412TW-PA-24121

HISTORY OF THE AFFTC, VOL 1
F-16 CHAPTER – PAGES 385-460

AFFTC HISTORY OFFICE

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE,
CALIFORNIA

1 JAN 79 – 31 DEC 81

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EDWARDS AIR FORCE BASE, CALIFORNIA
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UNITED STATES AIR FORCE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 23-04-2024	**2. REPORT** Historical Document	**3. DATES COVERED** *(From - To)* 1 Jan 79 – 31 Dec 81
4. TITLE AND SUBTITLE Pages from - History of the AFFTC, Vol 1 (F-16 Chapter) Pgs. 385-460		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) AFFTC History Office		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES) AFTC/HO 305 East Popson Ave Edwards AFB CA 93523		**8. PERFORMING ORGANIZATION REPORT NUMBER** 412TW-PA-24121
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) 412th Test Wing 195 E Popson Ave Edwards AFB CA 93524		**10. SPONSOR/MONITOR'S ACRONYM(S)** N/A **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
12. DISTRIBUTION / AVAILABILITY STATEMENT		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS AFFTC Histories, F-16		

16. SECURITY CLASSIFICATION OF: Unclassified			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** 412 TENG/EN (Tech Pubs)
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	None	77	**19b. TELEPHONE NUMBER** *(include area code)* 661-277-8615

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

F-16

Although the great bulk of full-scale development testing on the F-16 Air Combat Fighter was completed by the end of 1978, flight testing continued at a relatively brisk pace throughout the current reporting period. The aircraft flew approximately 2900 sorties, averaging over 80 flights per month throughout 1979-81.[1/] Even before the full-scale development flight test program was officially completed in March of 1979,* the F-16 Combined Test Force was involved in a major and unprecedented multinational evaluation of the F-16's performance in a variety of European environments. These tests were to comprise the lightweight fighter's final obstacle before entering service. In addition to this major effort, the F-16 would undergo a battery of follow-on development tests which would focus on specific problems which had surfaced during the full-scale development program. The test force would also be concerned with new modifications to the aircraft--most notably, a larger horizontal tail.[2/]

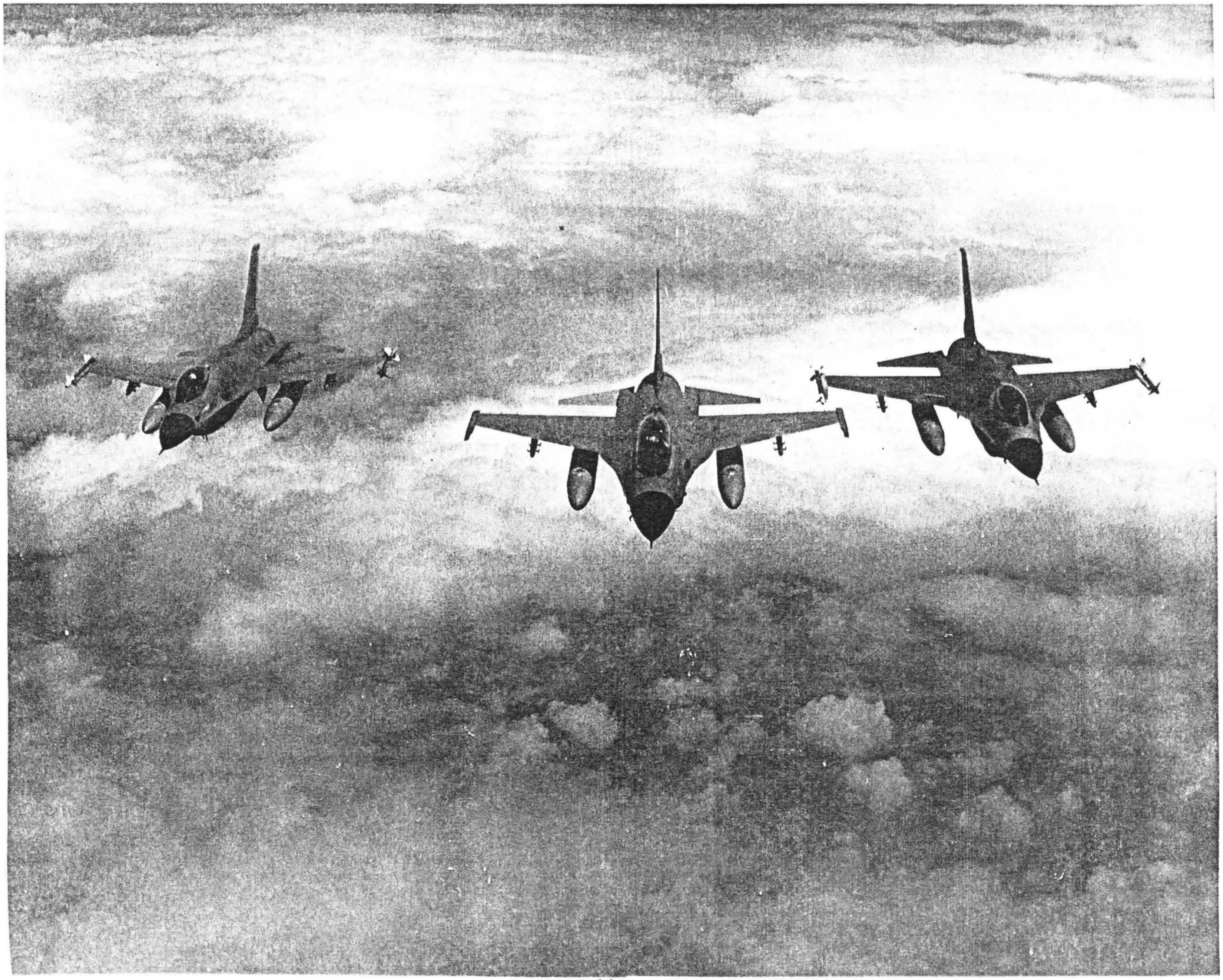
European Test and Evaluation

On 6 February 1979, four F-16s took off from Pease AFB, New

1/These figures were extrapolated from F-16 Monthly Summaries of Activites, Jan 79-Dec 81. Obtaining exact figures was not possible because the reports for June 79, Aug, Oct-Dec 80, and Jan, Nov 81, were not available.

2/F-16 Monthly Summaries of Activities, Jan 79-Dec 81; AFFTC News Release No. 4-10-79, 16 Apr 79.

*For a detailed analysis of the full-scale development testing which occurred during early-1979 (especially the high angle-of-attack tests), see The History of the Air Force Flight Test Center, 1977-78.



F-16s

Hampshire, for a trans-Atlantic flight to RAF Mildenhall, England. Accompanied by three KC-135 tankers, the aircraft were on the first leg of an unusual mission which would combine developmental and operational test disciplines into a single test plan to conduct off-site testing. The European test and evaluation program would truly be an international effort. Joining the team of pilots and engineers from the Flight Test Center, and pilots and operation analysts from the Air Force Test and Evaluation Center (AFTEC), would be pilots from Norway, Denmark, and The Netherlands. These were three of the nations involved (European Participating Governments) in the F-16 program. The test team was rounded out by US Air Force maintenance and General Dynamics logistics personnel.[3]

The purpose of the test program was twofold: to qualify the F-16 for operations in adverse weather (the responsibility of AF Systems Command), and to complete operational test and evaluation (AFTEC's responsibility). The 3 1/2-month program was conducted at four different test sites: Bodo Air Station, Norway (5 weeks); Skrydstrup Air Station, Denmark (5 weeks); Hahn Air Base, Germany (2 weeks); and RAF Alconbury, England (3 weeks). These sites were selected because they were representative of the environment of intended European operations and they provided adequate support and facilities to create realistic scenarios and

[3] Ltr, Col John S. Burklund, Vice Commander, AFFTC, to the Honorable Barry Goldwater, US Senate, Washington, DC, 11 Apr 79; Lt Col Thomas P. McAtee, F-16 CTF, AFFTC, and Lt Col Loren Timm, F-16 CTF, AFFTC, "F-16 European Test and Evaluation," The Society of Experimental Test Pilots Twenty-Third Symposium Proceedings (26-9 Sept 79), Technical Review, Vol. 14, No. 4.

accomplish a wealth of adverse weather testing. The tests in Norway and Denmark were primarily concerned with adverse weather and conventional combat operations. At Hahn AB, in Germany, emphasis was placed on special weapons applications. The tests at RAF Alconbury focussed on composite operations with F-15s. In general, the testing at these sites provided an excellent opportunity to determine if "real world" operations could uncover any new deficiencies that might have gone unnoticed in the relatively benign environment of southern California's high desert.[4/]

Although four aircraft initially deployed to Norway, the bulk of the testing was conducted with three vehicles (2 F-16As and an F-16B). The fourth aircraft returned to Edwards after completing three weeks of special drag chute testing in Norway. Each of the other three aircraft had a full complement of avionics and was comparable to a production configuration. One was equipped with a special instrumentation pod for measuring weather conditions.[5/]

Initially, 110 sorties were planned. The aircraft, however, proved to be more reliable than predicted and 171 sorties (totaling 356.9 hours) were actually flown. The sortie rate (average number of sorties per aircraft per day) was an

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[4/] Msg, F-16 System Program Office, ASD, Wright-Patterson AFB, to Public Information Officer, Bodo Air Station, Norway, et al, subj: Draft News Release for F-16 Arrival at Bodo, 23 Jan 79; McAtee and Timm, "F-16 European Test and Evaluation."

[5/] McAtee and Timm, "F-16 European Test and Evaluation."

impressive 0.78.[6]

The test flights were integrated into the normal operational flights of the host bases. Host Wing participation in the tests and test support was encouraged throughout. Each host Air Force exercised operational control over the test team. They were responsible for local area familiarization, scheduling, weather, and NOTAM (notice to airmen) meetings. Each provided a supervisor of flying who worked with his F-16-qualified counterpart to guarantee safe operations at all times. Host Wing aircraft were used for safety and photo-chase and as targets and adversaries. Whenever possible, the F-16s were integrated into host Wing missions in order to investigate composite operations and make operational comparisons.[7]

In evaluating the results, the test team was concerned with four principal areas: routine operations, air-to-air effectiveness, air-to-surface effectiveness, and operational suitability. Adverse weather conditions were a part of the routine operations category. Freezing rain and blizzards, ice-covered taxiways and runways were all common to the Air Station at Bodo, Norway. In general, the test results in these conditions were quite gratifying. As one of the test pilots later reported:[8] "It was almost as if the airplane became climatized as a result of the exposure." A few problems,

[6] Ibid.; F-16 CTF Monthly Summary of Activities, May 79.

[7] McAtee and Timm, "F-16 European Test and Evaluation."

[8] Ibid.

however, did crop up:[9]

o Snow collected in the gun bay (a cover would be required).

o Several static leaks developed in the integrated servo actuators.

o Ice formed on the engine inlet whenever the engine was run while parked over standing water in near-freezing conditions. Subsequent shedding of the ice could have caused engine damage (at the same time this was being observed in Europe, the first F-16 Wing at Hill AFB, Utah, experienced a number foreign object damage incidents because of the same problem). A test program in the climatic laboratory at Eglin AFB, Florida, was scheduled to find a solution for this problem. (It was discovered that the best interim solution to this problem was to place grating over puddled areas. See AFFTC-TER-I/R-4, F-16 Icephobic Materials Test and Evaluation, 15 Oct 79.)

o Although pilots found that they could consistently pull 9 g's (the F-16's limit) for extended periods without any of the normal disabling effects, potential problems existed when stores were carried that had g limits less than the aircraft's. The traditional cues--such as aerodynamic buffet--were non-existent and thus the pilots had no feedback to tell them they were exceeding the limits. This was particularly true when the aircraft was configured with 370-gallon external fuel tanks (which had a 7.33 g limit). The pilots concluded that overstressing the stores would be preferrable to limiting the

[9] Ibid.

aircraft g's in the flight control computer to correspond to stores limitations. The preferred solution, however, would be to certify stores to aircraft limits whenever possible and to educated pilots on the potential for overstress with those stores that could not be so certified.

o The external lighting on the F-16 was inadequate to perform aerial refueling at night under less than ideal conditions (a new light was subsequently designed and successfully tested which solved this problem).

o Several aircraft vented fuel during aerial refueling. At times, in fact, as much as 50 percent of the fuel taken on board was dumped overboard. The problem was traced to a sticking shuttle valve.

Radar problems were the major concern throughout the test program. The radar was still under development at the time the European test program got underway. Fixes to known problems--unreliable target acquisition, unstable tracking, breaklocks, etc.--had been evaluated at the Flight Test Center but there had not yet been any opportunity to evaluate the system in environmental conditions comparable to those in Europe. As a result, a number of new problems were encountered when the radar was first used in Norway.[10]

The Norwegian coastline, with its fjords and mountains, turned out to be a "worst case" for the pulse Doppler radar in the air-to-air search mode. As two of the pilots later

[10] Ibid.

reported:[11]

> The water provided a low-clutter background which lowered the target threshold (or increased sensitivity), while the mountains provided large discreet returns that came booming through the radar Doppler notch. It was found that a main beam frequency instability was partly responsible for this. Side lobes and main beam reflections from the radome also contributed since these possessed sufficient Doppler shift to qualify as a target and only needed enough power to exceed the threshold.

Another source of false alarms was the water itself. As the two pilots explained:[12]

> As a specular reflector, it made the 90-degree side lobe returns powerful enough to exceed the threshold so that a line of false alarms appeared at a range equal to the aircraft's altitude (an "altitude line").

Besides complicating the pilot's job of identifying real targets, these false alarms also nullified the effectiveness of the auto-acquisition mode. When in this mode, the radar was designed to automatically lock onto any target within a specified range and field of view. In the overwater tests, however, the radar readily accepted a false alarm, locked onto and tracked it, so that real targets went unnoticed. Because of the frequency of this problem, subsequent air-to-air gunnery tests against overwater targets had to be cancelled.[13]

A final area of concern had to do with real but unwanted targets. Ground vehicles on European highways commonly traveled fast enough to exceed the Doppler "notch" (the range of speeds that are assumed to be stationary and are therefore eliminated). In some areas there were so many of these "ground movers" that it

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11/ Ibid.

12/ Ibid.

13/ Ibid.

was impossible to identify actual airborne targets and thus the radar was rendered virtually useless in the look-down mode.[14]

These deficiencies provoked a concerted effort on the part of the radar contractor, Westinghouse, to identify their causes and implement fixes. By the time of the composite operations with the USAF F-15s at RAF Alconbury, a number of software modifications had been incorporated and the radar performance during these tests was significantly improved. Although the radar was now judged capable of effectively performing the air-to-air mission, the Alconbury environment was relatively benign and considerable work was still required to make it acceptable for world-wide operations. Both software and hardware modifications would continue to be rigorously evaluated at the Flight Test Center so that an operationally suitable radar could be fielded.[15]

A total of 61 sorties focussing on air-to-air operations were flown. The areas isolated for evaluation included: air-to-air gunnery, operational comparisons, air combat maneuvering, beyond visual range intercepts leading to within visual range air combat maneuvering, combat air patrol, and composite operations with F-16s and F-15s flying against F-5E aggressor squadrons. The poor performance of the radar throughout most of the program had a very definite adverse impact

14/ Ibid

15/ Ibid.

on the overall test results in many of these areas. The results were as follows:[16/]

o Air-to-air gunnery - These tests not completed because of radar lock-on problems.

o Operational comparisons - The F-16 was compared in level accelerations and decelerations, maximum power zooms, and maximum rate rolls and turns, against F-104, F-100, F-5, and F-15 fighters. The performance of the F-16 was far superior to the first three and comparable to that of the F-15 up to the Mach 1.4 to 1.6 range. The F-15's performance was superior above Mach 1.6 because of its variable engine inlet ramps.

o Air combat maneuvering - Two significant problems were encountered here. Radar problems once again degraded attack positioning and interface problems with the AIM-9L missiles adversely affected their performance in simulated launches. The missile problems had been previously identified during tests at the Flight Test Center and included: incorrect wing twist algorithms in the fire control radar which provided inaccurate indications on the head-up display of where the missile was looking; and there was no feedback from the missile to the head-up display indicating what it was actually tracking. Apart from these problems, the F-16's performance in air combat maneuvering was excellent. The aircraft was aggressively flown throughout the envelope without encountering any problems. The F100 engines, modified with the proximate splitter to prevent

16/ Ibid.

stall stagnations,* provided outstanding performance. The F-16's reclined seat significantly improved the pilots' ability to perform efficiently under high g loads, increasing their g tolerance by an estimated 2 g's. The fly-by-wire flight control system permitted pilots to instantly maneuver at maximum performance without concern for aircraft departure or excessive loads. F-5E aggressor pilots repeatedly commented that the F-16's turn rate was faster than that of any other fighter they had flown against. Once interim fixes had been implemented for the radar and missile problems, the F-16 proved to be unbeatable. As two of the pilots later reported:17/

> Basically, when carrying AIM-9L missiles, if we saw the threat we got him. It was simply a matter of pointing the aircraft, getting the missile chirp, verifying within missile launch parameters, and shooting.

o Beyond visual range - Prior to the tests at Alconbury, radar deficiencies significantly diminished opportunities for head-on AIM-9L missile employment and, even more important, degraded the pilot's situation awareness. At Alconbury, the radar worked well but the fixes were considered "interim," the environment was benign (no mountains), and some of the pilots' work-around solutions would not have been acceptable in an operational situation.

o Combat air patrol - When the radar was functioning effectively, combat air patrol was satisfactorily demonstrated

17/ Ibid.

