Integrated Airplane Health Management System

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Abstract

The National Air Space System-Wide Simulation (NAS Sim) program advances the development and implementation of a comprehensive, integrated health management system contributing to safety and modeling of the national aviation system. This program integrates different disciplines to develop an accurate and insightful method for real-time modeling of the local integrated airplane risk exposure and monitoring of operations of the global national air space.

Introduction

Air transportation is a vital component in our growing economy for the movement of people and goods. From the safety point of view, the Federal Aviation Administration (FAA) predicts an increase on air traffic by a factor of three in the next twenty years, and the present rate of less than two accidents per million flights will become unacceptable[1]. Moreover, information technology has provided a fast economic expansion with aggregated benefits, which has to be applied into our National AirSpace (NAS) system[2].

NASA and FAA have established a partnership in Global Civil Aviation to develop an air transportation system for the next century of unquestioned safety that improves the Nation s mobility. It focuses on research leading to technologies that best promote aviation safety and can be implemented rapidly. In particular, the goal of NAS Aviation Safety Program[3] (AvSP) is to develop and demonstrate technologies that contribute to a reduction in aviation accident and fatality rates by a factor of 5 by year 2007 and by a factor of 10 by year 2022. Within this program, the Aviation System Modeling & Monitoring (ASMM) Thrust[4] provides real-time risk assessment and warning of operation hazards. Its challenges are to develop techniques to access and integrate vast quantities of operational data from world-wide sources, to develop analysis techniques that establish aircraft and airspace operations baselines and real-time, distributed modeling and simulation capability, to assess off-nominal conditions and trends for safety issues and solutions. The Analytical Tools and Environment for Design (ATED) is an Information Technology (IT) program of NASA to develop technologies with streamlined access to data, including data fusion tools for combining data from remote, geographically dispersed sources, across multiple disciplines with intelligent computational systems and interfaces. The present program, NAS System-wide Simulation is a combined effort of the ASMM program led by Mr. Y. Gawdiak and the ATED program led by Dr. D. Korsmeyer designed to fulfill its challenges of real-time, distributed modeling and simulation of the National AirSpace.

The general scope and method of approach is a distributed model connected in a national network system within a process of continuously measuring operational performance against expected performance and established operational procedures in order to identify deviations or trends that may be indicative of unsatisfactory performance. The purpose is to develop the tools and methodologies to obtain a perspective of what is happening today and of the impact of any changes that are introduced into the system. A user would execute and interact with a system that is monitoring, modeling, and evaluating risk exposure in air traffic over the entire United States, and the integrated airplane health management of engines, wings, tails, landing gear, airframe, flight controls and human models. The initial goal is to use Flight data to exercise and validate subcomponent models of the NAS.

Architecture

The general architecture of the NAS System-wide Modeling is based on data collection of airborne and surface flight operation data, digital flight data, radar tracks, airline schedules, and terrain data being pulled together under NASA AvSP. The data is stored and transferred through a secure network under the Information Power Grid (IPG) [5] and connected to all the Centers of Expertise (CoE) to provide the modeling and simulation baselines. The technological requirements and their diversity bring up the challenge to build a scenario-based to serve as prototype for all models in this exploratory effort.

