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Application Based Case Study

<<Title>>

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INTRODUCTION

We are living in an era of technology. Technology is booming today and it has touched every aspect of life. Either we talk about our daily life or highly skilled tasks. They can be related to earth, water and space which are considered as main factors of life. Every country keeps a progressive thinking for its space programs. Either they are related to satellites or aircrafts. These are very economic programs so for their working and maintenance some techniques are available. One of them is Flight simulator. Flight simulator is actually a simulation of flight considering every aspect of the flight environment.

A **flight simulator** is a device that artificially re-creates aircraft flight and the environment in which it flies, for pilot training, design, or other purposes. It includes replicating the equations that govern how aircraft fly, how they react to applications of flight controls, the effects of other aircraft systems, and how the aircraft reacts to external factors such as air density, turbulence, wind shear, cloud, precipitation, etc.

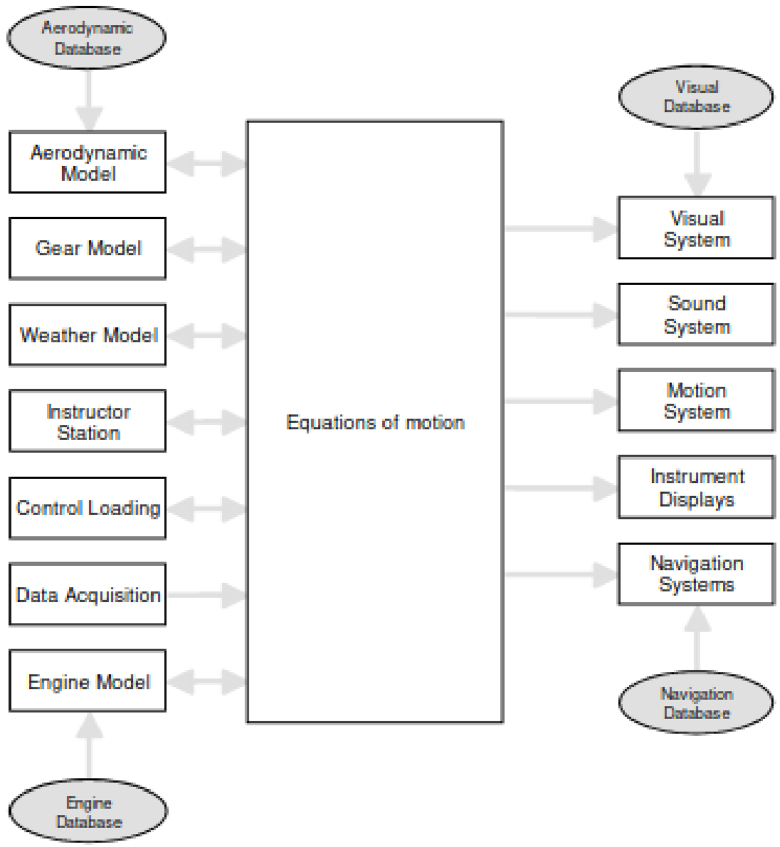
Modern flight simulators meet two main aviation objectives: (1) to provide pilot training at the instructor's level, and at the student's level to learn to fly and to earn virtual flight hours that are useful for flying real aircrafts and (2) to simulate normal flight conditions, as well as adverse situations and spatial disorientation such as navigation instrument faults, power losses, loss of control of the aircraft, confusion illusion of references, illusion of the effect of black holes, among others, that would be dangerous and even catastrophic in a real flight; so, they must be well analysed, controlled, and learned.

ORGANIZATION OF A FLIGHT SIMULATOR

A modern civil airline full flight simulator is shown in Figure 1. The simulator consists of a cabin where the flight deck is fully replicated, accommodating the flight crew and the instructor.

The cabin is mounted on six hydraulic (or electrical) actuators and projection systems mounted on the cabin are used to display the scene seen by the flight crew. The rear portion of the cabin includes an instructor station to enable the instructor to monitor and control a training session. For a military simulator, the instructor is usually located in a control room, communicating via a head-set, similar to airborne instruction.

