Graphics Generation as a means to support Simulation Applications and Synthetic Environment in Alenia Aeronautica

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Abstract

As flying machines progressively evolved into complex aircraft systems, flight simulators took on an increasingly flexible and versatile role. The initial need for real-time, man-in-the-loop flight simulations grew into the necessity to represent several complex interactions between the aircraft system and the surrounding operational scenario.

Alenia Aeronautica have taken advantage of the increased availability of new computational and visualisation tools to develop multi-functional simulation facilities and complex, realistic scenarios intended to enable the real-time interaction of simulators flown by real pilots with other actors: remote-controlled aircraft, semi-autonomous aircraft endowed with various levels of intelligence (e.g. Uninhabited Aerial Vehicle - UAV, Uninhabited Combat Aerial Vehicles - UCAV), real systems (test rigs).

Even so, the essential cues needed in a flight simulator have not dramatically changed and can be still classified in three major groups: visual cues, motion cues, aural cues. The visual sensing system is, in order of magnitude, the most sensitive human capability, which makes simulating reality for an observer very challenging. Yet, because of the importance of the vision in any training task, it is necessary to reproduce the required visual cues with optimum fidelity, at least with regard to: out of the window view, cockpit displays, monitoring and control formats.

The present paper gives an overview of activities in Alenia Aeronautica aimed at providing their flight simulation assets with the required graphics capability:

- Creation of an extended geographical database, with different level of detail in different areas, so to enable sufficient realism of both high and low altitude flight, within an ample range of velocities;
- Development of proprietary image generation systems for Out-of-The-Window view representation;
- Development of graphic formats employed both for cockpit displays simulation and for monitoring and control interfaces for the Instructor Operating Station;
- Development of stereoscopic visualisation tools.

Keywords: *Alenia Aeronautica, Image Generation, Sapphire, Simulation, Graphics, Synthetic Environment*

1 INTRODUCTION

Alenia Aeronautica S.p.A., a Finmeccanica Company, is the Italian aeronautics industrial leader, with products ranging from military defense and transport aircraft to commercial aircraft, aerostructures, advanced mission systems and aircraft maintenance and modification. Since 1912, the Company and its predecessors have built more than 12.000 aircraft, often on original design.

Some of the world's most advanced aircraft came out of Alenia Aeronautica plants, built either directly or through international co-operation ventures. In its role as system integrator, Alenia Aeronautica designs and develops complete aeronautical systems with full responsibility toward the final Customer. Alenia Aeronautica is also involved in the design and development of complete state-of-the-art aeronautical systems in partnership with other world-wide Companies. As a risk-sharing supplier, it designs and manufactures entire airframe components and assemblies.

Based on its sound experience in aircraft integration, the Company has also developed the capability of designing and operating Flight/Mission Simulators and Training systems. These systems are developed in the Company's **Systems and Simulation Laboratories**, located at Torino and Caselle (Italy).

These Flight Simulators have evolved through the years into mission simulators: today the four Flight Simulators available in Torino (i.e. the AMX, the two Eurofighter Typhoon and the C-27J Spartan simulators) are used in supporting aircraft development throughout their entire life-cycle, from concept to development, flight test and in-service support. In addition, these simulators have been included in the initial training syllabus for aircrews of the Italian and other Customers' Air Forces. The Alenia Aeronautica Flight Simulators, together with other ancillary simulation facilities such as the Typhoon Aircrew Cockpit Procedure Training (ACPT), are an integral part of the Company's **Synthetic Environment (SE)**[1]**,** an extended network

[1] According to the particular definition applicable to the Alenia Aeronautica's operational range, the SE represents the combination of humans, models, simulations and real equipment which are necessary to develop and operate specific weapon systems in a virtual fashion. Essential characteristic of the SE is the reproduction of the context under which the system operates with an adequate level of realism. Such a context is intended as the collection of the physical environment

of applications, models, simulations and equipment, up to and including the aircraft systems themselves – manned and unmanned – in the frame of a common virtual representation of the real world.

