Implementing a Cloud-Based Flight Management System

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Achieving Trajectory Based Operations (TBO) beyond the FAA's current NextGen plans will require the introduction of new technologies, systems, and procedures. Similarly, new Air Traffic Management (ATM) capabilities will be required to permit routine Unmanned Aircraft Systems (UAS) and Urban Air Mobility (UAM) operations, and UAS Traffic Management (UTM). To enable these new aviation operations in a safe, scalable, and efficient manner within the National Airspace System (NAS), some of these advancements will require new automation capabilities on the air vehicles. However, aircraft avionics evolve very slowly. Flight Management System (FMS) manufacturers develop new models infrequently, usually with only incremental changes. To help ameliorate the problems outlined above, we are building a prototype Cloud-Based Flight Management System (CFMS), whereby safety-critical functions residing on the flight deck are separated from non-safety-critical functions that reside in a cloud-based environment on the ground. This paper discusses the CFMS concept and its initial implementation.

I. Introduction

This paper is an update to the ongoing work in developing a cloud-based Flight Management System. Earlier work in this area can be found in reference [1] [2]. Achieving Trajectory Based Operations (TBO) beyond the FAA's current NextGen plans will require the introduction of new technologies, systems, and procedures. Similarly, new Air Traffic Management (ATM) capabilities will be required to permit routine Unmanned Aircraft Systems (UAS) and Urban Air Mobility (UAM) operations, and UAS Traffic Management (UTM). To enable these new aviation operations in a safe, scalable, and efficient manner within the National Airspace System (NAS), some of these advancements will require new automation capabilities on the air vehicles. However, aircraft avionics evolve very slowly. Flight Management System (FMS) manufacturers develop new models infrequently, usually with only incremental changes, typically only when releasing a new aircraft model. Flight operators also upgrade avionics infrequently due to the high installation and certification costs. Overall, this slow progression of FMS and other avionics capabilities, including navigation and communication systems, results from the economics surrounding the safety of avionics, including high costs to certify systems, certification of systems for specific aircraft types, and installation of new systems on existing aircraft. In addition, the standards that provide means of compliance for certification often evolve slowly due to pressing operational needs for increased efficiency while maintaining safety.

To help ameliorate the problems outlined above, we are building a prototype Cloud-Based Flight Management System (CFMS), whereby safety-critical functions residing on the flight deck are separated from non-safety-critical functions that reside in a cloud-based environment on the ground. Our Cloud FMS is based on General Electric Aviation System's TrueCourse™ FMS (TrueCourse is a trademark of GE). This product enables Trajectory-Based Operations (TBO) by sharing the flight plan (planned route) as well as aircraft state with a secure cloud environment, enabling accurate trajectory prediction. Additional computations such as wake vortex estimation and ground noise footprints are feasible with Cloud FMS but infeasible with a traditional FMS.

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II. Architecture of the Cloud Flight Management System (CFMS)

Two slightly different architectures have been developed. The first is for testing purposes. The test environment exists to demonstrate the concept and measure its ability to deliver desired benefits. The second architecture is for flight experiments, in which the CFMS connects to an onboard TrueCourse^{TM} FMS aboard a King Air aircraft.

A. Architecture of the CFMS Lab Simulation System

The figure below shows the architecture for the Cloud FMS laboratory configuration used for simulation tests.