The structure of a modern flight simulator is outlined in Figure 2. The equations of motion, which underpin the flight model of the simulated aircraft, are the focal point of the simulator. The forces and moments which define aircraft motion are solved as a set of non-linear differential equations to compute the aircraft motion and trajectory.



These equations are solved by a computer program (typically executed on a PC) with sufficient accuracy that the simulator model faithfully replicates the aircraft motion (linear and angular) throughout the flight envelope. In addition, the equations must be solved at least 50 times per second (every 20 ms) so that the resultant aircraft dynamics appear to be smooth and continuous. This constraint of simulation is referred to as real-time simulation.

Finally, the aircraft systems must also be faithfully replicated, including the displays and instruments. In addition, the aircraft navigation systems are also simulated so that the simulator is flown and navigated in exactly the same way as the aircraft. Two methods are employed; actual aircraft systems can be used but they must be stimulated with the same signals as an aircraft; alternatively, the equipment can be fabricated to emulate the actual aircraft functions. The decision to 'simulate or stimulate' depends on the relative cost of the implementation.

EFFECTIVENESS OF FLIGHT SIMULATION

In flight training, the flight simulator is used to capture and practise skills that can subsequently be applied in an aircraft. If the training is effective, minimal time is needed to transfer the skill to the aircraft. Alternatively, if it is not effective, additional airborne training is needed. Clearly, considerable effort is given to ensuring the effectiveness of a flight trainer, matching the simulator technology to the training requirements.

Technology developed for flight simulation has also been applied in other sectors of aviation, where the cost difference of synthetic training versus live training offers significant benefits:

- Aircraft technicians can practise fault finding and equipment removal, without using actual aircraft parts, as shown in above figure.
- Cabin simulators are used to enable cabin staff to practise evacuation procedures.
- Military simulators can link flight crew trainers with mission crew trainers, enabling crews to practise specific mission profiles and to train in crew resource management.

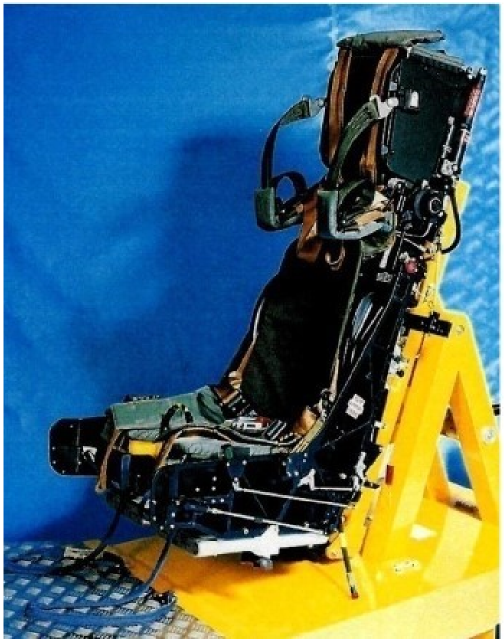
The results from a number of studies suggest that the effectiveness of training is not necessarily linked to the fidelity (and therefore cost) of the flight simulator (Caro, 1988). Effective training has been demonstrated with part-task training devices, where emphasis on matching the simulator technology to the training requirement produces better training and in many cases can reduce the cost of training.

TECHNOLOGY DRIVEN INDUSTRY

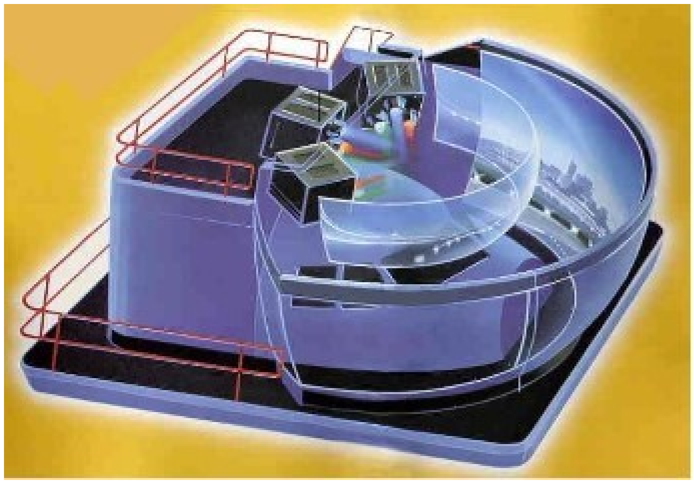
The advances in the processing speed of modern computers have been exploited in flight simulation. Complex models of airframe dynamics, rotor dynamics and engine thermodynamics have been derived from analysis of flight data and also from computational fluid dynamics (CFD) packages.

