ICAS 2021 SHANGHAI
32nd Congress of the International Council of the Aeronautical Sciences
September 6-10, 2021
Pudong Shangri-La, Shanghai, China

Flight management system Requirement Analysis for trajectory based operation

Han C.-L.[1], Chen F.[1], Sun X.-M.[1], Li W.-H.[1]

[1] China National Aeronautical Radio Electronics Research Institute, Shanghai, China

Abstract

Trajectory based operation (TBO) is the foundation of next generation air traffic management system. Currently, the global TBO research is still in the stages of proof-of-concept and preliminary test. The requirements for airborne equipment, such as flight management system, stay in the stage of preliminary decomposition and framework demand of operational concepts. There have been few in-depth requirements for TBO-targeted FMS in various operation scenarios and flight phases. In this paper, flight scenario analysis of TBO is presented based on the 4D trajectory operation concept of SESAR and NextGen. Model-based system engineering is adopted to capture and confirm the TBO operational requirements of the aircraft level and avionics level. Meanwhile, the specific activities of the FMS are analyzed to form in-depth FMS requirements.

Keywords: Trajectory based operation; Model-based system engineering; Flight management system

1. Introduction

In recent years, there has been an increasingly prominent contradiction between the rapid development of the air transport industry and the limited airspace resources due to the remarkable progress of global avionics transportation. Modernization plans for air traffic management (ATM) have been drawn up worldwide to solve this contradiction. Aviation System Block Upgrade (ASBU) plan has been formulated by the International Civil Aviation Organization (ICAO); The Next Generation Air Transportation system (NextGen) upgrade plan has been launched by the United States; The Single European Sky Air Traffic Research (SESAR) has been proposed by Europe. Trajectory Based Operation (TBO) is treated as the foundation for the next ATM, which is an important means to solve the problem with flight delay and improve the flight efficiency.

The research on key technology, standards, verification, and engineering application of TBO is being carried out in the global aviation field. The flight tests of initial four-dimensional (4D) trajectory operation has been completed twice by European Union in 2012 and 2014, which preliminarily verified the technical feasibility. In December 2011, the United States also carried out the TBO terminal flight tests with Boeing B737NG aircraft of Alaska Airlines to evaluate the capabilities of ground control system, data link and airborne equipment. In 2015, China started the project of “air traffic trajectory operation technology and verification”, and conducted the research on key technologies of air traffic track operation, development of core equipment, ground simulation verification and practical flight test of civil aviation aircraft. In March 2019, the first domestic flight test of initial 4D trajectory operation was carried out on the Tianjin-Guangzhou route with Airbus A320 Civil aircraft.

In a TBO operation environment, flight management system (FMS) develops from independent operation to air-ground cooperative operation. It not only needs to focus on the organization and management of flight process, but also cooperates with the Air Traffic Control (ATC) and the Airline Operation Center (AOC), which is essential to realize TBO. In general, FMS is still in the stages of concept verification and preliminary test, so that the requirements for airborne equipment, such as flight management system, stay in the stage of preliminary decomposition and framework demand of operational concepts, without in-depth requirements for TBO-targeted FMS in various operation scenarios and flight phases. Therefore, it is necessary to comprehensively analyze those functional requirements, in order to provide the basis for the development of TBO-targeted FMS.

In this paper, flight scenario analysis of TBO is presented according to SESAR and NextGen based on the 4D trajectory operation concept, adopting model-based system engineering (MBSE)[1][2] to capture and confirm the TBO operational requirements of the aircraft level and avionics level, and the specific activities of the FMS is analyzed to form in-depth FMS requirements.

2. Operation scene analysis of TBO

In a TBO operation environment, during the whole flight process from taxiing to landing, the aircraft receives weather information, coordinates and shares 4D trajectory with ground stakeholders such as Air traffic control, Air traffic flow control, airline and so on, through the Air-space-ground integrated information communication network. Therefore, all the stakeholders can accurately grasp the flight intention of the aircraft at the management level to improve the operation efficiency of all departments and ensure the smooth operation of the air traffic system.

The TBO process consists of the following steps:

1) The airline makes the flight plan of a certain flight before taking off, and shares it with the crew, ATC, and other stakeholders;

2) According to the flight plan and weather information, the aircraft makes a preliminary prediction of the 4D trajectory;

3) The aircraft transmits the preliminarily calculated 4D trajectory to the ground ATC;

4)The ground ATC shares and negotiates the 3D flight path with other air traffic control departments, airports, airlines and other stakeholders, and uploads the confirmed 3D path to the aircraft;

5)The aircraft calculate the time window of ETA (Maximum and Minimum of estimated time of arrival) of the waypoints on the flight path according to aircraft performance and weather information, and download the time window to the ground ATC;

6)The ground ATC share the time window of ETA with the other ATC, airport, airline and other stakeholders, and negotiate the constraint time of arrival(CTA) for the waypoints on the flight path, and upload CTA to the aircraft;

7) The aircraft assess the received CTA. If the CTA is accepted, the aircraft will send confirm information to ATC, otherwise the aircraft will negotiate the CTA with ground ATC again;

8) The aircraft calculates 4D trajectory according to 3D flight path and CTA, and fly along the calculated 4D trajectory;

9) If the aircraft is unable to fly as the 4D trajectory due to bad weather, and need to change the flight plan, the aircraft will calculate updated 4D trajectory, and send 4D trajectory update request to the ground ATC. Stakeholders negotiate 4D trajectory again, and send 4D trajectory acceptance to the aircraft.

3. Aircraft level MBSE modeling

3.1 Case of TBO operation scene

Aircraft-level Case Figure is constructed according to operation scene of TBO to identify the cases and participant during TBO. Case is an integral service provided to the participant by the aircraft, which includes a series of activities to achieve Expected operation of participant. Participant consists of the crew and other outer system interacting with the aircraft. The case figure of TBO include 4 cases which are 4D trajectory prediction, 4D trajectory negotiation, and 4D trajectory execution, and participant composed by airline operation center(AOC),air traffic control (ATC),and weather service department, as shown in figure 1.

