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CHARACTERISTICS AND APPLICATIONS OF BLUFF BOMBS

VOLUME I - CHARACTERISTICS AND APPENDICES

AIRCRAFT COMPATIBILITY BRANCH
MUNITIONS DIVISION

MAY 1975

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Bluff shaped bombs are of interest as an internally carried munition because they package well in internal bays and can be delivered throughout the flight envelope of the carriage aircraft. A proposal was made to develop bluff bombs through use of adapter kits consisting of nose and tail castings to convert inventory warheads to bluff shapes. It was further proposed to modify an F-111 weapons bay to carry five such bluff bombs based on the M117 warhead. A program was established to develop and test the hardware proposed and to investigate

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potential applications of bluff bombs to tactical and strategic conventional weapons roles. The bluff bomb tested, called the M117M6, exhibited good separation characteristics up to Mach 2.0 but ballistic performance at altitudes above a few thousand feet is characterized by excessive dispersion due to aerodynamic stability considerations. Analyses were conducted that show bluff bombs may have minimal application to the B-52, FB-111, and F-111 aircraft but appear to be a promising weapon for B-1 applications.

PREFACE

The work described in this report was accomplished during the period from June 1970 through September 1974 by the Aircraft Compatibility Branch (DLJC), Munitions Division, Air Force Armament Laboratory, Armament Development and Test Center, Eglin AFB, Florida. Funding was provided through Program Element 64602F, Project 5064, Supersonic Weapons Separation. The program manager was Mr. Charles S. Epstein. The principal engineers were Mr. Epstein and Mr. Robert A. Hume, Jr.

Significant contributions to the hardware development, fabrication, wind tunnel testing, and flight test data reduction discussed in Volume I were made by General Dynamics Corporation, Convair Aerospace Division, Fort Worth Operation, Fort Worth, Texas, under Air Force Contracts F08635-71-C-0065 and F08635-72-C-0104. The program manager at General Dynamics was Mr. A. B. Riley. Significant contributions to the effectiveness analyses contained in Volume II were made by the Strike Studies Branch (DLYA), Weapon Systems Analysis Division of the Air Force Armament Laboratory. The principal investigator for that branch was Mr. Jon G. Bailey.

This report consists of two volumes: Volume I - Characteristics (Unclassified), and Volume II - Applications (Confidential).

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

WILLIAM F. BROCKMAN, Colonel, USAF
Chief, Munitions Division

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LIST OF ABBREVIATIONS AND SYMBOLS

Q, q	-	Dynamic Pressure
RMS	-	Root Mean Square
t	-	Time, Seconds
x	-	Longitudinal Displacement
y	-	Lateral Displacement
z	-	Vertical Displacement
α	-	Angle of Attack
θ	-	Pitch Angle
ψ	-	Yaw Angle
Λ, Λ_{LE}	-	F-111 Wing Leading Edge Sweep Angle

SECTION I

INTRODUCTION

One of the few radical departures from conventional design practices in aerially delivered ordnance is the bluff bomb. Bluff shapes are not a new concept but only in the past few years has any recognizable effort been made to develop bluff bomb technology to the point where it would be usable with weapon systems. There are several reasons for interest in this shape of weapon. First, the short compact shape allows high density packaging in aircraft bays. This is especially true in short wide bays since most conventional weapons are long and narrow. Second, bluff weapons exhibit relatively high free stream drag due to their basic shape and therefore can allow the delivery aircraft to safely escape bomb fragments even during low altitude delivery. Third, bluff bombs exhibit relatively low lift and moment coefficients curve slopes and therefore separate well at all speeds by passing through the flow field rapidly with minimal perturbation.

There were several programs that provided major impetus to the M117 bluff bomb program addressed herein. First, during the Supersonic Munition Program conducted by the Air Force and the Boeing Company during the mid-1960's, a 500-pound-class bluff shaped bomb, the BLU-58/B (Figures 1 and 2), was developed and successfully flight tested (References 1 and 2). Second, the AF, NASA, and General Dynamics Corporation have conducted a program to gain improved performance capabilities with the F-111, called the Transonic Aircraft Technology Program. This program incorporated wing shape and structural changes that would allow improved cruise and dash performance. However, the wing, in order to be effective, had to be clean, meaning that ordnance had to be carried internally in the small weapons bay. Although the bay was designed with only two bomb racks it was apparent that there was room in the bay for many more bombs if these bombs exhibited better packaging efficiency in the bay. A bomb such as the BLU-58/B appeared to be an excellent candidate. Third, as the conventional weapons capabilities of the B-1 became better defined, it became apparent that the bay dimensions were such that maximum compatibility with inventory conventional weapons would not be achieved because the usable bay length of about 168 inches was excessively long for a single stack of weapons (most of which are about 90 inches long) but not long enough for two stacks of weapons. Also, from experience with the B-52, it was assumed that significant separation problems could be anticipated during releases from the deep bays of the B-1 at high speeds with conventionally shaped munitions. It was expected, however, that short bluff bombs would package well in the B-1 bays and also separate well from the bays throughout the expected B-1 subsonic/supersonic flight envelope. Finally,

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References:

1. The title of this reference is available to qualified agencies upon request to AFATL (DLJC), Eglin Air Force Base, Florida.

2. ADTC Technical Report ADTC-TR-69-169, Contractor Support Test of BLU-58/B Supersonic Bomb, November 1969, UNCLASSIFIED.

a contractor, General Dynamics Corporation, had proposed a unique and inexpensive way to create bluff bombs. That technique was to cast metal nose and tail caps. After removing the normal tail from a bomb and reversing the warhead, and caps would be installed on the warhead and held in place by the fuze. The resulting bluff bomb would be approximately 60 percent as long as its inventory counterpart. Also through such a concept a whole family of bluff bombs could be envisioned, based on available warheads with known terminal effects, thereby avoiding the time consuming and costly development of a whole new family of bombs. Further, the contractor proposed to fabricate a rack assembly using MAU-12 ejectors that would allow carriage of five modified M117 bluff bombs in the weapons bay of an F-111. The five-bomb configuration constitutes a high density load configuration.

Although a single continuous effort was conducted to provide information on bluff bombs, the various studies can be generally characterized as addressing either the characteristics of the bombs (such as their physical, fabrication, loading, separation or ballistic characteristics) or their applications (such as tactical, strategic, high altitude, low altitude, subsonic or supersonic delivery utility). While the characteristics are documented by observation, the applications represent best estimates of potential utility based on projected physical characteristics. Accordingly, this report is divided into two volumes to separate the factual data from the projected estimates. Volume I, Characteristics, addresses the design, fabrication and flight testing of some bluff shaped bombs. Volume II, Applications, contains estimates of the potential utility of some bluff bombs with several aircraft in tactical and strategic roles. Volume I is unclassified; Volume II is classified CONFIDENTIAL.

SECTION II

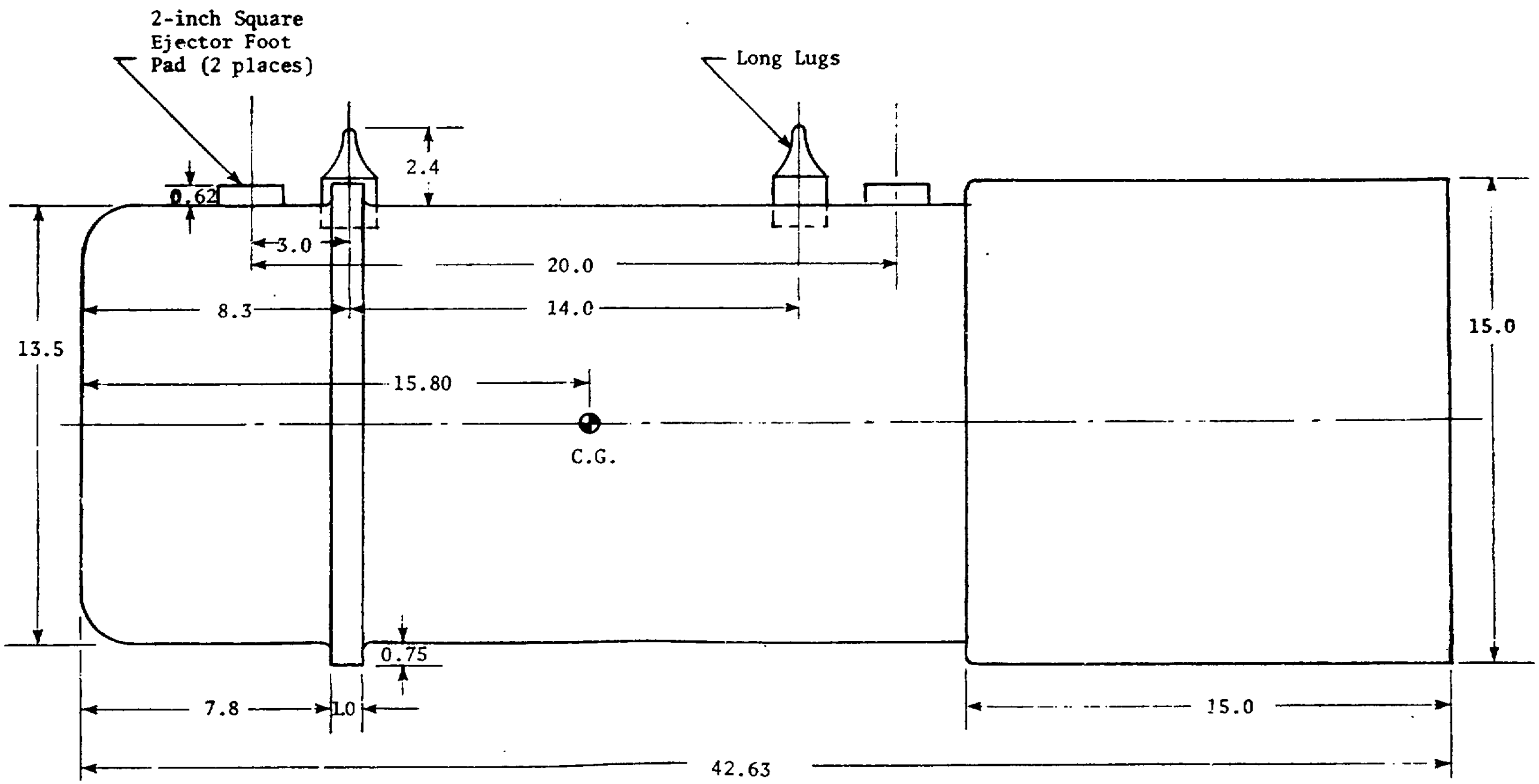
DISCUSSION

An engineering development program was established to conduct the necessary bluff bomb hardware development and fabrication, wind tunnel tests, separation and ballistic analyses, and flight testing. Primary program objectives were to demonstrate the feasibility of a kit-type bluff bomb based on an inventory warhead, to establish the delivery characteristics of such a weapon, and to gather information on high speed delivery of ordnance from high density internal bay configurations.

Hardware design and fabrication were conducted for the Air Force by General Dynamics through an unsolicited proposal. Hardware was initially to be similar in shape to the BLU-58/B but based on the M117 warhead. The M117 warhead provides a length-to-diameter ratio ($L/D \approx 3$) very similar to the BLU-58/B but the bluff bomb based on the M117 (termed the M117M) is larger and weighs about 800 pounds. Wind tunnel testing was conducted as appropriate to establish the aerodynamic characteristics of M117M variations and to provide safe separation predictions. Flight tests were conducted to verify separation characteristics and to gather ballistics and pattern information. The program was originally structured to gather terminal effects data (to establish any effect the kit had on warhead fragmentation characteristics) but arena testing was determined to be too costly. As a partial substitute, a release was made with fuzed live bombs to demonstrate feasibility of concept.

F-111/BLU-58

During flight tests discussed in Reference 2 BLU-58/B bombs (Figures 1 and 2) were released from F-105 and F-4 external pylons. At the completion of that test there were eight bombs available as residual hardware. Contractor wind tunnel data were already available to show that the BLU-58/B would separate well from the existing F-111 bay. Since flight tests with these bombs could be supported at minimal costs, the first phase of flight tests under this effort was the single and ripple release of two BLU-58/B bombs from the normal F-111 weapons bay at transonic Mach numbers from 0.8 to 1.3. Additionally, since a kitted type bluff bomb was envisioned for later test programs, a wind tunnel test program was conducted to determine the exact bomb shape desired. Although it was desirable to simply fabricate a kit that would convert an M117 warhead to a scaled-up BLU-58, it was also desirable to gather parametric information to assess the effects of factors such as nose length, aft end length and position, forward ring height and position, and the shape of the aft face. A series of fifth-scale models were tested at the General Dynamics high speed wind tunnel in San Deigo, California. Tests were conducted at Mach numbers from 0.6 to 2.2 and angles of attack of up to ± 23 degrees.



NOTE: All dimensions in inches

Figure 1. BLU-58/B

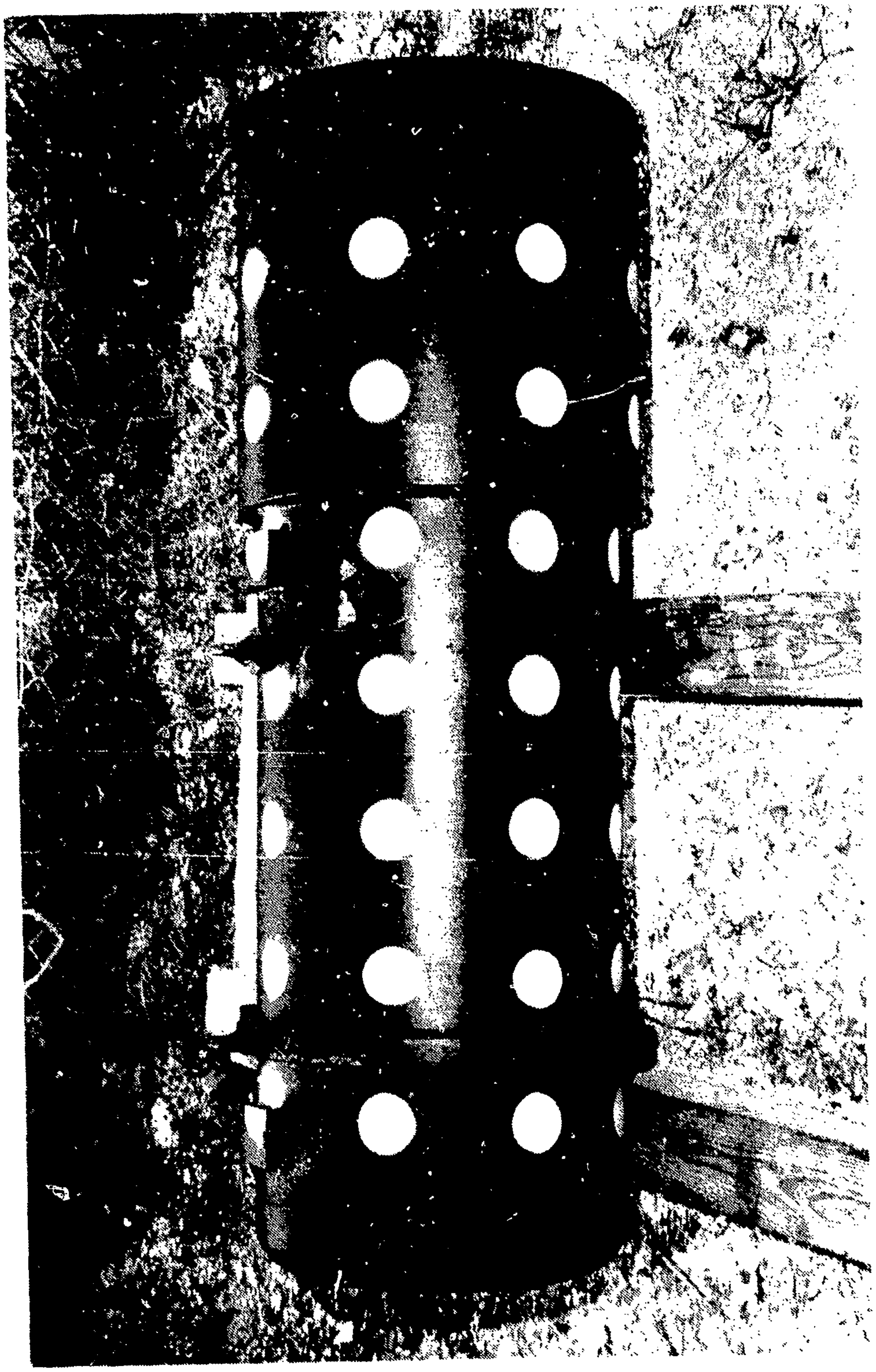


Figure 2. Inert BLU-58/B

In general, the results of the wind tunnel test show that the aerodynamic characteristics of the scaled up M117M compare well with BLU-58/B data. Although variation of geometric characteristics of the basic shape could be shown to affect drag and stability, the stability levels were all felt to be insufficient. Based on the test data, further wind tunnel testing was recommended for conduct during later program phases. The basic M117M is shown in Figures 3 and 4.

