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Analysis of the Benefits of Motion Simulators in 5th Generation Fighter Pilots' Training

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***Abstract*—**In military aviation, the use of flight simulators has proliferated recently in order to train fifth generation fighter pilots. With these simulators, pilots can carry out real-time flights resulting in seeing their faults and can perform emergency drills prior to real flights. Since we cannot risk losing the aircraft and the pilot himself/herself in the flight training process, flight simulators are of great importance to adapt the fighter pilots competently to real flights aboard the fifth generation aircraft. The real flights are impossible to simulate thoroughly on the ground. To some extent, the fixed-based simulators may assist the pilot to steer aircraft technically and visually but flight simulators can't trick the pilot's vestibular, sensory, and perceptual systems without motion platforms. This paper discusses the benefits of motion simulators for fifth generation fighter pilots' training in preference to the fixed-based counterparts by analyzing their pros and cons.

***Keywords*—**Centrifuge, g-loc, military, pilot, sickness, simulator, VMS.

I. REVIEW OF THE LITERATURE

A. Motion Simulators

A motion simulator is a kind of simulation which moves the same way the aircraft does in the three dimensional axis or just tilts and vibrates to some extent, in which the pilots feel the effects of the flight. A motion simulator can also be called a motion seat, motion chassis, or a motion base. When the simulation is synchronized to maps one to one and to the real characteristic sounds of flight, the result is of great efficiency and importance for the pilot training.

Motion simulators can create six degrees of freedom which are three linear degrees of freedom (surge, heave, sway) and three rotational degrees of freedom (roll, pitch and yaw). Since our context is flight training, mainly we are going to refer to the occupant controlled motion simulators.

1.Vertical Motion Simulators

At the present time, the air forces utilize high-end, costly, state-of-the-art simulators of high fidelity for their training purposes to realize virtual reality.

A simulation system has been created called Vertical Motion Simulator (VMS). Michael R. Corder describes it in a quite strange way:

> "Picture a big empty building that is 120 ft. high, 73 ft. wide and 36 ft. deep. Put your simulated cockpit inside this big empty space and let it move anywhere it wants to. Oh yes, don't forget to add some hydraulics to make it pitch, rotate and yaw at the same time that it is moving around inside the building. That's the VMS." [5]

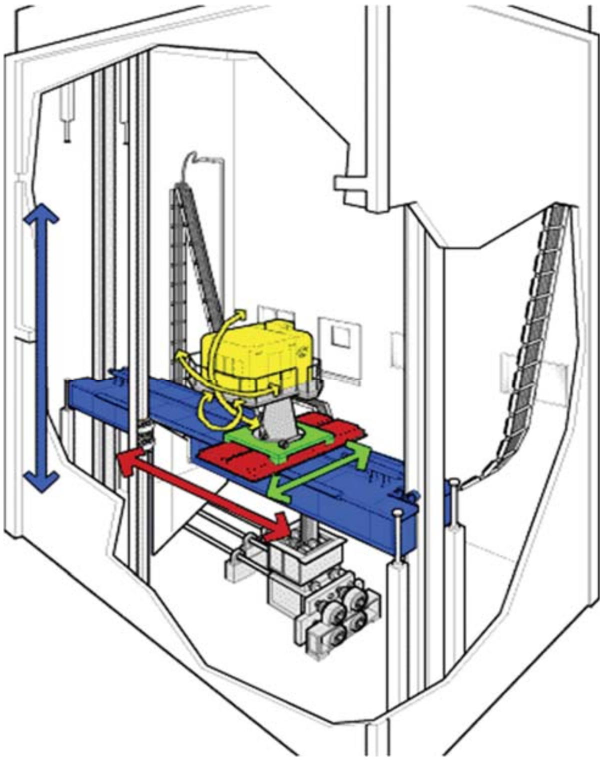

Fig. 1 Illustration of the VMS, showing the position of the ICAB in relation to the building's structure [9]

VMS's are mainly used for helicopters' and low g-force required aircraft's pilots' training due to the g-force restrictions. But thanks to F-35 Joint Strike Fighters' vertical landing and take-off capability, VMS's are going to be efficiently used for this fifth generation aircraft's training. VMS's are presently used for the shipboard rolling vertical landing procedure, air refueling, flight readiness and the take-off maneuvers for F-35 JSF trainees in USAAF.

