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APPROACH AND SOFTWARE FOR THE QUICK DEVELOPMENT OF THE FLIGHT SIMULATORS SOUND SYSTEMS

The approach is based on the tuning of the controllable sound samples and enables to construct the sound system software using the easy accessible aircrafts cockpits sound records and the special constructor. This approach and tools are adopted for the projects (e.g. reengineering) under condition of the inaccessible modelling aircraft. The case study for the turboprop airplane simulator is presented.

Introduction

Sound system is the integral part of the any modern flight simulator that provides the imitation of the real sound environment for the pilots training. Sound is the important informational source for pilots about states of the board mechanisms and equipment, runway touchdown etc. Modern sound systems for commercial flight simulators are the hardware&software systems that generate the aircraft noises for all flight modes with defined adequacy and quality [1].

Creation of the quality sound system is the complex and expensive process that requires acquisition and analysis of the object aircraft noises for the different work modes, synthesis of the set of noises generators, tuning the sound dependencies on the flight parameters and verification of the sound adequacy [2, 3].

Problem statement

Under inaccessible aircraft condition the sound characteristics analysis and adequacy checking are difficult. This condition can be appeared at the small budget projects or during the modification of the legacy simulators, implemented independently from manufacturer and operators. However, developer is able to get the flight audio and video records from the aircraft cockpit, made by any appropriate compact record device. This article propose low-cost approach to creation of the sound system using accessible aircraft sounds records and describes the case study of implementation for the turboprop aircraft simulator.

Model and implementation of the sound systems

Model. The study of sound environment includes the perception and recording of the aircraft sounds in the different work modes and analysis for the single noise sources separation and definition of their characteristics [3]. Under access to the aircraft the developer is able to study noises sources separately, using control of the aircraft mechanisms and recording using the measurement tools the audio characteristics, associated to the aircraft work mode and conditions of observations.

The model M of the sound environment is usually presented as the additive set of noises; each of them is created by single source (aircraft mechanism or the environment effect):

$$M = \sum_{i=1}^{n} m_i ,$$

where m_i – model of the single noise.

For each model m_i should be described the sound characteristics and their dependencies on the set of the noise source parameters. Sound control can be described by the functional that defines sound parameters $Y = \{y_1, y_2, ... y_k\}$ dependencies on the input parameters of source $X = \{x_1, x_2, ... x_l\}$:

$$m_i(Y) = F(X).$$

It is useful to cast the functional F to the set of the independent functions; each of them describes the one output parameter, depending on input set:

$$y_i = f_i\{x_1, x_2, ... x_m\}.$$

For example, the simple model of the turbojet engine sound can includes only two noise sources – starter m_s and turbine m_t:

$$M = \{m_s, m_t\}.$$

The general starter sound model has the formulae

$$m_s(V) = f_{sv}(S_s),$$

where V – is the noise volume;

f_{sv} – is noise volume function of the starter state dependency;

S_s – is starter state (on/off).

Then model can be reduced to the noise volume function of the starter state dependency:

$$V = f_{sv}(S_s)$$

Here, function f_{sv} can be reduced to binary function:

$$V = \frac{0\_if \quad \_S = OFF,}{1\_if \quad \_S = ON}$$

The model of turbine can be formulated as

$$m_t(V, F) = f_t(R_t),$$

where V – is the noise volume;

F – is the noise frequency bandwidth;

f_t – is volume and frequency functional of the turbine turnover dependencies;

R_t – is the turbine turnover frequency.

Here, we can present the volume and frequency bandwidth as independent functions of the turnover $V = f_{tv}(R_t)$ and $F = f_{tF}(R_t)$, which can be reduced to the linear dependencies at the simplest case.

Implementation. The general simulator structure (fig.1) includes set of the controlled noise generators which output signals are rendered, summarized and amplified for each cockpit speaker. Simulators are distinguished by the playback channels number (mono, stereo, quadro and more) and functions balances between hardware and software. The control parameters of sound are provided by transfer from the simulator of the aircraft systems [2]. For each single noise source using characteristics of its model m_i the noise generator and control dependencies are selected. The generators syntezis and tuning are the quite expensive process.

