Building ATC Simulator through Scenario-Driven Requirements Engineering

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The Federal Aviation Administration (FAA) Academy is challenged with limited availability of Air Traffic Control (ATC) training technologies for their trainees. Training is conducted over simulation scenario runs in dedicated ATC lab spaces under the supervision of ATC instructors. Current ATC training tools lack flexibility and cost effectiveness to provide 24/7 service to the trainees as well as providing dynamic fast prototyping environment for scenario development. Due to the number of trainees and cost of operation of ATC labs, trainees can only practice for limited amount of time, hindering their learning experience. Through a recent funded research project, Embry-Riddle Aeronautical University is tasked with building a web-based ATC En route simulator that mimics the FAA En route automation environment, allowing trainees to practice ATC scenarios at their own pace. The proposed simulation technology, namely ATC Scenario Training Technology (ASTT) mimics En route Automation and Modernization (ERAM) functionalities and provides a web-based practice platform to en route trainees.

One technique in capturing software requirements is to study various system usage and functionalities scenarios that highlight top-level and low-level details. To apply this approach to ASTT project, a set of en route scenarios were developed and discussed during the requirements elicitation phase. For each given scenario, key elements were highlighted and relationships amongst them were established. Requirement modeling diagrams and documentations were then constructed, fully capturing ASTT details.

In this paper, we demonstrate a rather non-traditional requirements engineering approach in extracting information for building an ATC simulator. Similar to the concept of user stories in software development projects, simulation scenarios can be used to extract essential details for designing and building simulators. ASTT requirements modeling and system architecture are discussed in this paper by presenting a sample ATC en route scenario and discussing our approach in extracting requirements details from it.

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I. Air Traffic Control Training Program

Air Traffic Control (ATC) training occurs over two main phases: Federal Aviation Administration (FAA) Academy training and on-site facility training. All official training for air traffic control starts at the FAA Academy, which is located in Oklahoma City, Oklahoma. All new air traffic controller students hired by the FAA for training at the FAA Academy, known as developmental ATCs, are hired from one of three pools: previous controllers, Air Traffic-Collegiate Training Initiative (AT-CTI) developmentals, or the general public [3]. There are three major flight control divisions in ATC and ATC training: Tower, Terminal Radar Approach Control (TRACON), and En Route. Each division has a unique training track, with each track specifically designed to teach the required materials for only one division; however, all three tracks follow the aforementioned training phases. The Tower track focuses on air traffic management activities within a radius of a few miles of the airport and utilizes simulators to replicate real ATC towers and airport views. The TRACON track is comprised of the job jeopardy Terminal Basic Radar Training Course (RTF) for developmentals proceeding to a standalone radar facility. This course incorporates classroom and simulation training focused on managing traffic outside the radius managed by Towers, generally extending only a 40-mile radius from the primary airport. The En Route track is comprised of the most detailed courses at the FAA Academy and focuses on managing air traffic along defined routes. This track consists of classroom instruction, medium-fidelity skills practices utilizing interactive computer-based instructional systems, and high-fidelity En Route Automation Modernization (ERAM) simulation in an En Route lab [1][2].

Through a recently FAA funded project, Embry-Riddle is developing a web-based ATC simulation technology that focuses on en route scenario-based training. The project, namely, ATC Scenario Training Technology (ASTT) is designed and constructed based on the Academy's need for a training tool that is available to trainees 24/7 and provides en route scenarios for practice. ASTT's requirement elicitation was conducted over non-traditional requirements engineering methods, where various en route scenarios were provided to the development team and tool architecture was designed through series of scenario negotiation and discussion sessions. In this paper, we demonstrate how scenario-driven requirements engineering was utilized to fully capture ASTT functional and non-functional requirements and design the architecture.

II. Requirements Modeling through Scenario Exploration

Scenarios are stories or examples from the real world. These may be narratives that bring out a problem situation, or sequences of behavior and possible contextual description. They are used to guide design decisions and are commonly used for guiding software design and system development. Scenario-based requirements engineering has been long identified as a technique for requirements elicitation and modeling since late 1980's [4]. Some of the initial work and proposals in this area have been well documented in [5].

