Aircraft Modeling and Flight Simulation

Integrated airspace and procedures research, development of new criteria as well as assessments of alternative operational assumptions for a National Airspace System (NAS) requires the use of flight simulation software which continues to levy requirements that are growing in complexity and tend to be unique for each effort.

Flight simulation software developed in the Java Flight Model (JFM) project is designed to be robust, in particular to support simulation of the Performance-Based Navigation (PBN) concepts used in the terminal area, where the Flight Management System (FMS) plays a key role in defining aircraft trajectories. Alternative models lack PBN features specific to the FMS such as path following with associated control law logic used in the aircraft’s planning and guidance operations. These types of FMS specific features are needed to provide the operational variation observed in modern aircraft for PBN procedure execution, as has been documented by over five years of FMS variations research done by The MITRE Corporation’s Center for Advanced Aviation System Development (MITRE/CAASD). These variations, among other details, are needed to inform most PBN procedure development activities along with other applications including NextGen.

Feature Set

JFM software is developed in Java and provides a robust, flexible, and validated engineering tool set capable of modeling aircraft, their various principal systems, and simulating flight at varying levels of resolution and scale with stringent computational performance standards. Its architecture uses a modular design based on principal models that include: simulation, aircraft, entities that aircraft interact with (such as Air Traffic Control (ATC)), and the physical world in which aircraft operate. Simulated aircraft are able to respond dynamically to events such as ATC vectoring, which result in an amendment to the flight plan used by the FMS. These processes are entirely automated and are highly customizable thus accommodating varying levels of experimentation and analysis. The actual physics model used to propagate the aircraft to produce Four Dimensional (4D) trajectory is based on Six Degrees of Freedom (6DOF) aerospace engineering models, including implementation of all of the common frames of reference along with customizable coordinate system models. The flexible design allows for the substitution of various modeling components and integration with other software that utilizes a flight simulation/prediction model. The following diagram depicts these concepts along with associated features.

In 2011, research was conducted to inform a strategy for producing a high fidelity flight simulation model capable of meeting the requirements for PBN procedure design and development which could be used in lieu of airline simulators. Successful development of such a capability would streamline PBN procedure development, reduce costs, and enable a more robust
testing of proposed procedures. This work identified several different simulation solutions and confirmed that the modeling approach taken by the JFM project is consistent with industry and academia; including CAE (formerly known as the Canadian Aviation Electronics Ltd.), the National Aeronautics and Space Administration (NASA), and the Massachusetts Institute of Technology (MIT). In the case of industry, it was observed that establishing a scalable modular flight simulation model that is scientifically accurate was the pinnacle capability from which other products and services originated. An example is CAE’s training flight simulators of varying fidelity which all inherit from one flight simulation model. The JFM flight simulation model is well suited to follow in similar footsteps and serve as the principal PBN flight simulation model for MITRE/CAASD.

The following highlights some of the areas where JFM software has served as a key enabler.

**Operational Analysis**

Tools such as the Monte Carlo FMS Aircraft Simulation Tool (MFAST) and runwaySimulator leverage JFM’s flight simulation models to provide fast-time benefits analysis (e.g., fuel savings), airspace interactions analysis of proposed operational changes to PBN procedures, and runway throughput metrics. The results have been used to inform multiple site specific benefit analysis efforts for Optimization of Airspace and Procedures for the Metroplex (OAPM) and other Area Navigation (RNAV) optimization initiatives. JFM software is also being used in Matlab to conduct airport specific Optimized Profile Descent (OPD) throughput analyses in order to characterize the trade space between runway throughput and OPD usage and percentage of conformance.

**Human-in-the-Loop Simulation (HITL)**

Integration of JFM flight simulation software in the Terminal Area Route Generation Evaluation and Traffic Simulation (TARGETS) tool provides internal MITRE/CAASD lab access to real-time simulations of multiple aircraft simultaneously to inform pilot and ATC human factors analysis. The HITL simulations support a variety of highly visible initiatives including the New York/Philadelphia airspace redesign, OAPM, and 4D Trajectory Based Operations (TBO) research.

**PBN Procedure Design and Evaluation**

TARGETS flight simulation uses JFM software to enable procedure designers and other PBN Working Group stakeholders to conduct flight evaluation (i.e., aircraft performance-based flyability) checks on proposed PBN procedures as they are being developed, helping provide detailed and timely feedback during the five phase PBN procedure development process.

**PBN Concepts and Criteria**

Many of JFM’s components can be leveraged independently and combined with real world systems, such as the MITRE/CAASD FMS Test Bench Suite or metering applications such as the Traffic Management Advisor (TMA), to explore current and future PBN concepts that serve to inform ongoing policy and criteria development activities. JFM software provides a platform for prototyping future FMS concepts such as Required Time of Arrival (RTA) modeling, ARINC Radius to Fix (RF) bank angle criteria changes, and Required Navigation Performance (RNP) to Instrument Landing System (ILS). This research informs industry standards decision groups such as the PBN Aviation Rulemaking Committee (PARC).