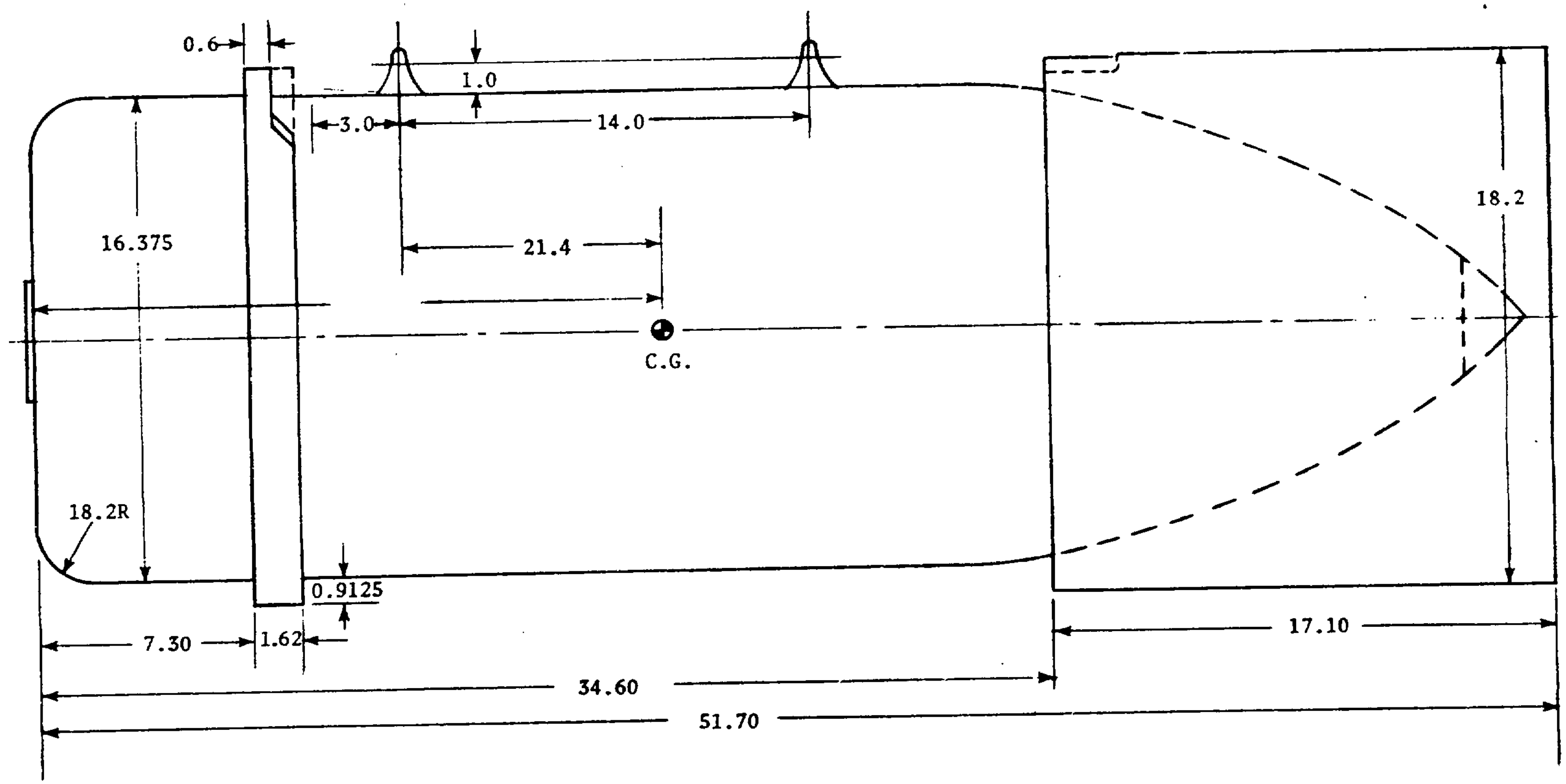
Since flight test program could be conducted at minimal cost, one was established. Releases were made at the Armament Development and Test Center from an F-111A bay (Figure 5) as part of the Supersonic Munitions Project, Reference 3. Test parameters are shown in Table 1. All releases were in straight and level flight. Wind tunnel and flight test separation data are shown in Figures 6, 7, 8, and 9. Due to an ejector rack problem (rear ejector foot vented prematurely) the first store released pitched nose down about 90 degrees and oscillated all the way to the ground. The fifth store released picked up a coning motion about 10 seconds after release and eventually went unstable. Releases 7 and 8 were to be a ripple release but were inadvertently released in salvo. As these two bombs separated, they each yawed slightly nose outboard and their tails collided.

TABLE 1. RELEASE OF BLU-58/B FROM F-111 BAY

Release	Bay Position	Mach	Altitude (Feet MSL)	ALE	Remarks
1	Left	0.82	2.2K	45°	90° nose down pitch due to vented ejector. No onboard photographic coverage.
2	Right	0.87	2.1K	45°	No onboard photographic coverage.
3	Left	0.92	6.5K	45°	
4	Right	0.97	6.8K	45°	Ballistic data showed excessive drag.
5	Left	1.19	20.4K	63°	Coning after 10 seconds, went unstable.
6	Right	1.29	20.0K	63°	
7	Left	1.20	20.0K	--	Salvo released, tails
8	Right	1.20	20.0K	--	collided after release.

References:

3. ADTC Technical Report, ADTC-TR-71-55, Test of High Density Bombs (BLU-58/B) on the F-111 Aircraft, May 1971, UNCLASSIFIED.



NOTE: All dimensions in inches

Figure 3. M117M

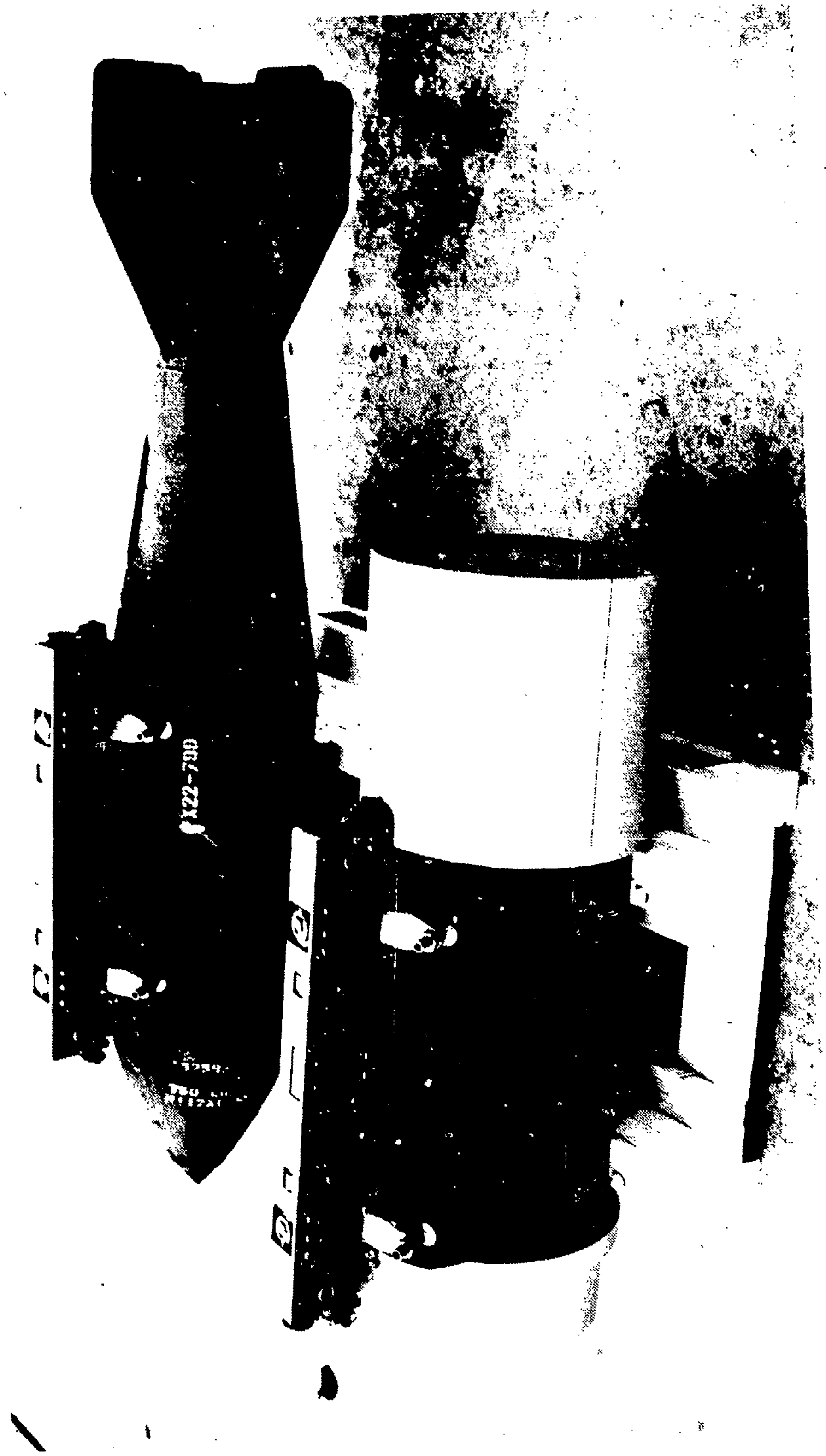


Figure 4. Comparison of Basic M117 and M117M

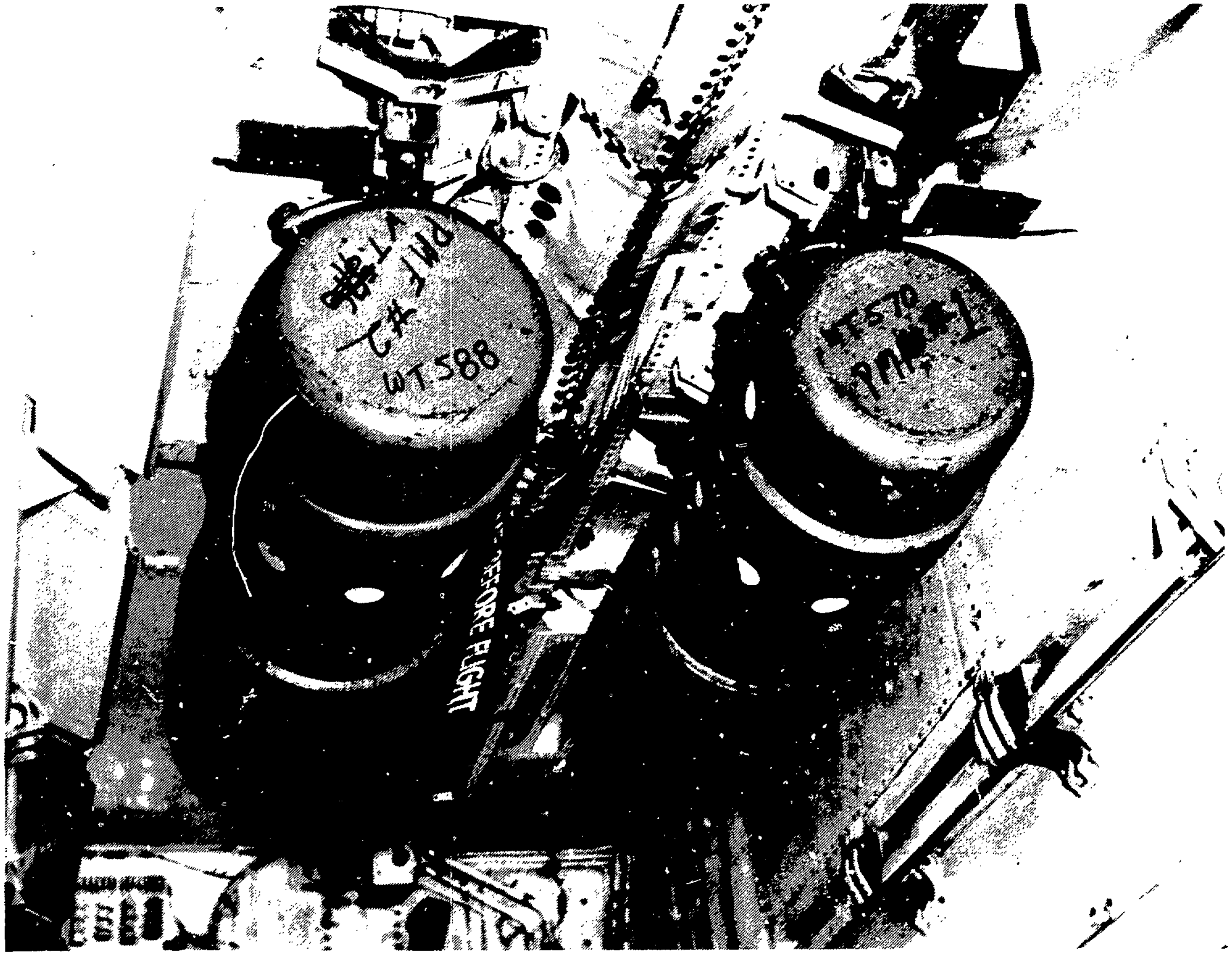


Figure 5. Two BLU-58/B Bombs in F-111 Bay

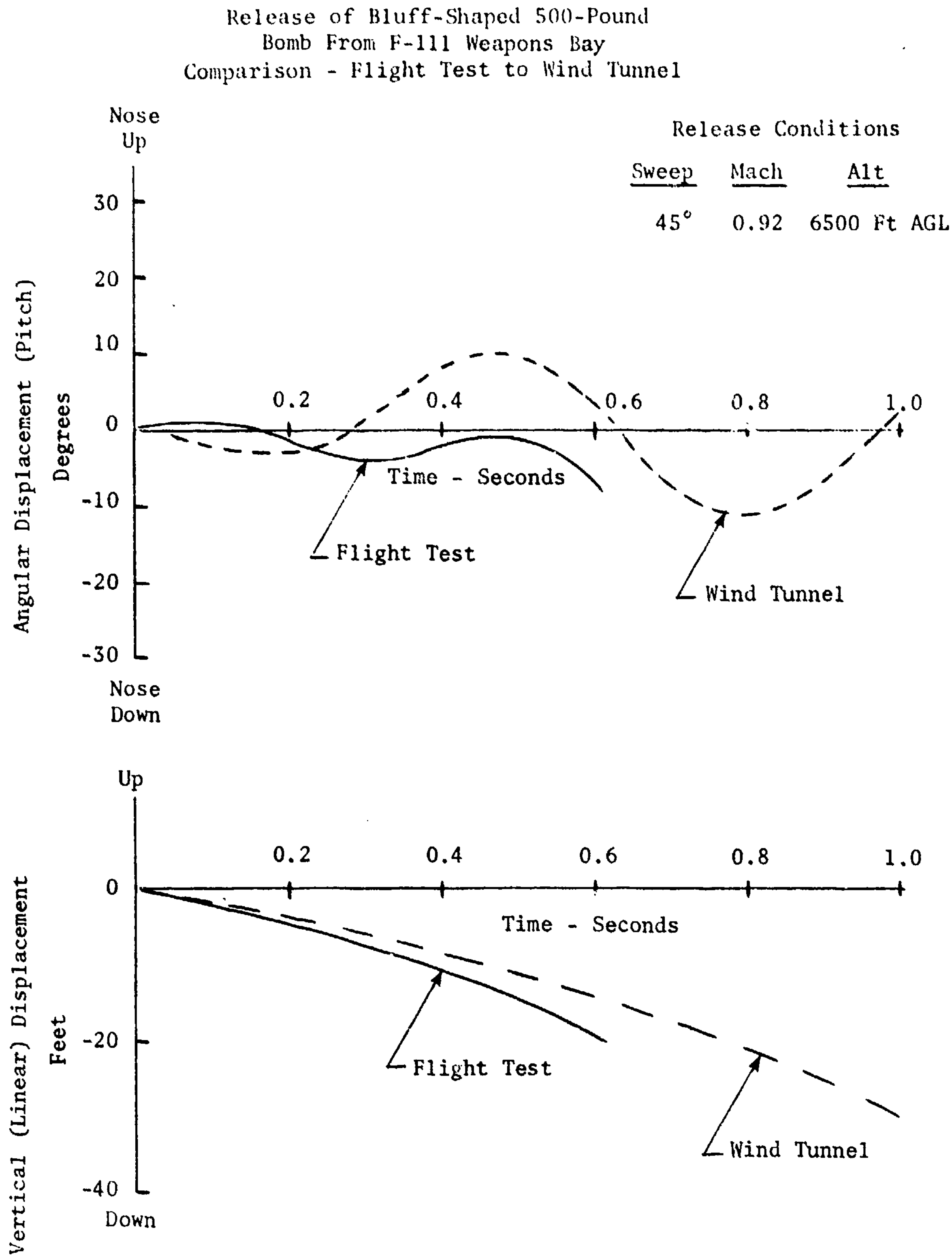


Figure 6. Release of BLU-58/B (0.92M)

