Università degli Studi di Napoli “Federico II”

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Appunti
di
Tecniche di Simulazione di Volo

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Chapter 1

An introduction to Flight Simulation

1.1 What Is a Flight Simulator?

A flight simulator is a device that reproduce the dynamic response of an aircraft in a real-time and interactive manner.

A flight simulation implements sophisticated mathematical models that represent all of the physical properties of the simulated aircraft and ambient air. This makes the flight simulator to act according to the pilots input. The responds of the aircraft are represented by the image, instrument readings and motion cue systems which can be seen or felt by the pilot. A typical airliner training simulator is shown in fig. 1.1.

1.2 Purpose of Flight Simulators

With the increased calculation power of PC, lots of flight simulation and the simulation of other vehicles games are found in the market. Flight simulation has become in fact a cheap and available entertainment to every family, but simulators that are so popular in the video game world are of minor interest here. An overview of flying training devices, flight simulators which are the subject of these notes, will be given in the

Figure 1.1: A typical airliner flight simulator.

following pages.

1.2.1 Flight Training Devices

An important category of flight simulators, both for practical and research reasons, is that of flight training devices (FTD), i. e. those machines designed for the purpose of pilot training.

There are many training devices for many training purposes. The term “flight simulator” covers a wide range of training capabilities. Ideally, a FTD could also be as simple as a moving picture projected on a screen.

The term flight simulator (or “flight sim”, or “sim” as short) is widely used to mean a training device that accurately models *a specific* type of aircraft. Sometimes a term “generic simulator” is used to describe a simulator that models an “airplane" or a “helicopter” – not a specific type such as Boeing 707 or Bell Jet Ranger. Generic simulators are found in the civilian world while in the military world, where cost is a bigger issue, a generic simulator is rare. Flight simulators which supply better training than generic simulators are usually much more expensive.

There are so many reasons that flight simulators with different level of fidelities are broadly used by military, airlines, researchers and, of course, entertainment purpose. The low costs of money and time for training are usually the best reason military and airlines want to go for a state-of-art flight simulator. It is also much safer to use a flight simulator for training stall, malfunctions and emergency situations, including situations that are not often found, such as wind-shear, unusual mechanical failures and some tactical situation. Flight simulators provide more flexibility to simulates such conditions for accident investigation and military mission evaluation. Researchers also use flight simulator to review the design of an airplane in airplanes physical aspects and flight control/fly-by-wire logic before the aircraft is actually built. This will greatly reduce the cost of money and time for development cycle and the risk of aircraft testing.

Pilot training generally falls into 4 categories:

- basic Visual Flight Rule (VFR) training;
- basic Instrumental Flight Rule (IFR) training;
- Advanced / Recurrent training;
- Mission training (Emgency Medical Services, Law Enforcement, Search and Rescue, carrying external load, aerial photography, crop dusting, cattle herding etc.)

An organization who is planning to acquire a flight simulator should select such a device or FTD so that it is suitable for the organization's requirements and of course, the device needs and maintenance costs are affordable.

There is a general accordance on 4 primary items that have to be taken into consideration prior to contracting for a simulator or FTD:

- *Negative transfer of training.* This is where a simulator or FTD does not behave like the aircraft. Negative transfer of training is a dangerous item because the pilot will possibly learn the incorrect procedure or method and apply it in the actual aircraft resulting in a damaged aircraft or injury or death. So, the simulator needs to accurately model the aircraft type that the pilot is actually flying.

- *Controlled environment.* For flight training nothing beats the actual aircraft. However, a simulator can aid the student by making a situation easier to grasp such as setting a calm day. Also a simulator can easily set up to quickly repeat a maneuver such as a final approach which means that a pilot can practice a maneuver many times in the same amount of time as flying the maneuver only once in the actual aircraft.
- *Malfunctions.* A FTD has a huge advantage over an actual aircraft for this subject. A simulator can safely and cost effectively simulate the failure of numerous items such as an engine or airspeed indicator.
- *Environment.* A simulator has an advantage over the real world because the simulator can control nature. Examples are: temperature, ambient light, wind magnitude and type, etc. This translates to never stay down due to the weather.

1.2.2 Impact of flight simulation on safety

In 1986, an important American insurance company conducted a statistical study to compare the accident rates of piston-twin pilots who had been trained with a flight simulator to those who had not. This study analyzed US-registered Cessna and Piper piston twin-engine aircraft that were involved in fatal accidents during the years 1983 and 1984.