In a recent paper, Moallemi et al, describe the pathway to tackle aviation scenario generation challenges using the recently proposed Aviation Scenario Definition Language (ASDL) [11], where complex operational scenarios were translated into executable scenarios.

Scenarios are not only used during requirement elicitation and system design, but can also aid in the evaluation of the final product and towards system's acceptance. In Agile processes such as SCRUM, user stories are example of scenario-driven system development and verification. Scenario-based Requirements Analysis Method (SCRAM) [8][9][10], focuses on the use of scenarios and early prototyping to elicit requirements in reaction to a preliminary design. SCRAM poses high emphasis on user engagement at requirements elicitation and initial system design for collecting effective feedback and improving requirements engineering. The use of scenarios in this approach drives the nature of discussion among system designers/developers and user, such that each scenario reflects on different product context and usability perspective. By merging the elicitation and validation role of scenarios, the user has the opportunity to assess the product design at early stages and further provide details on expected product features. SCRAM takes a 4-step approach to requirements modeling [5]:

(1) Initial requirements capture and domain familiarization.
(2) Storyboarding and design visioning.
(3) Requirements exploration.
(4) Prototyping and requirements validation.

Adopting SCRAM, we have used simulation scenario descriptions to capture ASTT requirements. Given ASTT's focus on en route training, a number of en route scenarios were provided to the development team to implement ASTT system requirements. Each scenario was analyzed and dissected, highlighting key terms and their associations. Series of key and secondary features for ASTT tool were then identified, ensuring that scenario concepts were covered. Since ASTT needs to replicate ERAM capabilities, given the focus of the project, only a subset of ERAM capabilities had to be developed. This process was repeated iteratively, developing subsets of ASTT features and demonstrating the resulting tool to the customer for further elaboration and feedback. At the end of each iteration, enhancements are implemented at ASTT and the next set of tool features are developed during the next cycle, repeating SCRAM 4-step mechanism.

En route scenarios contain several aircraft, usually a combination of active flights and departure flights, the latter of which are activated in the middle of the scenario. The en route controller trainee's job is to handle all traffic within their sector. This includes maintaining separation, coordinating point-outs and handoffs with neighboring sectors, issuing clearances and responding to any issues, conflict alerts and other emergencies.

For the purposes of training, several tasks are selected for the student to be tested on, and a record of their response to each situation is used for grading their proficiency. The nest section describes the actions and events within one such sample scenario to illustrate the workings of an ERAM controller's tasks. The following is a description of an example en route scenario [6].

A. Sample ATC En Route Scenario

The scenario has a total of 26 aircraft, and tests users on events including point outs, arrivals, departures and conflict alerts. The scenario lasts for 45 minutes, and has events occurring at random intervals in that timeframe, thus requiring the controllers to be alert and focused throughout the period.

At the 5-minute mark, an aircraft that is currently in a high sector right above the trainee's sector of control calls in, requesting a lower altitude. The controller must verify that there would be no conflict with traffic under their control and appropriately accept or reject the request. A minute later, there are two events that need to be coordinated simultaneously – a departure from one airport and an arrival into another. The trainee is required to assess which one to respond to first and ensure that clearances are issued after the traffic situation has been assessed. Three minutes after this event, there is a red alert between two aircraft. A red alert occurs when there is an aircraft to aircraft conflict, with a separation of less than five miles or one thousand feet. This is considered an emergency, and the trainee must change the altitude or heading of one or both flights to increase separation, without letting the aircraft come into conflict with any other flights in the area. A minute after this, there is a yellow alert between two other aircraft, which occurs when separation is greater than five miles, but still within the detection range (five to twelve miles). This requires similar rerouting action on the controller's part so that no red alert is triggered. The scenario continues with another arrival three minutes after the yellow alert, then another request for a lower altitude from a high sector, two more arrivals, two departures and a red alert and a yellow alert. Twenty-six minutes into the scenario, an aircraft is identified as coming into the sector with an IAFDOF. The general rule is that all aircraft flying east must do so at odd levels of altitude, and those heading west should fly at even altitudes. The IAFDOF requires the controller to update the altitude or give clearance to continue on the inappropriate altitude in case of possible conflicting traffic before the aircraft can be accepted into their sector. The scenario ends with two more departures, two arrivals, two alerts and another IAFDOF over the rest of the allotted time.