*For a detailed analysis of the proximate splitter, see The History of the Air Force Flight Test Center, 1977-78.

(these scenarios placed heavy emphasis on the radar's look-down capability). Target detection range was adequate for intercepting multiship formations over both land and water.

o Composite operations - These exercises were flown at Alconbury after many of the radar problems had been cleared up. The F-16s and F-15s, flying together against representative threat formations and tactics by F-5E aggressors, demonstrated an impressive capability. The two aircraft complemented each other extremely well. Because of their performance similarities, mutual support during the intercept and maneuvering phases of these engagements was very easy to maintain. The radar systems also complemented each other. The F-15's long-range radar provided early target detection and advantages in pre-engagement positioning. The F-15 radar typically locked onto the target beyond visual range while the F-16 radar remained in search for target formation resolution and additional threat detection. The significant difference in size between the F-15 and the F-16 permitted a significant tactical advantage. Aggressor pilots had difficulty in detecting the F-16 once the F-15 had been visually acquired. This frequently permitted the F-16s to achieve unobserved "shots" against F-5Es in pursuit of the F-15s. The F-16's small size also caused identification problems for the aggressor pilots. They commonly converged on other F-5Es, mistaking them for F-16s.

A total of 55 air-to-surface missions were flown. The F-16's capabilities were supposed to be evaluated during air-to-surface bombing and strafing runs, close air support and interdiction scenarios, sea surveillance scenarios, AGM-55 (Maverick missile) employment, and special weapon scenarios.[18]

Strafing was not evaluated during these tests and several problems were encountered during the bombing evaluation. Bomb accuracy was not consistent for the different munitions used in each of the bombing scenarios. Basically, all bombs would hit in a tight group but not close enough to the target. Test team members believed there was a lesson to be learned in light of this poor performance:[19]

> To save money during the full-scale development (FSD) program, it was decided to significantly reduce the number of full-scale munition accuracy tests. In addition, instrumentation sufficient to perform an error analysis was not purchased. Had accuracy been satisfactory, this would have resulted in significant cost savings. However, because of poor results during ET&E, a new weapon accuracy test with adequate instrumentation was necessary.

Despite the inaccuracy of the weapon deliveries, close air support and interdiction operations were rated as satisfactory. Excellent cockpit visibility, short turn radius with various external stores configurations, the head-up display, and the integrated weapon system permitted successful visual attacks even in conditions of reduced ceilings and visibility. The F-16's range capability provided significant tactical advantages. The radar's ground mapping was rated as "good"; resolution was adequate for making navigation corrections, particularly in the expand mode. While the Doppler beam sharpening mode provided excellent resolution, it had certain limitations. As members of

18/ Ibid.

19/ Ibid.

of the test team reported:[20]

> The greater-than-15-degree offset requirement for good resolution limits its usability. To effectively use DBS, a lot of permission planning is required. We feel more tactical experience is required to fully exploit this mode.

Pilots also recommended that their workload should be reduced by moving the radar gain control to the throttle. When flying at low level in poor weather conditions, a pilot's natural instinct was to keep his hands on the controls (the throttle and stick). Removing his hand from the throttle in order to optimize his radar video could prove to be very hazardous. Pilots also agreed that the planned relocation of the fire control navigation panel, from the right to the left console, would definitely enhance flight safety at low levels. Pilots would no longer have to remove their hands from the control stick in order to push the programming keys.[21]

The sea surveillance scenario was satisfactorily demonstrated in Norway and Denmark. Both the SEA 1 and SEA 2 radar modes provided excellent capability. SEA 1 was essentially the same as the ground map mode except that it slightly enhanced radar returns under calm sea conditions. SEA 2 took advantage of the Doppler to remove clutter caused by rough seas.[22]

Both AGM-65A and B inert Maverick missiles were successfully launched against sea targets in Norway and Denmark. Five out of six live firings resulted in hits. The single miss was attributed to pilot error. The primary recommendation to come

[20] Ibid.

[21] Ibid.

[22] Ibid.

out of these tests was that the launch sequence should be simplified.23/

Finally, the air-to-surface special weapons scenario was demonstrated at Hahn AB and RAF Alconbury. Weapon accuracies for both radar laydown and low-altitude drogue deliveries were rated as satisfactory to excellent.24/

The overall assessment of the test force was that the F-16 could effectively accomplish its planned missions in the European environment. A total of 64 deficiencies were reported. Roughly 80 percent of these, however, had been detected prior to deployment and fixes were, in many cases, already being evaluated at the Flight Test Center. The European test and evaluation program had served two very important purposes. First, it had provided the test force with the opportunity to see the operational impact of known deficiencies in a realistic environment. These deficiencies could then be accurately prioritized so that appropriate fixes could be implemented in order of importance. Second, the tests permitted the early identification of previously undetected weaknesses. Implementing the required modifications at the aircraft's current stage of development would mean a substantial reduction in future costs.25/

When the three test aircraft returned to Edwards in May of

23/Ibid.

24/Ibid.

25/Ibid.; F-16 CTF Monthly Summaries of Activities, Feb-May 79.

1979, the multinational evaluation program was actually just getting underway. The first operational aircraft had already been delivered to Hill AFB, Utah, in January. By the summer of 1979, a multinational operational test and evaluation and training program would be in full gear at the Utah facility. During these tests, aircraft which were built by some of the European consortium nations--such as Belgium and The Netherlands--would be evaluated. The entire multinational program would last roughly 18 months and include yet another European deployment in the summer of 1980.[26]

F100 Engine Testing

The Pratt & Whitney F100 engine had already undergone a long development process as the current historical reporting period opened.* The controversial engine had originally been developed for the F-15 and most of the problems relating to it had been resolved in tests with the twin-engine Eagle. The evaluation of problems--such as the engine's susceptibility to stalls and stagnations--was much more limited on the F-16 because its single-engine configuration would have made such testing unduly hazardous. The basic pattern, then, was for the basic problems to be worked on the F-15 and then, when acceptable fixes had been thoroughly demonstrated, the F-16 would be cleared to proceed

26/ Ibid.; Ltr, Maj Gen James A. Abrahamson, Director, F-16 SPO, ASD, Wright-Patterson AFB, to Brig Gen Philip J. Conley, Jr., Commander, AFFTC, 9 Jan 79.

*For a detailed description of the F100 engine, its development, and the various modifications to it, see the F-15 and F-16 sections in The History of the AFFTC, 1977-78.

into previously hazardous areas.* This, of course, is not to suggest that substantial engine testing was not performed on the F-16. Development testing with the engine got underway on 20 September 1976 and extended through 28 April 1981. It is impossible to determine the number of flights from which engine data was collected because, in the interests of economy, so much F-16 development testing was conducted in a "piggy-back" fashion. Thus, for example, much of the engine data was collected during missions dedicated to flying qualities and stability and control.[27/]

Altogether, 13 different engines were used during the development test program (see fig. 102). All of them were F100-PW-100 Arabic 3 engines (three of them were early production models and the rest were pre-production experimental models configured with many of the modifications already developed in F-15 testing). The production model which would be installed on operational aircraft would be designated F100-PW-200. All F-16 engine development testing was conducted using JP-4 fuel.[28/]

The primary test objectives during the developmental program

27/ The History of the AFFTC, 1977-78; AFFTC-TR-81-10, F-16 FSD Engine/Inlet Compatibility and Engine Stability Evaluation Using JP-4 Fuel: Final Report, Nov 81.

28/ AFFTC-TR-81-10.

*See, for example, AFFTC-TER-PR-1, "F-16 Light-Off Detector Evaluation, 28 Oct 81, which describes the testing of a modification to reduce augmentor-induced stalls and stagnations. The light-off detector had already been successfully demonstrated on the F-15.

F100-PW-100(3) ENGINES EVALUATED
DURING F-16 FSD PROGRAM

Engine S/N	Date First Installed in an FSD F-16	Total Operating Time as of 28 April 1981 (hr)
P680350	29 Apr 77	1,048
P680360	21 Apr 77	572
P680385	08 Dec 76	1,154
E680501	24 Feb 77	877
E680532	03 May 77	938
E680571	27 May 77	977
E680585	08 Aug 77	536
E680685	17 Oct 77	816
E680781	19 Apr 77	577
E680825	16 Feb 78	594
E680853	19 Jan 78	802
E680883	16 May 78	416
E681002	01 Nov 78	504
	Total	9,811 hrs

NOTE: P prefixes denote production engines (prior to the F100-PW-200 engine). E prefixes denote experimental engines.

Fig. 102

were as follows:[29]

- o To evaluate engine control and response (in both the unified fuel control and back-up control modes) during ground and flight operations
- o To evaluate augmentor control and response during ground and flight operations
- o To evaluate engine and inlet compatibility throughout the flight envelope
- o To determine the ground start and airstart capabilities of the engine.

The overall test results indicated that engine and inlet compatibility was satisfactory throughout the angle-of-attack and sideslip envelope specified for the F-16. A total of 136 engine and inlet compatibility tests were completed during which both augmented and nonaugmented throttle transients were performed while the aircraft was in maneuvering flight. Eleven recoverable compressor stalls occurred during Idle to Maximum and Military to Maximum power throttle transients. However, since these stalls were also common at the same or similar flight conditions during 1-g flight, none of them were considered to be due to high inlet distortion.[30]

Successful engine operation was demonstrated well in excess of specification requirements for angle-of-attack and sideslip combinations during high angle-of-attack testing. These tests

[29] Ibid.; AFFTC-TR-80-34, F100-PW-100(3) Engine Starting Evaluation in the F-16 FSD Aircraft Using JP-4 Fuel: Final Report, July 81.

[30] AFFTC-TR-81-10.

were conducted with engines configured with both remote and proximate splitters (see fig. 103). In tests with the remote-splitter configured engine, six nonrecoverable stalls were encountered during 100 departures from controlled flight. In each case, engine shutdown and restart was accomplished. In subsequent tests using a proximate-splitter configured engine, 121 departures resulted in 14 recoverable and only one nonrecoverable stall. These results confirmed the value of the proximate splitter and it would be incorporated into production engines for the F-16 operational fleet.[31/]

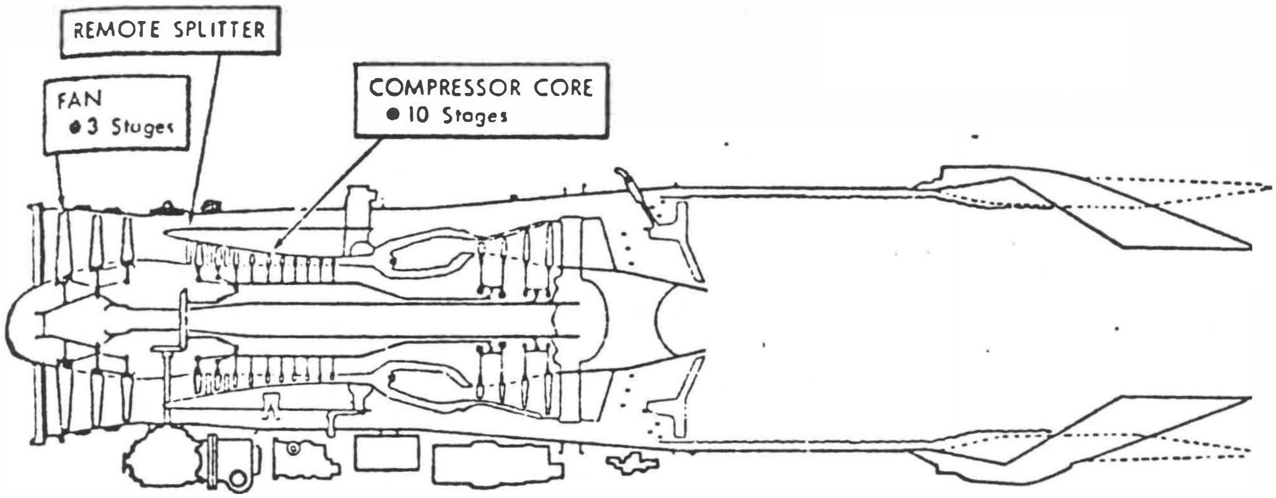
Engine stability during non-augmented operation was rated as "excellent." Only 14 instabilities were detected throughout the entire development program. Of this total, four were caused by malfunctions in the high compressor rotor speed sensor, the unified fuel control, or the electronic engine control. The remaining ten were within Flight Manual limitations and thus no maintenance action was required.[32/]

The engine experienced significant problems, however, during augmented operation (for a summary of augmentor anomalies, by types and regions, see figs. 104-106). More than 10,000 throttle transients to augmentation were performed during the test program and, of these, 381 resulted in some type of engine anomaly (i.e., blowout, rumble, or compressor stall) either during augmentor initiation or stabilized operation. Most of these anomalies

31/ Ibid.

32/ Ibid.

F100-PW-100(3) Engine



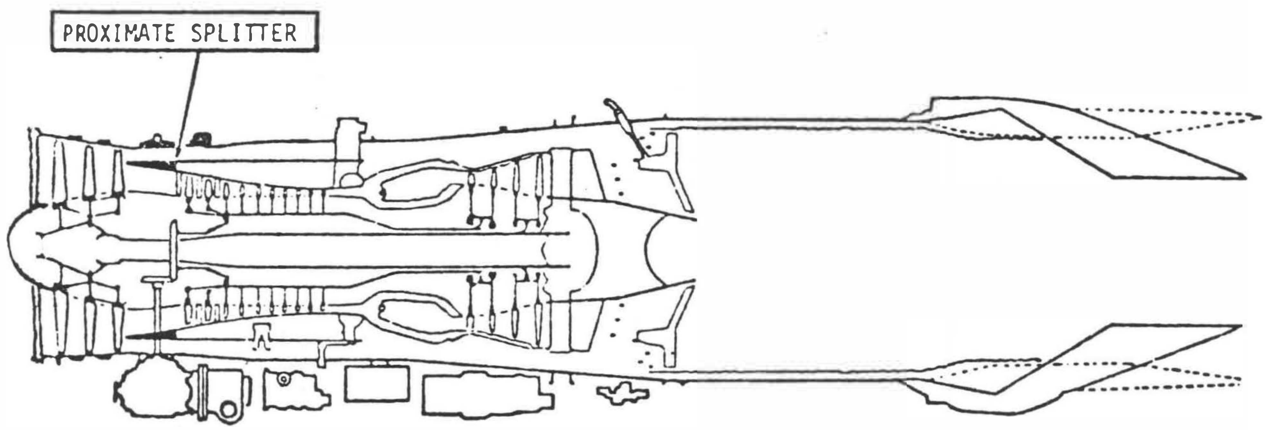


Fig. 103

F-16 ENGINE ANOMALIES SUMMARY
Region 1
F100-PW-100(3) Engine
JP-4 Fuel

		Augmentor No-Lights	Augmentor Blowouts	Augmentor Rumble	Recoverable Compressor Stalls						
					Rumble Induced	Segment Sequencing	No-Light/Auto-ignition	Blowout/Auto-ignition	Augmentor Initiation	After Aircraft Departures	No Engine Data
Stabilized Throttle Setting	MIL	----------	----------	----------	------	---------	-------------	-------------	--------	1	1
Throttle Transients into Augmentation from:	IDLE	----------	----------	33	11	---------	-------------	1	--------	----------	3
	Part-Power	----------	----------	----------	------	---------	-------------	1	--------	----------	--------
	MIL	3	1	27	2	2	1	2	6	----------	10
Throttle Transients within Minimum to Maximum Augmentation		----------	----------	----------	------	2	-------------	-------------	--------	----------	--------
TOTALS		3	1	60	13	4	1	4	6	1	14

NOTES:
1. More than 10,000 throttle transients to augmentation were performed during the program.
2. An aircraft departure was defined as an uncommanded angular excursion (yaw divergence or AOA greater than 29 degrees).
3. Refer to Appendix C for specific details of engine anomalies.
4. The Flight Manual defined Region 1 as follows: Unrestricted AB (augmentor) operation. Mislights, blowouts, or stalls should not occur. Some AB rumble may occur but should not induce blowouts or stalls.