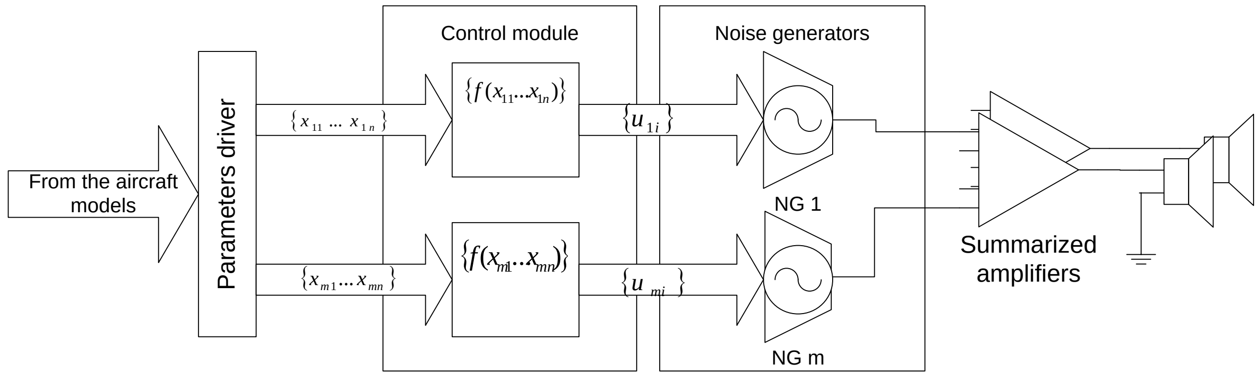


Fig.1. General structure of the noise simulator

Simulator’s adequcy is verified by the quantity and quality evaluations [4]. The final adequcy have to be verified by the experienced pilot. On the beginning stages of the developing the developers apply also own subjective evaluation, using generated noise comparing with the sample records.

The objective approach to the adequacy verification is realized using the generated noise parameters mesurement and comparable spectrum analysis of the generated and sample noises.

Approach, based on the controllable samples

The idea of the aircraft sound records usage for the sound environment imitation is not new, but is not applied for the professional simulator owing to different reasons, particularly because perfect digital audio technologies became accessible for simulator developers later than advanced analog noise generation. The controllable sound file playback is used at the some game flight simulators, e.g. MS Flight Simulator [5], but roughly and sometimes with the low adequcy. Here is proposed the sound system constructor that is based on the playback of the aircraft sound digital record samples. These samples are played once or iteratively with the controllable parameters, depend on the work mode of the noise sources. The sound system developing includes the following steps: samples aquizition; sound environment model developing; implementation and tuning.

The samples acquizition. In general, simulator developer, having one or several records of the aircraft sound, made by the thirty people, can only indirectly guess about recording conditions, using the sound panorama or associated video. The first problem of the samples acquzition is the sources separation and identification. The second one is the association of the noise characteristics to their sources work parameters. The third problem is the absolute noise level definition, because the usual recorders do not fix it. Automatic record control systems worsed this problem, made even relative sound levels of record unauthentic.

The noises can be identified subjectively (by ear) and approved using spectral analysis and comparing the spectral components with the aircraft modes. Then, for ifentified sources the appropriate samples must be extracted by selection and cutting. This task usually is complicated because of other noise sources, outside noises (pilots talking, switches clicking etc). In addition, sample has to be long enough (5 seconds and more) to be played iterativly without spectral structure loosing. These conditions may require the careful exploration of records, using flight documentation.

Sound environment model development. The sound environment model for the controllable samples approach is different from the traditional. The models of the single sources can not be considered as independent, because the records not contain the “pure” noises, but mix of them. Hereby, single model is depended the several other noises:

$$m_i(Y) = F(X, \{m_k\}, k \neq i),$$

where m_i – selected model,

Y – noise parameters set,

X – noise source parameters set,

$\{m_k\}$ – set of the other noises models.