Point outs are key elements of this scenario that need to be taken when an aircraft is entering the sector (Take Pointout), and made when an aircraft is leaving the sector and entering another one (Make Pointout). The issuance of clearances and ability to recognize an IAFDOF is also tested several times in the scenario. The trainee must be able to handle conflict alerts and resolve them to maintain separation within their sector at all times.

B. Extracting Scenario Information

The process of extracting requirements from the given scenarios starts with identifying key training concepts aimed by each scenario. For the given sample scenario, the following key requirements can be identified:

- Accept/reject requests from pilot
- Change of altitude
- Hand off
- Take/Make Pointout
- Conflict detection/resolution
- Color coded conflict alerts
- Verification of appropriate altitude for direction
- High/low sector operations
- Target type identification
- 4D trajectory modeling and prediction
- Aircraft flight simulation
- Surveillance data generation from simulation
- Flight plan management and handling

- Sector boundary crossing detection and prediction
- Handling required level of controller-pilot communication
- Simulating adjacent sector's controller actions

The information extraction process takes place iteratively, by requesting additional information from the customer (FAA Academy instructor) to further collect detailed requirements. This technique, or namely, scenario-driven requirements engineering, is conducted over all the given en route scenarios until the development team felt confident about understanding the system requirements to perform requirements modeling. The next section discusses such activities.

III. ATC Simulator Requirements Design and Modeling

Upon extracting information from the given en route scenarios, a pattern could be identified as a common scenario routine, which is depicted in Fig. 1 as Scenario Attempt Life Cycle. The scenario attempt resembles the generic idea behind en route scenarios, regardless of the specific goals that has to be met by each scenario. This pattern aided in summarizing information extraction process explained in Section II. Furthermore, by referring to ERAM manual [7], scenario activities and their relation with the EARM graphical user interface were identified. This helped with identifying the appropriate location for scenario events (front-end/back-end).