Fig 104

F16 ENGINE ANOMALIES SUMMARY
Region 2
F100-PW-100(3) Engine
JP-4 Fuel

		Augmentor No-Lights	Augmentor Blowouts	Augmentor Rumble	Recoverable Compressor Stalls: Rumble Induced	Segment Sequencing	No-Light/Auto-ignition	Blowout/Auto-ignition	Augmentor Initiation	After Aircraft Departures	No Engine Data
Stabilized Throttle Settings	MIL	-------	-------	-------	-------	-------	-------	-------	-------	-------	2
	Seg.1	-------	1	-------	-------	-------	-------	-------	-------	-------	-------
	MAX	-------	1	-------	-------	-------	-------	-------	-------	-------	-------
Throttle Transients into Augmentation from:	Idle	-------	22	62	16	5	-------	11	-------	-------	1
	Part-Power	-------	-------	5	2	1	-------	-------	-------	-------	-------
	MIL	1	9	33	3	12	-------	5	9	-------	-------
Throttle Transients within Minimum to Maximum Augmentation		-------	1	-------	-------	3	-------	-------	-------	-------	-------
TOTALS		1	34	100	21	21	0	16	9	0	3

NOTES:
1. More than 10,000 throttle transients to augmentation were performed during the program.
2. An aircraft departure was defined as an uncommanded angular excursion (yaw divergence or AOA greater than 29 degrees).
3. Refer to Appendix C for specific details of engine anomalies.
4. The Flight Manual defined Region 2 as follows: Most AB (augmentor) transients can be expected to be successful; however, AB mislights, light-off stalls or rumble blowouts or stalls may occur during AB light-off or during throttle transients within the AB range but should not occur during steady-state AB operation.

Fig. 105

F-16 ENGINE ANOMALIES SUMMARY
Region 3
F100-PW-100(3) Engine
JP-4 Fuel

		Augmentor No-Lights	Augmentor Blowouts	Augmentor Rumble	Recoverable Compressor Stalls: Rumble Induced	Segment Sequencing	No-Light/Auto-ignition	Blowout/Auto-ignition	Agumentor Initiation	After Aircraft Departures	No Engine Data
Stabilized Throttle Setting	MIL	---------	--------	---------	-------	-------	--------------	-------------	---------	13	---------
	MAX	---------	--------	1	-------	-------	--------------	2	---------	------------	2
Throttle Transients into Augmentation from:	Idle	1	8	6	7	-------	--------------	4	---------	------------	---------
	Part-power	---------	--------	3	-------	1	--------------	-------------	---------	------------	---------
	MIL	2	6	6	1	-------	--------------	1	3	------------	---------
Throttle Transients within Minimum to Maximum Augmentation		---------	--------	---------	-------	1	--------------	-------------	---------	------------	---------
TOTALS		3	14	16	8	2	0	7	3	13	2

NOTES:
1. More than 10,000 throttle transients to augmentation were performed during the program.
2. An aircraft departure was defined as an uncommanded angular excursion (yaw divergence or AOA greater than 29 degrees).
3. Refer to Appendix C for specific details of engine anomalies.
4. The Flight Manual defined Region 3 as follows: Steady state AB (augmentor) operation or AB cancellations only in this region. AB mislights, light-off stalls, blowouts and rumble-induced stalls are probable during transients from all power settings. AB rumble and blowout are possible during steady - state operations.

Fig. 106

occurred in the upper left-hand corner of the flight envelope (high altitude and low airspeed) but well within the region originally required by specifications. As a result of the engine's poor performance in this area of testing, a series of throttle restrictions were placed in the Flight Manual which corresponded to the regions where anomalies were most frequently encountered. The effect of these restrictions was, of course, to reduce the F-16's combat effectiveness. Pratt & Whitney proposed some modifications designed to eliminate the need for restrictions. These involved changes to the unified fuel control scheduling which would improve upper left-hand corner augmentator operation and the installation of a quiet (damped) quickfill sensor to reduce afterburner rumble. These, and other modifications would be evaluated in the ongoing F100 Component Improvement Program.*[33]

The engine's stability during in-flight fuel control transfers was rated as excellent. A total of 29 transfers from the unified fuel control to the back-up control and 27 from the back-up control to the unified control were all successfully accomplished. On the ground, however, the engine's stability during transfers was rated as only marginal. Three nonrecoverable compressor stalls occurred during a total of 171 transfers from unified fuel control to back-up control. All three stalls resulted from problems relating to the back-up

[33] Ibid.

*See the F-15 section of this chapter.

control system which had a lower Idle fuel flow rate than the unified control. This was considered a serious problem; the possibility of overheating the engine, because of nonrecoverable stalls during fuel control transfers, could increase the number of hot section overhauls. The back-up fuel control system would require modification.[34]

More than 4,200 ground starts were successfully performed in the unified fuel control mode under ambient temperatures that ranged from -40 (after a -65 degree F cold soak) to 125 degrees F and under environmental conditions that included rain, light and heavy snow, and fog (see fig. 107). Only 57 starts in this mode were unsuccessful because of engine-related problems. The major causes of these failures were improperly adjusted start schedules and malfunctions in the unified fuel control system. Most of them occurred early in the development program and after fixes were implemented they were rarely encountered.[35]

A total of 38 unassisted spooldown airstarts were attempted in the unified fuel control mode. Twenty-eight of these were planned and the other ten were performed after the engine was shut down to clear an unplanned stall-stagnation. Four of the attempted airstarts resulted in hung start conditions. Subsequent airstarts were jet fuel starter assisted and were, in every case, successful. Test results indicated that the hung starts may have been prevented if the unified fuel control

34/Ibid.

35/Ibid.

F-16A/B F100-PW-100(3) ENGINE START SUMMARY

Inclusive Dates: 20 September 1976 to 29 September 1980

Fuel Type: JP-4

Start Condition	Start Result	Unassisted		JFS Assisted	
		UFC	BUC	UFC	BUC
Ground	Successful	---	---	4,227[1]	11
	Hot Start	---	---	31	0
	Hung Start	---	---	5	0
	Auto-acceleration	---	---	1	0
	No-Start	---	---	20	0
Inflight	Successful	37	8	11	5
	Hot Start	0	0	0	0
	Hung Start	4[2]	0	0	0

Notes: 1. Known successful ground starts during F-16 climatic and ET&E deployments, and at Edwards AFB, California. Includes ground starts performed during engine trim checks, engine start problem investigations, engine start schedule checks, and normal (UFC mode) preflight engine starts.

2. Three of the four were cleared by the pilot selecting EEC (derich off). One did not clear due to the pilot inadvertently selecting DERICH (derich on). The subsequent airstart was JFS assisted in the UFC mode and was successful.

Fig. 107

system were adjusted so that derich on minimum starting fuel flows was above 340 pounds per hour. The results also indicated that none of the engines tended to get hot if the unified fuel control derich on minimum starting fuel flows was adjusted to a pressure below 390 pounds per hour. The test force therefore recommended that all unified fuel control systems coming from the vendor should be adjusted within the 340 to 390-pounds per hour band.[36]

The major difficulty encountered while performing airstarts after engine stagnations was insuring that the high compressor rotor speed did not decrease below 25 percent while waiting for the fan turbine inlet temperature to decrease below 700 degrees C. During inflight stagnations the throttle was retarded to cutoff with the inlet temperatures ranging from 715 to 1,040 degrees C. With only one exception, all airstarts were initiated after the inlet temperature decreased below 700 degrees C. Again, with one exception, rotor speed dropped below 40 percent before the inlet temperature fell below 700 degrees C. Pilots complained that the time within the airstart window (rotor speed between 40 and 25 percent and inlet temperature below 700 degrees C) was too brief, too much altitude was lost (from 12,300 to 19,000 feet) in dives while trying to increase airspeed to prevent the rotor speed from dropping below 25 percent and, in the event of a hot start, this significantly reduced the

[36] Ibid.

possibility of achieving a second start.[37]

An engine emergency warning system was proposed to combat this problem. The warning system would provide both visual and audio warnings to the pilot during inflight operation if the engine stagnated or died out (rotor speed fell below 55 percent). With the new warning system, the pilot would be provided with a cue permitting him to retard the throttle to cutoff prior to letting the inlet temperature rise above 1000 degrees C. Plans were already underway at the Flight Test Center to evaluate a prototype model of such a system in 1982.[38]

A total of 11 jet fuel starter-assisted spooldown airstarts, and eight unassisted and five jet fuel system-assisted backup mode airstarts were also attempted. All were fully successful with the jet fuel starter-assisted airstarts requiring less time to complete.[39]

Overall, the engine had performed quite well throughout the airstart evaluation. It had demonstrated successful operation throughout the airstart envelope defined in the F-16 Flight Manual.[40]

[37] Ibid.

[38] Ibid.

[39] Ibid.

[40] Ibid.; For the results other engine-related tests, see AFFTC-TR-81-11, F-16A/B Full Scale Development Auxiliary Power Plant Evaluation: Final Report, Apr 82, and AFFTC-TR-80-24, F-16A/B Full Scale Development Fuel System Evaluation with JP-4 Fuel: Final Report, June 81. The results of these and a number of other engine-related tests were reported in the last History.

During the winter of 1978-79, the potential for serious foreign object damage (FOD) to the engines had been discovered both at Hill AFB, Utah, and during the European test and evaluation program. The F-16 created an inlet vortex which, under certain environmental conditions, could suck in water droplets from pools on the ramp into the engine inlet where ice would form on the inlet strut and the front frame of the engine. If the ice accumulated in large enough particles before shedding, it could seriously damage the engine. A series of tests, accomplished largely in the McKinley Climatic Laboratory at Eglin AFB, were conducted between May 1979 and May 1981 in an effort to find a solution to this problem.[41]

A number of modifications were initially evaluated as possible interim solutions. Thus, for example, icephobic materials were applied to the inlet strut and inlet guide vanes in an effort to reduce the amount of ice buildup and to induce continuous shedding of the ice that did accumulate. When this failed, the test force investigated a method of breaking the vortex. This involved placing a steel lattice grate on the ground beneath the inlet to reduce the amount of water lifted into the inlet by the vortex. While this method did succeed in reducing the amount of water sucked into the inlet to acceptable levels, it could only serve as an interim solution. A permanent solution, involving modification to the aircraft itself, would

[41] AFFTC-TR-81-25, F-16 Full-Scale Development Artificial Icing and Rain Evaluation: Final Report, Nov 81.

be required for operational conditions.[42]

The testing ultimately involved modifications to most of the engine's anti-ice system. Three different inlet strut heater configurations were tested. A two-loop heating element configuration produced the best results by a slight margin over a single-loop element. None of them, however, completely eliminated potentially damaging ice accumulations (the F-16 System Program Office selected the single-loop configuration for production). The test force discovered that "cutback" (reduced leading-edge thickness) inlet guide vane struts used in conjunction with the maximum allowable thirteeth-stage compressor bleed airflow (2.1 percent of the engine core mass flow) eliminated the struts as a source of foreign object damage. In the most effective total configuration, this bleed airflow was also forced through hollow double-baffled compressor inlet variable vanes (the heated bleed air was forced down along the vanes' leading edges, went up through their mid-sections, and then back down the trailing edges). These, and other modifications significantly reduced the potential for damaging ice accumulations but they did not solve the problem altogether. The test force recommended that a comprehensive in-flight icing test should be conducted as soon as possible to fully evaluate the collective impact of these modifications and to examine additional modification possibilities.[43]

[42] Ibid.; AFFTC-TER-No. I/R-4, F-16 Icephobic Materials Test and Evaluation, 15 Oct 79.

[43] AFFTC-TR-81-25.

F101 Derivative Fighter Engine Testing

While testing with the F100 engine was ongoing, the Air Force and Navy began to evaluate a derivative fighter engine which could conceivably replace Pratt & Whitney's powerplant if it demonstrated greater performance and durability. The General Electric F101 derivative engine was an advanced technology powerplant developing 26,000 to 29,000 pounds of thrust. It combined components of the F101 engine first developed for the B-1 bomber with technology from the YJ101 and F404 engines used in the YF-17 prototype and follow-on YF-17 programs (thus, for example, it used the core engine design from the F101 and a scaled-up F404 front fan and augmentor nozzle).44/

A limited preliminary flight test program got underway at the Flight Test Center in February of 1981. The F-16A (Serial No. 75-0745) testbed aircraft flew 51 sorties, for a total of 67.5 hours, between then and May when the prototype engine was sent back to General Electric for refurbishment prior to being subjected to a similar evaluation in a Navy F-14 fighter. Testing with the engine was expected to resume at the Flight Test Center in March of 1982.45/

No formal technical reports were prepared after this preliminary evaluation. In general, however, test force members were favorably impressed with the engine's performance.46/

44/F-16 CTF Monthly Summaries of Activities, Feb-May, Dec 81.

45/Ibid.

46/Ibid.; Discussion, AFFTC Center Staff Meeting, 26 May 81.

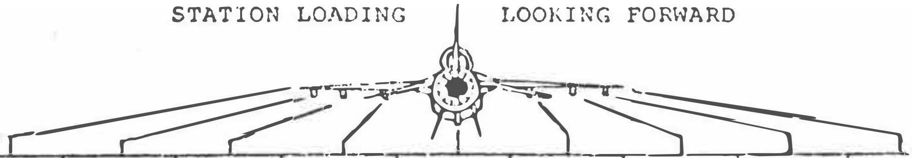
Flying Qualities

The F-16's unique aerodynamic design and fly-by-wire flight control system represented a radical departure from previous aircraft.* A substantial flying qualities developmental flight test program had already been completed as the current historical reporting period opened. This, however, had largely been confined to tests with the aircraft in the "clean" configuration (No. IA on fig. 108). A number of modifications, such as the moveable stick, and problems, such as the "deep stall" phenomenon at high angles-of-attack, had been thoroughly evaluated and the basic flying qualities of the F-16A and B had been judged as quite satisfactory. Pilots regarded some features, such as full-stick rolling performance, as "excellent"--very clearly adequate for the F-16's air superiority mission. Much testing, however, remained to be done. During the current reporting period a substantial test program was dedicated to evaluating the fighter's flying qualities when configured with a variety of external stores (see fig. 108). While these tests were being conducted, various modifications which had been proposed during the original full-scale development program would also be evaluated. Among these, the most important would be changes to the roll prefilter in the flight control computer and an

*For a detailed description of the F-16's unique design and the full-scale development flying qualities test and evaluation program, see The History of the AFFTC, 1977-78.

LOADING SUMMARY

STATION LOADING LOOKING FORWARD



LOADING	1	2	3	4	5	6	7	8	9
1A	AIM-9	-----	-----	-----	------	-----	-----	-----	AIM-9
1	AIM-9	-----	-----	370 Gal Tank	-----	370 Gal Tank	-----	-----	AIM-9
4	AIM-9	-----	ALQ-119-12	(6) MK-82 on MER	300 Gal Tank	(6) MK-82 on MER	-----	-----	AIM-9
9A	AIM-9	-----	-----	-----	ALQ-119-12	-----	ALQ-131	-----	AIM-9
10	AIM-9	-----	(3) AGM-65 on LAU-88	370 Gal Tank	ALQ-119-12	370 Gal Tank	(3) AGM-65 on LAU-88	-----	AIM-9
12 CA	AIM-9	-----	GBU-8/B	-----	ALQ-119-12	-----	Weapon Pylon	-----	AIM-9
23	AIM-9	-----	ALQ-119-12	-----	300 Gal Tank	-----	-----	-----	AIM-9
23A	AIM-9	-----	-----	-----	300 Gal Tank	-----	-----	-----	AIM-9

NOTE: Loading 1A was discussed in reference 1 and is presented here for comparison.

Fig. 108

angle-of-attack limiter for air-to-ground operations.47/

The overall flying qualities of the F-16 with external store loadings were rated as satisfactory throughout the flight envelope. The aircraft's handling qualities during takeoff were conventional. In the cruise configuration, the F-16 exhibited neutral* apparent speed stability throughout the Mach range at angles-of-attack of 15 degrees and below. Most pilots liked this neutral stability because it relieved them of the necessity to retrim during maneuvers involving gross airspeed changes. Above 15 degrees angle-of-attack and in the power approach configuration, apparent speed stability was positive.** Maneuvering stick force gradients with the "moveable" stick were rated as satisfactory and were essentially constant over a large portion of the flight envelope.48/

Pilots regarded the F-16's maneuvering characteristics with most external store configurations as quite similar to those of the "clean" aircraft. There were a few differences. Large external stores on stations 3 and 7 had a small aerodynamic

47/AFFTC-TR-80-29, F-16 Flying Qualities With External Stores: Final Report, Feb 81. For the results of a similar seriesof tests, see AFFTC-TR-81-29, F-16 SEEK EAGLE Testing ofParent Carriage Loadings: Final Report, Dec 81. Theresults of these tests were essentially the same as those forthe program discussed here.