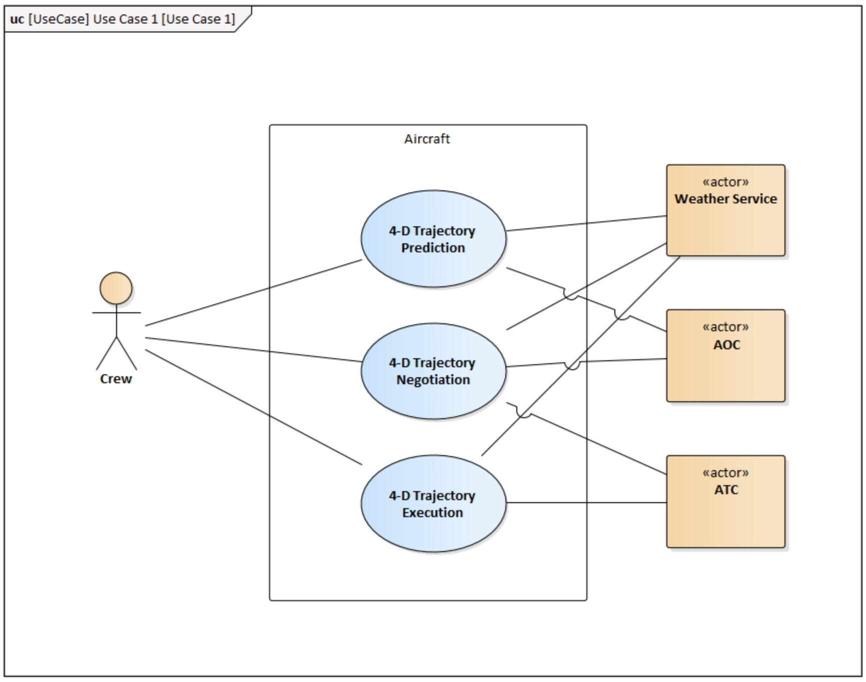

Figure 1–Aircraft level case of TBO

3.2 Activity and sequence of TBO operation

For each of the aircraft level cases, activity figure analysis is performed first, and the aircraft needs to complete each action to deliver the case, then sequence figure analysis is performed based on activity figure, which describes the communication message between aircraft and outer participant, the action and its sequence of the aircraft. Take 4D trajectory execution case for example, its activity figure and sequence figure is shown in figure 2 and figure 3.

In figure 2, the actions that the aircraft is supposed to deliver include receive and display CTA, send CTA confirmation notice, load CTA to avionics, generate 4D trajectory and download it to ATC, fly as CTA requires and download real time trajectory. In figure 3, the aircraft receives CTA from ATC at first, and display CTA to the crew. When CTA is confirmed by the crew, the aircraft will send the confirmation notice to ATC, then load CTA into avionics, generate 4D trajectory according to CTA and weather information, download it to ATC, and fly as CTA requires and download real time trajectory finally.

