A PILOT'S OPINION OF THE F-8 DIGITAL FLY-BY-WIRE AIRPLANE

Gary E. Krier
NASA Flight Research Center

SUMMARY

The handling qualities of the F-8 digital fly-by-wire airplane are evaluated by using the Cooper-Harper rating scale. The reasons for the ratings are given, as well as a short description of the flying tasks. It was concluded that the handling qualities of the airplane were good in most situations, although occasional ratings of unsatisfactory were given.

INTRODUCTION

A standard F-8C aircraft was equipped with a roll damper, a yaw damper, and an aileron-to-rudder interconnect. The airplane had no pitch damper. Handling qualities were satisfactory throughout a large portion of the flight envelope.

This paper evaluates the airplane's handling qualities on the basis of the Cooper-Harper rating scale (ref. 1 and fig. 1) after the removal of the mechanical control links and the addition of the Apollo hardware digital fly-by-wire control system.

A force side stick controller was mechanized in the analog backup control system and was evaluated by using the same tasks as those used to evaluate the digital primary control system.

The yaw axis was not extensively evaluated, so results are not reported in this paper.

The primary purpose of the program was to expeditiously demonstrate the feasibility and reliability of a digital fly-by-wire control system for an airplane. The space-proved Apollo system was adapted to the airplane, forcing compromises that did not allow optimization of the airplane's handling qualities. Nevertheless, the handling qualities were mostly satisfactory.

SYMBOLS AND ABBREVIATIONS

BCS	analog backup control system
CAS	command augmentation system
DIR	direct mode of control
q	dynamic pressure
SAS	stability augmentation system
x-plane	from wingtip to wingtip of a target aircraft
y-plane	from nose to tail of a target aircraft

CENTER STICK HANDLING QUALITIES

Takeoff

Takeoffs with the F-8 digital fly-by-wire airplane were normally made using the stability augmentation system (SAS) in all axes. This gave a well damped aircraft that handled turbulence effectively. Bank angle control was good and could be set quickly and relatively precisely. A pilot rating of 2 on the Cooper-Harper scale was given for the takeoff and climbout (figs. 2 and 3).

Cruise

Control for cruising flight was easily adequate and is not further discussed in this paper.

Gross Maneuvering and Aerobatics

Pitch and roll control for any moderate to high rate maneuver was similar in each flight control system configuration. Maneuvers performed with the backup control system (BCS), direct mode (DIR), SAS, and command augmentation system (CAS) appeared very much alike to the pilot, which suggests that these were not good tasks for an evaluation.

Formation Flight

The ability to fly good wing and trail formation (fig. 4) is a requisite for fighter aircraft. It is also a task that rapidly exposes deficiencies in the flight control system. Poor control harmony between pitch and roll, poor damping, incorrect time constants, undesired force gradients, and other problems are all revealed when the aircraft is put to the formation task. With a good formation-flight aircraft, vertical position can be held consistently within 30 centimeters and lateral displacement can be held as desired. The task rated with the F-8 digital fly-by-wire airplane was the ability to hold a close wing position and to assess the workload required to do it.

While the airplane was in the backup control system, pitch sinusoidal oscillations of ±60 centimeters from a base position were caused by the slight delay in response to pitch stick inputs. Considerable pilot compensation was required to achieve even that amount of control. The response in the stability augmentation system was satisfactory but slightly sluggish because we were operating in the flat portion of the stick curve (fig. 5). Control in the direct mode was inferior to control with the stability augmentation system because of underdamped short period oscillations.

By far the most difficulty was encountered in trying to conquer the roll axis. Considerable attention was required on the part of the pilot any time formation was attempted in the roll backup control system or the direct mode. Response was objectionable because of small control deflections when low stick displacements were used and fast response when the apparent lag was overcome by using larger stick displacements. Using the roll stability augmentation system markedly improved the ability to hold close position, possibly because the stability augmentation system tended to initially oppose a rapid response to a pilot input. The stability augmentation system made the aircraft well behaved up to speeds where quantization became a factor.

Tracking

Gunsight tracking with a fixed reticle (fig. 6) was flown because it was an excellent way to assess the response of the airplane to pilot commands. The film was analyzed frame by frame to determine the miss distance, which was referenced to the plane running through the target airplane's wingtips (x-plane) or to the plane running from the target airplane's nose to its tail (y-plane). This allowed control difficulties to be classified as either a lateral-directional or a pitch problem (figs. 2 and 3).

The pilot's ability to keep the gunsight aiming point (pipper) on the tailpipe of the target airplane in a dynamic, tight loop situation was the task rated.

Tracking in the pitch stability augmentation system was unsatisfactory unless considerable trim was used to return the stick to the flatter portion of the parabolic deflection curve. If the trimming was omitted, quantization and its accompanying short period oscillations caused pipper oscillation in the pitch plane. Tracking in the stability augmentation system with a trimmed stick was good enough to perform the mission without improvement. The same problems arose in the direct mode, but this mode was without pitch rate damping, and was thus rated moderately objectionable.