Release of Bluff-Shaped 500-Pound
Bomb from F-111 Weapons Bay
Comparison - Flight Test to Wind Tunnel

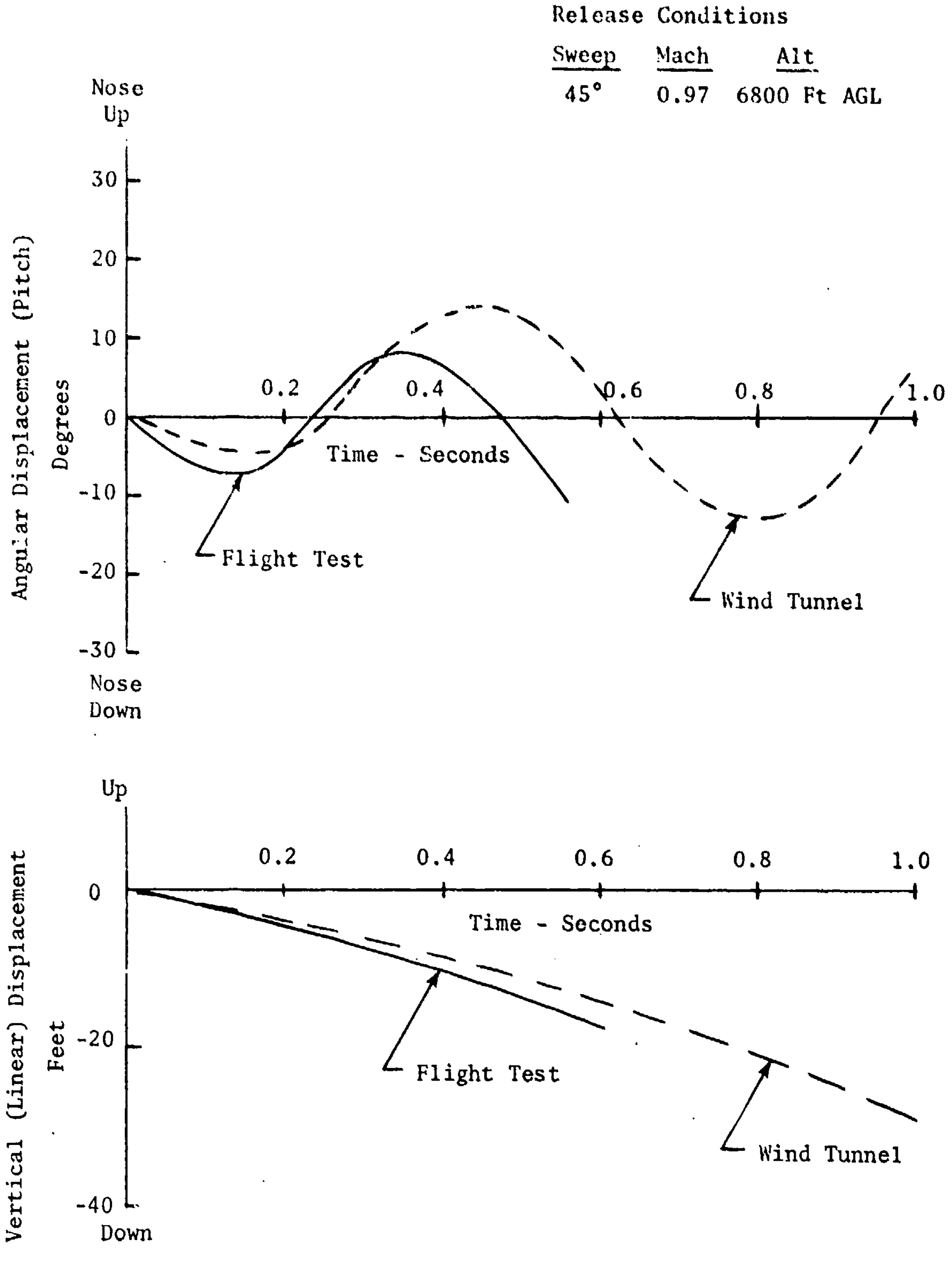


Figure 7. Release of BLU-58/B (0.97M)

Release of Bluff-Shaped 500-Pound
Bomb From F-111 Weapons Bay
Comparison - Flight Test to Wind Tunnel

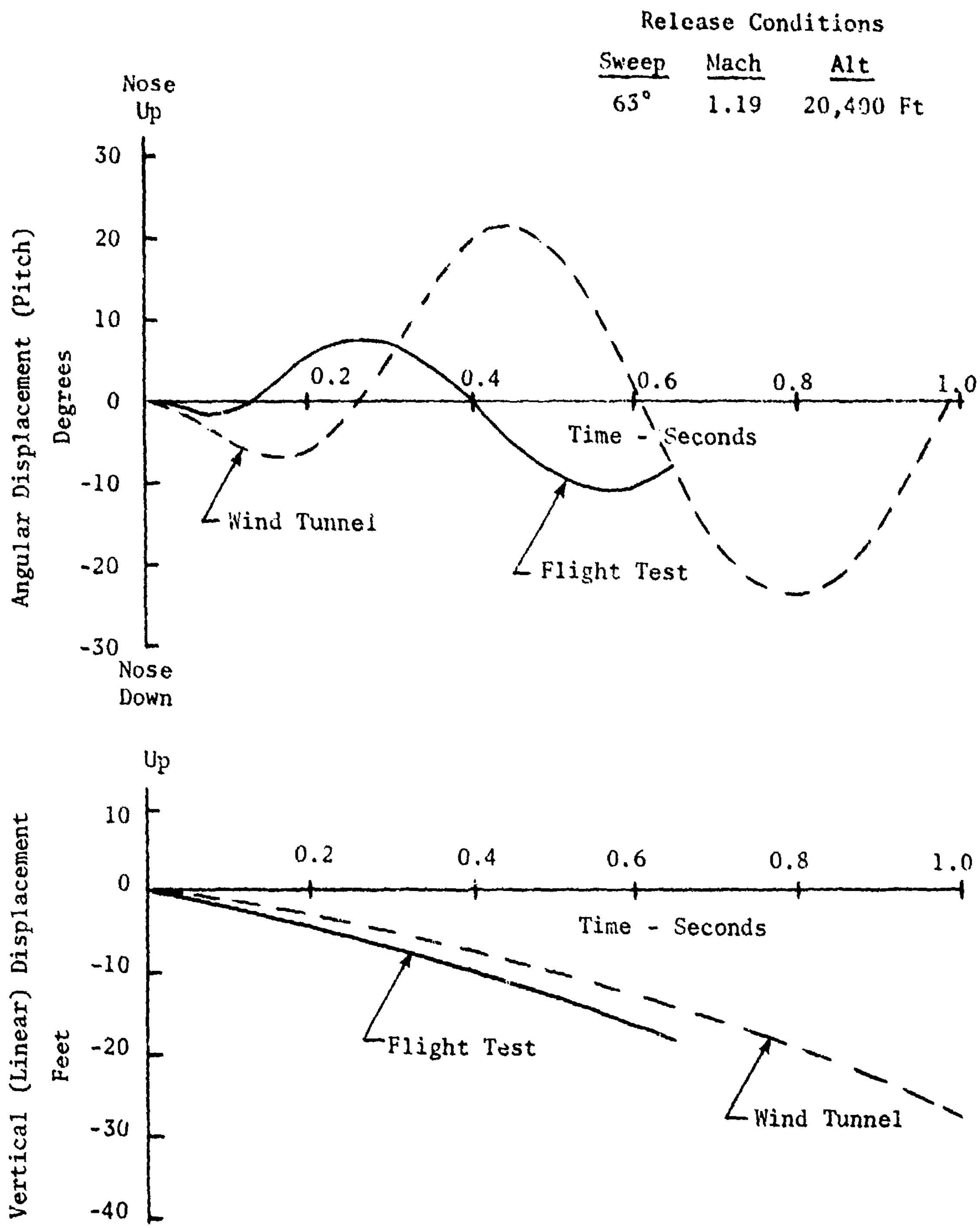


Figure 8. Release of BLU-58/B (1.19M)

Release of Bluff-Shaped 500-Pound
Bomb From F-111 Weapons Bay
Comparison - Flight Test to Wind Tunnel

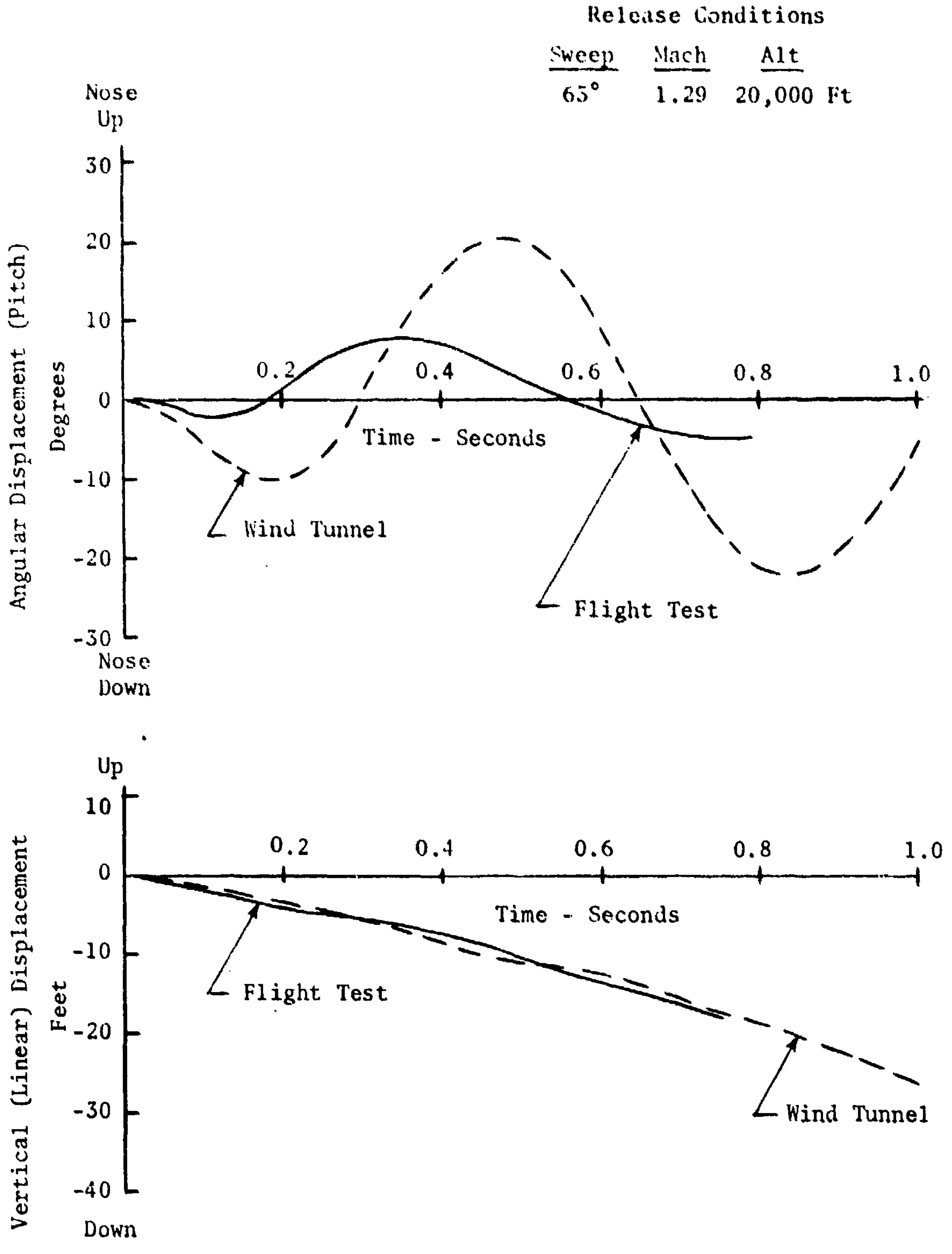


Figure 9. Release of BLU-58/B (1.29M)

As can be seen from the comparison of wind tunnel and flight test separation data, these bombs separated with very little pitching motion, less in most cases than predicted by the wind tunnel tests. However, the instability exhibited during the fifth release was cause for concern. It was known that bluff bombs had minimal static and dynamic stability; however, unstable bombs were considered unacceptable from ballistics considerations Contractor study of the instability problem, discussed in Reference 3, determined that it was a direct result of inertial/aerodynamic coupling. The particular bomb in question exhibited center of gravity off the longitudinal axis and all bombs were found to exhibit less static and dynamic stability than wind tunnel data predicted. The low stability coupled with the off cg resulted in the bomb exhibiting a coning motion. Therefore, in order to ensure coning tendencies are minimized, the contractor recommended changes to the mass (center of gravity control) and physical (tail fin) characteristics of the bomb.

F-111/M117M and M117M6

The second phase of bluff bomb development was to conduct free stream wind tunnel tests to identify bomb shapes with improved static and dynamic stability, and then to conduct wind tunnel and flight tests at transonic and supersonic speeds to establish separation and flight characteristics of the bomb chosen. Additionally, a brief flight test program was conducted to compare M117M separation and flight characteristics to those of the BLU-58/B.