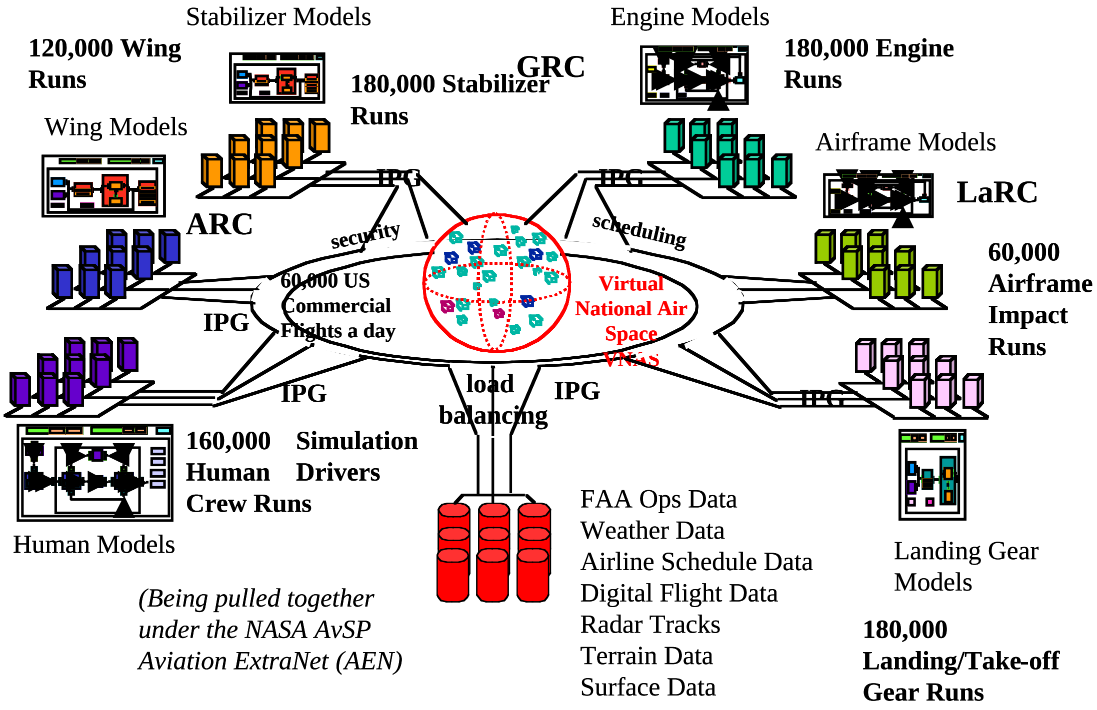


Figure 1. Daily NAS Simulation Baseline Generation (Y. Gawdiak)

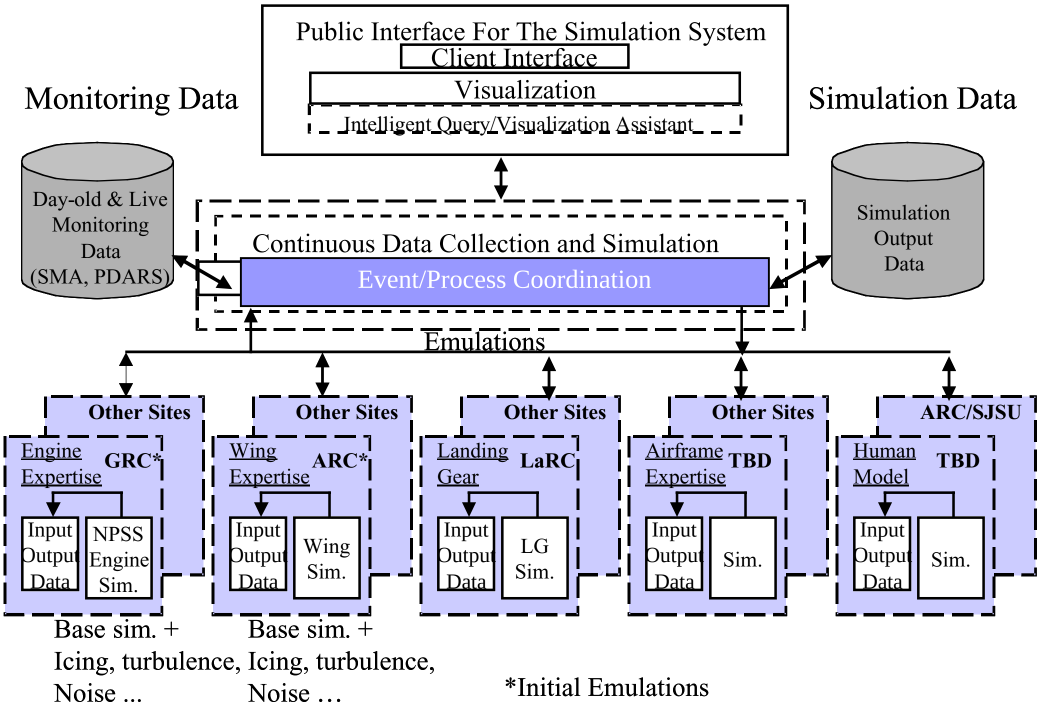
The initial effort is a feasibility analysis using a subset of traffic data and system models. This phase is being implemented for batch-processing now and real time later of arrivals and departures data through take-off or landing and surface movement at the Hartsfield Atlanta International Airport, which is one of the busiest airports in the world, generating near-real time modeled engine data at Glenn Research Center and modeled wing data at Ames Research Center. Weather information, aircraft models, and engine models representative of the flight conditions at this high-traffic airport in a combined systems executing within an integrated framework accessible from UNIX to NT platforms.

In this process, a tool allows a user to initiate processing of a particular day s flight-data. Raw data is pre-processed to provide a unique reference to all models and transferred to the particular CoE. Pre-processing involves generating Mach number, angle of attack, wind speed and general modeling parameters and data transferring to different nodes for simulation. For the Engine Model, the simulation software, NPSS V1.0, produces modeled engine values and checks anomalies and sources for risk assessment, and transfer this data to the user s node. Engine-operating parameters include shaft rpm, compressor inlet and outlet temperatures and pressures, turbine inlet and outlet temperatures and pressures, and fuel burn rate. Flight data is also transferred to a computing node for Wing simulation. The wing simulation software, Wing 1.0, will produce modeled values of the associated wing parameters, and check anomalies and sources for risk assessment. The aerodynamic simulation system provides wing and control surfaces forces and moments for the wing and its control surfaces. In the future, a visualization tool will allow the user to monitor the plane, engine, and wing flight components and determine the vehicle health and risk assessment based on the expected plane trajectory.

The demands imposed on this system will increase to the present requirements of about 60,000 flights per day, with 13,000 aircrafts in the air at any one time; radar data from a dozen Level V airports, large number of small airports, and FAA centers. The CoE simulations and single and multiple users are distributed at disparate geographical locations with continuous batch processing for data mining from FAA, aeronautical industries and airlines.