The pitch backup control system was by far the smoothest of the modes tested and afforded good pitch steering at all angles of attack. Some short period oscillations occurred, but they were not significant.

The difficulties were considerable in the roll axis. There was a definite tendency toward pilot-induced oscillations whenever precise, rapid corrections were required. This was evident in both the backup control system and the direct mode. The roll stability augmentation system reduced the magnitude of the problem, but its sensitivity degraded the airplane's ability to track precisely.

The fixed-ratio aileron-to-rudder interconnect produced slight proverse yaw during roll-in. This was considered desirable, since it provided a slight lead in the direction of the target.

Ground-Controlled Approach

Ground-controlled approaches were flown using radar for positioning. This was an excellent task for the evaluation of precision control during tight loop instrument flight. Deviations from a preset position and altitude were radioed to the pilot, who then maneuvered the airplane back toward zero deviation. The response of the airplane to the pilot-initiated corrections was rated.

Pitch control was fair in the backup control system and the direct mode because of the short period oscillations generated by pitch corrections. Pitch response in the stability augmentation system was excellent, in that 30-meter-per-minute changes could be made in the rate of descent. Corrections in the pitch command augmentation system were initiated satisfactorily, but a distracting tendency to overshoot was noted that increased the pilot workload and therefore worsened the pilot rating.

Lateral control with low damping gains showed some deficiencies because of continuous low amplitude oscillations up to $\pm 6^\circ$ of bank. No attempt was made to correct this deficiency during the flight test program.

Landing

A portion of several flights was devoted to the assessment of the aircraft in various control modes in the landing pattern. The pitch backup control system was relatively smooth, and there was little tendency for the pilot to couple with the aircraft. In the direct mode, however, there was a tendency toward a pilot-induced oscillation during wing and gear transients. Sink rate control was fair with both of these modes. The stability augmentation system offered good pitch control throughout the pattern, with reduced transients and good flare control. The pitch command augmentation system was the best mode evaluated, but it masked the speed stability, which tended to lead the pilot to believe that changing stick force meant changing aerodynamic conditions; that was not always true.

Flare and touchdown control were satisfactory as long as a slight amount of back stick pressure was held to keep the airplane off the flat portion of the parabolic pitch curve. If this was not done, the delay in response caused firm landings or ballooning.

Lateral control in the landing pattern was characterized by low damping, overresponsiveness, and some periods of continuous low amplitude bank excursions.

The effects of these characteristics were reduced somewhat by consciously lowering the pilot's response and having him accept 1° to 2° deviations from the bank angle desired. This was considered moderately objectionable in itself, and coupled with a strong crosswind it became unacceptable.

The stability augmentation system reduced the airplane's response to gusts and small inputs and therefore it was rated better than the simpler control modes.

SIDE STICK HANDLING QUALITIES

The side stick in the F-8 digital fly-by-wire airplane (fig. 7) was installed to ascertain whether a force side stick could be used to control an airplane during most phases of flight, especially takeoff and landing. No attempt was made to optimize the control parameters, although some changes were made for the flights near the end of the program. The side stick was mechanized in the analog backup control system, which had no dampers. A side stick takeoff was considered the most uncertain phase of flight and was therefore performed only after side stick control was evaluated in up and away flight.

Takeoff

During side stick takeoffs, the pilot applied nosewheel steering (with the center stick) until rudder power was sufficient and then moved his right hand to the side stick. He made no inputs until lift-off speed was reached, when he applied a smoothly increasing pitch force to the stick. No lateral force was used near the ground to reduce the tendency for pilot-induced oscillations. Lift-off was smooth and similar to center stick takeoffs except that the pilot did not know the elevator and aileron positions through stick position (figs. 8 and 9).

Gross Maneuvering

Gross maneuvering was easy with the side stick. Maneuvers such as large pitch attitude changes, wind-up turns, wingovers, and aileron rolls were performed without difficulty. Crosstalk between pitch and roll was not apparent.

Formation Flight

Formation flight, a high pilot gain task, was enlightening during the early development of the F-8 digital fly-by-wire control system, when it exposed the severity of the task. Formation flight was also difficult with the side stick.

Loose wing formation flight could be satisfactorily performed with the side stick, although there were occasional random force pulses in pitch or roll. As the distance between the two aircraft diminished, the pulsing became more frequent and pronounced, indicating the tightening of the pilot in the loop. This resulted in a tendency for pilot-induced oscillations in pitch or roll or both with the system as it was mechanized, that is, without dampers and without attempts at optimization.

Some crosstalk (force interaction) was apparent during formation flight. Although its effect was not severe, it did start a disturbance in one axis while the pilot was trying to control the other axis.

Tracking

Side stick tracking was typified by good to excellent control over the lateral-directional axis and continuous oscillations in pitch caused by pitch commands that were too abrupt and could not be smoothed. Crosstalk was absent in the tracking task.

