A NEW FUNCTIONAL FRAMEWORK FOR A SOUND SYSTEM FOR REALTIME FLIGHT SIMULATION

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ABSTRACT

We will show a new sound framework and concept for realistic flight simulation. Dealing with a highly complex network of mechanical systems that act as physical sound sources the main focus is on a fully modular and extensible/scalable design. The prototype we developed is part of a fully functional Full Flight Simulator for Pilot Training.

1. INTRODUCTION

Advances in Computer Technology and modeling make it possible to simulate complex systems and machines for design or training purposes.

Education Programs in Aviation rely heavily on simulation based training. The higher the degree of simulated reality the higher are the requirements for realistic simulation of the aircraft, its motion, vision, and sound. The American (FAA) and European (JAA) aviation authorities define various categories of flight simulators, where the highest quality level of flight simulation is represented by a so-called *Level D* simulator [1]. In such a *full-flight* simulator training lessons in the simulator can replace all lessons in a real aircraft when experienced pilots have to learn to fly a particular aircraft type – and especially to handle abnormal situations. Especially in emergency situations the sound at the flight deck may be a highly disturbing factor for the flight crew and should be simulated during flight training as realistic as possible.

In this paper we show a new approach for a realistic and fully modular sound concept for such a full-flight simulator based on real sound data enriched with digital audio effects. This paper will address mainly the underlying system design and principles. The topics *data acquisition, feature extraction, sound synthesis, and 3D rendering* and their challenges are being discussed in an additional specialized paper [2].

2. EXISTING CONCEPTS

Sound-Systems are an important component of flight simulators because of their strong contribution to creating the illusion of realism. However the focus of traditional system design is mainly on flight mechanics and functionality of aircraft systems. Also, the certification guidelines for flight simulators do not specify the requirements for the sound systems with the same precision as for other aircraft systems. As a result, the realization of sounds lags far behind the other functional modules of a flight simulator. The use of modern sound recoding, analysis and rendering techniques is very limited [3][4][5][6].

3. FLIGHT SIMULATION FRAMEWORK

In order to understand the basic design requirements for a flight simulation sound system it is necessary to understand the basic building blocks of a flight simulator:

- Input/Output Devices
  - Cockpit Instruments
  - Controls (Thrust Lever, Flight Controls, Pedals,..)
- Aircraft-Systems Representation
- Flight Dynamics
- Motion Platform
- Sound System
- Vision System
- Instructor Station

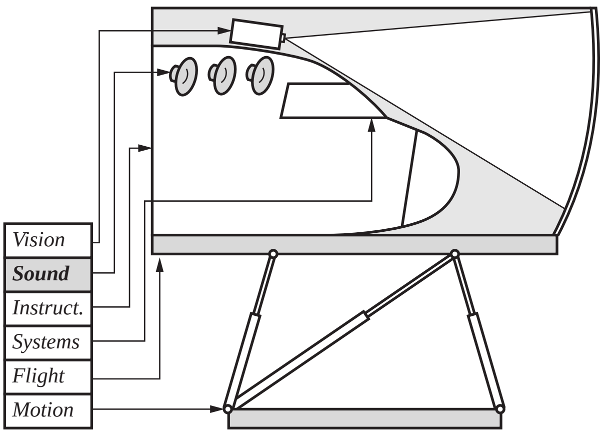

Figure 1: *System components of a flight simulator.*

Whereas all cockpit components and controls are exact, physical replicas or even genuine aircraft parts, the underlying simulation engine is a complex computer program based on analytical models and flight data of the real aircraft.

The Motion-, Sound- and Vision System are part of the human interface to the pilot and mainly responsible for creating the illusion of realism. A system configuration which is common to full-flight simulators is shown in figure 1. Usually each module runs on a separate computer for performance reasons, which is indicated by the rack-type setup.

3.1. Aircraft System Model and Components

The aerodynamic model is the heart of the flight simulator. It represents the aircraft as a rigid body exposed to aerodynamic-, propulsion- and other forces induced by the environment as shown in Figure 2. Usually all effects of elasticity or multibody interaction are delegated to the respective models (gear, aerodynamics, fuel sloshing) [8].