The goals of this model are multiple and complex to achieve real-time modeling, simulation and risk assessment, and its components and system integration can be applied to many technological problems of present interest, such as the engineering models and simulations of complete propulsion systems.

Main Elements



Base sim. + Icing, turbulence, Noise ...

Base sim. + Icing, turbulence, Noise …

*Initial Emulations

Figure 2. NAS Wide-Simulation Overview

Major elements of this process is the acquisition, storing and processing of the monitoring data, the simulations in each CoE, and the visualization of all the surface, arrivals, departures, and airborne data in the client interface through a secure and reliable grid.

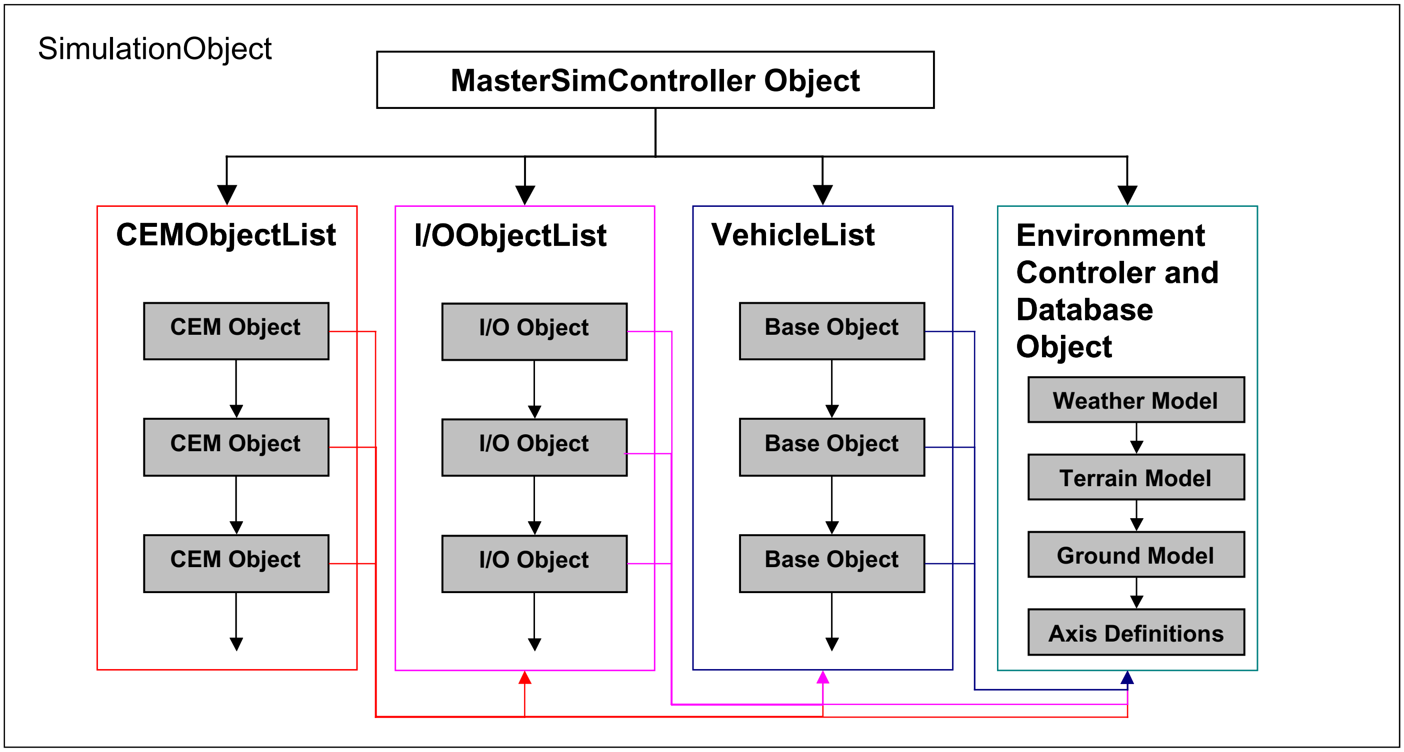


Figure 3. Simulator Architecture.

The integration of these different disciplines is fundamental to develop an accurate and insightful method for real-time modeling of the local integrated airplane health management and monitoring of operations of the global national air space. It is a distributed model connected in a national distributed network system. It processes continuously measuring operational performance against expected performance and establishes operational procedures in order to identify deviations or trends that may be indicative of risk exposure. It provides a baseline for development of tools and methodologies to obtain a perspective of what is happening today and of the impact of any changes that are introduced into the system. It is a comprehensive system with developments and implementations contributing to the modeling of the National Aviation System. The simulator architecture shown in figure 3 provides a hybrid simulation for synchronous event/process coordination of asynchronous objects and elements.