This problem should be solved by the extraction of maximum disconnected samples and correction of the residual dependencies by the parameters control. The technique of exctraction may be following: listener finds the enough long records fragment, where single source noise is most “clear’, then correlates this noise with the source modes. It can be executed using indicator information from the videorecord or using the spectral analysis and knowledge about aircraft mechanisms modes. For example, the air screw noise has the spectral “peaks” of the main screw rotary frequency and its harmonics, multiplied by the screw blades:

$$\omega_i^g = \omega^s \times n \times i,$$

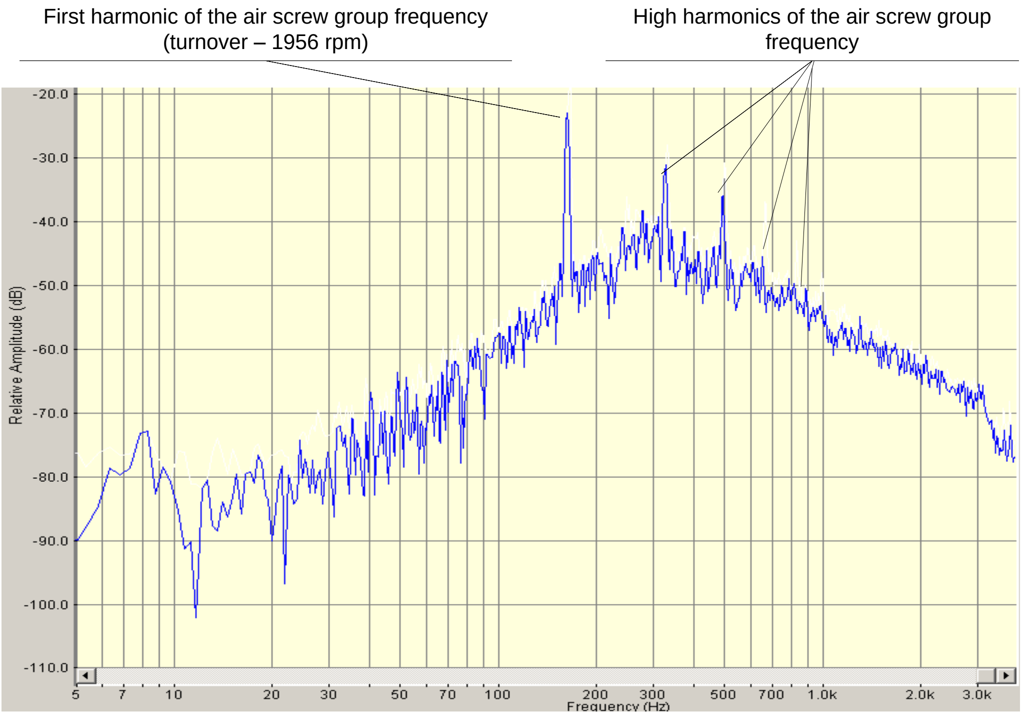
where ω_i^g – frequency of the i harmonic,

ω^s – screw frequency,

n – screw blades number,

i – number of harmonic.

Calculating the harmonics frequencies to the screw frequency and comparing it with the nominal engine modes (fig.2) enable to define the appropriate record fragment.



Take off mode

Fig.2. Spectral analysis of the turboprop airplane noise

The dependencies between single noises models can be taken into account based on knowledge of the mutual dependencies of the appropriate mechanisms of aircraft. For instance, air screw noise can not be separated from the turbine noise during takeoff and cruise modes. And linear changing of the volume and frequency of this sample is not relevant to the turbine noise control and leads to dip one at the low turnover mode. The turbine noise sample has to be extracted from the other record fragment, where the air screw noise is unsignificant, for example, during the some interval after engine start. Then, the control dependencies of the both samples must take into account the mutual component (fig.3).

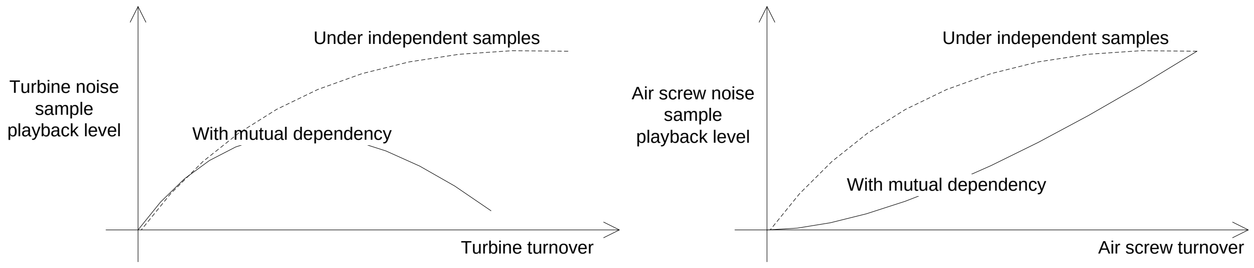


Fig.3. Correction of the volume control for the mutual dependent noise samples

The problem of the absolute noise levels at the cockpit can be solved using only expert evaluation.