Ground-Controlled Approach and Landing

Power approaches from both pitch out and ground-controlled approach patterns were flown easily with the side stick. Roll control was good with respect to bank angle itself, but continuous left and right lateral force inputs had to be made. This did not degrade bank control, but it did drive the workload up quite a bit. Pitch control was precise.

Many of the approaches were flown in turbulence, which had little adverse effect on control.

Landings were characterized by final approaches that were well controlled down to the flare point. The flare was easy to initiate, and control was good almost to touchdown. Just before touchdown on every flight, the flightpath was stairstep-like. This was caused by pulsing pitch inputs from the pilot.

No large extraneous motion was generated by a simulated go-around if the trim kept the forces down to low levels.

CONCLUDING REMARKS

The F-8 digital fly-by-wire airplane was generally well behaved throughout the flight envelope tested. Most of the handling qualities deficiencies encountered were a result of the original compromises made to adapt the Apollo system to the airplane. No extensive attempt to improve the Apollo-related deficiencies was made.

REFERENCE

1. Cooper, George E.; and Harper, Robert P., Jr.: The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities. NASA TN D-5153, 1969.

Controllable	Acceptable	Satisfactory	Excellent	1
			Good	2
			Fair	3
		Unsatisfactory	Some minor but annoying deficiencies	4
			Moderately objectionable deficiencies	5
			Very objectionable deficiencies	6
	Unacceptable		Major deficiencies which require mandatory improvement	7
			Controllable with difficulty	8
			Marginally controllable in mission	9
Uncontrollable Control will be lost during some portion of mission			Uncontrollable in mission	10

Figure 1. Cooper-Harper rating scale (ref. 1).

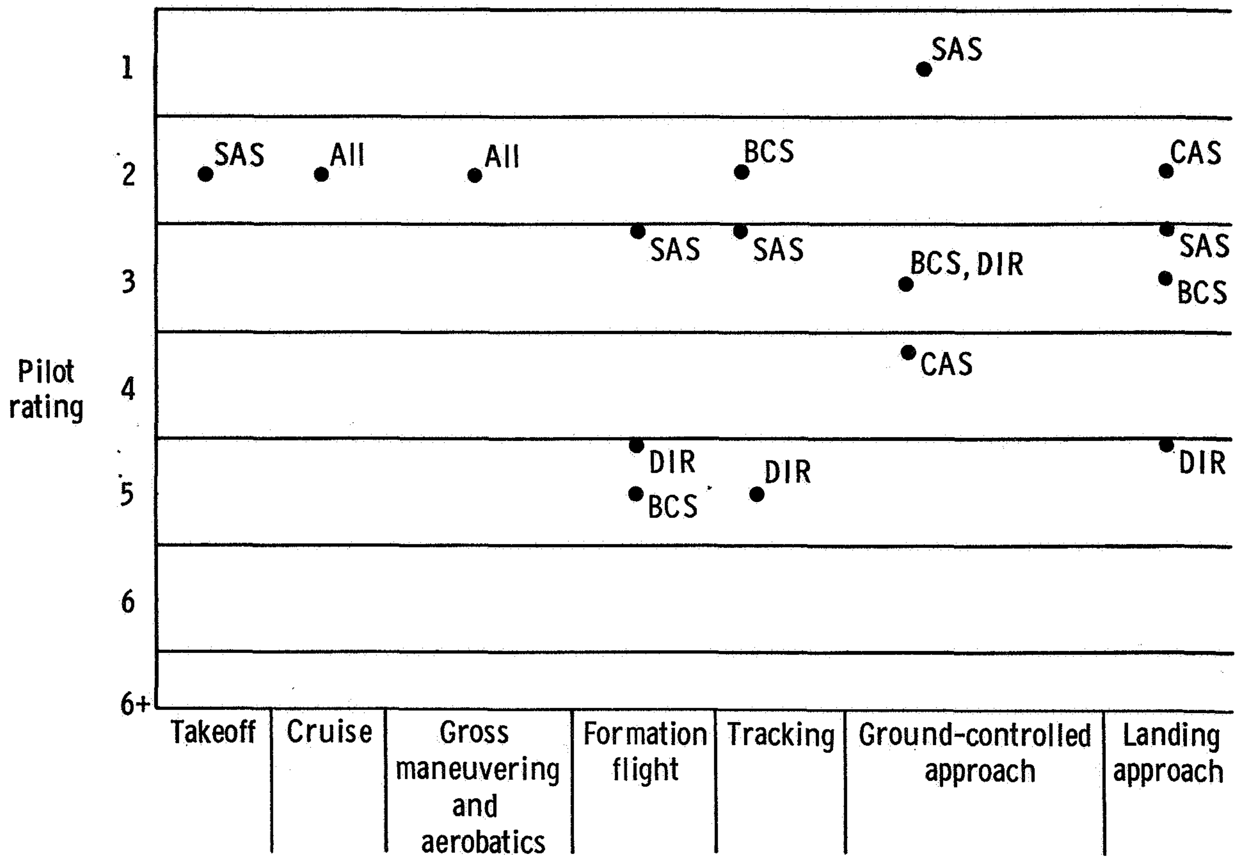

Figure 2. Center stick pilot ratings in pitch.