Environment

User executes and interacts with a system that is monitoring, modeling, and evaluating risk exposure in air traffic over the entire United States, and the integrated airplane health management (engines, wings, tails, landing gear, airframe, flight controls,). resent phase is being implemented to process real time gathered data of arrivals and departures through take-off and landing of the Hartsfield Atlanta International Airport, one of the busiest airports in the world, generating near-real time modeled engine data at Glenn Research Center and modeled wing data at Ames Research Center/

In the present process, a tool allows a user to initiate processing of a particular day s flight-data. Raw data is pre-processed and transferred. Pre-processing involves generating Mach number, angle of attack, wind speed and general modeling parameters and data transferring to different nodes for simulation. Engine simulation software, NPSS V1.0, produces modeled engine values and checks anomalies and sources for risk assessment, and transfer data to user s node. Engine-operating parameters include shaft rpm, compressor inlet and outlet temperatures and pressures, turbine inlet and outlet temperatures and pressures, and fuel burn rate. Flight data is also transferred to a computing node for Wing simulation. The wing simulation software, Wing 1.0, produces modeled values of the associated wing parameters, and will check anomalies and sources for risk assessment. The aerodynamic simulation system provides wing and control surfaces forces and moments for the wing and its control surfaces. In the future, a visualization tool will allow the user to monitor the plane, engine, and wing flight components and determine the vehicle health and risk assessment based on the expected plane trajectory.

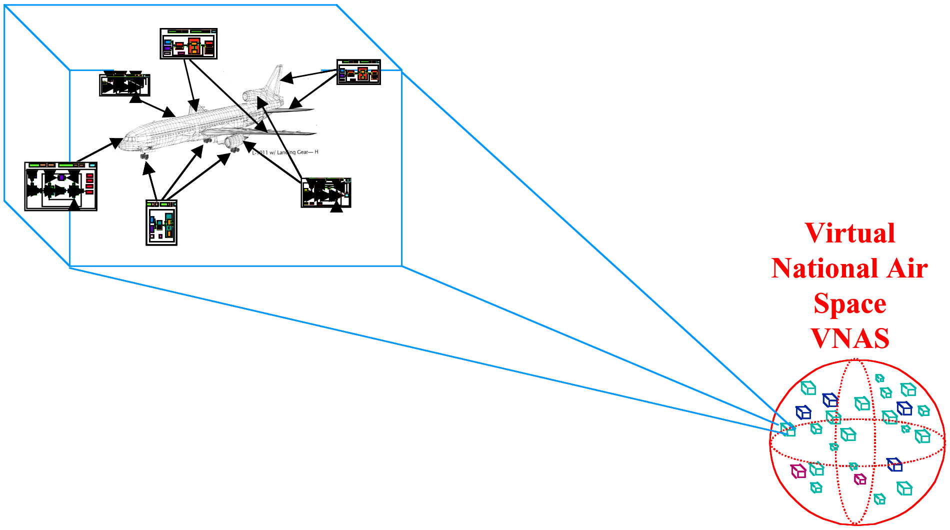


Figure 4.National AirSpace (Y. Gawdiak)

Simulation Models

The surface data, airborne data, radar tracks, weather data is enriched with the addition of modeled data added at each CoE. The first model implemented was the engine model, which is described below. The Wing Model is under current implementation, and the Landing Gear and Human models planned for implementation in the next months. These models are all dynamics; their processing time is correlated with levels of accuracy and the complexity included in each model. New versions are implemented with better available technologies and processors.
The integration of all these technologies is a major challenge in aviation safety.

Figure 5. Aviation System Monitoring Modeling (Y. Gawdiak)

Engine Model

Within NASA's High Performance Computing and Communication (HPCC) program, NASA Glenn Research Center is developing an environment for the analysis/design of aircraft engines called the Numerical Propulsion System Simulation (NPSS)[8-13]. NPSS focuses on the integration of multiple disciplines such as aerodynamics, structures, and heat transfer along with the concept of numerical zooming between 0- Dimensional to 1-, 2-, and 3-dimensional component engine codes. In addition, the NPSS is refining the computing and communication technologies necessary to capture complex physical processes in a timely and cost-effective manner. The vision for NPSS is to create a "numerical test cell" enabling full engine simulations overnight on cost-effective computing platforms.

To contribute to the goals of the Aviation Safety Program (AvSP) within the Aviation System Monitoring and Modeling (ASMM) project, the Numerical Propulsion System Simulation (NPSS) will contribute the engine modeling to the NAS Sim program. NPSS V1.0 is used to characterize the performance and risk exposure of commercial turbofan engines by processing radar tracked data from commercial flights originating from a major US Airport. The NPSS V1.0 is a 0 Dimensional aero-thermal dynamic code that accepts radar data inclusive of parameters such as Mach number, altitude, and weather. The NPSS V1.0 calculates engine-operating parameters including shaft rpm, compressor inlet & outlet temperatures and pressures, turbine inlet & outlet temperatures and pressures, and fuel burn rate. Additionally, by exercising NPSS ability to numerically zoom to codes of higher fidelity, NPSS will zoom to higher-order models of the compressor and turbine providing insight to the Risk Exposure of the engines by in depth modeling of these two components.