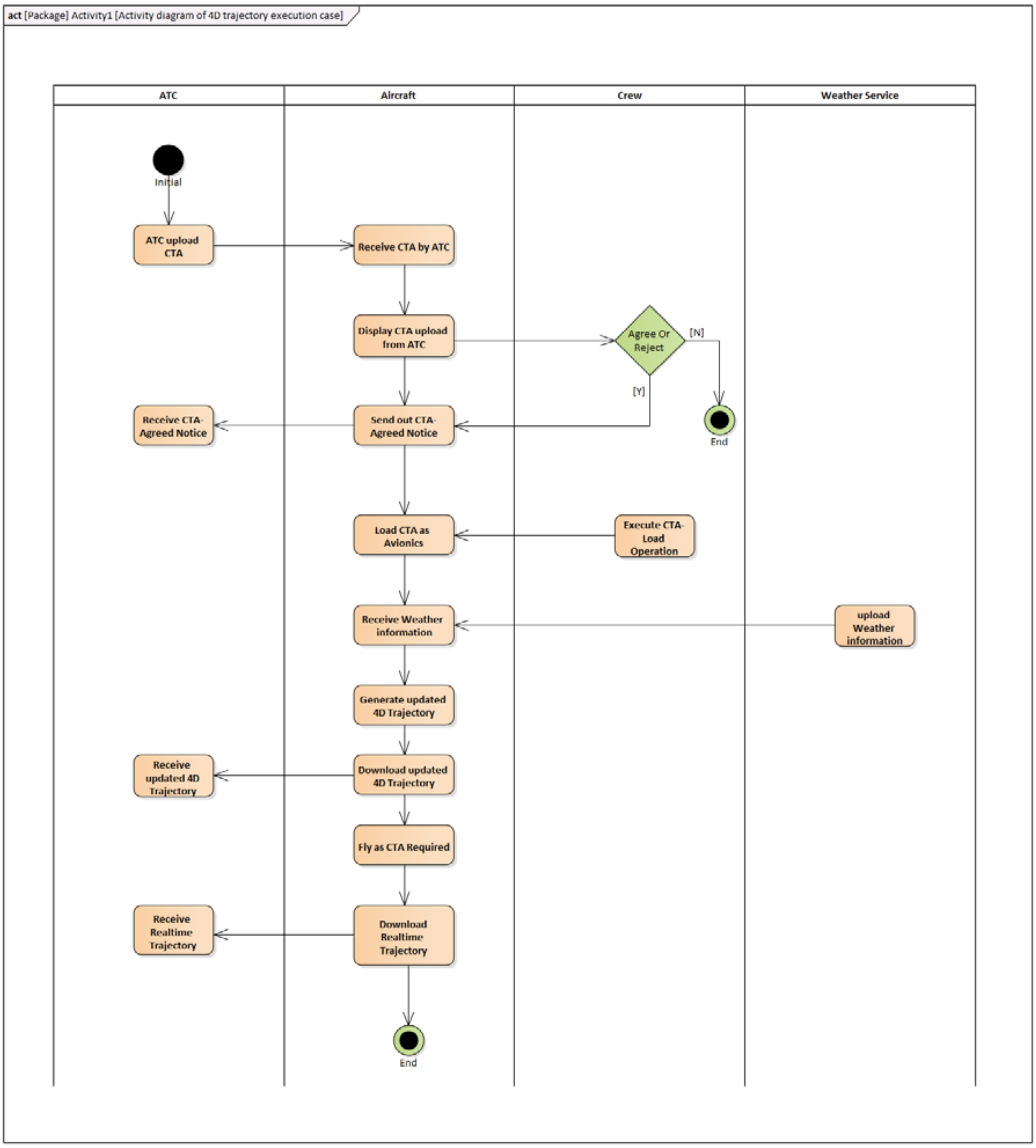

Figure 2–Activity of 4D trajectory execution case

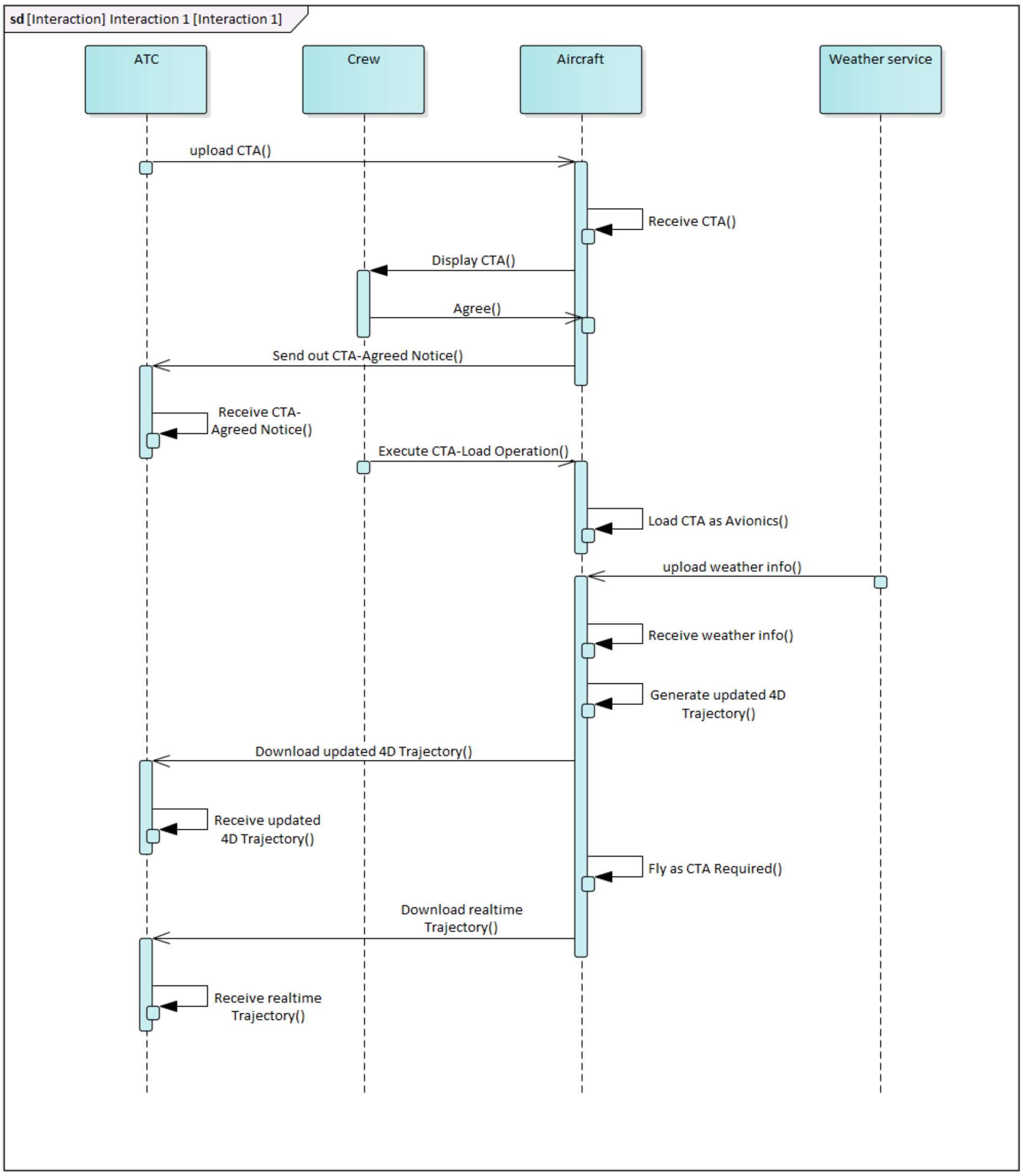

Figure 3–Sequence of 4D trajectory execution case

3.3 Aircraft requirement for TBO

According to activity figure and sequence figure of the aircraft level case, the requirement for the aircraft are captured. Take 4D trajectory execution case for example, the requirements for the aircraft from this case are:

1) The aircraft shall receive CTA uploaded by ATC;

2) The aircraft shall display CTA uploaded by ATC;

3) The aircraft shall provide man-machine interface for accepting or rejecting CTA;

4) The aircraft shall download the crew confirmation notice of CTA;

5) The aircraft shall receive weather information;

6) The aircraft shall generate 4D trajectory as required by CTA;

7) The aircraft shall download 4D trajectory meeting the requirements from CTA to ATC;

8) The aircraft shall fly as the given CTA requirements;

9) The aircraft shall download real time trajectory.

3.4 Activity and sequence allocated to systems

The airborne systems relevant to TBO is identified in terms of engineering experience, including avionic system and flight control system. Take 4-D trajectory execution case for example, the activity figure of 4D trajectory execution case allocated to systems is gotten by allocating the activity delivered by the aircraft in figure 2, as shown in figure 4. The activity figure of 4D trajectory execution case allocated to systems is derived from figure 4, as shown in figure 5.

In figure 4, the actions that avionic system shall deliver include receive and display CTA, send CTA confirmation notice, load CTA to avionics, generate 4D trajectory and download it to ATC, calculate and send 4D guidance command, download real time trajectory. The actions that Flight control system shall deliver include receiving 4D guidance command, and steering the flight control Actuator to realize 4D flight.

