LIVE, VIRTUAL & CONSTRUCTIVE SIMULATION FOR PILOT AND AIR TRAFFIC CONTROLLER TRAINING

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ABSTRACT

Air transportation demand increase drives the development of new systems and regulatory changes to support higher operation volume. Better qualification of related personnel is paramount to guarantee the safe operation in this environment. We propose a simulation environment for pilot and air traffic controller (ATCO) training. The environment is composed of live, virtual and constructive elements that support training to develop skills related to: procedures and air traffic control (ATC) rules; familiarizing with ATC systems; ATC phraseology compliance. On simulation scenarios, pilot uses a commercial flight simulator, ATCO uses real operating ATC systems and communication through a VoIP compliant system.

Keywords: Simulation, Training, System Integration.

1. INTRODUCTION

Air transportation demand is growing every year and is expected to double by 2036 (IATA, 2017). In order to capitalize on this rate, airlines and general aviation providers must increase the operation volumes and air traffic control (ATC) service providers must guarantee airspace efficient and safe usage with this increased volume operations. On both ends (flight and air traffic control providers), the operation tasks are human-centered, therefore the number of qualified professionals must increase to support the higher operation volume. In this paper, we present the LVC (Live, Virtual & Constructive Simulation for Pilot and Air Traffic Controller Training), a simulation environment for pilots and air traffic controllers training. This simulation environment will be referenced as LVC on the remaining of the text.

This environment will be composed of the X-Plane (X-PLANE, 2018) flight simulator, the SAGITARIO air traffic control system, the AMAN (Arrival Management) system and a VoIP compliant system. The X-Plane simulator is certified by FAA (Federal Aviation Administration) due to its high fidelity simulations (X-PLANE, 2018). The simulator allows the development of plugins, enabling X-Plane integration with other systems. SAGITARIO is the air traffic control system used in several ACC (Area Control Center) and APP (Approach Control Center) on Brazil, so the professionals under training will be using the same system of the real scenario. The AMAN system is an auxiliary air traffic control system, used along SAGITARIO that issues advisories regarding the arriving air traffic. These systems are then integrated on the network (via UDP or TCP/IP), so systems will not be physically constrained. Figure 1 represents the general structure of systems integration.