Implementation and tuning. The structure of the proposed sound system includes the set of the controllable palyers with summarized outputs (fig.4). The playback can be controlled by speed (for the frequency change effect), by volume and by several additional parameters, like the flange-effect, echo, etc. The playback mode can be one-time (for the one-time sounds, similar gear extension/retraction) and looped (for continuous, like turbine or air screw noise). The dependencies between the controlled players parameters and modeled aircraft parameters are realized by the special converters. Each converter can execute the function of the single parameter of player from the one or several parameters of the model. Usually, the playback speed is the function of the one parameter. The sound volume can be product of the several functions:

$$V = V_{\max} \times \prod_{i=1}^{n} f_i(x_i),$$

where V – playback volume;

$V_{\max}$ – maximum noise volume;

$f_i(x_i)$ – normalized function of parameter V of model parameter x_i .

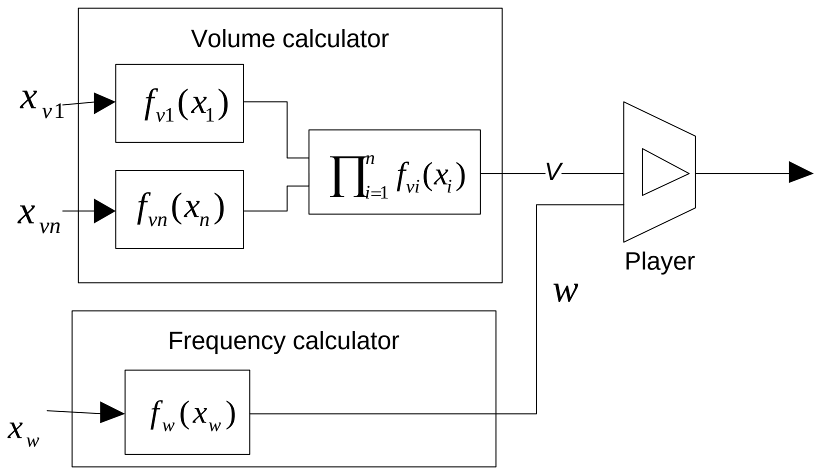


Fig.4. Structure of the controlled player – the noise simulator element

This elaboration is possible due to multiplicative character of the mechanisms volume dependencies. For example, the air screw volume depends multiplicatively on the rotor frequency and pitch (blade angle); wheel touch volume – on horizontal and vertical landing speeds. In these cases the control function can be realized as the product of the normalized approximation functions, defined for the each parameter. This approach enables to create the suitable user tool for the control function specification as the set of the aircraft parameters $\{x_i\}$ and functions $f_i(x_i)$, (fig.4) defined by the piecewise-linear approximation.

Case study

The proposed approach was developed and used at the reengineering project of the full flight simulator TL410 of National Aviataion University [4, 6]. The universal short-range airplane L410 «Turbolet» is the classic two-engine turboprop highpalne, equipped with engines Walter M 601A and controllable pitch air screws [7]. Since 1961 more than 1100 airplanes where produced and most of them are exploited at the former USSR countries. Considerable part of the L410 is flying at the Easten Europe, Latin America and Africa.

Obsolete computer system of the simulator was unrepairable; the original hardware sound sysyem was out of order, but main mechanical and electrical systems where operable. Pending the reengineering, the computer system was replaced to new; legacy software was reworked. Under the low-budget and aircraft inaccessible conditions the developers created the new one, used the audio and video records obtained from the L410 airplane cockpit and the developed software constructor.

Sample aquizition. The original sound system provided considerable noise set: engine exhaust fumes, airscrew, wind, starters, taxing [6]. The first task was the acquiring the airplane sound records for the new system. The base record was gained by recorder at the L410 airplane cockpit during flight. This record gave the general presentation about sound at the different flight stages and was cliped for the several samples. The fragment of the record oscillogram is shown on the fig.5. The main problem of this record was the absence of noise sources identification. This identification was executed using record hearing and comparing with the airplane exploitation documentation. Thereby the main flight stages (fig.5) and noise sources where identified (starters, engines, screw etc). The correlation of these noises to the mechanisms modes where provided using spectral analysis, based on the air screw noise components (fig.2). Screw turnover frequencies, calculated for different flight stages, match accuracy to the pilots’ flight guide. Because turbine turnover is hard correlated with air screw rotary its modes where defined too. Then, the most independent noise samples where extracted.