2.Centrifuge Flight Motion Simulators

For many years, human centrifuge systems were used in order to measure the G-duration of pilots and trainees. With the recent advancements in the technology, Air Forces use them as realistic, state-of-the-art, high fidelity flight simulations with advanced vision systems for high-G force requiring missions.

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> "The gondola/cockpit section contains a realistic replica of a single seat cockpit that can be reconfigured to match different tactical fighter aircraft." [11]

As of World War II United States Army Air Force (USAAF), German Air Force (GAF), Royal Canadian Air Force (RCAF), Japanese Army and Russian Air Force utilize their own centrifuge flight motion simulators. [10]

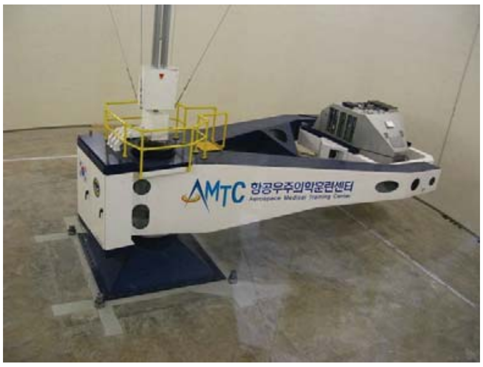

Fig. 2 Royal Korean Air Force ATFS-400 [13]

In the future, they are considered to be used in certain areas such as G-LOC exposure and recovery, pilot-in-the-loop, high acceleration maneuvers, with high onset rates, pressure breathing to combat G, high angle of attack departures/flat spins with sustained negative G's, altered states of awareness (AWA), emergency procedures under environmental stress, familiarization with various aircrew equipment when failures occur and so on. [6]

B. Pilot-Simulator-Aircraft Correlation

1.Visual and Motion Cues in Human Body

Humans have an ability to perceive their movement with some sensory cues in their body. The more senses are tricked, the more the flight environment in the simulator is alike the real onboard flight.

Fixed-base flight simulators use only visual cues which is not very efficient in the flight training. Visual cues make the trainee pretend that he was onboard flying. When the trainees start flying with aircraft, g-force and other unfamiliar effects of the flight make them uncomfortable. To minimize the alienage to the flight, and to shorten the time for flight training phase, the trainee should be exposed to the effects of the flight as much as it could be with the flight simulators on the ground. In this context, the logic of the motion flight simulators is crystal clear. They aim to trick the pilot's body as much as they could so that they can familiarize the trainee to the real flight environment more.

2.Transfer of Training (ToT)

There are three types of transfer of training as zero transfer, negative transfer, and positive transfer. A zero transfer is a situation in which the trainees' performance doesn't change with or without a prior training. Negative transfer occurs when the simulators give false cues to the trainee. This way, the trainee gets used to the false habits which are not close to the real flights. And a positive transfer is a situation which makes the trainee learn his objective faster and perform better than he would ever do without prior training.

> Transfer of training occurs whenever the effects of prior learning influence the performance of a later activity. The degree to which trainees successfully apply in their jobs the skills gained in training situations, is considered "positive transfer of training" [2]

In our condition -as far as transfer of training concerned- motion simulators are considered useful if they supply an obvious positive transfer of training.