48/Ibid.

*A system has neutral stability when a disturbance changes its performance, and it does not return to its original state, and if, when the disturbing force is removed, no further change takes place.

**Positive stability is present when a system or vehicle resists disturbance, or tends to return to its original position, condition, or direction if it is disturbed.

effect on static longitudinal stability (the tendency of the aircraft to return to equilibrium conditions following a disturbance) and moved the aircraft's center of gravity to the aft. Large external stores on stations 4 and 6 significantly degraded static longitudinal stability and moved the center of gravity forward. These aerodynamic and center-of-gravity changes would impose some restrictions on the aircraft when configured with large stores on the stations in question. Pilots also discovered that, with the heavy store loadings, the aircraft had a tendency to overshoot the desired bank angle because of the high roll inertia involved. Pilots would have to exercise considerable care to remain within Flight Manual bank angle change limits for air-to-ground store loadings.[49/]

Landings, in visual meteorological conditions were rated as satisfactory. The F-16's handling qualities when loaded with external stores were, in fact, considered better than with the aircraft in the clean configuration. At the Flight Manual recommended 13-degree angle-of-attack for approaches, pilots still found that flight-path instability, low Dutch roll damping, imprecise attitude control, and problems with the head-up display contributed to an excessive workload during landings. The workload during precision instrument approaches magnified the effects of these factors. None of them could be singled out as the primary cause of pilot dissatisfaction but, clearly, their combined effect required close, on-going attention.[50/]

[49/] Ibid.

[50/] Ibid.

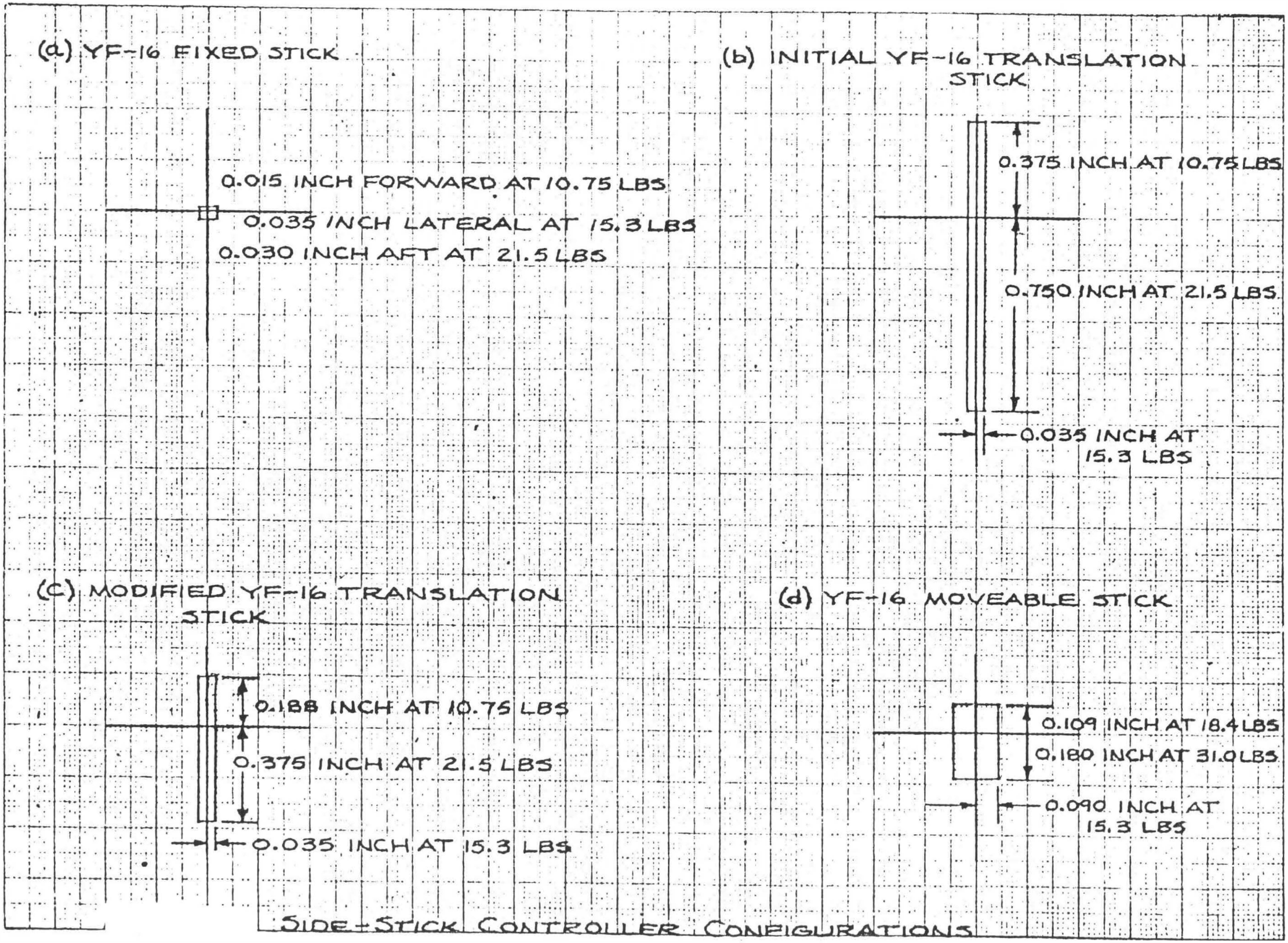
Throughout 1977 and 1978, the test force conducted a series of tests in which a "moveable" control stick was evaluated (see figs. 109a-c).* The moveable stick, with skewed axes and a force gradient reduced to 80 percent of that found on the YF-16 prototype, proved to be an immense improvement over the original "fixed" stick. Pilots felt much more comfortable with the motion cues provided by the stick. The moveable stick enhanced the F-16's handling qualities, especially during high gain tasks, and it substantially reduced pilot fatigue. Despite these improvements, there were still some notable stick-related problems at the end of the full-scale development program.[51]

The most disturbing problem was "roll ratcheting" which pilots encountered during moderate 360-degree rolls, decreasing roll-rate rolls, and formation flying. Roll ratcheting was a phenomenon characterized by high-frequency lateral oscillations (2 to 3 Hz) which appeared to be partially related to a physiological feedback of aircraft motion through the inertia of the pilot's hand and his grasp of the controller. The pilot's inability to adjust to a nonlinear lag in the roll prefilter was isolated as another possible factor. This prefilter managed the roll axis in the flight control computer. The roll prefilter employed throughout the full-scale development program was a nonlinear filter which provided a 0.4-second time constant for

[51] Ibid.; AFFTC-TER-FQ-3, F-16 Side-stick Controller/Roll Prefilter, 29 Nov 79.

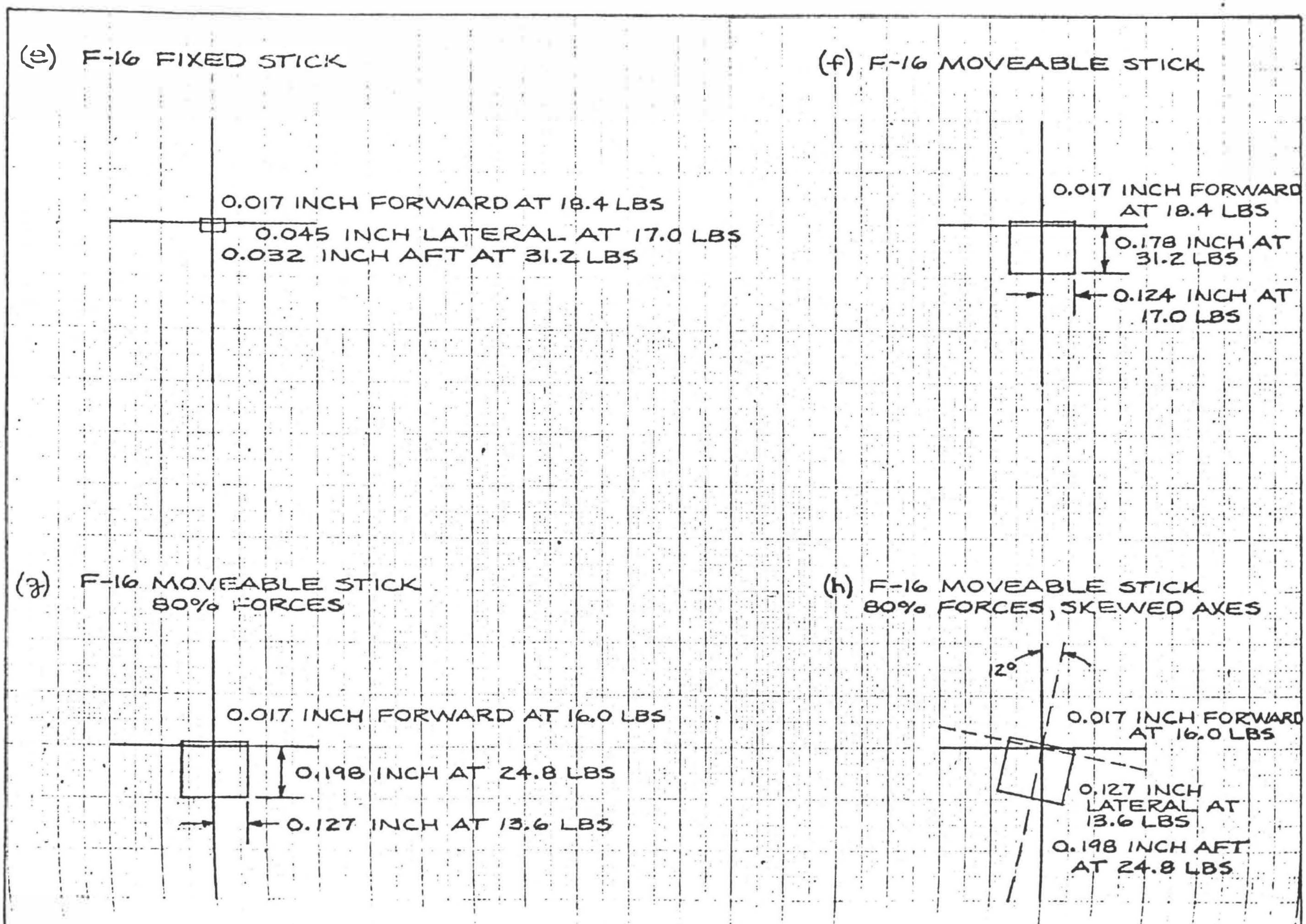
*For a detailed analysis of this subject, see The History of the AFFTC, 1977-78.

Fig 109a



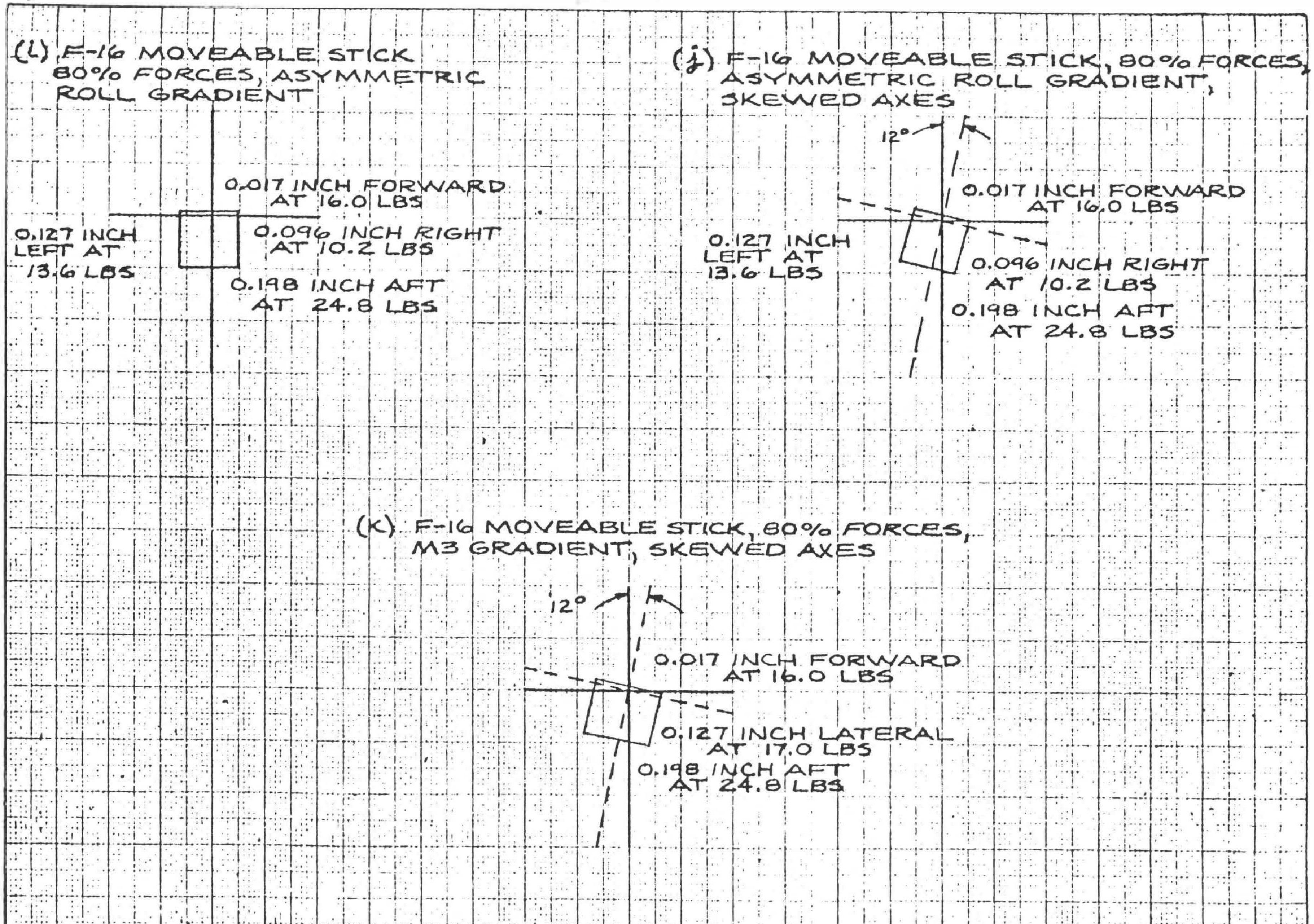
SIDE-STICK CONTROLLER CONFIGURATIONS

Fig. 109b



SIDE-STICK CONTROLLER CONFIGURATIONS (CONTINUED).

Fig. 109c



SIDE-STICK CONTROLLER CONFIGURATIONS (CONCLUDED) roll commands (ratios such as this are presented in a 0.4/0.1 format in the accompaning graph and table). Pilots found it difficult to adjust to the nonlinear lag--that is, to the wide variation between the roll-in time constant and the roll-out time constant. The 0.4-second time constant was, for example, considered too slow for roll-in during high gain tasks such as formation flying.52/

Engineers theorized that roll ratcheting could be reduced, or even possibly eliminated, by modifying the roll prefilter so that it would provide a linear response--that is, the same time constant for both the roll command input and its removal (for a comparison of the response characteristics between a typical linear roll prefilter and the 0.4/0.1 nonlinear prefilter, see fig. 110). The test force evaluated a series of linear and nonlinear prefilters, and combinations of both (see fig. 111), in an effort to find a blend of stick force gradients, stick motion, and prefilter time constants which would prevent problems such as ratcheting, pilot-induced oscillations, and over control.53/

This was no simple task. Pilot-induced oscillations occur when the initial aircraft response is less than expected, leading the pilot to make excessive initial stick inputs in order to achieve the desired response. Pilot-induced oscillations, then, were primarily due to time phase lag. Pilot overcontrol occurs when the aircraft's response is greater than desired. It could

52/AFFTC-TER-FQ-3.

53/Ibid.