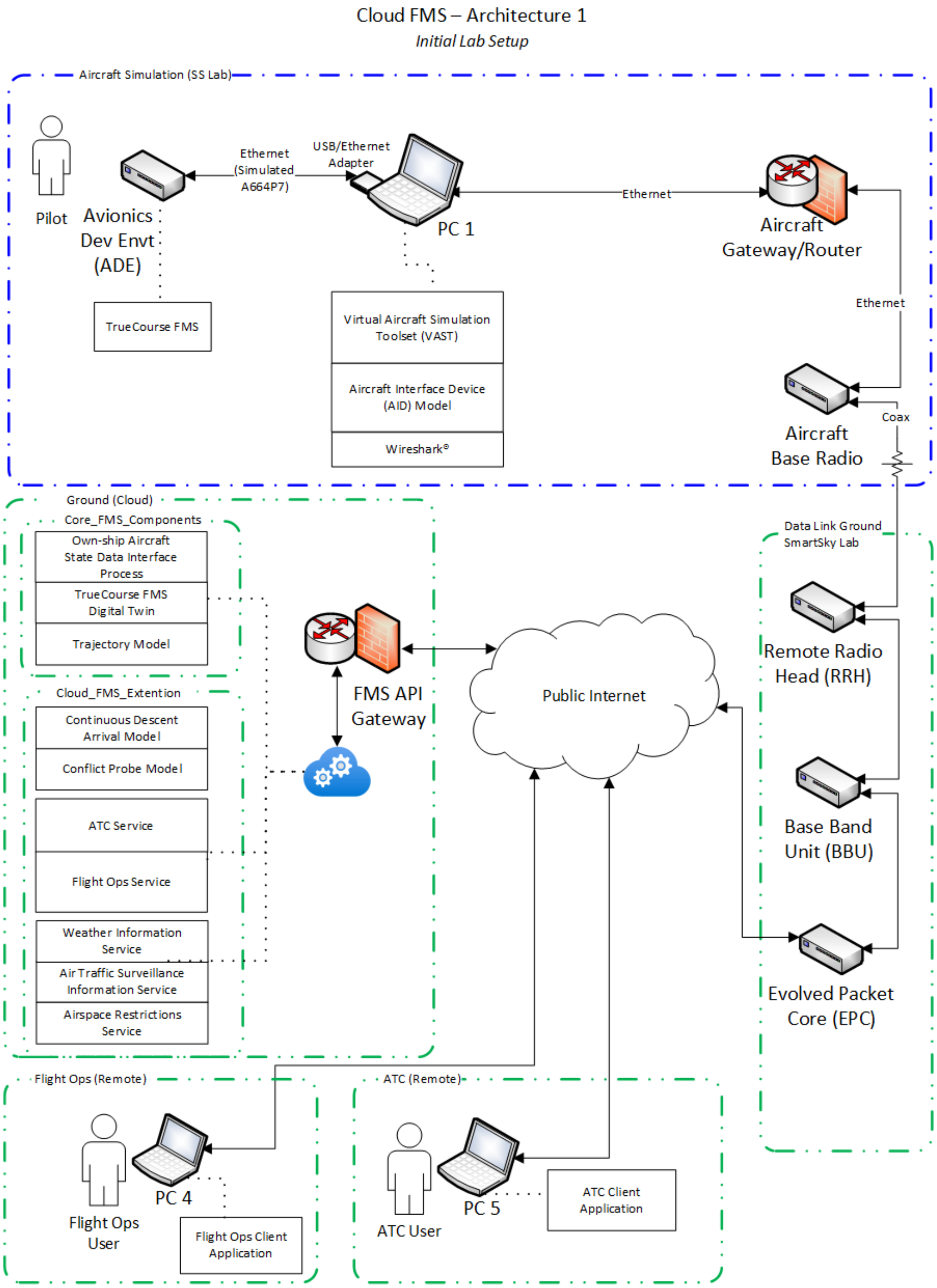

Figure 1. Architecture of the laboratory simulation setup for Cloud FMS

The dotted blue line at the top of the figure outlines the parts that are on the simulated flight deck. This includes a pseudo-pilot operating the TrueCourse™ FMS cohosted on an Avionics Development Environment (ADE) that is connected to a computer that in turn hosts the Virtual Aircraft Simulation Toolset (VAST) and a simulated Aircraft Interface Device (AID). The User Interface (UI) is part of the VAST. In this initial lab architecture, a single aircraft will be simulated using one ADE-PC pair. This simulated flight deck in turn is connected to a Gateway that routes traffic to and from the SmartSky simulation network. The SmartSky simulator reproduces the conditions that would occur in an operational air/ground data link and supports emulation of a variety of network conditions such as link degradation and bandwidth throttling. The Aircraft Base Radio (ABR) simulates the physical transmission of messages to, and receipt of messages from, the ground side of the link. In this initial lab architecture, the air and ground sides will be connected via coaxial cable.