This extensive experience has allowed the Laboratory, in collaboration with its industrial partners, to participate in major Simulation and Training System programs that include the AV-8B Harrier II Avionics and FCS Trainers for the US Marines, the Eurofighter Typhoon Aircrew Synthetic Training Aids (ASTA) and Ground Training Aids (Maintenance Simulation Trainer - MST and Desk-Top Trainer – DTT), the C-27J Spartan Operational Flight Trainer, Cockpit Avionics Part Task Trainer and Computer Based Trainer.

2 FLIGHT SIMULATION AT ALENIA AERONAUTICA

The history of flight simulation at Alenia Aeronautica dates back to 1961. A number of development and production standard flight simulators has been developed in-house since then, closely following technological advances in the field of computation, visual systems, and man-machine interfaces that have taken place since that time. From the first analogue calculators to state-of-the-art super-computers, things have changed quite dramatically, and an ever increasing realism has been brought to more and more affordable systems.

2.1 Flight simulation resources

Over the years, Alenia Aeronautica have developed and operated, among several others, flight simulators for the G91, G91-Y, G222, Tornado, up to the present-day fully operational four flight simulators: Eurofighter (EF) "Typhoon" in two versions, development and production standard, AMX, and C-27J "Spartan".

The original task of the engineering flight simulators developed in Alenia Aeronautica is to support the development of the aircraft. They have occasionally been employed for training, as in the late eighties with the AMX simulator, or in the near future for interim training on a twin dome Eurofighter platform. More recent ones, such as the C-27J, are still born specifically for aircraft development, but are intended to be used interchangeably also for training.

The **C-27J simulator** cockpit is populated with a mix of actual production hardware and instrumentation built specifically for this facility. The visual system includes an Equipe Electronics "Blue Sky" image generator based on SGI "Infinite Reality2", and three SEOS-modified Barco projectors fitted to a SEOS “Panorama” display system. The image of the outside world is collimated for both pilot and co-pilot, thus enabling an adequate field of view from both seats. A three-axes, five-channel FCS Simulation Systems Control Loading System is used for the modeling of the forces on flight controls in every operational setting.

The C-27J simulator is presently used to support the development activities and flight testing of this evolution of the G222 aircraft, and has also been conceived for training aircrew of the Customers’ Air Forces.

Figure 1: The C-27J Spartan engineering simulator.

The **AMX simulator** is housed inside an inflatable dome. This simulator is the most senior within the department, and has been used for training of more than one hundred Italian and Brazilian Air Force pilots, between 1989 and 1993. The visual system includes a PC-based version of Sapphire image generator (see § 3.1.2), three Barco scenario projectors and one dedicated Head-Up-Display (HUD) projector, that can be used alternatively to a real equipment adding flexibility to the system, and is based on a Digital Alpha host computer. The simulator is being upgraded to be used as support in avionics modernization activities on this aircraft; furthermore, it has been offered to the Italian Air Force as an effective tool to provide recurring training to operational pilots.

Figure 2: The AMX flight simulator

surrounding the systems, all other co-operative or non-co-operative "actors", air, land, or sea entities, defense and attack facilities.

The **EF development standard flight simulator** has a visual system which also includes a PC-based version of Sapphire image generator (see § 3.1.2) with three 3D-Perception background projectors and one dual-target projector, and runs on a Digital Alpha host computer, while the **EF production standard flight simulator** includes a fully integrated Equipe Electronics visual system supported by a SGI platform. Based on a five pipe Equipe "Blue Sky" image generator, and covering the pilot's entire field of view, this system also includes two high-performance target projectors for high-resolution visualization of mobile targets, to be used for dogfight simulations. This simulator is characterized by a representative cockpit, placed within the 6-meter diameter rigid dome.