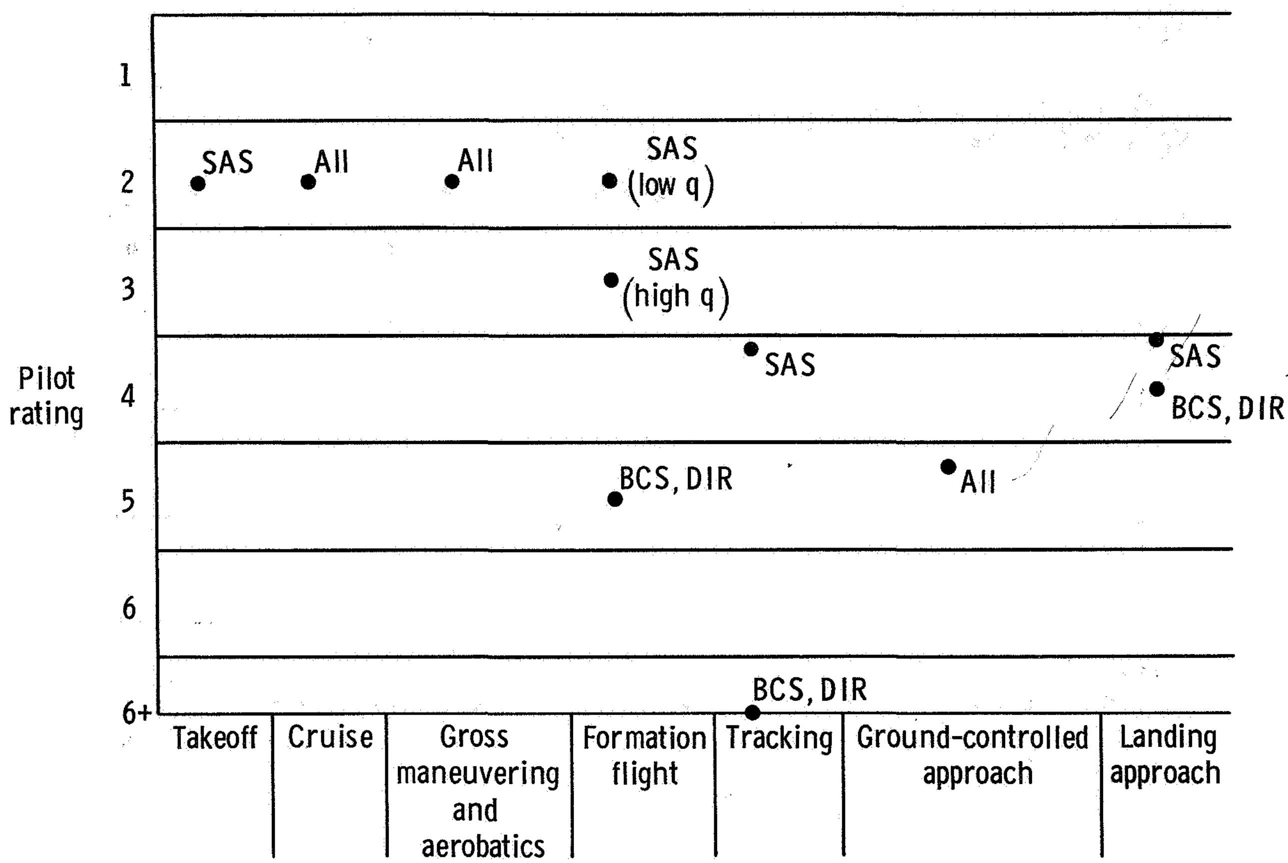

Figure 3. Center stick pilot ratings in roll.