The dotted green box on the right of the figure represents the ground side of the air/ground datalink. It consists of a Remote Radio Head (RRH), a Base Band Unit (BBU), and an Evolved Packet Core (EPC). The dotted green box on the left of the figure represents the Ground Cloud. Messages flow between the air/ground datalink and the Ground Cloud through the public internet and are protected via Transport Layer Security (TLS).

The Ground Cloud is subdivided into two primary areas: the Core FMS Components, and the Cloud FMS Extension. The Core FMS Components contains the TrueCourse FMS ground-side system, a predictive modeling capability, and the software to support data synchronization and messaging with the air-side system. The Cloud FMS Extension provides extended capabilities for the FMS system via a variety of modeling capabilities, such as a Conflict Probe model, and a Continuous Descent Arrival (CDA) model. Additional data and services to support experimental exercise and demonstration of the Cloud FMS system are included in this component as well.

Two additional test systems are shown in the bottom dotted green boxes. A notional Flight Operations Center (FOC) user and client application are represented, along with a notional Air Traffic Control (ATC) user and client application. These supporting systems are external to the lab environment and connect with the ground cloud via TLS-secured public internet links.

This cloud-based FMS has considerable resources available within the Ground Cloud, including current weather forecasts, accurate trajectory information from all aircraft in the vicinity of the "ownship," access to filed flight plans that may affect the ownship downstream, current and planned airspace constraints, and many other data sources. This information, combined with highly accurate and detailed information about the ownship transmitted by the on-board FMS, allows computations to be executed in the cloud that, due to lack of compute power and bandwidth to transmit all the necessary data, cannot be carried out in the flight deck. By maintaining all operationally significant data (some of which might be propriety in a secure cloud environment), this technique may be a way to allay the concerns of the operators by sharing an interaction with the performance model without revealing the individual proprietary values.

These computations include a very accurate trajectory prediction of the ownship, including very accurate updates of any Required Times of Arrival (RTAs) that the ownship has contracted with the FAA via a future Trajectory-Based Operations (TBO) contract. In addition, because the cloud has an accurate weight and other state data of the aircraft from the onboard FMS, detailed computations such as the ownship's noise profile as well as its wake vortex signature can be accurately computed and updated moment-by-moment.

With accurate trajectory information, wake vortex information, and noise information, the planned trajectory can be modified to increase NAS capacity (for example, by lowering the spacing between the ownship and the trailing aircraft, if atmospheric conditions are such that the ownship's wake is rapidly decaying), or by changing arrival routes to avoid excessive noise in neighborhoods surrounding the airport.

Air Traffic Control will have access to all this derived information (perhaps the weight remains proprietary to the airline; may be covered by SWIM MOAs with airlines), and other airspace users, with appropriate authority, and also access the information. ATC can update the cloud with other aircraft flight plans, flight plan amendments, and course corrections (vectors) assigned to other aircraft.

The Airline Operations Center also has access to the cloud-based information, and can use it to fine-tune operations, understand causes of vector-induced delays, and possibly replan the future trajectory to avoid bottlenecks and make the flight more efficient. The replanned trajectories can then be submitted to ATC as a flight plan amendment.

B. Architecture of the In-Flight CFMS

The CFMS architecture that will exist during our flight tests is similar to that used during the simulation tests, except that the CFMS will be interfacing with the TrueCourse™ FMS, which itself will be interfacing with an on-board FMS that is standard equipment for the King Air aircraft. This section discusses the airborne architecture.