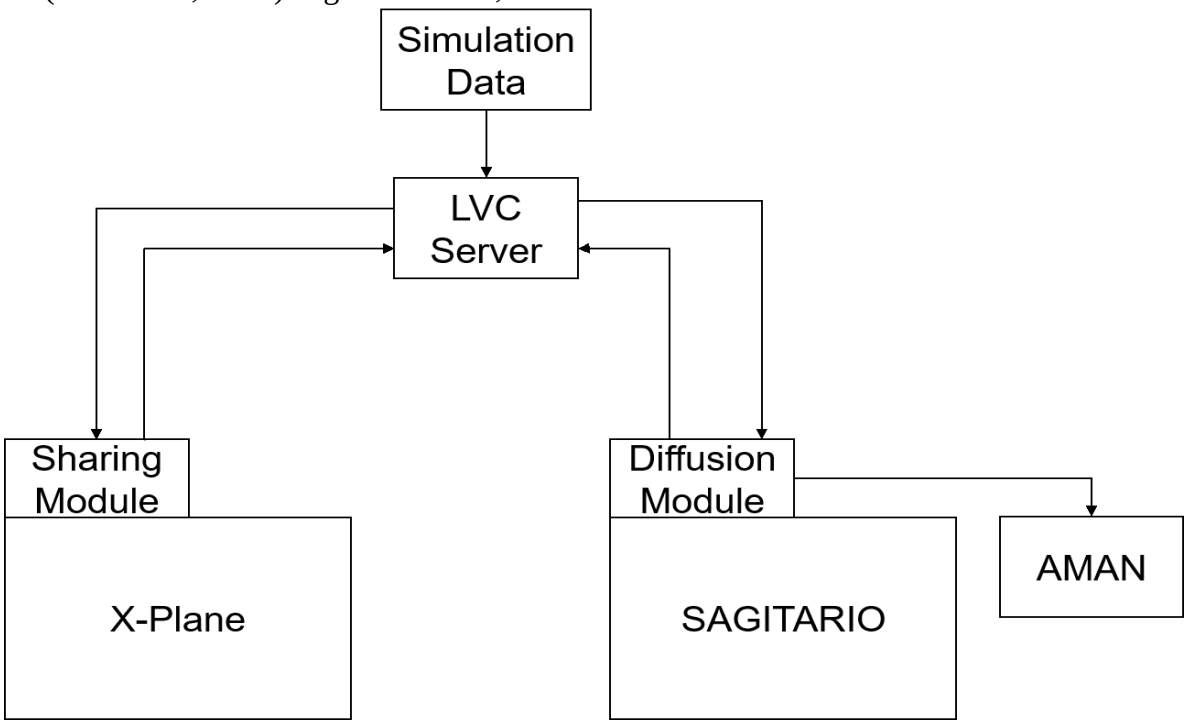


Figure 1- System Integration General Structure

The basic simulation scenario is as follows: the pilot (the user on the X-Plane position) and the Air Traffic Controller (the user on the SAGITARIO and AMAN position) will voice chat using the VoIP system. The controller will issue advisories to the pilot based on the information provided on SAGITARIO and AMAN and the pilot must perform the corresponding actions on X-Plane. The dialogue between users must be the standard ATC phraseology. Two main scenarios are initially proposed. In the first one, pilots will be trained. Users using the X-Plane will communicate with an experient Air Traffic Controller. In the second scenario, the air traffic controller will be trained. Pilots will be flying around an aerodrome and the air traffic controller must

issue actions based on SAGITARIO and AMAN advisories. In both scenarios, it is possible to use live data (real time air traffic data) from the radars network and simulated air traffic data.

The concept of the LVC simulation environment is based on the integration of three different domains: live domain, virtual domain and the constructive domain. The live domain is represented by the real operating systems that are used on the simulation and the professionals that take part on simulations. The virtual domain is represented by the simulation tools used to execute the scenarios. The constructive domain is achieved with systems that simulate human behavior on simulation systems and the infrastructure that enables real and virtual systems integration, so LVC has the capacity to add, replace and remove simulated elements in order to modify the simulation fidelity or the aspect of the training on course.

Simulation systems may be integrated using industry standard protocols. High Level Architecture (HLA) (Dahmann, 1997) is an interoperability standard for distributed simulation, used traditionally in military applications. The LVC environment uses an implementation of HLA, so it is ready to integrate with HLA-compliant simulation systems, enhancing the virtual and constructive side of the environment. HLA is implemented with a Real-Time Infrastructure (RTI). Each simulation system is a federate, and federates join a federation. This federation connect federates via the RTI, using a common Object Model Template (OMT). The OMT defines the simulation data that will be exchanged on the federation.

Simulation environments that mix live, virtual and constructive simulation elements have been used for training and qualifying process and systems test. Frank, Helms and Voor (2000) present the FAPV learning model. This model is composed of 4 steps and the authors discuss which type of simulation (live, virtual or constructive) is better for each step. Varshney, Pickett and Bagrodia (2011) present StealthNet, a LVC framework for simulation of cyber threats. This framework can integrate with physical networks and is used to test them. Bezdek, Maleport and Olshan (2008) described the development of a live, virtual and constructive simulation used on network centric operations experiments.

In this paper, we address the technological challenges of these systems integration and explore other system integration to enhance the simulation scenarios, for example, the presentation of airspace elements on X-Plane.

2. METHODOLOGY

The elements of the LVC were adopted to support the training and qualifying process regarding skills related to the following competences.

Pilots must fly following a set of rules and procedures. The set of rules depends on the aircraft capacities, while the procedures depend on the aerodrome and airspace the flight will take place on.

Air traffic controllers (ATCo) must follow a set of rules as well, for the safe and efficient airspace usage. Different ATC systems are used to support the decision-making process for ATC operations. These systems have different objectives and should be used complementarily to provide advisories to ATCo and increase their situational awareness. ATCo must be trained to follow ATC rules using these systems as support tools.

During operations, pilots and ATCo are on constant voice communication. The phraseology of the communication is defined by air transport organizations. So pilots and ATCo must use the expressions defined on the phraseology.

A flight simulation software is used to train the pilot to follow ATC advisories and flight procedures. Real ATC systems are employed to provide ATC apprentices the practical experience with systems that will be used on real operations. A VoIP system is used to provide voice communication between the pilot positions and ATCo position of the simulation. In the following sections, these elements will be further detailed.

2.1. X-PLANE

X-Plane is a commercial flight simulator published and developed by Laminar Research available on different platforms.