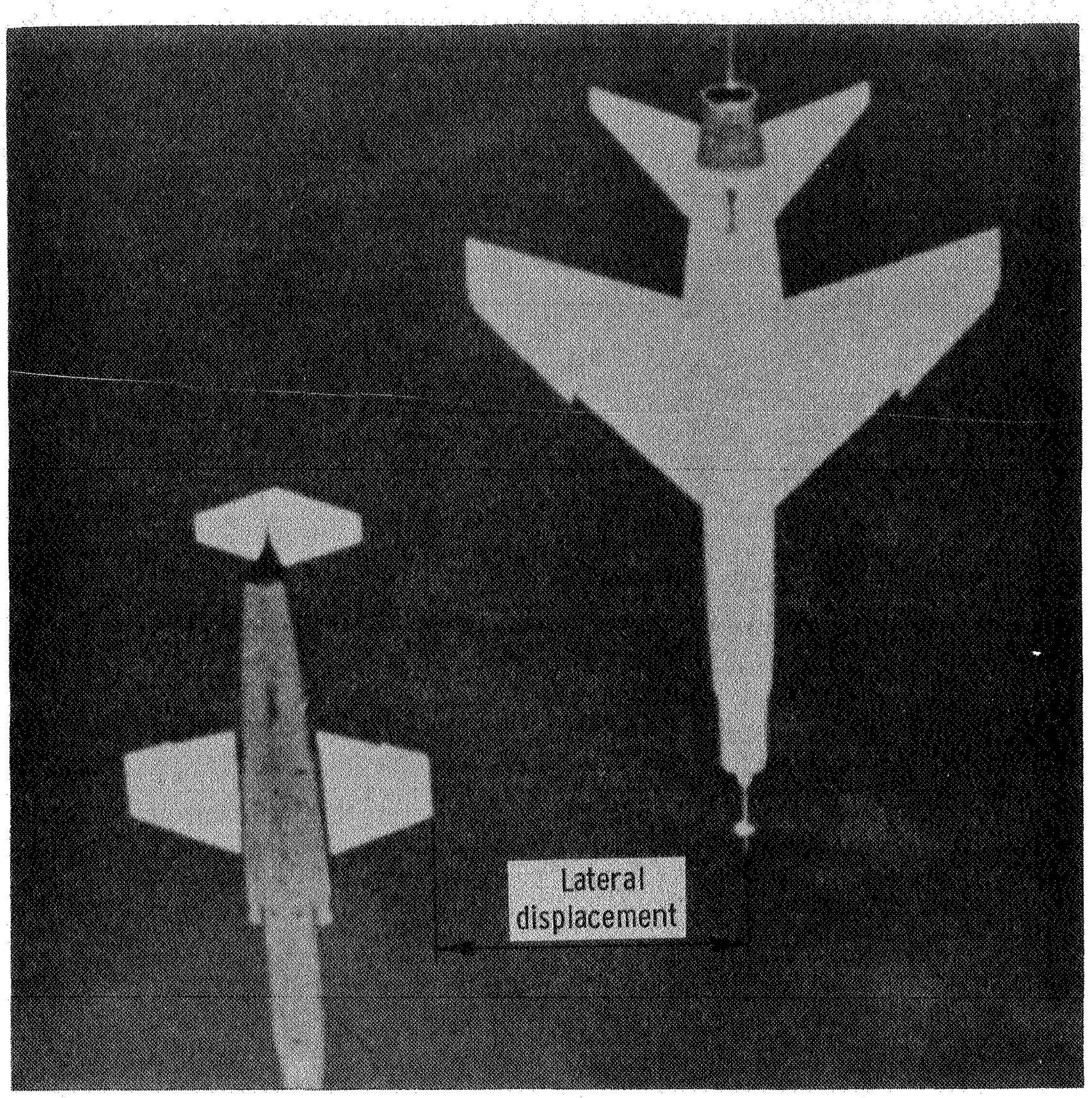

Figure 4. Formation flight.