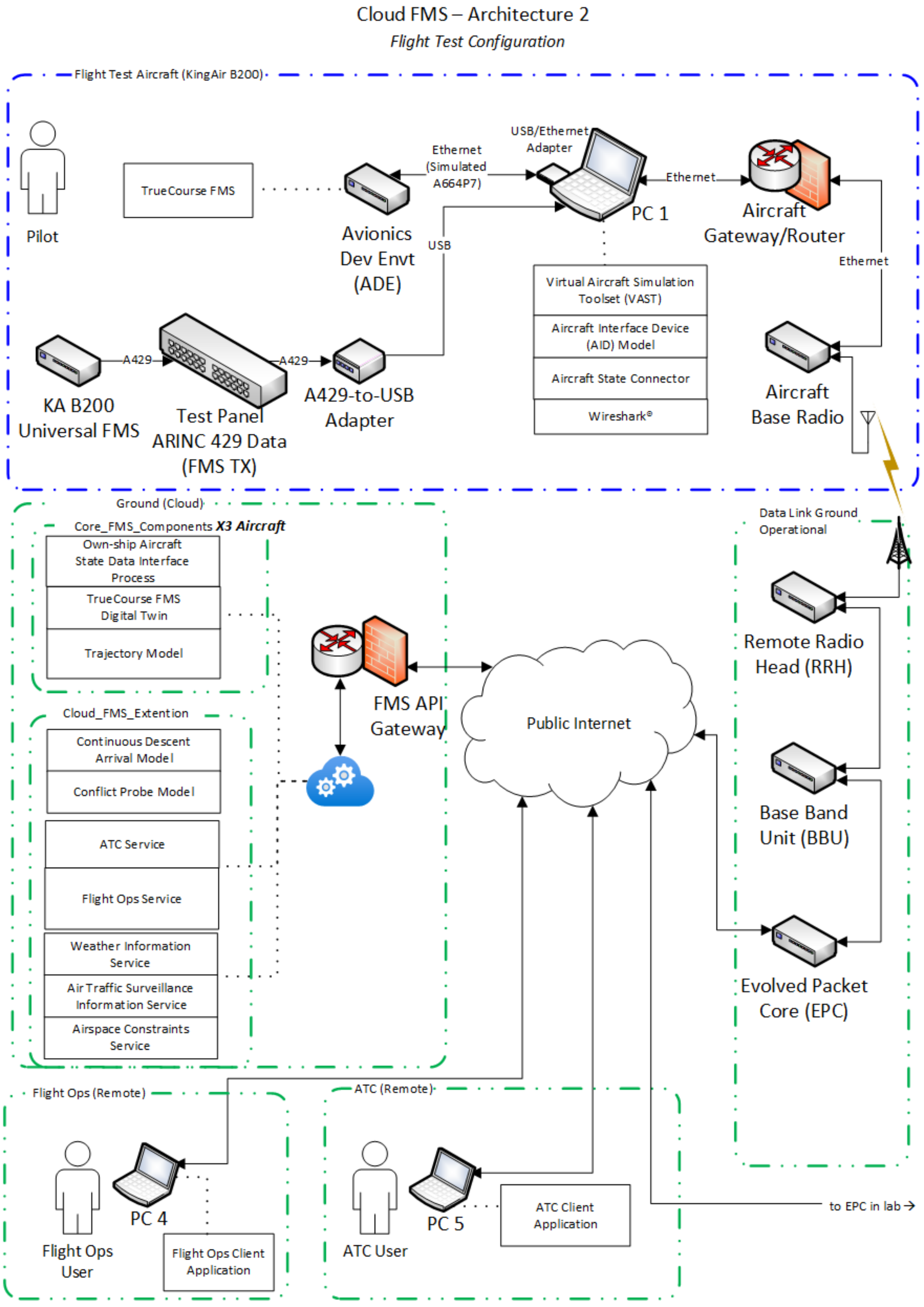

Figure 2. Initial Architecture for the Flight Test Environment for Cloud FMS

Figure 2 shows the high-level architecture for the flight tests. Starting at the bottom of this figure and working up, the cloud-based component in this flight test is identical to the cloud-based component in the simulated test. On the right side of the diagram, reading bottom up, there is the EPC, the BBU, and the RRH, all part of the SmartSky Network. However, instead of these three components existing in a simulated bench, these three components are the components of the operational SmartSky Network.

