Aerospace Science and Technology 30 (2013) 79–82

Contents lists available at SciVerse ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

New concept of dynamic flight simulator, Part I

Antônio O. Dourado *, C.A. Martin

Dept. of Mechanical Engineering, Federal University of Santa Catarina, Brazil

ARTICLE INFO

Article history:
Received 24 March 2012
Received in revised form 15 July 2013
Accepted 16 July 2013
Available online 23 July 2013

Keywords:
Simulator
Pilot
Training
Fighter

ABSTRACT

The use of simulators for pilot training is extremely important due safety and economic factors. It is unthinkable nowadays to discard these advantages and use the conventional approach, practicing only in the real aircraft. For civilian aircraft, the use of hexapod architectures has been successful for more than 40 years, due fidelity of visual and motion systems. For military aircraft, the motion cues of simulators based on hexapod systems are not enough, due high accelerations achieved by combat aircraft. In this sense, it has been created the concept of Dynamic Flight Simulator (DFS), capable of achieving nine times the acceleration of gravity or even more. Unfortunately, these intensive motion cues cannot be achieved without side effects that constrain the behavior of the trainee pilot. This paper is the first of a series of papers that presents a new concept of flight simulator that copes with the problems of current generation Dynamic Flight Simulators.

1. Introduction

Since the dawn of military aviation, the skill of the pilots has been the key to achieve victories in combat operations. The pilots have relied on vision to find the enemies and stamina to endure continuous maneuvers to get into a firing position. Modern weapons carried by current aircraft have achieved a greater level of accuracy and reliability, so the combats turned to be in most cases beyond visual range. The cannon has been put into a status of backup weapon, and there are aircrafts that are not carrying it anymore. If the engagements turn into within visual range, the new generation of image infrared (IIR) guided missiles, can be aimed with the aid of helmet mounted sights. Again, the use of human vision is important to keep the enemy in sight to get into a firing position.

Some may think that with all this new technology the maneuverability of the aircraft is not necessary as it was used to be, but this kind of thought can lead to repeat the mistakes of the past. Despite the use of advanced radar technologies and high probability of kill missiles, the defensive means of the aircraft have also improved. The use of decoys, deceptive jamming, and directional infrared countermeasures can lead missiles not to hit their targets. Also, stealth technology (both radar and infrared) has dwindled detection range of enemy aircraft. One alternative is the use of electro-optical systems, but they are limited by weather conditions.

With the possible increase of the use of stealth aircraft like J-20 and T-50, it is not impossible to see the definition of engagements in short range dogfights, since the cannon cannot be fooled by deceptive systems. This means that the pilot will be again the decisive key of success in achieving air superiority over the enemy, and again training will be more important than ever.

Training pilots is a very demanding task, with strict procedures and details that have to be followed. Today there are several approaches to reach the results, one of them is the use of flight simulators. To avoid misconceptions, American FAA (Federal Aviation Administration) considers a device as a flight simulator only if it has a motion mechanism, everything else is called flight training device [5].

The main reasons to use flight simulation for training are: reduction of transference time between land training and real flight, safety because training pilots can make mistakes and learn to avoid them safely in the ground, economy and also less pollution. Simulators may also be used for: systems and equipment design, development, test and evaluation; research on human performance; and licensing and certification. The high fidelity of civilian flight simulators ensures that full transfer is allowed, the pilots do not have to train in real aircraft before real flights [2].

For military pilots, normal hexapod motion platforms are not enough. The motion cues achieved are very weak compared to combat aircraft accelerations. In this sense, the human centrifuges were adapted to work in real time, as the accelerations profiles are produced in the virtual flight. These systems are known as Dynamic Flight Simulators (DFS). The DFS are capable of reaching up to 15 g's, and they can sustain these accelerations for undefined periods. For physiologic training, these systems are suitable for the job, but in terms of combat training, there are limitations: the pilot must keep his head in a fixed position, otherwise he will have motion sickness due to Coriolis acceleration as noted in [7] and [5].

* Corresponding author.
E-mail address: aod@uol.com.br (A.O. Dourado).

1270-9638/$ – see front matter
http://dx.doi.org/10.1016/j.ast.2013.07.005

As previously stated, for air combat, the pilot must keep his situation awareness high, to avoid being shot down. If the training is done in a DFS, the posture of the pilot will be different from the in flight posture, which is negative training [4]. Also due to the high complexity of the current generation of combat aircraft, mishaps may lead to ground the entire fleet until the discovery of the causes of the accidents. If a high fidelity simulator is available, the pilots will be able to keep the level of proficiency even without flying the real aircraft, which does not happen today with current generation DFS [7].

2. Motion sickness in current generation DFS

The problem with current DFS is that the trainee pilot must keep his head position fixed to avoid motion sickness due Coriolis acceleration. It can be explained by a bad interpretation of stimuli by human perception model, formed by the vestibular, visual, and somatosensory systems. When the head moves, Coriolis force summed with centripetal acceleration, start to stimulate the vestibular system in another direction than the centripetal acceleration [7]. The evaluation of the current posture depends on the visual, somatosensory and vestibular systems. If there is a disconnection between the perceived stimuli, the evaluation cannot be properly done, and motion sickness occurs [8]. According to Stevens [9], the total acceleration measured in inertial frame $\boldsymbol{F}_a$ of a point $\boldsymbol{P}$ in a moving frame $\boldsymbol{F}_b$ can be described by the following formula:

$$\mathbf{a}_{P/a} = \mathbf{a}_{P/b} + \mathbf{a}_{Q/a} + \boldsymbol{\alpha}_{b/a} \times \mathbf{r}_{P/Q} + \boldsymbol{\omega}_{b/a} \times (\boldsymbol{\omega}_{b/a} \times \mathbf{r}_{P/Q}) + 2\boldsymbol{\omega}_{b/a} \times \mathbf{v}_{P/b} \tag{1}$$

