AIAA 4th Aviation Technology, Integration and Operations (ATIO) Forum
20 - 22 September 2004, Chicago, Illinois

AIAA 2004-6399

Efficient Air Traffic Scenario Generation

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A significant investment has and continues to be made by the FAA, NASA, and other organizations to improve the state of the National Airspace System (NAS) and avoid the impending air traffic grid-lock. Much of this effort involves developing and testing new concepts to improve the efficiency and safety of the NAS. Human-In-The-Loop (HITL) simulations play an important part in evaluating critical human factors issues related to these new concepts. The current method of developing HITL scenarios tends to be a highly iterative, labor intensive process. This paper describes the ongoing research and development of a software tool intended to significantly increase the efficiency of researchers generating and manipulating scenario data for real-time HITL air traffic simulators. This goal is achieved by allowing researchers to quickly and easily generate and evaluate scenarios on a single desktop computer rather than using a target simulator to create scenarios. The tool, AvScenario, is a modern graphically oriented application that automates and simplifies many of the tasks associated with scenario generation. AvScenario is a general-purpose tool that will work with multiple input data formats and produce generically formatted scenario data that can be targeted to specific simulators.

I. Introduction

Fast-time simulations of the NAS are widely used to investigate current and future aspects of the NAS and generally require fewer resources (time and money) than real-time simulations. However, real-time simulations remain an essential step in the process of evaluating specific concepts at a more detailed operational level, specifically evaluation of human performance. These detailed evaluations are required prior to fielding new procedures and Decision Support Tools (DST). A combination of both real-time and fast-time simulations is required to investigate concepts designed to increase NAS capacity.

Generating scenarios for real-time simulators is currently a resource intensive activity. Typically the design of a simulator does not concentrate on generation and manipulation of input data, but instead is focused on the execution of the simulation. When scenario generation capabilities are provided, these scenario generation methods are tightly coupled to a specific simulator and cannot be used to generate or manipulate scenarios for other simulators. Additionally there is growing emphasis in building distributed real-time simulators, which tie together legacy systems to simulate more aspects of the NAS in one simulation. This requires that scenarios be capable of working

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across multiple individual simulation components. Generating and manipulating input data for these systems is a technical challenge.

This paper describes current research and development of a software tool that will assist researchers in generating and manipulating scenario data used as input to real-time (RT) human-in-the-loop (HITL) air traffic simulators.

II. Background

A. Real-time Air Traffic Simulations

Worldwide, government organizations utilize HITL air traffic simulations to study the feasibility, robustness, and effectiveness of advanced Air Traffic Management (ATM) concepts and the human role in these concepts.[1-5] Scenario development is critical to the effective analysis of these concepts.[6] Researchers construct and utilize distributed simulations of medium and high-fidelity cockpit and ATM simulations to evaluate new operational concepts.[7-10] State-of-the-art cockpit simulators include advanced motion-based cockpit simulators such as the Advanced Concepts Flight Simulator (ACFS) at NASA Ames Research Center and the Aircraft Simulation for Traffic Operations Research (ASTOR) at NASA Langley Research Center.[11] State-of-the-art ATC simulations include NASA's Airspace Operations Laboratory (AOL), NASA's Center TRACON Automation System (CTAS) Verification and Validation (V&V) Laboratory, and the FAA's Target Generation Facility (TGF) [12, 13] and Human Factors Laboratory.[14, 15] Additionally, a number of pseudo-pilot software applications exist such as NASA's Pseudo Aircraft System (PAS),[16] and the Nationaal Lucht- en Ruimtevaartlaboratorium (NLR) Traffic and Experiment Manager (TEM/TMX)[17] that enable multi-aircraft human control of aircraft as well as the setting up of scripted background air traffic. Moreover, distributed remote access to human-in-the-loop simulations are being enabled by advanced, virtual reality simulation techniques.[18]

NASA is in the midst of the five-year Virtual Airspace Modeling and Simulation (VAMS) project.[19] The VAMS project will utilize multiple scenarios of the future NAS driving real-time and fast-time simulations as a primary method of evaluating the capacity-improving System Level Integrated Concepts (SLIC).[20] The real-time simulation capabilities being developed to support VAMS are extensive and include simulators representing air traffic control and flight deck environments.[21, 22]

B. Typical Scenario Generation Process of Today

Currently, generation of realistic and useful scenarios for real-time human-in-the-loop simulations can take several months of manual effort. The reasons this process is so laborious are primarily related to the lack of sophisticated processing techniques for the wide range of disparate data sources which have limited standardization of content. There is also a fairly wide range of capabilities between the various research organizations.

The general scenario generation process is illustrated in Figure 1. This is a generic representation and is more accurate of some research organizations than others. The scenario generation process begins by defining the simulation objectives which includes understanding the operational environment and stakeholder input.[15] Next, the experiment is further defined by specifying metrics and determining scenario characteristics.

Typically, the next step is to obtain operational and aircraft traffic data as a starting point for the scenario and then modifying the data to the particular requirements of the desired scenario. This can be a significant effort as the operational and traffic data resides on FAA computers that non-FAA personnel may not be able to access. Scenarios typically use current data as a starting point, as that ensures a reasonable level of realism that is more difficult to acquire when starting from scratch. The practice of starting with existing data is acceptable when creating a scenario that represents current NAS traffic and operating conditions. The various data used in scenario generation are discussed in Section III. Use of existing data to represent future traffic and operational conditions will require significant modifications. In some cases it may be easier to start from scratch, which would represent a basic form of airspace redesign likely to be desirable by researchers who propose new concepts of operation for the NAS.

Once the initial data have been acquired, the researcher focuses mainly on manipulation of flight data to construct the desired scenario. This includes specifying the simulation and operational conditions of each flight (e.g., simulation start time, altitude and cruise speed) and the initial version of the route flown during the simulation for each flight. The routes (and flight characteristics) of specific flights are the intended objectives of the aircraft, but are often modified during the actual HITL experiment. The current process for manipulating flight data during scenario generation typically involves direct data access (e.g., spread sheets and text files) and manual changes.

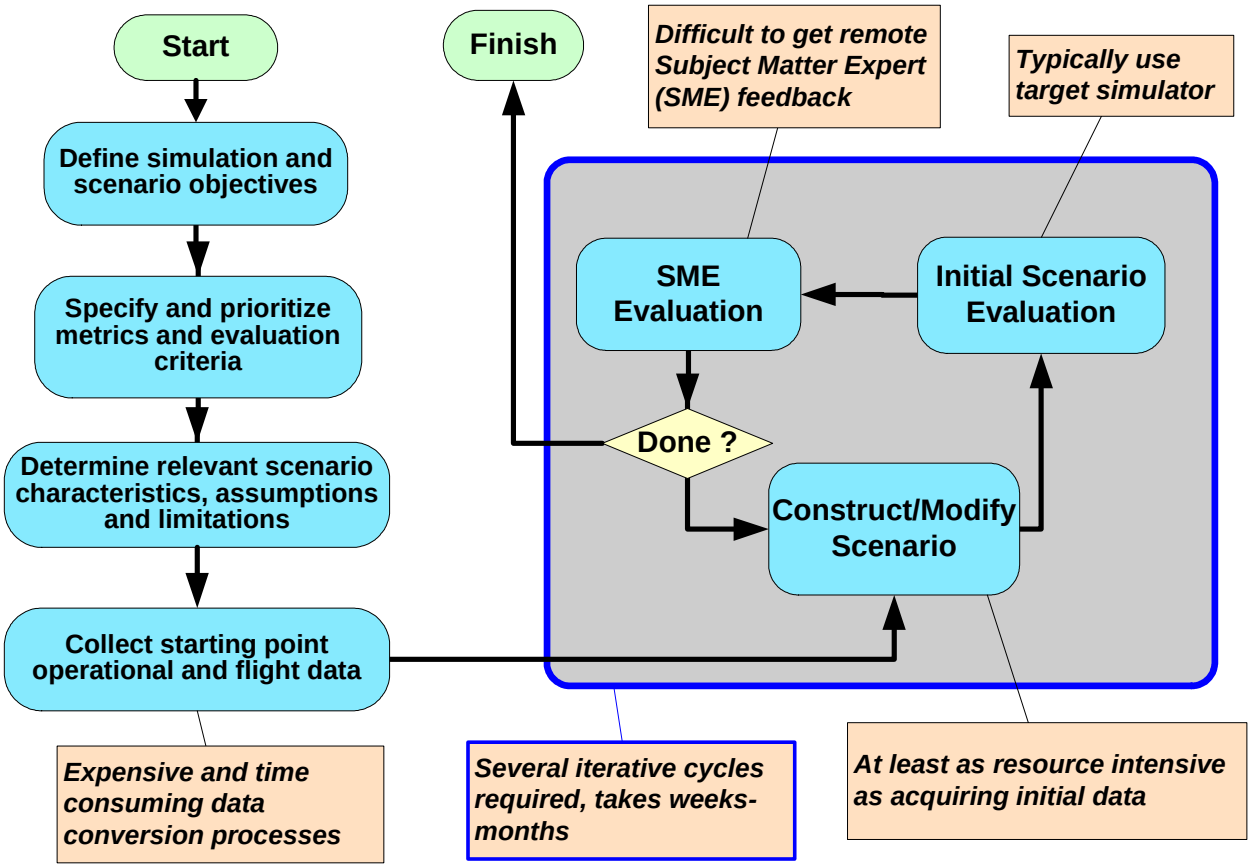

Figure 1. Typical real-time scenario generation process of today

Evaluation of the scenario is typically done using the simulator that will be used in the final experiment. This has the advantage that what is seen during the evaluation closely follows what may happen during the actual experiment. The big disadvantages of using a large simulator for evaluating the scenario is the high cost and slow turnaround time, especially if multiple iterations are performed.