X-Plane provides a set of aircraft models to be used on simulations. The simulator provides resources import models and the X-Plane users community is active regarding aircraft models development, so it is possible to find or create a model that matches the real aircraft. These models may represent the aircraft with different level of details and interaction. On the models provided by Laminar Research the external and internal parts of the aircraft are modeled. On LVC, the preferred view is the first person view, so the aircraft components that must be modeled are those related to the flight navigation operation. Flight instruments of the aircraft dashboard must be functional (the altitude indicator must present the altitude of the flight for example) and interactive (the pilot must be able to set the flight SSR code by clicking on the transponder device buttons for example).

Besides aircraft models, X-Plane provides scenarios of the aerodrome (with information of runways, apron) and its surroundings. The simulator has models of most aerodromes and it is able to import new ones.

On the X-Plane side of the simulation, the player aircraft will be presented on the airspace the flight takes place, along with other aircraft of the scenario. These aircraft may be simulated by other X-Plane positions or may be provided by other system (SAGITARIO, for example). X-Plane has a multiplayer feature that enables the simulator to receive data of other flights and present aircraft that represent those flights. The data integration may be accomplished by using the built-in multiplayer and data sharing feature or by developing a custom X-Plane plugin.

The built-in feature shares the player's flight data over UDP. In the X-Plane user interface, it is possible to choose which flight data will be shared over UDP. The application that will listen to this data processes it. Multiple X-Plane instances on the same network may be configured to connect to each other, presenting their player aircraft on other instances. ***Figure 2*** is a screenshot of X-Plane that presents the configuration of shared data via UDP. In this screenshot, aircraft speed (ground speed, air speed) and pitch, roll and heading information will be sent via UDP.

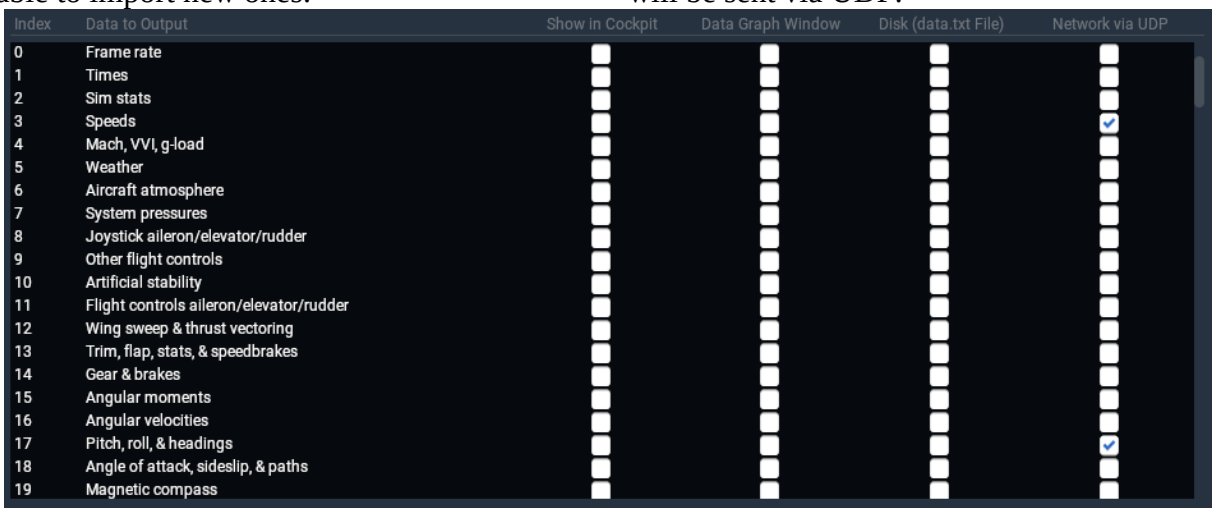


Figure 2 - X-Plane data sharing configuration

X-Plane allows the development and use of custom plugins. These plugins are developed in C++ and may expand the simulator functionalities. On LVC, plugins were developed to implement data exchange over TCP/IP. One plugin provides a buffer with simulation data regarding aircraft position, speed, attitude, and identification. The application that will listen to this data will process the buffer, and will send a message with this data to a consumer plugin.

The X-Plane is used to achieve the virtual domain of LVC and the multiplayer, data sharing and plugin development capacity is used to achieve the constructive domain. The users (pilots) of X-Plane are part of the real domain of LVC.