The centripetal acceleration is given by:

$$\mathbf{a}_{cp} = \boldsymbol{\omega}_{b/a} \times (\boldsymbol{\omega}_{b/a} \times \mathbf{r}_{P/Q}) \tag{2}$$

and Coriolis acceleration is given by:

$$\mathbf{a}_C = 2\boldsymbol{\omega}_{b/a} \times \mathbf{v}_{P/b} \tag{3}$$

It can be seen that Coriolis acceleration depends on the angular velocity $\boldsymbol{\omega}_{b/a}$. On the other hand, centripetal force is a function of $\boldsymbol{\omega}_{b/a}$ and the radius $\mathbf{r}_{P/Q}$. A modern aircraft to achieve 9 g's in a turn of 1500 ft (radius) has an angular velocity of about 24.96 degrees per second. On the other hand, DFS have space and inertial limitations constraining the arm radius. In order to achieve the same g's as in the real aircraft, for a 15 meters of radius DFS it is needed 139 degrees per second angular velocity. The drawback of the DFS is apparent now, it is that any movement of the head (speed $\mathbf{v}_{P/b}$), leads to a Coriolis acceleration much higher in the DFS than in the real aircraft, which explains why the pilots are not constrained in flight as if they are in the DFS.

To avoid motion sickness, modern DFS have adopted the solution of building the gondola in a way that the position of the head is at the centers of rotation (pitch and roll). The pilot must keep his head fixed (to keep $\mathbf{v}_{P/b} = 0$) to minimize the Coriolis accelerations. To keep the head position fixed to avoid motion sickness is acceptable for physiologic training and research in human centrifuges, but not for combat training. In combat situations, pilots must be aware of the tactical picture around the aircraft, to avoid being shot down, and part of this is done by looking around. In combat situations, it is common to move the head constantly to keep the enemy in sight, to get into a firing position.

If the DFS constraints the posture of the pilot, the value of training in the DFS is limited to physiologic evaluation, which can be done in open loop centrifuges. Training must be as real as possible, otherwise, it is considered negative training [4]. In fact this issue was pointed by Ray [7] with the recommendation that DFS must be improved.

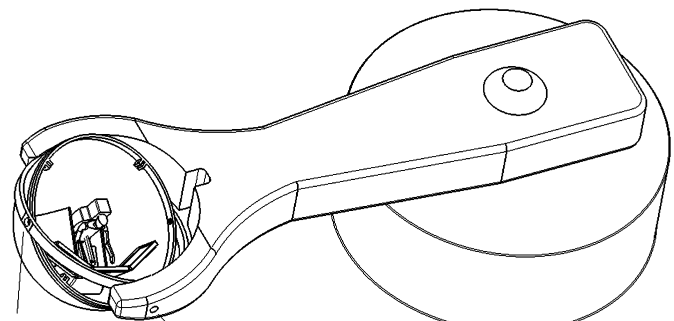

Fig. 1. The modern DFS design: the head is positioned at the center of the 2 axes, pitch and roll (the top half of the gondola is not shown).

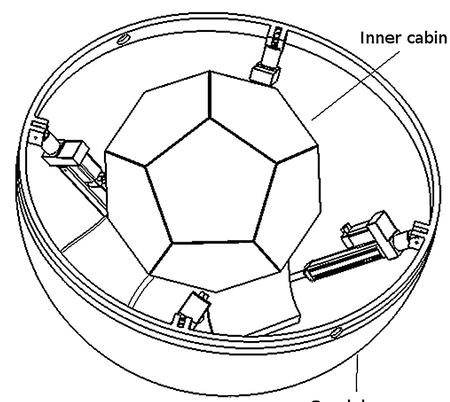

Fig. 2. The proposed concept: the pilot moves the head freely inside the inner cabin. The motion platform moves in the opposite direction to keep $\mathbf{v}_{P/b}$ close to zero, the desired goal.

3. Coriolis compensation in DFS

As pointed before, modern DFS are built with the head position centered at 2 rotation axes of the gondola, Fig. 1. Since is desirable to move the head to improve the field of view inside the simulator, a feasible solution is to create a secondary cabin inside the gondola. Inside this new cabin, the pilot can move his head, but the cabin is attached to a motion system that moves in the opposite direction of the head. Inside the cabin, the pilot has the same attitude as in flight, but relative to the gondola, the head position is almost fixed due compensation of the moving cabin. The idea of the concept can be viewed in Fig. 2.

The inner cabin inside the gondola must move in the opposite direction of the head, but the orientation must be the same. The movement of the inner cabin in opposite direction of the head will lead to reduce to a minimum $\mathbf{v}_{P/b}$ (head velocity in respect to gondola center of rotation). If the orientation of the body inside the cabin changes, the resulting force in the centrifuge will be perceived in a different way that it is perceived in flight. That means that the manipulator must have at least 3 translative degrees of freedom. Other works have considered the physiology of the vestibular system to create or improve the control algorithm of the DFS. It is a valid approach, but it depends on variables that vary in each individual, and there is not a definitive model of the vestibular system. So the approach here is to go straight to the cause of the problem, the Coriolis force.