The interim architecture presently implemented at both Ames Research Center (ARC) and Glenn Research Center (GRC) is shown in Figure 6. Main factors in this system are the Secure Sockets Layer (SSL) protocols, the CORBA server/client, and the Globus Scheduler. SSL protocols provide communications privacy, reliability, encapsulation, encryption and authentification over the Internet. CORBA is the acronym for Common Object Request Broker Architecture that computer applications use to work together over networks and allows the NAS Sim to use different applications in the model within the same architecture. The Globus Scheduler in collaboration with the NASA Information Power Grid (IPG) team is being implemented to handle the assignation of computer resources used in the simulations. One of the objectives of the NAS Sim plan is to integrate the NAS Sim architecture with the NASA IPG to provide network access to high performance computers to all the widely geographically distributed models for batch processing of all the NAS System-Wide data.

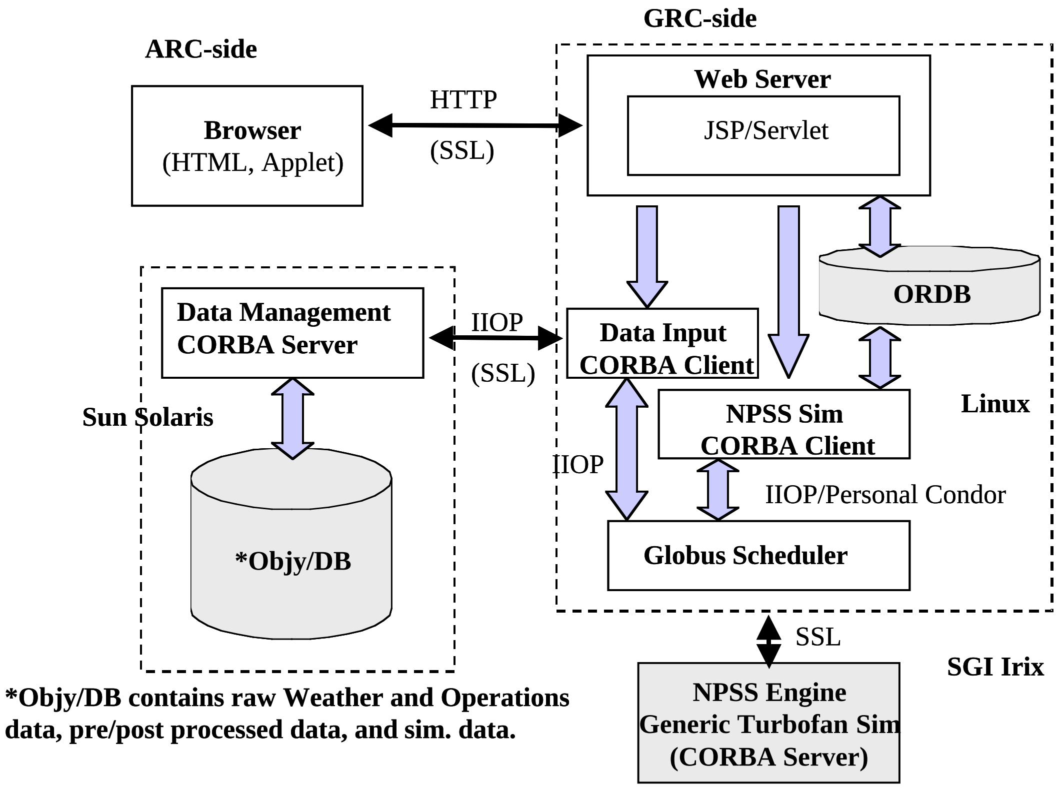


Figure 6. Interim Architecture

Demonstration

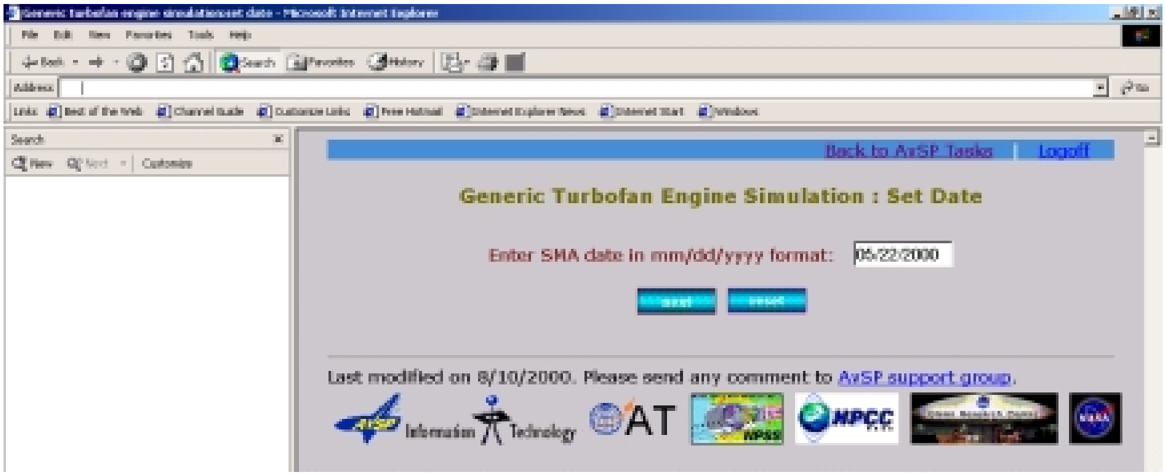
Surface Operations data consists of information about changes and position of a flight s state on the ground and in the air in the immediate area of the airport. For example, a departure s "pushback" time is the time the aircraft pushed back from the gate into the ramp area. Similarly, the flight s "spot" time is the time the aircraft moved from inside the ramp area into one of the taxiways. The time and coordinate information from radar-tracks shows the aircraft's position in the sky. However, Surface Operations data from Surface Movement Advisor (SMA) [6] or from

