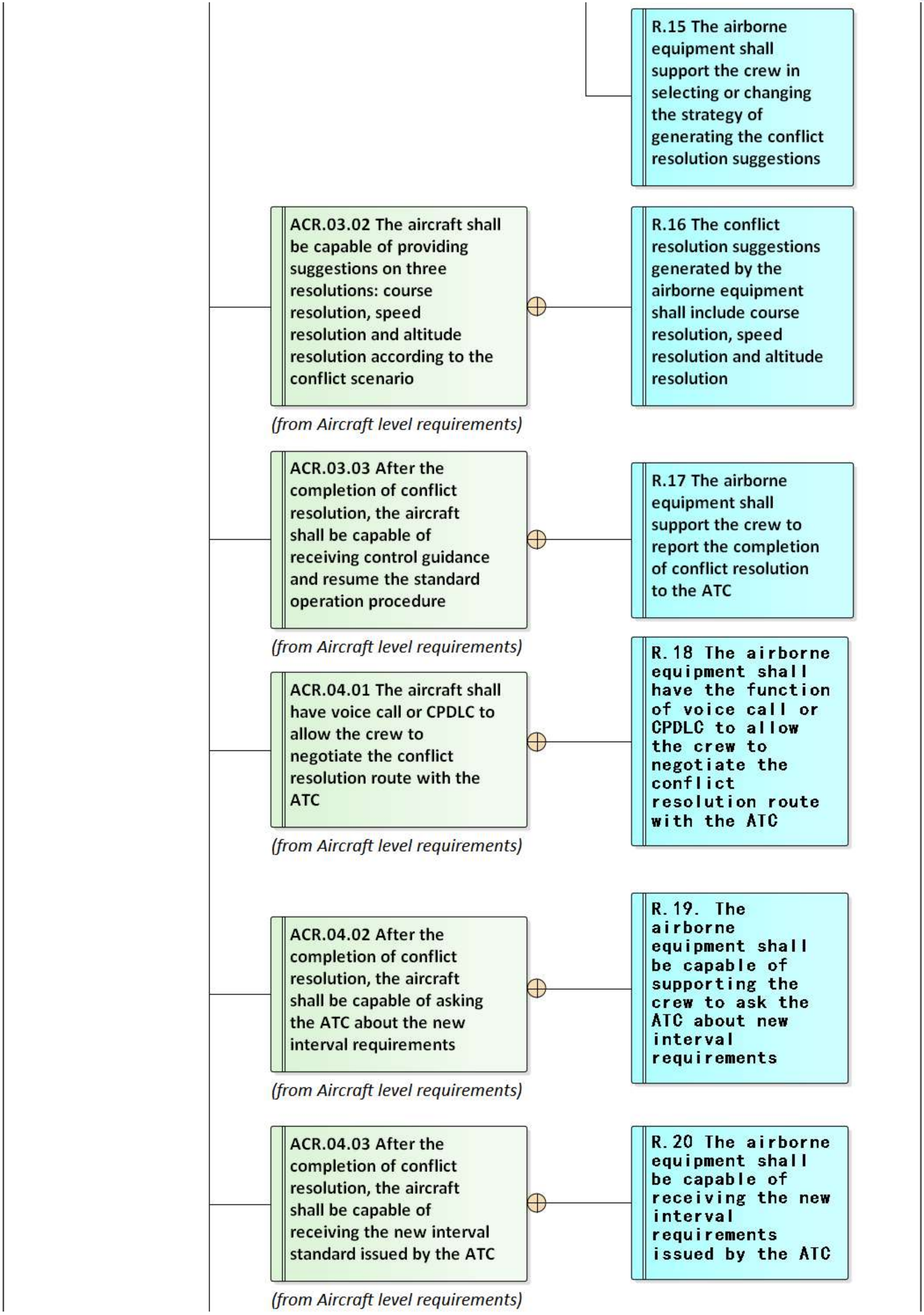
R.12 The airborne equipment shall be capable of providing different real-time resolution suggestions for three conflict levels

R.13 The airborne equipment shall be capable of providing display of resolution suggestions for the crew

R.14 The airborne equipment shall support a variety of strategies for generating resolution suggestions, such as maximum maneuver, minimum fuel consumption, etc.