3.5th Generation Aircrafts

Although there is not a precise definition, US Congressional Research Service defines fifth generation aircraft as follows:

> "Fifth-generation aircraft incorporate the most modern technology, and are considered to be generally more capable than earlier-generation (e.g., 4th-generation and below) aircraft. Fifth-generation fighters combine new developments such as thrust vectoring, composite materials, supercruise (the ability to cruise at supersonic speeds without using engine afterburners), stealth technology, advanced radar and sensors, and integrated avionics to greatly improve pilot situational awareness." [7]

Many of the modern aircrafts carry some of those abilities but unless the aircraft has them wholly it is not considered as fifth generation aircraft.

II. How Did the Efficacy of Motion Simulators Change?

Due to the lack of technology in the early years to provide high-fidelity motion, it was proved that the no-motion was better than the bad motion. The synchronization among control inputs, visual and motion cues, was not accurate, the visual display systems were not satisfactory and especially were not realistic. Poor synchronization led to simulation sickness. Besides, because of the negative transfer of training, righteously it was not dared to make the trainees carry out unsafe missions such as recovering from the emergency in the sky. On the other hand, it was not possible to expose the pilot with high G's and the trainees who carried out their flight training with static no-motion simulators who were giving nearly the same results as the trainees who did it with dynamic motion simulators. [4]

III. Benefits of Motion Simulators

The issue of trainees' motivation arises, not only in the context of motion platforms, but in other areas of military training as well. "Military training media that share characteristics with video games, for example, are said to be motivating because enlisted personnel have experience playing video games." [3]

People tend to learn better and faster from the deeds they are doing with pleasure. The most successful people in the world do their job in funny ways. They consider their jobs as their hobbies. In this respect, motion simulators can motivate the trainees because they are more enjoyable than their fixed base counterparts.

> "Fidelity of simulation can operate as a motivational variable. If the simulator looks, acts, feels and sounds like the airplane, then the trainee is more likely to be convinced that practice in the device will be beneficial to him." [3]

Motivating the trainees and the instructors may be a significant key to a positive transfer of learning. The prospective pilots of fifth generation aircraft are Z generation people who are more engaged in technology than the X and Y generations. They are more likely to be motivated by the motion simulators.

To consider all the beneficial aspects of motion simulators, our analysis will be divided to the topics as follows:

A. Simulator Sickness

Fixed-base simulators cause trainees to feel nauseous. That's because, in fixed-base simulators, trainees are exposed with only visual stimulation. Just the visual cues are sensed in this situation and the absence of motion and other sensory cues such as vestibular and proprioceptive cues may induce simulator sickness.

In order to understand this situation better, we can give an example from our daily life. Car sickness is one of the most common motion sickness types. It occurs when our eyes are fixed inside the car because our eyes say to our brain that there is no motion. On the other side, our vestibular system feels the other way around -that there is motion-. This discrepancy between what we feel and what we see triggers nausea.

B. G-Need

Static simulators have generally high fidelity vision systems, functionality, but they do not expose the pilot with physical stress operating without G force which has a crucial role in pilots' performance.

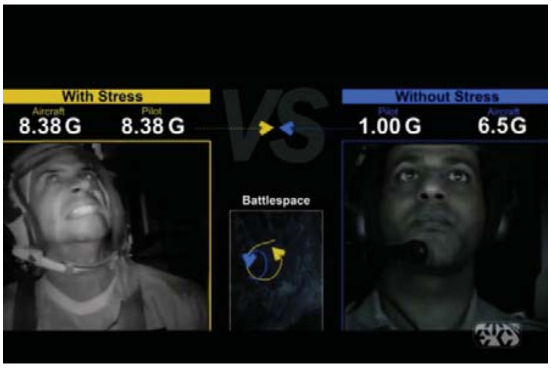

Fig. 3 ATFS-400 [1]

The accelerations in the motion simulators not only causes longitudinal G stress resulting from the spin but also gives the stresses and the strains of the flying task similar to those present in real flight. [5]

If the positive transfer of training is desired, the trainee's hands should weigh more and he should feel it when raises his hand to push a button. He should feel the physical stress on him. He should practice his breathe exercise when G-force suppressed.