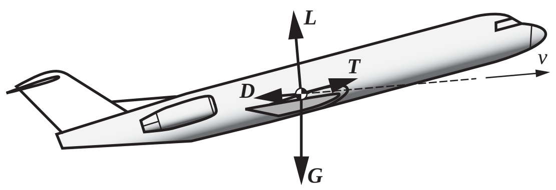

Figure 2: *Elemental forces (Gravity G, Lift L, Drag D, and Thrust T) and resulting speed of an aircraft.*

3.2. Discrete Time Simulation and Hardware Components

The equations of motion represent a system of second order differential equations. Normally they are reduced to first order and solved for discrete and constant time intervals of 20 ms or less by numerical integration [7] in order to simulate the aircraft's motion in three-dimensional space.

A controller program generates at that clock rate events at which the current simulation inputs (controls, environment, ...) are read and flight-mechanics related outputs like position, attitude, speed, and other data are being computed. (Simulation of other, slowly reacting aircraft systems is done by particular models using bigger time steps.) Data are shared over a common high-speed data bus.

Hardware concepts for flight simulators vary – however, it is common to separate the computation of flight dynamics, aircraft systems, instrument/control I/O, motion, vision and sound for performance reasons as can be seen in Figure 1. It must be shown during certification of a flight simulator that the data flow through the distributed system shows a time-lag within given tolerances.

4. SOUND FRAMEWORK

Due to the structure of the simulated system, which is from our point of view a highly complex network of sound emitting mechanical systems, it is necessary to develop a fully modular design. This allows on one hand to manage the sound complexity and ensures scalability on the other hand.

4.1. Requirements

As it is true for all sound simulation systems, the basic requirement is to generate a realistic sound impression in real time. When used in flight simulation for pilot training purposes it is especially important to model sounds that are being created by operation and failure of the various aircraft system components. It is therefore not sufficient to generate an excellent sound impression as a whole but rather required to model all effects individually.

Another requirement is to generate a realistic 3D sound impression in a rather small cockpit replica in terms of direction and characteristics of sounds. This requires careful design of the sound rendering algorithms as well as of the positioning of the speakers due to space constraints.

The most important requirement however is full modularity to allow for easy configuration, exchange, and testing of system components.

4.2. Design Principles

Discretization: The sound simulated is considered to be the sum of various discrete sources that create sounds based on their internal state or operation.
Superposition: The discrete sources are combined by use of superposition to generate the resulting sound. Effects generated by interference of the individual sounds have been evaluated and considered being neglectable.
Local Sound Creation: Sound creation in the discrete sources (like aircraft system components) depends on their sound generating interaction with the environment. This interaction is determined locally by internal mechanics and functionalities and can be described with a set of relevant sound parameters. These sound parameters can efficiently only be generated in the discrete sources themselves – not outside.
Central Sound Rendering: Contrary to sound generation, sound rendering can only be done in a central module that combines all sounds from all the sources and renders them for 3D output by taking into account position of the individual sources and sound transmission functions with respect to the cockpit.
Modularization: All systems modeled in the simulator are seen as individual modules having a clearly defined functionality and interface to the rest of the simulation system. Real aircraft systems can be exchanged provided that they have the same functionality (e.g. it is possible to change the engines). In order to provide that same possibility in a flight simulator it is necessary to store all module specific data – mechanical as well as sound data needed for rendering – in the module context.

4.3. Sources and Types of Sounds

There are multiple sources of sounds that can be observed from an aircraft's cockpit. The most dominant ones are being caused by noise due to air current around the plane´s airframe and by the engines. Depending on the flight maneuvers some additional sources become dominant as well. An example would be the landing gear during taxiing on the ground or additional air-current noise caused by extended flaps. Figure 3: shows the most important sources of sounds in an aircraft.