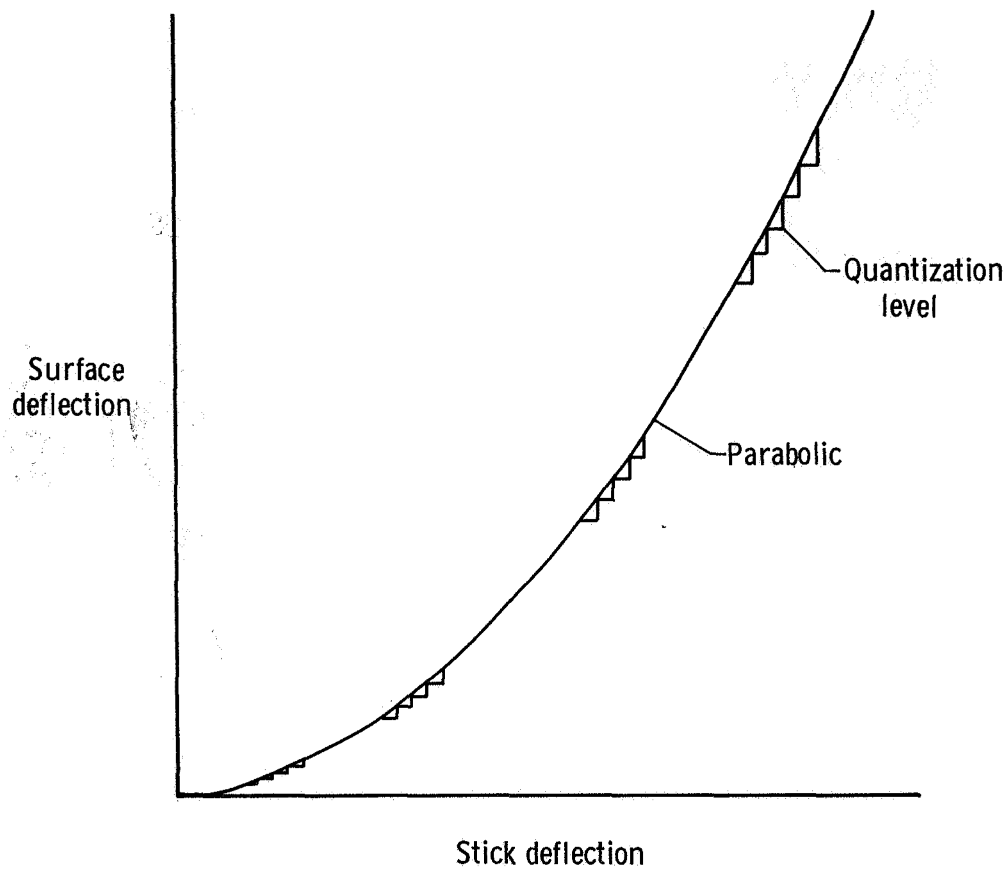

Figure 5. Control gearing.

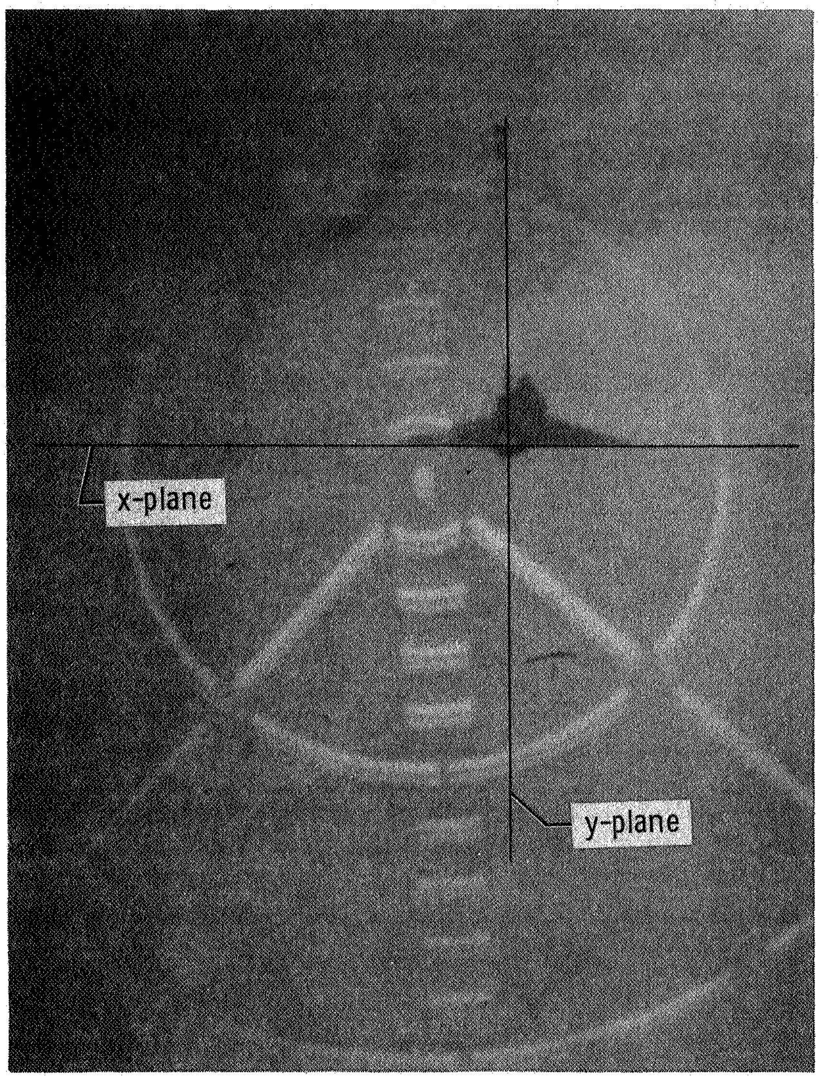

Figure 6. Gunsight tracking display.