The flight test aircraft is a Beechcraft King Air Model 200. At the top of Figure 2 within the dotted blue line, there are several differences from the initial lab environment. In the flight test, the pilot is guided by an installed Universal FMS, while the True Course FMS is running in "shadow mode" in parallel. This change is necessary for the safety of flight. However, the TrueCourse FMS "thinks" that it is running the aircraft because it receives real-time state data from the actual FMS via ARINC 429 test panel (FMS TX). The TrueCourse FMS synchronizes aircraft state and flight plan data to the Cloud FMS via the operational SmartSky Network air/ground link, which is protected using radio-layer encryption.

The on-board TrueCourse FMS uses one ADE-PC pair (Sim Aircraft 1), while two additional ADE-PC pairs (Sim Aircraft 2 and Sim Aircraft 3) are configured in the laboratory environment for parallel operation.

III.Example CFMS Use Case

We shall use Trajectory Negotiation (TN) as our primary use case for the CFMS. TN involves all the entities directly controlling the flight, which includes the pilot, the controller, and the airline dispatcher. When a trajectory needs to be "re-negotiated," all three players are involved.

In this simple use case, the aircraft is on a pre-planned, conflict-free, four-dimensional trajectory (4DT) when an unexpected TFR arises in the future flight path of the ownship. The TFR has a ceiling at FL320, which is the current altitude of the ownship during its cruise phase of flight. The ownship is too heavy—too much fuel onboard—to efficiently climb to a higher flight level, but that fact is unknown to the controller. Although it can always descend, the dispatcher would rather it stay at its flight level, if possible, as descending into a denser atmosphere would increase fuel burn, possibly beyond its reserve requirement. The controller is aware of all flights in the vicinity of the ownship's 4DT as well as flights in the vicinity of the new TFR. The pilot is aware of some of the flights immediately ahead of it on the flight plan but lacks a clear view of all flights in the airspace that may be affected by either the TFR or the ownship's 4DT or both.

Because of the lack of full situational awareness among all the players, the TN becomes more difficult, and requires multiple steps. For example, the controller might issue a command for the ownship to ascend to FL340, or to descend to FL300, both of which either the pilot or dispatcher will reject. The pilot is likely to reject the climb because the on-board FMS rejects it. The dispatcher is likely to reject the descent because of fuel burn issues (the on-board FMS might reject the descent as well).

As a second try, the controller might suggest a heading change at the same flight level (FL320). This change will likely be accepted by the pilot because the onboard FMS indicates that the new course is flyable. However, the dispatcher might reject the change because it adds too much time to the flight, such that flight block time parameters are exceeded. The flight, for example, might get to the gate at a much later time such that gate management at the destination airport becomes problematic. This alternate suggestion by the controller, while acceptable to the controller and the FMS and pilot, causes an unacceptable disruption to gate management at the destination airport such that the dispatcher rejects the recommendation.

Finally, the controller develops a third recommendation, a course change at FL320 that is acceptable to all. Perhaps this third recommendation also involves a speed change and vectors for other flights in the vicinity, so it is a more complicated, but acceptable, change for the controller. This third recommendation is accepted by all and implemented as a flight plan amendment.

This sequence of negotiations among the controller, pilot, on-board FMS, and dispatcher is shown in the message sequence diagram below.