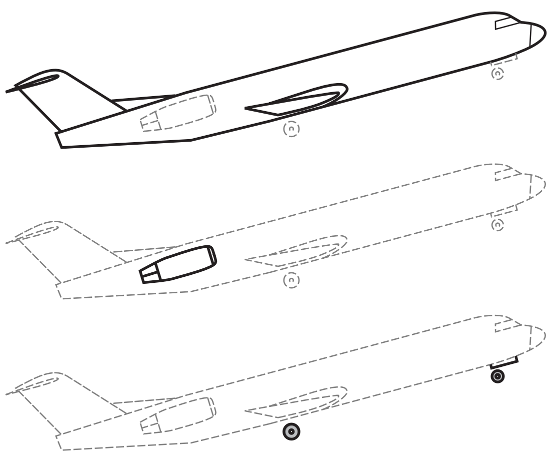

Figure 3: *Sound sources in an aircraft: airframe, engine, landing gear.*

We define two basic types of sounds that can occur:

Discrete Sounds (event driven): Sounds that are generated by discrete system events and can not be interrupted by the simulation are called *"discrete sounds"*. They can incorporate the sound of a sequence of sub-events and may last for several seconds. An example for a discrete sound would be the (big) bang the landing gear makes at touch down.

Continuous Sounds (permanent): Sounds that are generated by continuous processes and that can be changed/interrupted during the simulation are called *"continuous sounds"*. Continuous sounds represent the corresponding sound to the current system state. Air-current noise is a good example for this type: Depending on the aircraft´s altitude, airspeed, angle of attack, flaps and landing gear configuration and other environmental conditions, the airframe will continuously generate noise that varies in intensity and spectral characteristic.

All other sounds, even of complicated nature can be realized using these two building blocks. To illustrate this let us consider the following example: Approaching an airport for landing the pilot pulls the lever for lowering the landing gear, thus triggering the following sequence of events: The latches in the hull open, a hydraulic motor lowers the landing gear. The resulting air resistance creates additional air-current noise depending on the degree the gear is extended. If the landing gear has reached the final position, the mechanics locks with a possibly loud rumble so that the gear is secured in place (Figure 4).

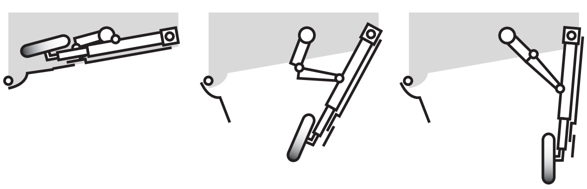

Figure 4: *Example extension of landing gear.*

We model the corresponding sound sequence with two continuous and two discrete sounds. Continuous sounds are:

- *Air-current noise* which is (simplified for this example) determined by the parameters airspeed and the landing gear extension parameter (0-100%)
- *Hydraulic motor noise,* the characteristic of which depends solely on the motor speed (0-100% of max. rpm) for both, repeating sound patterns – similar to a starter engine in an automobile – and fundamental frequency. Let us assume it takes the motor about 5 seconds to lower the gear fully.

The following two events are modeled as discrete sounds:

- *Latch opening* creates a non interruptible characteristic noise that lasts about 0,5 seconds.
- *Gear locking* causes a fairly loud and short rumble.

According to our design principles the computation of the sound influencing parameters like airspeed, motor speed, and gear extension is done within the individual modules. The same is true for the triggering of the discrete events. Figure 5 puts the sound events on a simulation timeline and shows the corresponding mechanic situation.

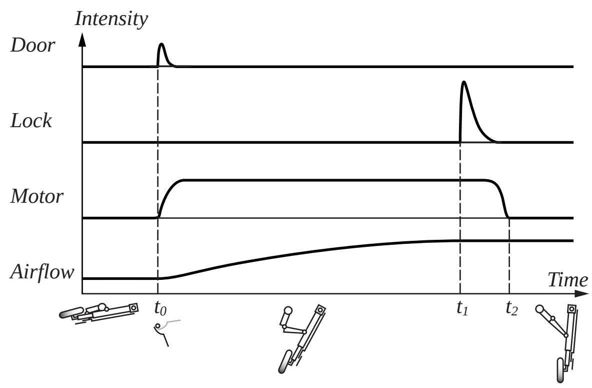

Figure 5: *Landing gear simulation timeline.*

To demonstrate the modularity of the concept, let us now assume the following mechanical landing gear extension failure: the hydraulic motor spins up to 50%, stays there for a second and gets stuck. As a result the landing gear will be extended to about 60%. What would be the effect on our sound simulation?

