FORCE AND VIBRATION CUEING WITH A MULTI-AXIS DYNAMIC SEAT

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ABSTRACT

Flight or part task trainers are often restricted to fixed based operations due to budget or facility constraints. Studies have shown that the training in fixed based devices is generally less effective than the training in a full motion device. Early generation hydraulic or pneumatic powered G seats attempted to overcome this deficiency with mixed success. Limited axis cueing and excessive latency were just two of the deficiencies which prevented universal acceptance of these devices as adequate replacements for motion bases.

A prototype, multi-axis dynamic seat has been developed to evaluate the effectiveness of small motion or force cues in performing mission related tasks. The design is based on a dynamic seat developed and tested by the Defense Research Agency (DRA)/Cranfield in Bedford U.K. The design concept of the dynamic seat is to produce skin pressure and limb orientation giving the pilot the impression of motion from limited seat movements. Force and vibration cueing is provided by vertical movement of the seat pan and seat bucket independently, and by forward and lateral movement of the seat back pad. Although all of the seat motion is translational, movement of the proper component can simulate rotational motion. A tactile sound transducer is mounted to the seat frame to provide vibration at the higher frequencies. An initial pilot evaluation of the dynamic seat in a flight training device produced a very favorable response.

ABOUT THE AUTHORS

Mr. Corlyon is presently the senior mechanical design engineer for Camber Flight Simulation in Albuquerque, NM with over 40 years experience in flight simulation. He is the former Manager of Product Design for AAI Corp. and Reflectone and has held numerous engineering and management positions at both Reflectone and Singer-Link Corporations. He has had responsibility for the design and development of motion systems, control loading systems, g seats, and visual display systems for a wide variety of military fixed wing and rotary wing, commercial airliners, and space vehicles.

Mr. Humphrey is presently the Engineering Section Head for Camber Flight Simulation in Albuquerque N.M. Mr. Humphrey spent his first nine years in the aerospace industry as a flight test engineer supporting the flight testing of high performance military aircraft. For the past twenty four years Mr. Humphrey has worked in the flight training industry where he has been involved in the design, development and testing of high fidelity flight simulators for the U.S. and foreign military. His work has included flight dynamics and project engineering on training devices for the UH-60 Black Hawk, the SH-60 Seahawk, the AH-64 Apache, the AH-1W Cobra, the F-16, and the F-5 Freedom Fighter.

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INTRODUCTION

There has been considerable debate over the years regarding the necessity of motion or force cueing on flight simulators and how much transfer of training takes place. It has been demonstrated that pilots training in devices with only visual cueing are more prone to simulator sickness. References 1 and 2 are the results of two such studies which examine the simulator sickness phenomenon. Force cueing may also, in fact, facilitate training by providing redundant cues which reinforce the pilot's reaction and allow attention to parallel task activities. The visual cues available (such as instrument response) lag the high response of the individual's motion sensory systems and different control strategies may be developed when force cueing is absent.

Motion cues are an important part of the pilot's environment and provide him or her with the necessary feedback for proper situational awareness. With repeated experience, pilots develop certain expectancies and reaction time is reduced. This kind of environment can easily contribute to pilots' acceptance of that particular training device.

An alternative to motion systems has been hydraulic and/or pneumatic G seats. These have had limited success due to high latency and low user acceptance of the bladder cell concept. G seats also tend to cost as much as full motion systems.

Camber Flight Simulation has recently developed a low cost dynamic seat system specifically for the Apache Longbow Aircrew Trainer which provides force cueing in four degrees-of-freedom using electric servos. These cues provide realistic kinesthetic (sense of movement of limbs) and somatic (skin pressure) response with motion algorithms designed to duplicate those effects of the simulated vehicle in various mission profiles. It is expected to be an especially useful device in fixed based rotary wing or fighter type simulators to provide some degree of sensory stimulation to improve pilot skill level. This program was based, in part, on some original work done on a dynamic seat developed by the Defense Research Agency (DRA), Bedford, England and Cranfield University.