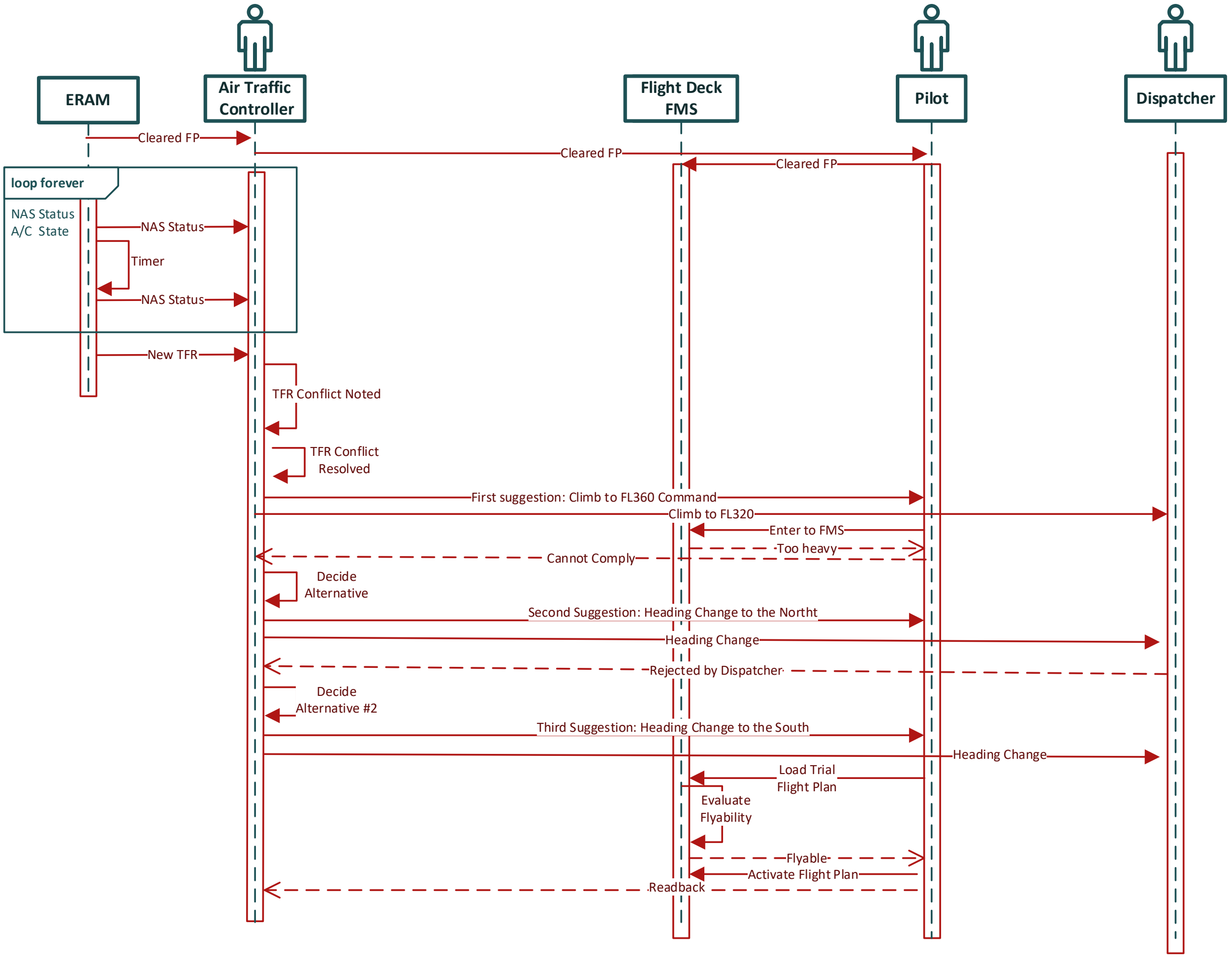

Figure 3. Message Sequence Diagram for a Trajectory Negotiation Without CFMS

The top left part of Figure 3 shows how the Air Traffic Controller is kept up to date on the current traffic situation by the enroute automation system. Not shown here but equally important would be weather effects and forecasts. When the new TFR occurs, it is highlighted to the controller. The sequence of TNs that were described in the previous few paragraphs are then enacted, and the associated flow of information is shown in Figure 3.

When the Cloud FMS is involved, the TN becomes much simpler. That occurs because the CFMS is involved in all the information flows. The CFMS knows the status of the air traffic control system, the current weather and forecasted future weather, the weight as well as all other important parameters of the aircraft, and the constraints that the dispatcher must enforce. Armed with all this information, the CFMS can propose a new trajectory that should be acceptable by all the players. This situation is shown in the message sequence diagram below.