In the current/typical process, after a scenario is developed, it is not generally portable to any other simulator other than the one on which it was developed. This impacts the review process – if the only way to visualize a scenario is to run it through the simulator, then subject matter experts (SME) who review the scenario need to be co-located with the experiment (at least temporarily).

The intensive resource requirements of scenario generation and modification (for use in real-time simulations) have historically limited the quality, frequency, and depth of NAS simulation investigations. Real-time (RT) -HITL experiments will always be expensive by virtue of the number of people involved. However; increasing the efficiency of scenario generation and manipulation in the pre-simulation environment can reduce the overall resources required to perform HITL simulations and allow HITL simulations to be developed in a more timely manner.

C. Current Scenario Generation Tools

Researchers who generate air traffic scenarios use various simulators and associated tools supplemented with customized data processing programs to modify an existing data set into the desired scenario. The simulators and tools are generally custom built to support the research. The scenario data, from those applications, are not designed to be used by other simulators.

The FAA at the William J. Hughes Technical Center has developed mature scenario generation processes, tailored to their specific needs. The Human Factors (HF) group can develop scenarios, from scratch or from existing data, for use in their RT-HITL simulation experiments. The HF group uses AWSIM[23] which was custom built under contract, to assist subject matter experts (SME) in development of scenarios from scratch and from existing data for use in the simulators located at the FAA Technical Center. The FAA Simulation and Analysis Group have also

developed scenario generation methodologies. One of their scenario generation techniques involves the use of genetic algorithms to time-shift flights taken from recorded data to produce specified conflicts.[24, 25]

NASA Ames has been generating scenarios for their HITL NAS research for many years and has developed in-house scenario generation capabilities which service their needs. Current work is in conjunction with Multi Aircraft Control System (MACS)[26] which is used in the Airspace Operations Lab (AOL)[27]. The AOL is part of the VAST-RT simulation capabilities. The Trajectory-Centered Simulator (TCSim)[28] is a fast-time simulator developed at NASA Ames which contains automated scenario generation capabilities designed specifically for use in conjunction with the AOL.

D. Purpose of Research

The purpose of this research is to develop a software application that increases the efficiency of generating and manipulating air traffic scenarios for use in real-time HITL simulation experiments of both the current and future NAS. The demand for real-time simulations taking place in the current and future NAS is expected to increase, as researchers work towards increasing the efficiency and capacity of the NAS. Our research and development effort will produce an application which simplifies and automates many of the time-consuming steps in the scenario generation process. The scenario generation application will provide features to support the creation and manipulation of flight plan information as well as NAS, environmental, and aircraft performance data. The application will include capabilities that allow a user, i.e., the researcher, to quickly evaluate and modify a scenario. The scenario output files will contain the initial conditions subsequently used as input by real-time air traffic simulators. RT-HITL air traffic simulations typically contain 200 to 300 flights per scenario and generally cover a time-frame of no more than 2 hours.

The scenario generation application will initially be used by NASA's Virtual Airspace Simulation Technologies – Real-Time (VAST-RT) system which is part of the VAMS project. The distributed VAST-RT simulation capability combines several simulators. We expect to acquire invaluable user feedback from the first usage of this tool. The feedback will be incorporated into the future product. The focus of our current research, conducted during the Phase-II SBIR (Small Business Innovative Research), is in four major areas:

1) Identification of essential data types and sources (and specific parameters within those sources) and reading those data into the scenario generation tool,
2) Efficient generation and manipulation of data into scenarios,
3) Rapid evaluation of the scenario and a mechanism for rapid iterations of manipulation and evaluation, and
4) Analysis of both the scenario and the output data. The output data will be designed (content and format) so that it can readily be transformed and subsequently used as input to other simulators.

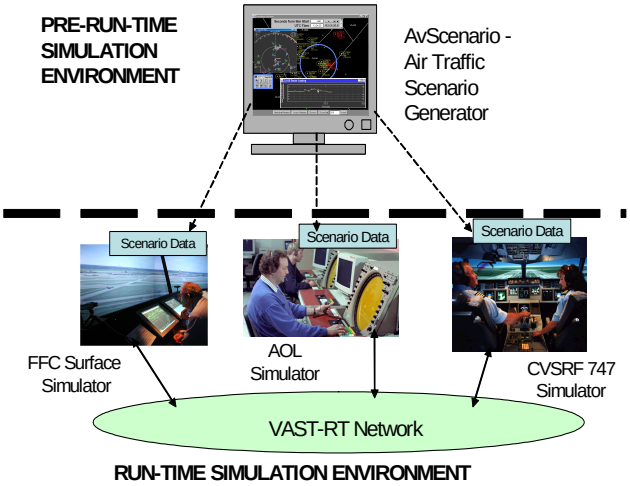

Figure 2. Example AvScenario environment

AvScenario is the tool being developed under this research to provide efficient scenario generation functionality to air traffic simulation users. AvScenario is intended to be used in the pre-run environment of subsequent RT-HITL simulations. An example of this usage as applied to the NASA Ames VAST-RT system is shown in Figure 2. VAST-RT includes Future Flight Central (FFC) which is an advanced tower cab HITL simulator, the Airline Operation Laboratory (AOL) which provides target generation and control/pilot stations, and the Crew Vehicle Systems Research Facility (CVSRF)[29] which provides cockpit simulation. AvScenario will generate the data file(s), i.e., the "scenario", that are used as input to the RT-HITL simulators. The scenario will contain the initial conditions for the simulation. The actual simulation results will likely differ from those seen during scenario evaluation for several reasons, one of which is that the human participants in the experiment will affect the course of specific flights – which is the intent of the HITL experiment. The example shown in Figure 2 illustrates that AvScenario is separate from the simulation and is intended to produce scenario data that can be used in a variety of simulators.

AvScenario will not entirely replace the current evaluation process, but it will reduce many of the iterations on the target simulator and thus decrease the resources necessary to produce the final scenario. AvScenario is also expected to be useful for making changes to existing scenarios that are resurrected for new purposes.

III. An Efficient Scenario Generation Tool

AvScenario functionality, which will provide efficient scenario generation capabilities to air traffic simulation users, is divided into four basic categories, as shown in Figure 3; Input Data, Scenario Generation, Scenario Evaluation, and Output Data. This section provides an overview of the features, in each of those four categories, required to efficiently generate air traffic scenarios. Section IV provides more details on selected features.

The first functional category of AvScenario is processing input data. The four primary types of input data, common to all air traffic scenario generation, shown in Figure 3 are: 1) air traffic or flight data (e.g., aircraft initial state, flight plans), 2) NAS data (e.g., airspace and sector geometry, airport configurations and operational procedures), 3) environmental data (e.g., wind speed/direction and convective weather), and 4) aircraft performance data (e.g., maximum and minimum speeds as a function of altitude per aircraft type). Acquisition of initial input data is a huge task by itself. Each of the four primary types of input data has a wide variety of potential sources. The input data are known to contain errors and inconsistencies which will be filtered (at least partially) during initial reading of the data. The primary types of input data are described below.

Starting from existing flight data has its own set of problems but is generally easier than starting from scratch[‡‡] for the case of a scenario that represents the existing NAS. Flight data can be obtained from vendors who specialize in this area, from the FAA or from NASA. There are several difficulties associated with this step, such as lack of a data "standard," data cost, and additional processing to render the data usable in the desired simulation. Potential sources of flight data include the following: Enhanced Traffic Management System (ETMS), Center TRACON Automation System (CTAS) captured data, Pseudo Aircraft Systems (PAS), System Analysis Recording (SAR) data files from the FAA Host computer, Critical FAA Data Recording (CDR) data files, Archived Out-Off-On-In (OOOI) data, and Aviation System Performance Metrics (ASPM) data. AvScenario will initially focus on using ETMS, CTAS and PAS flight data. As shown in Figure 3 AvScenario will also be able to re-read its output scenario as input data.

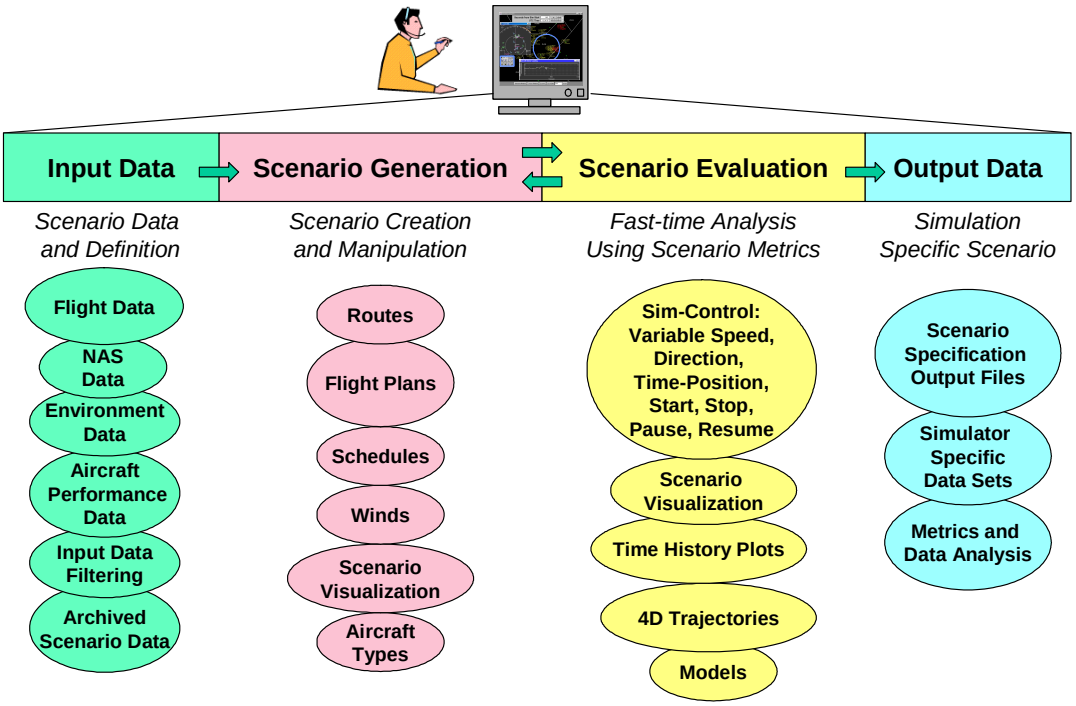

Figure 3. AvScenario functional categories and associated features

[‡‡] The FAA (William J. Hughes Technical Center) researchers have an advantage in this area, as they have direct access to most of the flight data that is desired, e.g., SAR.