SYSTEM OVERVIEW

The seat motion consists of four degrees of control in three axes of movement. Independent motions are applied in the heave directions of the entire seat bucket as well as the seat pan. In addition, the seat back has independent motions in the surge and lateral directions. The motions are provided by high response, low inertia PMI DC servo motors and low noise planetary gearboxes. The lap belt and shoulder harness are connected to the drive linkage to loosen or tighten with positive or negative g's respectively. Figure 1 shows the general arrangement of the prototype Apache dynamic seat.

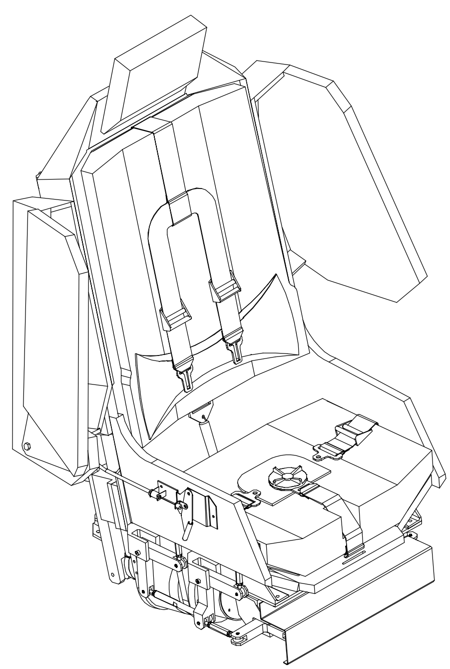

Figure 1. Dynamic Motion Seat General Arrangement

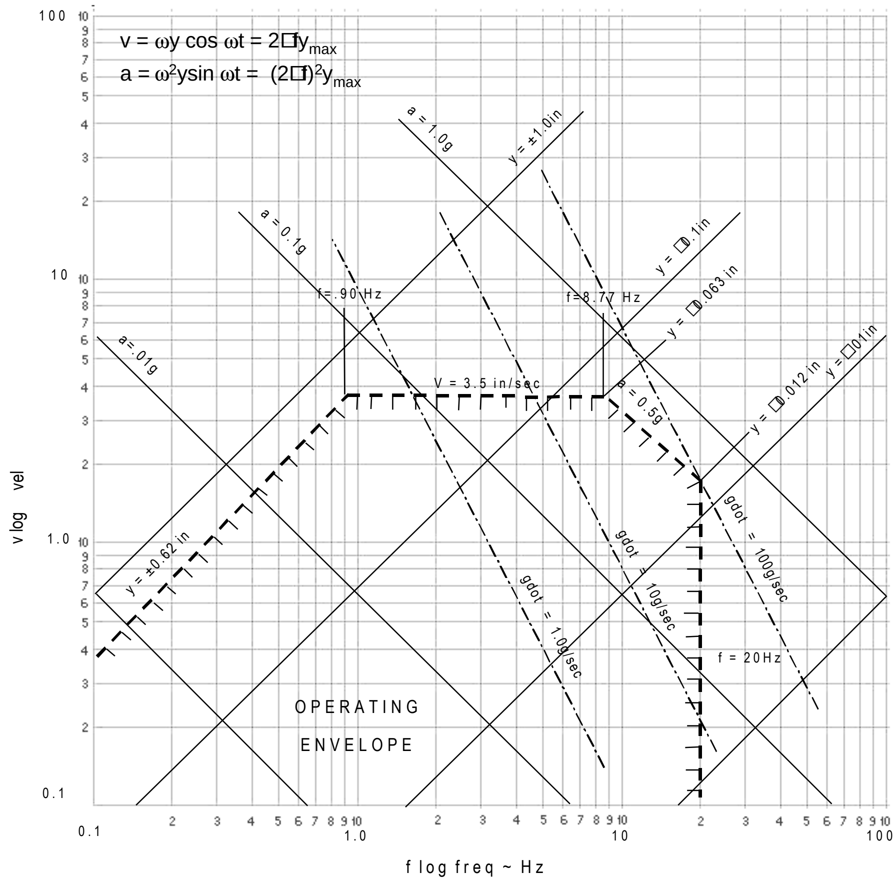

Figure 2. Typical Dynamic Seat Performance

The motion provides force cueing as the simulated aircraft performs various flight maneuvers as well as buffet and vibration levels in all axes up to 20 Hz and 0.5 g's. A tactile sound transducer is mounted on the seat frame to provide high frequency vibrations. The servos are controlled by a standard PC utilizing motion algorithms cycling at greater than 200 Hz. Aircraft state variables from the flight model resident in the host computer are passed to the PC via reflective memory or ethernet. The performance level of the dynamic seat is shown in the log-log graph in Figure 2. The operating performance of the dynamic seat is contained within the envelope shown by the maximum excursion of ± 0.62 inches up to .9 Hz, the maximum velocity of 3.5 in/sec up to about 9 Hz, and the maximum acceleration of .5 g's up to 20 Hz.

PRIMARY CUEING CAPABILITIES

