Cost-Effective Flight Simulator Approach for Ultralight Aircraft, Motor Gliders and Sailplanes

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Abstract

The affordability and utilization of flight simulation is considered for ultralight aircraft, motor gliders and sailplanes. A new approach is presented to significantly reduce costs while keeping system fidelity at a level required for the simulation purposes. Focus is on a solution comprising low-cost hardware and efficient software, with the goal to realize a flight simulator featuring all relevant system functions with correct operational characteristics. Achievement of a realistic, low-cost flight simulator is also supported by appropriate solutions in the fields of system architecture, data generation and modeling.

Introduction

Flight simulation is a well-established means for pilot training and instruction. It is used for basic learning in aircraft flight, for instrument and navigation procedure training as well as for type-specific training. In the past, flight simulation was an issue primarily for large airplanes or high-performance vehicles, but not for light aircraft. This is basically due to cost reasons since flight simulation was regarded as an expensive endeavour that can be justified, however, in the case of the high cost of real flight-time. To make simulation also available and useable for pilots of light aircraft, motor gliders and sailplanes, new approaches are needed in order to significantly reduce costs while keeping system fidelity at a level required for instruction and training.

This paper is concerned with a solution for a cost-effective flight training device for pilots of light aircraft. As a representative application, the development and realization of a flight simulator for the ultralight aircraft Flight Design CT2K are described. The flight simulator was built in a cooperative effort of the following industry and university partners:

- Flight Design GmbH, Leinfelden Echterdingen, Germany
- AeroLabs AG, Neufahrn, Germany
- Institute of Flight Mechanics and Flight Control of the Technsiche Universität München, Germany

The experience gained with the development and realization of the flight simulator for the ultralight aircraft FlightDesign CT2K can be used for motor gliders and sailplanes. This includes the experience of scaling down high-performance solutions involving higher costs, to a level that can meet the requirements of a useful training simulator for the target airplane group[1-3].

Basic considerations

A primary goal of the development of a flight simulator, for the airplane segment, is cost effectiveness in order to offer a reasonable training system at a competitive price. For this purpose, new approaches to various tasks are required to achieve a balanced relationship between performance and cost. This holds for hardware and interface issues concerning the aircraft cockpit with the controls and the instrumentation in order to attain a realistic training simulation environment for the pilot. It also holds for efficient software tools for simulating the dynamics of the aircraft, for the visual system and for controlling the simulation process as well as for the networking between the various elements.

Despite the low-cost approach, a high performance and fidelity can be achieved with the following main elements:

- For the hardware elements of the simulator, commercial-off-the-shelf components are applied, based on a trade-off between cost and required quality. Furthermore, spin-offs and components from non-aerospace applications can be used, offering high quality at significantly lower cost than common to aerospace items.
- For the software which constitutes an essential part of the flight simulator, efficient computer programs for real-time application need to be available and linked together to a powerful simulation environment. With an efficient software, it is possible to use low-cost PC based computer hardware in terms of commercial-off-the-shelf components.

The concept and design of the flight simulator depends on the purpose and the tasks for which it is intended. For the student pilot or simulator user it should be possible to perform the following training tasks at a high level of realism:

- *Aircraft system familiarization*

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The cockpit environment should resemble the original one. Furthermore, operation of all relevant systems should be possible, e.g. engine, ignition and fuel system, flaps, radios, transponder and circuit breakers. The simulated systems have to show correct stimulus-response characteristics.

– *Basic flight training*

The dynamics of the simulated airplane should be as similar to the behaviour of the real vehicle as possible. This concerns the flying qualities as well as the performance characteristics.

– *Flight under visual flight conditions*

The visual system should enable different visibility and time conditions. Furthermore, it should be such that a realistic impression of the height during approach and landing is possible.

– *Demonstration of adverse effects*

Effects of cross- and tail-wind, hot and high conditions or wrong aircraft loading should be demonstrated in a realistic manner for flight safety education.

Based on the above considerations, a flight simulator was developed and realized for the ultralight aircraft Flight Design CT2K. The solution for the Flight Design CT2K simulator is regarded as a representative possibility for the simulation of comparative vehicles, like other ultralight aircraft or motor gliders and sailplanes. For this purpose, the flight simulator for the ultralight aircraft Flight Design CT2K will be described and presented in the following sections.