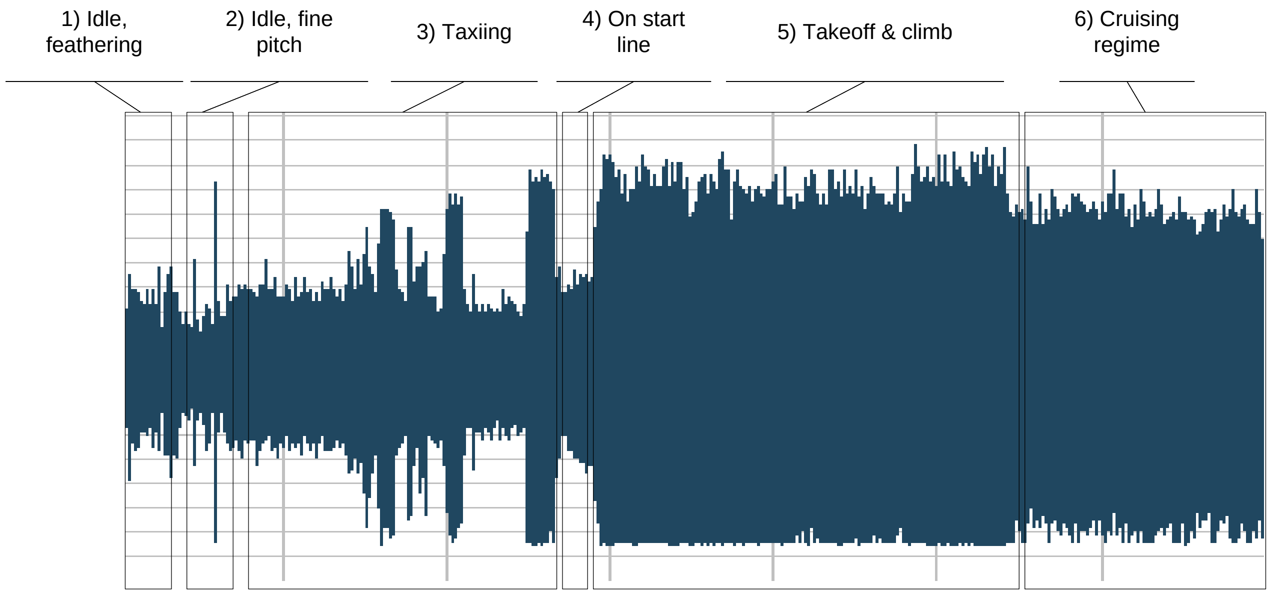


Fig.5. The airplane noise oscillogram

The lacking noises where acquired from the open Internet resources, like “youtube” or specialized portal “avsim.su” [8]. The result was the complete set of noises, including electricity converters, fuel pumps, engine fire, blade pitch mechanism, wheels touch and screetch and so on.

Thereby, the proposed approach and special program constructor enabled to recover all noise features of the legacy simulator and extended theirs with noises of additional components.

The sound system constructor. The sound system constructor is the software tool, developed for the proposed approach that provides the following:

- creation of the random number of the sound players;
- association the noise samples with players;
- definition of the dependencies of the sound players with the aircraft model parameters by the piecewise-linear approximation;
- tuning of the additional playback effects;
- sound players testing;
- GUI for the sound system developers;
- complex noise imitation testing with the parameters receiving;
- simulator compilation to the ready to use console application.

The constructor was implemented on the .NET platform by the C# language (fig.6). Software architecture is based on the «Model–View–Presenter» [9]. The division of model and presentation enables the separation of the model and GUI, simplifing the testing and permiting to replace the GUI or model components.