2.2. SAGITARIO

SAGITARIO is the Air Traffic Control system used on most control centers in Brazil. This system is composed of different modules

with functionalities that provide airspace situational awareness, flight data, conflict detection and other information that are used to assure aircraft fly on the airspace according to the established ATC rules.

The main functionalities used on the current version of LVC and the simulation scenarios are flight data provision and conflict detection advisories. On these scenarios, SAGITARIO will always receive the simulated X-Plane flights and may receive real flight data, previously recorded flight data and procedure-specific simulated data.

SAGITARIO and the ATCo are part of the real domain of the simulation.

2.3. AMAN

AMAN is a system that automates the landing sequence of aircraft. It provides advisories based on the flight plan and the flight current data (position, speed, attitude). This system is used along with other ATC systems (in our case, SAGITARIO), using the same data, to support the decision-making process. On current simulation scenarios, the AMAN system will use the same data provided to SAGITARIO.

The main objective of the AMAN system integration on LVC is to prepare the ATCo to use the system's advisories while interacting with real pilots, but on simulated environment.

2.4. TeamSpeak

TeamSpeak is the VoIP application to implement the voice chat between pilot and ATCo. The application has client and server versions. On LVC, the ATCo position uses the server version, while the pilots use the client one. In this structure, one ATCo is able to communicate with different pilots. As previously stated, the voice communication is used to train the ATC phraseology.

The TeamSpeak application is part of the constructive domain, and the usage of ATC phraseology is part of the real domain.

3. SYSTEMS INTEGRATION AND SIMULATION DATA

The simulation data provided by different entities compose a shared scenario. Systems integration provides this shared scenario to simulation participant. This integration is mainly achieved with a server application. This server (referenced as LVC-server on the rest of the text) was developed for the LVC environment so simulation participants do not need to know details about data paths and connections to receive and send data. The server exchanges data using either UDP, TCP/IP or HLA connectors.

This paper proposes some training scenarios on section 4. Regarding these scenarios, the data sources are the X-Plane positions and the flight data replay. The data consumers are the SAGITARIO and AMAN positions. Because of the shared scenario and the connectors, it makes no difference to the data consumers whether data is being generated on an X-Plane position or flight data replay. This implies on a low coupling among data sources and consumers. When a new system is integrated on the shared scenario, the participants will process the new data seamlessly.

LVC can use two different network topologies. On the first one, the participating systems are on the same local network and on the second one the systems are on different networks, referenced as the cloud structure.

On the local network structure, the X-Plane positions share data among themselves using the built-in multiplayer feature. Positions share their simulation data with other systems by sending UDP packages to the LVC-server. The server parses the message and sends this data to SAGITARIO on ASTERIX (EUROCONTROL, 2016) Categories 62 and 63. This data includes information regarding flight position, speed, attitude and identification. SAGITARIO may receive flight data from other sources on ASTERIX format; in this case, the LVC-server will receive the same data (on ASTERIX categories 62/63, 34/48 or 10/34), parse the ASTERIX message and send the message to all X-Plane positions of the simulation. This is achieved using the same