NAS data can be obtained from vendors or from the FAA. There are multitudes of NAS data types and associated sources that can be considered when constructing a scenario. Fortunately, NAS data do not change too much between successive simulations of a region for simulations representing current operations. However, researchers often need to efficiently modify NAS data to reflect what the future NAS may look like as well as accurately represent the NAS of today. Modifying NAS data can be a tedious and error-prone process. AvScenario will focus on use of National Flight Data Center (NFDC) data that are provided by the FAA.

Environmental data, which includes winds and weather, can be obtained from vendors, National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) and, for the case where the scenario requires the environment data associated with specific flight data from NASA or the FAA. As with NAS data, the environmental data are significant in volume and diversity. AvScenario will initially use Rapid Update Cycle (RUC) data and wind aloft data acquired from FAA/NASA.

The last of the four primary types of input data is aircraft performance. The most common source of such data is Base of Aircraft Data: BADA[30] which AvScenario will use. AvScenario will supplement BADA data with internal models of performance for various types of aircraft. Aircraft performance data does not change frequently, but acquiring accurate and consistent data has long been an issue.

AvScenario input data will be re-used as much as possible to minimize the effort in creating a new scenario. For example, a new scenario representing DFW may re-use existing NAS, aircraft and environment data and only change the flight data to investigate some other operational condition.

The second functional category is scenario generation and manipulation. This is the step where a scenario is first created, which may include generation of data but more typically it involves manipulation of existing data. The user will be able to generate scenarios based on the recorded historical data. The user will also be able to generate scenarios that are not based on an existing data set. Since such scenarios are often intended to represent the future (e.g., 2022), AvScenario must allow the user to quickly adjust parameters that would otherwise be considered fixed when generating a scenario to represent the current NAS. For example, the FAA Standard Terminal Arrival Routes (STARs) and Departure Procedures (DPs) that affect the aircraft trajectories do not change frequently in scenarios that represent the current NAS. However, for scenarios that represent the future NAS, AvScenario will allow the user to build scenarios where the procedures are user-defined, easily changed, and not constrained by current operational limitations.

The third functional category is scenario evaluation which is accomplished with an internal simulator. The internal simulator allows immediate evaluation of the scenario. The simulator must be capable of reasonably evaluating the scenario, but it is not necessary for it to be an advanced simulator. Based on the results of the scenario evaluation, the researcher will manipulate the scenario as needed using the same features that were used to create the initial scenario. Successive iterations between evaluation and manipulation will be necessary before the scenario is complete. The goal of this tool is to make this iterative scenario development much more efficient than it is with the current scenario generation tools.

The fourth functional category is generation and processing of the scenario output data. The generated scenario data will be output in a well documented format. This format will easily be converted to the input format of other real-time simulators (e.g., VAST-RT, PAS, MACS, TMX) or analysis tools such as the FAA's Integrated Noise Model (INM) or Boeing's Global Aircraft Emissions Model (GAEM). The result of metric analysis will also be an output from the simulation evaluation.

IV. Selected AvScenario Features

This section describes selected AvScenario features from each of the four functional categories outlined in Section III.

A. Data Input

Creating an air traffic scenario requires an extensive amount of supporting data including; schedules, routes, flight plans, airports, navigational aids, airspace sectors and wind fields. AvScenario will read these and other types of input data from a variety of sources.

1. Flight Data

Currently, many researchers use recorded flight data as a basis for creating new air traffic scenarios. Recorded flight data contains information about individual flights, schedules, routes and flight plans. Starting with the captured flight data, the researcher adds, subtracts, and modifies flights creating a realistic scenario to meet the needs defined by the simulation requirements. Although AvScenario users will be able to create scenarios without

relying on preexisting flight data, it is anticipated that a majority of scenarios will be created using recorded flight data or by modifying flight data from an existing scenario. For this reason, AvScenario provides strong support for reading and manipulating preexisting flight data.

Initially, AvScenario will support two sources of recorded flight data: ETMS and CTAS. These data are generally the most readily available and contain the necessary flight information. ETMS data files[31] are expected to be an important basis for scenarios, as ETMS data are reasonably available to researchers and contain details about each flight. Since ETMS data can have slightly different formats and content depending on the data provider, AvScenario will be limited to a single source of ETMS data, at least initially.

Flight information from CTAS data files (a.k.a. "cm_sim") is also expected to be used for creating scenarios. CTAS data are available, from NASA Ames, for most Air Route Traffic Control Centers (ARTCC) and can be used to supplement ETMS data. Documentation regarding the content of CTAS data exists but is sparse and not in the public domain.[32]

In addition to recorded flight data, AvScenario will also support PAS input data files. CTAS data can be converted to PAS data. PAS is one of the tools that NASA uses to drive and create air traffic scenarios for real-time ATM simulations. A large number of PAS data files currently exist. Allowing researchers to use these existing data allows them to efficiently exploit years of previous scenario development work.

Future sources of flight data may include System Analysis Recording (SAR), Critical Data Recording (CDR), Out-Off-On-In (OOOI), and Aviation System Performance Metrics (ASPM) data files. SAR data files from the FAA Host computer are a valuable starting point for scenarios, but are difficult to obtain and require expensive conversion. Use of FAA Data Analysis and Reduction Tool (DART) data (a derivative/filter of SAR data) may be useful, but are equally difficult to obtain.

CDR is the mechanism that records all the ARTS-IIIe/a critical information. There are many levels of filtering available (just as in the DART for the HOST), but the CDR data are very useful in determining exactly what the controller was seeing including radar. CDR is very analogous to the SAR data in the HOST. CDR data files are valuable but difficult to obtain and are purged after 15 days from origin.

Archived OOOI data can be used to supplement ETMS or CTAS data. The OOOI data contain detailed time data regarding push-back (out) takeoff (off), touchdown (on) and gate arrival or block-in (in) times. These data are valuable for generating schedules that reflect current airline practices. OOOI data are also included in ETMS data.[31]

ASPM data is another source of information about individual flights. Access to FAA ASPM data is via the ASPM website[33] with permission from the FAA.

2. Flight Data Filtering

Recorded flight data are expected to contain errors that will need to be handled before the flight information can be accurately extracted and used. ETMS data in particular are known to contain errors. Examples of flight data errors include duplicate flights with inconsistent times, altitudes, speeds. AvScenario will provide several levels of filtering to detect and handle the most common types of errors for each flight data source. The filtering will significantly reduce the number of errors, while allowing users to identify and correct problem flights if desired. Any flights that are discarded are logged along with the reason for rejection.

3. NAS Data

There are many types of data needed to describe the NAS. These data are necessary as the basis of scenarios representing the current and future NAS. AvScenario will be able to read in the necessary NAS data that are directly usable for scenario generation. Selected data will be provided with AvScenario, but due to licensing and data acquisition issues, the user will be required to independently acquire and supply a majority of the NAS data.

AvScenario will initially use NAS data supplied by the FAA through the National Flight Data Center. NFDC data are updated and published every 56 days. The data provided by NFDC include airways, navigational aids, airports, STARs, DPs, instrument approach procedures and special use airspace (SUA). The NFDC occasionally change data file formats. AvScenario will be maintained to support any format changes.

An important NAS data set not included with the NFDC data are ATC sector boundary definitions. AvScenario will provide a version of these data although the user will be able to modify and update it as desired.

4. Environmental Data

Scenarios can be highly dependent on environmental conditions, i.e., wind and weather. The ability to import recorded wind and weather data and use them in a scenario is critical. This is especially true for the case where a researcher is creating a scenario based on existing flight data which inherently includes the actual wind field data for that particular day and time. The AvScenario trajectory generator needs to know the wind field to calculate the

ground speed and calibrated airspeed. If the flight data are used without the associated wind data the airspeeds may be incorrect and modifications to the flight parameters will be necessary. If the user wants to apply a different wind field, the initial wind field needs to be subtracted off before a new one can be applied. The goal is to allow the user to apply any recorded wind data set to any existing flight data set.

AvScenario will support RUC wind data.[34, 35] RUC data provide a 3-D grid of wind vectors. Using a series of RUC files will allow a 4-D wind field to be used. In addition to RUC wind data simple 1-D wind vectors at multiple altitudes will also be supported.

Weather storm cells can cause significant air traffic deviations and are a major factor in NAS throughput. AvScenario will allow the user to modify weather cells' location and intensity. Recorded weather cells will be provided from NEXRAD (Next Generation Weather RADAR) files.

Other identified sources of weather data[36] which may be included in future versions of AvScenario include: Integrated Terminal Weather System (ITWS), Weather and Radar Processor (WARP), Collaborative Convective Forecast (CCFP), Surface Meteorological Airways Format (METAR), Aviation System Performance Metrics (ASPM), Terminal Area Forecast (TAF), ARINC's Meteorological Data Collection and Reporting System (MDCRS), and AIRman's METeorological Information - weather advisory (AIRMET).

5. Aircraft Performance Data

Each aircraft type used in a scenario needs to have an associated performance model. The AvScenario trajectory generator uses aircraft performance data to model the flight dynamics of a particular aircraft. The default AvScenario trajectory generator is Seagull Technology's Multi-Purpose Aircraft Simulation (MPAS).[12, 37] MPAS aircraft performance data are based on BADA[30] data. BADA is updated annually; however, because of additional MPAS constraints[§§], AvScenario will initially only support a specific version of BADA. This is not expected to be significant issue, as BADA does not change significantly from one version to the next.