Performance Data Analysis and Recording System (PDARS) [7] cannot be used without first being preprocessed and encapsulated within a protocol. SMA and PDARS are joint FAA and NASA programs to help current airport facilities to operate more efficiently and to promote data sharing between facilities within California and FAA Headquarters, respectively.

Surface Operations data must be filtered to eliminate incorrect data and augmented by information based on weather. A separate program to properly reconcile radar tracks and other information about a flight checks the raw data. In this way the correct information is associated with the correct flight. In addition, information about local weather conditions is extracted from a NOAA weather source and linked with each flight. The combined information is used to calculate velocity and Mach number. Furthermore, a protocol is required to properly communicate information about each stage of a flight’s departure or arrival journey to the simulation sites.

The input data from the integration site is formatted into pre-arranged record types to form a communications protocol. For example, a flight s engine-start time is placed in a record that is formatted to indicate the nature of the information within the record. In this way simulation sites know, from the record type, the nature of the information within the record. This protocol is extended to cover simulation parameters sent back from the simulation sites to the integration system. Record types are used by the integration system to connect simulation parameters with the corresponding state and positional data points that were the matching stimuli for the simulation parameters that were generated. This integration (and the protocol mechanism upon which it depends) is a necessary condition if there is to be further analysis and visualization of the combined data.

A demonstration of the Engine Model processing flight data was conducted. This demonstration simulates a turbofan engine operating on an aircraft from takeoff through its climb to cruise altitude. NPSS processes the information data from a standing start on the runway to an altitude of 5000 feet, and the engines operating at take-off power level. Above 5000 feet, the engines operate at cruise power level. Radar data is available within a fifty-mile radius of the airport.



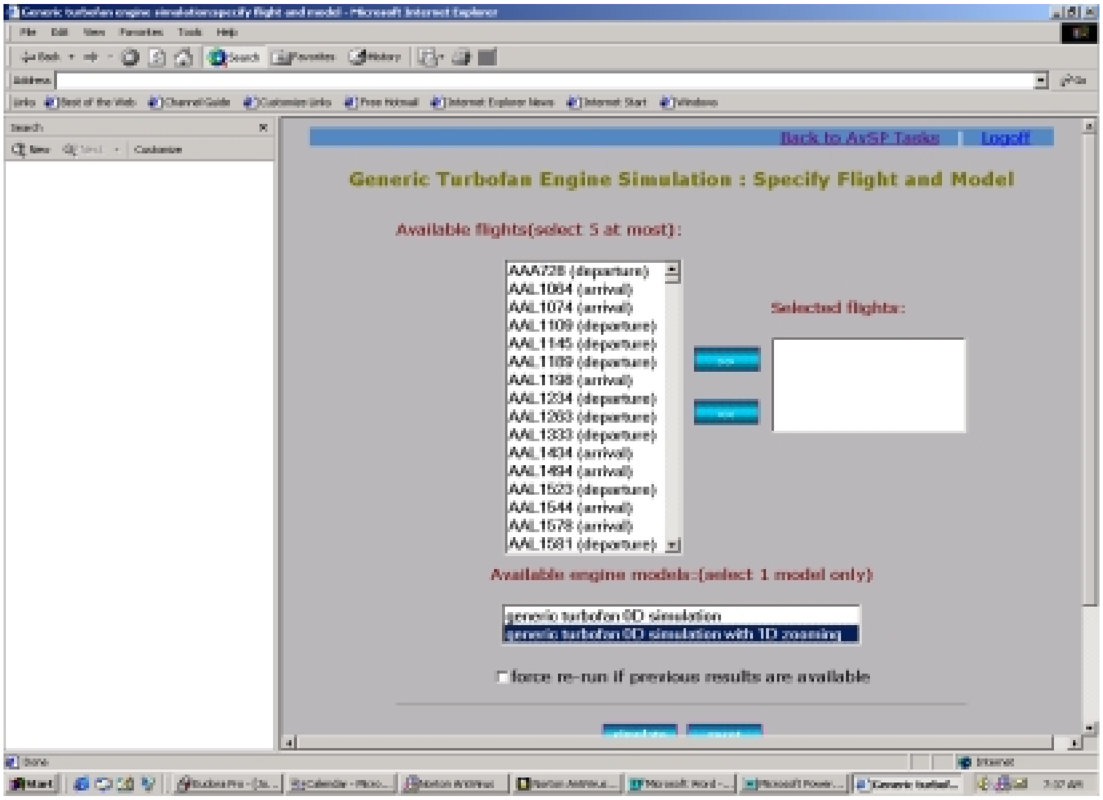
Generic Turbofan Engine Simulation : Set Date

Enter SMA date in mm/dd/yyyy format: 05/22/2000

Last modified on 8/10/2000. Please send any comment to AvSP support group.