In figure 5, avionic system receives CTA from ATC at first, and displays it to the crew. When CTA is confirmed, the aircraft will send the confirmation notice to ATC, then load CTA, generate 4D trajectory according to CTA and weather information, download CTA to ATC, calculate and send 4D guidance command to flight control system, and download real time trajectory to ATC. Flight control system receives 4D guidance command from avionic system， and steers the flight control actuator to realize 4D flight.

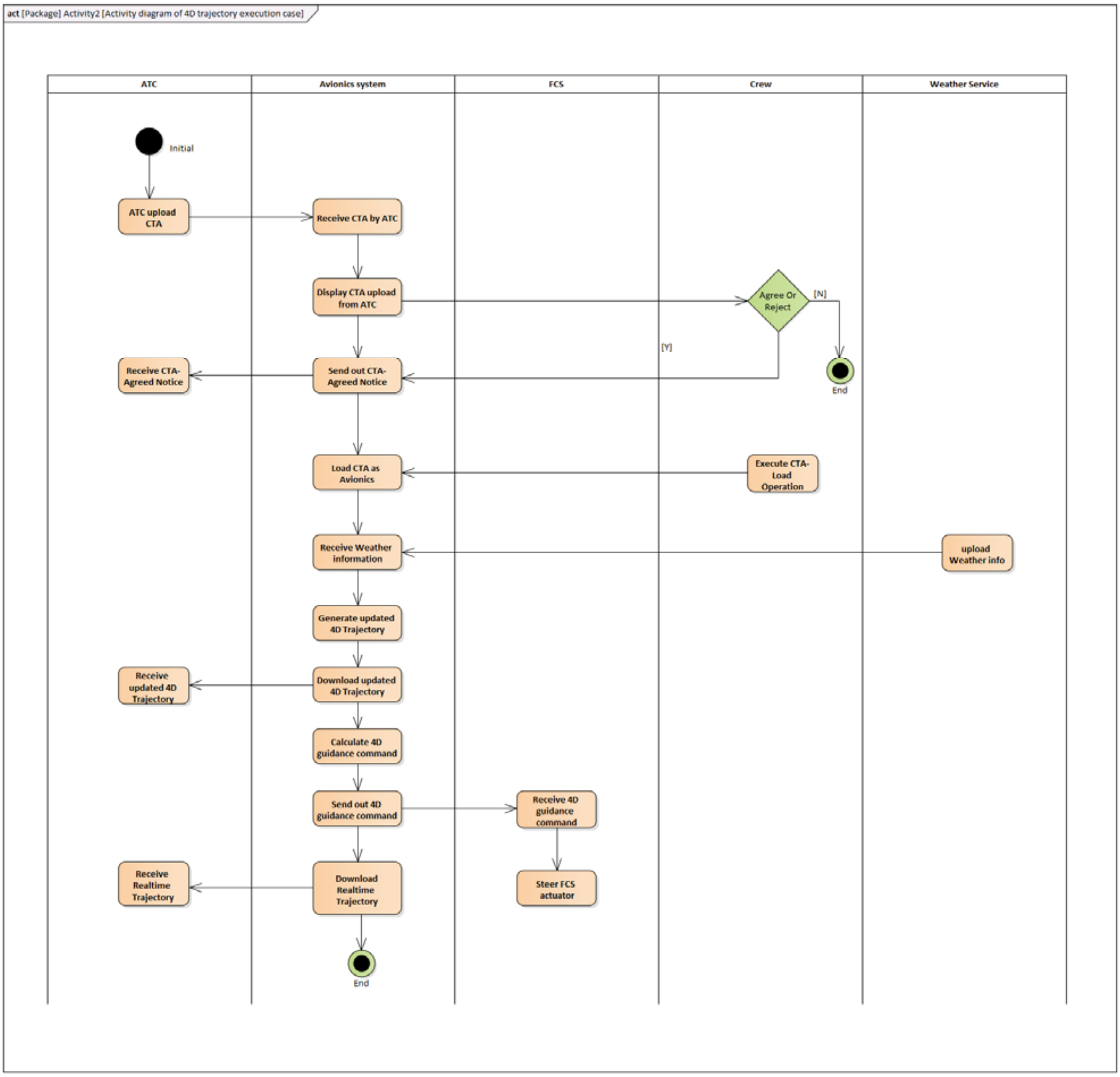

Figure 4–Activity of 4D trajectory execution case allocated to systems

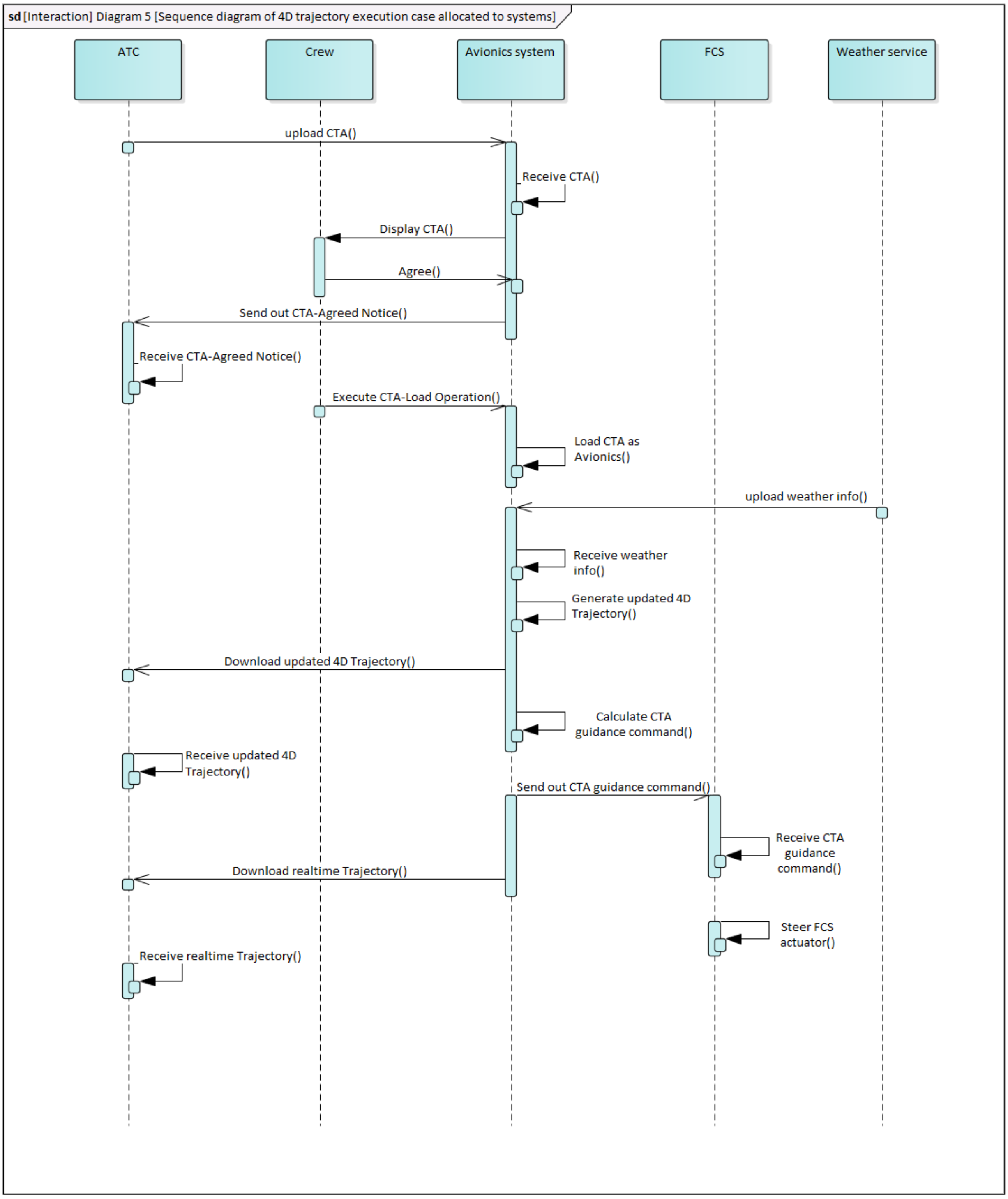

Figure 5–Sequence of 4D trajectory execution case allocated to systems

3.5 Avionic system requirement for TBO

According to activity figure and sequence figure allocated to systems, the requirements allocated to avionic system from aircraft level cases are captured, and the Avionic system requirements supporting TBO are gotten. Take 4D trajectory execution case for example, the requirements for avionic system from this case are:

1) Avionic system shall receive CTA uploaded by ATC;

2) Avionic system shall display CTA uploaded by ATC;

3) Avionic system shall provide man-machine interface for accepting or rejecting CTA;

4) Avionic system shall download the crew confirmation notice of CTA;

5) Avionic system shall receive weather information;

6) Avionic system shall generate 4D trajectory as required by CTA;

7) Avionic system shall download 4D trajectory as required by CTA to ATC;