Figure 3 shows the primary flight parameters passed to the Dynamic Seat processor from the host. Figure 3 also depicts the flight dynamics cueing basically divided into short term and long term cues. The short term or cue onset transients are primarily driven by acceleration parameters. The appropriate vibration frequency with an adjustable gain is summed with the input cue for each axis. This permits different vibration frequencies and amplitudes being input for different axes as appropriate. For example, a gunfire vibration would be input into the back pad surge axis simulating the gunfire recoil effects along the longitudinal axis.

For the seat back surge cue the short-term transient is driven by longitudinal acceleration at the aircraft C.G. (udot) and pitch acceleration (qdot). Each of these terms are passed through a high pass filter and scaled with a gain before summation. This allows individual scaling of the gain and washout time constant for each parameter. The long-term effect, such as the back pad pressure felt when pitched up in a hover or during a landing flare, is created by passing the sine of the aircraft pitch attitude through a low pass filter, scaled with a gain, before summation with the short-term transient cues. The gain and time constant for the long-term effect is also adjustable.

For the seat back sway cue the short-term transient is driven by lateral acceleration (vdot), yaw acceleration (rdot), roll acceleration (pdot), and roll rate (p). Adding the roll rate term to the equation was demonstrated (ref 1) to produce a more realistic cue during roll maneuvers. Like the surge axis each of these terms are passed through a high pass filter and scaled with a gain before summation. The long-term effect, such as a steady-state hover roll attitude or an uncoordinated turn, is created by passing the lateral load factor through a low pass filter, scaled with a gain, before summation with the short-term cues. All of the time constants and gains are individually adjustable for the sway axis also.

