Rapid Prototyping and Exploration of Advanced Air Traffic Concepts

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Summary

This paper describes the use of rapid prototyping by researchers in the Human Factors Research and Technology Division at NASA Ames Research Center to explore advanced air traffic concepts. The paper addresses the main software components and their use throughout different prototyping and evaluation stages. Ongoing and future research on novel air traffic concepts is presented. Funding for this work was provided by the Advanced Air Transportation Technologies (AATT) Project of NASA'a Airspace Systems Program.

Introduction

A number of concepts aimed at improving air traffic efficiency and safety have been investigated over past decades. Advances in computer technology and automation have opened up many more avenues for evolutionary and revolutionary concepts that are intended to ensure safe, secure, fast, affordable, and timely air travel in the future.

Traditionally, the exploration of such concepts is a slow and costly process and requires a number of different research and development platforms and phases. These phases range from fast-time simulation addressing potential benefits, via human-in-the-loop (HITL) simulations, to field tests. One of the biggest challenges in this process is to prototype a sufficiently accurate implementation of concept components relevant to the respective research objective. HITL simulations must provide practitioners like flight crews and air traffic controllers with a realistic virtual environment. If a simulation does not reflect all aspects appropriately, the implications of operations according to an envisioned concept might not be evaluated sufficiently. This insufficient evaluation can have negative effects ranging from undetected design flaws on the one end of the spectrum to abandoning a very promising idea on the other end.

One dilemma facing many researchers is that actual practitioner workstations like flight decks and controller input devices and displays are extremely difficult to integrate into a simulation. Even if the integration could be achieved the software is often proprietary or inaccessible, or cannot quickly be adapted to the required research functionality. Simulators and emulators often lack the required fidelity or are only available in large-scale laboratories where access to the simulation system is limited and costly.

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In order to alleviate some of these problems researchers in the Human Factors Research and Technology Division at NASA Ames Research Center developed a versatile and powerful simulation architecture and research platform [1][2]. This platform allows many different configurations. One or multiple instantiations of only two to three core applications enable the rapid prototyping and exploration of advanced air traffic concepts at many different levels, from standalone laptop or desktop computers to large-scale distributed simulations with numerous pilot and controller participants. Furthermore, the simulation can be integrated with other simulators and thus can become one component of an even more comprehensive virtual air traffic environment.

Research Platform and Simulation Architecture

The simulation architecture is described in detail in [1] and [2]. Air traffic operations with advanced ground side automation and current day aircraft capabilities can be simulated with the following components: The *Aeronautical Datalink and Radar Simulator* (ADRS) is the "distributed simulation hub" and air traffic host computer emulator. The *Multi Aircraft Control System* (MACS) combines target generator and user interface for air traffic controllers, pilots, experiment managers, observers and analysts [3]. For simulating air traffic operations with advanced flight deck displays the *Cockpit Display of Traffic Information* (CDTI) [4] and additional display controls are added to individual flight deck simulators.

The ADRS maintains all aircraft state and trajectory information and all pilot and controller flight data inputs. ADRS applications with identical source code are available for Windows and Solaris operating systems. A network of ADRS servers can be launched that distributes the communication load and provides access points for a nearly unlimited number of MACS and CDTI client processes. It also provides access points for other simulators like full mission flight simulators or other air traffic laboratories. Examples for already connected simulators and laboratories are the *Air Traffic Operations Laboratory* (ATOL) at NASA Langley Research Center [5], the *Advanced Concepts Flight Simulator* (ACFS) and the *Future Flight Central* (FFC) Tower simulator at NASA Ames Research Center [6]

The information management infrastructure provided by the ADRS and the specific research area of advanced flight deck displays addressed by the CDTI are beyond the scope of this paper. The design philosophy and capabilities of MACS are reviewed in the next section.

The Multi Aircraft Control System (MACS)

Each MACS station is a platform independent Java program that provides target generators, user interfaces and views for pilots, air traffic controllers/managers, airline dispatchers, experiment managers, and observers. Any station can serve as a desktop-based flight simulator simulating one or many aircraft concurrently. The pilot displays can reflect the look of a modern glass cockpit emphasizing the correctness of the controls or present generic input devices designed for quickly entering commands for multiple aircraft. A MACS station can also serve as a mid-fidelity ATC input device, an autonomous agent or a display for numerous perspectives of a distributed air traffic simulation.

When the MACS development started at the end of 2001, it was based on lessons learned from various earlier simulations and prototyping experiences. MACS is designed as a research tool only, which provides a realistic look and feel, a realistic behavior and emulations of real systems. None of the software is taken from an actual fielded system or intended to ever be used in a real system. This reduces the coding requirements and increases versatility significantly, making rapid prototyping easy.

MACS is implemented in JAVA with no exceptions. This makes it platform independent and the same small "executable" (a .jar file) can be used on Windows, LINUX, UNIX or MacIntosh platforms and can easily be transferred from one computer to the other. Another big advantage of using JAVA is that it is future-oriented, interesting and fun for programmers, which increases productivity.

The same software is used for many different applications. Flight simulators, flight management systems, pseudo pilot systems, air traffic displays and advanced air traffic management tools have many common requirements. All applications need to maintain aircraft state and environment information, have models of aircraft dynamics, and have trajectory generation capabilities. Only the information is presented and accessed in different formats. For example speed advisories displayed to controllers for delivery of aircraft at a certain time can be implemented using the exact same software as a required time of arrival functionality for aircraft.