ACR.03.01 The aircraft shall be capable of providing different resolution suggestions in real time for three conflict levels

(from Aircraft level requirements)



R.15 The airborne equipment shall support the crew in selecting or changing the strategy of generating the conflict resolution suggestions

ACR.03.02 The aircraft shall be capable of providing suggestions on three resolutions: course resolution, speed resolution and altitude resolution according to the conflict scenario

(from Aircraft level requirements)

R.16 The conflict resolution suggestions generated by the airborne equipment shall include course resolution, speed resolution and altitude resolution

ACR.03.03 After the completion of conflict resolution, the aircraft shall be capable of receiving control guidance and resume the standard operation procedure

(from Aircraft level requirements)

R.17 The airborne equipment shall support the crew to report the completion of conflict resolution to the ATC

ACR.04.01 The aircraft shall have voice call or CPDLC to allow the crew to negotiate the conflict resolution route with the ATC

(from Aircraft level requirements)

R.18 The airborne equipment shall have the function of voice call or CPDLC to allow the crew to negotiate the conflict resolution route with the ATC

ACR.04.02 After the completion of conflict resolution, the aircraft shall be capable of asking the ATC about the new interval requirements

(from Aircraft level requirements)

R.19. The airborne equipment shall be capable of supporting the crew to ask the ATC about new interval requirements

ACR.04.03 After the completion of conflict resolution, the aircraft shall be capable of receiving the new interval standard issued by the ATC

(from Aircraft level requirements)

R.20 The airborne equipment shall be capable of receiving the new interval requirements issued by the ATC

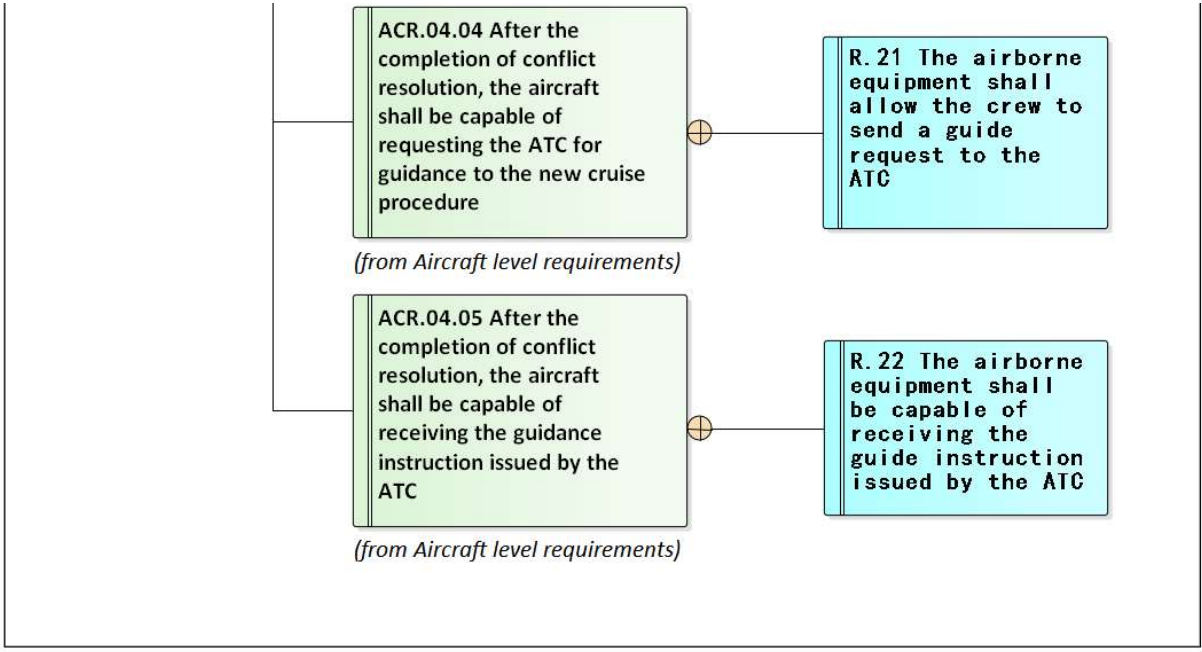


Figure 11: Avionics Level Functional Requirements of Conflict Detection and Alarm

4.2. ALLOCATION OF FUNCTIONAL REQUIREMENTS

This section completes the allocation of functional requirements based on the results of functional requirements extraction in Section4.1 in combination with the functional composition of the avionics system to lay the foundation for generating the functional architecture of the avionics system.