Simulator system architecture

The layout of the flight simulation system is presented in Fig. 1. The main components of the simulator and their interconnections are shown, details of which are described as follows.

The computer hardware comprises three off-the-shelf X86 architecture PC. These computers feature 2.8 GHz hyperthreading Pentium IV processors, each equipped with 512MB DDR RAM. The computer driving the visual system additionally possesses an Vidia GeForce FX5900 Ultra graphics card.

Networking is performed by means of standard on-board Ethernet.

The task of one PC is assigned for the visual system, with no other task. The two other PCs have multiple tasks. The simulation computer is concerned with the simulation process, the analog I/O interface and the simulation control. To allocate sufficient resources for the simulation process, hyper-threading is used to assign that process as the only one running on the virtual CPU 0, while all other processes on this computer are routed to the virtual CPU 1.

The tasks of the third PC are instrument simulation and sound generation, interfacing the discrete I/Os, controlling the RS-232 driven LCD display for the engine status instrumentation FlyDAT and connecting to the simulated radio panel.

The simulation model is implemented in MATLAB/SIMULINK. For the particular application, this offers the advantage that high fidelity simulation component libraries can be used

The Ethernet communication is performed using a switch. A data protocol termed VisIO is used[4]. This high-level data protocol relies on UDP for cyclic data and on TCP/IP for discrete event data.

For indicating the status of the engine, a display called FlyDAT is used which features a 240 × 64 pixel graphics LCD. It is connected to the instrument PC via RS-232. The radio panel, which is a low-cost replica of an aircraft radio frequency selector panel for simulator use, is connected via USB.

The discrete cockpit I/Os (flap lights, warning lights, switches and circuit breakers) are linked to the instrument PC via a low-cost USB I/O box. Analog-digital conversion of the primary cockpit controls is also performed by means of a data logging box with USB interface. This box is connected to the simulation PC.

Simulator cockpit

For the flight simulator, the forward fuselage part of a real CT2K-airplane is used to provide a highly realistic cockpit environment (Fig. 2). The realism is supported by the fact that the cockpit interior is kept the same as in the original airplane. This concerns the instrument panel, the control devices for the pilot, the seats, etc. Modifications are limited to components specific for the simulation. Sensor elements are used to provide data of the control inputs of the pilot.

Emphasis was placed on a realistic simulation of the primary controls. Replicating them as realistically as possible was considered to contribute to the simulation fidelity and training quality of the system. Therefore, a solution has been developed which simulates the control forces for elevator, aileron and rudder. A spring loading system is used for this purpose. The neutral point of the spring is shifted using the trim lever, according to characteristics in aircraft with an all-moving horizontal tail featuring small hinge moments. For other tail configurations, it is a method that may be regarded as applicable with a proper selection of the load characteristics, particularly under cost-effectiveness considerations. The control deflections are measured using linear and angular potentiometers. The throttle, brake and choke lever positions are also made available in the form of analog signals. An analog-digital-conversion box is used to generate digital signals for computing purposes. As an example, Fig. 3 shows the attachment of a potentiometer for measuring the roll control input.

Instrument simulation was performed using a computer based approach. This will be described in a separate section.

The sound environment is simulated by a Dolby 5.1 system. The forward center box is located in the instrument panel, the other forward boxes are in the wing root and the two rear boxes in the baggage compartment. The subwoofer is fixed in the engine area. With this geometric arrangement, an adequate spatial assignment of the sound sources is possible.

All modifications necessary for using the CT2K fuselage in the simulation were designed with CATIA V5 and the original CT 3D-CAD model.

The simulator cockpit is placed on a metal truss with wheels so that the complete flight simulator is mobile. Thus, the flight simulator can easily moved and transported to different places, like flying schools and other users.

The described approach for the simulator cockpit yielded a low-cost solution. Such a low-cost solution is generally possible if a real cockpit shell which is decommissioned or no longer needed is available.

Instrument simulation

A computer based solution was developed for the simulation of the instruments at the cockpit panel. The instrument panel in the simulator cockpit is depicted in Fig. 4. The instruments are simulated on a 10.4" TFT display that is mounted behind the instrument panel. The panel itself features instrument front rings and cover glasses (Fig. 5). Thus, the appearance accurately replicates the real panel. Furthermore the attitude indicator, the altimeter and the directional gyro are equipped with rotational encoders to allow setting the reference values for attitude, pressure and direction respectively. Besides the basic six instruments, the left part of the panel also houses the flap switch and flap deflection display for which the original aircraft parts are used.