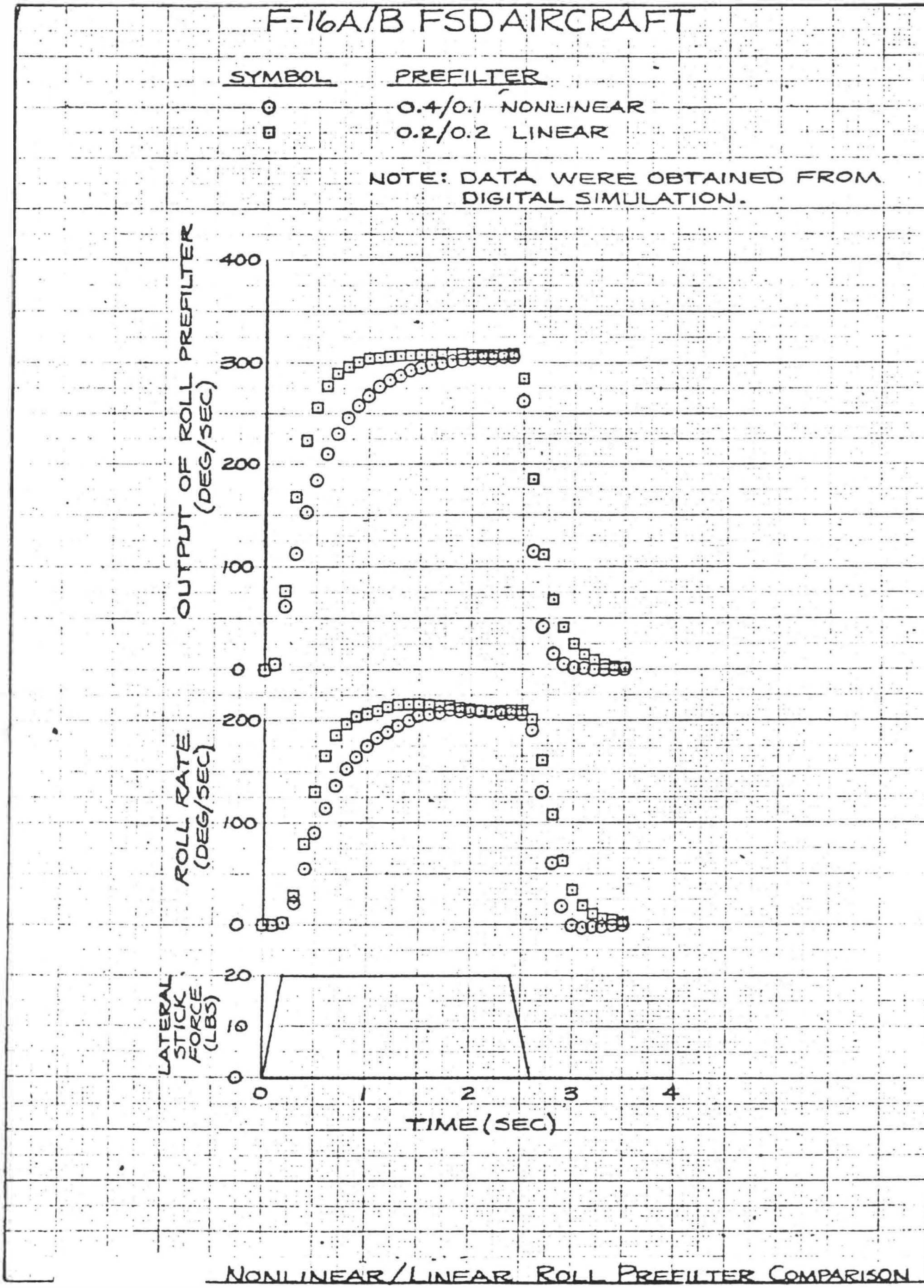

F-16A/B FSD AIRCRAFT
SYMBOL
PREFILTER
0.4/0.1 NONLINEAR
0.2/0.2 LINEAR
NOTE: DATA WERE OBTAINED FROM DIGITAL SIMULATION.
OUTPUT OF ROLL PREFILTER (DEG/SEC)
400
300
200
100
0
ROLL RATE (DEG/SEC)
200
100
0
LATERAL STICK FORCE (LBS)
20
10
0
0
1
2
3
4
TIME (SEC)
NONLINEAR/LINEAR ROLL PREFILTER COMPARISON

Fig. 110

PHASE	DATE	CONFIGURATION	FLIGHTS	PILOTS
V	21 Mar 1979 - 16 Oct 1979	9. F-16 Moveable Stick, 80% Force Gradient, Skewed Axes (Displacement Same As Configuration 5) Linear Roll Prefilter 0.2/0.2	4	4
		10. Same As Configuration 9 Except: Linear Roll Prefilter 0.267/0.267	14	7
		11. Same As Configuration 9 Except: Linear Roll Prefilter 0.333/0.333	1	1
		12. Same As Configuration 9 Except: Nonlinear Roll Prefilter 0.4/0.2	10	9
		13. F-16 Moveable Stick, 100% Force Gradient, Skewed Axes (Displacement Same As Configuration 9) Nonlinear FSD Roll Prefilter 0.4/0.1	4	4
		14. F-16 Moveable Stick, 80% M3 Force Gradient, Skewed Axes (Displacement Same As Configuration 9) Nonlinear Roll Prefilter 0.4/0.2	6	5
		15. Same As Configuration 14 Except: Linear Roll Prefilter 0.267/0.267	10	9
		16. Same As Configuration 14 Except: Variable Roll Prefilter 0.2/0.2 V 0.4/0.2	22	17
		17. Same As Configuration 14 Except: Variable Roll Prefilter 0.267/0.267 V 0.4/0.267	4	4
		18. Same As Configuration 14 Except: Nonlinear Roll Prefilter 0.3/0.2	4	4
		19. Same As Configuration 14 Except: Variable Roll Prefilter 0.22/0.22 V 0.4/0.22	2	2

Fig 111

very easily be caused, then, by very light stick forces and short prefilter time constants. Thus the prefilter time constants had to be short enough to prevent pilot-induced oscillations and slow enough to prevent overcontrol. And these time constants were, of course, related to the correct blend of controller force gradients and controller motion.54/

Thus, for example, during the course of this testing engineers found it necessary to modify the 80-percent force gradient which had been approved during the full-scale development program. While the 80-percent gradient (see fig. 112) proved to be acceptable for small roll commands (up to ±8.8 pounds--the first two slopes on the graph), it was "too steep" for the tolerance of the flight control computer's voting logic during roll commands higher than 80 degrees per second. Engineers determined that the 80-percent forces could be made acceptable be modifying the third slope of the roll command gradient. The 80-percent forces were retained for commands up to ±8.8 pounds but the third slope was modified so that, by the time a pilot commanded 310 degrees per second, he was required to exert 17 pounds of force (this equalled the original--or 100-percent--force gradient). This gradient was referred to as the 80-percent M3 (80 percent modified third slope) roll command gradient and it was incorporated in all of the later roll prefilter evaluations (see fig. 113).55/

54/Ibid.

55/Ibid.

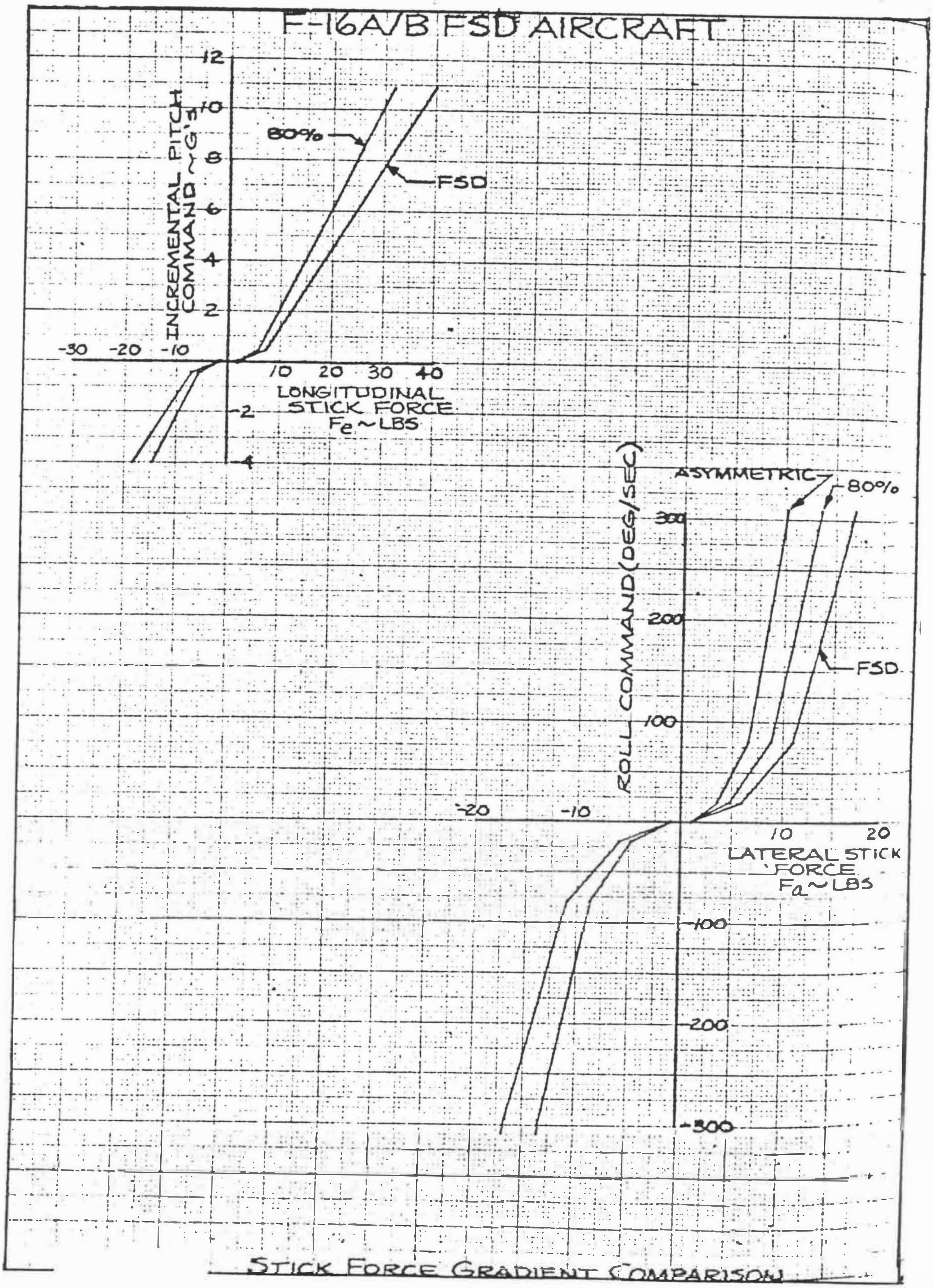

F-16A/B FSD AIRCRAFT
INCREMENTAL PITCH COMMAND ~ G's
12
10
8
6
4
2
-2
-4
-30
-20
-10
10
20
30
40
80%
FSD
LONGITUDINAL STICK FORCE
Fe ~ LBS
ROLL COMMAND (DEG/SEC)
300
200
100
-100
-200
-300
-20
-10
10
20
ASYMMETRIC
80%
FSD
LATERAL STICK FORCE
Fa ~ LBS
STICK FORCE GRADIENT COMPARISON

Fig. 112

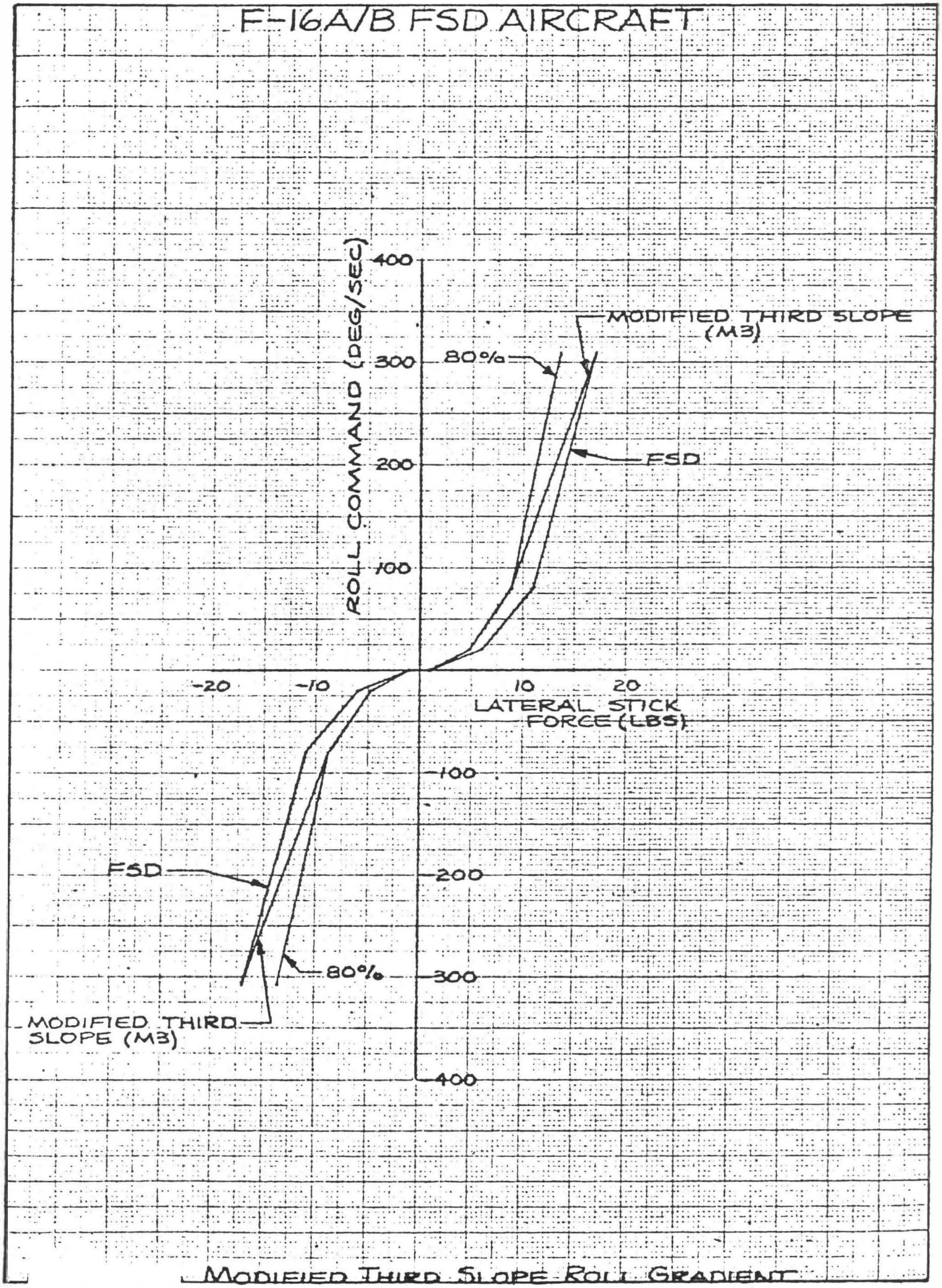

F-16A/B FSD AIRCRAFT
ROLL COMMAND (DEG/SEC)
400
300
200
100
-100
-200
-300
-400
-20
-10
10
20
LATERAL STICK
FORCE (LBS)
MODIFIED THIRD SLOPE
(M3)
80%
FSD
FSD
80%
MODIFIED THIRD
SLOPE (M3)
MODIFIED THIRD SLOPE ROLL GRADIENT

Fig. 113

After looking at a variety of linear and nonlinear prefilters, the test force found that neither type, by itself, provided completely satisfactory results. Thus, for example, while pilots found the quickness of the 0.2/0.2 configuration desirable for high gain tasks such as formation flying, they also found that aircraft response was too quick for gross maneuvering in the high speed-low altitude regime. A nonlinear roll prefilter combination of 0.4/0.2 eliminated roll ratcheting in gross maneuvering but it generated sluggish roll control during formation flying and tracking. So it went with each of the early combinations; they would eliminate one problem while amplifying others.[56]

Finally, in order to retain the best features of both the linear and the nonlinear prefilters, a variation to the filter was produced. This variable roll prefilter permitted linear operation for low-rate roll commands (up to ±20 degrees per second) and then provided nonlinear operation for high-rate roll commands. This filter was referred to as 0.2/0.2 v 0.4/0.2.[57]

Pilots found that this configuration offered precise attitude control without pilot-induced oscillations, racheting, or over control. In fact, the blend of stick movement, forces, and roll prefilter time constants with this configuration was so natural that pilots did not even have to consciously think about roll control. The test force, in its final report, recommended

[56] Ibid.

