STOL SIMULATION REQUIREMENTS FOR DEVELOPMENT OF INTEGRATED FLIGHT/PROPULSION CONTROL SYSTEMS

by

K. E. Sanders, Senior Engineer
Dr. D. C. Anderson, Senior Engineering Specialist
J. H. Watson, Engineering Chief
Flight Control Systems Section
General Dynamics Fort Worth Division

ABSTRACT

The role and use of simulation as a design tool in developing integrated systems where design criteria is largely unavailable is well known. This paper addresses additional simulation needs for the development of Integrated Flight/Propulsion Control Systems (IFPCS) which will improve the probability of properly interpreting simulation results. These needs are based on recent experience with power approach flying qualities evaluations of an advanced fighter configuration which incorporated Short Takeoff and Landing (STOL) technologies and earlier experiences with power approach flying qualities evaluations on the AFTI/F-16 program. Specific topics addressed in this paper are:

(1) The use of motion base platforms with axial and normal degrees of freedom will help in evaluating pilot coupling and workload in the presence of high frequency low amplitude axial accelerations produced by high bandwidth airspeed controllers in a gusty environment. This would also help quantify the airspeed controller bandwidth necessary for adequate STOL performance.

(2) The use of high resolution visual scenes or helmet mounted displays capable of providing better depth perception, HUD symbology, and simulated FLIR imagery will help in evaluating precision (no flare) all weather landing techniques.

(3) The use of higher computational capability to adequately model and execute more complete visual display, landing gear, and engine models will help in evaluation of high speed roll out dynamics.

These needs can be met with unique government simulation facilities such as the NASA Ames Research Development Center (NARDC) which have special capabilities.

INTRODUCTION

Development of a STOL integrated flight control system will require extensive manned simulation because design criteria and guidelines are incompletely developed for the STOL task (References 1 and 5). Therefore, the requirements on ground-based simulation equipment to aid in the development of a STOL control system become very important to developers of STOL aircraft. Specifically, simulations must be capable of supporting evaluations in the following areas:

1. Evaluations of normal axis and axial axis gust sensitivity effects on pilot workload and control effectiveness
2. Cockpit constraint system evaluations
3. Control gradient evaluations
4. PIO susceptability and cross control axis coupling
5. Crew station human factors evaluations
6. Safety evaluations
7. High speed roll-out and ground handling evaluations
8. Hydraulic flow demand evaluations
9. Evaluation of more complex landing gear and engine/nozzle/reverser operations
10. Low altitude ground effects and flying qualities evaluations with good visual peripheral cues and depth perception.

Realistically, pilot workload and effectiveness in precision STOL control tasks cannot be fully measured without these evaluations.

MOTION CUES

Recent STOL studies (Reference 1) and IRAD results (Reference 2) indicate that landing precision may be obtained to the required level by providing high-bandwidth pitch rate control for flight path adjustments in combination with tight, high bandwidth regulation of aircraft airspeed. This combination of control features is readily implemented on a STOL configuration which utilizes the thrust reversing feature of a 2-dimensional thrust vectoring/thrust reversing (2-D TV/TR) nozzle to achieve more then 0.2 g acceleration capability axially (fore and aft) and 0.5 rps^2 pitch acceleration. The high bandwidths achievable with this nozzle permit pinpoint control precision in piloted simulations of STOL landings in fixed base simulations, but aircraft gust sensitivity is high in the normal and axial axes due to the high system control loop gain associated with the powerful control forces available from the nozzle. For instance, from Reference 2, a generic STOL longitudinal axis control law was designed to provide decoupled pitch rate/airspeed control. The desired bandwidth of the pitch rate controller was well defined from the simulation results, but the desired bandwidth of the airspeed controller was not as clearly indicated. The airspeed controller was designed to provide the maximum decoupling purity between pitch rate and airspeed while maintaining a critically damped airspeed response to an incremental step command. The resulting design demonstrated the capability of providing very precise airspeed control, as shown in the left column of