Figure 3: The Eurofighter Typhoon production standard simulator

The two EF simulators are very tightly interdependent, since they have been devised as a twin dome facility able to provide air-to-air combat training. Most of the hardware components within the twin dome are linked by a high-speed optical link, a VME-based reflective memory ring. A similar architecture is also deployed in another optical loop, connecting the various elements of the C-27J simulator. By including in this loop the host computer for the AMX simulator, a direct exchange of data between C-27J and AMX simulators is possible. This second loop does enable formation flights with the two EFs.

The twin dome has a further important component, fully integrated within the reflective memory optical loop: a proprietary tactical scenario generation and visualization tool, named STEP (Scenario for Test and Evaluation Purposes).

Additionally, an independent EF Aircrew Cockpit Procedure Trainer (ACPT) is being finalized, thus providing to the actors pool an instrumented pilot station as well, when connected to the rest of the department resources. These tools are presently integrated with the four full simulation facilities.

The local network of all available Alenia Aeronautica flight simulators, in association with the tactical scenario, forms a first-level Synthetic Environment (SE), susceptible to be progressively enriched with additional components.

The most recent facility added to the Company's SE is the "Uninhabited Combat Aerial Vehicles Lab" (**UCAV Lab**).

The development of remote-controllable UCAVs can gain a great deal from the availability of a SE, especially when used for: concept design and development; fine-tuning of procedures and of remote control stations functionality and layout; training activity; planning, fine-tuning and rehearsal of joint operations between manned and unmanned aircraft.

The UCAV Lab, specifically developed to support the Human Machine Interface (HMI) of Alenia Aeronautica UCAV projects, consists of:

1. a re-configurable active mock-up, capable to represent different Remote Operator Station (ROS) displays and controls layouts;
2. a real-time simulation environment;
3. an image generation system for the simulation of the external world view as seen by the on-board cameras;
4. link to the Company's Synthetic Environment.

The UCAV Lab allows man-in-the-loop simulation in the SE, evolving dynamically and reacting in real-time. In such an environment, the "virtual HMI" is dynamically evaluated in recreated operational situations, in order to identify any potentially unsafe/ unacceptable psycho-physical effects and identify possible solutions.

The UCAV Lab is the Alenia Aeronautica prime environment for designing, developing and evaluating:

1. ROS displays and controls concepts and layouts;
2. automation philosophies and algorithm development;
3. Situation Awareness information presentation;
4. UCAV operational modalities.

Figura 4: The design station for the UCAV's ROS

3 GRAPHICS IN FLIGHT SIMULATION

The essential cues needed in a modern flight simulator can be classified in three major groups:

- Visual cues
- Motion cues
- Aural cues

The visual sensing system is, in order of magnitude, the most sensitive human capability, which makes simulating reality for an observer very challenging. Yet, because of the importance of the vision in any training task, it is necessary to reproduce the required visual cues with optimum fidelity, at least with regard to:

- Out-of-The-Window (OTW) view
- Cockpit displays
- Monitoring and control formats

3.1 OTW view

OTW view requires the availability of the following major items:

1. A geographical database (DB): an appropriate representation of the area where the simulation task takes place;
2. An image generator (IG): a dedicated computer system that draws the DB view in real-time, according to the instantaneous observer(s)'s point(s) of view;

The images drawn by the IG are then presented to the user (e.g. test pilot, student pilot) by means of a dedicated display system.

3.1.1 Geographical databases

Over the years Alenia Aeronautica have developed an autonomous capability to generate the databases needed for the operation of their simulation facilities by following a well-established procedure, outlined in the following paragraphs.

A geographical data base is generally created in three steps: raw terrain acquisition, geospecific or geotypical texture acquisition, and point / linear / areal feature acquisition.

The first phase consists in the generation of a digital map constituted of a number of adjacent triangles, non co-planar. The surface, following with known and selectable approximation the digital terrain elevation data (DTED), is the canvas over which graphical textures (images) will be laid later.