4.2.1. FUNCTION COMPOSITION OF THE AVIONICS SYSTEM

The avionics system functions are separated as follows based on the extraction results of avionics level functional requirements combined with relevant standards and specifications.

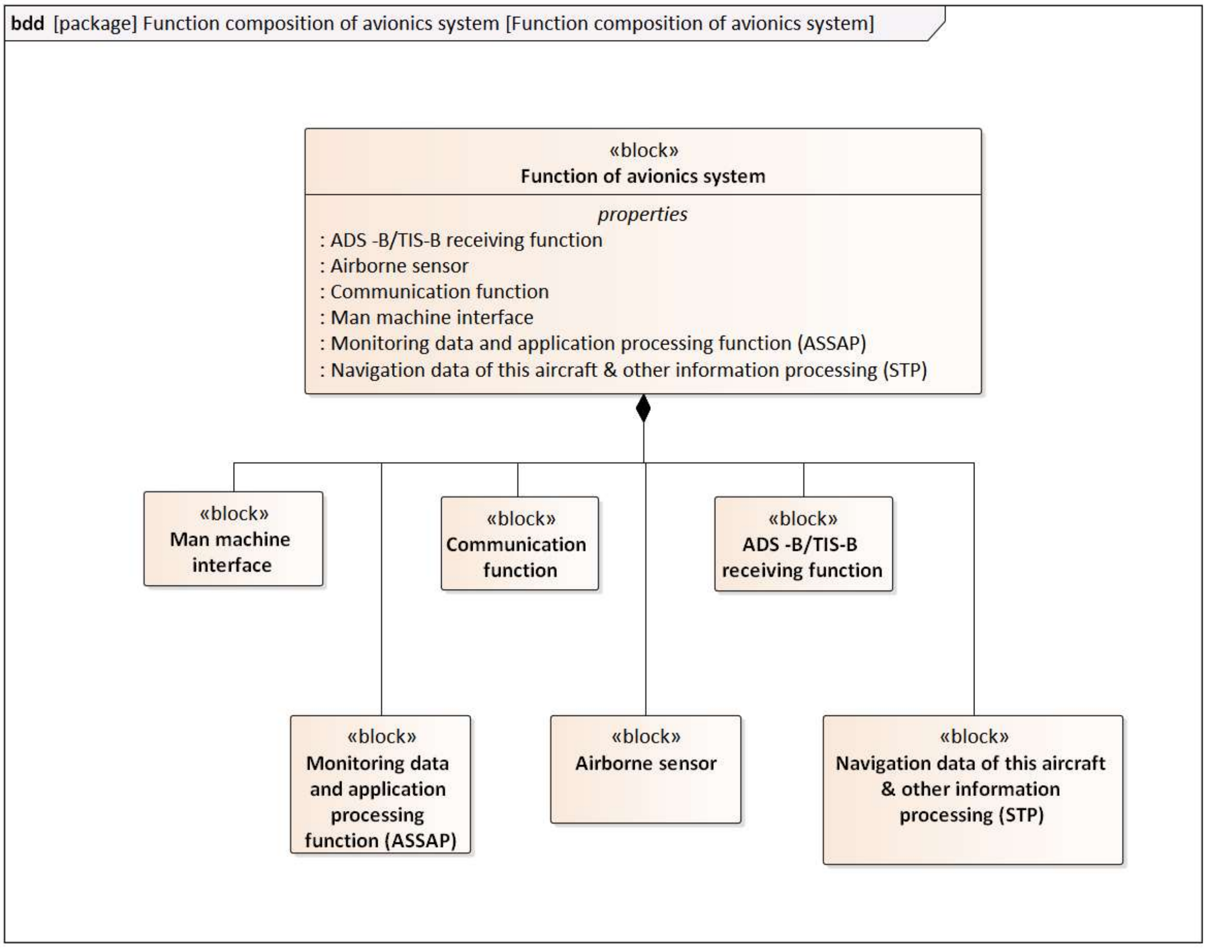