C. Cost, Time and Personnel

Since the expenses of a separate two-seat training variant (F-22B) of a fifth generation aircraft -F-22 Raptor- were costly, the production was cancelled by the government and by the army. And for another fifth generation aircraft F-35 Lightning II, it was never intended to create a two-seat variant due to exorbitant costs. Now, pilots are trained on the ground with simulation systems and were sent to missions like going on solo flights with no prior dual flight instructions.

High-fidelity motion simulators save thousands of training flights in the process of making combat ready pilots. Also the time between the training sessions is reduced so that the trainee learns faster how to pilot the plane and recover from emergency.

Every year, in flight trainings, air forces lose some of their trainees whom the air force trained and educated for many years. There is the opportunity to reduce this risk.

IV. Experiments and Comparisons

A. F18 Real Flight G Data Test and Centrifuge Flight Motion Simulator Comparison

Edwards Air Force Base, NASA Dryden Flight Research Center released F18 flight data test from their Adaptive Aeroelastic Wing program. The performance was tested with 6 wind up maneuvers and the G exposure was limited with maximum 5 Gz. The test was made on the different weather conditions, G forces, altitudes and speeds. When compared, there have been no significant discrepancies between the simulator's test outputs and real F18's. The results can be seen on Figs. 4-6.

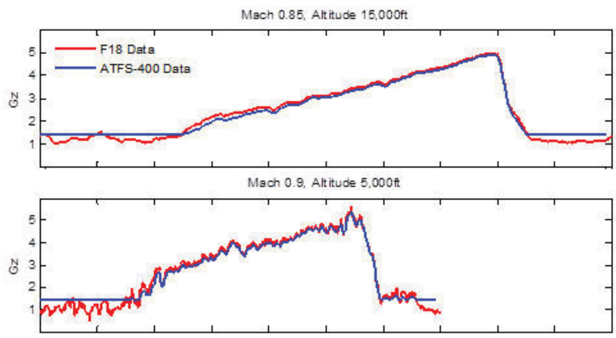

Fig. 4 Comparison Data 1 [8]

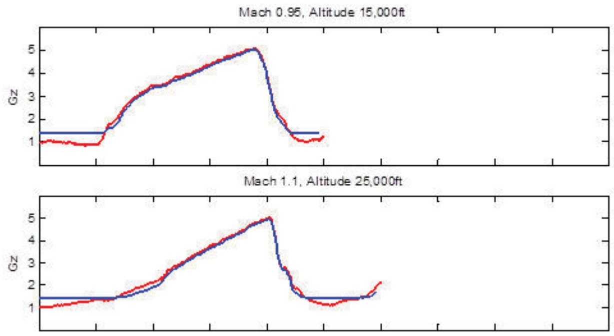

Fig. 5 Comparison Data 2 [8]

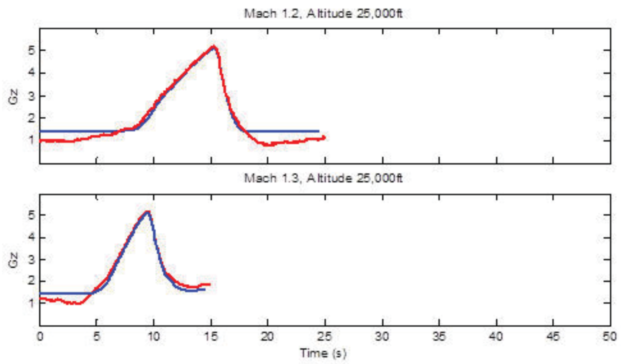

Fig. 6 Comparison Data 3 [8]

Root-mean-squared error values of the comparison of these 6 maneuvers can be seen on Fig. 7.