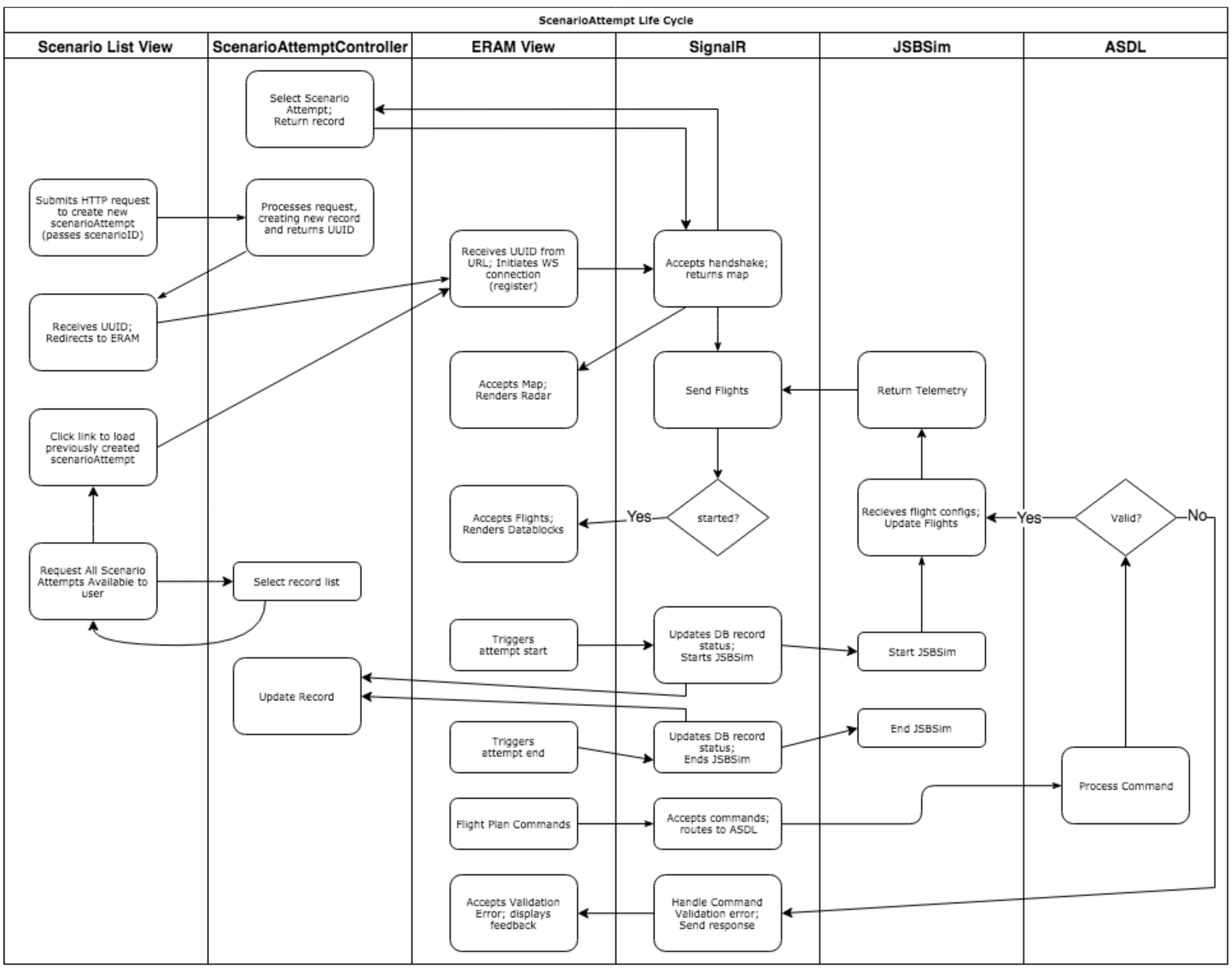

Fig. 1 ASTT Scenario Attempt Life Cycle

The next step was to construct a requirements model that lays out ASTT features and maps development tasks to each feature. For illustration purposes, a snapshot of ASTT requirements model is given in Fig. 2. The requirements model was developed in Enterprise Architect software which allows for an object oriented scheme in defining requirements and establishing the relationships between them.

The requirements were separated into two categories: Visualization and Function. Since a web-based development and product is the goal and the user interface is a very important requirement in ATC operations, the front-end components were captured in the Visualization category which is mainly comprised of the views, menus and hardware visualizations (controller keyboard, keypad and trackball). Function category, consisted of functional requirements that captures the essential operations of ERAM R and RA (D) sides. Requirements such as ERAM messages (commands), sector crossings, conflict detection, kinetic modeling of the aircraft performance including trajectory prediction, aircraft flight dynamics simulation, data distribution as well as authentication and user grading functionalities. The object oriented relationships (inheritance, association, and composition) among these components were captured to streamline the software design.

This approach allowed for requirement tracing to the design, development and testing by directly mapping the requirement components into design components and then classes and methods in the code. The development process traced back to the requirement by adopting a color coding scheme, where those components from the requirements model that were initially captured were colored in yellow, then once they were under development, the component color would change to light green, and once completed and tested, they would change to dark green. This approach was very helpful to the customer as well, to trace the tool development progress.