Further systems are located on the right part of the panel (Fig. 4). These are the engine status panel (FlyDAT), the radio panel and the transponder.

For simulating instruments in a photo-realistic manner and for modeling the logic behind the cockpit controls and systems, the software tool SCAMSY (Simulation Control And Management SYstem) was used which has been developed at the Institute of Flight Mechanics and Flight Control of the Technische Universität München. This tool offers high flexibility in the generation of instrument displays, as a scripting language is used to specify the relative motion of graphical elements and textures as a function of the aircraft variables. The instruments are displayed on a TFT in front of which a mask with instrument rings is mounted to increase the level of realism.

For the CT2K instrument replication, high-resolution photos were taken from original cockpits. Textures of gauges, dials and pointers were then extracted from these photos. The SCAMSY software allows building up instruments from primitives which can be filled with textures and then grouped in a hierarchical structure. Every contributing object possesses properties which can be dynamically changed by the application as a function of simulation variables. This means for example that pointers can be rotated, scales can be shifted or colors can be changed. As an easy access is possible to the referring commands, specific or complex programming knowledge is not required. The objects can be grouped, shifted or rotated collectively without applying the transformations to all elements separately. An example for the capabilities of the SCAMSY software is presented in Fig. 6 which shows how objects with various properties can be linked.

Another important feature of the SCAMSY software is the scripting language that allows access to dedicated hardware. For example, the engine status display is interfaced by the SCAMSY software via a serial RS-232 connection.

If more complex tasks are to be performed that are not possible with SCAMSY functionalities, own C/C++ or even compiled MATLAB code can be included as the SCAMSY software offers an open API and a plug-in architecture.

Visual system

An important aspect of flight simulation concerns the visual scene. The solution developed for the flight simulator of the ultralight aircraft FlightDesign CT2K is based on the visual system software VisEngine Visual Scene Generator of the AeroLabs AG company. This system was scaled down to meet the requirements of a useful training simulator that is still affordable to the target group of microlight operators and flying schools. Thus, a low-cost solution was achieved. The use of PC based computer hardware for the visual scene simulation contributed to the low-cost solution. The experience gained with this system is encouraging in terms of high fidelity and performance.

VisEngine is implemented in C++ and relies only on OpenGL, eliminating the need to purchase third party software licenses. The system works on any PC architecture featuring nVidia, ATI or any other hardware accelerated graphics card supporting OpenGL.

Besides the normal image generator the system includes a large number of additional and auxiliary functionalities like geometry database optimization, import of OpenFlight databases, an extensive enhancement architecture as well as multiple mathematical models, e.g. an analytical lighting model. Examples for the performance of the visual system are presented in Figs. 7 - 9.

In many multi-channel systems geometry correction and blending of the channels is performed using dedicated hardware solutions that have high purchase and maintenance costs. To eliminate this expensive requirement, AeroLabs AG developed a new, software-enabled solution. After computing the geometries to be displayed, a further processing step is executed on the graphics card which is correcting the deformations due to the non-planar projection geometry, blending the channels for arbitrary beamer arrangements and finally adjusting color temperatures. With this solution, no additional hardware is required to support multi-channel beamer-screen-setups with smooth blending between the channels.

Furthermore, a capability of engineering visualization is possible. Thus, forces, moments, velocities, fields, flight path ribbons, etc. are beneficial as training aids, to increase the insight of the pilot student in the physics and the dynamics of the aircraft (e.g. sailplane) and for post flight analysis.

The CT2K flight simulator features a one-channel vision system using a retractable projection screen and a low-cost

LCD beamer with a resolution of 1024×768 pixels. The beamer is mounted on top of the fuselage with an adjustable platform, so that height and angle of the beamer can be changed (Fig. 2). The visual system was configured in a way that the horizontal and vertical viewing angles correspond to reality.

A realistic visual system can be regarded as adequate for normal flight tasks, particularly for landing approaches. Therefore, great emphasis was put on the application of a realistic visual system which can be generated by PCs. For high maneuverability flight operations, like dynamic soaring, the motion is an issue. Furthermore, a realistic motion system with a 6-degree-of freedom capability cannot be attained with a low-cost approach.