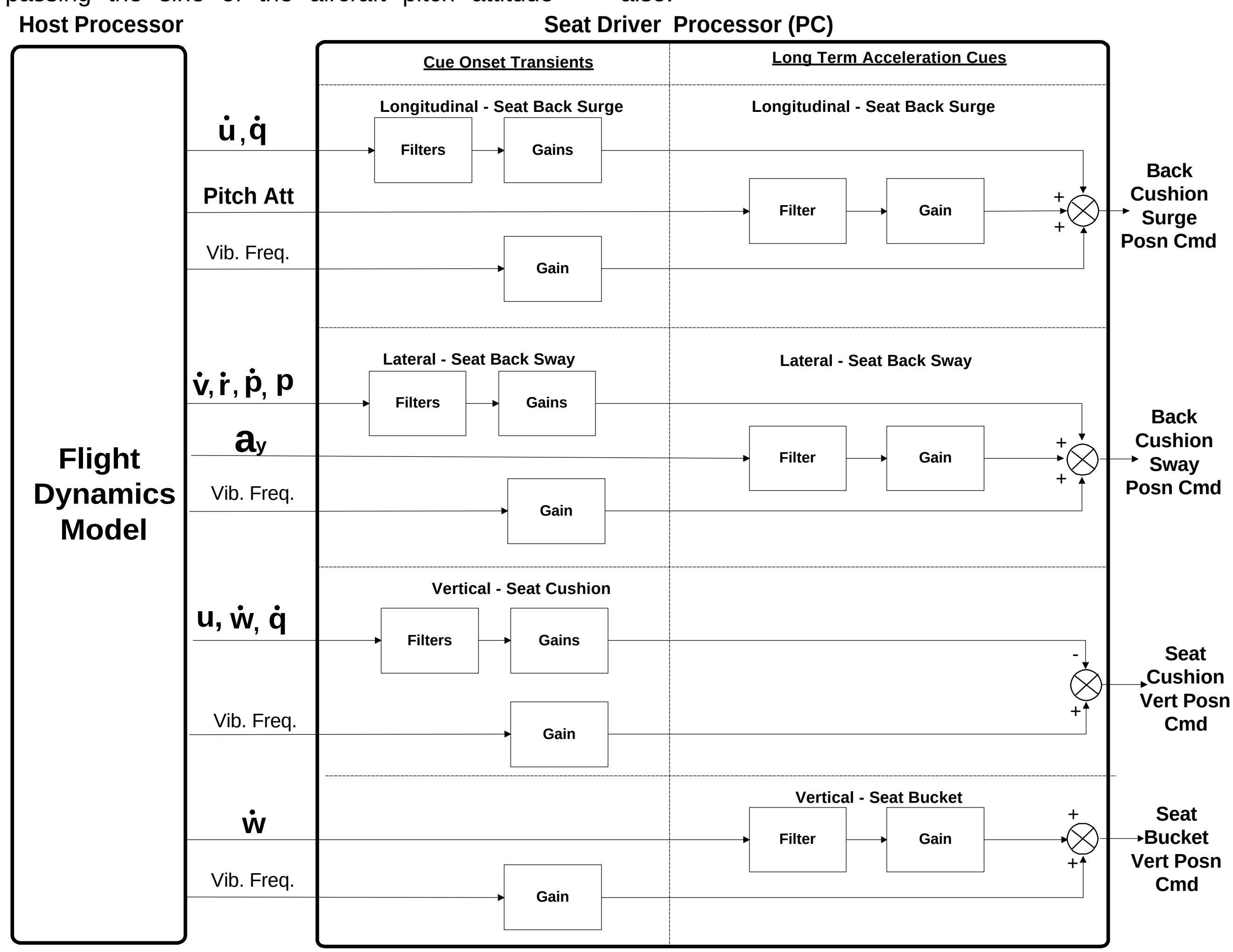

Figure 1. Weapon File Input Screen

For the seat pan cue, vertical acceleration and pitch acceleration are used to create the short-term effect. These are also passed through a high pass filter and scaled with a gain before summation. Since the seat pan motion is the dominant vertical or normal acceleration cue, a non-linear scaling of the vertical acceleration input has been demonstrated to be more effective than just a linear scaling. This permits a more sensitive response at the lower accelerations, such as hovering, but still retains a discernable movement or pressure change cue at the higher accelerations such as a high-speed tight turn. The magnitude of the non-linear gain is still tunable. The long-term effect for this cue is created by making the time constant very large (near zero washout). This holds the pressure on the pilot's buttocks during a sustained turn.

The seat bucket is driven in the opposite direction to the seat pan to help create the long-term effect by moving the eye point, arms, and body torso down simulating the sinking in the seat from vertical or normal acceleration. The seat bucket is driven by vertical acceleration passed through a low pass filter with an adjustable gain and time constant. The seat bucket time constant is set to slightly lag the seat pan movement so as not to offset the effect of this cue.

SPECIAL EFFECTS CUEING

In addition to the basic response of the seat due to flight accelerations and vibrations, special effects cues are also provided. Table 1 lists the special effects cues that are generated by the Dynamic Seat along with the required parameters from the Host.

Airframe buffet (approximately 10 Hz for the Apache) is generated in two flight regions. The first region is the translational lift region between 16 and 24 knots of airspeed. The next region is high-speed buffet starting at 150 knots. The buffet magnitude is programmed as a function of airspeed and collective control position with an adjustable gain. The collective is used as a scaling parameter because the magnitude of the buffet is nearly proportional to the loading on the rotor which is directly generated by the collective input.