Figure 7. Generic Turbofan Engine Simulation.

At each time step provided by the radar data, NPSS simulates the operation of the engines, calculating engine operational values. NPSS treats these series of time steps as a sequence of steady-state cases: that is for each time step, calculations are made independent of the previous time step(s) calculations. From these calculations, NPSS writes high-speed shaft rpm, low-speed shaft rpm, and temperatures for the burner and the inlet, exit temperature and pressure for the high-speed compressor and the high-speed turbine.



Generic Turbofan Engine Simulation : Specify Flight and Model

Available flights(select 5 at most):

AAA728 (departure)
AAL1064 (arrival)
AAL1074 (arrival)
AAL1109 (departure)
AAL1145 (departure)
AAL1189 (departure)
AAL1198 (arrival)
AAL1234 (departure)
AAL1263 (departure)
AAL1333 (departure)
AAL1434 (arrival)
AAL1494 (arrival)
AAL1523 (departure)
AAL1544 (arrival)
AAL1578 (arrival)
AAL1581 (departure)

Selected flights:

Available engine models:(select 1 model only)

generic turbofan 0D simulation
generic turbofan 0D simulation with 1D zooming

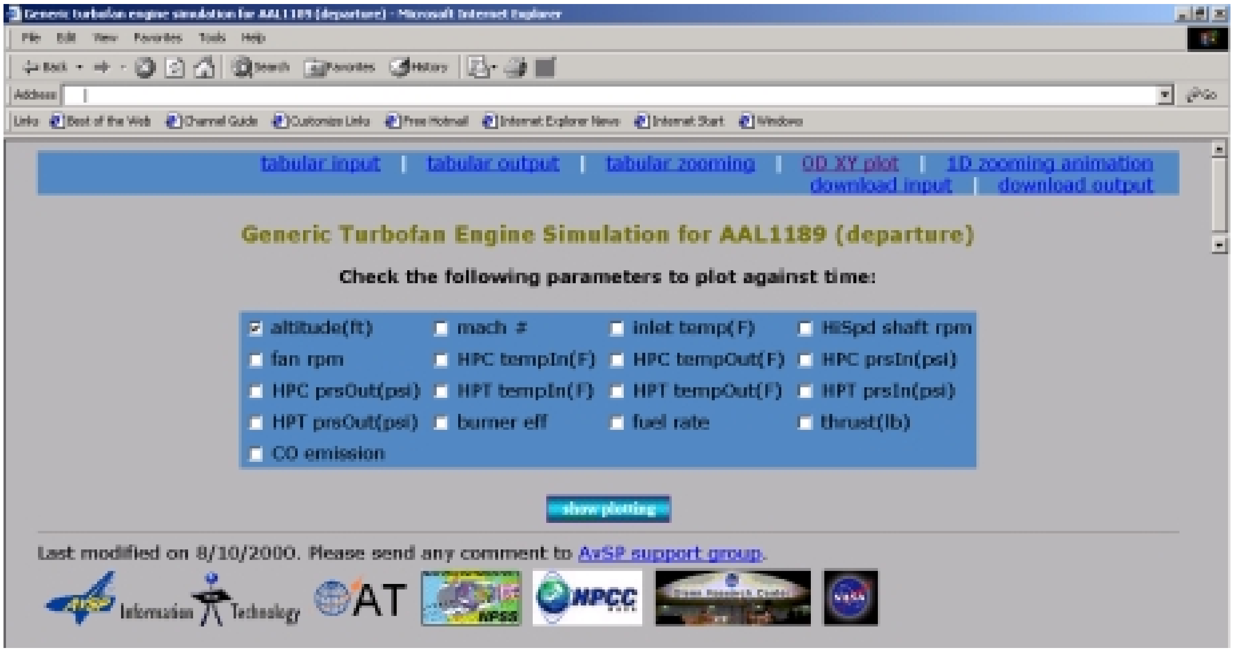
☐ force re-run if previous results are available

Figure 8. Engine parameters

For departing flights, the NPSS computations are made from beginning of takeoff until radar data ends. For arriving flights, these computations are made from the beginning of radar data until completion of landing. Specifically, the prototype built begins by asking for a selection of a particular day to investigate as shown in figure 7.

Once the day is selected, a search is conducted on all available flights for that day. These flights are presented for selection and labeled as arrivals or departures. Up to 2000 flights can be selected within one day, which is defined to be midnight to midnight. After the flights have been selected, the choice of a zoomed engine simulation or a non-zoomed engine simulation is highlighted per figure 8.