Extensions in the applications of the flight simulator approach

The described flight simulator concept which was realized for an ultra light aircraft can be considered to be applicable also for motor gliders and sailplanes. This is basically due to the flexibility which is inherent in the system. Thus, applications which are specific for motor gliders and sailplanes can be accounted for by adding appropriate features. The developed high-performance software offers a high degree of flexibility, enabling the simulation of different types of vehicles, flight conditions, etc. This also holds for the cockpit instrumentation which can be easily changed to simulate a great variety of airplanes. Correspondingly, many models for simulating other airplanes are available. Furthermore, the visual scenery of the computer generated image system can be easily adapted to other environments or flight conditions.

There are several specific issues for motor gliders and sailplanes. Examples are described in the following and it is shown how these can be incorporated in the described simulator concept.

Training objectives

Basic aspects of learning can be included in the simulation. This concerns fundamental effects of control inputs on the response of the vehicle. Another aspect relates to control coordination for different flight conditions, like that for straight flight, turns, etc. It can be used for performing/training of approaches and landings, including the preparation for these flight tasks prior to an approach. Furthermore, landing in a crosswind can be a learning objective. Another aspect of basic learning can be the energy management.

Instrument simulation

The software tool SCAMSY which is used to simulate the instruments employs a high flexibility and is user friendly. Thus, different instrumentation types can be simulated by interchanging the corresponding data stets. Dynamic instrument features, like delay effects in the variometer, can also be accounted for in a realistic manner.

Wind and weather simulation

The simulation of wind and weather conditions can be used for basic learning in order to utilize the effects of thermals or other wind phenomena (e.g. rising air at hills) for soaring. For this purpose, dynamic models for replicating such wind conditions can be included in the overall simulation process. The simulation implies also the realistic presentation of wind and weather phenomena in the visual scenery.

An accurate simulation of the sun position during the day affecting the occurrence of thermals can be performed and displayed to the pilot. Other conditions of rising air, like the upward deflection of the wind over a slope, can be included in the simulation.

For example, a thermal may be visualized and its image displayed in order to support the student pilot in the learning process. Such a thermal condition is presented in Fig. 10. The rising air of a thermal can be added to the pictorial representation of the outside world, in accordance with appropriate cloud configuration.

Head-mounted display

The visual scene can be presented to the pilot with various types of displays, requiring only small software modifications. An option is to use a head-mounted display, instead of one or more projection screens. This is schematically shown in Fig. 11. With a head-mounted display combined with a head-tracking system, it is possible to provide the pilot with a full 360 degree view. The head-tracking system provides movement within the 360 degrees. Capable head-mounted displays with a head-tracking system are available at low cost. Thus, the overall cost-effectiveness goal can be maintained for the flight simulator.

Debriefing aspects

A debriefing of training exercises is possible with the flight simulator in order to support learning effectiveness. For this purpose, a replay of flight exercises can be made using computer animations of tasks performed by a student pilot. Such computer animations may show the flight path in a 3-dimensional format, the energy management or other quantities. It may be supplemented by time histories of quantities which are relevant for the flight task, such as properly approaching a thermal and circling in order to optimally utilizing the rising air (as simulated in Fig. 10).

Conclusions

A flight simulator for an ultra-light aircraft is presented. The approach for this device and the experience gained with it can also be used for cost-effective flight simulations of motor gliders and sailplanes. The concept presented in this paper allows a significant reduction of the costs while keeping the system performance and the simulation fidelity at a level required for the purpose aimed for. This is possible with a low-cost hardware and high-performance software, including an appropriate system architecture.

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[4] M. Heise, „Development and Implementation of a Communication Interface for a Research Flight Simulator“. *Semesterarbeit*, Lehrstuhl für Flugmechanik und Flugregelung, TU München, 2004.