Out of a total population of 12810 of these aircrafts, there were 53 fatal accidents in the two years under study. In 89% of the accidents, the investigators determined that “pilot error” was the primary cause or a major contributing factor. Nearly 38% of the accidents were due to improper IFR procedures or decision making. Engine failure with subsequent loss of control was the next most frequent cause, accounting for 13% of the accidents. The typical pilot involved in a fatal accident had an average total flight time of 3225 hours with 420 hours in type. 69% held Commercial or ATP certificates. Four of the 53 fatal-accident pilots-in-command had more than 10000 flight hours.

During the study period, 1521 pilots attended a flight simulation service company to be trained in the Cessna and Piper piston twins under study. Statistically, a randomly-selected group of 1521 piston-twin pilots would have been expected to include approximately six pilots who were involved in a fatal accident. But in fact, none of the 1521 flight-simulator-trained pilots were involved in a fatal accident. The probability of this occurring strictly by chance is less than one percent.

This and other statistical studies show clearly that pilots who receive regular recurrent training have far lower accident rates than those who don't. Interestingly enough, the traditional belief that high-time pilots are safer does not seem to be supported by these studies.

The above conclusion seems to be obviously true even for pilots of airliners, which are required to have higher piloting and flight management skills, due to the presence on board of more complex systems.

1.3 How a Flight Sim Works

1.3.1 Conceptual Model (Mathematical Model)

The core of a flight simulator is its *conceptual* or *mathematical* model. Conceptual model works like the "brain" of the simulator, which "thinks" and "behaves" like the real airplane, the whole process being computer-driven. Several sophisticated mathematical models are implemented in a computer program that make the system able to simulate an aircraft. On the basis of those models, the aircraft's mass properties, aerodynamic forces and moments respect to aircraft's presenting attitude and position, are calculated, at each timestep, with a given frequency, in order to predict the accelerations for the next time instance.

After the accelerations are obtained, they are integrated over the time increment