In cases where a BADA performance model is not available for a particular aircraft, a model for a similar aircraft type can be substituted. AvScenario will provide a default mapping of BADA aircraft types to additional types found in ETMS data. The mapping can be modified and extended by the user as needed.

Eventually, the AvScenario user will be able to create and add models for aircraft types not in BADA (see Figure 3). Aircraft manufacturer's data are not available for all aircraft types, but are of higher quality than BADA. Industry representatives (e.g., Boeing) suggest that the aviation industry is planning to work more closely with BADA to improve data accuracy, which bodes well for the continued use of BADA by the aviation research community.

B. Scenario Generation

The ability to rapidly generate and manipulate a scenario is one of the key features of AvScenario. The objective is to streamline the process and make powerful features available as needed. This section describes features associated with generation and modification of the flight plan, route and schedule.

1. Route Generator

The route of a flight is the 2-D ground track, consisting of a series of waypoints[***] connecting the origin airport with the destination airport (the route with AvScenario may begin at an arbitrary point in space – which is typical for arrival aircraft in a HITL experiment and terminate at an arbitrary point in space – as for departures). Waypoints include: departure airport, gate push-back (block out time), wheels-up time, top of climb (TOC), each waypoint in the route, top of descent (TOD), wheels on (landing), gate arrival (block in time), and arrival airport. Altitude and speed at each waypoint are not part of the route data (these are contained in flight plan and trajectory). AvScenario will provide three mechanisms for the user to rapidly generate and manipulate route data. Starting with the assumption that the most common course of scenario generation is to begin by AvScenario reading existing flight data (e.g., ETMS), the first method allows the user to drag (via the graphical user interface, or GUI) the existing route way points to specific lat/long locations. The second mechanism is to edit existing route parameters directly. The user does not need to employ other spread sheet tools – any necessary text editing can be done directly from AvScenario. These first two mechanisms are shown in Figure 4. The third mechanism is show in Figure 5 for the

[§§] MPAS uses a system of gains that are adjusted for each aircraft type. Therefore, allowing the user to add new aircraft types or modify existing types is more involved than simply changing the performance (BADA) data from a particular type. This issue may be addressed in subsequent versions of MPAS.

[***] Waypoints are typically referenced by name or by a latitude/longitude location. In the case of waypoint name, NAS data exist that allows the mapping of name to location.

case where the user is creating a new route which is performed by simply clicking desired points on the 2D map in the Plan View Display (PVD). In this case the route data are automatically inserted into the data sheet shown in Figure 5. The route waypoints can be associated with existing NAS fixes or NAVAIDS or arbitrary lat/long locations.

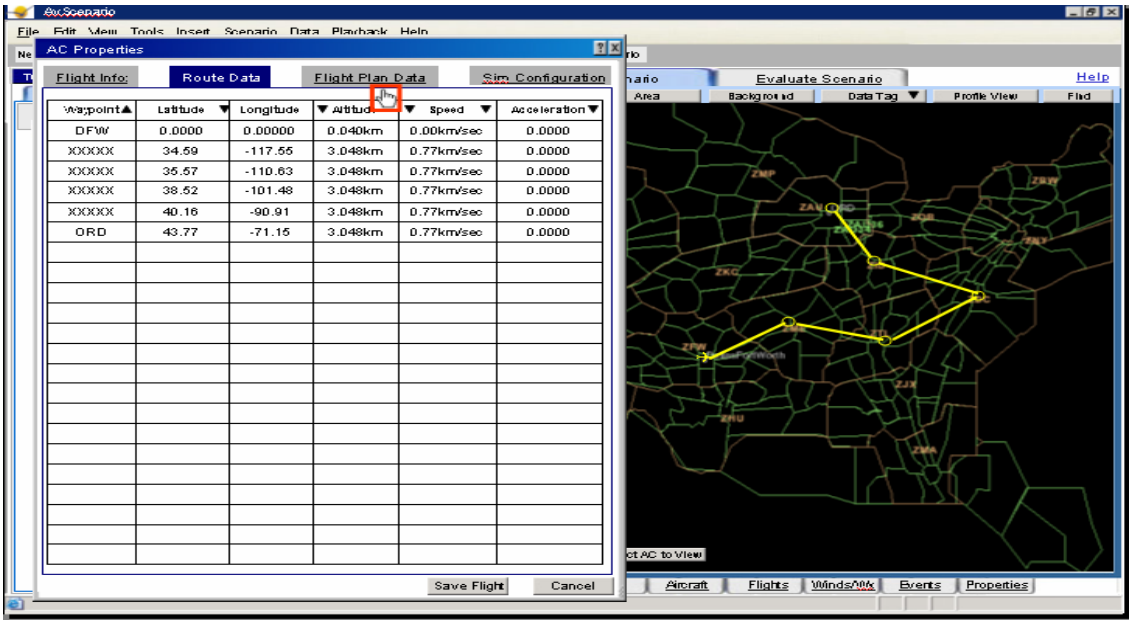

Figure 4. Prototype illustration showing AvScenario Route editing via GUI and direct data access. Copyright © 2004, Seagull Technology, Inc.

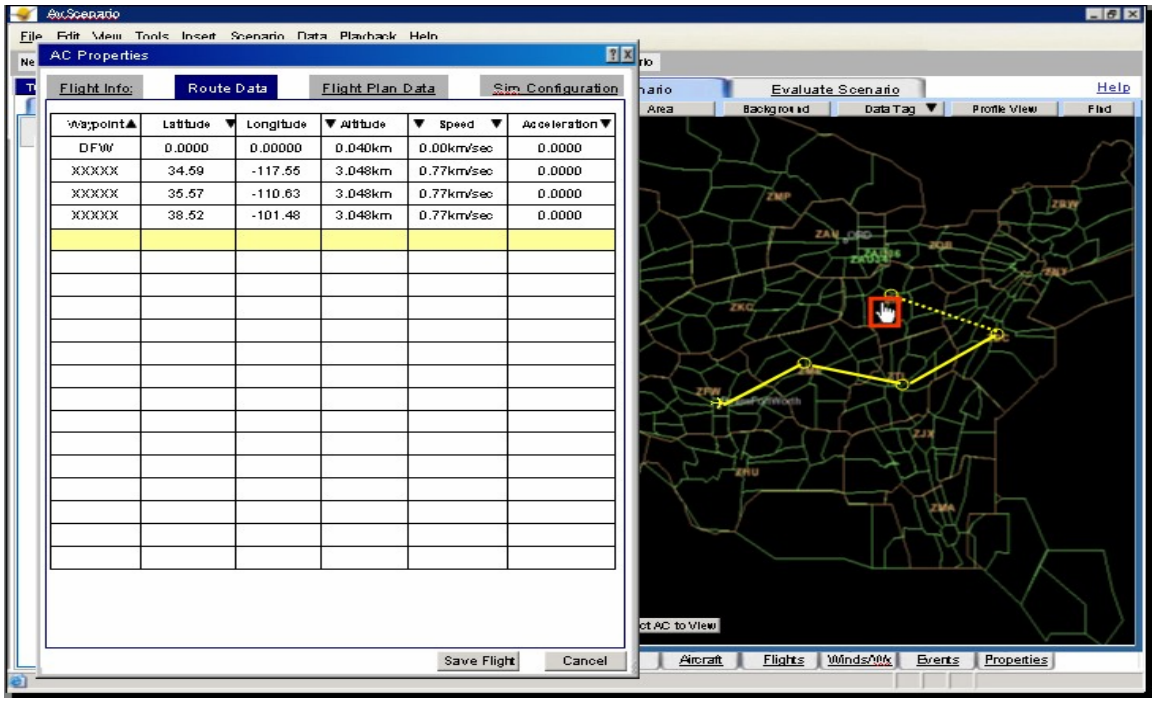

Figure 5. Prototype illustration showing AvScenario Route creation via point and click on the GUI. Copyright © 2004, Seagull Technology, Inc.

The route generation and manipulation capability of AvScenario, coupled with the ability to read existing flight data and output a scenario, is a key flight data editing feature which will allow rapid construction and editing of routes for use in multiple simulators. Although initially manual, the construction of routes according to prescribed rules can be automated in the future.

2. Flight Plan Generator

A flight plan consists of the complete set of data required to fly an aircraft from one airport to another. The flight plan includes the route, typically constructed previously. All flights are assumed to have instrument flight plans. However they may be operating in Visual Meteorological Conditions (VMC) which may change the arrival rate at an airport.

AvScenario will allow the user to read in existing flight plan data and edit it or create the flight plan data shown in Figure 6 and associate it with a route.