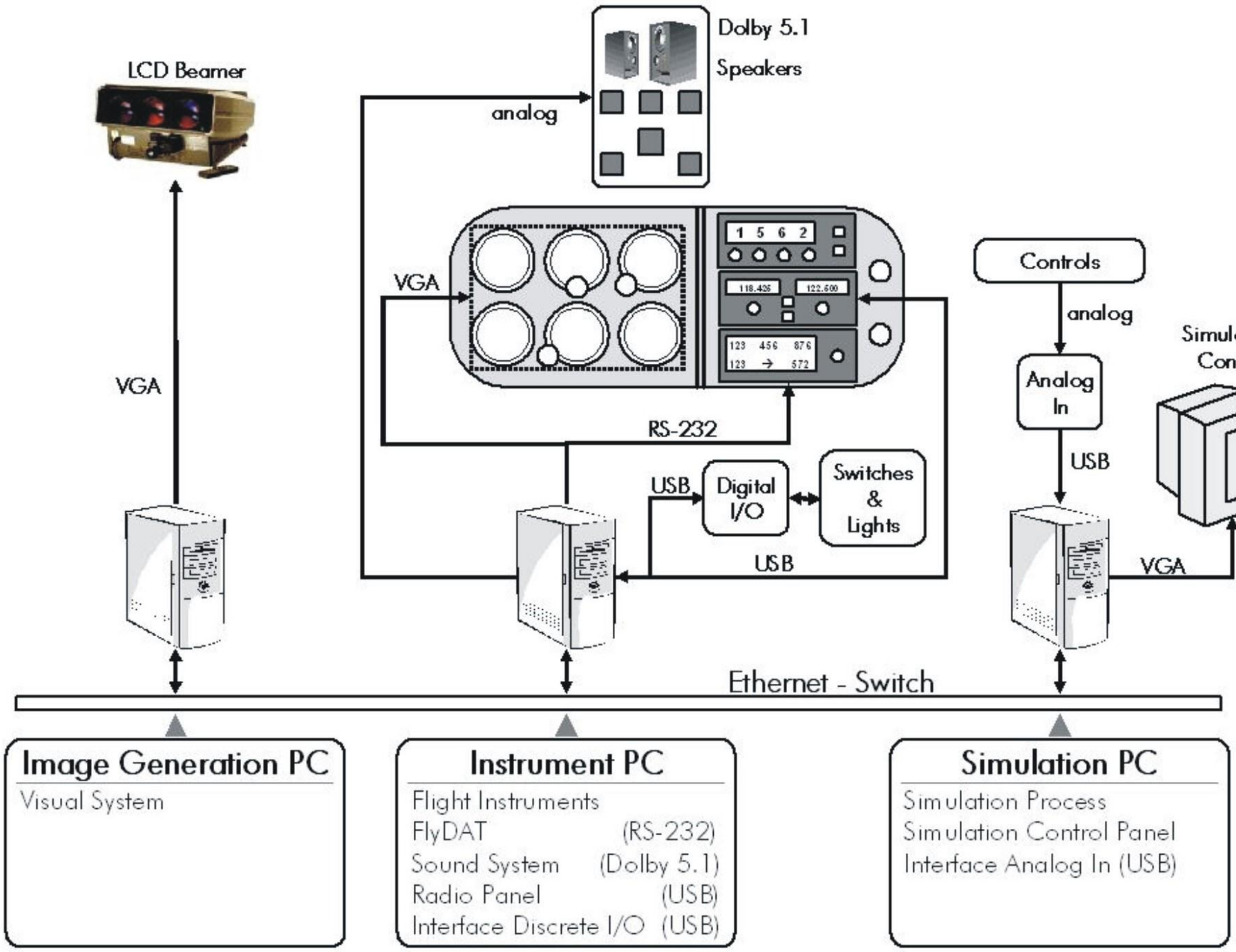


Figure 1

Figure 2

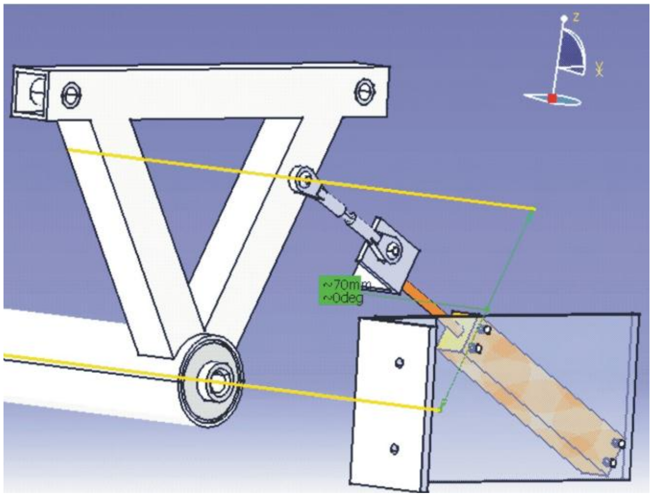