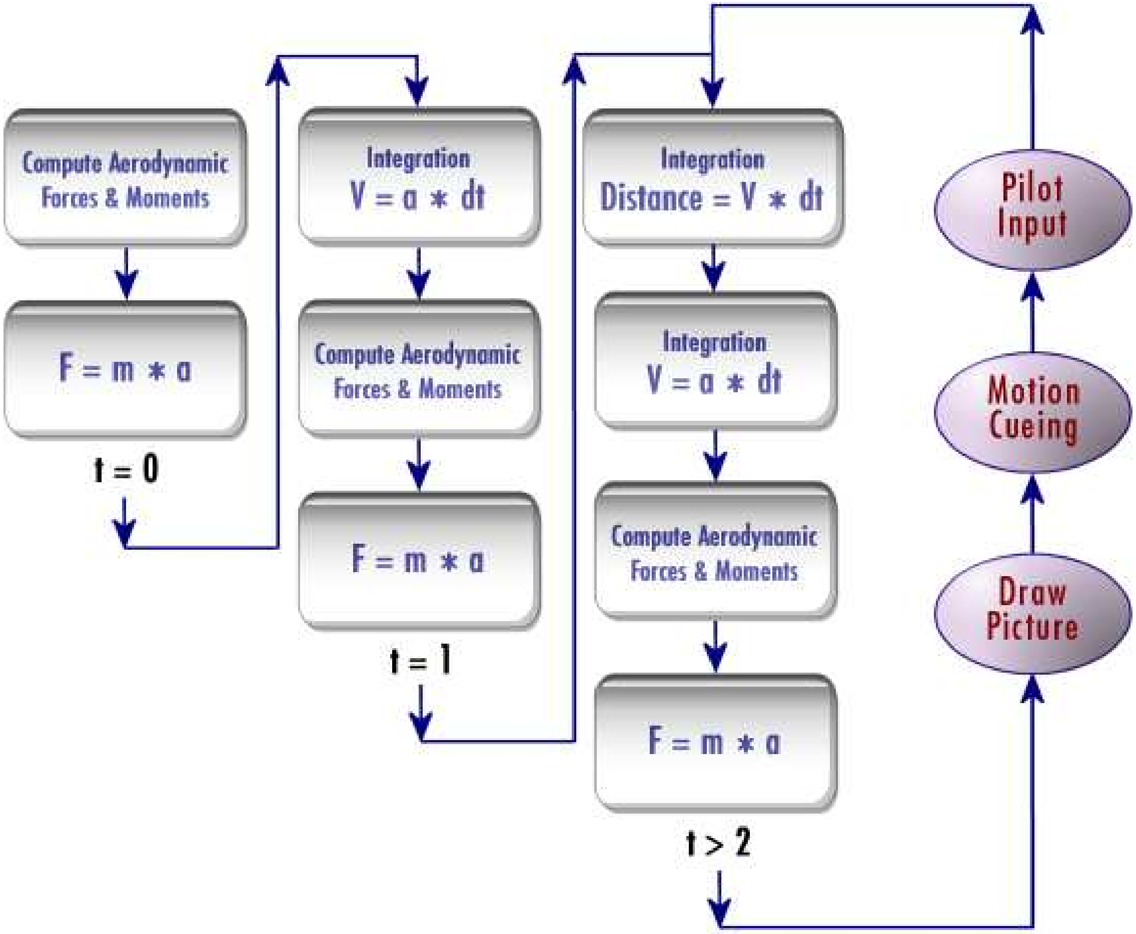


Figure 1.2: The scheme of how a simulator model works.

to get the velocities. The process therefore goes through another iteration and velocities are integrated into the displacement of the aircraft. By repeating these steps and including the pilot's input in the loop, i. e. pilot's actions on flight controls, the flight simulator is able to simulate the dynamic response of an aircraft in a real-time manner. The chart in fig. 1.2 resumes the process of how the simulation is conceptually implemented.

Details on the mathematical model of a flight simulator will be given elsewhere in these notes.

Figure 1.3: The cockpit of a SAAB 340 simulator using the latest in panoramic collimated displays. Notice the un interrupted view and cross cockpit viewing.

1.3.2 Visual system

Out-of-window visual is one of the most important cueing for the pilot to sense the motion of the aircraft. Modern technology can generate visual scenes which create simulations of sufficient fidelity that their utility is considerable greater.

The visual system is by far the most expensive and demanding aspect of a simulator. Out-of-window scenes of most modern flight simulators are done by the mean of computer graphics which are similar to those used in video games. Objects like buildings, and runways or terrain are constructed by 3-D polygons. The positions of those 3-D objects are defined in the visual database.

Medium to high end simulators have *collimated* display systems. They provide the observers (pilots) with near infinite focus which in turn deceives them into seeing the scenario they are flying in to be many kilometres deep and wide. The pilot's eyes position will follow the movement of the aircraft while the simulator keeping update aircrafts position in the "virtual space" by integrating aircrafts velocities. Sophisticated computer graphing software will transfer those 3-D polygons into 2-D drawing and project the image onto the screen. The rate of this process is usually 60 times per second, which gives the pilot a continuous animation.

Collimated display systems come in two flavours: monitor based and panoramic.

Monitor based collimating displays. This kind of visual system consists of a vertically mounted CRT monitor projecting its image down on to a reflective pane of glass called a beam splitter. This image is then reflected away from the viewer on to a curved collimating mirror. The image is then fired back through the beamsplitter to the viewer giving the impression that the projected image varies from a few metres away to many kilometres away. While this system is very effective, it suffers from a few problems. To maintain a correctly focused and collimated view, the observer must stay within a specified viewing area of the display. This area is usually about $700mm$ from the beamsplitter and will usually tolerate head movement of about $100mm$ in either direction before the image starts to look incorrect. This is known as the *design eye point* or *eye relief position*. A second major problem is cross cockpit viewing. If the Captain looks across to the First Officers's side window with this system, he will see a distorted and somewhat inaccurate view of what the First Officer would see looking out of the window from the correct eye relief position. The most apparent problem is that vertical black bars appear at the sides of the viewed area. This is far more pronounced during day mode.

Panoramic collimating displays From the outside, a flight simulator using a *panoramic display* can be identified by a large, semi-circular bulge that spans the front. Three to five back projectors are fired through a special lens on to the screen, a high gain collimated mirror, that forms the panoramic viewing area, i. e. reflects the image to pilot's eyes providing depth perception. When viewed, these screens show a continuous view of the outside world, fig. 1.3. Unlike monitor based collimating displays, cross cockpit viewing is almost perfect and the eye relief distance is not anywhere as critical. These systems usually cost in excess of one million of USD. A sketch of such a type of visual system if reported in fig. 1.4.