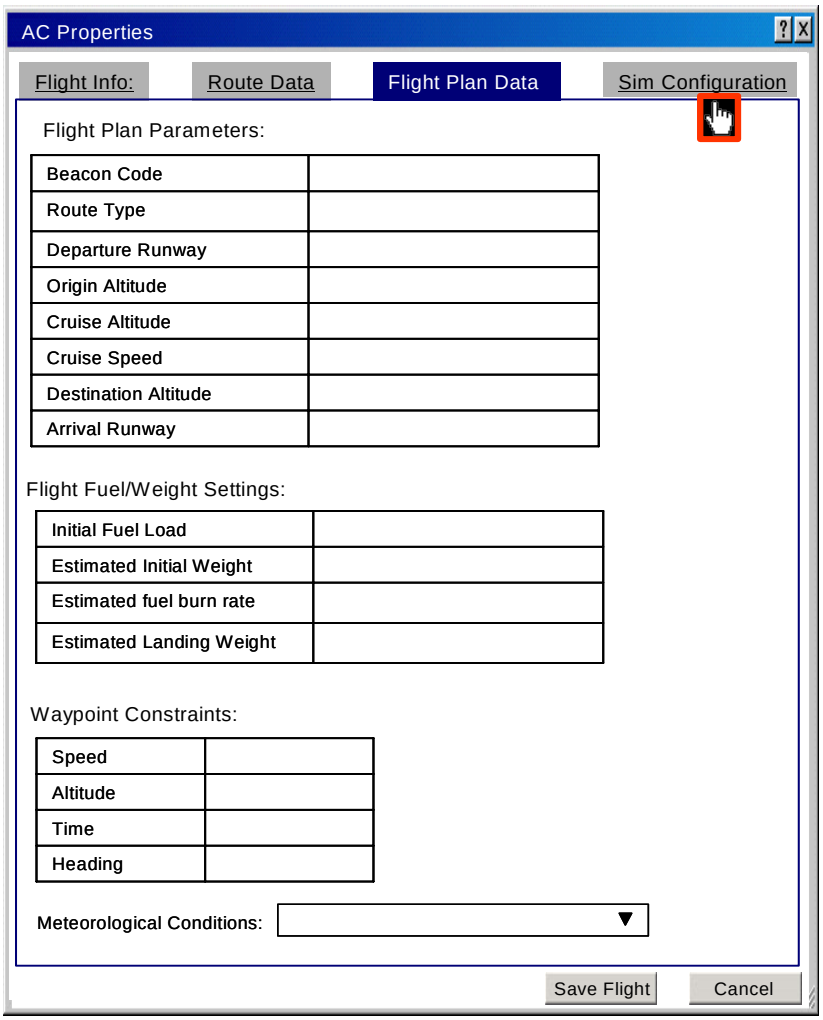

Figure 6. Prototype illustration showing AvScenario flight plan data interface. Copyright © 2004, Seagull Technology, Inc.

3. NAS Modification

Part of researching future ATM concepts entails changing the way the NAS looks and operates. To support modeling future airspace configurations, AvScenario allows the user to create, delete and modify any of the NAS data elements. User changes to the NAS data are stored independently of the original NAS data so that they can easily be distinguished from the actual data and removed when necessary. AvScenario provides powerful features for managing the NAS data. All NAS data are categorized and the properties of individual elements can be edited

graphically. Search functionality allows the user to quickly find a particular element. Cross referencing allows the user to determine dependencies of a particular NAS element. For example, while looking for specific navigational aid (NAVAID) a user can quickly see which airways or flight plans use that NAVAID. The AvScenario interface to NAS data is shown in Figure 7.

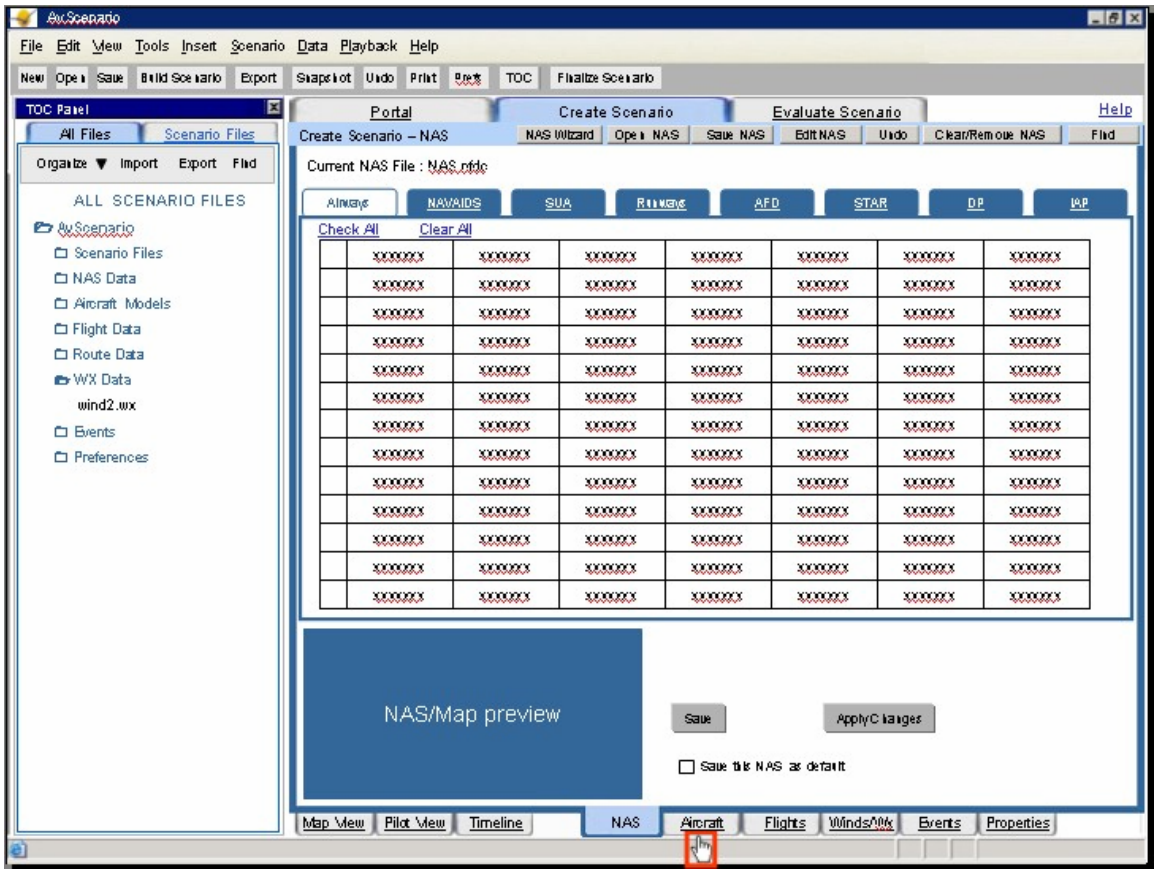

Figure 7. Prototype illustration showing AvScenario interface to NAS data. Copyright © 2004, Seagull Technology, Inc.

4. Event Creator

Event Creation is summarized by: automatic calculation of initial conditions, given a user-specified event that occurs later in simulation-time. This feature has been requested by users and would add efficiency to the current scenario generation capabilities. In brief, the user needs to be able to specify the attributes of an event. Examples of possible events are: conflicts, sector loading, and airport arrival rates. This specification would include all the desired information, such as conflict angle, speed, minimum separation distance, (for a conflict) and any other relevant parameters. Then AvScenario will automatically calculate the initial conditions that would result in the specified event. Some iteration may be necessary and some bound on the initial conditions would need to be provided by the user (to limit the infinite possibilities of initial conditions that would result in the event). This functionality would add efficiency by replacing the current method of guessing at initial conditions (e.g., start time in the simulation of a flight) and trajectory leading to the event, running the simulation to evaluate the event and then iteratively adjusting the initial (or trajectory) conditions until the event is as desired.

As an example of an event, consider a conflict. Much of HITL air traffic research and simulation involves investigating conflicts between aircraft. By creating potential conflict situations between aircraft researchers can study how operational concepts, DSTs and humans participants detect and resolve these conflicts. Creating a conflict, which is a typical event in a HITL scenario, is not as easy as it would seem at first glance. Even the conflicts with simple geometry require the researcher to pull out the calculator to determine what starting conditions will produce the desired conflict. When more complicated (and realistic) routes are given to aircraft the problem is magnified. Sometimes the best way to create aircraft conflicts is through a lot of trial and error. AvScenario will

include a utility that takes the trial and error out of conflict creation. The Conflict Creator will allow the user to specify when or where a conflict should occur and between what aircraft, and the various required parameters – such as conflict altitude, crossing angle, approach speed. The Conflict Creator will then compute the initial conditions or route constraints of the aircraft, to guarantee a conflict will occur at the specified time and/or location.

5. Scenario Randomizer

Researchers using HITL simulations often need to run the same scenario many times to gather enough statistical data. Ideally, new human test participants would be used for each run. However, due to the specialized skills of the human pilots and controllers and their limited availability, researchers must make multiple runs using the same test participants. The problem with this is that once a participant has experienced a particular scenario, the scenario cannot be reused because the participant may begin to show a learning effect, and the results will be biased. Consequently, researchers disguise the scenario so that the objectives are the same or very similar, so the human participants are not likely to recognize that it is essentially the same scenario. The Scenario Randomizer function in AvScenario, will aid the researcher in disguising a scenario. For example, randomly changing the call signs of the aircraft may help to camouflage some of the scenario characteristics. Future versions of AvScenario will include more advanced randomization capabilities, such as the ability to identify portions of the scenario (event) as constants and the remainder of the scenario will be randomized around it. Randomizing the non-critical aspects of conflict events is another example of disguising particular aspects of scenarios.

6. Schedule Generator

Automated schedule generation will not be included in early releases of AvScenario. However, users have asked for this feature and we recognize its value. A description of possible future functionality follows.

The user needs to be able to quickly generate the future schedule (e.g., year 2022) for several flights simultaneously. The number of separate flights envisioned for a human-in-the-loop scenario that takes about 90 minutes to run in a real-time simulation is expected to be 200-300 (1000 is considered a practical maximum that would ever be needed in such a simulation). AvScenario needs to accommodate user requested schedule changes for these flights, based on the quick addition of extra aircraft, simple schedule multiplication (e.g., 2x, 3x, 3.5x) and generating a schedule for a given set of passenger flows. The minimal definition of "schedule" is the estimated time and location identification (airport ID or waypoint) of departure and estimated time and location identification (airport ID or waypoint) of arrival for each flight (a flight is identified by call sign). The "schedule" in AvScenario is similar to the schedule data in the Official Airline Guide (OAG), for a specific flight. The user also needs to be able to efficiently change these values subsequent to initial generation. The schedule generation needs to be able to accommodate flights between airports contained within the region of interest as well as schedules that originate and terminate at airports outside the region of interest. For example, omitting international flights would dramatically alter a scenario involving ZNY (New York Air Route Traffic Control Center – ARTCC).