Figure 12: Function Composition of Avionics System

4.2.2. FUNCTION ALLOCATION OF AVIONICS SYSTEM FOR LEVEL CHANGE

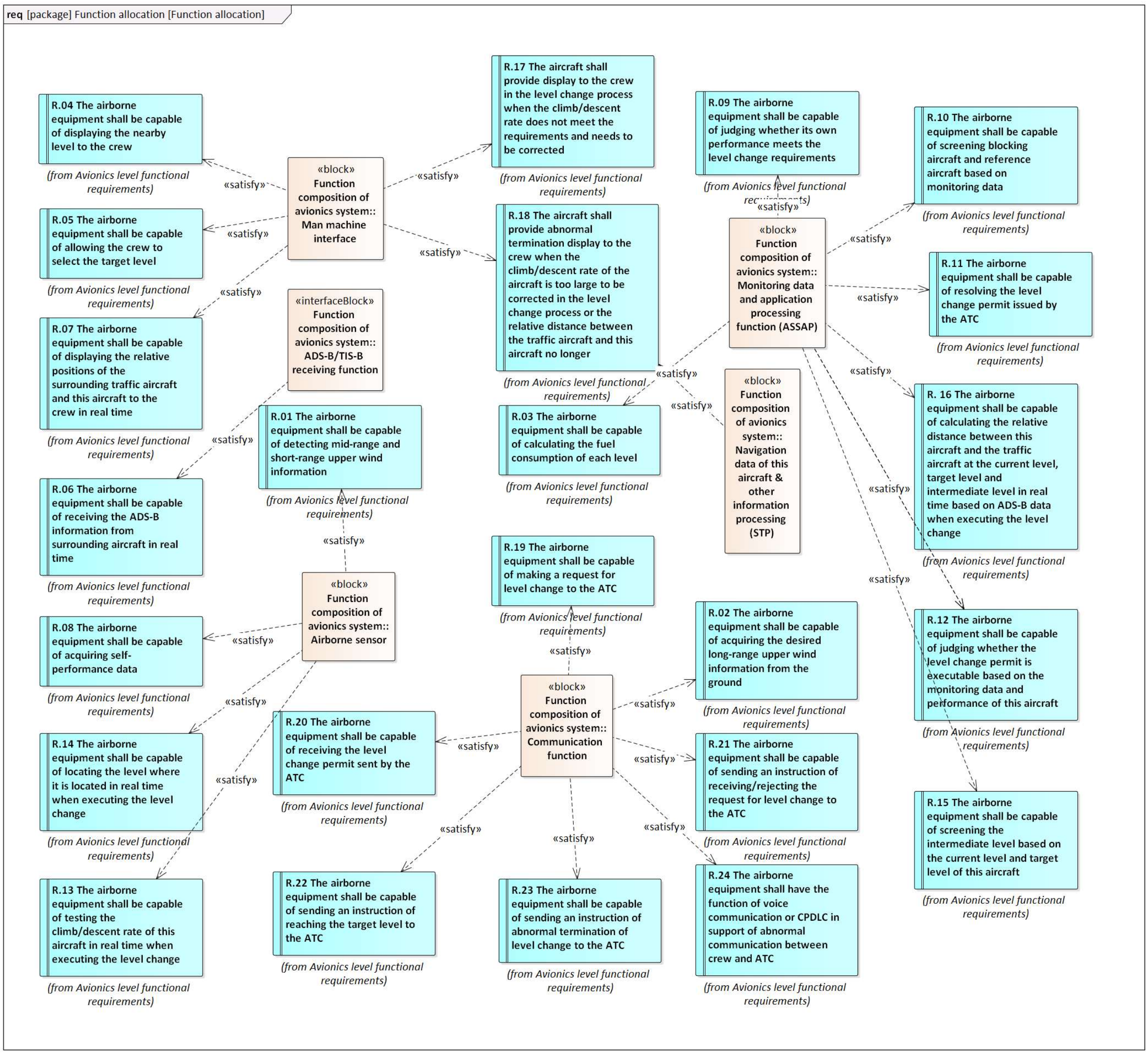


Figure 13: Results of Function Allocation for Level Change

The above models can be summarized as follows:

Table 7.Results of Function Allocation for Level Change

Functional Module	Function Allocation
Function composition of avionics system:: ADS-B/TIS-B receiving function	R.06 The airborne equipment shall be capable of receiving the ADS-B information from surrounding aircraft in real time
Function composition of avionics system:: Airborne sensor	R.08 The airborne equipment shall be capable of acquiring self-performance data
	R.01 Airborne equipment shall be capable of detecting mid-range and short-range upper wind information
	R.13. The airborne equipment shall be capable of testing the climb/descent rate of this aircraft in real time when

	executing the level change
	R.14 The airborne equipment shall be capable of locating the level where it is located in real time when executing the level change
Function composition of avionics system:: Navigation data of this aircraft & other information processing (STP)	R.18-1 The airborne equipment shall be capable of processing the position and trajectory of this aircraft
Function composition of avionics system:: Man machine interface	R.04 The airborne equipment shall be capable of displaying the nearby level to the crew
	R.05 The airborne equipment shall be capable of allowing the crew to select the target level
	R.07 The airborne equipment shall be capable of displaying the relative positions of the surrounding traffic aircraft and this aircraft to the crew in real time
	R.17. The aircraft shall provide display to the crew in the level change process when the climb/descent rate does not meet the requirements and needs to be corrected
	R.18 The aircraft shall provide abnormal termination display to the crew when the climb/descent rate of the aircraft is too large to be corrected in the level change process or the relative distance between the traffic aircraft and this aircraft no longer meets the requirements
Function composition of avionics system:: Monitoring data and application processing function (ASSAP)	R.03 The airborne equipment shall be capable of calculating the fuel consumption of each level
	R.09 The airborne equipment shall be capable of judging whether its own performance meets the level change requirements
	R.10 The airborne equipment shall be capable of screening blocking aircraft and reference aircraft based on monitoring data
	R.11 The airborne equipment shall be capable of resolving the level change permit issued by the ATC
	R.12 The airborne equipment shall be capable of judging whether the level change permit is executable based on the monitoring data and performance of this aircraft
	R.15 The airborne equipment shall be capable of screening the intermediate level based on the current level and target level of this aircraft
	R.16 The airborne equipment shall be capable of calculating the relative distance between this aircraft and the traffic aircraft at the current level, target level and intermediate level in real time based on ADS-B data when executing the level change
Function composition of avionics system::	R.02 Airborne equipment shall be capable of acquiring the desired long-range upper wind information from the ground

Communication function	R.20 The airborne equipment shall be capable of receiving the level change permit sent by the ATC
	R.22 The airborne equipment shall be capable of sending an instruction of reaching the target level to the ATC
	R.19 The airborne equipment shall be capable of making a request for level change to the ATC
	R.23 The airborne equipment shall be capable of sending an instruction of abnormal termination of level change to the ATC
	R.21 The airborne equipment shall be capable of sending an instruction of receiving/rejecting the request for level change to the ATC
	R.24 The airborne equipment shall have the function of voice communication or CPDLC in support of abnormal communication between crew and ATC