The second phase consists in the characterization of raw terrain, by inclusion of geotypical or geospecific textures. The former are based on generic images of hilly regions, farm land, wooded areas, water bodies and so on, while the latter are obtained through satellite or aerial pictures, and faithfully represent the specific area with various degrees of resolution. At this level linear features (e.g. rivers, roads, railways) and areal features (e.g. cities, lakes) are inserted.

The third phase is important in that the data base is viewed tri-dimensionally at mid-to-low altitudes, and not simply being perceived as a smooth manifold. The inclusion of point features (isolated objects) becomes necessary as buildings, bridges, industrial complexes become visible. Inclusion of specific waypoints is thus recommended, as is the inclusion of generic entities such as trees, rock, trenches, urban areas.

The most recent database developed in Alenia Aeronautica, currently in use, includes the entire Italian peninsula with high resolution geotypical textures in which the following are included:

⇒ 17 airports, four of which surrounded by extremely high-detail areas, with textures obtained from aerial photography;

⇒ One target area (100 Km X 100 Km wide), located in North-West of Italy, characterized by a diverse geotypical texture and a dense 3D objects population.

Figure 5: Geographical Databse - Caselle Torinese airport

Even if the visual database is the essential component of a geographical database, mention must be made that the generation and integration of non-visible components (electromagnetic and surface properties, IR emissivity) into the database itself is of paramount importance, as well as availability of threat databases and libraries, which may be dynamically updated.

3.1.2 Image Generators

Traditionally Alenia Aeronautica have acquired commercial IG systems from the market:

- initially OTW view was provided by early visual systems based on a mobile camera that framed a rolling plastic model, in accordance with the aircraft position computed by the simulation program;
- passing through wire-frame representation of the territory by means of calligraphic displays;
- coming to General Electric CompuScene systems, capable to manage colored textured databases;
- ending up with the modern image generation systems based on SGI hardware.

In general, the major features of a modern IG can be schematized as follows:

- Update / refresh rate – cycles of computation / update per second
- Transport delay – time elapsed since the acquisition by the IG of an input command from the host computer, up to its complete execution on the display output
- Number of polygons / pixels per channel – values limiting the maximum database complexity that can be managed
- Light source types
- Number of moving models the system can simultaneously display

- Maximum texture dimension – relevant for geotypical texture management
- Amount of texture memory – value limiting the texture resolution when using texture paging (i.e. dynamic loading in RAM memory of terrain and culture texture employed in currently displayed database portions)
- Priorities management of polygons / faces located at the same distance from the viewpoint
- Mission functions – feedback that the IG can provide to the host in real-time (e.g. Height Above Terrain - HAT, Line Of Sight - LOS, Collision Detection – CD, both for viewpoints and moving models).

Based on their wide experience in flight simulation, Alenia Aeronautica have recently developed an autonomous capability of designing and producing their own image generator systems.

The proprietary IG, called "**Sapphire**", using SGI Performer and OpenGL graphic libraries, can be hosted both on PCs and on SGI hardware, according to Customer's requirements.

The system is being developed for a variety of different applications, ranging from transport to high-performance fast-jet aircraft Flight Simulation; moreover, it can be tailored to other simulation applications when required.

Figure 6: An image generated by Sapphire

With reference to the above features list, Sapphire is endowed with:

- Update / refresh rate: programmable up to 180hz – 60hz typical;
- Transport delay: 2 update frames plus 1 display refresh field (48ms at 60hz);
- Number of polygons/channel: more than 11,000;
- Number of pixels/channel: 1.3M;
- Light source types: own-ship, cultural, airfield, light lobes;
- Texture size: up to 2048X2048; amount of texture memory: 256Mbyte;
- Priorities management: Z buffer;
- Mission functions – up to 32 HAT; up to 32 LOS; CD: 3 returns for specified locations on own-ship monitored each frame.