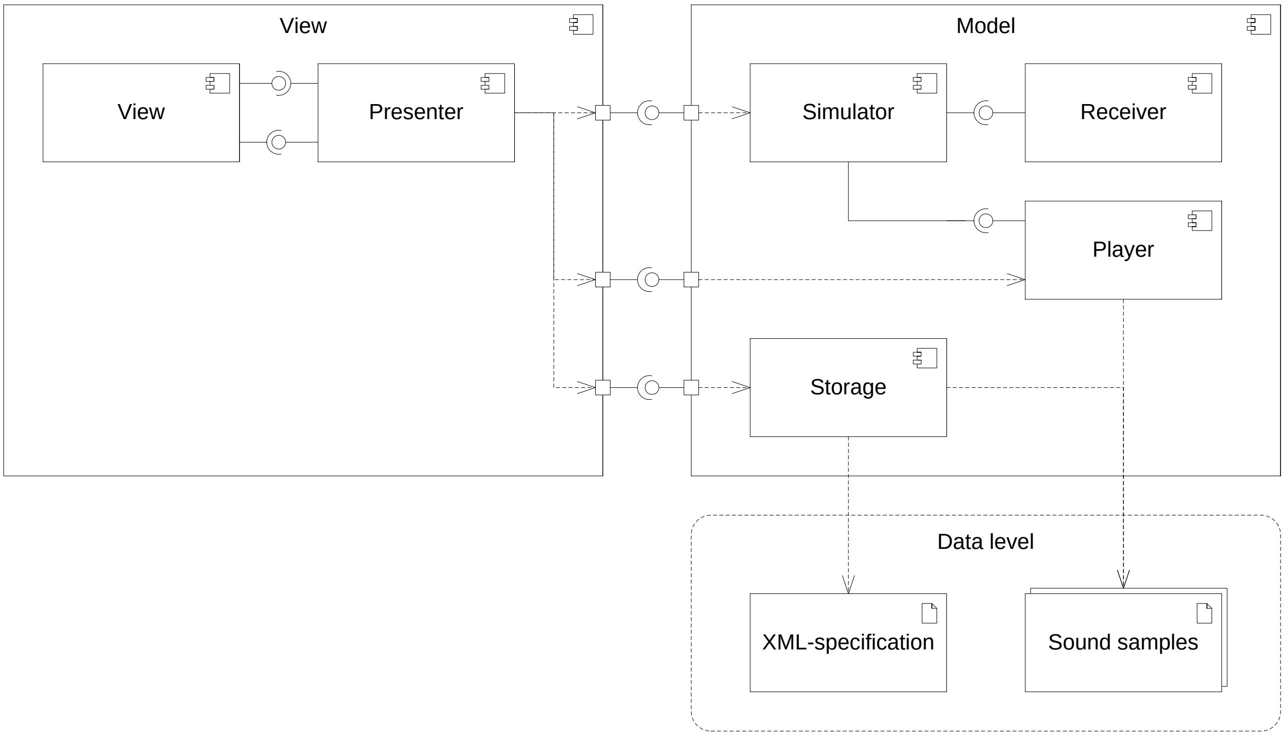


Fig.6. Architecture of the sound system constructor software

The simulator specification file example is shown on the fig. 7 and includes the airplane right air screw noise description.

```
        …
<sound name="Right screw" type="Continuous">
  <!—Sample file -->
  <soundFile>C:\sound-system\Sounds\Screw_1896.wav</soundFile>
  <!—Sound channel (Left/Right) -->
  <position>"Right"</position>
  <!--  Set of input volume parameters -->
   <volumeParameters>
    <parameter name ="R_SCREW_RPM">
    <!--  Volume approximation points table for the screw rotation -->
   <tableOfValues>
       <entry x ="0.0" y ="0.0"/>
       <entry x ="2700" y ="0.9"/>
       <entry x ="3800" y ="1.0"/>
     </tableOfValues>
    </parameter>
    <parameter name ="R_SCREW_PITCH">
    <!--  Volume approximation points table for the screw pitch -->
     <tableOfValues>
       <entry x ="0" y ="0.5"/>
       <entry x ="90" y ="1.0"/>
     </tableOfValues>
    </parameter>
  </volumeParameters>
   <!—Playback speed input parameter -->
  <frequencyParameter name ="R_SCREW_RPM">
   <!--  Frequency approximation points table for the screw rotation -->
  <tableOfValues>
     <entry x ="0" y ="0.0"/>
     <entry x ="1896" y ="1.0"/>
     <entry x ="3800" y ="2.0"/>
    </tableOfValues>
  </frequencyParameter>
 </sound>
        …
```

Fig.7. The part of the sound specification XML-file

Simulator model is realizing the initialization and functioning of sound system and includes the samples players, control module and approximator.