8) Avionic system shall calculate 4D guidance command;
9) Avionic system shall send 4D guidance command to Flight Control System;
10) Avionic system shall download real time trajectory.

4. Avionic system level MBSE modeling

4.1 Avionic system case for TBO

Aimed at Avionic system, the avionic system requirements supporting TBO are analyzed, and Avionic system cases and outer participants supporting TBO are identified, as shown in figure 6. Cases include ground-air communication, TBO display and control, 4D trajectory prediction, 4D flight guidance, while outer participants interacting with avionic system include ATC, weather service department, crew, and Flight control system.

Ground-air communication case performs trajectory negotiation by interacting with weather service department, AOC, ATC. TBO display and control case performs man-machine interaction interface for TBO by interacting with the crew. 4D trajectory prediction case generates 4D trajectory by interacting with weather service department. 4D flight guidance case guides the aircraft fly along the predicted 4D trajectory by interacting with flight control system and crew.

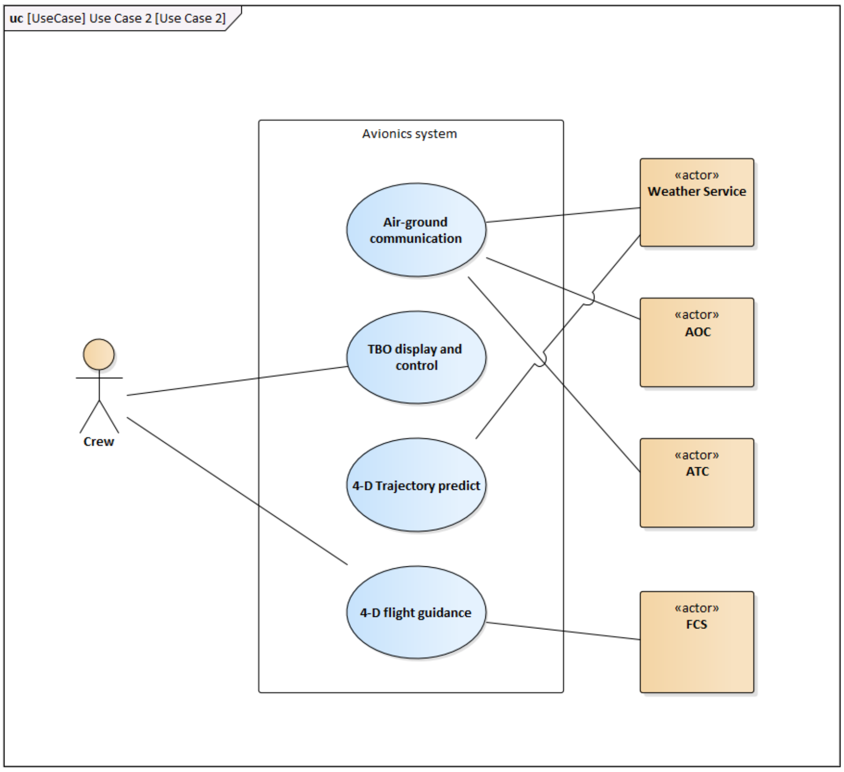

Figure 6–Avionic system case

4.2 Avionic system activity and sequence

Activity figure and sequence figure analysis of avionic system cases are performed to identify the activities and communication messages by operated activities and interaction information with outside. Take 4D flight guidance case for example, activity figure and sequence figure of which are shown in figure 7 and figure 8 separately.