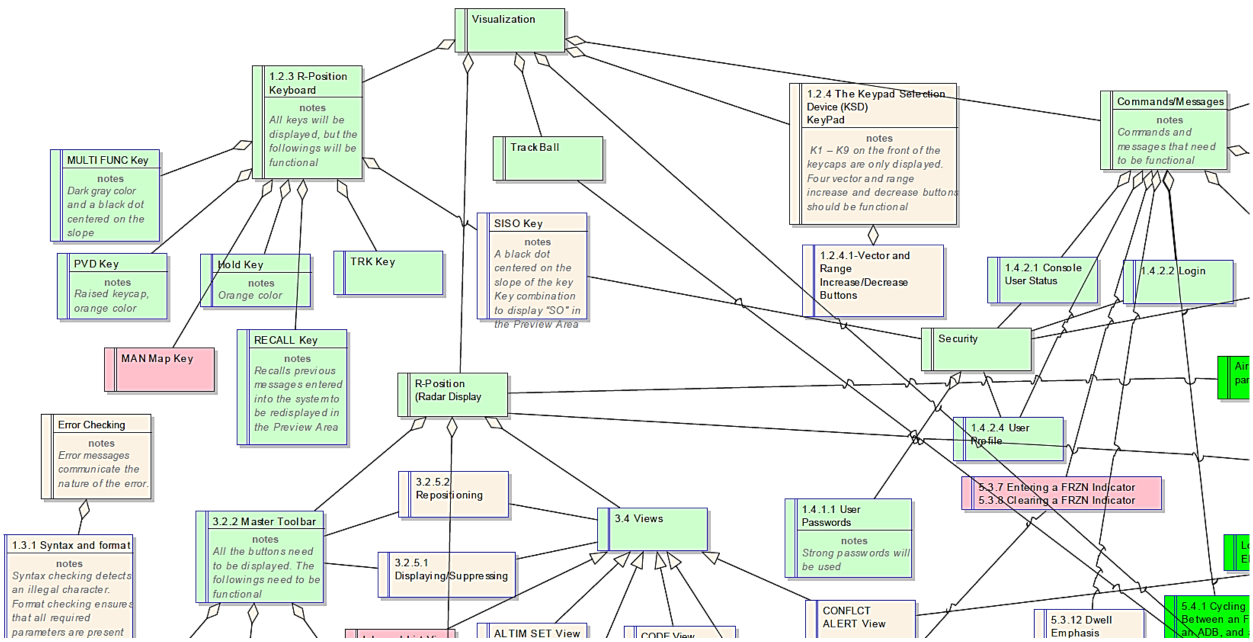

Fig. 2 ASTT Requirements Modeling Snippet

By identifying ASTT features list and based on the design of ERAM user interface, a high-level ASTT architecture, adopting Model-View-Controller style was designed. Fig. 3 represents this architecture, separating various user views (windows) from backend simulation entities. ASTT was designed with high adaptability and configuration in mind. The tool will be able to serve various training facilities, allowing for the selection of airspace, scenarios and aircraft performance data.

The ERAM processor is the main brain of the system providing ERAM core functionalities. It communicates with ERAM view which is comprised of all of the ERAM R and RA (D) side views and menus. The data flow between FlightSim, ERAM processor, and ERAM view is the essence of ATC operation, transferring the flight state vector from FlightSim component - simulating a high fidelity aerodynamic model of the aircraft - to the radar scope and decision support tool, once core trajectory analysis has been performed on this data. The scenario model contains definitions of the scenario events, such as flights, weather, special activity areas, duration, and so on. Facility database contains the definitions and geometry of all the sectors, the air route and navigation data, airport and airspace specifications and constraints. Scenario Evaluator consists of evaluation and grading categories and acceptable performance data that is used to grade the students' performance.

ERAM command window emulates the voice communication between the controller and pilot, as well as controller to Flight Station Service (FSS) radio and Air Traffic Management (ATM) units. Since the tools is supposed to be standalone and fully automatic, all of the communications between the controller and the mentioned entities must happen outside of the ERAM view, via external menus and user interfaces. In the future, text to speech features will be used to create more realistic ERAM command functionality.

The Management View and associated controllers enable the administrators and instructors to specify scenario configurations, grading requirements and user management. It also provides them with student performance metrics taken from grading recordings. One of the future goals is to add visual scenario generation capability to the management view, enabling the instructors and admins to generate scenarios with graphical interfaces and prediction of events.