1.3.3 Motion Cueing

To provide the simulator with the sensation of aircraft movement, the cabin and display structure are usually mounted on hydraulic rams called motion jacks. These jack are

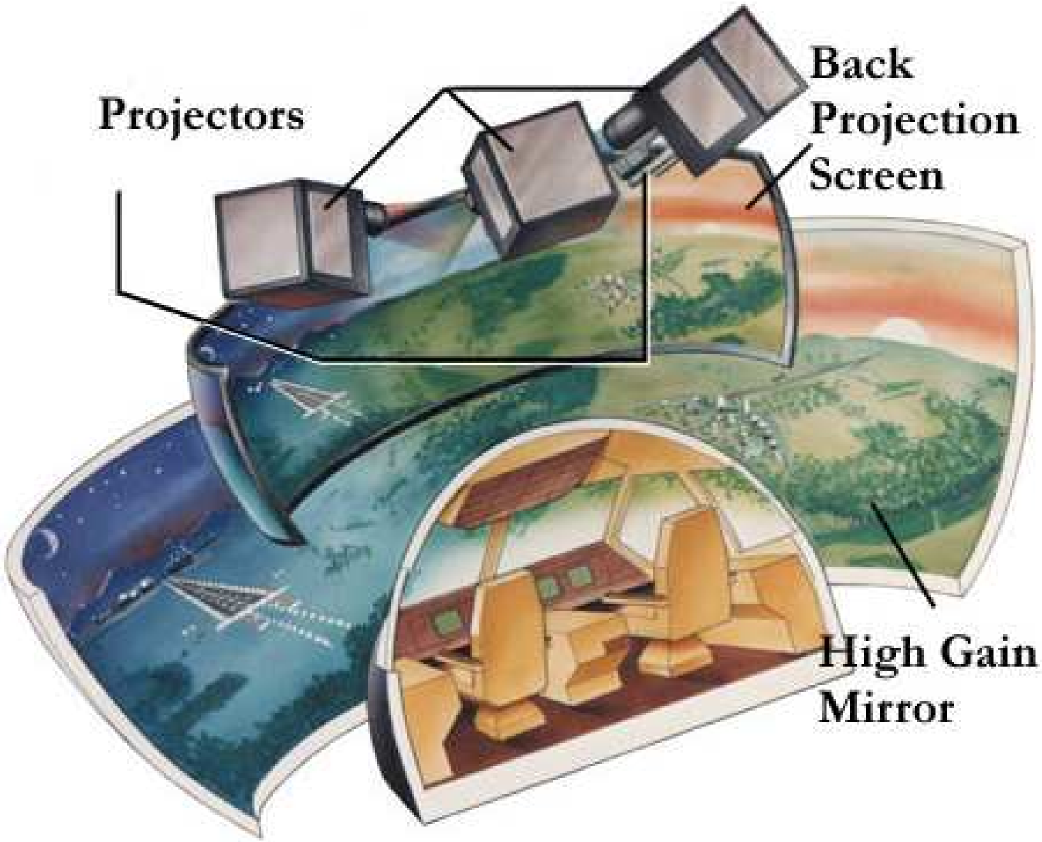
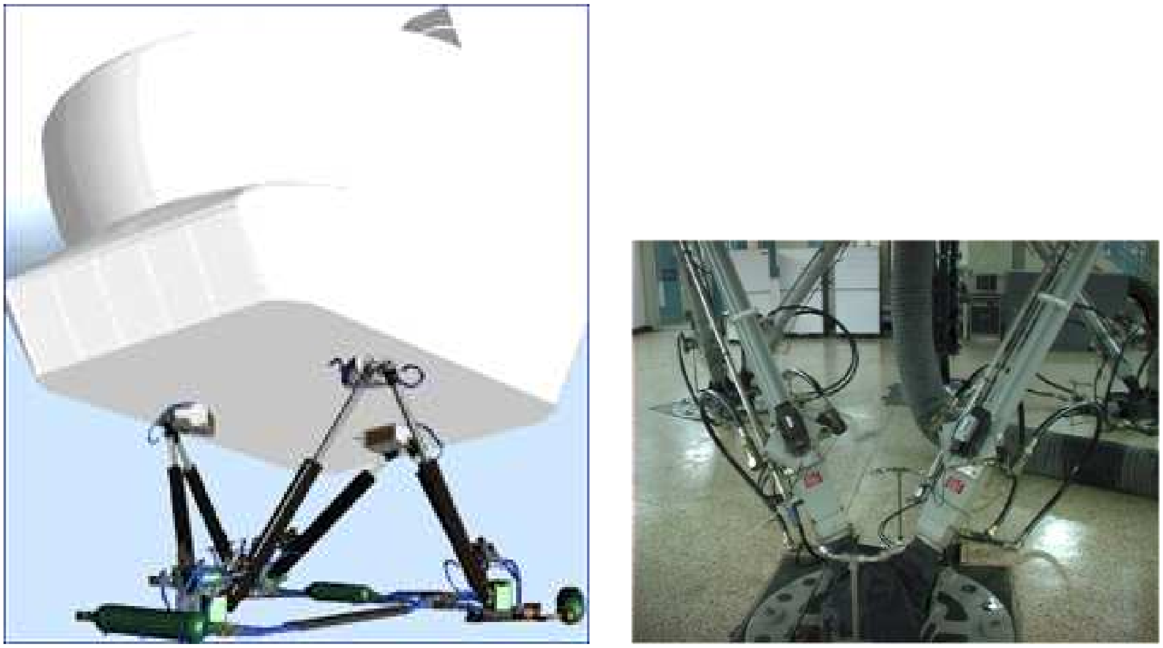