➢ The graphical processing used in image generation provides detailed textured 3D scenes which include haze and fog effects, dynamic objects and a continuous view typically 220 by 40 but as much as 225 by 60 in demanding applications. A typical image is shown in the figure below (3), which includes several aircraft, detailed airfield scenery and surrounding countryside.

- For a military flight simulator, the high frequency buffet and sustained g-forces cannot be provided by a standard 6-DOF platform but a g-seat combined with a vibration system and a wide field-of-view projection system, provides acceptable motion cues. A typical g-seat is shown in the figure below (4).



- The projection of the outside world scenes needed for flight simulation introduces three problems. Firstly, the projected view must give a natural sense of distance (or depth). Secondly, the view must be seen by both pilots. Thirdly, the mass of the projection system adds a significant load to the motion system. These problems have, to a considerable degree, been overcome by the curved mirror projection system developed in the UK (Blackman, 1995). The blended image from three or more projectors, is projected onto a translucent screen and viewed through the hemispherical mirror. At the pilot station, this image is 'collimated', i.e. appears at optical infinity, reproducing the effect of depth perceived in the outside world. A typical curved mirror projection system is shown in the figure below.



- For civil flight training the prime advantage of this form of projection is the accurate distance of the scene as viewed through standard flight deck windscreens. However, such a scheme is not appropriate for military flight training, where a pilot needs a much wider field-of-view.

FLIGHT VISUAL SIMULATION SYSTEM (FVSS)

The Flight Visual Simulation System (FVSS) is an important integral part of flight simulator. The system can provide vivid 3D scenes and effective flight information including realistic flight environment and flight attitude. Flight equipment operations can be quickly, safely and skillfully mastered by using the system. Building an independent FVSS can reduce the cost and development circle of flight simulator. Internal and unforeseen faults within aircraft body or caused by complex flight environment can be avoided through the FVSS.

DESIGN AND DEVELOPMENT PROCESS OF FVSS

The FVSS contains two main modules, flight simulation and visual simulation. For flight simulation module, the main focus is on the modeling of flight motion equations including aircraft aerodynamic and dynamic equations.The 3D motion status of aircraft in flight simulation module is controlled and updated continuously in accordance with the calculation results of these equations. Main structure of the system is shown in Fig.1.

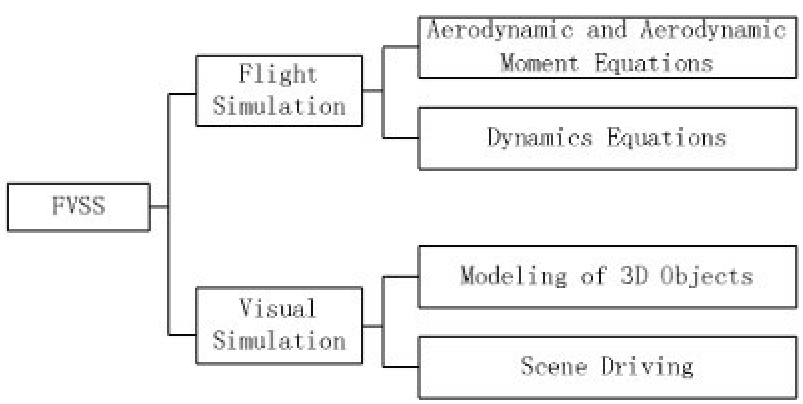


Fig. 1. Main structure of the FVSS

In order to accelerate development speed, assure system quality and improve system maintenance, software Creator and Vega Prime from MultiGen-Paradigm are used for the development of visual simulation module. Calculation for flight simulation module is carried out by Matlab and generated results are exported to Visual Studio 7 for mix programming which implements the real-time control of aircraft model flight motion in Vega prime. Actual development process is described by the following steps and the process is depicted in Fig.2.