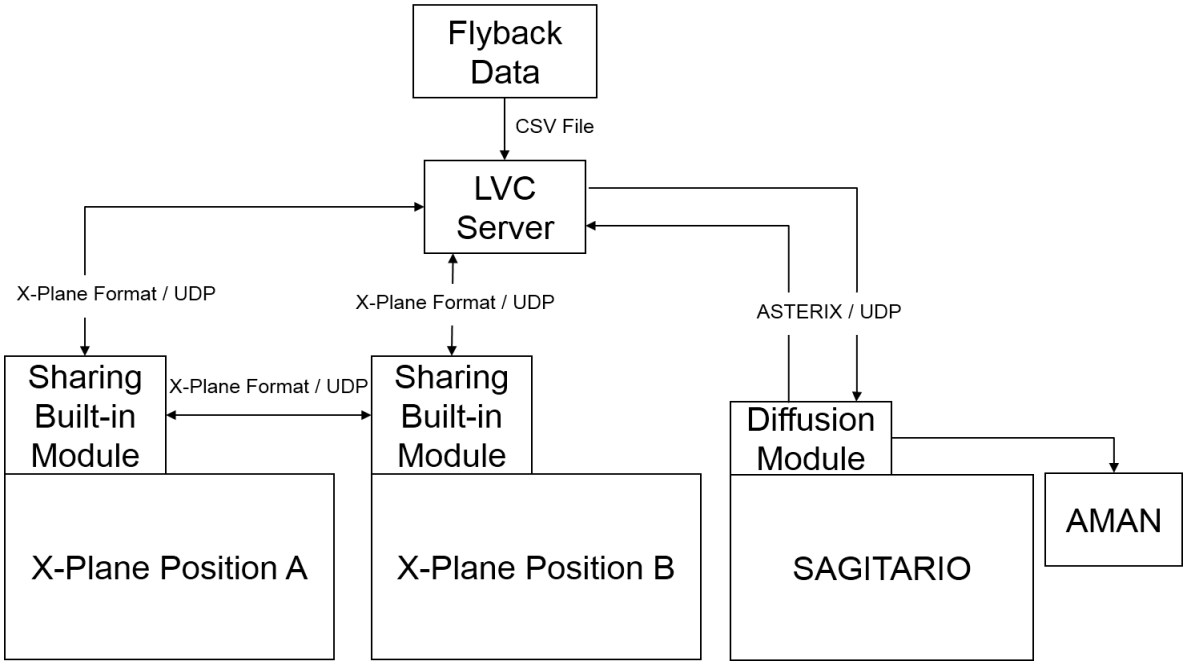


Figure 3- Local Network Structure

multiplayer feature used for data sharing among X-Plane nodes. Figure 3 represents this structure.

On the cloud structure the message exchange regarding SAGITARIO is the same of the local network structure. The main difference is the integration with the X-Plane positions. Two X-Plane plugins were developed: the DataProducerPlugin establishes a TCP/IP connection with the LVC-server and sends packages with flight simulation information. The DataConsumerPlugin establishes a TCP/IP connection with the LVC-server as well and listen to massages on a specific format. The message is parsed and the corresponding aircraft is presented on the X-Plane position. The DataProducerPlugin sends messages over TCP/IP to the LVC-server; the LVC-server parses the message, verifies which X-Plane position produced the message (so the X-Plane position will not receive data from itself) and sends a structured message to the DataConsumerPlugin; the consumer plugin receives the structured message and presents the aircraft represented on the message. The set of data shared with the plugins is the same of the local network. The cloud network structure is represented on Figure 4.