Figure 3

Figure 4

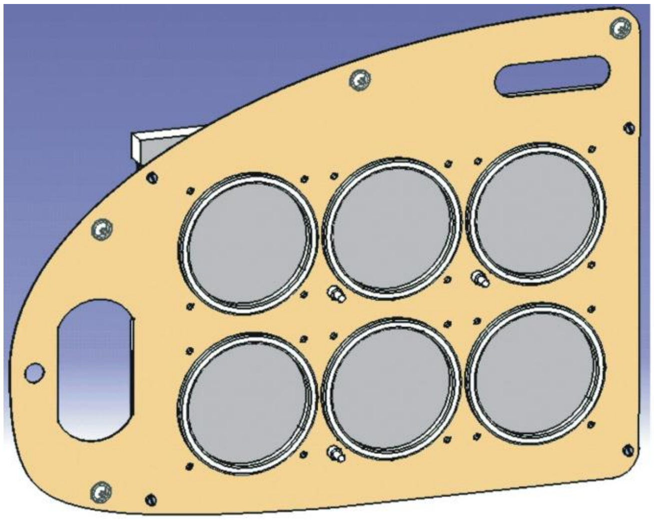
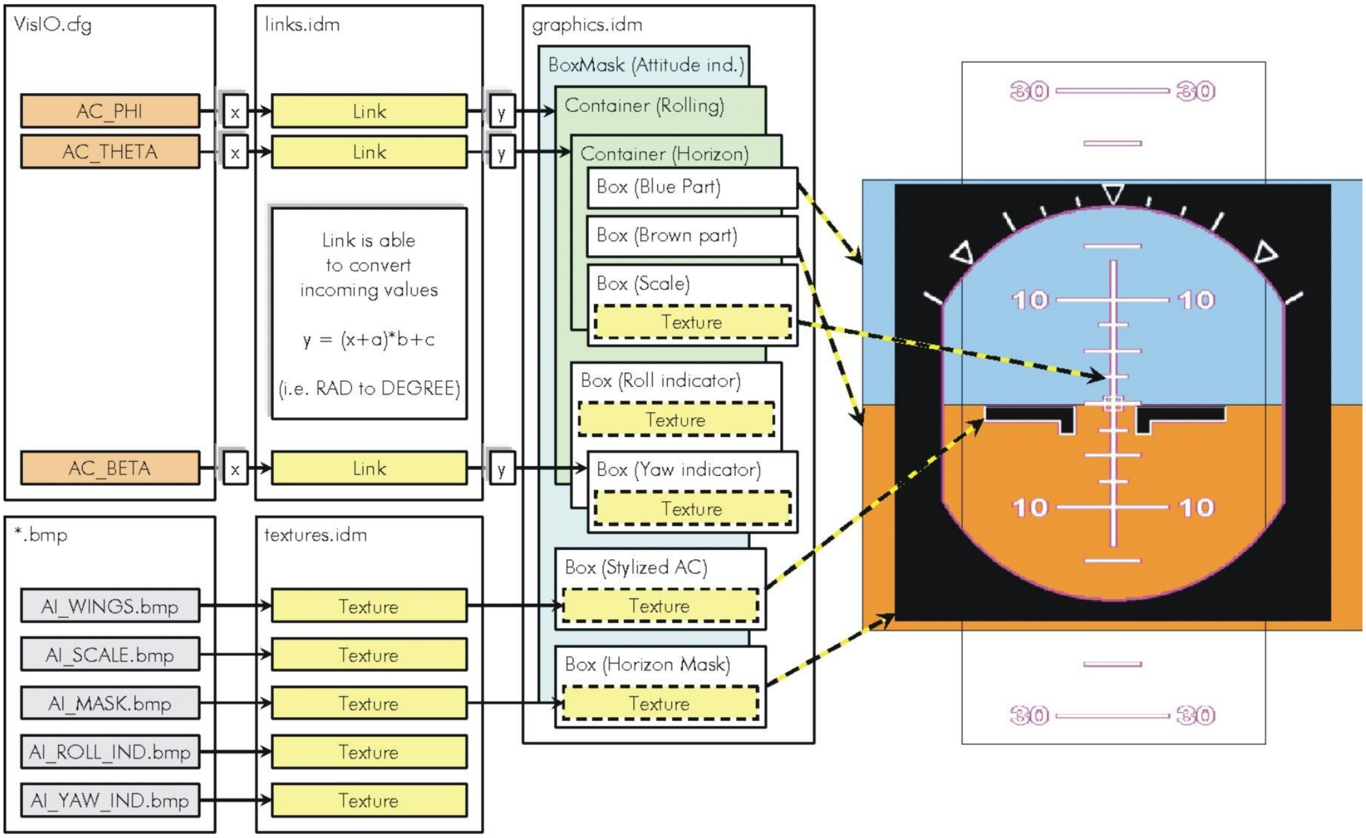