Step1: Software Creator is used for 3D modeling and flight motion simulation is created by light kinetic equations.

Step2: Configuration, run and rendering of flight scene are through the call for .acf file in Vega Prime.

Step3: Parameters of aircraft in visual simulation, such as flight attitude, velocity, acceleration and so on, are calculated by Matlab.

Step4: .exe file is generated by using the integrated simulation platform of Visual Studio 2003. In this platform, generated data from Matlab are used for real-time connection between flight attitude and visual scene of aircraft model in Vega Prime. The visual simulation module and flight simulation module are combined together through the real-time connection and control.

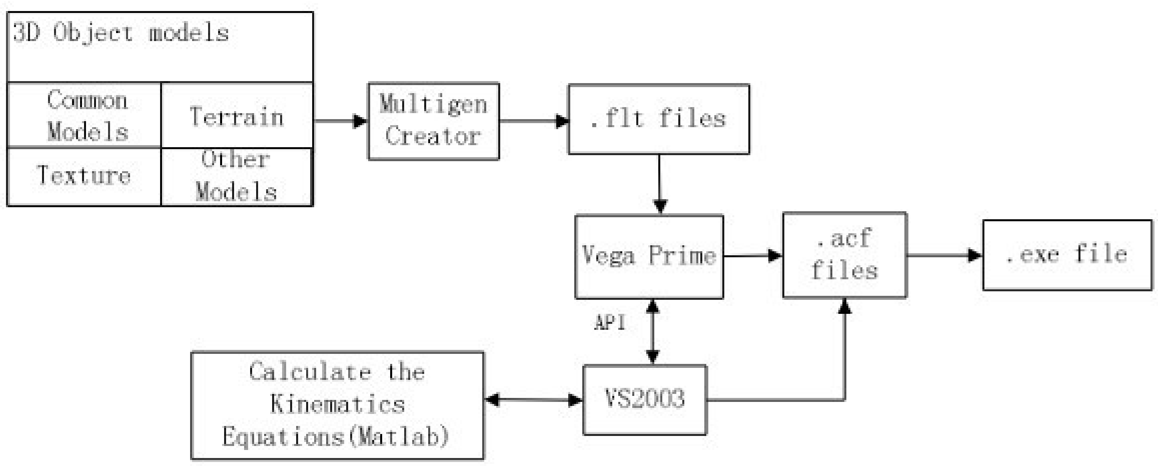


Fig. 2. Actual development process of the FVSS

MATHEMATICAL MODELING OF FLIGHT SIMULATION

The aircraft flight motion simulation, as an important part of FVSS, directly affects the reliability and authenticity of the system. The FVSS is based on two assumptions:

1. Flight area is the space above ground level where the rotation of earth and the curvy motion of the mass center of earth are neglected.
2. Aircraft is an ideal rigid body and influence from aircraft body elastic deformation and rotating parts are not considered.

MODELS OF AERODYNAMICS AND AERODYNAMIC MOMENT

When an aircraft is in the air, besides gravity and motor power, aerodynamic forces, drag X, lift Y and lateral compression Z which are all caused by relative airflow also act on the aircraft. Rotational inertia exists as a moment of inertia and would generate three moments; rolling moment M_x, yawing moment M_y and pitching moment M_z.

These aerodynamic forces and moments are as follows:

Where, C_x, C_y and C_z are coefficient of drag, lift and lateral compression separately; m_x, m_y and m_z are coefficients of rolling moment, yawing moment and pitching moment separately; q is speed pressure, S is wing area, b is wingspan and c is the average aerodynamic chord.

$$\begin{aligned} X &= qSC_x \\ Y &= qSC_y \\ Z &= qSC_z \end{aligned} \qquad \textbf{(1)}$$

$$\begin{aligned} M_x &= qSbm_x \\ M_y &= qSbm_y \\ M_z &= qScm_z \end{aligned} \qquad \textbf{(2)}$$