1. Wind Tunnel Tests

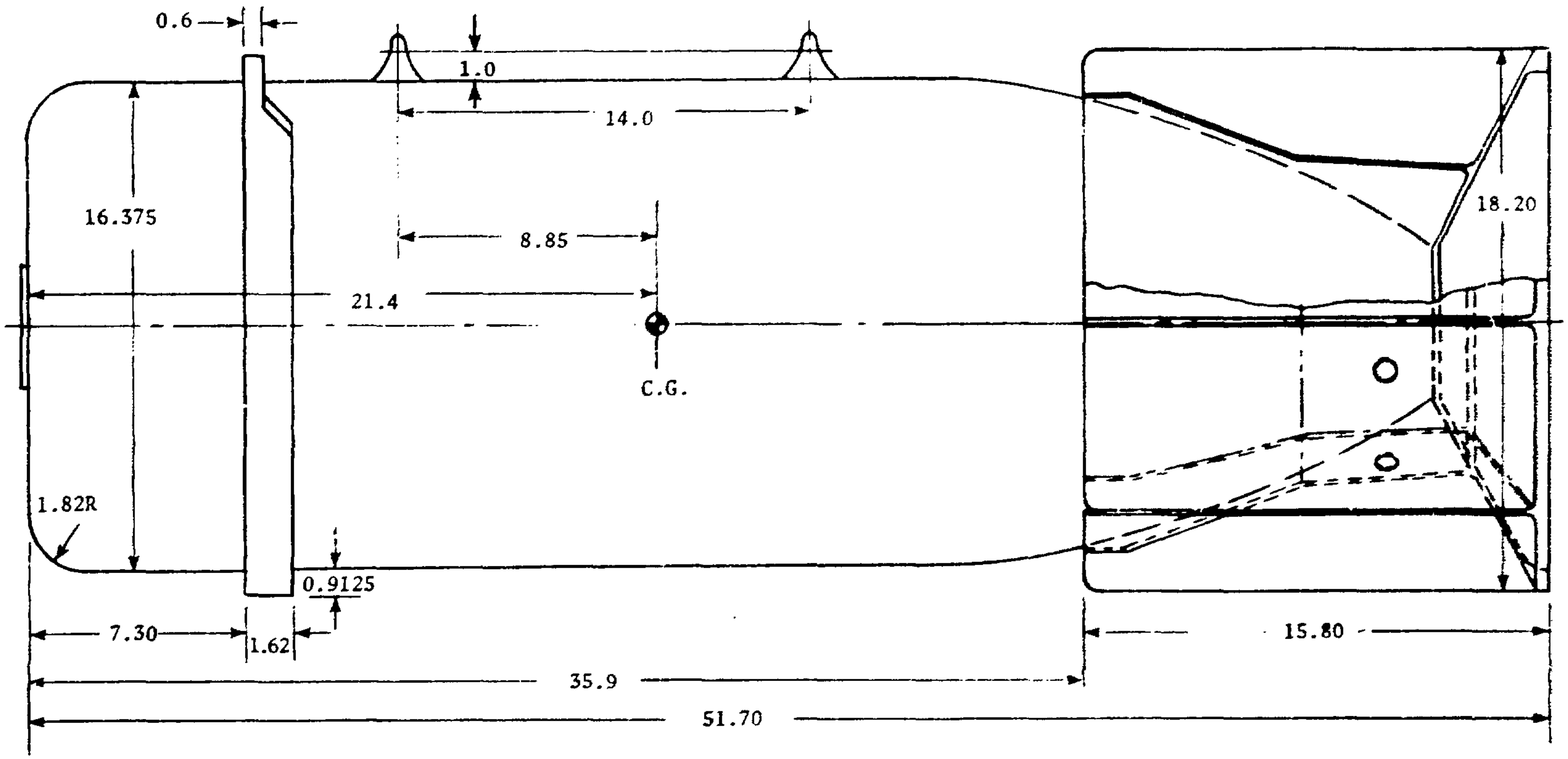
Fifth scale wind tunnel tests were conducted at the General Dynamics Convair high speed wind tunnel. The primary parameter investigated was the effect of bomb tail design on bomb static and dynamic stability, although ring variations were also investigated. Mach Numbers from 0.6 to 2.0, and angles of attack from -5 to +25 degrees were investigated.

From the various tail shapes tested, one termed the M117M6 (Figures 10 and 11) was chosen. The M117M6 exhibits approximately twice the static stability and five times the dynamic stability of the M117M barrel tail configuration. Aerodynamic data were then used to generate ballistic tables to support later flight tests.

In order to support flight tests, separation data were also needed. Since testing was to be with an F-111 configured to carry five bombs in the weapons bay, that configuration was installed in a 1/24th scale F-111 drop model (Figure 12). Transonic wind tunnel testing was conducted at Arnold Engineering Development Center (AEDC) in the 4-foot transonic wind tunnel (4T) at Mach numbers from 0.7 to 1.3 to investigate the separation characteristics of the M117M6 and several variants (Reference 4). Supersonic

References:

4. AEDC Technical Report, AEDC-TR-71-103, Freedrop Trajectory Characteristics of Bluff-Shaped Bombs Released from the F-111 Aircraft Weapons Bay at Mach Numbers from 0.70 to 1.30, May 1971, UNCLASSIFIED.



NOTE: All dimensions in inches

Figure 10. M117M6

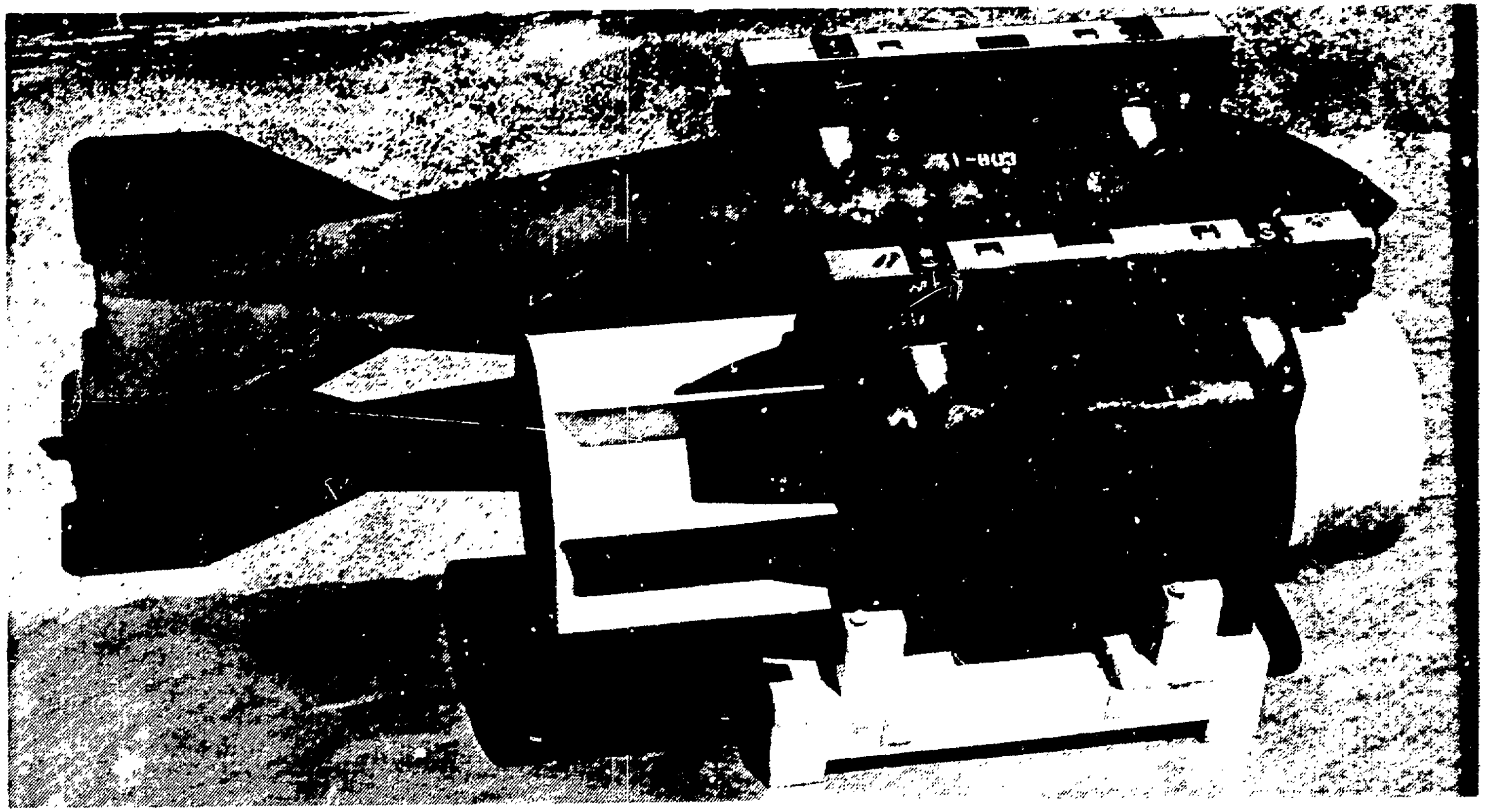


Figure 11. Comparison of Basic M117 and M117M6

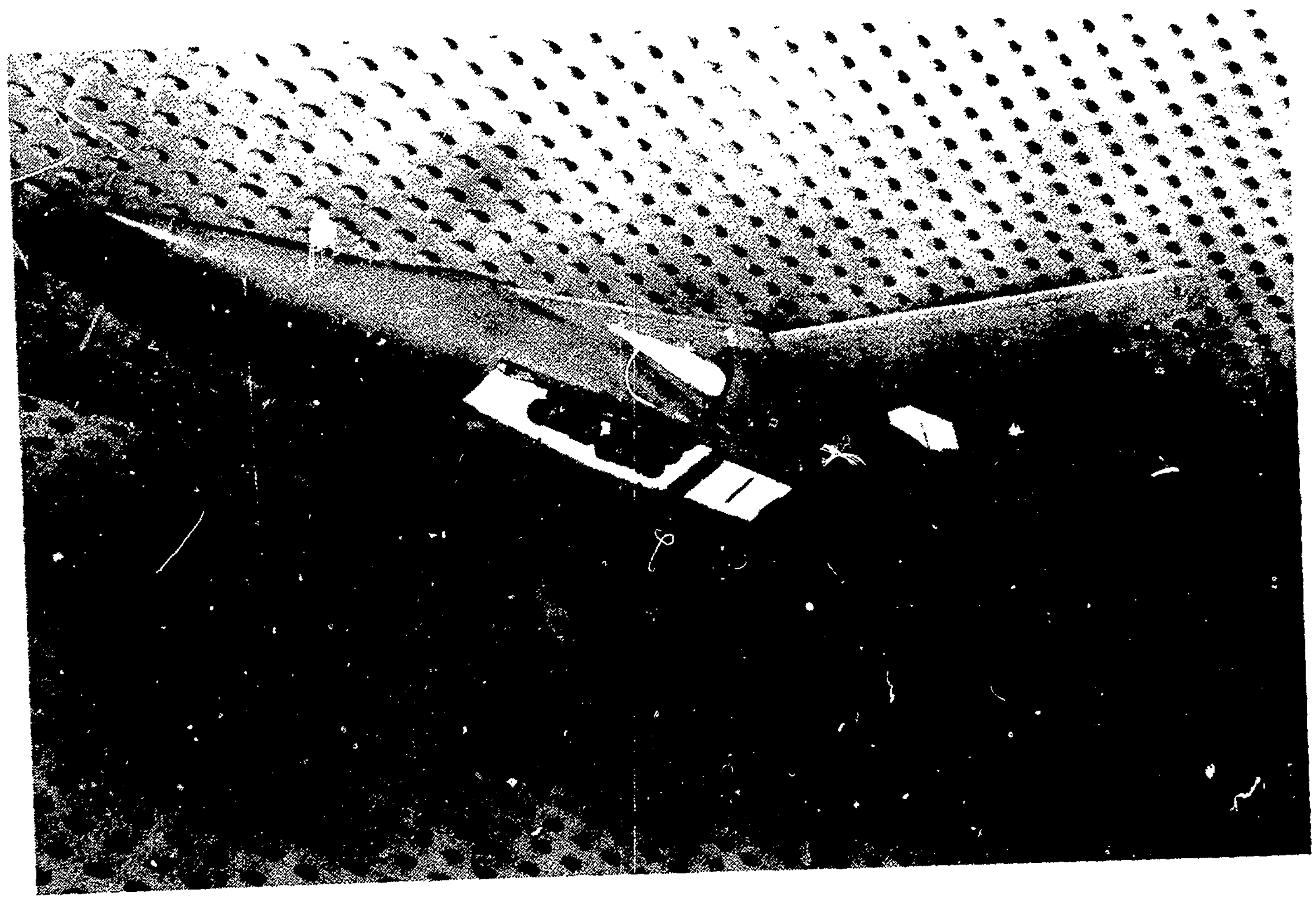


Figure 12. Wind Tunnel Model of F-111 with M117M6 in Weapon Bay

wind tunnel separation testing was conducted in the Convair 4-foot high speed wind tunnel at Mach Numbers from 1.3 to 2.0. All separation tests employed dynamic drop models with heavy scaling relationships. The test plans were structured to investigate single and multiple release modes. Release sequence was varied to show effects of dropping forward bombs in the presence of aft bombs and vice-versa. In this manner information was gained on out-of-sequence releases. Store pitch rate at release was also varied.

Review of wind tunnel data showed that all stores separated safely with slight initial nose-down pitching motion. Parameters other than store shape had little effect on separation characteristics. The M117M6 exhibited excellent separation characteristics throughout the flight envelope desired for investigation during the flight test program.

2. Hardware Fabrication

Bluff bomb modification kits were designed, fabricated, and proof tested by General Dynamics in the M117M and M117M6 versions. The M117M kits were made because it was desired to release M117M versions at the same release conditions as BLU-58/B releases to show the effects of the scale-up. However, since it was known that the M117M exhibited unacceptable aerodynamic stability, all flight testing to be conducted from the F-111 bay modified to carry five bluff bombs was to be with the M117M6 version. The designs of the modification kits are documented in Appendix I. Basically, each kit consists of one nose and one tail casting. The M117 bomb body is reversed for use with the kit. For purposes of this program, the nose casting is affixed to the aft end of the warhead by an FMU-81 fuze or with the hexagonal shipping plugs that come with the M117 bomb. Other fuzes could have been used but this would have required development of additional means of attaching the kit. The tail casting also attached to the warhead. Cutouts are required in the ring of the nose casting to permit sway brace feet to rest on the warhead surface and to preclude interference between the ring and the bomb rack. The tail casting is prevented from rotating and is held in proper orientation by a set bolt inserted through a hole in the tail casting into an existing set screw hole in the bomb body. The castings are aluminum and add a total of about 60 pounds to the weight of the warhead (Appendix I). Due to the short length of the M117M6, three weapons will fit aft of the existing two racks in the F-111 weapons bay. A rack and beam assembly containing an additional three MAU-12 racks was designed and fabricated by General Dynamics. An electronics module was also fabricated to link the existing weapons release system to the three new racks. The design of the assembly is depicted in Figure 13 and documented in Appendix II. Hard points are installed in the weapons bay structure and the rack and beam assembly is then bolted in. The electrical controls are part of the assembly and are connected after the assembly is mounted in the weapons bay. The release sequence is controlled by which rack connector is mated to which control unit connector, but throughout this test the release sequence intended was as depicted in Figure 14, which also shows the weapons bay loaded with five M117M6 bombs. Bomb assembly, rack installation, and