Figure 1, even in the presence of 1.2 FPS RMS (1-Sigma, Dryden Spectrum) random atmospheric gusts. However, it is not apparent what effect the small amplitude, high-frequency gust-generated axial accelerations will have on pilot performance. It is also clear that the desired engine actuator requirements will have a direct impact on the bandwidth of the airspeed controller. A first-order-lag filter was placed in the airspeed feedback path in the studies of Reference 2 to evaluate the capability to reduce axial gust responses. As shown in the right column of Figure 1, a .02 filter time constant significantly reduced the axial acceleration activity. With the control system gain levels used in this study, a filter with time constants as large as .2 seconds could be used without adversely affecting system performance or stability. Therefore, there is a large range of airspeed control bandwidths which appear to be acceptable to pilots on a fixed base simulator. Figure 2 illustrates nozzle control activity during a typical approach in a gusty environment with the 0.2 second time constant airspeed feedback filter. While the illustrated control activity is not unreasonable, the actuators were occasionally operating near their assumed maximum rate. Figure 3 shows the relationship between nozzle control activity and axial acceleration. Since the degree of airspeed augmentation provided by the controller can have an impact on other aircraft systems such as the hydraulics, pilot vehicle interface, and engine control, it is important to determine the pilot acceptance of high frequency axial accelerations and how these accelerations are coupled through the pilot into axial control and into other axes. One example of pilot coupling experienced in flight but not experienced during simulation evaluations is the pilot coupled oscillations encountered during the AFTI/F-16 flight tests (Reference 3). Gust sensitivity in the normal axis can be evaluated, to some degree, based on common pilot experience, however, notable failures in evaluation of normal axis gust sensitivity have been experienced (e.g., Reference 4) on fixed base simulation equipment in the AFTI/F-16 program. Gust sensitivity effects on pilot workload in the axial axis will be difficult to evaluate with fixed base simulation equipment since pilots have not previously experienced the combination of high axial acceleration levels and bandwidths which are possible on a STOL aircraft. A study of this type can be accomplished on a moving base simulator with axial and normal degrees of freedom similar to capabilities on NASA-Ames moving base simulator facilities.

VISUAL CUES

Important primary visual cues used during a landing approach are associated with depth and peripheral vision. In the simulation of a STOL approach, the use of a limited area projection type of visual system does not provide the best result such as a wide field of view and good depth perception would provide. Also, because the scene is projected out in front of the pilot, landing biases can occur causing the pilot to land short of the intended touchdown point. Our recent experience (Reference 2) points to the need for a wrap-around virtual image type visual system which is mounted closer to the pilot. The use of a vertically collimated raster display utilizing simple solid color pastels to form a cartoon-like picture could significantly increase resolution near the ground. The wrap around feature would improve peripheral vision. Peripheral vision provides the pilot with sink rate information he cannot obtain very well over the nose at STOL approach angles of attack. This reinforces the pilot's perception of descent through the visual-motion system and thus increases his stress level. Since pilot gain is strongly influenced by stress level, real pilot workload could be more accurately determined with improvements in the visual system. The pilot must subconsciously feel that he is in real danger if the landing maneuver is not successfully executed for best evaluation results.

Helmet mounted displays have a significant application to a STOL approach and landing. They enhance peripheral and depth perception in simulation applications but also provide HUD information and simulated FLIR imagery in actual aircraft applications to perform precision all weather and night landings. Operational use of Helmet Mounted Sight/Displays (HMSD) allow the pilot to view the landing scene under poor visual conditions and safely land the aircraft with a minimum of additional workload. This technology can give the pilot night vision, allowing the pilot to look anywhere in the forward quadrant through the aircraft to locate the landing field by merely directing his line-of-sight (LOS) to the desired area. The pilot's line of sight (LOS) commands the FLIR to follow his helmet (head) movements thus providing a large field of view (FOV) for landing the aircraft at large crab angles and high angles of attack. Symbology to aid the pilot in landing with minimum dispersion is superimposed on the FLIR video and projected onto the pilot's visor by a miniature CRT mounted on the helmet. The aircraft becomes "transparent" and he experiences a true kinetic sense of where the landing field is, relative to the aircraft, thus enabling him to land the aircraft using the scene on his visor. Proof of application and operational readiness will first have to be shown in a realistic simulation environment before deployment in the field.

COMPUTATIONAL CAPABILITY

Computer power may be the most easily attainable, yet least definable, quantity in a development simulator. Computers are constantly being improved from the standpoint of speed and memory capabilities. What is difficult to define is how the computing power is to be assembled to provide engineering flexibility, growth, and eventual hot-bench support. A STOL development simulator must provide capabilities in several key areas. First, adequate input/output (I/O) capability is important to support visual scene and motion base drives, advanced cockpit development, output data recording (both analog and digital), and eventual flight control and avionics hardware-in-the-loop simulation. Secondly, several simulation models which have traditionally been kept simple in their implementation such as engine, actuator, and landing gear models must be made more complete in order to lower program risk by providing timely hydraulic demand, engine operation, and critical high speed ground roll-out information. And thirdly, the addition of an all new Nozzle Drive Unit (NDU) complex will further tax existing computer modeling computational power. In order to achieve adequate computational fidelity several computers, operating at different rates, must be employed in parallel. Most importantly the computer simulation complex architecture must be such as to not compromise the fidelity of the presentation of the flight characteristics to the pilot.