An automated method (such as a genetic algorithm) will be investigated to populate the schedule with the user specified constraints, including: demand, fleet mix, Origin-Destination pair(s) and airport capacity (A/D rate). However, genetic algorithms are more relevant for fast-time scenarios that have a much larger number of flights (e.g., 30,000 instead of 300) and may not be necessary for scenarios used in real-time HITL simulations.

AvDemand is another tool being developed by Seagull Technology, primarily to generate the demand load for the VAMS fast-time simulator: Airspace Concept Evaluation System (ACES).[38] AvDemand will have schedule generation capabilities, but the generated schedules may not include all that is needed by AvScenario, hence the need for to AvScenario to have some real-time scenario specific schedule generation capabilities.

C. Scenario Evaluation

The ability to quickly switch between editing and evaluating a scenario is a key AvScenario feature. The scenario generation/evaluation process is highly iterative so it is important to have a full-featured yet fast evaluation tool. Scenario evaluation with AvScenario includes running the scenario, visually observing the behavior of the aircraft and events, and analyzing the captured metrics.

1. Compiler

To offer the greatest flexibility in evaluating the scenario, the trajectory of each aircraft in the scenario is computed, i.e., flown, in fast time. Once all of the trajectories have been computed, metrics can be calculated and additional analysis can be performed. The alternative to this approach is to compute the trajectories in real time as the user is watching the scenario being played out. For this approach any metrics and analysis would also have to be

done in real time. The pre-computation of the aircraft trajectories allows AvScenario to provide features not found in a typical simulation such as going backwards in time or rapidly jumping to a discrete point (a.k.a. "simulation – time" or "sim-time") in the simulation. When the user makes a change to the scenario, the trajectories, metrics and other analysis are recomputed and made available to the user for evaluation.

For the reader familiar with developing software, the scenario generation and evaluation paradigm is analogous to writing, compiling, testing, and debugging software. Creating and modifying the scenario corresponds to writing and editing the source code. Computing the trajectories and metrics is similar to compiling the source code. Playing and stepping through the scenario is the same as testing and using the debugger. Creating software, just like scenario generation, is an iteration of all these steps. Software development also includes the additional pre-iteration tasks of requirements gathering and design and the post-iteration tasks of deployment and maintenance. Scenario generation also has these additional steps, however these will mainly be done outside the scope of AvScenario, but are important nonetheless.

A potential issue with "compiling" the scenario before allowing the user to view it is the amount of time required to complete all of the computations. It is unacceptable for the user to have to wait 10 minutes, 20 minutes or longer for a scenario to compile. The time to compile the scenario must be fast. Preliminary evaluation has shown that reasonable times for scenarios that meet our requirements (200 to 300 aircraft for 1 to 2 hours) can be achieved with AvScenario. Further optimization can be achieved by re-building/compiling only the portions of the scenario that are or might be affected by a change made by the user.

The AvScenario trajectory generator, MPAS, computes the 4-D trajectory consisting of x, y, and z position data at regular time intervals. Aircraft speeds and weights are also computed at each time step. MPAS contains a 4-Degree-of-Freedom (4-DOF) model; three translations plus roll angle. The computation of the trajectory is based on the aerodynamics and propulsion models (performance data) of the particular aircraft type.

As part of the scenario compilation process, automated checks of the scenario are performed. For example, before attempting to compute a particular aircraft trajectory, a simple flight envelope check is performed to determine if that particular aircraft's performance characteristics can indeed fly the requested route. If it cannot then an error (or warning depending on severity) is generated and the user must choose to either ignore the error or change the aircraft type or route to fix the problem. Thus, the scenario compiler provides the first level of scenario evaluation by checking for potential errors.

2. Visualization

Visually evaluating the scenario at a macroscopic level is done by observing the AvScenario Plan-View Display (PVD) and watching aircraft trajectories update on the screen. Because the trajectories have already been computed the user can easily slow down or speed up the playback. The user can pause and reverse the playback or jump to a specific point in time. With the PVD the user can pan in any direction, zoom in/out and control the display of individual aircraft trajectories, routes, airways, sector boundaries and other information. The scenario can also be viewed from the perspective of an individual aircraft using the Pilot View, which simulates the moving map mode of a cockpit Navigation Display (ND), an example of which is shown in Figure 8. Visualization provides the second level of scenario evaluation and allows the user to spot obvious errors and get a good feel of the flow of the scenario. Visualizing the scenario, however, does not provided the hard analysis numbers that the will ultimately help the user evaluate the effectiveness of the scenario.

Figure 8. Example of moving map mode of Navigational Display (ND) pilot

3. Analysis

While visualizing the scenario is an important step in evaluating the scenario, ultimate evaluation comes from quantifying, via metrics analysis, the adherence of the scenario to the researcher's established criteria.

Analysis of scenario metrics can be done in a number of ways with AvScenario. Time history plots, as shown in Figure 9, can be created and viewed for a number of selected metrics. The user can then see how specific parameters change throughout the duration of the simulation. By examining these plots the user can quickly identify trends, anomalies and areas of further interest. Additionally, the user can quickly move to a specific time in the scenario to examine and investigate what is occurring.

Analysis of aircraft conflicts includes listing each of the conflicts and their relevant data (time, aircraft IDs, and other statistics). By selecting a particular conflict the user can jump to the point in the scenario where the conflict first occurred or where the point of closest approach occurred.

Additional analysis includes looking at summaries and detailed data of the final results/metrics. For example by looking at a summary report the user can quickly see such statistics as number of conflicts and sector loading (min, max, and average). The analysis summaries can be saved and then compared with successive runs to determine what impact a particular modification has on the scenario.

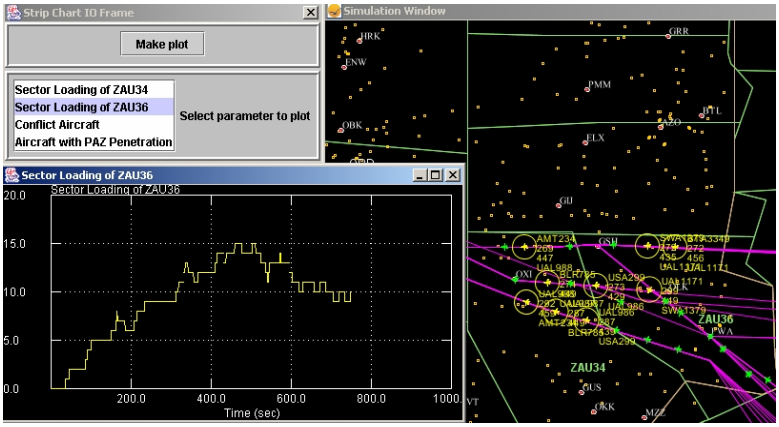

Figure 9. Scenario analysis with time history plots and PVD

D. Scenario Output

The output of a scenario in a format usable by other simulators is one of the main purposes of AvScenario. The output data will have two forms: generic and simulator specific.

1. Generic Format

AvScenario uses the generic scenario format to store and archive working versions of scenarios. AvScenario can re-open these previously created scenarios. The generic scenario format contains all of the scenario information. The generic format will be well documented and allow other applications to read in and use the scenario data. The AvScenario generic scenario format is based on the eXtensible Markup Language (XML). XML will allow the format to be self-documenting and be flexible enough to handle only the data needed for a particular scenario.

2. Simulator Specific Format

While the generic format is very powerful, most AvScenario users will eventually want the scenario data in a format that can be directly used by their specific simulator(s). This is accomplished by translating the generic format scenario data to a simulator's specialized format. To do this a mapping between AvScenario generic format parameters and the parameters required by a specific simulator is created. Included in the mapping is a description of the format required by the target simulator for the input data. It is very likely that a specific simulator will require parameters that are not available in AvScenario. Specific or default values for these parameters can be supplied via the user interface to reduce the amount of hand editing.

V. User Interface

Sophisticated systems, such as AvScenario, are often accompanied by cumbersome user interfaces. This is because such systems are complex in nature and historically have been designed for, and used by, software or simulation developers. However, anything but a usable interface would defeat the main goal of this project; that is, to empower researchers, rather than just programmers, with the ability to specify the complex set of parameters that makeup their desired simulation, without writing any "code."

Our usability objectives for the AvScenario user interface are the following:

- *Compatibility*: The visual interface must be compatible with the control interface.
- *Intuitiveness*: Trial and error is not the way for users to navigate this interface. We will design an interface that guides the user and communicates its underlying behavior before the user has to guess how to control it. We use the term "feed forward" to refer to this important usability goal. We want to

design an interface that helps the user become aware of all of the features, options and capabilities of the tool

- *Efficiency*: Our design will allow users to specify their scenario parameters with a minimum of mental effort and time invested. In general there are multiple ways of doing specific actions via GUI, which include wizard, text-edit and mouse/GUI.
- *Learn-ability*: This is our most important goal - making technology usable. We want the tool to be usable by researchers and research assistants, without the need for extensive training.

The control features on the scenario evaluation GUI include the ability to:

- stop, edit re-compile and resume evaluation
- rapidly jump to any other simulation time, forwards or reverse from the current sim-time
- simulation play speed, ranging from slow to the maximum the CPU can achieve

The GUI will display various views: PVD, pilot-centric (moving map, with adjustable distance, example shown in Figure 8), side-view profiles of the routes as shown in Figure 10, and time-history plots of user-selected parameters as shown in Figure 9. Other various portions of the AvScenario user interface are shown in Figure 4 through Figure 7.