4.2.3. FUNCTION ALLOCATION OF AVIONICS SYSTEM FOR CONFLICT DETECTION AND ALARM

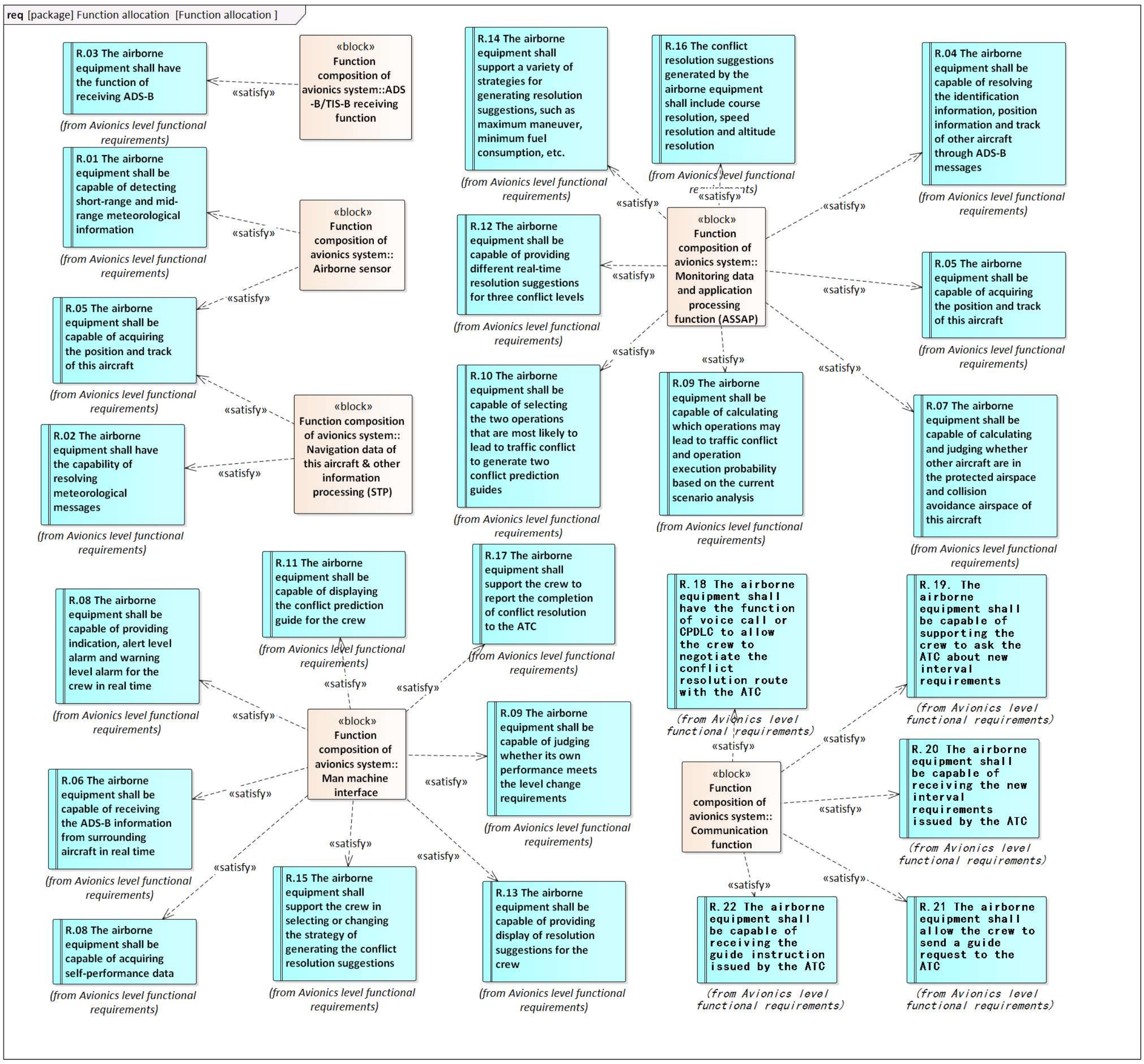


Figure 14: Results of Function Allocation for Conflict Detection and Alarm

The above models can be summarized as follows:

Table 8.Results of Function Allocation for Conflict Detection and Alarm

FunctionalModule	Function Allocation
Function composition of avionics system:: ADS-B/TIS-B receiving function	R.03 The airborne equipment shall have the function of receiving ADS-B
Function composition of avionics system:: Airborne sensor	R.01 The airborne equipment shall be capable of detecting short-range and mid-range meteorological information
	R.05 The airborne equipment shall be capable of acquiring the position and trajectory of this aircraft