3.2 Cockpit displays and Monitoring and Control formats

In addition to the OTW view image generation, a modern simulator requires the availability of two main categories of graphics:

- cockpit displays – graphics formats that reproduce relevant information as presented in the aircraft cockpit and used by the pilots;
- monitoring and control formats – all the graphics formats, usually displayed in the simulator Instructor Operating Station (IOS), needed to provide the simulator operator with proper means to:
  - control and interact with the simulation exercise, accessing the Simulator Specific Functions (SSF, e.g. start, freeze, initial conditions setting, repositioning, failures injection)
  - monitor simulation parameters evolution, simulator status and pilot's selections in the cockpit.

In general, all the aforementioned graphics formats are 2D, even though most innovative interfaces have a tendency to employ 3D symbology as well.

During the last years, graphics generation aimed at reproducing cockpit displays and monitoring / control formats in Alenia Aeronautica has been mainly carried out using **OpenGL**, since the related graphic libraries allow the user to generate a wide variety of formats, keeping total control over the source code. The consequent major advantage, the possibility to optimize the code, with benefits in terms of required computing resources, is however counterbalanced by the need of a software programming skilled developer to implement any format modification, in that source code changes are always implied.

Following the simulation industry trend, and taking advantage of recent powerful computing means availability with less need for code optimization, Alenia Aeronautica have consequently adopted additional high level tools that make it easier graphic formats generation, test and modification.

Among such tools, we wish to mention Virtual Prototypes **VAPS** (Virtual Application Prototyping System): even if still based on OpenGL graphic libraries, it is endowed with a user-friendly API (Application Programming Interface) with windows and menus, and allows the creation of any 2D graphic application without the need to develop directly the related source code.

The user can "draw" the format, accessing a wide objects / symbols library (e.g. geometric shapes, switches, sliders, knobs) and tuning a set of properties for each object, properties that will later on determine its appearance and behavior. Subsequently, Automatic Code Generation features take care of the generation of the source code itself, from which the executable file can be derived.

During the graphic formats design, any addition or modification can be easily tested within a Rapid Test Environment (run-time environment) without the need to re-compile the code every time.

High level tools like VAPS are of paramount importance for rapid prototyping activities, allowing the final user to cooperate with the graphic format developer with the capability to proceed to an immediate check of any design solution effectiveness.

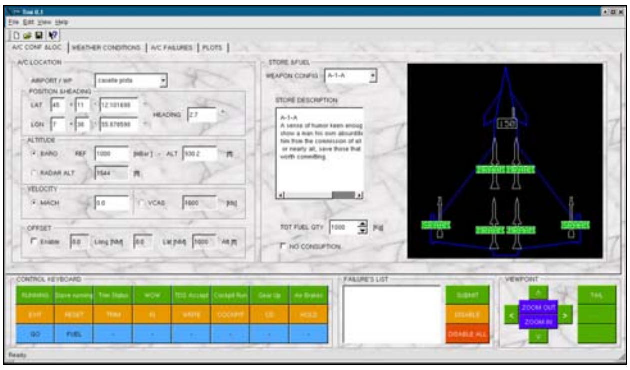

Figure 6: The Training Management Interface format

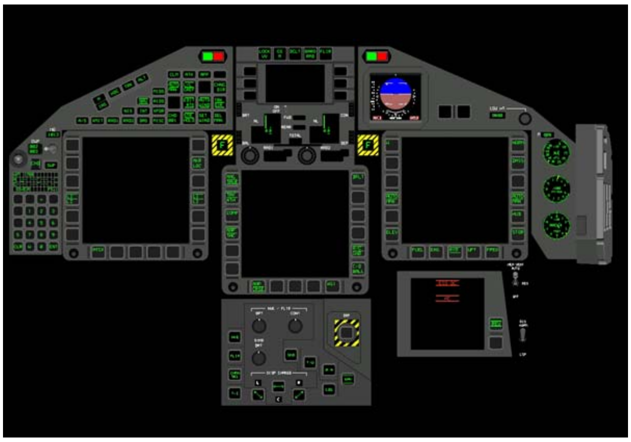

Figure 7: Virtual cockpit replica in the Eurofighter simulator IOS, for monitoring purposes

Figure 8: The Ground Controlled Approach format in the Eurofighter simulator IOS

3.3 Stereoscopic Visualization

The description of a stereoscopic visualization tool installed in Alenia Aeronautica deserves a special mention.