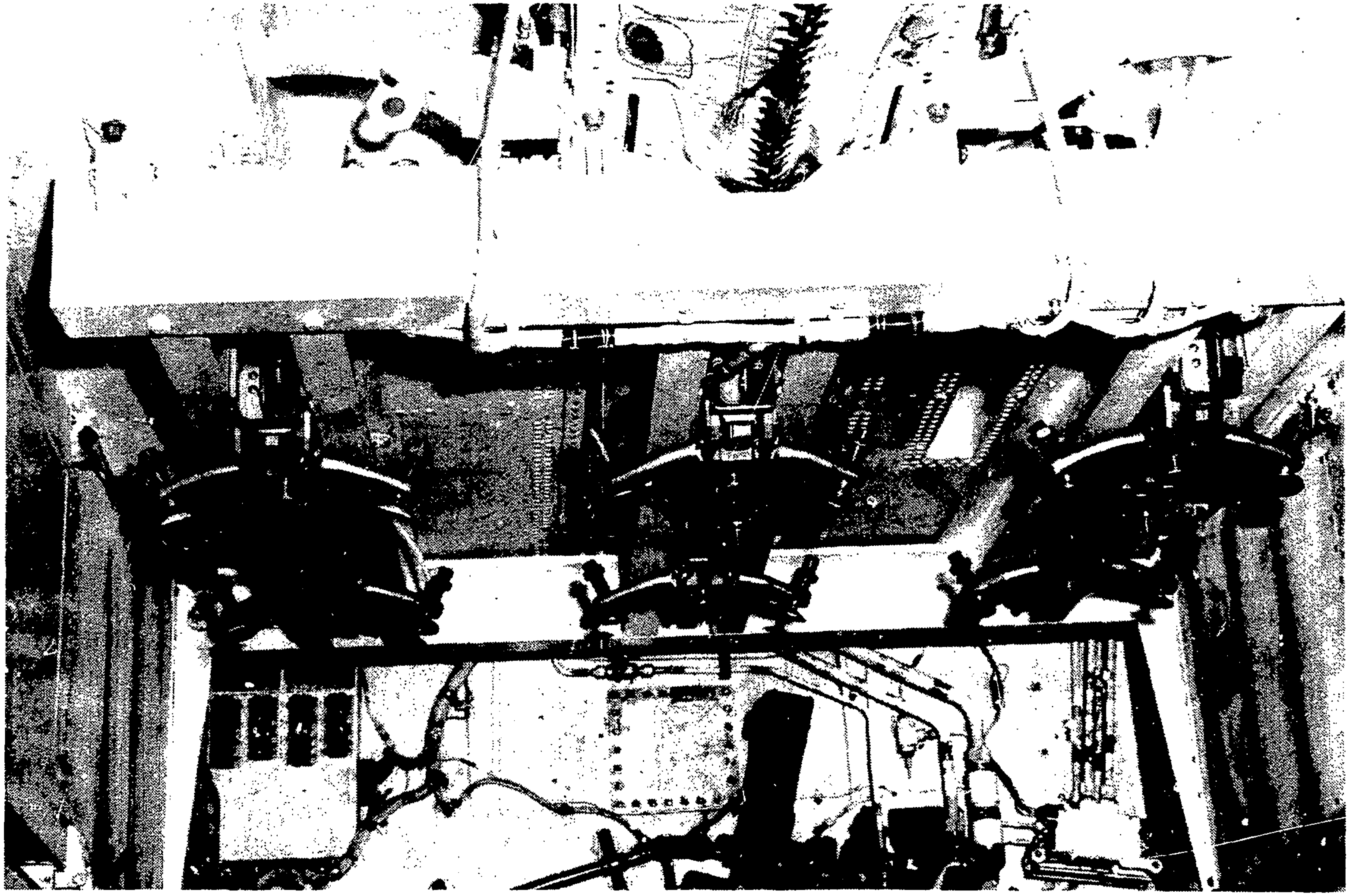


Figure 13. F-111 Aft Weapons Bay Rack Installation

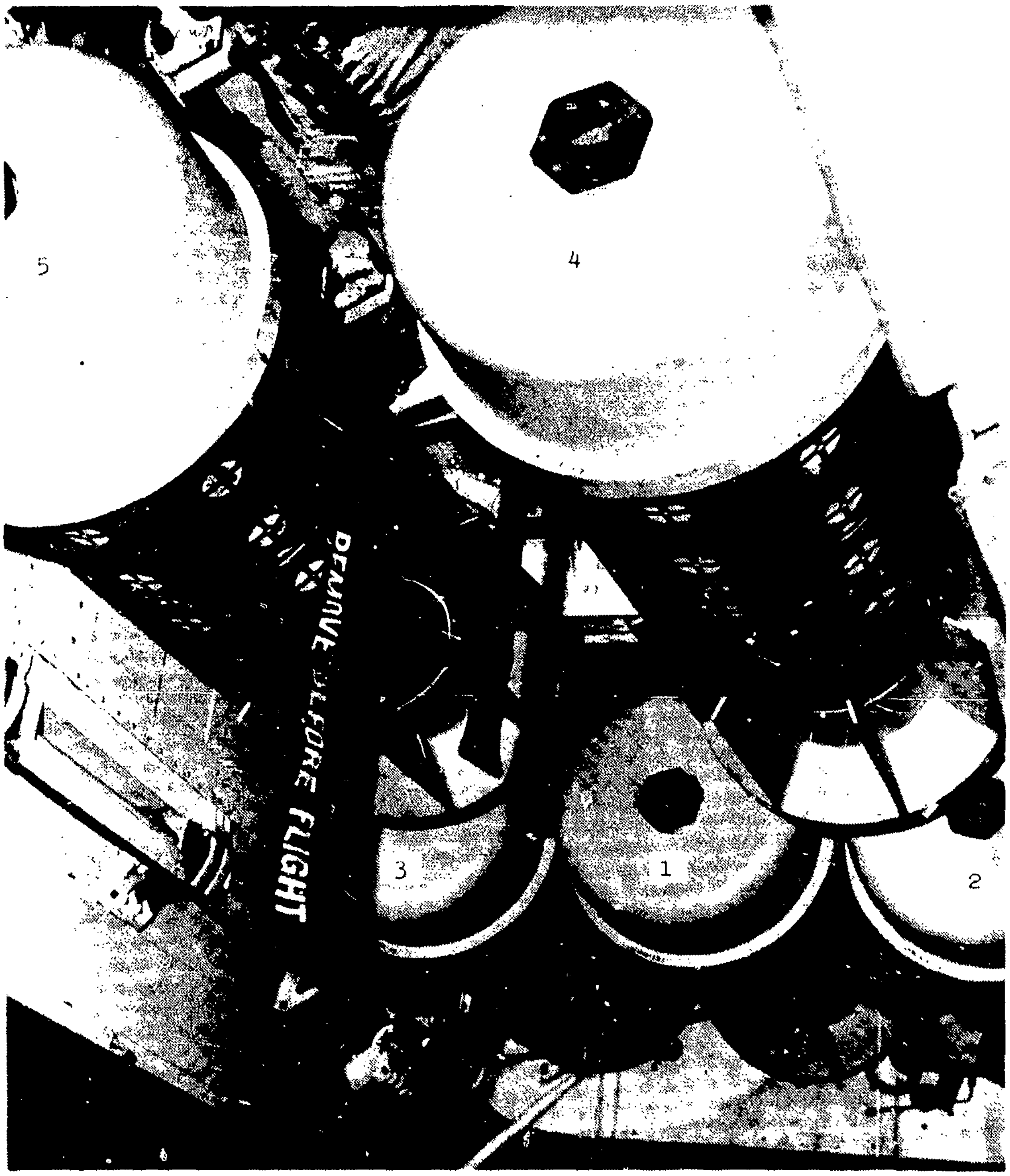


Figure 14. F-111 Weapons Bay with Five M117M6 Installed

bomb loading are discussed in detail in Reference 5.

3. Flight Tests

A test program was established and conducted at ADTC consisting of a fit test and a flight test series. Live and inert munitions were released. Separation and ballistic data obtained from flight test releases were reviewed by General Dynamics and compared to separation predictions. Onboard, chase, and ground motion pictures were made of each release. An attempt was made to recover all stores released to inspect the warhead for structural degradation. Concern had been expressed that warheads impacting tail first would split open on impact.

The primary source of separation data was the flight test film from the 16mm motion picture camera operating at 200 frames per second, located in the wing tip of the F-111 weapon drop aircraft. This film was sometimes unsatisfactory due to vapor, glare or other problems. In such cases analysis of the weapon motions was not possible, since there were no other data acquired.

Photogrammetric reduction (Reference 6) uses the onboard film to generate tabulated data of X, Y, Z, θ and ψ versus time in milliseconds. For weapons released from the weapon bay, data can only be obtained from the time the weapon is fully visible to a point about 160 inches below the bay. This data analyzed from the wing tip camera film usually provides a somewhat distorted value at the ends due to the high wind sweep angle, single camera solution, camera lens distortion and data smoothing methods. These limitations must be taken into account when analyzing the data, since in some cases trends were smoothed out of the raw data altogether.

The fit test consisted of an exercise of loading five M117M6 bluff bombs into a modified F-111 bay. In this manner, it was possible to critique the ability of the bombs to be loaded, the racks to be serviced, tightened, armed, and dearmed, and to otherwise evaluate the physical and electrical compatibility of the system. The fit test was conducted in accordance with MIL-STD-1289. All bombs were configured with nose plugs, rather than fuzes, for the fit check. The fit check was considered successful for test purposes but several problems were noted. The bombs are a very tight fit in the bay with only 1/4 inch between the bombs and the bay side and about 1/2 inch between adjacent bomb nose rings in the aft bay. The MIL-STD-1289 requirement for these dimensions is one inch. These close clearances render operations like sway brace foot tightening, rack locking, etc. very difficult. Also, the close fit requires that bombs be prefuzed, an undesirable situation. Complete fit test documentation is contained in Reference 5.

References:

5. ADTC Technical Report, ADTC-TR-74-19, Supersonic Weapons Separation from F-111 Aircraft (M117 Bluff Bomb), April 1974, UNCLASSIFIED.
6. 1969 Aircraft/Stores Compatibility Symposium Proceedings, Volume VI, Experimental Session, Paper entitled, The Limitations and Tolerances of the Store Separation Photogrammetry Technique, B.R. Bowers, R. Rawlings, R. Fanning, UNCLASSIFIED.

Flight testing consisted of a captive compatibility flight with five M117M6 bluff bombs installed in the weapons bay, then three release missions each with two M117M (round tail) bluff bombs in the weapons bay, then 19 release missions with the M117M6 (fin tail) bluff bomb. Flight testing is discussed in detail in Reference 5.

For the captive compatibility flight, five M117M6 bluff bombs were installed in the modified weapons bay. The captive flight was designed to demonstrate the structural integrity of the bay installation and to evaluate the performance, handling, and stability of the F-111 with bluff bombs installed. Mach Numbers from 0.6 to 1.3 were investigated. At each test point the weapons bay doors were opened for 30 seconds, then closed. After the flight, the pilot reported no unusual or adverse handling characteristics. There was no damage or degradation to the bombs, racks, structure or aircraft that could be attributed to the bluff bombs. (It is noted in Reference 5 that during the captive compatibility flight and on several release missions that damage occurred to various parts of the F-111 aircraft. All damage was attributed to aircraft related problems and none was the result of the bluff bomb program.)

Three missions were conducted with the M117M configuration to ensure M117 type bluff bombs did indeed have separation and flight characteristics that were basically similar to that observed for the BLU-58/B. These missions were conducted using an F-111A aircraft. Quantitative separation and ballistic data were not obtained from these first three missions. The M117M missions were conducted as:

Mission 1. Single releases of two M117M bombs at 0.8 and 0.85 Mach and from 2,000 feet were conducted as planned on 16 February 1971.Both bombs separated cleanly from the aircraft. The bomb from the right rack pitched down excessively upon release but stabilized prior to impact with the ground.

Mission 2. Single releases of two M117M bombs at 0.9 and 0.95 Mach and from 2,000 feet were conducted as planned on 18 February 1971. Both bombs separated cleanly from the aircraft. The side of the MAU-12B/A rack on the right station blew out when its bomb was released. That bomb pitched down excessively on release, became unstable and did not recover prior to ground impact.

Mission 3. Single releases of two M117M bombs at 0.9 and 1.2 Mach and from 20,000 feet were conducted as planned on 8 March 1971. The 0.9 Mach release was a repeat of the release condition from Mission 2 in which the bomb was unstable in flight. Both bombs separated cleanly from the aircraft.

Except for the one bomb from Mission 2, all bombs stabilized quickly in flight. Separation and ballistic characteristics of the M117 with the barrel tail proved to be very similar to the BLU-58 and confirmed that static and dynamic stability of the shape are adequate for aircraft separation, but marginal for ballistic performance.

Testing was then initiated with the M117M6 fin tail bluff bomb from the five-bomb weapons bay configuration. The first two missions were conducted without the fin interlock on F-111A No. 26. All subsequent missions were conducted with the fin interlock and on F-111E No. 4.

Figure 15 is a Mach-Altitude plot of M117M6 flight conditions. Table 2 lists, in chronological order, the subsonic and supersonic M117M6 bluff bomb flight test drops and the subsonic tests of live fuzes and live weapon drops. Weapons were released at Mach Numbers from 0.6 to 1.955 in single and ripple release modes. The following paragraphs discuss the results of each drop test conducted and compare flight test data to wind tunnel predictions.

Mission 4

Single drops were planned from all five positions at 0.8 Mach and 2,000 feet altitude. This mission was conducted on 24 March 1971. On the first pass the weapon from the number 2 position was released instead of the weapon from the number 1 position. On succeeding passes, weapons were inadvertently ripple released from positions 3, 4 and 5. Post-flight investigations showed that electrical circuit malfunctions caused the out-of-sequence release and the undesired ripple release. Separation data were not obtained for the drop from position 5.

Figures 16, 17 and 18 present the flight test data from positions 2, 3 and 4 and compare the flight test data to the drop model wind tunnel data. These data comparisons show good agreement for vertical displacement and show that the flight test pitch angle is less than the wind tunnel pitch angle for Figures 16 and 17. The pitch angle for Figure 18 was questionable on each end of the flight test data because of marginal camera coverage. A review of the ground tracking film revealed that one of the weapons dropped on this flight continued to oscillate to the ground.

All four of the weapons dropped on this flight separated satisfactorily. Figure 19 shows selected sequence photographs of the chase plane film of the drop from position 3 and is representative of the bluff bomb separation characteristics at 0.8 Mach and 2,000 feet altitude.