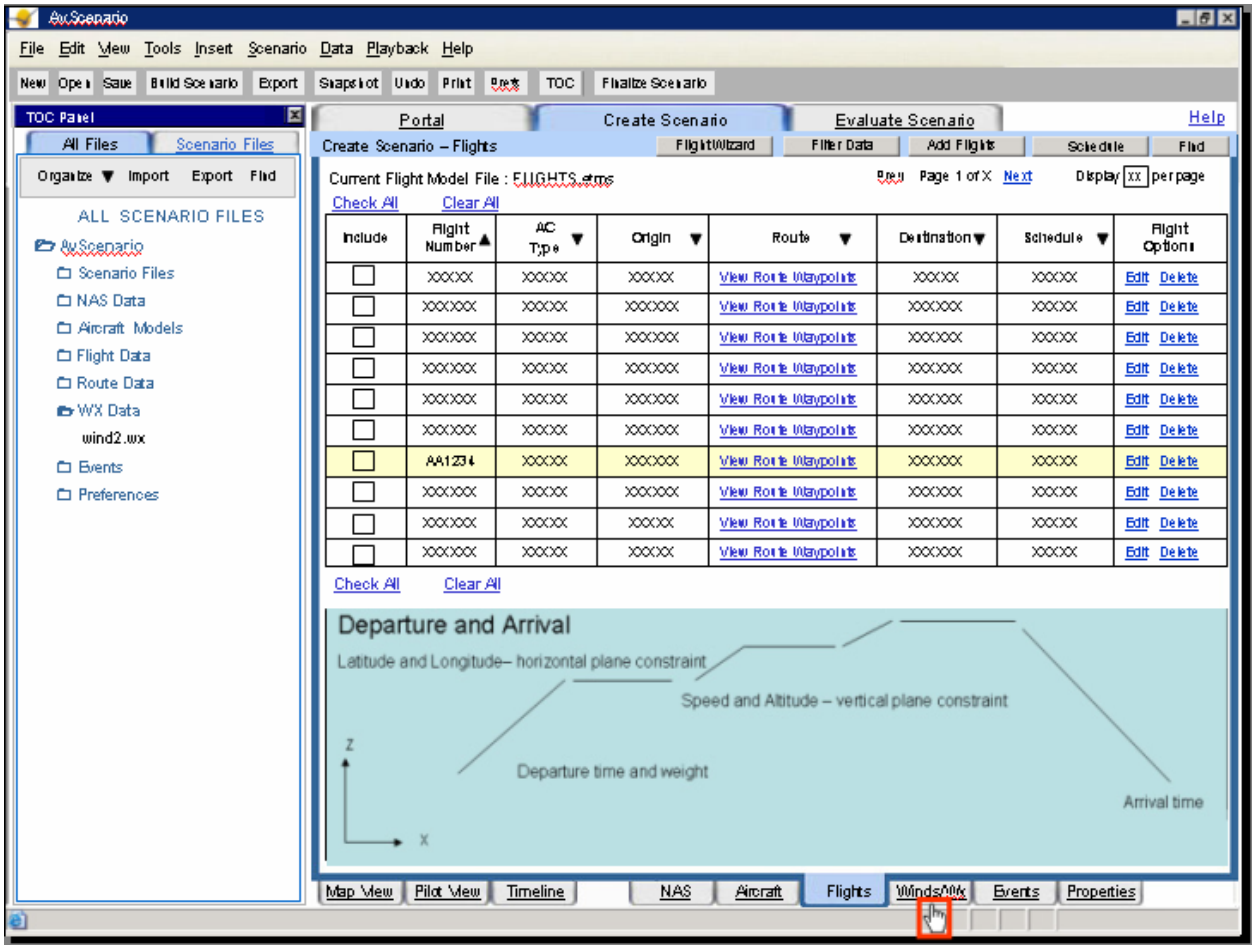

Figure 10. Prototype illustration showing AvScenario side-view route profile display. Copyright © 2004, Seagull Technology, Inc.

VI. Software Architecture

The software architecture of AvScenario is critical to its success as a product. The architecture must be flexible and extensible to accommodate change. AvScenario uses an object-oriented design (OOD) approach. OOD is a powerful and widely used paradigm for developing software. Nevertheless, using an OOD approach in no way

guarantees success and in many situations, as is the case with any technology that provides increased power, the results can be unsuccessful when used incorrectly. The guiding principal behind the design of the AvScenario software architecture is to provide an architecture that takes full advantage of the benefits of OOD, while avoiding the potential pitfalls. For this reason, the AvScenario architecture relies heavily on object-oriented "best practices" and the principal of leveraging rather than re-inventing technology.

Design patterns are perhaps the best known of the OOD best practices. Design patterns are proven methods for solving common and reoccurring software architecture problems. Many OO design patterns have been well known and well documented for almost a decade[39] and some even longer. The AvScenario design makes generous use of several design patterns.

The principal design pattern used in the AvScenario architecture is the Model-View-Controller (MVC). The intent of the MVC design pattern is to isolate the display (user interface) functionality from the data and other non-display functionality. By de-coupling these functions, the system becomes easier to modify, extend, and maintain. The user interface can easily be changed without having to change the system's underlying logic. The Model component contains the data and algorithms that comprise the core functionality of the application. The View component contains the display functionality, i.e., the windows and user interface controls. The Controller responds to user inputs and facilitates the appropriate changes to both the Model and the View components.

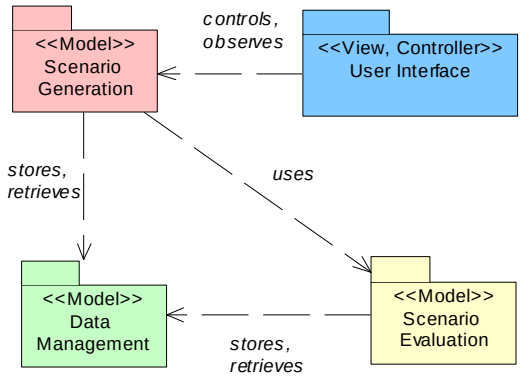

Figure 11. AvScenario subsystems, relationships and MVC roles

Another OOD best practice is to modularize the software. At the highest level AvScenario is modularized into four subsystems. These four subsystems are further modularized into packages. Figure 11 shows the AvScenario subsystems and the relationships between them. The MVC roles of each subsystem are also denoted. The User Interface subsystem contains both the View and the Controller portions of the MVC. The View and Controller tend to be somewhat coupled. If a new version of the user interface is created, a new View and a new Controller will need to be created. The Model is comprised of the other three subsystems. The Scenario Generation subsystem contains the functionality to create a scenario. The User Interface obtains the Model data from the Scenario Generation subsystem and presents it to the user. The Scenario Evaluation subsystem provides the functionality the user needs to analyze the generated scenario. The Data Management subsystem reads, filters, stores, and writes all of the scenario data. A detailed view of the subsystems and their functions is shown in Figure 12.

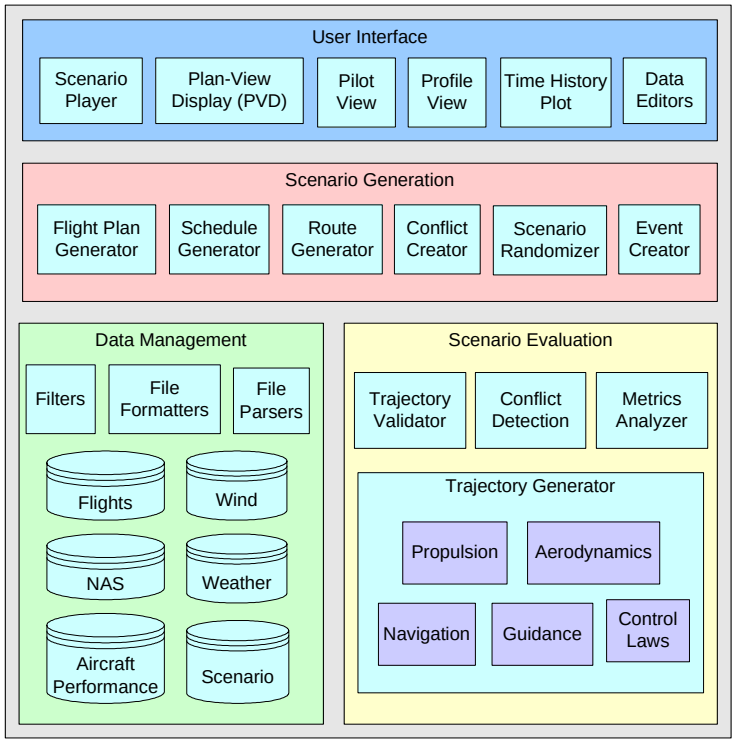

Figure 12. AvScenario subsystems and functions

The AvScenario architecture provides a generic trajectory generator interface that allows the default target generator, MPAS, to be replaced with another target generator. The other target generator could either be compiled into the AvScenario application or run as a separate process. The reason why another target generator would be used is that a scenario developed

with one target generator may not produce exactly the same results when used in a simulator with a different target generator. However, we believe that the differences between the target generators that are currently considered for use, e.g., PAS, are small and that the flight plans that would be created using MPAS can easily be altered if the trajectories are not exactly as desired.

OOD and design patterns provide a sound blue print for the AvScenario architecture. Nevertheless, the successful implementation of a good architecture is highly dependent upon the materials used to build it. The Java programming language provides the quality building materials needed for construction of the AvScenario application. The biggest architectural benefit that comes from using Java is the wealth of classes it provides. This immense library of code provides built-in language support for everything from networking to multi-threading to user interfaces. By leveraging Java, a significant amount of software is available for reuse, which adheres to the AvScenario architecture principal of leveraging existing technology.

VII. Future Plans

This paper describes the current plans for the AvScenario air traffic scenario generation prototype currently being implemented under a NASA Phase-II SBIR. The features to be included in that prototype and several that are under consideration for subsequent releases are described. An ongoing research task is to identify post-SBIR customers and collaborators and identify features that would be desirable in subsequent releases. Examples of future usages that are not fully described in this paper include use of AvScenario as a fast-time simulation scenario editor, use of AvScenario as a fast-time simulator, NAS related training applications and non-NAS simulation/scenario data generation and manipulation.