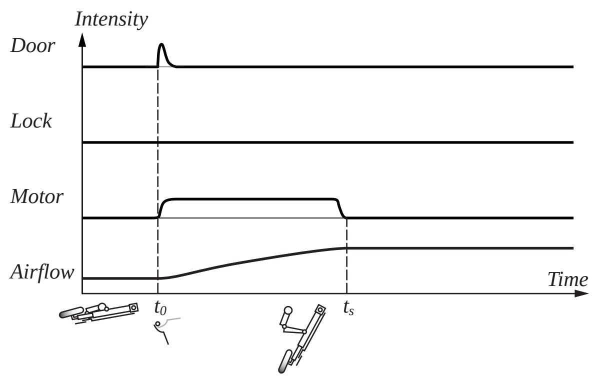

Figure 6: *Example extension of landing gear gets stuck.*

The latches will open with the same sound as before. Since the motor is modeled as a continuous sound device it would create the sound that corresponds to its speed. Because its speed will not exceed 50% of maximum speed, the sound simulation will mimic exactly this behavior. Getting stuck means for the motor that it will stop creating sounds (speed=0). The landing gear extension parameter provided by the corresponding simulation module will also stop at 60%. As a result the noise caused by air current will be a little less (gear extension is a sound parameter) and the gear locking bang will not happen, since the landing gear is stuck at 60% (Figure 6).

This shows an important feature of a sound system framework that closely models the mechanical behavior of the real system: Should it for example become necessary to incorporate other system failures – especially ones that generate audible effects (like explosions) these could easily be incorporated: One would have to add the failure logic to the respective module and add the desired sound either as additional discrete or continuous sound.

The advantages compared to other approaches which create a strong linkage between the logic of sound creation and sound rendering are simplicity and independence from knowledge of system internals.

4.4. Core Components

The core elements of the sound system are:

- ***Modules*** representing system components with system logic, mechanical and audio data.
- ***Sound Rendering Engine*** which has two closely related functions:
  - o Generating the individual sounds of all system components by using their defined sound parameters and data.
  - o Creation of a virtual three dimensional sound field by placing the generated sounds on their position with respect to the cockpit. In our case we assume that all our system components have a constant position during the entire simulation. This simplifies the rendering algorithm since they can pre-compute structure damping and other correction factors.
- ***Sound Generator*** produces the individual sound signals for the built in speaker system in the simulator cockpit taking into account the speaker configuration and special hardware setting.

The last two core elements usually run on a separate computer for performance reasons.

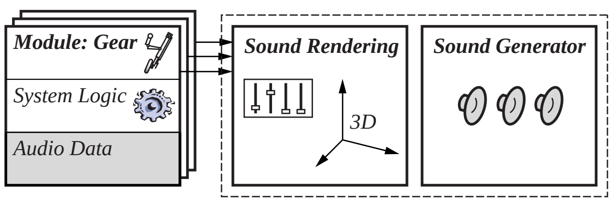

Figure 7: *Core components.*

Figure 7 shows the three core components with their functionality and data attached.

4.5. Integration in the Flight Simulation Framework

In order to integrate the sound simulation system seamlessly into the entire flight simulation framework we have chosen to use the same data bus that is common to all other modules. By design this data bus ensures a reliable and fast communication and satisfies the requirements for real time simulation.

Figure 8 shows the interaction of simulation modules and Sound Rendering Engine over the data bus.

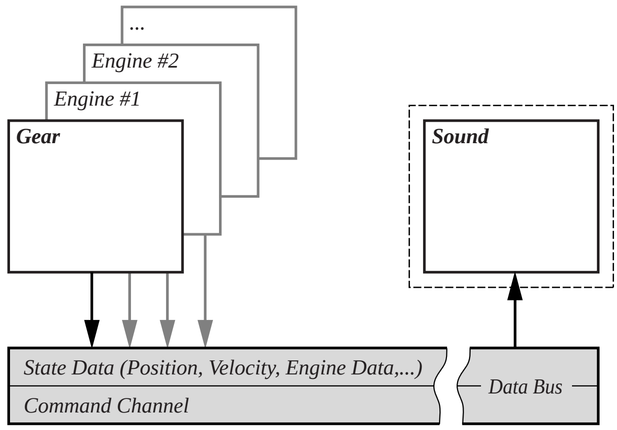

Figure 8: *Interaction between Modules and Sound Rendering Engine.*

At initialization the Sound Rendering Engine registers all sound emitting system components and loads the list of sounds and their parameters. For the simulation of the module *"hydraulic motor"* from the example above this would mean that the module registers one continuous sound with motor speed as the only parameter and an optional *"bang"* as a discrete sound with one parameter for the intensity of the effect. The module also provides all data like position information and component specific sound data necessary to render the sound. Figure 9 shows this for the *"hydraulic motor"* example.