Function composition of avionics system:: Navigation data of this aircraft & other information processing (STP)	R.02 The airborne equipment shall have the capability of resolving meteorological messages
	R.05-1 The airborne equipment shall be capable of processing the position and trajectory of this aircraft
Function composition of avionics system:: Man machine interface	R.08-1 The airborne equipment shall be capable of providing indication, alert level alarm and warning level alarm for the crew in real time
	R.08-2The airborne equipment shall be capable of providing alert level alarm for the crew before other aircraft intrude into the protected airspace and have not entered the collision avoidance airspace
	R.06 The airborne equipment shall be capable of providing indication level alarm for the crew
	R.11 The airborne equipment shall be capable of displaying conflict prediction guide for the crew
	R.15 The airborne equipment shall support the crew in selecting or changing the strategy of generating the conflict resolution suggestions
	R.17 The airborne equipment shall support the crew to report the completion of conflict resolution to the ATC
	R.09 The airborne equipment shall be capable of providing alert level alarm for the crew before other aircraft intrude into the collision avoidance area
	R.13 The airborne equipment shall be capable of providing display of resolution suggestions for the crew
Function composition of avionics system:: Monitoring data and application processing function (ASSAP)	R.04 The airborne equipment shall be capable of resolving the identification information, position information and trajectory of other aircraft through ADS-B messages
	R.05 The airborne equipment shall be capable of calculating and judging whether other aircraft will invade the protected airspace of this aircraft
	R.07 The airborne equipment shall be capable of calculating and judging whether other aircraft are in the protected airspace and collision avoidance airspace of this aircraft
	R.09 The airborne equipment shall be capable of calculating which operations may lead to traffic conflict and operation execution probability based on the current scenario analysis
	R.10 The airborne equipment shall be capable of selecting the two operations that are most likely to lead to traffic conflict to generate two conflict prediction guides
	R.12 The airborne equipment shall be capable of providing different real-time resolution suggestions for three conflict levels
	R.14 The airborne equipment shall support a variety of strategies for generating resolution suggestions, such as maximum maneuver, minimum fuel consumption, etc.

	R.16 The conflict resolution suggestions generated by the airborne equipment shall include course resolution, speed resolution and altitude resolution
Function composition of avionics system:: Communication function	R.18 The airborne equipment shall have the function of voice call or CPDLC to allow the crew to negotiate the conflict resolution route with the ATC
	R.19 The airborne equipment shall be capable of supporting the crew to ask the ATC about the interval requirements
	R.20 The airborne equipment shall be capable of receiving the new interval requirements issued by the ATC
	R.21 The airborne equipment shall allow the crew to send a guide request to the ATC
	R.18 The airborne equipment shall have the function of voice call or CPDLC to allow the crew to negotiate the conflict resolution route with the ATC

4.3. FUNCTIONAL FRAMEWORK OF AVIONICS SYSTEM

The functional architecture of the airborne avionics system in support of greener aircraft cruising operation is formed as follows by integrating the level change and the results of functional requirements allocation for conflict detection and alarm in Section 4.2.