Mission 5

Single drops were planned from all five positions at 0.9 Mach and 4,000 feet altitude. This mission was conducted on 25 March 1971. Only the three aft weapons were dropped on this flight because the chase plane pilot noticed a

TABLE 2. M117M6 MISSION SUMMARY

Drop No.	Flight Date	A/C	Mach	Altitude Feet	1_{AC}	2_{AL}	3[illegible]	4_{FL}	5_{FR}	Comments
1	24 Mar 1971	26	0.803	2,1[illegible]	$\underline{1}$	(1)	$\underline{1}$	$\underline{1}$	$\underline{1}$	#1 hung on rack on first pass
			0.798	2,188	$\underline{1}$		(1)	$\underline{1}$	$\underline{1}$	
			0.798	2,188	$\underline{1}$			(1)	$\underline{1}$	
			0.798	2.188	$\underline{1}$				(1)	No separation data
2	25 Mar 1971	26	0.911	4,134	(1)	$\underline{1}$	$\underline{1}$	$\underline{1}$	$\underline{1}$	Only chase data
			0.898	4,105		(1)	$\underline{1}$	$\underline{1}$	$\underline{1}$	
			0.895	4,085			(1)	$\underline{1}$	$\underline{1}$	Only chase data
								$\underline{1}$	$\underline{1}$	#5 fin came off and fell out
3	27 Aug 1971	E-4	0.95	2,000	(1)	$\underline{1}$	$\underline{1}$	$\underline{1}$	$\underline{1}$	
			0.95	2,000		(1)	$\underline{1}$	$\underline{1}$	$\underline{1}$	Right bay door was closed
			0.95	2,000			(1)	$\underline{1}$	$\underline{1}$	Bounced on right bay door and rolled out left side of bay
			0.95	2,000				(1)	$\underline{1}$	Right bay door still closed
			0.95	2,000					(1)	Ejected through right bay door
4	2 Jun 1972	E-4	0.80	2,000	(1)	(1)	(1)	(1)	(1)	100 ms ripple release
5	27 Feb 1973	E-4	0.95	2,000	(1)	(1)	(1)	(1)	(1)	100 ms ripple release

Note: ( ) Parenthesis, weapon(s) separated
____ Underlining, weapon(s) retained

TABLE 2. M117M6 MISSION SUMMARY (Continued)

Drop No.	Flight Date	A/C	Mach	Altitude Feet	^{1}AC	^{2}AL	^{3}AR	^{4}FL	^{5}FR	Comments
6	28 Feb 1973	E-4	0.60	2,000				(1)	$\underline{1}$	Low "q", high α condition
			0.60	20,000					(1)	Low "q", high α condition
7	22 Mar 1973	E-4	0.965	1,950	(1)	(1)	(1)	(1)	(1)	50 ms ripple release
8	5 Apr 1973	E-4	1.14	1,530	(1)	$\underline{1}$	$\underline{1}$	$\underline{1}$	$\underline{1}$	$\Lambda = 72.5°$
			1 15	1,400		(1)	$\underline{1}$	$\underline{1}$	$\underline{1}$	$\Lambda = 72.5°$
			1.15	1.900			(1)	$\underline{1}$	$\underline{1}$	$\Lambda = 72.5°$
			0.57	2,000				(1)	$\underline{1}$	$\Lambda = 33°$
			0.575	2,000					(1)	$\Lambda = 33°$ on pass of previous drop
9	10 Apr 1973	E-4	1.20	2,000	(1)	(1)	(1)	(1)	(1)	100 ms ripple release
10	30 Jul 1973	E-4	1.6	22,000	$\underline{1}$	(1)	$\underline{1}$	$\underline{1}$	$\underline{1}$	#1 skipped by error Mission 1031
					$\underline{1}$		(1)	$\underline{1}$	$\underline{1}$	No sep. data due to vapor
					$\underline{1}$			(1)	$\underline{1}$	No sep. data due to vapor
					$\underline{1}$				(1)	
11	1 Aug 1973	E-4	1.8	26,000	$\underline{1}$	(1)	$\underline{1}$	$\underline{1}$	$\underline{1}$	#1 skipped by error Mission 3036
					$\underline{1}$		(1)	$\underline{1}$	$\underline{1}$	

Note: ( ) Parenthesis, weapon(s) separated
___ Underlining, weapon(s) retained

TABLE 2. M117M6 MISSION SUMMARY (Concluded)

Drop No.	Flight Date	A/C	Mach	Altitude Feet	^{1}AC	^{2}AL	^{3}AR	^{4}FL	^{5}FR	Comments
11	1 Aug 1973	E-4	1.8	26,000	$\underline{1}$			(1)	$\underline{1}$	
					$\underline{1}$				(1)	No tab data due to vapor
12	22 Aug 1973	E-4	1.6	19,000	(1)	(1)	(1)	(1)	(1)	100 ms ripple Mission 3701
13	29 Aug 1973	E-4	0.9	2,000	(1)	(1)	(1)	(1)	(1)	100 ms ripple, live fuzes, Mission 3703
14	30 Aug 1973	E-4	0.95	2,000	(1)	(1)	(1)	(1)	(1)	100 ms ripple, live bombs, Mission 4005
15	1 Nov 1973	E-4	1.88	32,050	(1)					For ballistics, 720 KCAS, film 12/3/73 Mission 4012
16	2 Nov 1973	E-4	1.955	32,275		(1)				For ballistics, 740 KCAS, film 12/3/73 Mission 5008
17	6 Nov 1973	E-4	1.93	31,430			(1)			For ballistics, 750 KCAS, film 12/3/73 Mission 2009
18	13 Nov 1973	E-4	1.255	5,150	(1)					For ballistics, 775 KCAS, film 2/14/74 Mission 2015
19	14 Dec 1973	E-4	1.25	5,840		(1)				For ballistics, 760 KCAS, film 2/14/74 Mission 5013

Note: ( ) Parenthesis, weapon(s) separated
___ Underlining, weapon(s) retained

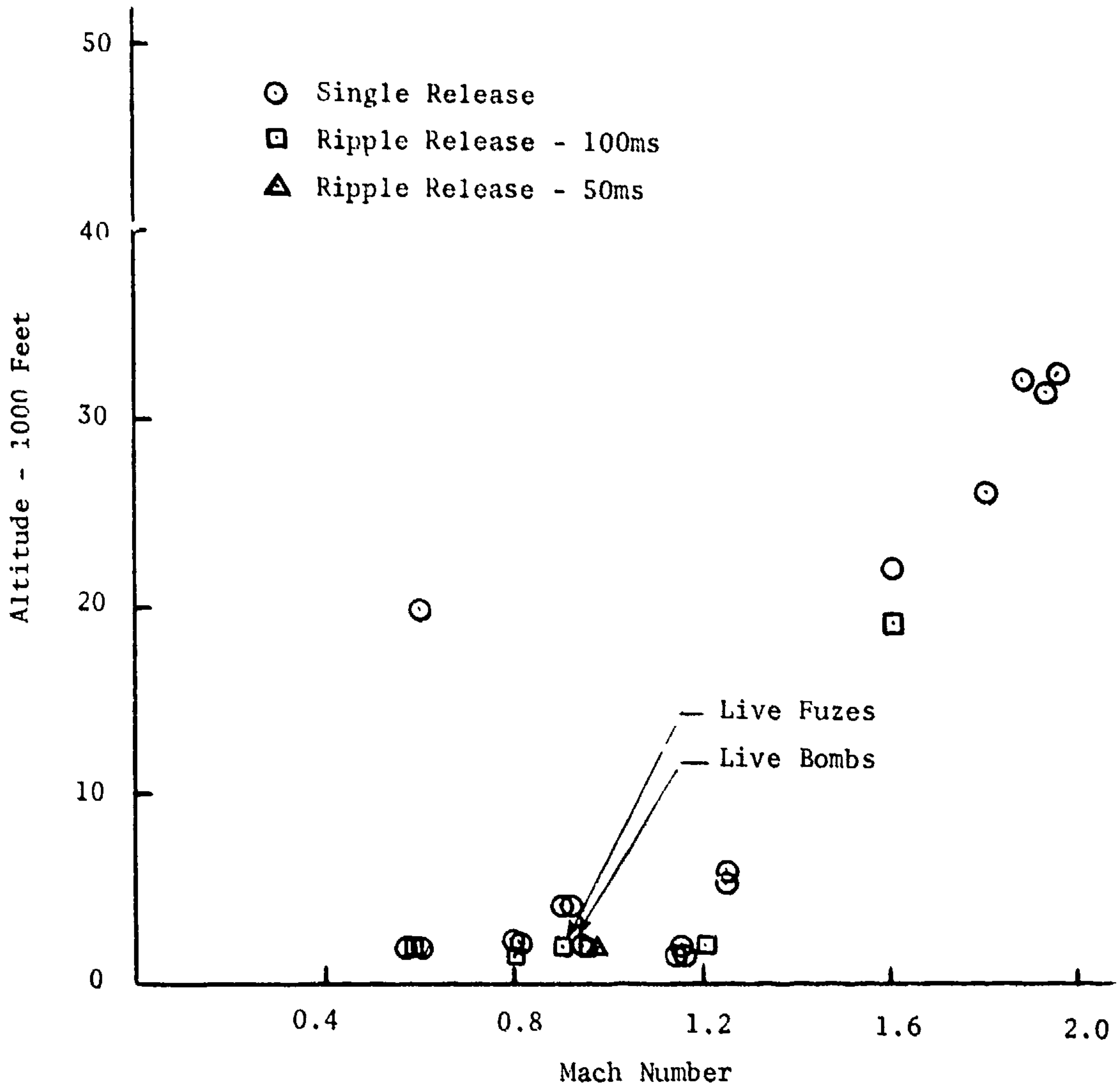


Figure 15. F-111/M117M6 Flight Test Release Conditions

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
24 March 1971 F-111A No. 26 Weapon Bay Position 2
Mach = 0.803   Altitude = 2179 Feet

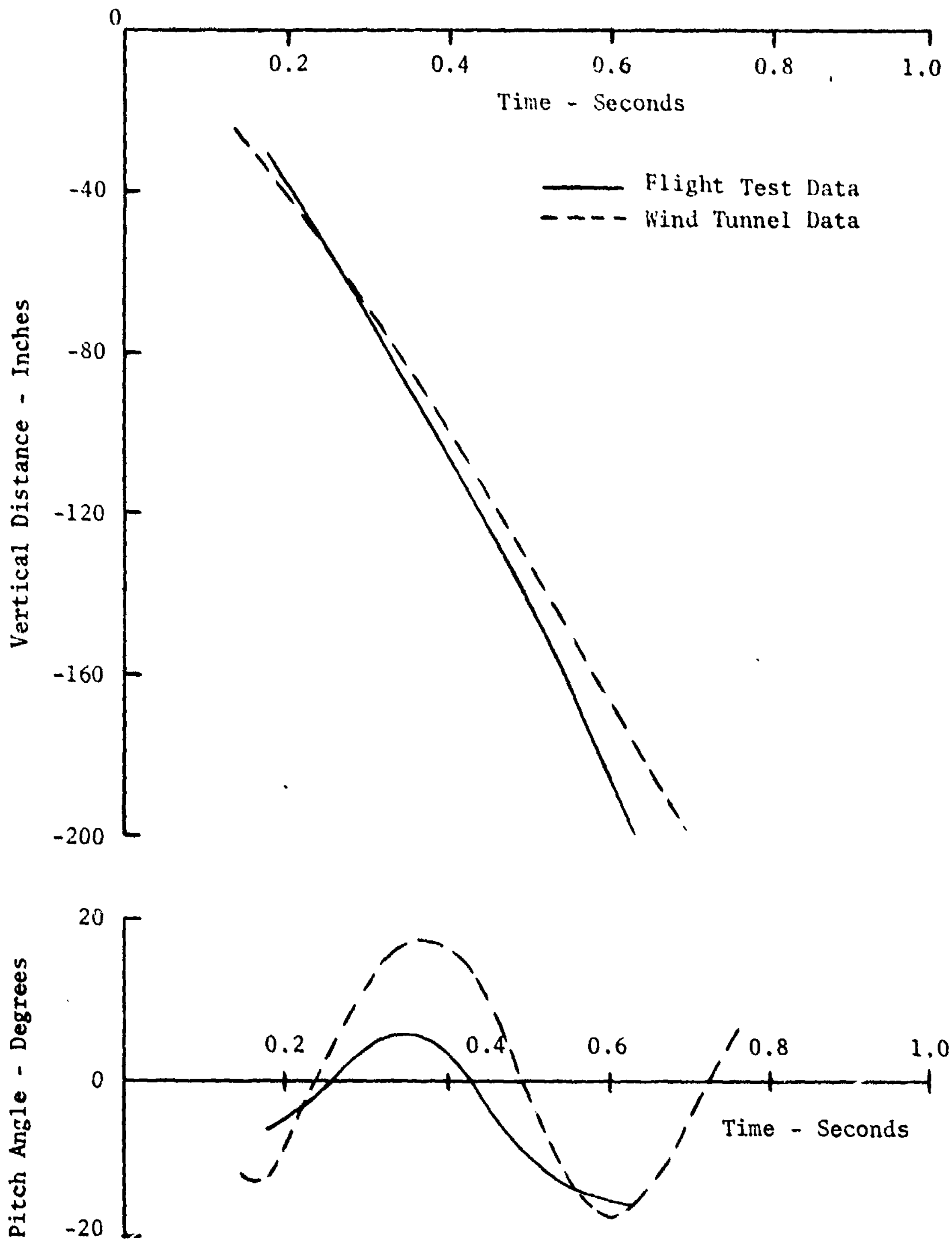


Figure 16. Single Release of M117M6 from Bay Position 2 at 0.8 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
24 March 1971 F-111A No. 26 Weapon Bay Position 3
Mach = 0.798 Altitude = 2188 Feet

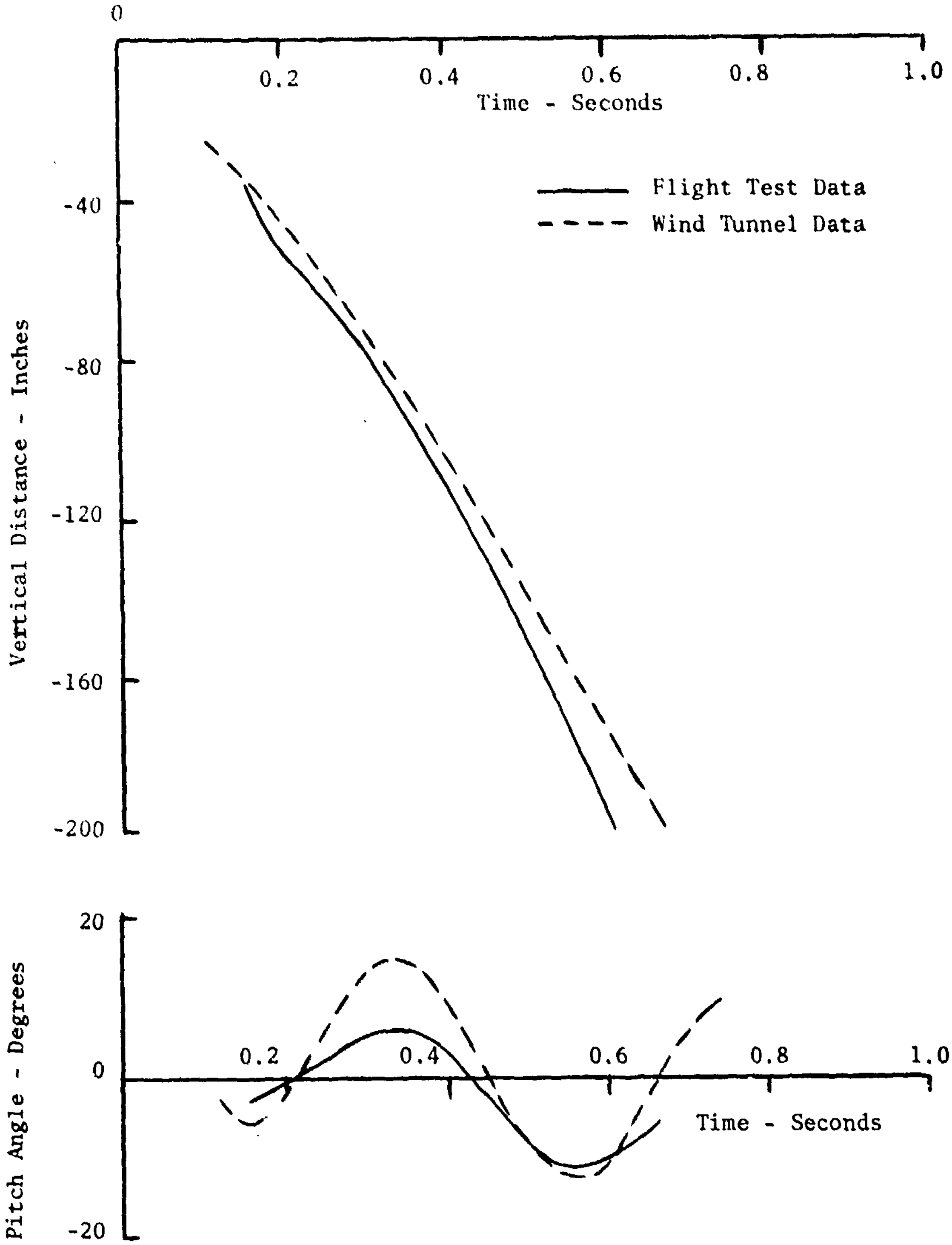


Figure 17. Single Release of M117M6 from Bay Position 3 at 0.8 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
24 March 1971 F-111A No. 26 Weapon Bay Position 4
Mach = 0.798 Altitude = 2188 Feet