VIII. Conclusion

A growing community of researchers is investigating concepts, procedures and DSTs to increase the capacity of the NAS. The most promising of these will need to be evaluated via human-in-the-loop experiments prior to fielding in the NAS. We anticipate the need to rapidly and efficiently generate and manipulate the scenarios used in those experiments, in order to make the best evaluations as possible.

Although some NAS research organizations have made significant progress towards scenario generation capabilities that service their internal simulators, there are significant efficiency gains that remain to be made and a NAS scenario generation and manipulation tool that services multiple simulators is not readily available. This paper describes the scenario generation tool, AvScenario, which focuses on making the scenario generation and manipulation process much more efficient and human-centered than is typically is today. AvScenario will facilitate a more thorough investigation of the wide range of NAS capacity improving concepts, procedures and DSTs.

Acknowledgments

This research is being conducted under a Phase-II Small Business Innovative Research (SBIR) contract funded by NASA Ames. Seagull Technology would like to thank NASA Ames Research Center for providing the SBIR Phase-I and Phase-II funding and Contracting Officer Technical Representative (COTR) Sandy Lozito for her interest in and continued support of this work.

References

[1] Tobias, L. and P.J. O'Brien, "Real-Time Manned Simulation of Advanced Terminal Area Guidance Concepts for Short Haul Operations," NASA TN D-8499, NASA Ames Research Center, Moffett Field, CA, 1977.

[2] Tobias, L., O'Brien, P.J., and E. A. Palmer "Simulation Study of the Effect of Fuel-Conservative Approaches on ATC Procedures and Terminal Area Capacity," SAE Paper No. 780523, Air Transportation Meeting, Boston, MA, May 1-4, 1978.

[3] Mackintosh, M-A., Dunbar, M., Lozito, S., et al., "Self-Separation from the Air and Ground Perspective," The Second United States/Europe Air Traffic Management Research and Development Seminar, Orlando, Florida, December 1-4, 1998.

[4] van Gool, M., and Schroeter, H., "PHARE Final Report," PHARE Doc. 99-70-09, Eurocontrol, Bruxelles, Belgium, November 1999.

[5] DiMeo, K., Kopardekar, P., Ashford, R., Lozito, S., and M-A. Mackintosh, "Shared-Separation: Empirical Results and Theoretical Implications," http://human-factors.arc.nasa.gov/ihi/research_groups/datalink/publications_files/shared-s.pdf

[6] Foyle, D., Hooey, B., "Improving Evaluation and System Design through the use of Off-Nominal Testing: a Methodology for Scenario Development," Proceedings of the 12th International Symposium on Aviation Psychology, Dayton, Ohio, April 14-17, 2003.

[7] Lockwood, S., Atkins, S., and Dorighi, N., "Surface Management Systems Simulations in NASA's Future Flight Central," AIAA Modeling and Simulation Technology, AIAA Paper No. AIAA-2002-4680, August 2002

[8] Anon., Air Traffic Control Research Simulator (NARSIM), NLR, 1997, http://www.nlr.nl/public/facilities/f75-05/f75-05.pdf

[9] Peters, M., Ballin, M., and Sakosky, J., "A Multi-Operator Simulation for Investigation of Distributed Air Traffic Management Concepts," AIAA Modeling and Simulation Technology, AIAA Paper No. AIAA-2002-4596, August 2002.
[10] Prevot, T., Palmer, E., Smith, N., and Callantine, T., "A Multi-Fidelity Simulation Environment for Human-in-the-Loop Studies of Distributed Air Ground Traffic Management," AIAA Paper No. AIAA-2002-4679, AIAA Modeling and Simulation Technology Conference, Monterey, CA, August 5-8 2002.
[11] Anon., "CTOD 16 – ASTOR Software Design Document, Revision B2b-a," Air Traffic Management System Development and Integration (ATMSDI) Acquisition, Prepared by Raytheon Company for NASA Ames, April 15, 2004.
[12] Peters, M., et. al., "The Detailed Design and Software Implementation of the Aircraft Dynamics Model for the FAA Target Generation Facility," Seagull Technology, Inc., Los Gatos, CA, June, 1998.
[13] Anon., FAA, Target Generation Facility (TGF), http://www.tc.faa.gov/act-500/nsb/tgf/index.html
[14] Misc., http://www.hf.faa.gov/wjhtc.htm
[15] Anon., "FAA/EUROCONTROL, COOPERATIVE R&D: Action Plan 5, Operational Concept Validation, Strategy Document," European Air Traffic Management Program, Edition 1.3, 8 December 2003, http://www.eurocontrol.int/faa-euro/AP-group-meetings/AP5/OCVSD%20-V1-3.pdf
[16] Weske, R.A., and Danek, G.L., "Pseudo Aircraft Systems: A Multi-Aircraft Simulation System for Air Traffic Control Research," Proceedings of the AIAA Flight Simulation Technologies Conference, Monterey, CA, August 1993.
[17] Anon., "Traffic and Experiment Manager (TEM)," Nationaal Lucht- en Ruimtevaartlaboratorium (National Aerospace Laboratory), 1997, http://www.nlr.nl/public/hosted-sites/freeflight/tmx.htm
[18] Anon., http://www.simlabs.arc.nasa.gov/vlab/
[19] Swenson, H., "The Virtual Airspace Modeling and Simulation (VAMS) Project," http://www.vams.arc.nasa.gov/
[20] Fong, R., "System-Level Integrated Concepts (SLIC)," VAMS Technical Interchange Meeting #1, Moffett Field, CA, May 21, 2002, http://vams.arc.nasa.gov/resources/index.html
[21] Sullivan, B. T., Malsom, S. J., "Development of a Real-Time Virtual Airspace Simulation Capability for Air Traffic Management Research," AIAA 2002-4592, *AIAA Modeling and Simulation Technologies Conference and Exhibit*, Monterey, California, 5-8 August 2002.
[22] Lehmer, R. D., Malsom, S. J., "Distributed System Architecture in VAST-RT for Real-Time Airspace Simulation," AIAA-2004-5436, *AIAA Modeling and Simulation Technologies Conference*, Providence, RI, August 16-19, 2004
[23] Anon., AWSIM, Aerospace Engineering and Research Associates Inc., http://www.freeflight.com
[24] Oaks, R., et. al., "Methodology for the Generation of Air Traffic Scenarios Based on Recorded Traffic Data," William J. Hughes Technical Center, Presented at the Digital Avionics Systems Conference (DASC), Indianapolis, IN, October, 2003, http://acy.tc.faa.gov/cpat/docs/oaks105-1b.pdf, http://acy.tc.faa.gov/cpat/docs/index.shtml
[25] Paglione, M. M., Oaks, R. D., Bilimoria, K. D., "Methodology for Generating Conflict scenarios by Time Shifting Recorded Traffic Data," AIAA 2003-6724, AIAA 3rd Annual Aviation Technology, Integration and Operations (ATIO) Conference, Denver, CO, 17-19 November 2003, http://acy.tc.faa.gov/cpat/docs/2003_6724.pdf
[26] Prevot, T., "Multi Aircraft Control System (MACS) Software," NASA Ames Research Center, 2002, http://human-factors.arc.nasa.gov/ihi/publications_details.php?id=70
[27] Prevot, T., et. al., "Distributed Air/Ground Traffic Management Simulation: Results, Progress and Plans," AIAA 2002, http://human-factors.arc.nasa.gov/ihi/research_groups/air-ground-integration/publication_papers/Pr2003-DAGrsltsPrgrsPlans.pdf
[28] Callantine, T.,J., "Modeling and Simulation of Trajectory-Oriented Air Traffic Management Concepts," AIAA 2004-5260, AIAA Modeling and Simulation Conference and Exhibit 16-19 August 2004, Providence, Rhode Island
[29] Anon., http://www.nasa.gov/audience/foreducators/informal/features/F_Ames_Simulation.html
[30] Nuic, A., "User Manual for the Base of Aircraft Data (BADA), Revision 3.5," Eurocontrol, EEC Note No.11/03, July 2003 http://www.eurocontrol.fr/public/reports/eecnotes/2003/11.htm http://www.eurocontrol.fr/projects/bada/
[31] Anon., Enhanced Traffic management System (ETMS), Reference Manual, Version 7.6, Volpe National Transportation Systems Center, Report No. VNTSC-DTS56-TMS-004, May 2003.
[32] Robinson, J., Eshow, M., DRAFT Data Recording / Playback Requirements, NASA Ames Research Center, January 3, 2003.
[33] Anon., "ASPM Overview," October 26, 2000 http://dmses.dot.gov/docimages/pdf56/117227_web.pdf
[34] Benjamin, S., NOAA, http://maps.fsl.noaa.gov/ruc2vars.html
[35] Anon., http://www.nco.ncep.noaa.gov/pmb/docs/on388/tableb.html#GRID1
[36] Schleicher, D., et. al., "Proposed VAMS SEA Scenario Requirements," NASA Prime Contract No. NAS2-98074, TR02226-01, Seagull Technology, Inc., Campbell, CA, November 27, 2002
[37] Peters, M., "The Engineering Analysis and Design of the Aircraft Dynamics Model for the FAA Target Generation Facility," August 11, 1999.
[38] Cobb, P., et. al., "A Modeling Architecture for Capturing CNS Uncertainty and Prediction Errors in the NAS," AIAA 2004-5263, AIAA Modeling and Simulation Conference and Exhibit 16-19 August 2004, Providence, Rhode Island
[39] Gamma, Helm, Johnson, Vlissides, *Design Patterns, Elements of Reusable Object-Oriented Software*, Addison-Wesley, Reading, Massachusetts, 1995.