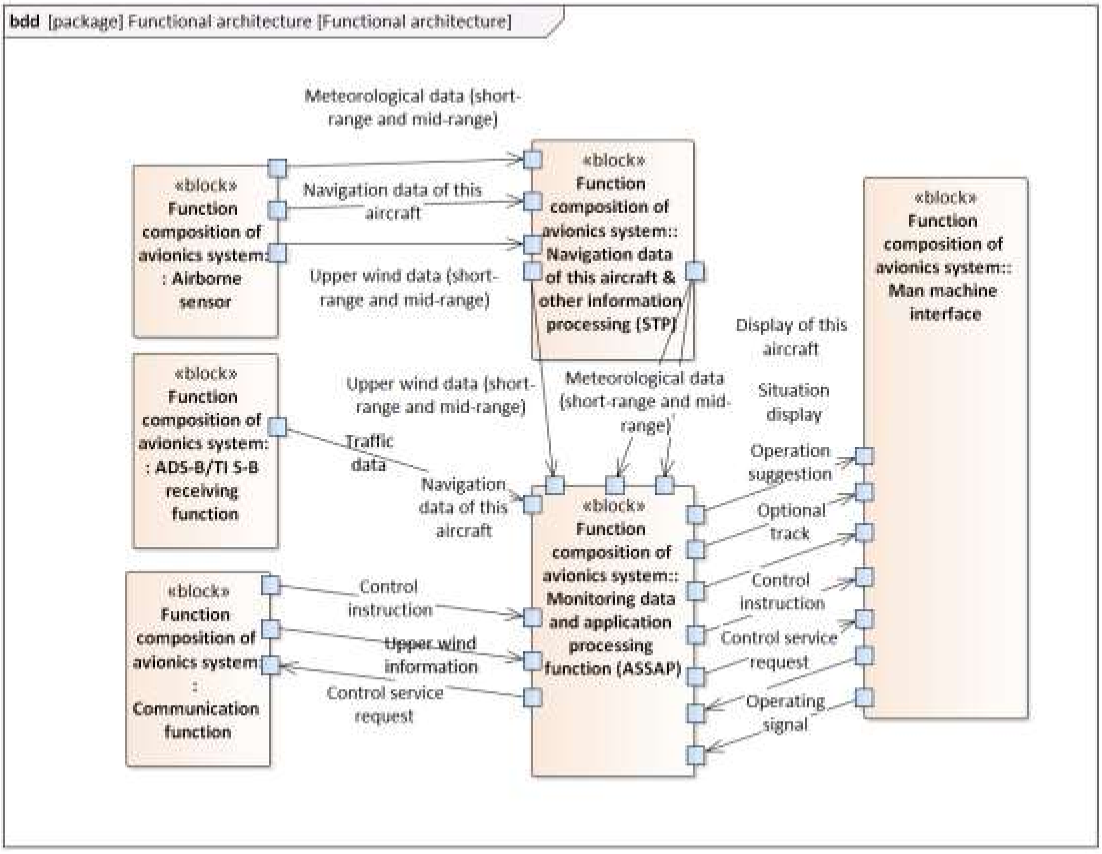


Figure 15: Functional Architecture of the Airborne Avionics System in Support of Greener Aircraft Cruising Operation

5. REFERENCES

[RTCA 2000] Application Of Airborne Conflict Management Detection, Prevention, & Resolution.

[RTCA 2001] Safety, Performance and Interoperability Requirements Document for Enhanced Traffic Situational Awareness During Flight Operations.

[RTCA 2002] Safety, Performance and Interoperability Requirements Document for Enhanced Traffic Situational Awareness During Flight Operations.

[ICAO 1969] ICAO ANNEX 2：Rules of the Air.

[IPCC 2014] IPCC (2014). Fifth Assessment Report, Intergovernmental Panel on Climate Change.

[Jungbluth 2018] Jungbluth, N. and C. Meili (2018). "Recommendations for calculation of the global warming potential of aviation including the radiative forcing index." International Journal of Life Cycle Assessment 2019(24): 404-411.

[Kibl 2020] Air Traffic Management Technology Demonstration Phase 1 Interval Management for Near-Term Operations Validation of Acceptability Experiment.

[Matthews 2017] Matthews, T. K. R., R. L. Wilby and C. Murphy (2017). "Communicating the deadly consequences of global warming for human heat stress." PNAS - Proceedings of the National Academy of Sciences of the United States of America: 114(15): 3861-3866.

[McCollum 2010] McCollum, D., G. Gould and D. Greenere (2010). Greenhouse Gas Emissions from Aviation and Marine Transportation: Mitigation Potential and Policies, Pew Center on Global Climate Change.

[Rahmstorf 2007] Rahmstorf, S., A. Cazenave, J. A. Church, J. E. Hansen, R. F. Keeling, D. E. Parker and R. C. J. Somerville (2007). "Recent Climate Observations Compared to Projections." Science 316(5825): pp. 709.

[RTCA 2015] Safety, Performance and Interoperability Requirements Document for Airborne Spacing Flight Deck Interval Management.

[RTCA 1997] RTCA DO-160D/ED-14 Environmental Conditions and Test Procedures for Airborne Equipment.

[SAE 2010] ARP 4754 Certification Considerations for Highly-integrated or Complex Aircraft Systems.

[RTCA 2008] Safety, Performance and Interoperability Requirements Document for the In-Trail Procedure in Oceanic Airspace Application