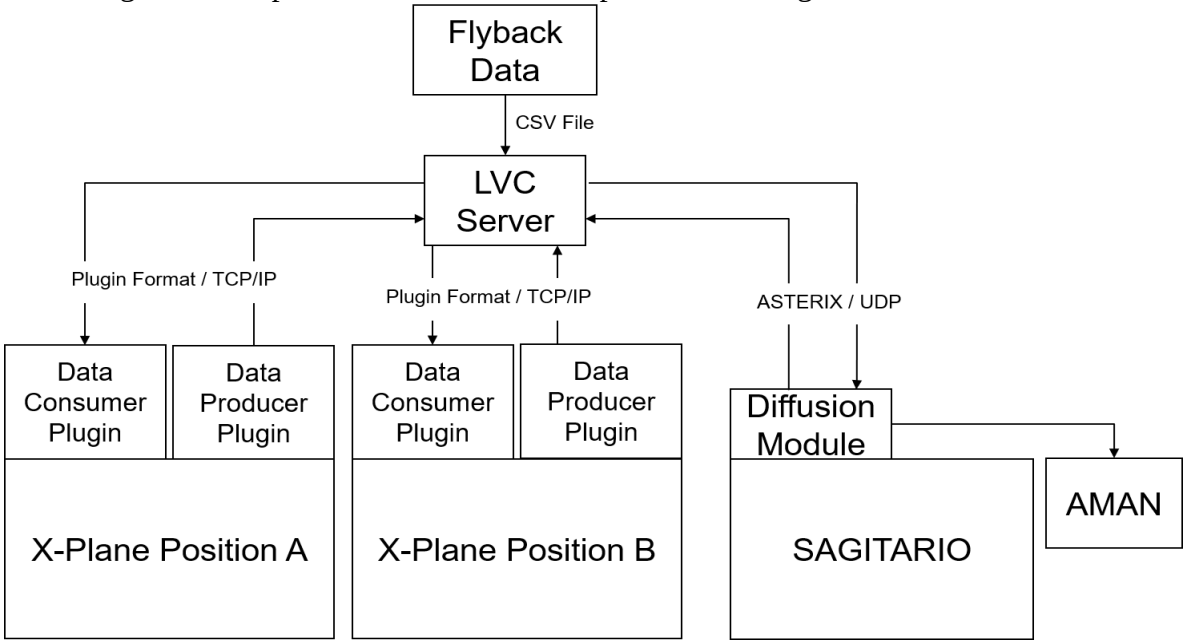


Figure 4- Cloud Network Structure

The LVC-server has the capability of producing flight simulated data. This simulated data may be based on real air traffic data of a specific time interval or may represent aircraft following a specific procedure. Since most of this data is available on samples discretized according to surveillance radar update rate, the samples must be processed to be used. For LVC, Flyback (Garcia et al., 2017) system was used for flight data sample processing. The LVC-server uses these data to simulate flights on SAGITARIO, AMAN and the X-Plane positions, using the resources presented previously. ***Figure 5*** and ***Figure 6*** are Flyback screenshots. ***Figure 5*** presents raw airspeed data graphic and ***Figure 6*** presents processed data. In this case, only data interpolation was performed, achieving a higher sample rate.

On the local network structure, HLA-connectors were developed to initialize HLA federations that provide X-Plane simulation data for other HLA-compliant simulations and consume simulation data from other systems. The X-Plane positions send UDP packages to HLA-connectors instead of sending to the LVC-server. The LVC-server creates a federation and waits for upcoming data. The connector joins this federation and publishes X-Plane simulation data on the federation. The Run-Time Infrastructure used is the Portico implementation.