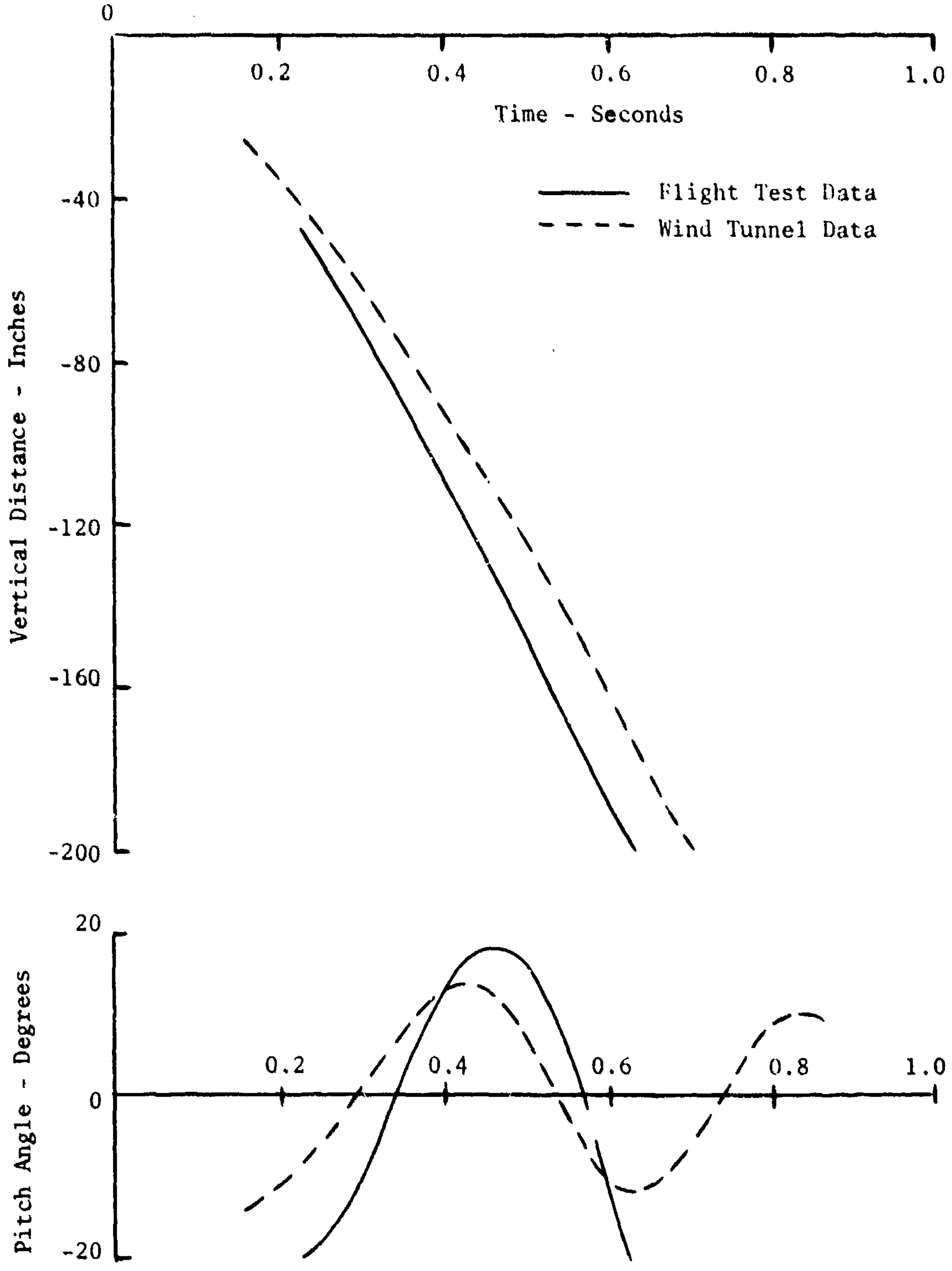


Figure 18. Single Release of M117M6 from Bay Position 4 at 0.8 Mach

CHASE SEQUENCE PICTURES

AIRCRAFT F-111A NO. 26
First Drop - 24 March 1971
Single Release - Position 3

RELEASE CONDITIONS
Mach = .80
2200 Feet

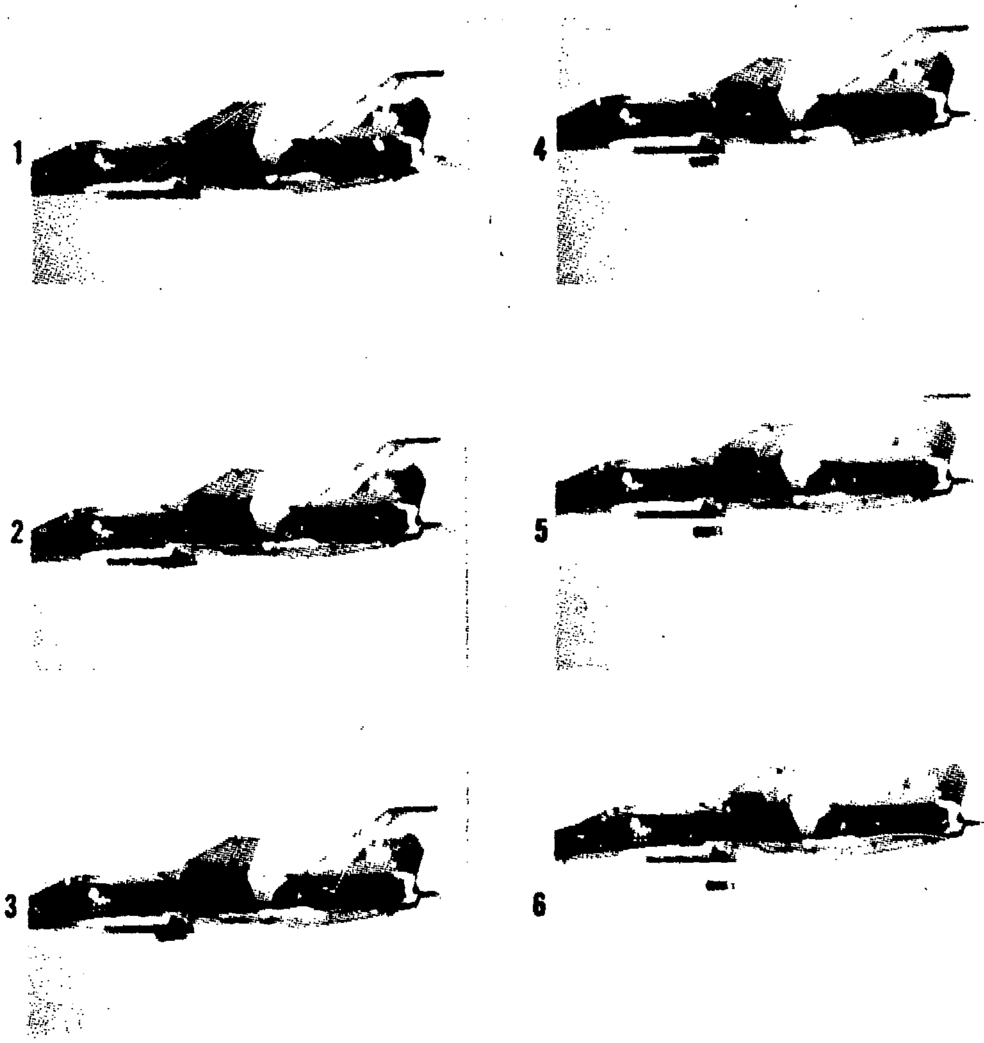


Figure 19. Chase Sequence of M117M6 from Bay Position 3 at 0.8 Mach

sizable object fall from the weapons bay before the weapon at position 4 was dropped. A closer investigation by the chase plane pilot revealed that the tail unit had come off of the bluff bomb at position 5. Neither position 4 nor 5 bombs were dropped. Investigation after the F-111 was on the ground showed that the tail unit from the position 5 bomb had come off and the tail unit on the position 4 bomb was quite loose. It was surmised that the attachment plug that mounts the tail unit to the bluff bomb was not torqued down correctly. The attaching system was thoroughly checked and a locking system was added to the kit design to prevent further problems of this nature.

Reduced flight test data were obtained only for the number 2 position. However, the chase plane film was used by the contractor to obtain data for positions 1 and 3. Figures 20, 21 and 22 present the flight test data and compare it to the drop wind tunnel test data.

The flight test data from positions 2 and 3 show less pitch excursion than the wind tunnel data. The flight test data from position 1 show considerably more nose-down pitch than the wind tunnel data. (This may have been caused by a rack malfunction which imparted an excessive initial nose-down pitch rate to the bomb. The 0.95 Mach drop discussed next did not pitch nearly as much for position 1.)

Each of the three weapons, dropped on this flight, separated satisfactorily. Figure 23 shows selected photographs of film from ground cameras of the drop from position 3 and is representative of the bluff bomb separation characteristics at 0.9 Mach and 4,000 feet altitude.

Mission 6

Single drops were planned from all five positions at 0.95 Mach and 2,000 feet. This mission was conducted on 27 August 1971. Post flight analysis of the photographic coverage of this flight showed that the right-hand weapon bay door was open properly for the weapon drop from position 1 but was closed for drop from positions 2, 3, 4 and 5. The weapon from position 1 was separated satisfactorily on the first pass. On the second pass the weapon from position 2 was safely separated because this weapon is on the left-hand side of the aircraft. On the third pass the weapon from the aft right-hand side of the aircraft was ejected onto the closed right-hand weapon bay door. The bay door sustained the force of the ejected weapon and did not break. The weapon finally rolled out the left side of the weapon bay in a tumbling manner which was noticed by the chase plane pilot. The chase plane pilot checked the aircraft; however, his lack of familiarity with the F-111 weapon bay configuration resulted in verification that bay doors were normal although the right-hand door remained closed.

On the fourth pass the forward left-hand weapon was dropped and separated satisfactorily. Again, everything appeared normal to the chase pilot. The forward right-hand weapon (position 5) was then ejected through the

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
25 March 1971 F-111A No. 26 Weapon Bay Position 1
Mach = 0.911   Altitude = 4134 Feet

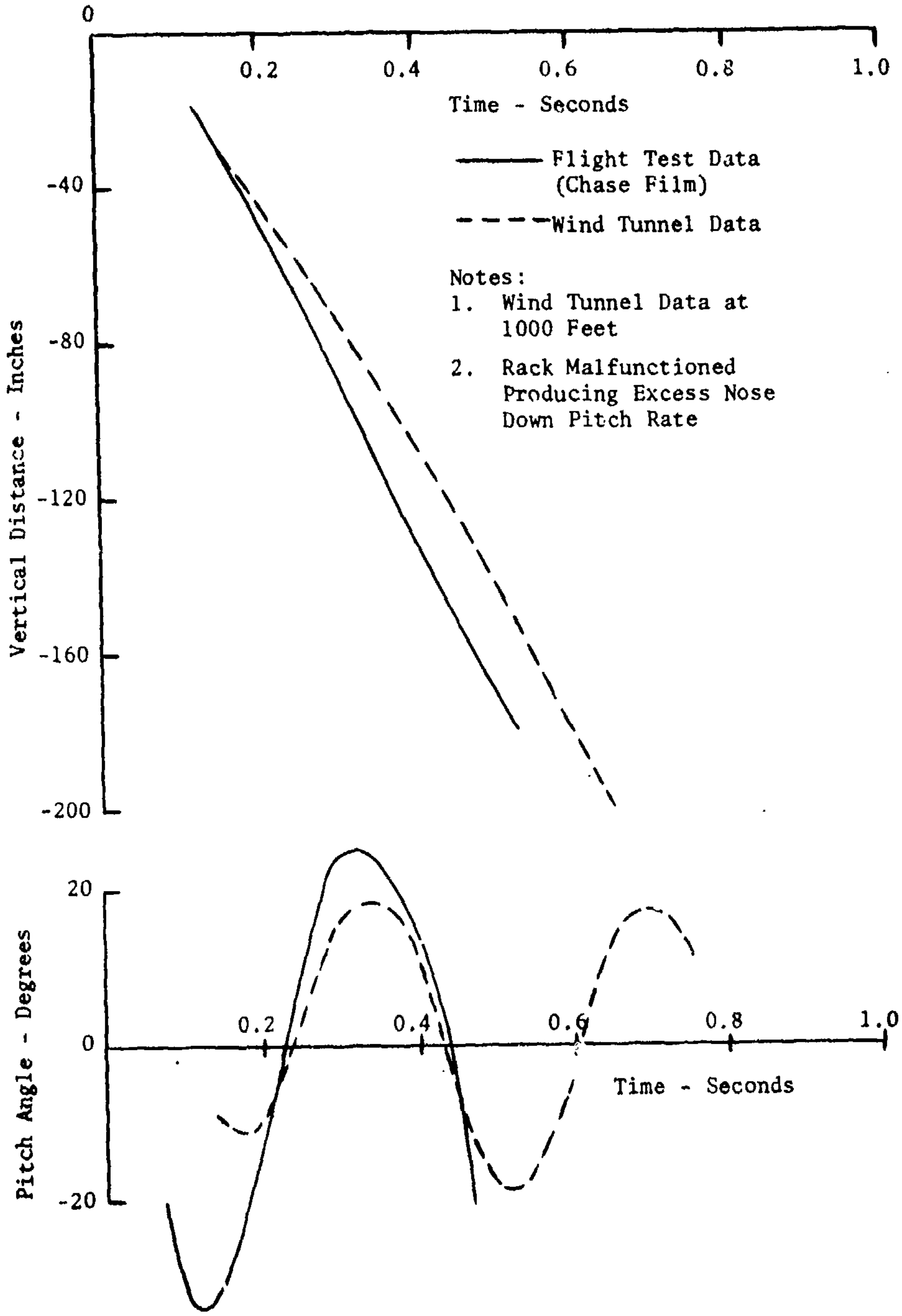


Figure 20. Single Release of M117M6 from Bay Position 1 at 0.9 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
25 March 1971 F-111A No. 26 Weapon Bay Position 2
Mach = 0.898   Altitude = 4105 Feet

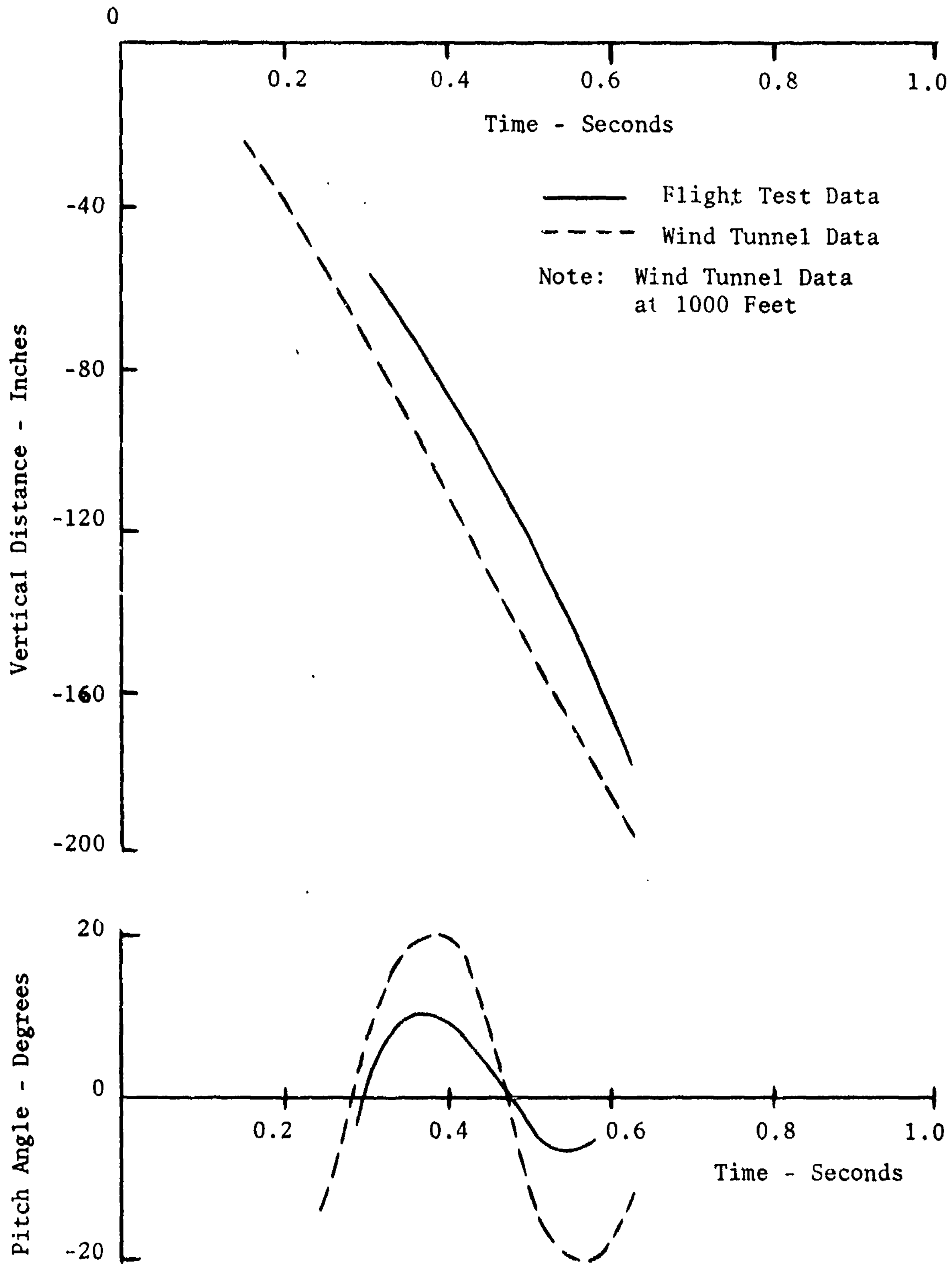


Figure 21. Single Release of M117M6 from Bay Position 2 at 0.9 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
25 March 1971 F-111A No. 26 Weapon Bay Position 3
Mach = 0.895   Altitude = 4085 Feet