SUMMARY AND CONCLUSIONS

Based on recent experience with power approach flying qualities evaluations of an advanced fighter configuration which incorporated STOL technologies, general requirements for adequate STOL flight simulation have been developed. Specific topics addressed in this paper were:

(1) The use of motion base platforms to and in evaluating pilot coupling and workload in the presence of high frequency low amplitude axial accelerations produced by high bandwidth airspeed controllers in a gusty environment. (This would also help quantify the airspeed controller bandwidth necessary for adequate STOL performance.)

(2) The need for high resolution visual scenes or helmet mounted displays capable of providing better depth perception, HUD symbology, and simulated FLIR imagery in evaluating precision (no flare) all weather landing techniques.

(3) The need for higher computation capability to adequately model and execute

more complete visual display, landing gear, and engine models.

The importance of a high fidelity presentation of the flight characteristics to the pilot cannot be overstressed.

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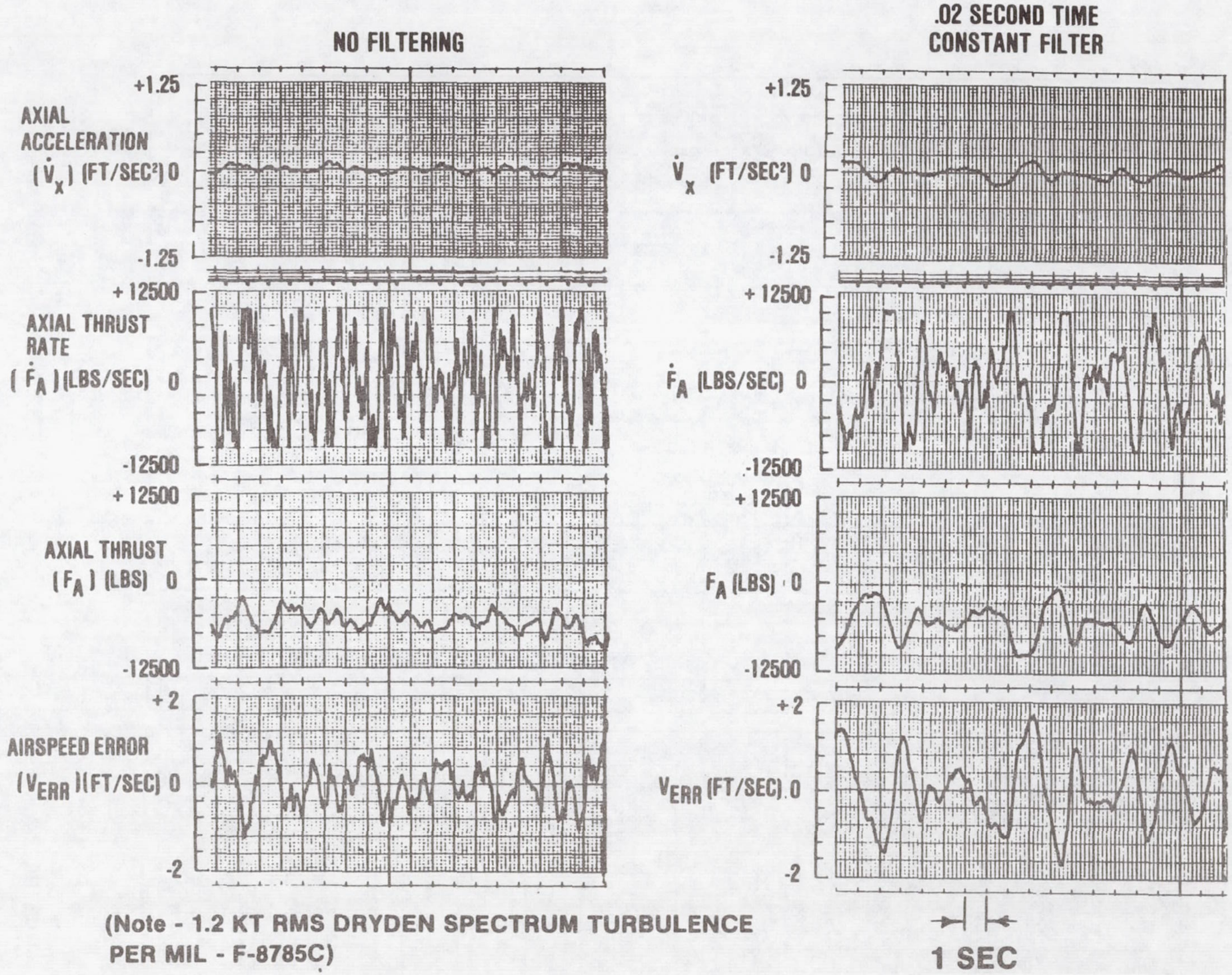