The GUI permits to engineer to add/delete the noise sources, define their attributes and dependencies, and test them (fig. 8).

The parameters' driver receives the required aircraft model parameters and notifies the simulator model about changes.

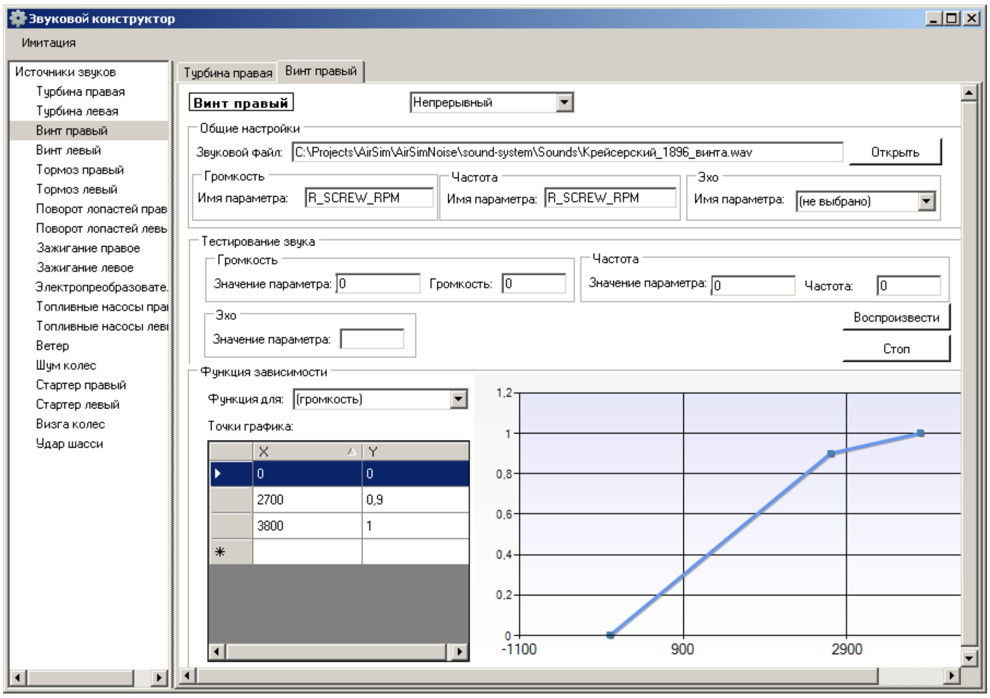


Fig.8. GUI of the constructor

Parameters' network receiver provides the obtaining of the parameters values from the modeling computer through the network. Receiver realizes the exchange, using special protocol, saves the values and notifies the sound system about updates.

The constructor software tools enables to generate ready to use noise imitator as console application (fig.9).

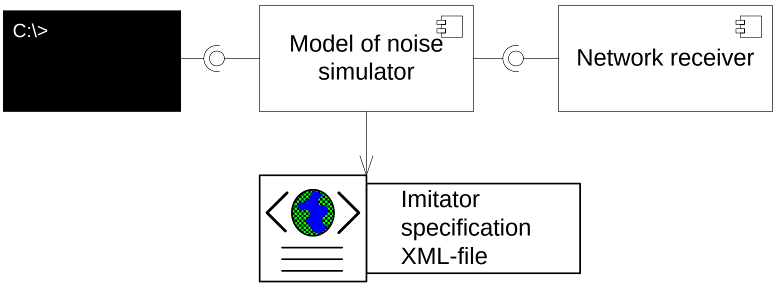


Fig.9. Generated noise simulator conponents

TL410 sound system adequacy evaluation. The sound system evaluation was executed by two methods – subjective assessment of the noise and comparing the oscillograms and spectrums of the generated and original airplane noises.

The subjective evaluation allows detecting the defects at the complex sound of several sources noises at the dynamic. The oscillogram and spectrums enables to check the relative volume levels for the various airplane modes and compare the adequacy of the spectral pictures.

Summaries

Formalization of the noise simulator enabled to create the software tools for the rapid construction of the flight simulator noise simulators, supporting their creation, testing and system integration.

The National Aviation University TL410 flight simulator reengineering case study demonstrates the approach and tool operability.

Approach requires the next research for the methods of the preliminary sample processing (influence filtering, spectral correction etc) and automation of the detection and correction of the samples interference.

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