MODELS OF DYNAMICS

During the process of simulation, the 6-DOF motion equation is used for flight motion calculation. Following is the dynamic equation group of mass center motion in aircraft body axis system.

$$\begin{bmatrix} \mathrm{m}\left(\dfrac{dV_x}{dt}+\omega_y V_z-\omega_z V_y\right) \\ \mathrm{m}\left(\dfrac{dV_y}{dt}+\omega_z V_x-\omega_x V_z\right) \\ \mathrm{m}\left(\dfrac{dV_z}{dt}+\omega_x V_y-\omega_y V_x\right) \end{bmatrix} = \begin{bmatrix} F_x+g_x \\ F_y+g_y \\ F_z+g_z \end{bmatrix} \qquad \textbf{(3)}$$

Where, V_x, V_y and V_z are components of flight acceleration in aircraft body axis system; ω_x, ω_y and ω_z are components of aircraft angular velocity; F_x, F_y and F_z are the components of total force in an aircraft body axis system.

$$
\begin{aligned}
&J_x \frac{d\omega_x}{dt} - (J_y - J_z)\omega_y\omega_z - J_{yz}\left(\omega_y^2 - \omega_z^2\right) - J_{zx}\left(\frac{d\omega_z}{dt} + \omega_x\omega_y\right) - J_{xy}\left(\frac{d\omega_y}{dt} - \omega_z\omega_x\right) = M_x \\
&J_y \frac{d\omega_y}{dt} - (J_z - J_x)\omega_z\omega_x - J_{xz}\left(\omega_z^2 - \omega_x^2\right) - J_{xy}\left(\frac{d\omega_x}{dt} + \omega_y\omega_z\right) - J_{yz}\left(\frac{d\omega_z}{dt} - \omega_x\omega_y\right) = M_y \; . \qquad \textbf{(4)} \\
&J_z \frac{d\omega_z}{dt} - (J_x - J_y)\omega_x\omega_y - J_{xy}\left(\omega_x^2 - \omega_y^2\right) - J_{yz}\left(\frac{d\omega_y}{dt} + \omega_z\omega_x\right) - J_{xz}\left(\frac{d\omega_x}{dt} - \omega_y\omega_x\right) = M_z
\end{aligned}
$$

And above is the dynamics equation group for aircraft rotation about center of mass. Where, Jx , Jy and Jz are inertia moment; J_{xy} , J_{yz} and J_{xz} are product of inertia; ω_x, ω_y and ω_z are angular velocities about each aircraft body axis separately and M_x , M_y and M_z are resultant moments about each axis separately.

Due to the symmetry of aircraft, J_{yz} and J_{xz} can be treated as 0, so above equation group can be simplified to the following form:

$$
\begin{aligned}
&J_x \frac{d\omega_x}{dt} - (J_y - J_z)\omega_y\omega_z - J_{xy}\left(\frac{d\omega_y}{dt} - \omega_z\omega_x\right) = M_x \\
&J_y \frac{d\omega_y}{dt} - (J_z - J_x)\omega_z\omega_x - J_{xy}\left(\frac{d\omega_x}{dt} + \omega_y\omega_z\right) = M_y \qquad \textbf{(5)} \\
&J_z \frac{d\omega_z}{dt} - (J_x - J_y)\omega_x\omega_y - J_{xy}\left(\omega_x^2 - \omega_y^2\right) = M_z
\end{aligned}
$$

Following is the calculation method for the quaternion by using aircraft body axis angular velocities xb , yb and zb .

$$
\begin{bmatrix} dq_0/dt \\ dq_1/dt \\ dq_2/dt \\ dq_3/dt \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 0 & -\omega_{xb} & -\omega_{yb} & -\omega_{zb} \\ \omega_{xb} & 0 & \omega_{zb} & -\omega_{yb} \\ \omega_{yb} & -\omega_{zb} & 0 & \omega_{xb} \\ \omega_{zb} & \omega_{yb} & -\omega_{xb} & 0 \end{bmatrix}\begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} .
$$