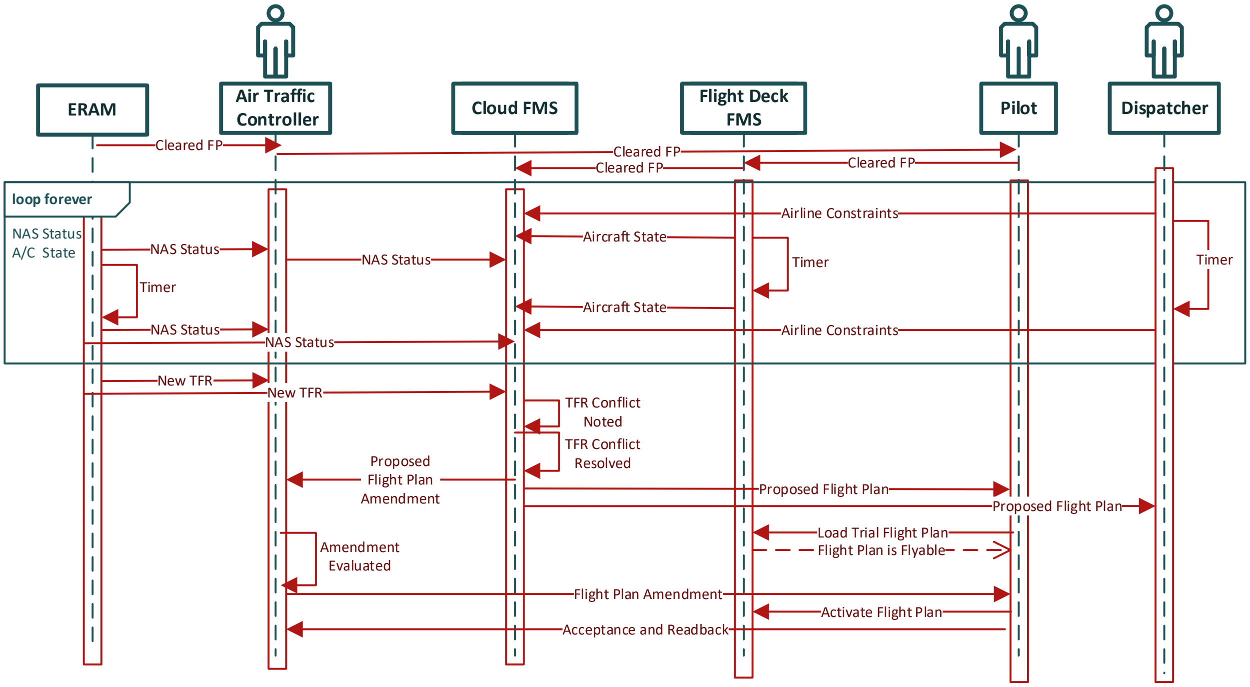

Figure 4. The TN Scenario with CFMS

In comparing Figure 3 and Figure 4, it is obvious that there are many fewer messages in Figure 4. The fewer messages is caused by the loop at the top of Figure 4, which includes the CFMS as part of the information flow prior to the introduction of the new TFR. The CMFS understand the full state of all the players in the decision and is uniquely able to develop a trail solution that will most likely be acceptable to all decision makers.

IV.Conclusions

The emerging CFMS concept has yet to be fully tested and vetted, and its many benefits yet to be explored. The immediate plans are to test the concept both in a simulated environment as well as with actual flight tests. In the simulated environment, many parameters can be changed, such as communications latency, network quality, bandwidth, signal attenuation, and frequency of status changes. In the actual flight environment, the CFMS will experience the challenges of an operational system.

V.Acknowledgements

The authors acknowledge the contributions of all the team member in CFMS, including Bryan Trainum and Brian Staik from SmartSky Networks, Joachim Hochwarth from GEAS, and Lou Toth of Mosaic ATM.

VI.References

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