[57] Ibid.

that "the moveable stick with 80 percent forces, M3 roll gradient, skewed axes, and the 0.2/0.2 v 0.4/0.2 variable roll prefilter should be incorporated in all F-16 aircraft."58/

The other major modification tested during the current reporting period was an angle-of-attack limiter for air-to-ground operations. The F-16 already had such a limiter for air-to-air operations. The aircraft had already demonstrated excellent high angle-of-attack flying qualities and satisfactory departure resistance with the air-to-air limiter. With air-to-ground loadings, however, satisfactory flying qualities and departure resistance could only be achieved by observing Flight Manual maneuvering restrictions. These limits were difficult to observe unless the pilot focussed his attention on the angle-of-attack guage and closely monitored his change in bank angle. The F-16's flight control system provided such uniform flying qualities that the conventional pilot cues--buffet, wing rock, high stick forces, etc.--which normally indicated an impending departure were not present. Thus, when maneuvering in an operational head-up situation, the pilot would be unaware of his proximity to departure boundaries and could easily continue to maneuver abruptly while exceeding the Flight Manual limits. In that event, departure from controlled flight would be quite probable and, in an air-to-ground mission, a departure would be lethal.59/

In order to provide the pilot with the same type of

58/Ibid.

59/AFFTC-TR-80-25, F-16 Air-to-Ground Angle of Attack Limiter Evaluation: Final Report, Feb 81.

automatic command limiting features which already existed for air-to-air loadings, an angle-of-attack limiter was developed for air-to-ground store loadings. With the air-to-ground limiter activated, the flight control system provided a lower angle-of-attack limit than with the air-to-air limiter. It produced an "average"* angle-of-attack limit of 16 degrees. The limiter also provided more restrictive roll rate and rudder pedal command limiting than the air-to-air version. The same load factor limiter value of 9 g's, however, was retained in order to provide emergency over-g" capability.[60]

Test results indicated that, with air-to-ground store loadings, the angle-of-attack limiter provided satisfactory departure resistance, although it did not make the F-16 absolutely departure free. It also permitted "head-out-of-the-cockpit" maneuvering and acceptable maneuvering performance for the air-to-ground mission if tactically sound airspeeds were maintained. With certain store loadings, the limiter permitted the expansion of the maneuvering envelope for maximum command rolls by up to 4 degrees angle-of-attack and a reduction of as much as 50 knots calibrated airspeed from what had previously been the minimum maneuvering airspeed limit. Pilots found that, with the limiter activated, there was no need to monitor angle-of-attack when performing maximum command maneuvers. The roll rates were more than adequate for

[60] Ibid.

*The actual limit was dependent on a number of factors such as center of gravity, altitude, store-loading configuration, etc.

positioning the lift vector in air-to-ground deliveries and for performing defensive maneuvers such as turn reversals.61/

Increased Area Horizontal Tail

In 1978, General Dynamics initiated a program to improve the design concept for the F-16's horizontal tail. This decision was based largely on manufacturing considerations, including:62/

- o To increase producibility
- o To reduce manufacturing manhours and life cycle costs
- o To eliminate dependency on titanium which was increasingly in short supply and subject to escalating prices.

Although it was not a part of the initial development motivation, analysis indicated that the larger tail would offer some aerodynamic advantages over the small tail. Predictions, based on wind tunnel data, indicated that:63/

- o The increased area horizontal tail would reduce takeoff distances by lowering rotation speeds. This difference would be most pronounced at higher gross weights and forward center-of-gravity positions where the small tail F-16's stabilator authority was fully taxed.
- o The larger tail would reduce the F-16's deep stall tendencies due to an improvement in pitching moment. With a small tail F-16 at nominal center of gravity (35 percent mean

61/Ibid.

62/"F-16 Increased Area Horizontal Tail (IAHT) Test Results," paper delivered by Lt Col David W. Milam and Capt Craig Dunn, F-16 CTF, to the Society of Experimental Test Pilots 12th Mini-Symposium, San Diego, Calif., 2-3 Apr 82.

63/Ibid.

aerodynamic chord), pitching moment went to zero with full trailing edge down stabilator at approximately 50 degrees angle-of-attack. At this angle-of-attack the horizontal tail was "saturated" and could not prevent a departure or deep stall. The larger tail would maintain a negative pitching moment with full trailing edge down stabilator for the same flight conditions. Specifically, wind tunnel predictions indicated that this improvement in pitching moment would prevent deep stalls for air-to-air (designated Category I) loadings with centers of gravity forward of 38 percent mean aerodynamic chord.

o The enlarged tail would permit relaxation of aft center-of-gravity limits for various store loadings (see fig. 114).

CENTER OF GRAVITY LIMITS

AIRCRAFT BLOCK NO.	CAT I	CAT II	CAT III	LIMITING FACTOR
BLOCK NO. 1 WITHOUT MPO	34%	32.5%	40.0%	CAT I AND II - DEEP STALL RECOVERY USING SPEEDBRAKE CAT III - ROLL COUPLING
BLOCK NO.s 1 05, 10 WITH MPO	38%	36.5% (W/TANKS) 38.0% (W/O TANKS)	40.0%	ALL CATEGORIES - ROLL COUPLING

Fig. 114

Center-of-gravity migration to 41.8 percent mean aerodynamic chord was predicted for Category I loadings and to 44.2 percent for Category III (air-to-ground) loadings.

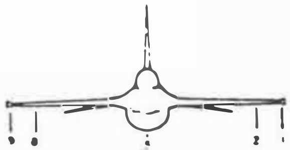
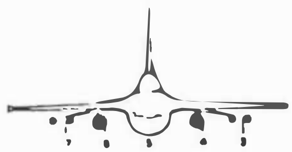
o The larger horizontal tail would also provide sufficient stabilator power to eliminate maneuvering limits with Category II loadings by allowing Category I maneuvers with external tanks and air-to-ground suspension equipment (see fig. 115). The increased stabilator power would also permit 360-degree rolls with symmetric Category III loadings.

The increased area horizontal tail (see figs. 116 and 117) was designed with graphite-epoxy skins mechanically fastened to a built-up corrugated aluminum substructure with an aluminum pivot shaft. In comparison, the original horizontal tail was composed of graphite-epoxy skins bonded to an aluminum honeycomb substructure with a titanium shaft and spar assembly. The new tail had an area approximately 30 percent larger than the original tail. Its surface authority was reduced to ±21 degrees as compared to the original tail's surface authority of ±25 degrees. The addition of the larger tail imposed only a few, relatively minor modifications to the original flight control system. These included a reduction in the gain in the pitch axis to 0.84 of the original tail's value, and a change in the differential horizontal tail-flaperon ratio in the roll axis (provided more differential horizontal tail deflection per flaperon deflection in subsonic flight and less in supersonic flight than the original flight control system configuration).[64]

Testing got underway on 25 March 1981 and was still ongoing as the current historical reporting period came to a close. During the period extending through 18 February 1982, when the initial test report was published, the F-16A (Serial No. 75-0746)

[64] AFFTC-TR-82-12, Flying Qualities and High Angle-of-Attack Evaluation of the F-16A/B With the Increased Area Horizontal Tail: Final Report, Aug 82.

EXTERNAL STORES CATEGORIES

	CATEGORY	STORE	STATION
	I	ANY STORE (SYMMETRIC OR ASYMMETRIC)	1. 2. 5. 8. 9.
	II	SUSPENSION EQUIPMENT OR MISSILES	3. 4. 6. 7
		370 GAL TANKS (STA 3 AND 7 CLEAN)	4. 6.
	III	AIR-TO—SURFACE STORES. SYMMETRIC ECM PODS. ASYMMETRIC STORES (GREATER THAN 200 LBS)	3.4.6.7
		370-GAL TANKS WITH STORES ON STA 3 OR 7	4. 6
		3 EXTERNAL TANKS	4. 5. 6

AOA AND ROLLING LIMITS

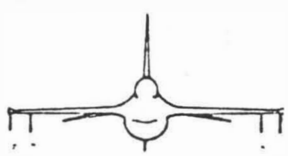
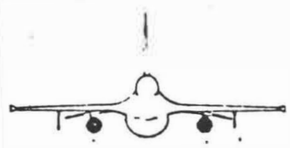
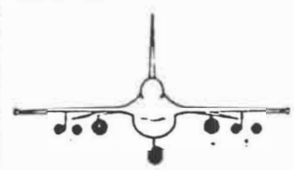
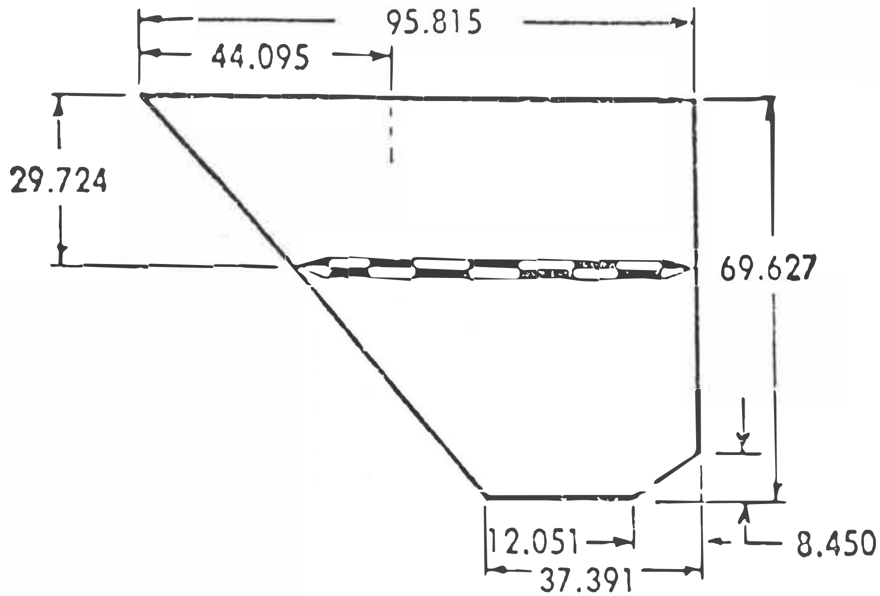
	AIR-TO-AIR		AIR-TO-GROUND
	CAT I  • ANY STORE AT 1. 2. 5. 8. 9	CAT II  • TANKS ONLY. OR • ECM OR MISSILES AT 3. 4. 6. 7	CAT III  • BOMBS AND TANKS OR BOMBS AT 3. 4. 6. 7 • 3 TANKS (AT 4. 5. 6.)
SYMMETRIC MANEUVERS	AOA LIMITER	AOA LIMIT (WITH FUEL MANAGEMENT) 18° AOA (WITHOUT FUEL MANAGEMENT)	ANGLE-OF-ATTACK MUST BE MONITORED (18° LIMIT)
ROLLING MANEUVERS	AOA LIMITER COMMAND 360° ROLLS	360° MAX COMMAND ROLLS UP TO 15° AOA; 180° ROLLS ABOVE 15° AOA (WITH FUEL MANAGEMENT) 360° MAX COMMAND ROLLS UP TO 12° AOA; 180° ROLLS ABOVE 12° AOA (WITHOUT FUEL MANAGEMENT)	12° AOA MAX COMMAND 180° ROLLS

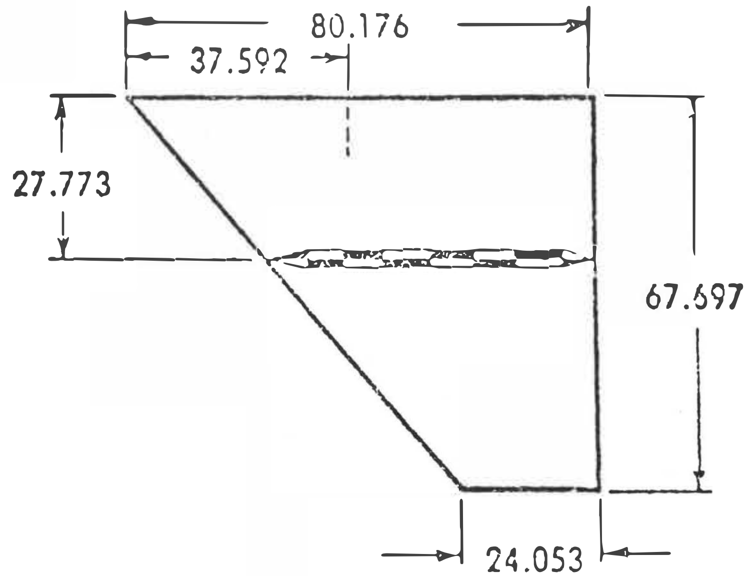
Fig. 115

IAHT



AREA	4586.4 IN^2
	31.85 FT^2
MAC	70.874 IN
ASPECT RATIO	2.114
AIRFOIL	BICONVEX
t/c ROOT	6.00%
t_{max} ROOT	5.749 IN
t/c TIP	3.50%
t_{max} TIP	1.309
AUTHORITY	± 21.0 DEG

ORIGINAL

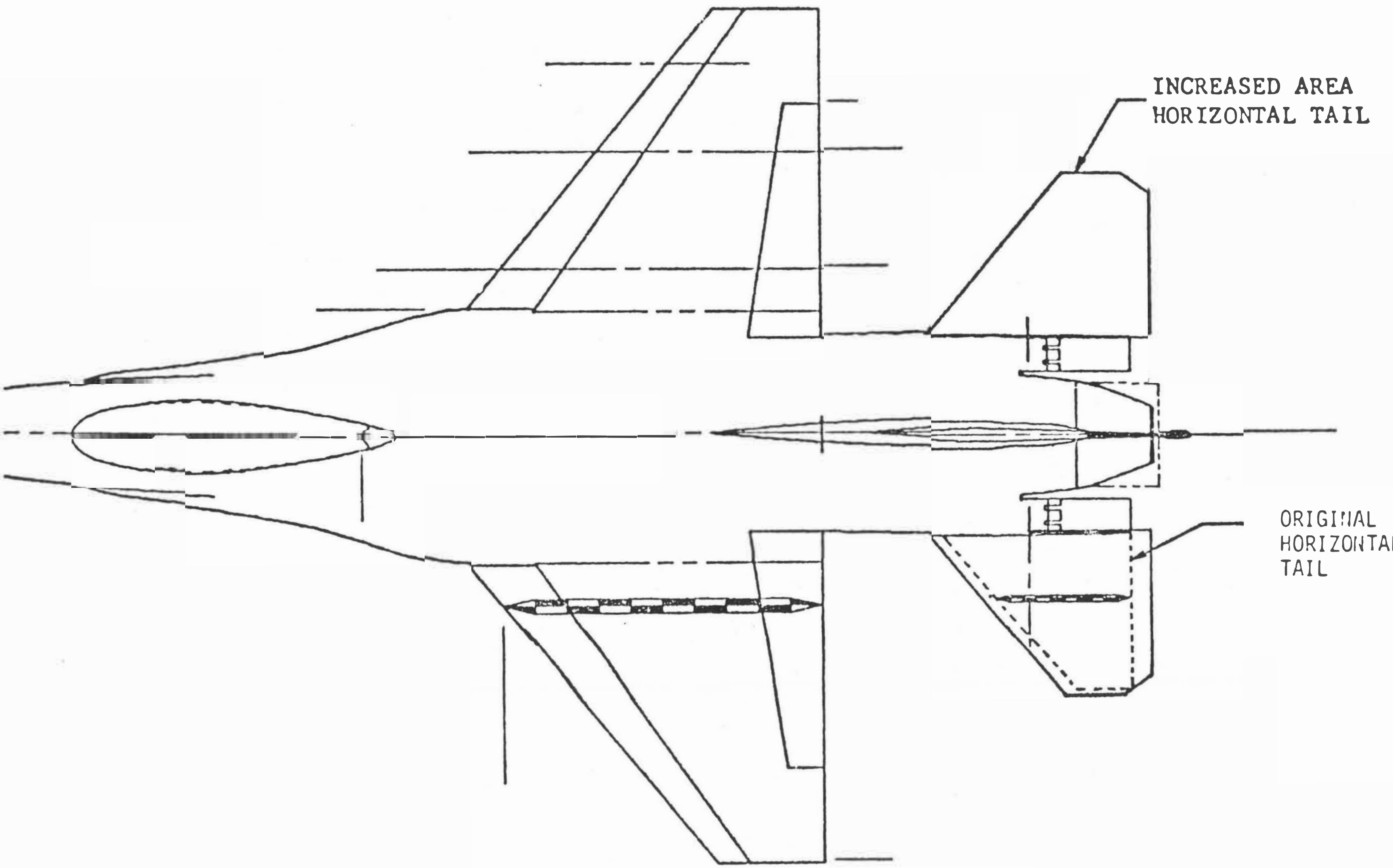


AREA	3528.0 IN^2
	24.50 FT^2
MAC	57.141 IN
ASPECT RATIO	2.598
AIRFOIL	BICONVEX
t/c ROOT	6.00%
t_{max} ROOT	4.811 IN
t/c TIP	3.50%
t_{max} TIP	.842 IN
AUTHORITY	± 25.0 DEG

GEOMETRIC COMPARISON OF THE IAHT AND OHT

Fig. 116

Fig. 117



COMPARISON OF IAHT WITH OHT

and F-16B (Serial No. 75-0751) aircraft were flown a total of 75 times. Thirteen of these sorties were dedicated to flying qualities, six to performance (data from these flights were invalid), and fifty-six to high angle-of-attack tests. The high angle-of-attack tests were accomplished in accordance with a two-phase plan. Phase I was designed to evaluate the high angle-of-attack flying qualities and to define the boundaries between controlled and uncontrolled flight. Phase II consisted of intentional departures from controlled flight to evaluate out-of-control characteristics and recovery techniques.65/

Basically, the test results supported the predicted improvements. Data from actual flight test indicated:66/

o The increased area horizontal tail did reduce rotation speeds, especially for high aircraft gross weights and forward centers of gravity. Due to the increased effectiveness of the larger tail, however, the possibility of over-rotation existed and takeoff attitude could be achieved well in advance of takeoff speed. This premature rotation increased drag and consequently lengthened the takeoff roll. The problem could be controlled by pilot technique and a caution about lower stick force requirements for takeoff with the larger tail was incorporated into the Flight Manual.

o The larger tail did significantly reduce the potential for deep stalls. A total of 46 departures were accomplished with 28 of these being self-recovering. The remaining 18 resulted in

65/Ibid.