Mach (M)	Altitude (FT)	Root Mean Squared Error (G)
0.85	1,5000	0.12058
0.90	5,000	0.12526
0.95	15,000	0.11386
1.10	25,000	0.13071
1.20	25,000	0.11776
1.30	25,000	0.15828

Fig. 7 Comparison Data 4 [8]

As can be seen on figures, ATFS-400 sustained-G flight simulator has a very high fidelity rate except for the idle G levels which is between 1 and 1.5 Gz. As the intent of high G motion simulators is tactical flight simulation, these low idle G discrepancies can be ignored. However, further work should be done by engineers for a better fidelity of simulation.

B. ATFS-400 Simulator Motion Sickness Experiment

The difference between visual and vestibular systems causes motion sickness. According to an experiment which was conducted by NASTAR Center to evaluate pilot's adaptation to the simulator in 2011, the second day, motion sickness rating decreased 40-90%. After 5th day, 16 days-rest was given without simulator flights and the results of 22th day were the same as 5th day.

On the first day, subjects reached motion sickness rate 2 in 4.14 minutes, the second day in 8.28, and the third day in 10.35. On the fourth and fifth days the score never reached to the level of 2.

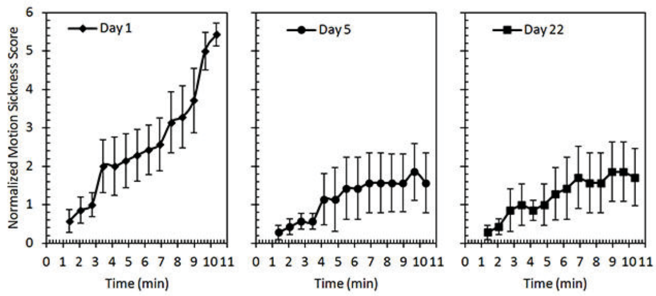

Fig. 8 Motion Sickness Rate [12]

Under the light of motion sickness experiment, Environmental Tectonics Corporation developed a ATFS simulator-specific two-day protocol in order to minimize motion sickness during the simulator flights. Active head movements, G transitions and time at various G levels are given in the adaptation protocol.

V. Conclusion

In earlier times in the military aviation history, the motion systems contribution to positive transfer of training to higher generation aircrafts was not considered as an important factor due to the lack of technology of that time. It is impossible to simulate, one to one, the overall flight and the flight stress stemmed from G force during in-flight missions but with the advent of recent technological advancements in the aviation, simulation systems have been more realistic and effective than ever.

Simulator sickness is minimized with the advent of high tech visual systems and G generating mechanisms. The first day the pilot feels nausea at a very tiny scale and the second day sickness subsides to unnoticed levels. In the near future, the pilot will not feel simulator sickness at all with simulator-specific exercises.

State-of-the-art centrifuge or vertical flight motion simulators can generate high fidelity G force (See Figs. 4-7). Pilot can drill the missions from emergency procedures to air to air refueling without any security risks.

A real flight requires all the entities in the base to be ready and present. Aircraft maintenance mechanic, instructor pilot, air traffic controller and all the subsidiary personnel have to be present during the flight. But a simulator technician will be adequate for a high-fidelity simulator flight.

The G error on the ATFS-400 simulation is close to zero (See Fig. 7). Comparison experiments show that real flight data and ATFS-400 simulator flight data give overlapping results (See Figs. 4-6). The trainees will be subjected to weapon systems and cockpit familiarization, all checklist and engine start procedures, aerobatic and basic flight maneuvering; instrument, night, and formation flying procedures, air to air refueling and navigation procedures. Aircraft carrier takeoffs and landings, air combat maneuvering energy management, high angle of attack maneuvering, aircraft kinematic flight envelope maneuvering, the recovery training and upset prevention missions with the state-of–the-art motion simulators. These devices provide the opportunity for creating flight realistic training and research environments on the ground at a fraction of the cost of aircraft operations and with a higher level of safety. [8]

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