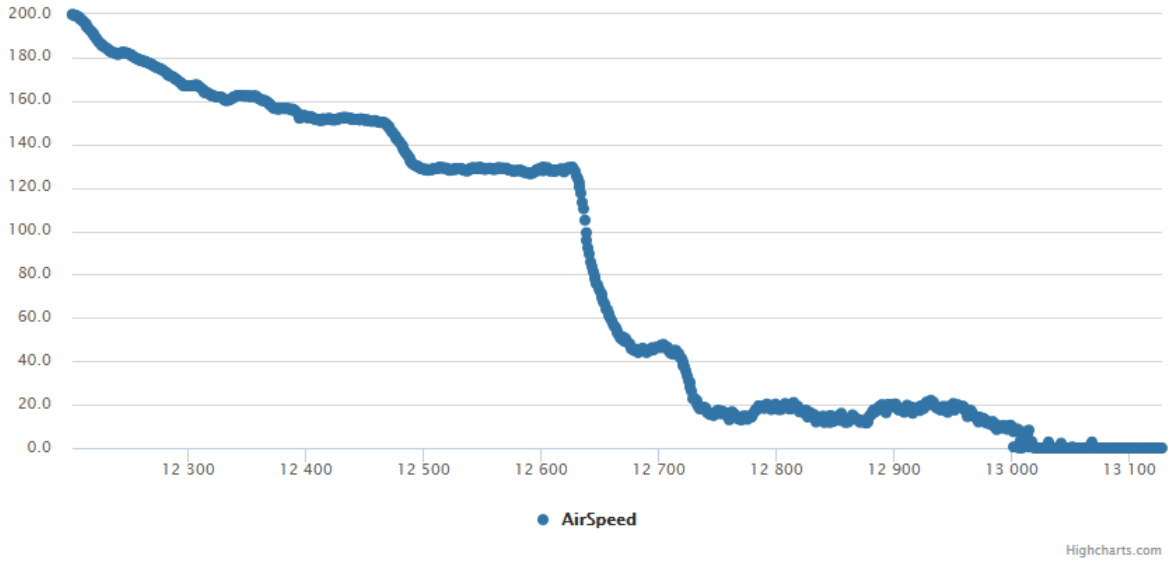


Figure 5- Raw air speed data

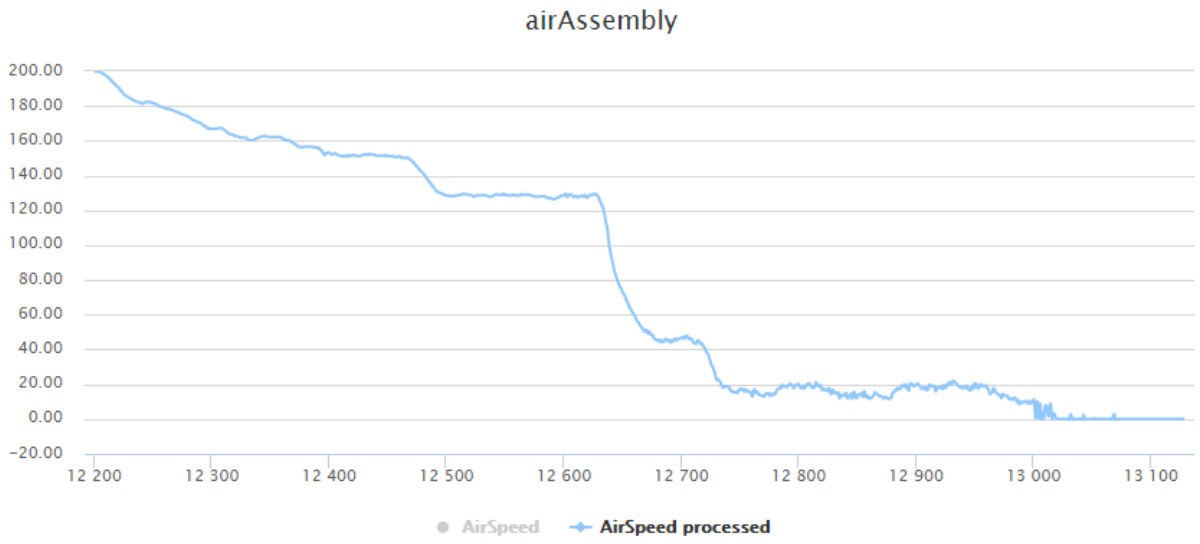


Figure 6- Processed air speed data

4. RESULTS

The LVC provides different simulation scenarios. The scenario depends on the way systems are organized, used and on the data of the simulation. This chapter will present the available scenarios regarding the current level of the LVC development. Other relevant results are the development of the LVC-server, that uses the building blocks framework to readily integrate different systems and some insights regarding the development of X-Plane plugins.

4.1. Pilot training

The simulation scenario for pilot training may be accomplished using the local network or the cloud network structure. In this scenario, an experienced ATCo will use SAGITARIO and will control the simulated flight(s) conducted by inexperienced pilots. The training objective is developing pilot skills related to following ATC rules and ATCo advisories, while using the expected phraseology.

The aircraft model used on our simulations provided a dashboard with functional and interactive instruments. ***Figure 7*** presents the PFD (Primary Flight Display) that responds to attitude, speed and altitude variations. ***Figure 8*** presents the SSR transponder interface. It is possible to set the SSR code that identifies the aircraft on the simulation.



Figure 7- Functional Primary Flight Display



Figure 8- Interactive SSR Transponder Interface

The pilot equipment proposed for this training is a stick joystick to control the aircraft on X-Plane and a headset to use TeamSpeak.

The tests were successful regarding the integration of systems and voice communication.

4.2. ATCo training

The objective of this training is to familiarize air traffic controller student with SAGITARIO and with ATC rules in general. Depending on the aspect of the training (conflict avoidance, phraseology, flight coordination) the flights of the simulation may be provided by X-Plane positions, LVC-server simulated data or real data. On tests of the platform, the data was provided from two X-Plane positions and simulated data based on real flight data.

4.3. Remote training

Tests were performed to validate the usage of the developed X-Plane plugins. The main idea of plugins development is providing pilots training from a remote position. In this configuration, the pilot and ATCo positions do not need to be on the same place, or connected to the same network. These positions need to connect to the LVC-server network, since the server shares the data among simulation participants. The following configuration was tested:

1. X-Plane with the developed plugins;
2. data and TeamSpeak over TCP/IP;
3. LVC-server using the TCP/IP connector

Tests regarding data sharing and aircraft visualization on X-Plane were successful on the local network. The cloud network structure was not tested.

4.4. AMAN Training

The objective of this training is to familiarize air traffic controllers with the AMAN system. Flights of the simulation are provided by X-Plane positions and by SAGITARIO publishing replay data. The controller must communicate landing sequence advisories for the pilots on the X-Plane positions. This scenario was configured on Atech's LabTech (Laboratório de Simulação, Ensaios e Treinamento) in São José dos Campos Technological Park. In this configuration, two X-Plane positions arriving on an aerodrome send data to SAGITARIO and the Air Traffic Controller must use the AMAN system to send landing advisories to these aircraft.