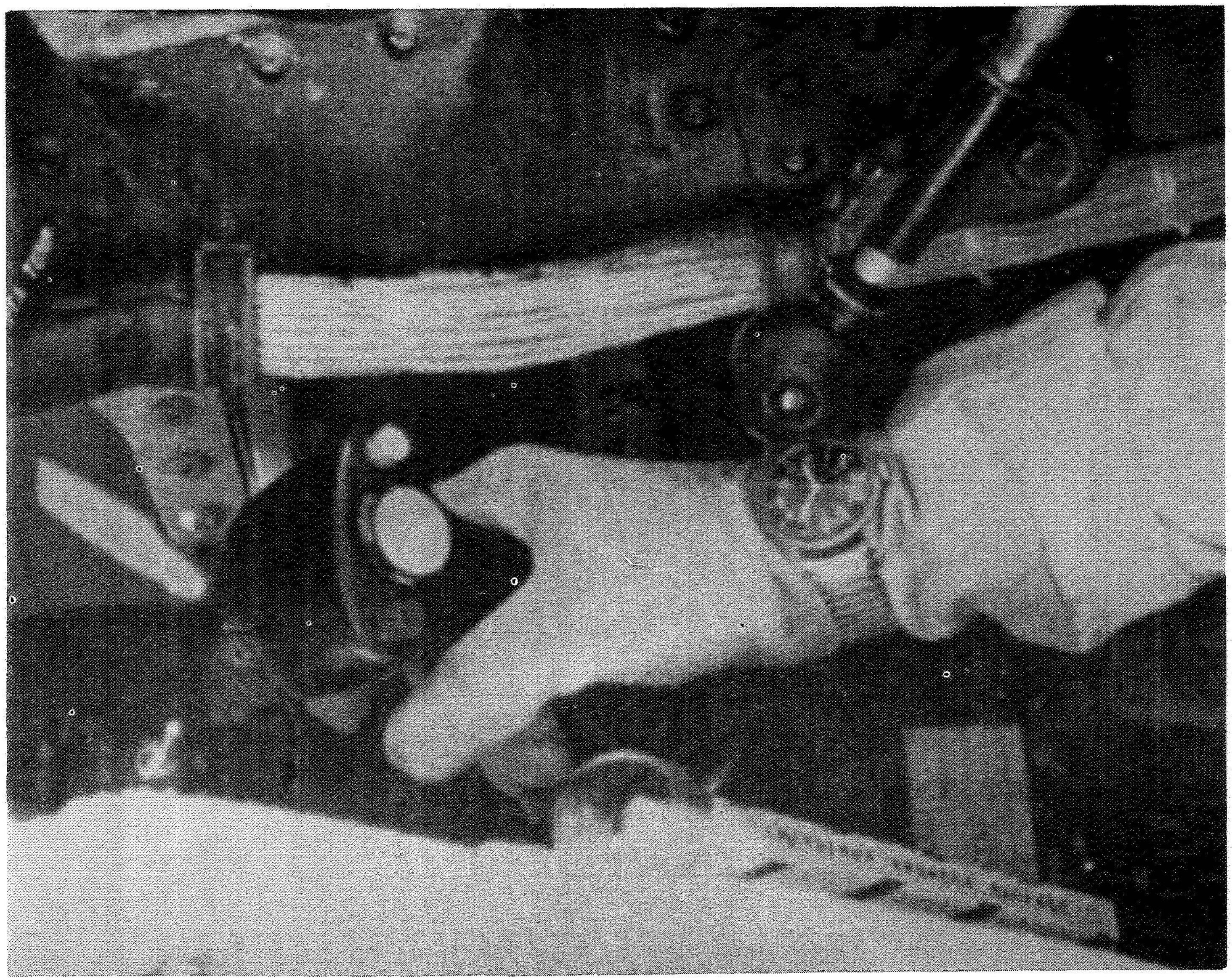

Figure 7. Force side stick in F-8 digital fly-by-wire airplane.