Individual gear touchdown bumps are implemented on receiving gear touchdown booleans from the Host for each gear. The magnitude of each bump, which is directed through the seat pan, will be a function of the rate of descent and the pitch rate of the vehicle. A scale factor will also be available to adjust the overall reaction level to each gear.

Runway spacer bumps, which are also directed through the seat pan, are also implemented based on the ground speed when taxiing or rolling during a takeoff or landing. A scale factor is available to adjust the overall level of the bumps.

Also when rolling on the ground a runway rumble vibration is input through the seat pan and the tactile transducer. The magnitude of this rumble is a function of ground speed and an adjustable scale factor.

When a crash boolean is set true by the Host computer a short duration pulse is transmitted to each seat component. This is followed by a freeze of the seat motion and the training device.

When the gunfire signal from the Host is set, a scaled 10 Hz vibration is input into the back pad surge axis. This is synchronized with the gunfire sound from the tactile transducer.

Table 1. Special Effects Cues

CUES	REQUIRED PARAMETERS
Airframe Buffet	Airspeed
	Collective Position
Gear Touchdown Bumps	Left Main Gear Touchdown Boolean
	Right Main Gear Touchdown Boolean
	Tail Gear Touchdown Boolean
	Descent Rate
	Pitch Rate
Gear Runway Spacer Bumps	Ground Speed
	All Gear Touchdown Booleans
Runway Rumble	All Gear Touchdown Booleans
	Ground Speed
Crash	Crash Boolean
Gunfire	Gunfire Signal

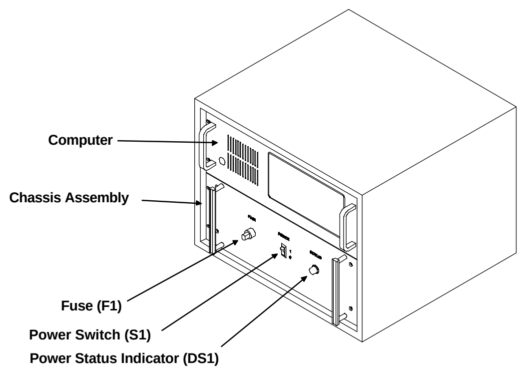

Figure 4. Electronic Cabinet

SEAT MECHANIZATION

Three of the drive motors are located beneath the seat while the bucket motor is located behind the seat. The bucket is counter-balanced with a gas spring to offset the one g weight of the seat. The seat belt and shoulder harness are connected to the seat pan linkage to tighten with negative g's and to loosen with positive g's. The dynamic seat is a self contained assembly that merely mounts to the normal crew seat attach points and lends itself for retrofit in virtually any flight simulator.

The seat computer and electronics are located in a remote standard 19 inch rack mounted cabinet. The computer is a standard Pentium PC using C language. The electronics consists of a drawer with two transformers and four motor amplifiers. The seat can be powered from either 120 volts or 240 volts 50 or 60 Hz source and will draw about 10 amps at 120 volts. Figure 4 is an illustration of the electronics cabinet.

CONCLUSIONS

The trend in the military training industry is toward inexpensive, fixed based training devices. Dynamic seats, as an alternative to motion systems or full G seats, show significant potential to enhance the environmental realism and training effectiveness of these fixed based devices at a relatively low cost. A dynamic seat offers the advantage of multiple axes force cueing without the complexity of hydraulics or pneumatics and the attendant plumbing and servo valves of traditional G seats.

Although this paper has focused on the dynamic seat developed for the Apache Crew Trainer, the dynamic seat is adaptable and can be retrofitted to any helicopter, fighter, transport, or tilt-rotor training device. Early pilot evaluations of the prototype Apache dynamic seat have been favorable and have, in general found that flying the mission with the seat operational required less workload and provided a more realistic training environment than with a passive seat. This is consistent with the results of pilot evaluations and performance analysis that were conducted in the U.K. and are included in references 3 and 4. It is believed that a dynamic seat is likely to become a standard component for future military and perhaps commercial flight training devices.

REFERENCES

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