4.5. LVC-Server

The LVC-server was implemented using the building blocks framework (Souza et al., 2016). This framework enables the reuse of software components. The LVC-server is composed of data-provider and parser building blocks. The data-provider building blocks are responsible for receiving and sending data on specific communication protocols and the parser building blocks process and writes messages on a specific format. For example, on the pilot training scenario, the server used the provider-udp building block (BB) and the parser-asterix BB. The provider-udp BB is used to receive messages over UDP from SAGITARIO and to send messages over UDP to X-Plane and SAGITARIO. The parser-asterix BB is used to process messages on ASTERIX format received from SAGITARIO and writes messages on ASTERIX Categories 62 and 63 that are sent to X-Plane and SAGITARIO.

With the HLA-connectors, the LVC simulation environment may provide and consume simulation data to/from other HLA-compliant simulation tools.

The advantage of this structure is the low effort of modifying the message format and the communication protocol of systems integration.

4.6. X-Plane plugin development

X-Plane provides a SDK for plugin development. The plugin must implement callback functions which are called during X-Plane execution. For example, the XPluginEnable function is called when the plugin is enabled. The callback functions that are implementing the connection and data sending and reception are XPluginStart and the FlightLoopCallback. The XPluginStart function is called when a simulation starts. This function registers the FlightLoopCallback function. This callback function returns a float that defines the time it will wait to call the function again, in seconds.

The FlightLoopCallback function connects the plugins to the LVC-server and, on every cycle, it checks if the connection is alive. If there is no connection to the server, the function attempts to establish the connection. The DataProducerPlugin function collects flight data, and sends it using the established connection; the DataConsumerPlugin function waits until new data is available on the established connection and once data is available, the function process it and plots the aircraft on that X-Plane instance.

The DataConsumerPlugin introduced performance problems on X-Plane. Since it depends on new data availability and the plugin runs on the same execution thread of X-Plane (its main thread), the whole X-Plane system waits until data becomes available. Because of this performance problem, two ideas were proposed: configuration of a connection timeout; and execution of data acquisition on another thread. The connection timeout improved X-Plane performance but resulted in package losses depending on the timeout value. The timeout solution requires further study to define this timeout value, since data volume may affect data loss. The acquisition thread solution presented no performance loss (comparing X-Plane with the plugin disabled and X-Plane with the plugin enabled) and had no package losses. This solution required modification on the received aircraft update mechanism, since simulation aircraft data must be updated on the main thread and data was acquired on another thread. The adopted solution was the acquisition thread one.

5. COMMENTS AND CONCLUSION

A simulation environment for pilot and air traffic controller training was proposed. This environment has live, virtual and constructive elements. The adopted solutions were able to integrate the proposed simulation elements. This integration was accomplished with the use of built-in features of X-Plane and the development of X-Plane plugins and a server application. Four different types of training were proposed and it was possible to test them with this simulation environment.

Different projects on Atech were applied to develop this simulation environment, which reduced the development time. The LVC-server was built under the building blocks framework that enabled the use of already implemented components. Replay and predicted flight data were processed by Flyback, generating flight

data that could be used on the simulation scenarios.

The X-Plane plugin development provided insights that will be useful for further plugins development. These insights are related to the X-Plane performance and the actions performed on the main execution thread.

The LVC environment development is not finished. The remaining of the text presents future directions for this research.

Atech is developing an airspace information service (Koroishi et al., 2017) that provides data on a standard format. The number of possible simulation scenario will expand if LVC consumes airspace information of this service. This is part of the live domain, since this data is the same used on operation ATC systems (SAGITARIO, for example).

A tower simulator for air traffic controller qualification was developed at Atech (Aguchiku et al., 2016). This simulator uses a top-view visualization of the airport. LVC could be used to improve the tower simulator fidelity and this integration would increase the number of elements simulated on LVC as well. Since LVC is HLA-compliant, the tower simulator integration may be achieved with the development of a HLA-connector to the simulator, making it possible to provide the entire shared scenario to the simulator and allowing the simulator to provide tower simulation data on the shared scenario.

HLA is a standard used traditionally in military applications. The LVC simulation environment may be used to integrate military simulators, resulting in a military simulation scenario.

SAGITARIO and AMAN were the systems used on the simulation on this first version of the LVC. Other systems could be integrated, so ATCo would familiarize with them on a simulated environment before operating them on a real scenario.

X-Plane has resources to include flight plan data on its simulations. Other trainings could be carried out once flight plan data is integrated on LVC scenarios.

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