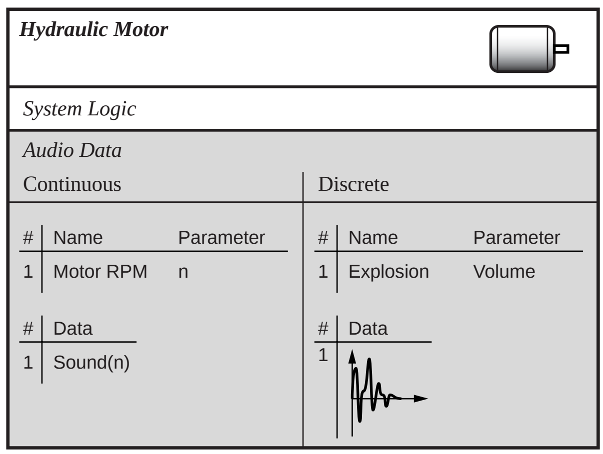

Figure 9: *Sound Data in System Modules.*

Once initialized, the Sound Rendering Engine gets all information necessary to create the continuous sounds by listening on the data bus for the respective sound parameters. Discrete events require in addition a special trigger message containing event number and optional parameters. Figure 10 shows the principle of sound generation within the flight simulator framework.

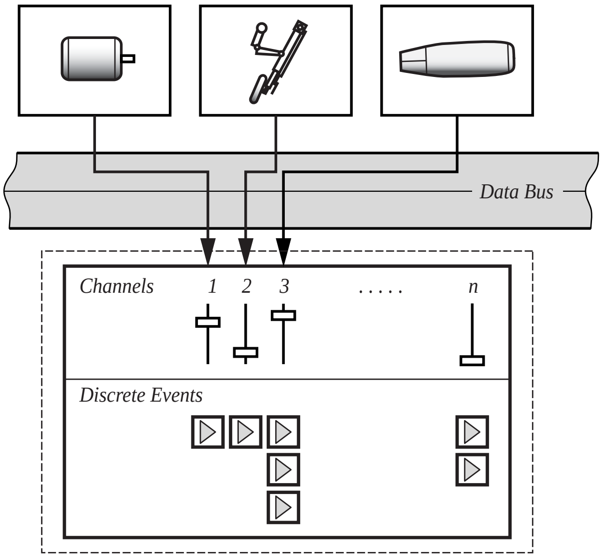

Figure 10: *Multi-Channel Transmission of Sound Information.*

Within this context it is important to point out that continuous sounds are *continuously on* which means that not only the airframe noise is generated permanently by observing the data bus for the relevant sound parameters (airspeed and gear extension in our example) but also the sound of the hydraulic motor is *on* – however, creating audible sound only if the motor speed is greater than zero. This can be compared to a professional studio mixing equipment where many channels are attached but only a few are opened.

With a limited number of noise creating system components, this approach has the advantage that the sound system can react immediately to changes of system state. The computational overhead for rendering zero-signals can of course be reduced by filtering only for non-zero channels.

4.6. Data Acquisition and Signal Processing

The sound data used in our research project are based on elaborate audio recordings and flight data analysis from real aircraft. Techniques and tools are not discussed as part of this paper [2].

5. CONCLUSIONS AND FURTHER WORK

As a proof of concept we have applied the framework laid out in this paper to designing a sound system prototype for a Full Flight Simulator for a particular airplane as a joint project with industry. Despite some technical and time constraints we were able to realize the core components and functionality of our framework.

The sound prototype was tested with airline pilots – some flying that very airplane on a daily basis and got high acceptance ratings. It turned out the additional effort in sound modularization and discretization leads to a sophisticated, detailed sound simulation, which is a major advantage in comparison to state of the art sound systems for flight training devices.

We will investigate further possibilities in modularization of this concept in the future and try to applying it to other areas like automotive.

6. ACKNOWLEDGEMENTS

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