The device, including a Barco Baron system, has proven a very versatile tool with several possible future extensions. The system consists of a 67" rear-projected CRT monitor, driven by in-house developed stereoscopic software. Stereoscopy is achieved through active LCD shutter-glasses, which are also tracked by a three degree of freedom IR tracker. This allows compensation in the projected image for the movements of the observer's head.

The first stereoscopy application, developed in the first quarter 2001, has been the study of the optimal position for the in-flight refueling probe of the C-27J aircraft. Starting from CATIA drawings of the fore fuselage, windows outline, and autopilot panel cover of the C-27J aircraft, a 3D model was reconstructed.

From it, a virtual representation of the point of view of the pilot, the co-pilot, or an external view centered on the receiving aircraft can be assessed.

Figure 9: C-27J in-flight refueling simulation (mono version)

Tanker aircraft models are available (including B707 and KC10), with a variable number of hoses. An external application, communicating via Ethernet, provides data for the shape, position and attitude of the hoses, in addition to the position and attitude of the tanker and the aircraft being refueled.

These positions can also be changed manually without external connection. Use of stereoscopy and tracking of the observer's position has allowed determination of the most suitable position for the in-flight refueling probe, and also to evaluate several alternative positions.

Another application of stereoscopy consists in the replay of a specific flight, as recorded from simulation, on-board recorders, or telemetry. The surrounding environment, the aircraft and contrails/smoke tracers are reconstructed synthetically in a stereoscopic visualization. The viewpoint can be changed as desired, and chosen from several possibilities (ground view, pilot's eye, formation viewpoint, over a wing, and so on).

Figure 70: The stereoscopic table displays the Eurofighter flight at Le Bourget

The system has been used by Alenia Aeronautica's test pilots (Eurofighter and C-27J) to prepare their exhibitions at Le Bourget 2001 and 2003 Air Show. At first they performed the flights and used the tool to replay them from the spectators' point of view.

In addition, in 2001 the system has been presented in Alenia Aeronautica stand at the Le Bourget International Air Show, offering the same replay capability to all visitors, recreating the air show from telemetry data of the actual performance.

Within the frame of the new UAV/UCAV program, Alenia Aeronautica plans to take advantage of their stereoscopic visualization capabilities to assess the effectiveness of stereoscopic cameras on-board the aircraft, as an enhanced display to support low-level altitude flight phases (e.g. typically take-off and landing).

4 CONCLUSIONS

Alenia Aeronautica possesses more than forty years worth of experience in flight simulation, during which they have increasingly developed autonomous capabilities of graphics generation.

These capabilities are being exploited in upgrading the current suite of own simulation facilities, as well as contributing to the development of new advanced simulation and training devices.

About Maria Allocca

Maria Allocca graduated in 1984 from the University of Trieste, where she studied Mathematics. She has been working for Alenia Aeronautica since 1987 in Systems & Simulation Laboratories. Over the years, her activity has principally involved: development of geographical databases for CompuScene image generators; technical management of commercial image generators; development of proprietary tactical scenario; responsibility of the Visual System Group. She is currently in charge of the Company Synthetic Environment integration.

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Cristiano Montrucchio graduated from the Polytechnic of Torino, where he studied Aeronautical Engineering. He has been working for Alenia Aeronautica for four years in Systems & Simulation Laboratories as a simulation engineer and coordinator. His work has principally involved the development, upgrade and management of the Engineering Flight Simulators suite available in the Company. He is currently leading the Company Simulators Group and engaged in several training provision commitments towards major Customers.

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