MACS utilizes these commonalities and all capabilities are part of each MACS process. Individual modes can be selected to tailor the active functions to user requirements and optimize the processing speed. Therefore a single MACS station can provide the exact same functionality as a distributed simulation with many Pilot and Controller MACS stations. New capabilities can be prototyped and tested on a single desktop computer and can immediately be made available to all pilots and controllers in the simulation alike.

At the present time MACS emulates modern flight decks with almost complete auto-flight and flight management system functions. It contains realistic emulations of the Display System Replacement (DSR) and the STARS air traffic controller displays. It includes advanced air- and ground automation like conflict detection and resolution (CD&R) capabilities and scheduling functions. All air traffic management functions are prototyped as emulations of what is or could be available from actual systems like the

Center TRACON Automation System. These actual systems can be connected to the simulation to provide the real functionality instead of the internal emulation.

Prototyping Distributed Air/Ground Traffic Management (DAG-TM) Concept Elements

As part of ongoing research within the Advanced Air Transportation Technologies (AATT) Project three Distributed Air/Ground Traffic Management (DAG-TM) Concept Elements – En Route Free Maneuvering (CE 5), En Route Trajectory Negotiation (CE 6), and Terminal Arrival Self-Spacing (CE 11) are being investigated. Controller participants manage simulated traffic using advanced Decision Support Tools (DST) while commercial pilot participants fly aircraft simulators equipped with a cockpit display of traffic information (CDTI) with conflict detection and resolution and required time of arrival capabilities. This research is conducted at NASA Ames and Langley Research Centers [7].

DAG-TM concepts require the integration of data link technologies for controller pilot data link communication (CPDLC) and aircraft initiated automatic dependent surveillance broadcast (ADS-B) with ground-based and airborne decision support tools. These tools facilitate coordination of self-separating and controller managed aircraft, conflict detection and resolution, and flow management tasks.

Earlier research at Ames used a complex simulation infrastructure integrating many different components including Center TRACON Automation System (CTAS) generic controller displays, the Pseudo Aircraft System (PAS), and desktop based PC plane simulators. While these simulations provided many meaningful insights [8][9], they suffered from insufficient flight management capabilities of the target generator and unfamiliarity of controllers with their workstations. Furthermore, it proved to be a difficult and time-consuming task to retrofit all components with the required data link and advanced automation capabilities as well as modifying the interfaces quickly. Therefore, the complete potential of the different concept elements could not be examined. For recent and ongoing simulations all required capabilities have been prototyped within the framework described above.

The revised prototype simulation for the DAG-TM concept elements integrates new functionality with state of the art systems that are familiar to controllers and pilots. The controller workstations include actual keyboards and realistic display emulations. Data link is integrated as an expansion to the currently field tested CPDLC implementation at Miami Center. CD&R tools can be accessed through a portal in the data tag based on the CTAS Direct-TO implementation, via keyboard entries or already fielded pop-up menus. Initial simulations indicate a significant reduction in controller training time and unwanted unfamiliarity side effects.

Airline pilots participate either at Langley's ATOL, use MACS/CDTI single or multi aircraft pilot stations or fly a CDTI equipped full mission simulator at Ames. All participant stations are therefore equipped with full FMS capabilities as well as advanced conflict detection and resolution functionality. The DAG-TM research focuses on far-term applications and assumes a very well developed infrastructure and many advanced automation capabilities. Final DAG-TM simulations will be conducted in Summer 2004.

Prototyping Trajectory-Oriented Operations with Limited Delegation

Another concept to be examined is Trajectory Oriented Operations with Limited Delegation (TOOWILD). This air traffic concept is investigated as part of the NextNAS program at NASA Ames Research Center [10]. First prototype demonstrations are planned for fall 2004. The concept is defined as

1. Use trajectory-based operations to create efficient, nominally conflict-free trajectories that conform to traffic management constraints and,
2. maintain local spacing between aircraft with airborne separation assistance.

The concept leverages of the findings from DAG-TM research as well as research conducted at Eurocontrol over the past years.

A fundamental element of this research is to investigate an evolutionary path to NAS modernization that may ultimately enable advanced concepts like DAG-TM. Therefore, air traffic operational environments have to be created that simulate different levels of equipage and automation capabilities. A near term implementation of the concept will be presented to pilots and controllers with only few aircraft having advanced equipment, while others are only represented with simulated current day radar information. Different levels of task delegations from the ground to the air from speed control to limited maneuvering authority need to be investigated as well as varying mixtures of aircraft and ground side equipage and capabilities to determine concept feasibility and benefits at different phases.

Concluding Remarks

Research on novel air traffic concepts needs to produce adequate results in a timely and cost-effective manner to provide knowledgeable recommendations and specifications to the operational community. The approach of accurately emulating rather than integrating actual capabilities relaxes many software and hardware constraints. It enables rapid prototyping in an easy to maintain and modify simulation architecture. This approach can certainly not replace all research and development phases, like fast time simulations or necessary field test. However, it will likely detect major flaws or benefits of a particular concept, can compare specific design alternatives and identify requirements and limitations early in the process.

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