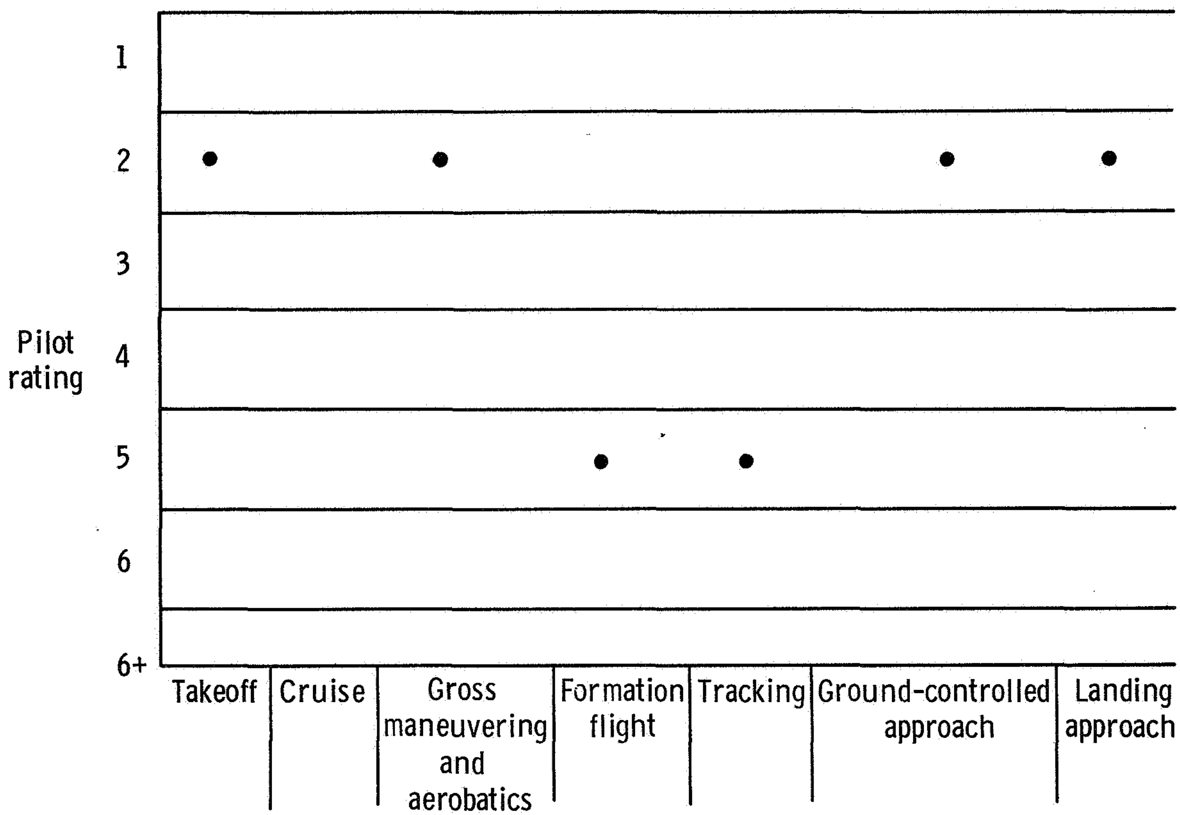

Figure 8. Side stick pilot ratings in pitch.

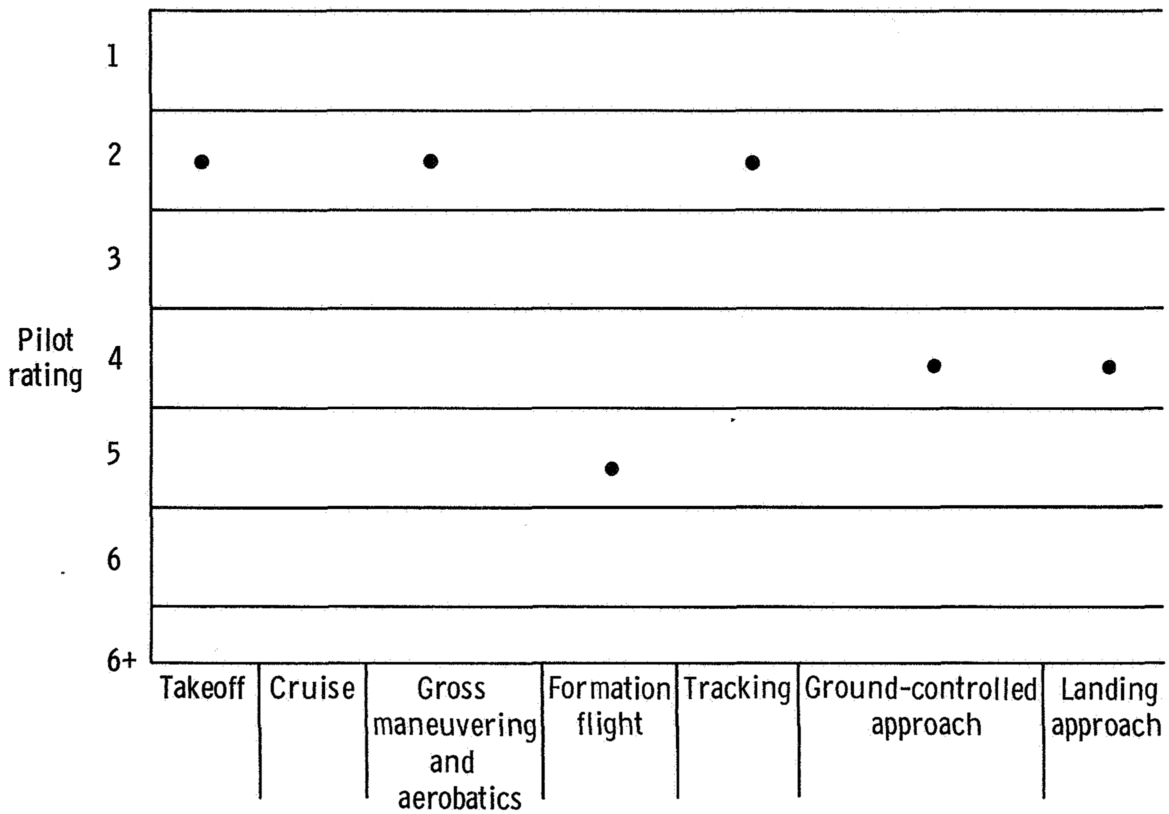

Figure 9. Side stick pilot ratings in roll.