Figure 5



VisIO.cfg
AC_PHI
AC_THETA
AC_BETA
x
links.idm
Link
Link
Link
Link is able to convert incoming values
y = (x+a)*b+c
(i.e. RAD to DEGREE)
y
graphics.idm
BoxMask (Attitude ind.)
Container (Rolling)
Container (Horizon)
Box (Blue Part)
Box (Brown part)
Box (Scale)
Texture
Box (Roll indicator)
Texture
Box (Yaw indicator)
Texture
Box (Stylized AC)
Texture
Box (Horizon Mask)
Texture
*.bmp
AI_WINGS.bmp
AI_SCALE.bmp
AI_MASK.bmp
AI_ROLL_IND.bmp
AI_YAW_IND.bmp
textures.idm
Texture
Texture
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Texture
30
30
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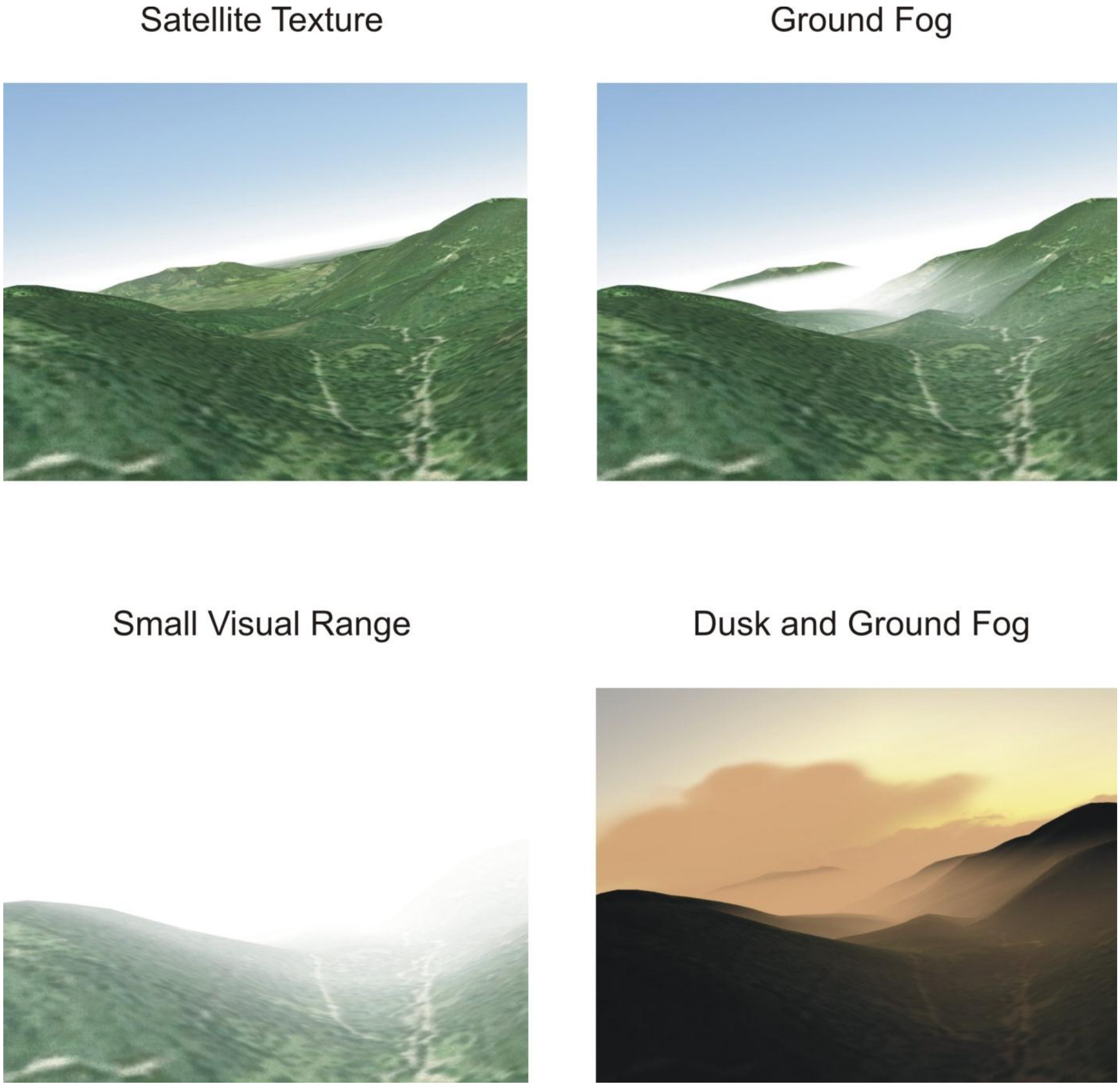
30