In figure 7, the activities of avionic system include calculating aircraft position, calculating lateral and vertical deviation, calculating 4D flight guidance command, sending 4D flight guidance command , downloading real time trajectory. In figure 8, avionic system calculates aircraft position at first, then lateral and vertical deviation according to predicted 4D trajectory, followed by receiving weather information from weather department, calculating and send 4D flight guidance command , moreover, downloading real time trajectory at last.

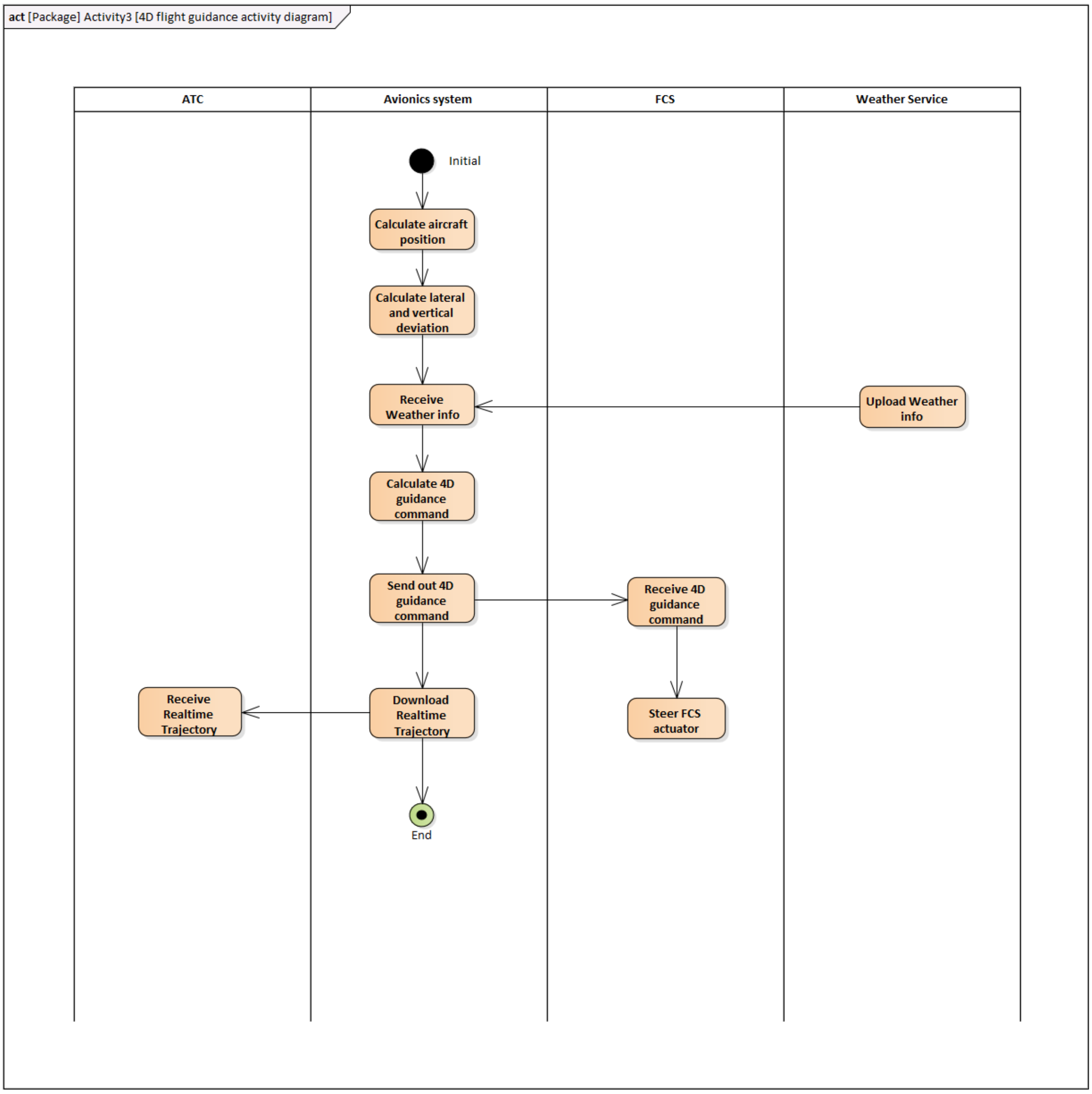

Figure7–4D flight guidance activity

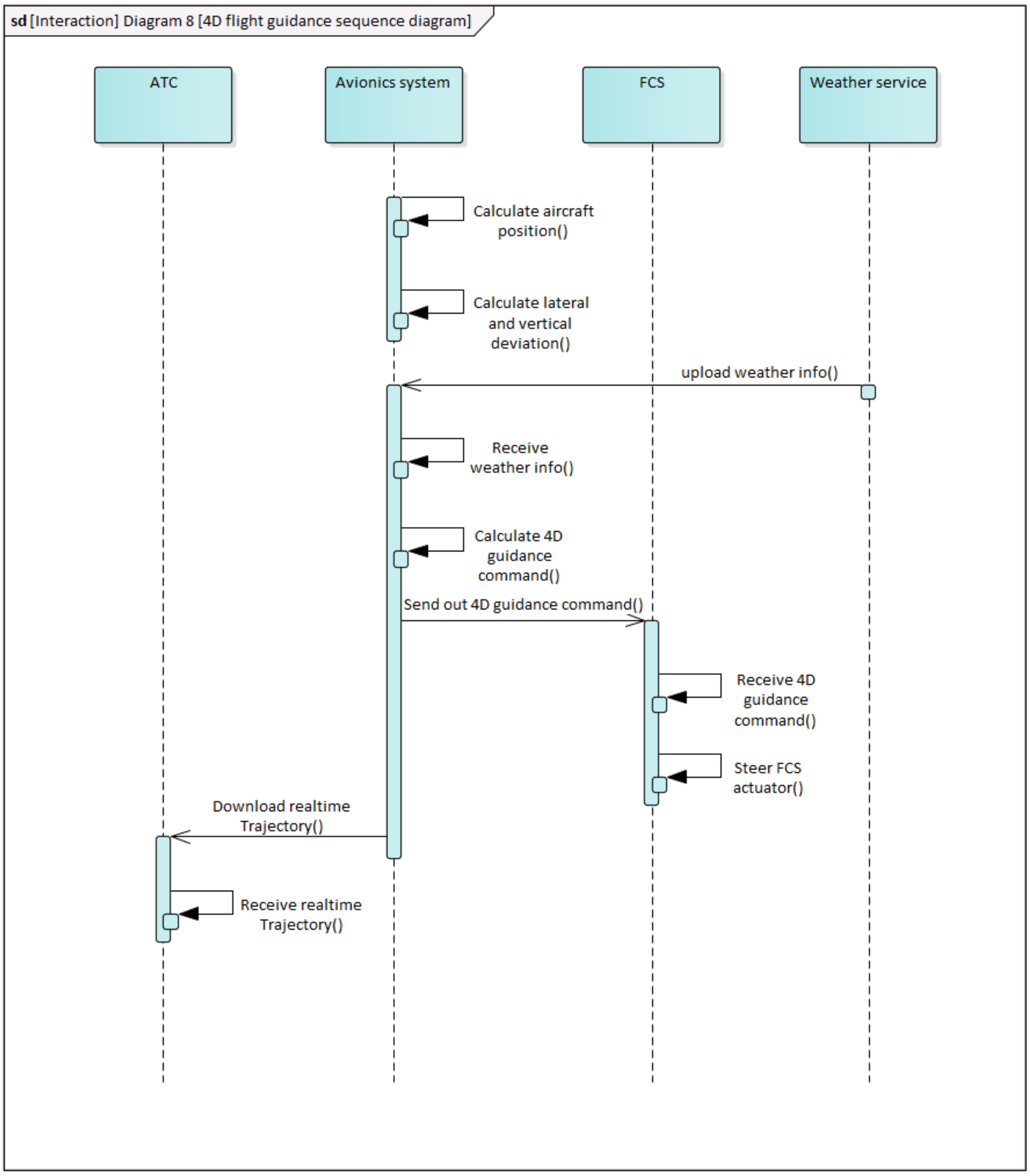

Figure 8–4D flight guidance sequence

4.3 Activity and sequence allocated to avionic subsystem

The avionic system activity figure is allocated to avionic subsystem according to engineering experience, in order to build avionic subsystem activity figure. Take 4D flight guidance case for example, activities in figure 7 is allocate to communication system, navigation system, flight management system, so that avionic subsystem activity figure of 4D flight guidance case is achieved, as shown in figure 9. Sequence figure is achieved according to figure 9, as shown in figure 10.