Figure 1.4: A sketch of a modern flight sim visual system.

individually controlled by a computer to move the cabin in the appropriate direction and work in unison to produce convincing motions cues.

Motion system provides more realism to the pilot by changing the gravity vectors at the flight compartment. Most of the state-of-the-art simulators equip with a *6 degree-of-freedom motion platform*, fig. 1.5. The 6 hydraulic stands provide the pitching, rolling, yawing, heave, side ward and forward movement to the platform. Those motion cues make pilots feel the maneuver of the aircraft for extra degree of realism.

The motion cue is made possible by complex computer codes and mechanics. The aircraft linear and angular acceleration vectors (x, y, z, and pitch, roll, yaw) are the step-by-step outcome of aerodynamic/dynamic calculations. This information is fed into the motion cueing computer code, which will command the hydraulic stands to



(a) A sketch of a 6 degree-of-freedom motion platform.

(b) A lower view of a 737 simulator that uses $60in$ jacks on a 6 DOF system.

Figure 1.5: Advanced 6 degree-of-freedom motion platforms.

move the flight compartment to appropriated attitude. Some maneuvers are difficult to simulate during the limited stroke the hydraulic stands can travel. For this reason a motion cue is not always a sustained action of the aircraft. In other words, because the jacks usually have a maximum travel of about 60 inches, it is impossible to sustain a $2G$ turn by the continuing extension or retraction of the jack. They are just not that long.

What actually happens in say a turn motion cue, is that the simulator will commence the bank with full displacement to produce the initial sensation of the motion and then slow the extension or retraction of the jack before it reaches the limit of its travel. It then attempts to return to a neutral, half way point along its travel so that it will be ready for the next motion cue. This gradual slowing and return to the center position of travel, is called *washout.* Motion platform designers take advantage of the fact that human internal equilibrium organs tend to adapt to sustained angular rates. In a sustained yawing of a long turn, for example, the simulator is designed turn back slowly before it reaches its physical limit, slowly enough so that the occupants do not detect what has happened.

What really makes the motion cue effective is the result that a visual system perfectly co-ordinated with the cue will convince the mind that the aircraft is really turning regardless of the fact that the actual G forces usually experienced in a aircraft motion have diminished to nothing. While there may be no more motion happening, the mind still believes that a tight $2G$ turn is in progress.

Other motion cues can be sustained such as acceleration and rotation. Acceleration is produced by retracting the rear jacks, extending the front jacks while moving the simulator forward for a few feet. This makes the sim sit back on its haunches and the natural position of being leaned back in ones seat induced pilot to think that sustained acceleration is taking place, fig. 1.6(b). The reverse goes for braking and deceleration, fig. 1.6(a).

(a) A simulator producing a braking motion cue by slightly tilting forward.

(b) To produce an acceleration and rotation cue this sim tilts upward sharply and moves forward on its haunches.

Figure 1.6: Motion cues of a state-of-the-art 6-DOF motion platform.

1.3.4 Control Loading

Control loading also provides important cue for the pilot. Pilot relies on the stick force to control the airplane. The control loading system combines with complex mechanical system and software. Position transducers are placed to sense the stick position.

Based on the stick position, the control loading code will calculate the respective surface position. From the surface position, aerodynamic moments on the hinge will be determined. The aerodynamic hinge moment will be scaled according to the actual airplanes rigging. The digital computer will tell how much the force will be send to the particular axis of the stick by a means of pneumatic, magnetic or friction mechanisms.