Figure 1 High Bandwidth Airspeed Controller Introduces High Frequency Axial Accelerations During STOL Approach

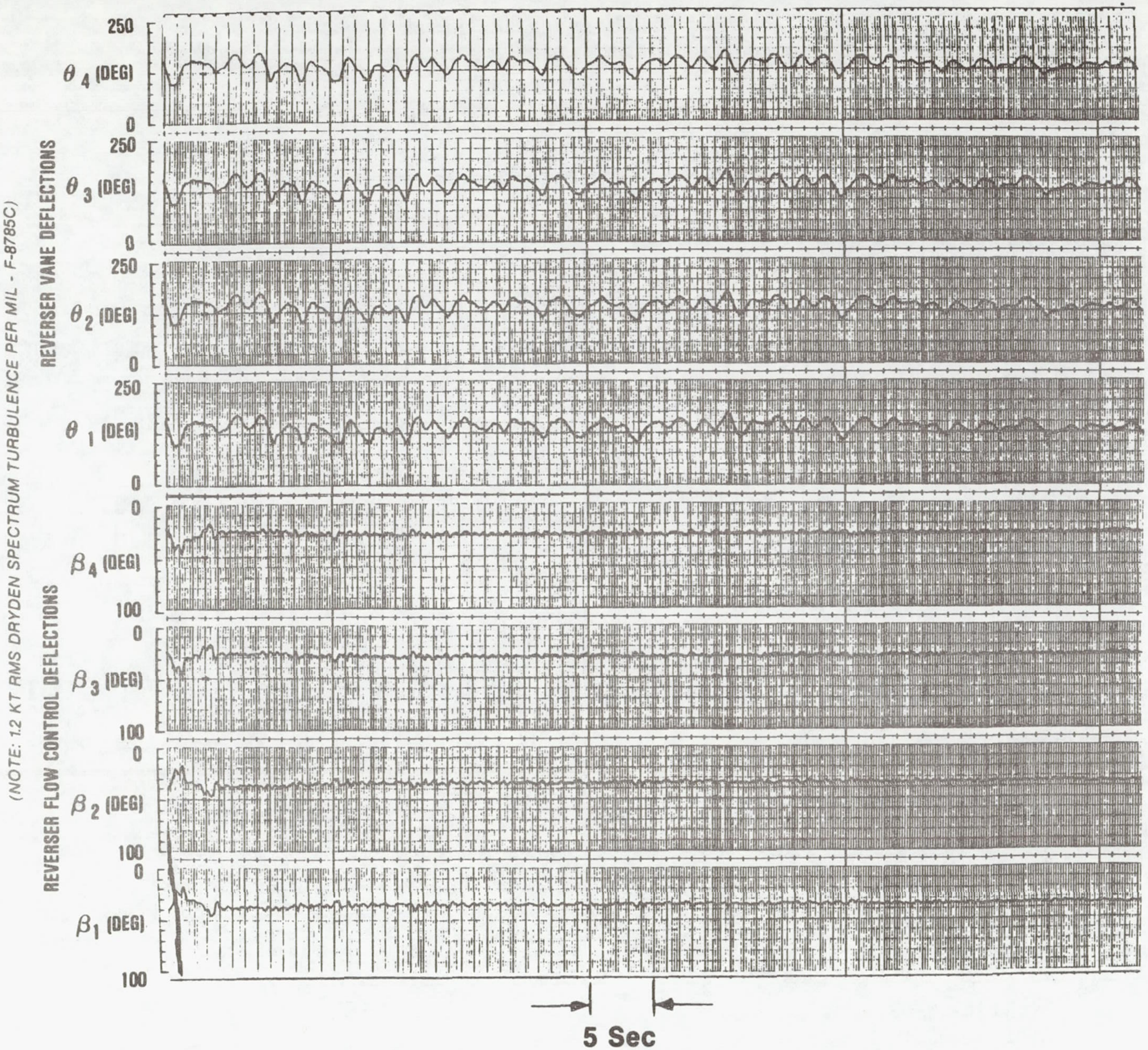