66/Ibid.; Milam and Dunn, "F-16 Increased Area Horizontal Tail."

either upright (15) or inverted (3) deep stalls which did not self-recover. With the small tail, departures and subsequent deep stalls had been produced in one of three ways--maximum command rolling maneuvers, abrupt longitudinal control inputs at low airspeed, and high pitch attitude maneuvers during which insufficient airspeed was achieved. With the enlarged tail, high pitch attitude, low airspeed maneuvers were the only way to repeatedly enter deep stalls. The manual pitch override (the "pitch rocker" first tested during the initial high angle-of-attack flight tests in 1978-79) once again proved to be an effective deep stall recovery device when properly utilized. Proper use of the override, however, remained a subject of concern. Six of the eighteen deep stalls had required two cycles of the stick with the pitch rocker activated before recoveries were achieved. The larger tail did not eliminate the possibility of deep stalls for some loading and center-of-gravity conditions as had been predicted by wind tunnel tests. Those tests had predicted that the improved pitching moment of the enlarged tail would prevent deep stalls for air-to-air loadings with centers of gravity forward of 38 percent mean aerodynamic chord. During actual flight test, deep stalls were encountered at centers of gravity as far forward as 36 percent mean aerodynamic chord. As Lt. Col. David W. Milam, the F-16 Combined Test Force director, later observed:67/ "This is just another example of theory not matching reality, and clearly emphasizes the continuing

67/As quoted in "F-16 Increased Area Horizontal Tail."

requirement for actual flight testing."

o The englarged tail essentially eliminated the potential for roll-coupled departures when the F-16 was configured with symmetric loadings and maximum bank angle change limits were observed. With symmetric air-to-ground loadings (Category III), for example, sufficient aircraft nosedown pitching moment was provided to prevent departures during 360-degree rolls with centers of gravity as far aft as 42 percent.

o The larger tail eliminated the need for pilots to manually balance fuel in order to maintain the aircraft within allowable center-of-gravity limits. Aircraft center-of-gravity limits were relaxed to the maximum aft percentage possible for worst case air-to-air and air-to-ground loadings (see fig. 118). The air-to-ground limit, however, was not as far aft as the 44.2 percent predicted by wind tunnel tests.

F-16 IAHT ALLOWS MORE AFT C.G. LIMIT

	BLOCK 01	BLOCK 05	BLOCK 10	BLOCK 15 AND ON (WITH BIG TAIL)
CATEGORY I	34	38	38	41/40*
CATEGORY II	32.5	36.5	36.5	NA
CATEGORY III	40	40	40	42

* WITH EXTERNAL TANKS

Fig. 118

o Most significantly, the increased area horizontal tail eliminated previously imposed maneuvering limits on Category II store loadings--and, in doing so, thereby eliminated the need for the category itself (see fig. 119). Air-to-air loadings with external wing tanks and weapons pylons would hereafter be designated as Category I and 360-degree rolls, at air-to-air limiter angles-of-attack would now be permitted.

IAHT AOA AND ROLL LIMITS

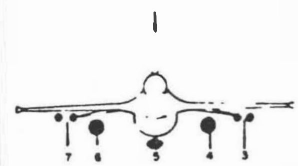
	AIR-TO-AIR		AIR-TO-GROUND
	CAT I		CAT III
			
	• ANY STORE AT 1, 2, 5, 8, 9	• TANKS ONLY, OR • ECM OR MISSILES AT 3, 4, 6, 7	• BOMBS AND TANKS OR BOMBS AT 3, 4, 6, 7 OR • 3 TANKS (AT 4, 5, 6)
SYMMETRIC MANEUVERS	LIMITER AOA		LIMITER (16°) AOA
ROLLING MANEUVERS	LIMITER MAX COMMAND 360° ROLLS		LIMITER

Fig. 119

The one significant area where the enlarged tail did not improve flying qualities was during landing approaches. Pilots detected virtually no difference between the original and the enlarged tails. The aircraft still exhibited imprecise pitch attitude control, poor angle-of-attack control, low Dutch roll damping, and flight path instability. During aft center-of-gravity approaches, in fact, the pitch attitude control problems of the original tail were compounded by the larger version upon entering ground effect. A statement was incorporated into the Flight Manual landing procedures which addressed this increased pitch sensitivity during aft center-of-gravity approaches. There was also a more noticeable pitchup when the weight-on-wheels switch engaged as aircraft speed decreased during landing rollout. A transient fader, which made the pitchup easily controllable, was incorporated into all enlarged tail production aircraft and a caution regarding the pitchup was incorporated into the Flight Manual.68/

The increased area horizontal tail did reduce production costs and, in the flight testing conducted through early 1982, it appeared to provide significant operational benefits. It would be incorporated into the design of all production aircraft, beginning with Block 15 models.69/

Avionics and Weapons Testing

Full-scale development testing on the F-16's avionics got underway in May of 1977, and various phases of it continued on until October of 1979.* During that time, a total of 364 flights had been dedicated to the fire control radar system alone. Overall, the radar system's performance progressed from unsatisfactory to marginally satisfactory during this two-and-one-half-year program. The large number of problems encountered during the early part of the program meant that

68/ AFFTC-TR-82-12.
69/ Ibid.
* For a detailed discussion of the early phases of this testing, see The History of the AFFTC, 1977-78.

approximately 60 percent of all flights had to be dedicated to development, while only 40 percent were concerned with evaluation. Thus a number of areas were not fully evaluated by the end of the full-scale development program--and a number of the radar's deficiencies remained. Some of these were eliminated during--or as a result of--the European test and evaluation program already discussed in this chapter. Other problem areas, however, required dedicated test programs during the current reporting period. Major programs were conducted which were aimed at improving the fire control radar's performance in air-to-air and air-to-ground combat modes.[70]

During both the Phase I full-scale development program and the European test and evaluation program, the F-16 had consistently demonstrated a "long-bomb bias" during air-to-surface weapon deliveries. Analysis of the test data uncovered two principal causes for the problem. The first was an aiming error and the second was an air-to-ground ranging error in the fire control radar.[71]

The aiming error was revealed in significant differences between the computed pipper-to-target depression angle and the actual depression angle at release as given by time-space-positioning information. The source of this sighting misalignment was found to be a ± 3 milliradian boresight error

70/ AFFTC-TR-80-6, F-16 Radar and REO Systems Evaluation: Final Report Apr 80; AFFTC-TER-AW-5, F-16 Adverse Weather and ET&E Tests, 25 Feb 80.

71/ AFFTC-TR-81-2, F-16 Improved Avionics Air-to-Surface Bombing Evaluation: Final Report, May 81.

caused by mechanical interference between the pilot display unit on the head-up display and the pilot display unit tray. This error was eliminated simply enough by relocating the pilot display unit nameplate.

Air-to-ground ranging errors appeared to be caused by a number of factors. Some were caused by erroneous radar returns from a 16-foot corner reflector located 2,000 feet short of the intended target. The aircraft, when on the established profile run-in line, overflew the reflector causing ranging errors of up to 600 feet. Another source of the ranging error was discovered when some test boom instrumentation wiring was found in the radome. The wiring had been inadvertently left in the radome after the boom had been removed from the aircraft. This, apparently, caused distorted radar antenna patterns with resulting ranging errors of up to 600 feet. A final source of error was determined to be a 5-milliradian misalignment of the fire control radar antenna elevation resolver.

The F-16 Combined Test Force conducted a 65-flight test program, between 4 January and 13 August 1980, in order to determine if modifications addressing these deficiencies effectively improve bombing accuracy. A total of 536 bombs were dropped during the evaluation. These included 108 BDU-33B/B's, 324 BDU-33D/B's, 74 MK-82's (low drag general purpose), and 30 MK-84's (low drag general purpose).

During the initial tests, bomb scores were improved but a long-bias was still evident with MK-82, BDU-33B/B, and BDU-33D/B releases. Data analysis revealed a 5.7-milliradian angular bias antenna pointing error. The required modification was made to the antenna elevation command software in the fire control computer and immediate improvements in accuracy were achieved. The test force, however, was unable to determine the original source of the bias error.

Tests were also conducted to determine if there was sufficient variation between ejector cartidge lots to cause differences in separation characteristics. No significant differences were detected. The test force also discovered that no significant changes in bombing accuracy could be achieved by shifting the radar antenna pointing bias from the fire control computer's operational flight program to the fire control radar's program.

Overall, the test program demonstrated that the F-16 had the potential to be an "excellent" air-to-surface weapon delivery platform. Both the continuously computed impact point and the continuously computed release point modes demonstrated satisfactory accuracy with most weapon and bomb rack combinations. While the dive toss mode demonstrated acceptable accuracy with most weapons, its delivery accuracy with MK-84 bombs was well outside of specification requirements. If these weapons were to be used in the dive toss mode, further testing would be required in order to improve accuracy.[77]

Air-to-air gunnery tests had also been hampered by the need to evaluate an excessive number of modifications and refinements during the full-scale development program. System improvements to the radar, fire control computer, head-up display, canopy optics and in gun boresighting were not refined to the point where meaningful quantitative evaluation could begin until August of 1979. And testing with a system comparable to a production configuration was not complete until August of 1980 (for a brief summary of the different phases of testing, see fig. 120).[78]

The F-16 had three air-to-air gunnery modes: lead computing optical sight, snapshoot, and dogfight.

o Lead computing optical sight - This mode provided a gunnery solution for smooth tracking of a target. These computations were performed in the head-up display using data from the head-up display rate sensor unit and the air data computer, and range from either the radar or stadiametric ranging. The gunsighting mode on the F-16 consisted of a disturbed reticle algorithm mechanized in the fire control computer and lead computing optical sight display on the head-up display. The basic computational flow is presented in fig. 121. After the values for bullet time-of-flight and velocity were solved, the kinematic

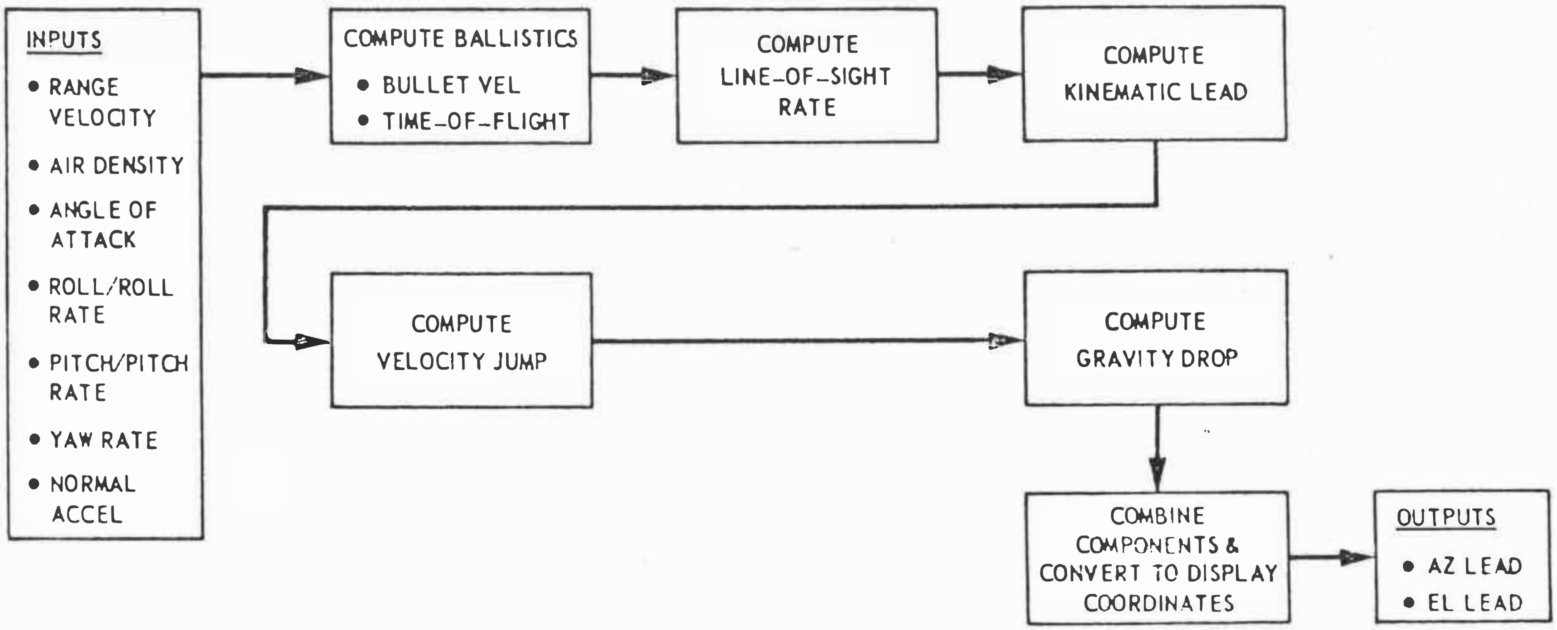
[77] AFFTC-TR-80-35, F-16 Improved Avionics Air-to-Air Gunnery Evaluation: Final Report, Feb 82 ; AFFTC-TR-80-35, F-16 Improved Avionics Air-to-Air Gunnery Evaluation Addendum 1 Dogfight Mode: Final Report , 15 June 82.

Fig. 120

AIR-TO-AIR GUNNERY TEST PHASES

Phase	Description	Inclusive Dates	TIS	Remarks
	Initial FSD Tests	August 1977 - August 1979	16PP211	Tests were highly developmental in nature. Frequent hardware/software changes to the radar, FCC and HUD along with refinements in canopy optics boresighting techniques and test procedures made quantitative accuracy assessment impractical.
II	Tests with FSD Avionics (Block 05)	August 1979 - November 1979	FA-401	These tests were structured to establish agreement between GD and AFFTC on the general accuracy level of the F-16 against a non-maneuvering target. Additionally, these tests were used to make ATAGAS compatible with the F-16 test aircraft. Some accuracy analysis was accomplished.
III	Accuracy Tests with Improved Avionics (Block 10)	November 1979 - August 1980	FA-711	Quantitative accuracy evaluation with Block 10 avionics. (Lag line added during test phase).

