CONCEPTS PERTAINING TO A CLOUD-BASED FLIGHT MANAGEMENT SYSTEM

By Frederick Wieland, Chief Research Scientist, Mosaic ATM and
Todd Kilbourne, Project Manager, Mosaic ATM

Introduction

Achieving TBO beyond the FAA's current NextGen plans will require the introduction of new technologies, systems, and procedures. Similarly, new ATM capabilities will be required to permit routine Unmanned Aircraft Systems (UAS), UAM, and UAS Traffic Management (UTM) operations. New automation capabilities will be required of the air vehicles to enable these operations within the NAS; however, aircraft avionics evolve very slowly. Flight Management System (FMS) manufacturers develop new models infrequently, usually with only incremental changes. Aircraft manufacturers upgrade FMS infrequently, typically only when releasing a new aircraft model. Flight operators rarely upgrade avionics due to the high installation and certification costs. Generally, this slow progression of the FMS and other avionics, including navigation and communication systems, results from the economics surrounding the safety of avionics, including the high costs incurred to certify new systems, to certify systems separately by aircraft type, and to install new systems on existing aircraft.

Existing FMS hardware also has limited computing power, generally using very old chipsets because they have been proven reliable over decades. Electronic Flight Bags (EFBs) offer some improvement in computational performance and the ability to be updated with new capabilities, relative to FMSs. EFBs, connected to the FMS through

Aircraft Interface Devices, have the potential to realize interesting operational concepts, such as trajectory negotiation, with much lower certification and installation costs than the high cost of certifying new FMS functionality.

There are many concepts that require information that is currently only known to the onboard FMS; some of them are outlined here. Identification of top-of-descent (TOD) is an important value for arrival planning algorithms. Computing TOD involves the weight of the vehicle as well as the settings of the vehicle's cost index. TOD is currently computed by the onboard FMS and rarely shared with ground-based aviation systems. Selecting flight levels that minimize or eliminate contrails will be important to combat adverse climate effects. Prediction of contrails behind aircraft requires the local atmospheric state, which is known by the aircraft, as well as detailed forecasts available from ground-based aviation weather services. Computation of the actual wake vortex created by each aircraft is useful for enhancing system safety and increasing system capacity. Wake vortex computation calculations require large amounts of processing power, and require access to data from the FMS. Creating a common understanding of an aircraft's future trajectory is needed in many en route, terminal area, and decision support systems. Currently there are a variety of such trajectory prediction models, each of which contains slightly different assumptions about the performance of each aircraft. The

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FMS contains its future trajectory and is arguably the most accurate prediction available. Sharing such predictions would harmonize ground-based planning systems and lead to a more efficient airspace system.

For all these reasons and many others, this article explores the concept of a CFMS, which contains a copy of the most important information from the onboard FMS, but resides in a cloud-based computing environment. One can think of the CFMS as a "digital twin" of the FMS.

CFMS Concept of Operations

The CFMS Concept of Operations (ConOps) is still evolving, but the basic idea is summarized in this section. The current ConOps calls for a separate CFMS – a separate digital twin – for each aircraft. The CFMS is owned by the airline that is responsible for the aircraft. The ConOps supposes a "thin interface" between the FMS and the CFMS, requiring minimal communications bandwidth to support the digital twin. However, the communications link must have low latency and high availability. The exact requirements for the communications link will be determined after further investigation.

The onboard FMS will periodically synchronize with the CFMS, providing it data about the aircraft's current state and its knowledge of the local atmospheric conditions. The state should contain the altitude, latitude, longitude, heading, vertical speed, and bank angle and turn rate (if applicable). The state should also contain the aircraft's current weight for use in CFMS calculations, as well as the outside air temperature, indicated airspeed, air pressure, and any other atmospheric conditions that are known to the FMS.

The resulting information residing in the CFMS will contain some quantities that an airline considers proprietary. The proprietary information will remain private to the CFMS, accessible only by the airline's Flight Operations Center (FOC), which may use this information to monitor the status of the flight and to compare it with expectations.

Besides the periodic synchronization of the FMS with the CFMS, there are discrete synchronization events as well. When the FMS recomputes its flight plan, for whatever reason, it will update the CFMS with the latest information. When the FMS recomputes the time to a critical waypoint, due to unexpected winds or other reasons, it will also update the CFMS. There may be other discrete synchronization events as well.

The concept prohibits the CFMS from accessing any flight control system. The flight control systems are solely the responsibility of the FMS and cannot be accessed by the CFMS. As a result, hackers who successfully penetrate the security protocols surrounding the CFMS will be unable to control the aircraft. While the CFMS can suggest a revised trajectory to the FMS, it is up to the operator – the local or remote pilot – to decide whether the revised trajectory should be activated within the FMS. The presence of a human in the loop breaks the electronic chain and prevents direct command of the aircraft from the CFMS.