Figure 2 Nozzle Control Activity During a Typical STOL Approach

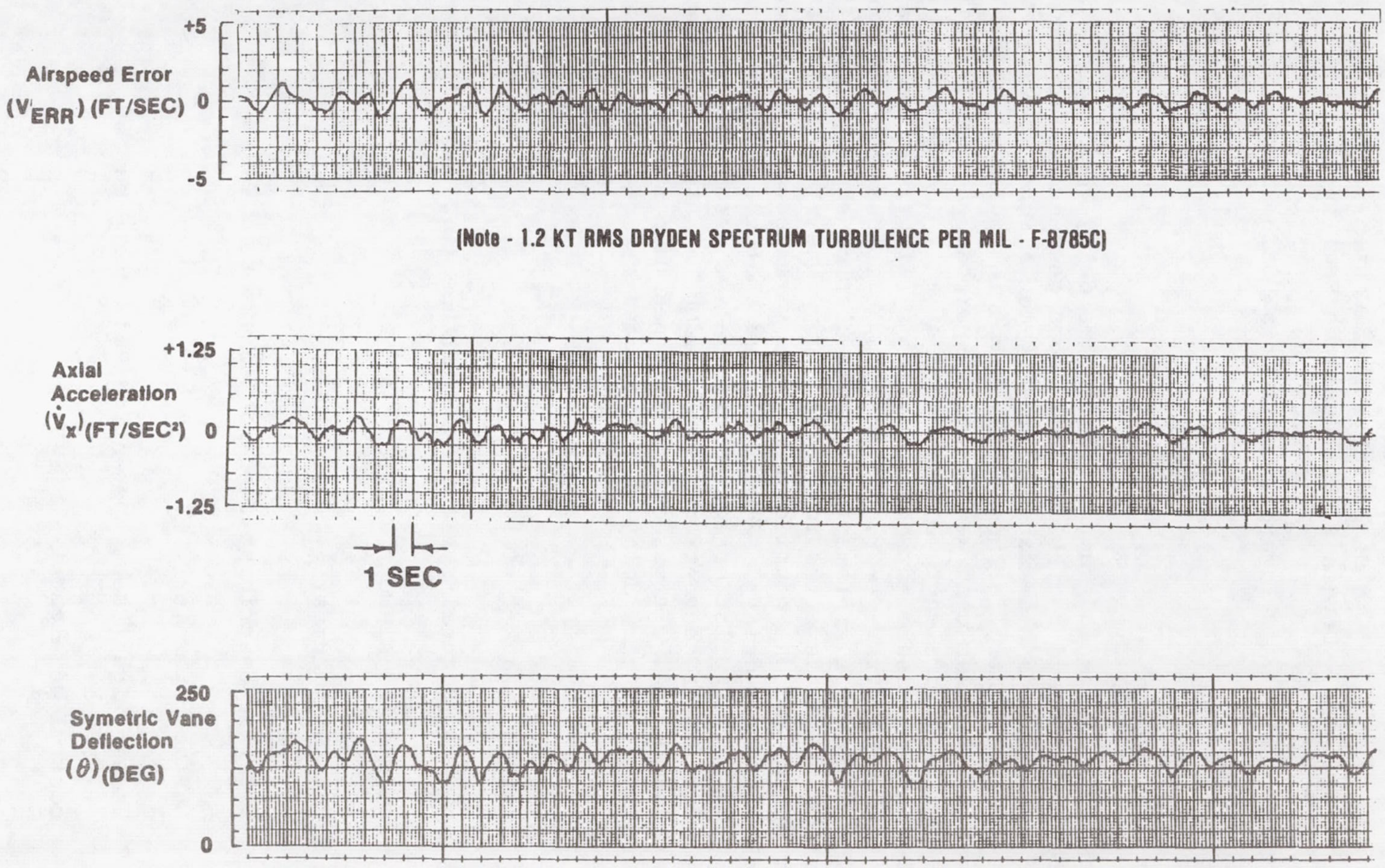

Figure 3 Nozzle Control Activity and Axial Accelerations as a Function of Airspeed Error