After obtaining the quaternion, attitude angles are computed by the following equation group:

$$
\begin{aligned}
&\sin\theta = 2\left(q_1q_2 + q_0q_3\right) = l_{12} \\
&\sin\gamma / \cos\gamma = -2\left(q_2q_3 - q_0q_1\right) / \left[1 - 2\left(q_1^2 + q_3^2\right)\right] = -l_{32} / l_{22} \\
&\sin\psi / \cos\psi = -2\left(q_3q_1 - q_0q_2\right) / \left[1 - 2\left(q_2^2 + q_3^2\right)\right] = -l_{13} / l_{11}
\end{aligned}
$$

The aircraft body axis system and the local rectangular coordinate system can be transformed by matrix

$$\begin{bmatrix} x_b \\ y_b \\ z_b \end{bmatrix} = \begin{bmatrix} \cos\theta\cos\psi & \sin\theta & -\cos\theta\sin\psi \\ -\sin\theta\cos\psi\cos\gamma+\sin\psi\sin\gamma & \cos\theta\cos\gamma & \sin\theta\sin\psi\cos\gamma+\cos\psi\sin\gamma \\ \sin\theta\cos\psi\sin\gamma+\sin\psi\cos\gamma & -\cos\theta\sin\gamma & -\sin\theta\sin\psi\sin\gamma+\cos\psi\cos\gamma \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

The attack angle, side slip angle and rate of change are computed by

$$\begin{bmatrix} \mathrm{V} \\ \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} \sqrt{v_{bx}^2 + v_{by}^2 + v_{bz}^2} \\ \arctan\dfrac{-v_{by}}{v_{bx}} \\ \arctan\dfrac{v_{bz}}{\sqrt{v_{bx}^2 + v_{by}^2}} \end{bmatrix} \Rightarrow \begin{bmatrix} \dot{\mathrm{V}} \\ \dot{\alpha} \\ \dot{\beta} \end{bmatrix} = \begin{bmatrix} \dfrac{v_{bx}\cdot\dot{v}_{bx} + v_{bv}\cdot\dot{v}_{bv} + v_{bz}\cdot\dot{v}_{bz}}{\sqrt{v_{bx}^2 + v_{by}^2 + v_{bz}^2}} \\ \dfrac{v_{bv}\cdot\dot{v}_{bx} - v_{bx}\cdot\dot{v}_{by}}{v_{bx}^2 + v_{by}^2} \\ \dfrac{\dot{v}_{bz}\cdot\left(v_{bx}^2 + v_{by}^2\right) - v_{bz}\cdot\left(v_{bx}\cdot\dot{v}_{bx} + v_{bv}\cdot\dot{v}_{bv}\right)}{\left(v_{bx}^2 + v_{by}^2 + v_{bz}^2\right)\cdot\sqrt{v_{bx}^2 + v_{by}^2}} \end{bmatrix}$$

In aerodynamics, angle of attack, usually denoted as , specifies the angle between the chord line of the wing of affixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere. Since a wing can have a twist, a chord line of the whole wing may not be definable, so an alternate reference line is simply defined. When the component of relative velocity along y_b axis is positive, angle of attack is positive, otherwise contrary.

SCENE DRIVING

After the generation of scene models, real-time rendering needs to be performed in Vega Prime which consists of a graphical user interface called LynX Prime and Vega Prime libraries and header files of C++-callable functions. LynX Prime is the graphical user interface for defining, editing, and previewing Vega Prime applications. During the runtime of the application, selection function in user interaction is completed by Vega Prime library function calls.

A convenient class called vpApp is shipped with Vega Prime. vpApp is constructed based on the initialization, define, configuration, frame loop, and shutdown flow.

```
#include <vpApp.h> int main(int argc,

char *argv[])

{

// initialize vega prime

vp::initialize(argc, argv); //

create a vpApp instance vpApp *app =

new vpApp; // load acf file if (argc

<= 1)
```

```
// acf file has the flight scene app-
>define("kitty hawk500.acf"); else app-
>define(argv[1]); // conFig. my app app-
>conFig.(); // frame loop app->run(); //
unref my app instance app->unref(); //
shutdown vega prime vp::shutdown(); return 0;
}
```

BENEFITS OF FLIGHT SIMULATION

Enhance training

Modern flight simulators make it possible for pilots to learn both basic and advanced skills. Most student pilots use flight simulation to enhance their flying lessons, but experienced pilots can benefit from simulation training, too. Today's modern flight simulators now offer customized options to augment training for different types of aircraft and ratings.