However, the CFMS should include interfaces that provide information to other aviation systems. For example, the CFMS can compute the aircraft's TOD using the information provided by the FMS. An interface that exposes this computed TOD to other authorized users should be made available. Other systems can use the TOD to plan airspace usage, compute more accurate arrival times, and approve (or deny) continuous descent requests, among other actions. Similarly, an interface that exposes the aircraft's future trajectory, as computed by the CFMS, will allow better four-dimensional trajectory (4DT)

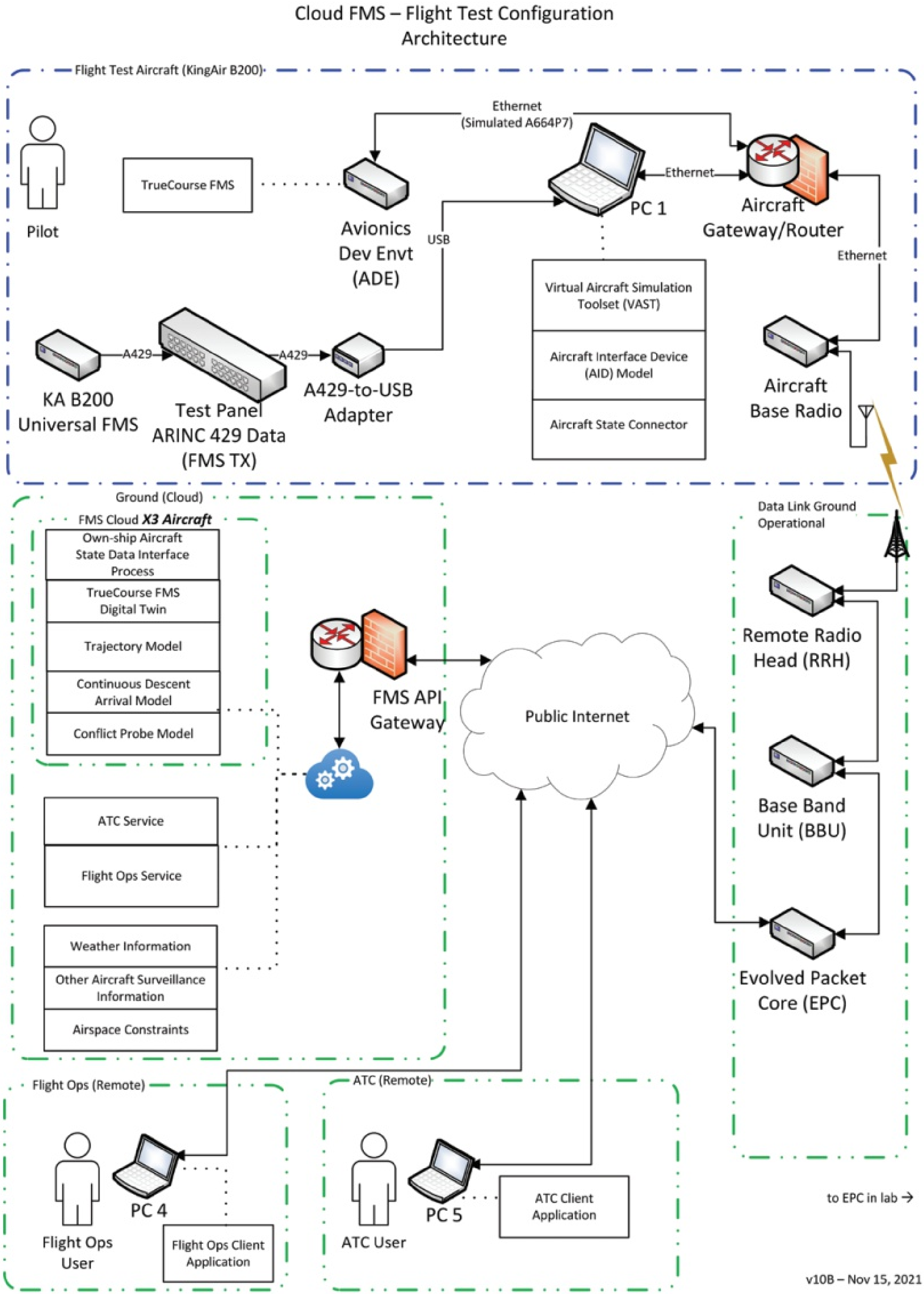

Figure 1.

Photo courtesy of Mosaic ATM

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The current ConOps calls for a separate CFMS – a separate digital twin – for each aircraft.

planning, faster trajectory negotiation when changes are required, and a better understanding of the current performance of the airspace.

In addition, with CFMSs collaborating with each other on the ground, there is another source of surveillance information (the latitude/longitude/altitude/heading). The CFMS can use this surveillance information, coupled with surveillance provided by the ANSP to probe for conflicts. If found, the CFMS can also coordinate on a potential conflict resolution. Such conflicts and their proposed resolutions could be forwarded to a decision support system available to an air traffic controller who is ultimately responsible for implementing the recommended resolution or implementing a different solution.