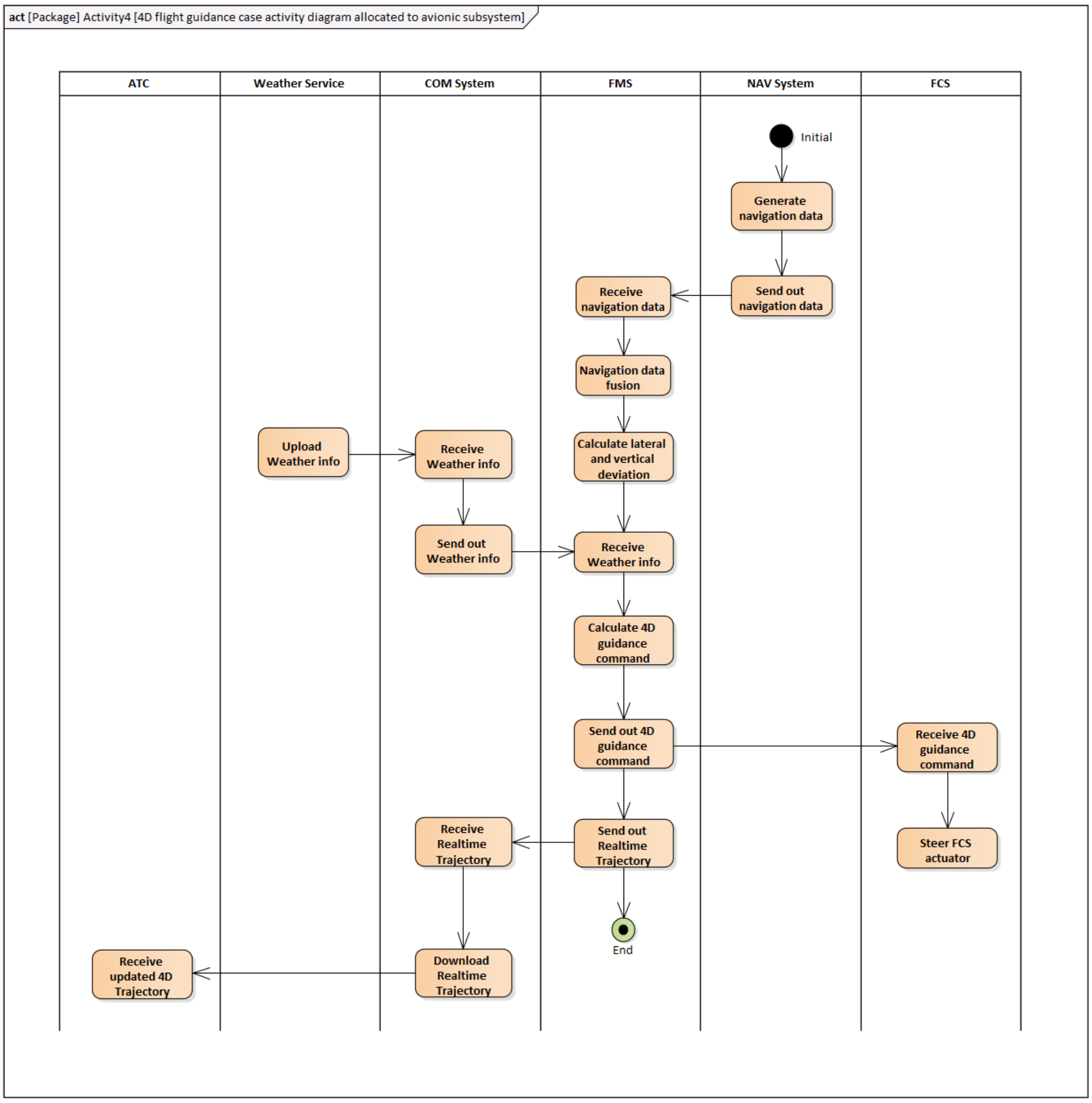

Figure 9–4D flight guidance case activity allocated to avionic subsystem

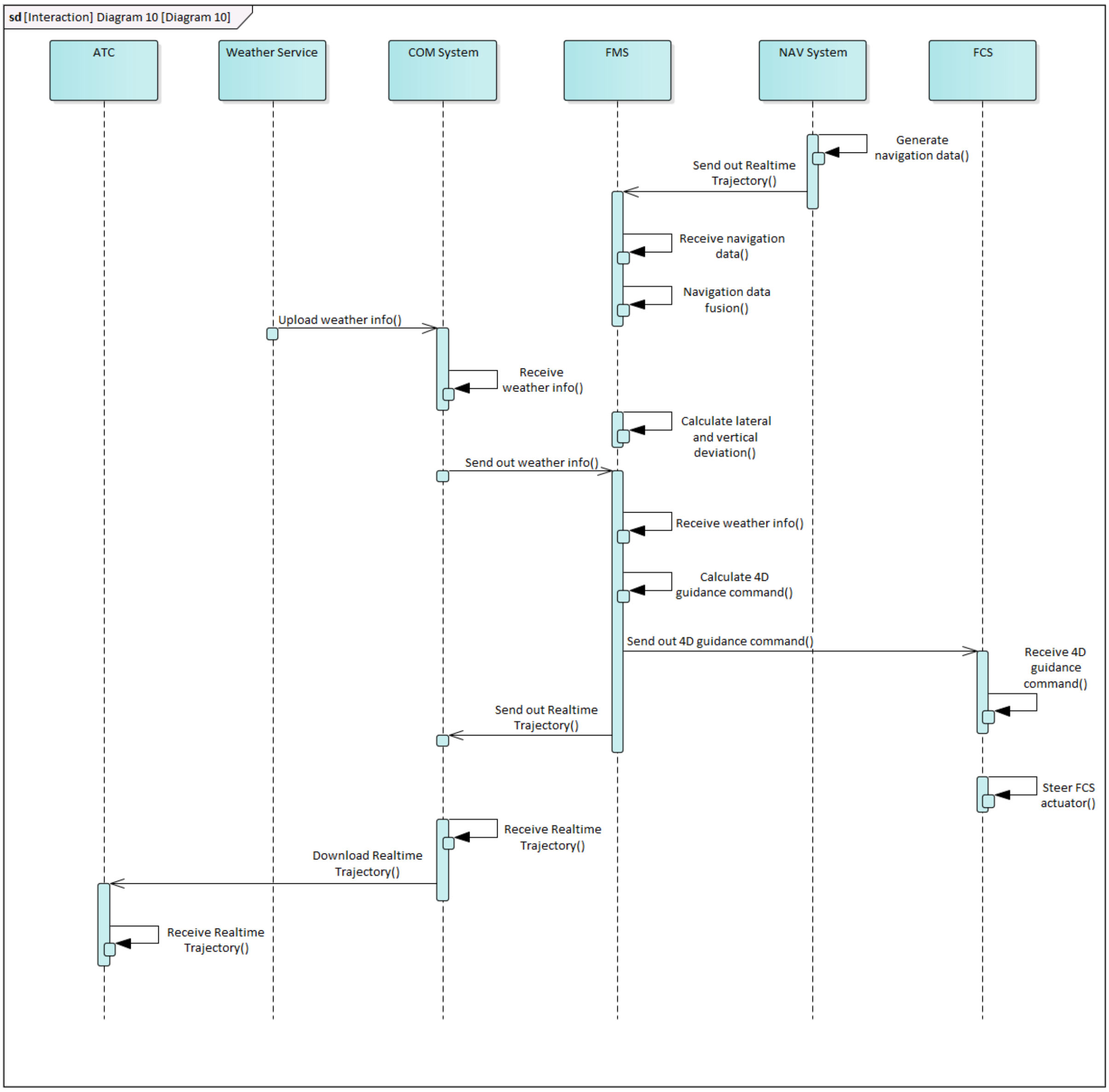

Figure 10–4D flight guidance case sequence allocated to avionic subsystem

4.4 Flight management system requirement for TBO

According to the case activity figure and sequence figure allocated to avionic subsystem, flight management system requirements derived from avionic system cases are captured, and those for TBO are achieved. Limited to space, only the flight management system requirements derived from 4D flight guidance are list below:

1) Flight management system shall fusion the data of navigation system;

2) Flight management system shall calculate lateral and vertical deviation;

3) Flight management system shall calculate 4D flight guidance command;

4) Flight management system shall download real time trajectory to ATC;

5) Flight management system shall receive weather information.

5. Conclusion

In this article, Flight scenario of TBO is analyzed based on the 4D trajectory operation concept of SESAR and NextGen, which focus on the requirements of aircraft and avionic system. Model-based system engineering (MBSE)[2] is adopted to capture and confirm the TBO operational requirements of the aircraft and the avionic system. Meanwhile, the specific activities of the FMS is analyzed to form in-depth FMS requirements. The next step is to design the sub function, architecture, and interface of the flight management system according to the flight management system requirements.

References

[1] NI Zhong jian,ZHANG Yan,LI Yi,XIAO Zhong bing,HONG Rong,HE Yi zheng. Application research on model-driven system design method.Avionics technology,Vol.42,No.1, pp18-23,2011.

[2] Howells A,Bushell S. Experiences of using model based systems engineering. IBM software，2010．

Copyright Statement