The selected flights are processed using the nominated engine model and are deployed over a cluster of UNIX and LINUX machines using the IPG GLOBUS software. As the NPSS V1.0 engine models complete, the output is retrieved using CORBA. Various outputs from NPSS V1.0 are now available for selection. These include tabular views of the input radar data and calculated NPSS engine parameters, X-Y plots of the engine data and zoomed animations of the compressor and turbine if zoomed a simulation were chosen. Representative figures of the output are shown below in figures 9 and 10.



Generic Turbofan Engine Simulation for AAL1189 (departure)

Check the following parameters to plot against time:

☑ altitude(ft)
☐ fan rpm
☐ HPC prsOut(psi)
☐ HPT prsOut(psi)
☐ CO emission
☐ mach #
☐ HPC tempIn(F)
☐ HPT tempIn(F)
☐ burner eff
☐ inlet temp(F)
☐ HPC tempOut(F)
☐ HPT tempOut(F)
☐ fuel rate
☐ HiSpd shaft rpm
☐ HPC prsIn(psi)
☐ HPT prsIn(psi)
☐ thrust(lb)

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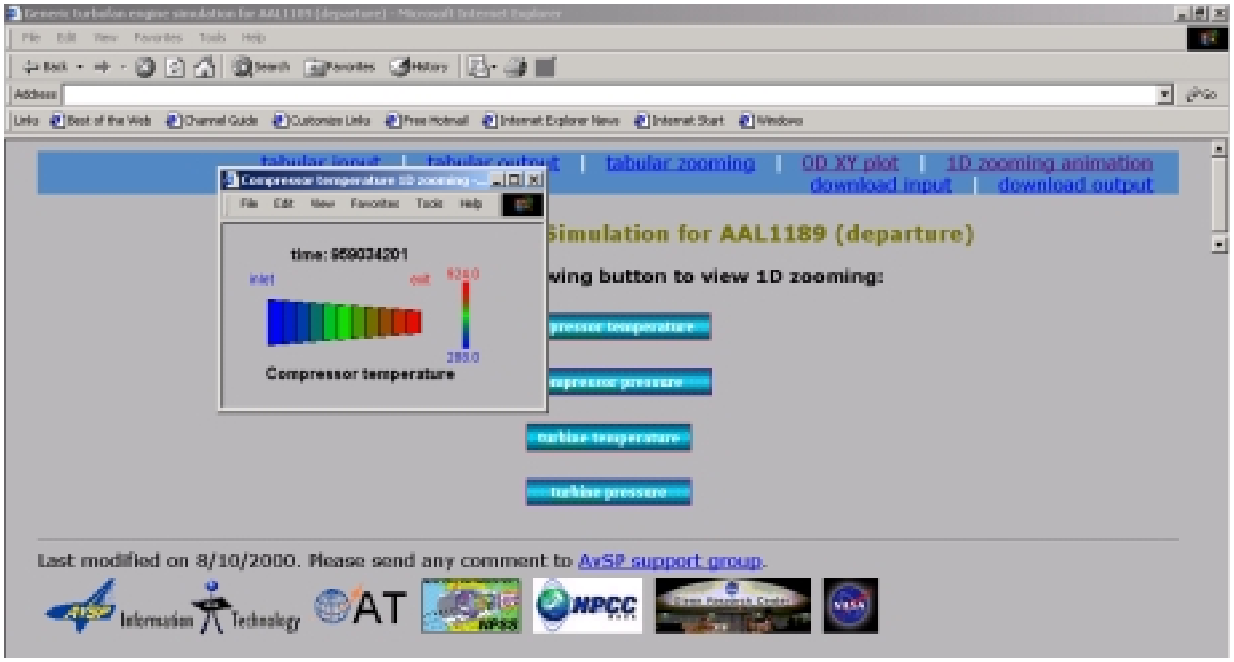
Figure 9 showing available XY Plotting selections



Simulation for AAL1189 (departure)

ving button to view 1D zooming:

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Figure 10 showing zoomed engine analysis

Future Simulation Work

The NAS Wide-System Simulation is beginning to integrate the Centers of Expertise and explore the implementation of the system architecture at both Ames and Glenn Research Centers.

In this coming year, the GRC Engine Model and the ARC Wing Model will be integrated with the IPG to deploy batch simulations of the SMA and PDARS data. The Landing Gear Model being developed at NASA Langley Research Center and the Human Model being developed at NASA Ames Research Center and San Jose State University will be tested and incorporated into the NAS Sim. CORBA and CORBA security will be activated for retrieval and storage of each model data object. Additionally, all these simulations will be coupled together to provide a realistic operational aspect to the simulation.

Integration of multiple disciplines such as aerodynamics, structures, and heat transfer along with the implementation of higher-order models will follow hand-on-hand in the Engine and Wing models to capture complex physical processes in a timely and cost-effective manner. The vision is to create overnight simulations on cost-effective computing platforms in Object Oriented system architecture to evaluate risk exposure and design elements.

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