Maintain proficiency

Great pilots know the value of proficiency. Maintaining a high level of proficiency will strengthen your skills, reduce safety risks, and ultimately help you become a better pilot. Flight simulators provide a cost-effective way for pilots to practice both routine and rarely-used skills. With simulator training, you can refine your skills in a variety of different flight scenarios that can be tailored to your specific goals.

Practice ATC communication

Learning the fundamentals of radio communication can be intimidating for student pilots, and even veteran pilots may sometimes struggle to keep up with the fast pace of ATC communication. Luckily, there are many simulation options available to help pilots practice proper radio technique and master the ATC communication skills needed for safe flying.

Improve navigation skills

Simulation can also help pilots improve and enhance both VFR and IFR navigation skills. If you're planning a cross-country trip or flying to an unfamiliar airport, you can use a simulator to practice flying the route ahead of time. Simulators can also make it easier to practice entering and executing instrument procedures using onboard navigational devices and equipment.

Mitigate risk

One of the most significant benefits of using flight simulation is the ability to practice handling in-flight emergencies and risky situations without the threat of any true danger. In a simulated flight, you have the freedom to make mistakes that might be impossible to survive in the "real world." Using simulation to practice identifying, assessing, and mitigating risk will help you learn how to avoid dangerous situations in the first place. Overall, flight simulation is a valuable way to practice dealing with emergency procedures in a low-stress environment. Whether it's used to learn something new, maintain proficiency, or practice emergency procedures, flight simulation is a powerful tool for pilots of all experience levels

CONCLUSION

Most general aviation pilots receive no flight training in a flight simulator, despite improvements in simulator technology and reductions in the cost of simulator equipment which enable flight simulation to be introduced into general aviation flight training. The main constraint to these advances is a financial one; there is no sound case for flying schools to invest in simulation technology. At the same time, while there are many proponents of simulation, the regulators are reluctant to approve the use of synthetic training without objective evidence of the benefits. The major lesson learnt from the use of simulation in airline pilot training is that a flight crew can practice for situations which might otherwise be hazardous in an aircraft, giving the flight crew the skills to appreciate the severity of these situations and the experience to cope with them, learnt in the safety of a simulator. A brief analysis of general aviation accidents shows that the majority of fatal accidents occur as a result of pilot error or poor pilot judgement. It is also clear that these classes of accidents can be replicated in a flight simulator, giving the general aviation pilot an opportunity to experience adverse flight conditions before they are encountered for real. Up to the last few years, the cost of simulator technology has been prohibitive for flying schools. However, if a way can be found to finance the widespread introduction of flight simulation in general aviation, there are potential benefits from the use of simulation technology in general aviation. It is certainly timely to review the contribution that simulation technology can make to general flight safety. A preliminary approach could be to undertake a series of objective trials in a university to assess the effectiveness of synthetic training in general aviation. One particular aspect of airline training that also offers improvements in general aviation is the introduction of recurrent checks in a flight simulator. These assessments would be based on situations that occur in fatal accidents and provide a syllabus to improve pilot judgement in a simulator. By making these checks mandatory, simulator centres could be established in flying schools, which could be financed by the assessment fee. For an annual fee, which is less than the cost of a medical examination, the scheme could be self-financing within two years and the extra simulation capacity could be used to improve flight training in flying schools. Flight simulation in airline pilot training has made a major contribution to flight safety and by exploiting the recent advances in simulation technology, these benefits could be extended to general aviation. Simulation affords one way to compress flight experience, so that training in a simulator transfers to flight situations. It is the contention of this paper that flight simulation offers a means to reduce the number of fatal accidents in general aviation. The technology is available to implement this advance and, with the support of the regulators, low-cost flight simulation can radically improve flight safety in general aviation.

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