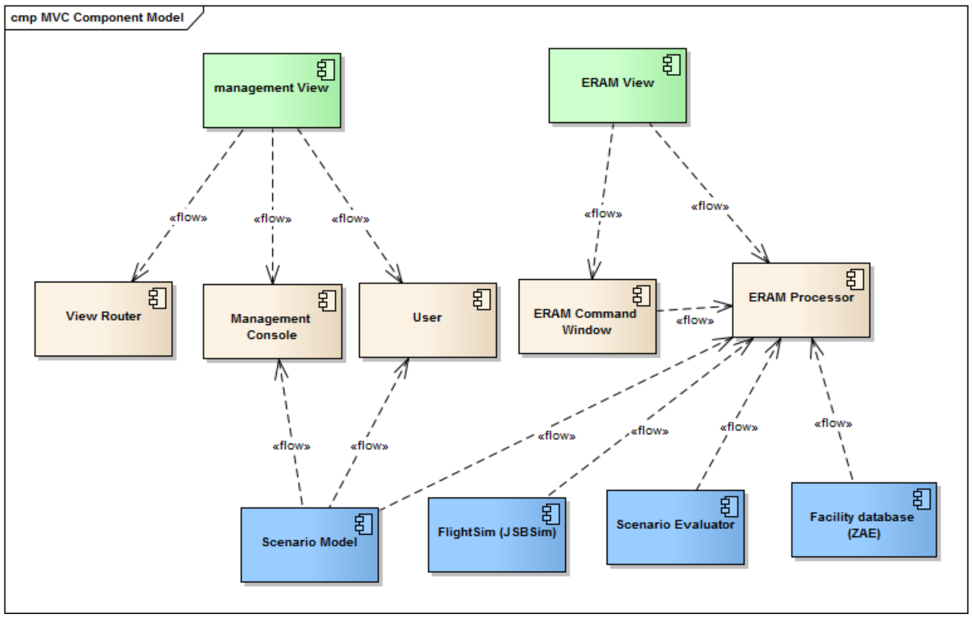

Fig. 3 ASTT Model-View-Controller (MVC) High Level Architecture

ASTT user interface is composed of two views: Radar-Position (R-Position) view with a radar display (representing sectors and aircraft position and surveillance data), and Radar Associate-Position (RA-Position or D-Position) view providing the ERAM Decision Support Tool (EDST), as well as controller keyboard pane at the bottom of each view. These two views are captured in Fig. 4.

ASTT currently supports the following ERAM functionalities:

- Maintaining flight data, including accepting flight plans and updates from controllers.
- Maintaining airspace configurations, including sectorization (airspace assignment to controllers), restrictions in effect, Letters of Agreement (LOA).
- Separating air traffic using surveillance information or manual procedures
- Detecting and resolving potential conflicts (supported by medium term conflict probe decision support tools and tactical alert software, which detect aircraft-to-aircraft, and aircraft-to-airspace conflicts)
- Monitoring conformance of flights to flight plan-based trajectories
- Posting, sequencing, and updating flight information for controllers
- Accepting and initiating flight handoffs and point outs with other facilities
- Kinetic 4-dimenssional Modeling in support of aircraft trajectory modeling providing trajectory prediction for conflict alerts, Time of Arrival prediction, Top of climb and Top of decent prediction, as well as sector boundary crossing predictions.
- Modeling and storing of speed constraints and window vertical constraints by route segment
- Using aircraft flight envelope and Base Of Aircraft Data (BADA) for aircraft performance modeling

In order to simulate real-time air traffic for the scenarios, ASTT uses accurate Flight Dynamic Models of several aircraft, each of them including simulated Flight Management System (FMS) and autopilot capable of steering the aircraft per the aircraft published flight profile. The simulated FMSs are capable of storing flight plans using 4D waypoint trajectories (latitude, longitude, altitude, and time constraints).