Note that some of these computations could be performed by an onboard EFB. However, even an EFB is limited in its capabilities. Computing an aircraft's wake vortex is a good example. Currently, separation and spacing are established using a generic understanding of wake vortices given an aircraft's wake vortex category. This "one size fits all" approach, even given different wake vortex categories, can be inaccurate. However, the CFMS knows all the parameters necessary to compute the flights' wake vortex accurately. These parameters include the weight of the aircraft, the current atmospheric conditions in which the aircraft is flying, as well as broader atmospheric conditions and forecasts available through the web. It can combine all this information to compute accurately the magnitude of the wake, how stable it is, how fast it will break down, whether it will sink or rise, and how quickly it will do so. This accurate understanding of the wake will make setting the spacing of trailing aircraft easier to determine. In some instances, the trailing aircraft may be able to space itself safely closer to the leading aircraft than current standards allow. In other instances, the trailing aircraft may need to be spaced further away from the lead aircraft to avoid a wake vortex interaction. These complicated computations require integrating data sources from a variety of different places. The computation is best done on the ground, in a CFMS, as opposed to in an EFB.

To date, Mosaic ATM, along with several subcontractors, has performed a limited investigation into the CFMS concept.

In summary, the ConOps envisions a CFMS as a digital twin of the FMS. The CFMS is owned by the airline operating the flight. It can use the CFMS to monitor its own flights and better understand its operations. It will provide access points (web-based services, application programming interfaces, or otherwise) to allow other authorized aviation users access to non-proprietary data to support other calculations (wake vortex profile, contrail reduction, noise footprint, and others). The non-proprietary information provided by each instance of a CFMS will benefit the ANSP, the airlines, and the traveling public. Proprietary information is unavailable to users outside the airline's own FOC, and flight security is maintained by the presence of a human operator between the CFMS and the FMS.

CFMS Work to Date

The ConOps raises a number of interesting questions. For example, how often should the FMS synchronize with the CFMS? If the communication between the FMS and the CFMS breaks down, how long until the data residing in the CFMS becomes "stale" and is unusable for any airspace calculation? If that happens, what is the backup plan (revert to the current method of managing flights, for example)? How would the implementation of such a backup plan affect throughput, delays, and the overall performance of the airspace? On a different note, how would CFMS improve or enable new business models, such as UAM or "Upper E" flight? Should CFMS be mandatory for every flight? If not, how does the system work with some flights having a CFMS and others lacking one? Should the CFMS be certified if it cannot access the flight controls? How is the information provided by the CFMS vetted and validated?

These are intriguing questions. To date, Mosaic ATM, along with several subcontractors, has performed a limited investigation into the CFMS concept. An example reference architecture, one of several that have been considered, is shown in Figure 1.

The top of Figure 1 shows the cockpit data systems for supporting a CFMS, including the pilot. In this diagram, the pilot is on board the aircraft, although in future concepts a remote pilot may be responsible for the flight. Below the flight deck and on the right side of Figure 1 is the stack of processes that handle the communication to and from the aircraft. The data to and from the communication stack is forwarded via the public internet to the cloud system, which is shown by the stack of systems and processes just to the left of the "cloud" icon in Figure 1. This stack is where the computations take place. These computations include, but are not limited to, TOD, continuous descent arrival paths, conflict identification and resolution, as well as wake vortex and aircraft noise footprint computations (the latter two not shown in the figure). Two users are shown below the computation stack. The first is the airline's FOC, which can instantly access the CFMS to monitor the progress of the flight and assess whether anything is amiss. The second user is the air traffic controller assigned to the flight, who can use the data in decision support systems to manage the separation and spacing of the flights in the sector better.

Other users, not shown in the figure, include other instances of CFMS for other flights and other airlines. The latter may be interested in the top-level state information (position and speed) for flight management purposes. These quantities are available via other surveillance sources and are therefore non-proprietary. However, the CFMS understanding of the aircraft's state is likely to be more up-to-date, and perhaps more accurate, than the alternate surveillance sources.

Results from preliminary experiments can be found in previously published papers.[1-3] To summarize these results, it was determined that the air-ground bandwidth used by the system fluctuated between 400 and 700 megabytes per hour, well below what current air-ground networks can deliver. In addition, latencies for all messages, but one, were well below 16 seconds, considered an upper bound for air-ground communications. In the preliminary experiment, gridded wind data was uploaded to the onboard FMS to see if it would improve the accuracy of its trajectory predictions. This message was so large that its latency frequently exceeded the 16-second threshold. As a result, it's recommended that accurate wind information be used by the CFMS to compute 4DTs with the result uploaded to the flight deck. 4DT data is relatively small compared to gridded wind data.

However, these initial investigations were limited in scope and the results are preliminary. As of the time of this writing, more comprehensive experiments involving both ground simulators and live flight experiments are being conducted that will help to understand the concept in more detail.

References

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