Fig. 121



LCOS Mechanization

lead term was computed. The pseudo line-of-sight rate was computed from body-mounted rate gyros. The velocity jump of the bullet was induced by the combined effects of aircraft velocity and muzzle velocity on the bullet as it emerged from the gun. The effect was computed as a function of angle-of-attack, muzzle velocity, and F-16 velocity. Bullet gravity drop was computed, and was combined with the kinematic and velocity jump terms to form the lead angle solution. After the lead angle was computed, the solution was transformed to display components for the placement of symbology on the head-up display. On the head-up display (see fig. 122), cues for closure rate, target range, and range at one second time-of-flight appeared on the aiming reticle. An 8-milliradian gunnery pipper appeared in the center of the aiming reticle.

o Snapshoot gunnery mode - This mode displayed a simulated tracer line that indicated to the pilot where the bullets would be if he had been firing his gun continuously. These computations were also performed in the head-up display using data from the display's rate sensor unit and the air data computer, and range from either the radar or stadiametric ranging. This mode was tested only in conjunction with each of the other modes (see fig. 123).

o Dogfight gunnery mode - This mode provided simultaneous computation and display of snapshoot and missile dynamic launch zones. Selection of this mode (1) overrode any weapon delivery modes previously selected, (2) selected an AIM-9 missile, (3) placed the radar in the automatic acquisition mode (the radar searched out a 20-degree by 20-degree sector centered about the

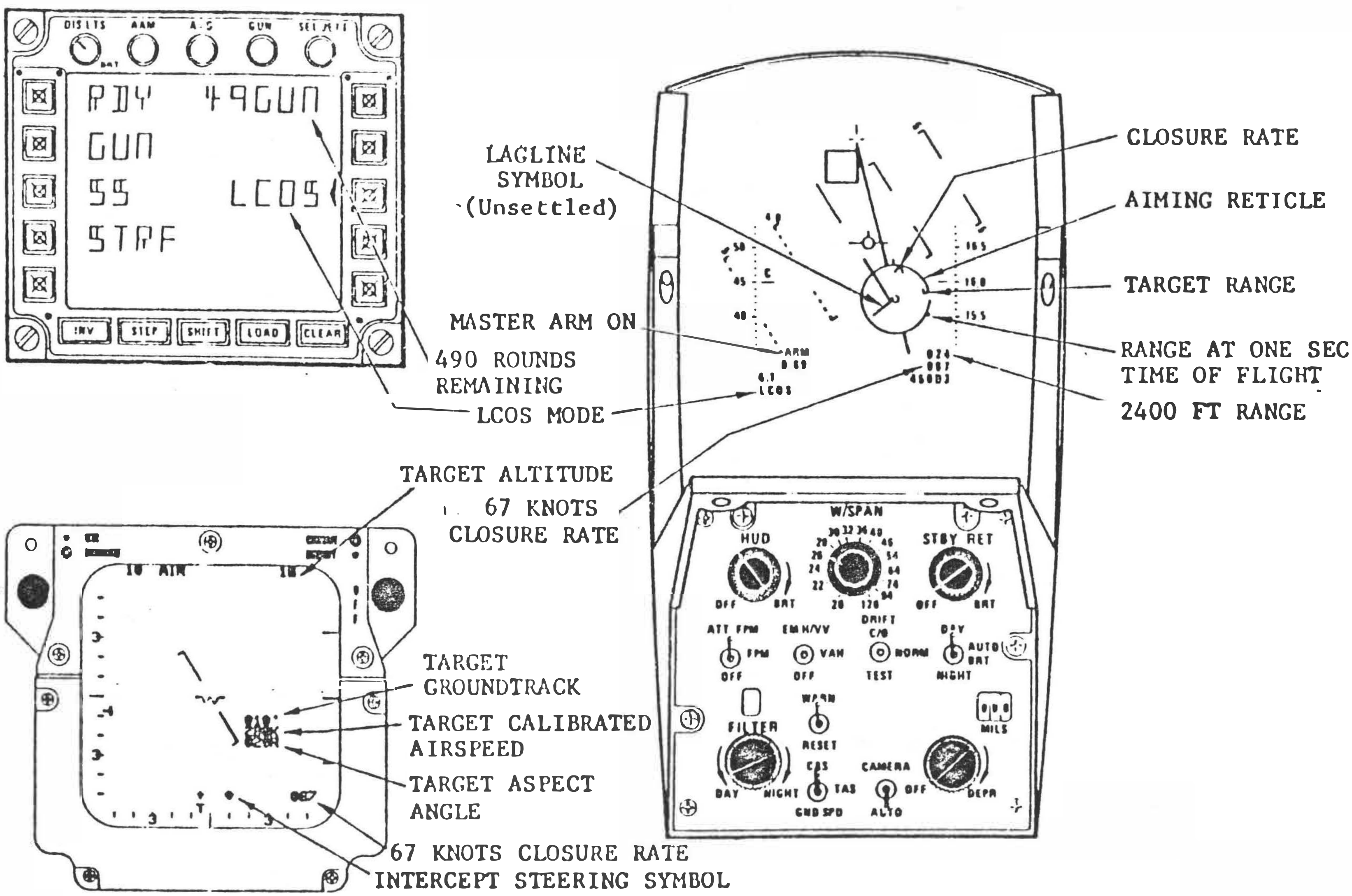
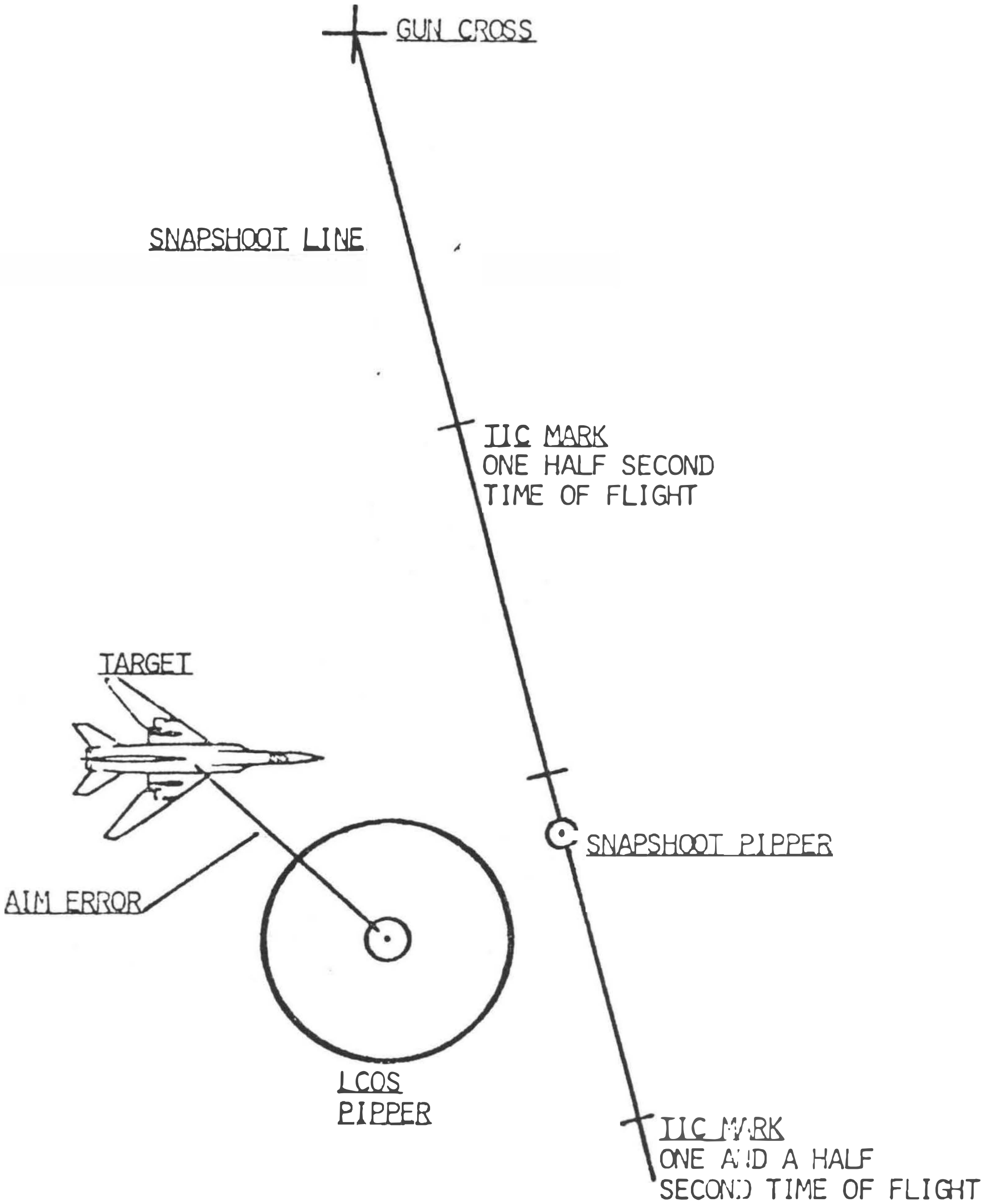


Fig. 122

LCOS Gunnery Symbology



F-16 Dogfight Symbology

Fig. 123

head-up display's field-of-view), (4) selected snapshoot computation, (5) selected dynamic launch zone computation, and (6) displayed snapshoot and missile cues on the head-up display. For air-to-air gunnery, the dogfight mode consisted of a snapshoot line and a lead computing optical sight pipper (see fig. 123). The snapshoot line displayed bullet positions on the head-up display that simulated where the bullets would be if the pilot had been firing continuously. Range marks were positioned on the line that showed where a bullet would be if it had been fired one-half, one, and one and one-half seconds previously. The snapshoot pipper position on the line represented how long it would take a bullet to reach the target. The pilot fired the gun when he judged that the target, the lead computing optical sight pipper, and the snapshoot pipper would coincide one bullet-time-of-flight in the future.

At the conclusion of the evaluation, the test force concluded that:79/ "The F-16 gunsight system can be highly effective for combat, but the pilot needs to understand its unique characteristics to achieve maximum capability of the system." A number of deficiencies were responsible for this rather qualified endorsement. With the lead computing optical sight these included:80/

o While the lead computing sight algorithm was accurate with zero roll rate, large errors occurred when roll rates were

79/AFFTC-80-35, Feb 82.

80/Ibid.

introduced.

o Distortion caused by the canopy was large enough to cause significant aiming errors.

o The F-16's flying qualities compromised the aircraft's capabilities as a gun platform. A "pitch bobble" characteristic (typical of flight control systems which command load factor rather than pitch rate) was evident throughout the testing. The pitch bobble could be minimized (and, in some cases, eliminated), but only at the expense of degraded tracking performance. This was accomplished by making slower stick inputs during attempts to minimize aiming errors and accepting the resulting increase in "pipper wander." In effect, this meant that precise tracking of the target with the lead computing optical sight pipper would be difficult to accomplish and probably result in very few hits--and attaining small (or zero) aiming errors when at firing conditions would require a high pilot workload.

o The radar "probably" provided accurate target g in stabilized track but there were lags and errors immediately after acquisition and during dynamic target maneuvering. Some means would have to be found to provide accurate information on how long to wait after radar acquisition to ensure that the target g estimation was correct.

o Success with this mode was very dependent on pilot technique. The techniques which would result in hits on target were the "slidding pipper" method and the "pulled pipper" method. The sliding pipper method required the pilot to move the pipper toward the target without attempting to gain a steady track. The pulled pipper required the pilot to track a point behind the target, start shooting, and then pull the pipper through the target while firing.

The following conclusions were drawn from the evaluation of the dogfight mode:[81]

o The dogfight mode did not provide any greater envelope than the lead computing optical sight, i.e., the snapshoot and lead computing optical sight both provided a limited all-aspect capability even when used properly.

o There was no significant difference between the dogfight gunsight and the lead computing optical sight in the areas of accuracy or pilot utilization. The snapshoot line was neither a significant benefit nor a significant degradation to the lead computing optical sight in the dogfight mode.

o The snapshoot line, however, did provide some cue of gunsight settling.

o Excessive pilot compensation was required to achieve hits on target.

o The only way to use the dogfight mode was to track with the lead computing optical sight and use the snapshoot line as a settling cue.

Tests to qualify the production radar had taken nearly two years longer to complete than other production system tests. The radar would continue to require substantial development effort. Nevertheless, completion of the basic qualifications tests was considered quite a significant milestone. Over the previous four

81/ AFFTC-TR-80-35 Addendum 1 , 15 June 82 years, the system had been improved from the "unacceptable" to the stage where it was at least suitable for operational use.82/

F-16/79 Low Cost Export Fighter

During December 1980 and January 1981, the Flight Test Center supported a brief, 15-flight program involving the new F-16/79 which General Dynamics and General Electric were hoping to sell as a low-cost export fighter. The F-16/79 was the product of a marriage between the F-16's advanced airframe and fly-by-wire flight control system and the venerable J79-17X turbojet engine which had already seen more than two decades of service in U.S. and foreign fighters. Although most of the testing on the F-16/79 was conducted at General Dynamics' Fort Worth facility, the brief flight test program at Edwards was required to accomplish engine airstarts, critical engine and airframe compatibility maneuvers, and performance maneuvers requiring supersonic flight below 30,000 feet pressure altitude. When fully developed, the aircraft was expected to compete against Northrup F-5G Tigershark for selection as this nation's next export fighter.83/

Other Testing

Neither time nor space permits a meaningful discussion of each of the many flight test projects involving the F-16. The

82/Memo, Mr. Frederick Stolicker, AFFTC Technical Director, to Mr. Ted Bear, AFFTC Historian, 4 Aug 80.

83/AFFTC Project Directive No. 81-14, F-16 Low Cost Export Fighter, 17 Nov 80; AFFTC Statement of Capability No. F-80-08-02, F-16 Low Cost Export Fighter, 11 Aug 80; AFFTC Program Introduction Document No. P-75-08-02, Revision 2, 15 Apr 78.

following list of technical reports and selected test and evaluation reports published during the current reporting period (or dealing with testing largely conducted during this period) will, however, provide an indication of the wide variety of projects with which the F-16 Combined Test Force was concerned.

AFFTC Technical Reports

Report No.	Title	Date
TR-79-13	DT&E Reliability and Maintainability Evaluation of the F-16 Aircraft	June 79
TR-79-11	Performance Evaluation of the F-16A Airplane With F100-PW-100(3) Engine	Oct 79
TR-79-18	F-16A/B High Angle-of-Attack Evaluation	Oct 79
TR-79-22	F-16 FSD Built-in-Test/Self-Test Systems Effectiveness Evaluation	Oct 79
TR-80-1	Human Factors Test and Evaluation of F-16 FSD Operations	March 80
TR-80-6	F-16 Radar and REO System Evalu- ation	April 80
TR-80-7	F-16 FSD Arresting System Evalu-ation, Vol. I	June 80
TR-80-13	F-16A Flameout Landing Evaluation	July 80
TR-80-7	F-16 FSD Arresting System Evaluation, Vol. II, Addendum 1, Structural Damage	Oct 80
TR-80-26	F-16 Full-Scale Development Airframeand Landing Gear/Brake Evaluation	Jan 81
TR-80-29	F-16 Flying Qualities With External Stores	Feb 81
TR-80-25	F-16 Air-to-Ground Angle-of-Attack Limiter Evaluation	Feb 81
TR-80-28	Performance Evaluation of the F-16 FSD Aircraft With External Stores	March 81

Report No.	Title	Date
TR-81-2	F-16 Improved Avionics Air-to-Ground Surface Bombing Evaluation	May 81
TR-80-24	F-16A/B Full-Scale Development Fuel System Evaluation with JP-4 Fuel	June 81
TR-80-34	F100-PW-100(3) Engine Starting Evaluation in the F-16 FSD Aircraft Using JP-4 Fuel	July 81
TR-81-19	Mobile Aircraft Arresting System Runway Configuration Compatibility Test Results	Sept 81
TR-81-10	F-16 FSD Engine/Inlet Compatibility and Engine Stability Evaluation Using JP-4 Fuel	Nov 81
TR-81-25	F-16 Full-Scale Development Artificial Icing and Rain Evaluation	Nov 81
TR-81-26	F-16 Full-Scale Development Environmental Control System Evaluation	Nov 81
TR-81-29	F-16 Seek Eagle Testing of Parent Carriage Loadings	Dec 81
TR-81-27	F-16 Full-Scale Development Secondary Power Systems and MIL-H-83282 Hydraulic Fluid Climatic Laboratory Evaluation	Dec 81
TR-80-35	F-16 Improved Avionics Air-to-Air Gunnery Evaluation	Feb 82
TR-81-11	F-16A/B Full Scale Development Auxiliary Power Plant Evaluation	April 82
TR-80-35	F-16 Improved Avionics Air-to-Air Gunnery, Addendum 1: Dogfight Mode	June 82
TR-82-12	Flying Qualities and High Angle-of Attack Evaluation of the F-16A/B With Increased Area Horizontal Tail	Aug 82

Selected Test and Evaluation Reports

Report No.	Title	Date
TER-AW-4	F-16 Arctic Weather Test	23 June 79
TER-I/R-2	F-16 Pre-European Deployment Artificial Icing Tests	4 Sept 79
TER-I/R-2	F-16 Pre-Tropical Deployment Artificial Rain Tests	4 Sept 79
TER-I/R-4	F-16 Icephobic Materials Test and Evaluation	15 Oct 79
TER-FQ-3	Side-Stick Controller/Roll Prefilter	29 Nov 79
TER-71.1	F-16 FSD Radio Navigation and ILS Evaluation	7 Feb 80
TER-11.1	F-16A/B Airframe Evaluation: General All-Weather	25 Feb 80
TER-AW-5	F-16 Adverse Weather and ET&E Tests	25 Feb 80
TER-13.1	F-16 FSD Landing Gear and Brake Evaluation	14 May 80
TER-74.1	F-16 FSD Inertial Navigation System	20 Jan 81
TER-45.2	F-16 Hydraulic System Climatic Operation	17 July 81
TER-PR-1	F-16 Light-Off Detector Evaluation	28 Oct 81
TER-HF-1	F-16 MISVAL Evaluation	18 Dec 81