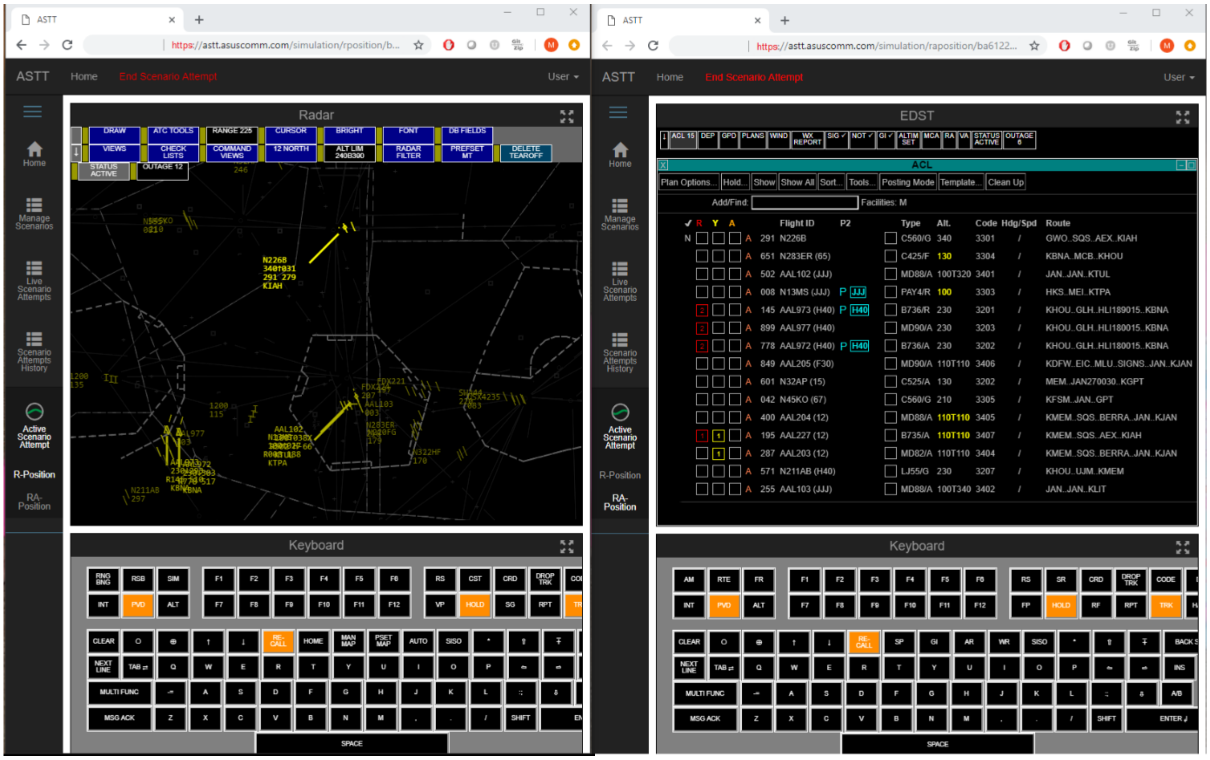

Fig. 4 ASTT R-Position (left) and RA-Position (right) User Interface

IV. Conclusion

The Federal Aviation Administration (FAA) Academy is challenged with limited availability of Air Traffic Control (ATC) training technologies for their trainees. Through a recently FAA funded project, called ATC Scenario Training Technology (ASTT), Embry-Riddle is developing a web-based ATC simulation technology that focuses on en route scenario-based training.

Testing software in Air Traffic Control (ATC) systems is not easy. There are many challenges including cost. Software engineers strive to find methodological and process-level solutions. One of the popular methods in critical systems engineering field is model-driven approach. In this project Scenario-based requirements engineering technique was used for requirements elicitation and modeling. The process of extracting requirements from the given scenarios starts with identifying key training concepts aimed by each scenario. It was tailored to meet the two category requirements namely visualization and function, and to create scenario attempt life cycle. Subsequently, the object-oriented relationships were captured to streamline the software design.

FAA is challenged by the ever-growing needs of the aviation industry. The challenges are manifold. It includes the burgeoning air traffic, and technological advances of the aircrafts. We believe that this project will fulfill the Academy's need for a training tool that is available to trainees 24/7 and provides en route scenarios for practice. A number of significant enhancements and further features are currently under development within ASTT project.

Acknowledgement

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