Figure 6



Satellite Texture

Ground Fog

Small Visual Range

Dusk and Ground Fog

Figure 7

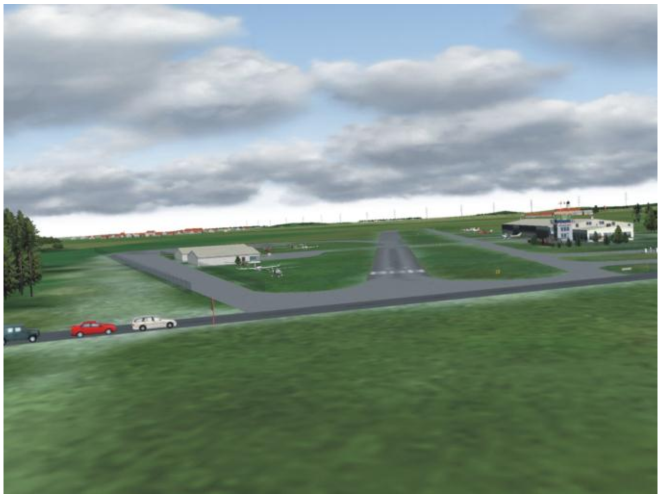


Figure 8

Figure 9

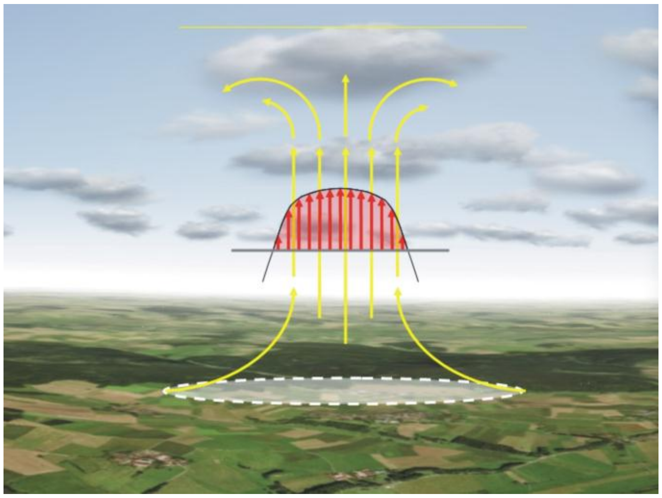


Figure 10

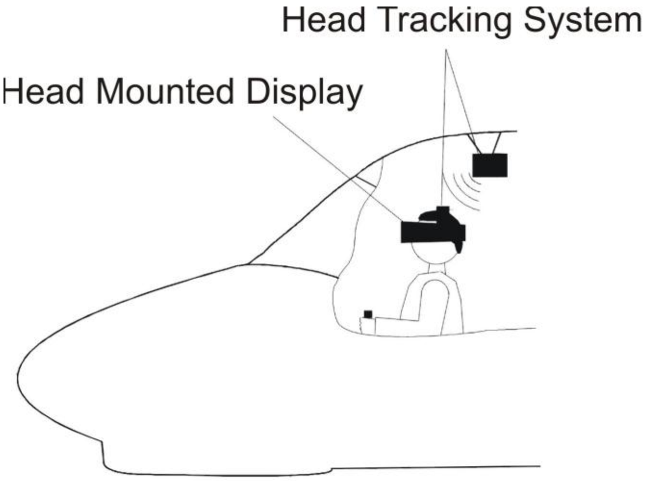


Figure 11