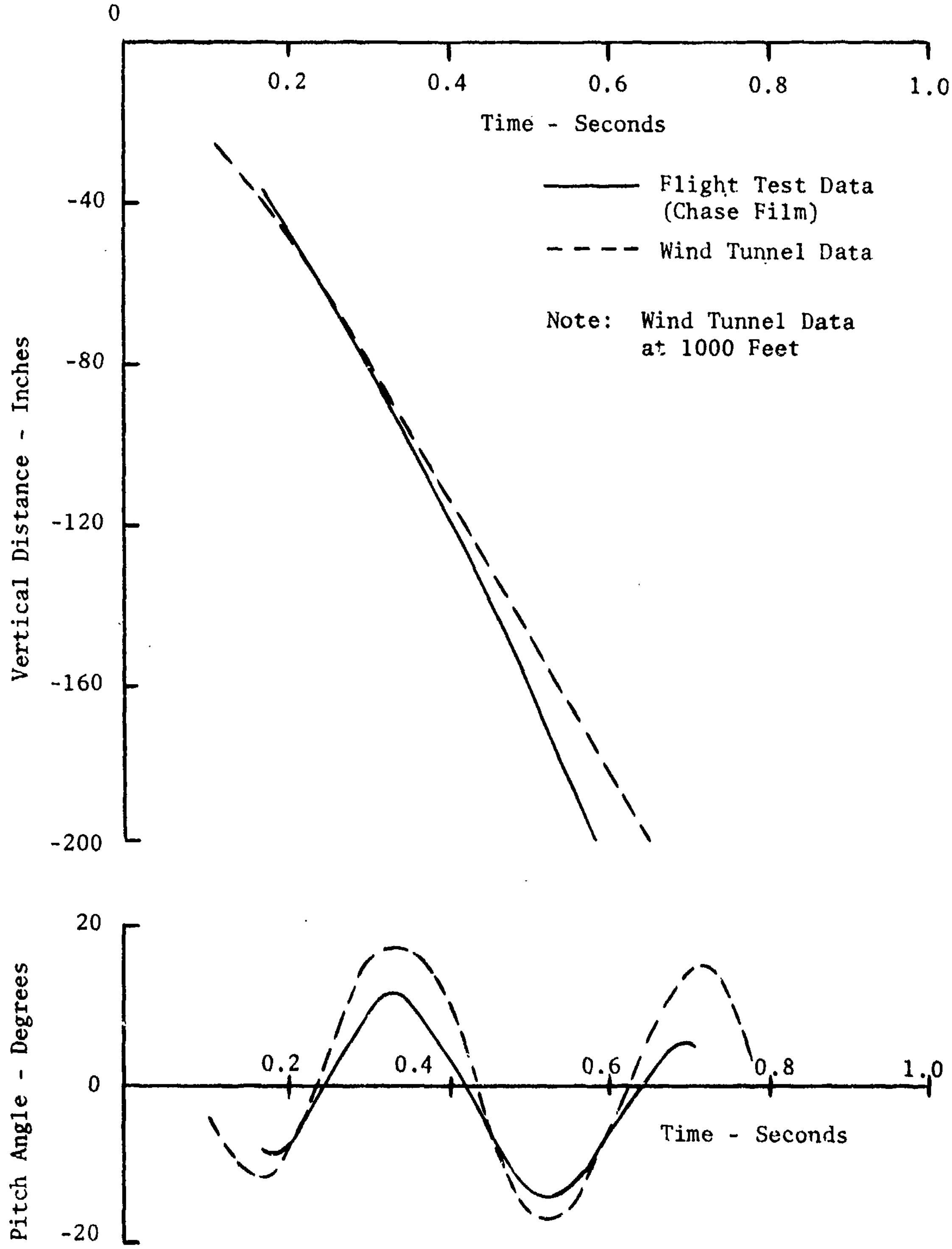


Figure 22. Single Release of M117M6 from Bay Position 3 at 0.9 Mach

GROUND SEQUENCE PICTURES

AIRCRAFT F-111A NO. 26
Second Drop - 25 March 1971
Single Release - Position 3

RELEASE CONDITIONS
Mach = .90
4100 Feet

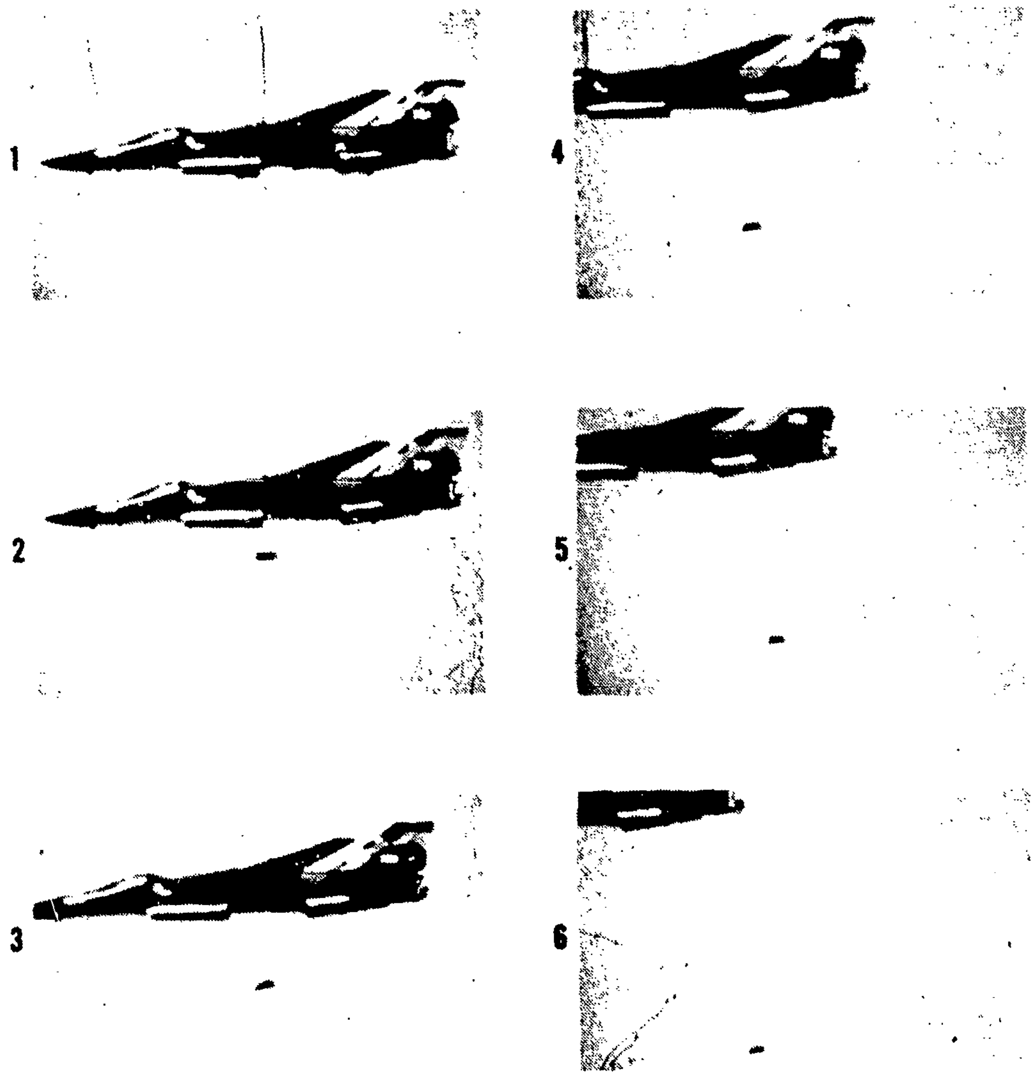


Figure 23. Ground Sequence of M117M6 from Bay Position 3 at 0.9 Mach

closed weapon bay door. Several large pieces of debris were noticed by the chase pilot and reported to the F-111 crew. The F-111 landed without incident.

Post-Flight investigation revealed that a spacer was missing from the splined shaft which transmits power to open and close the right-hand weapon bay door. The only significant damage was to the weapon bay door. Due in part to a logistics problem to obtain parts to repair the weapon bay door, the bluff bomb testing was delayed until early summer 1972.

The onboard camera film quality was not good enough to obtain reduced data. Therefore, chase plane film was used to obtain as much information as possible. Figures 24 and 25 show the flight test data for positions 1 and 2 which compare very closely to the wind tunnel data shown on these same figures. Since the weapon from position 3 hit the door and rolled out, it was not possible to obtain any useful data for this drop. Figure 26 shows the flight test data and wind tunnel data for the drop from position 4. The chase plane location on this drop was such that only very qualitative data was obtained. Therefore, the agreement between flight test and wind tunnel data is not close. Figure 27 shows the flight test data from position 5 which indicates that the weapon recovers and separates safely, even after being ejected through the weapon bay door.

All five of the weapons were dropped on this flight and all the weapons separated satisfactorily, even though weapons 3 and 5 hit the closed weapon bay door. Sequence photographs are not shown for this flight because the quality of the film was not good enough.

Mission 7

This drop was planned to be a ripple drop of all five weapons at 0.8 Mach and 2000 feet with a 100-millisecond interval between weapon drops. The mission was conducted as planned on 2 June 1972. This was the first ripple drop and all five weapons separated from the aircraft quite satisfactorily. Tabulated data were obtained for all five weapon drops. Figures 28, 29, 30, 31 and 32 present the flight test data from this flight. Wind tunnel data is presented for comparison in Figures 28, 29, 30 and 31. Flight test data from the single weapon drops at this Mach-altitude condition (first drop) are also presented for comparison in Figures 29, 30 and 31. These figures show good agreement between wind tunnel data and flight test data and good agreement between the ripple and single drop flight test data for weapon separation.

Figure 33 shows selected photographs of the chase plane film which indicates how cleanly the weapons separate from the aircraft.

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
27 August 1971 F-111E No. 4 Weapon Bay Position 1
Mach = 0.95 Altitude = 2000 Feet

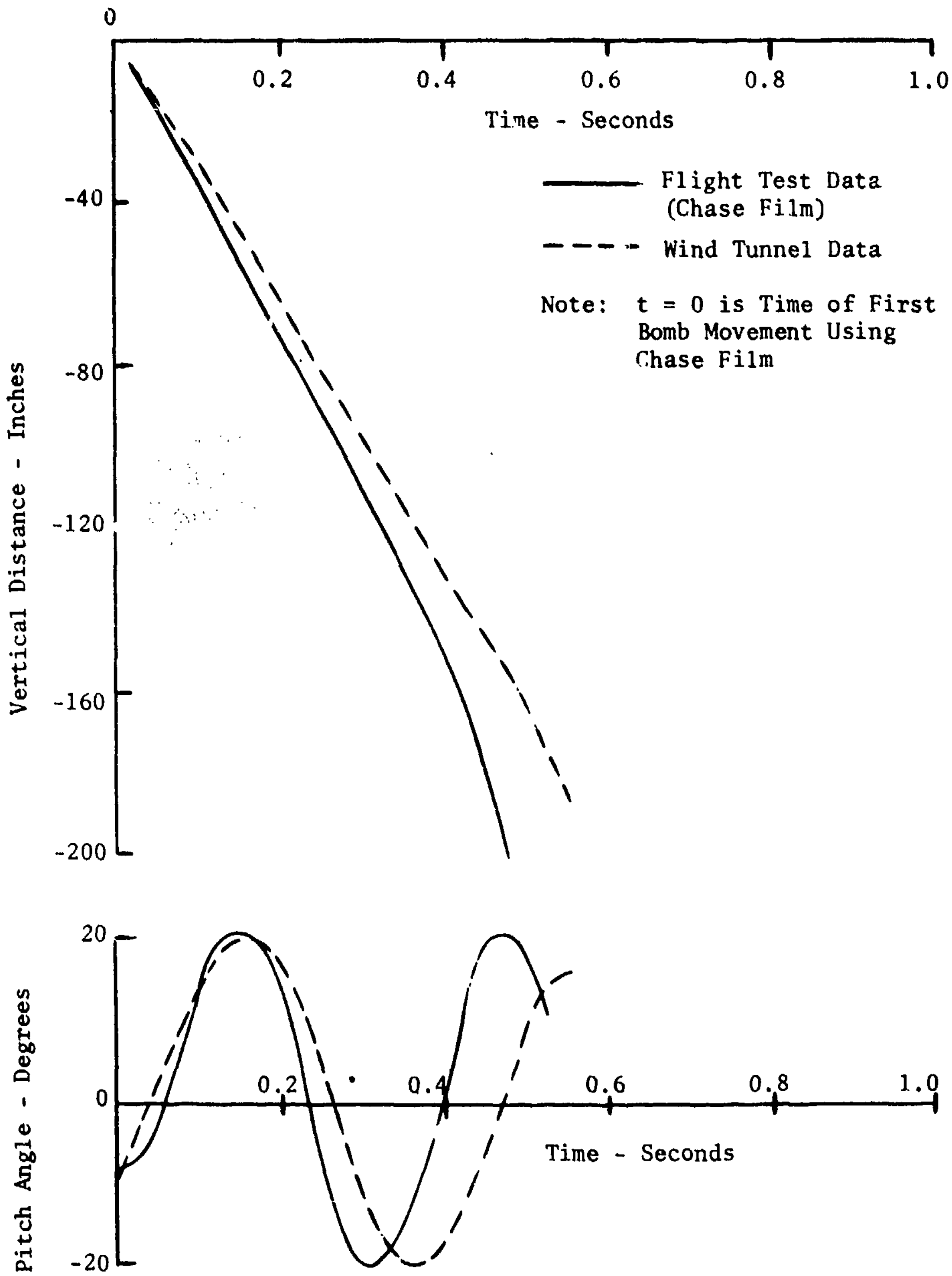


Figure 24. Single Release of M117M6 from Bay Position 1 at 0.95 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
27 August 1971 F-111E No. 4 Weapon Bay Position 2
Mach = 0.95 Altitude = 2000 Feet

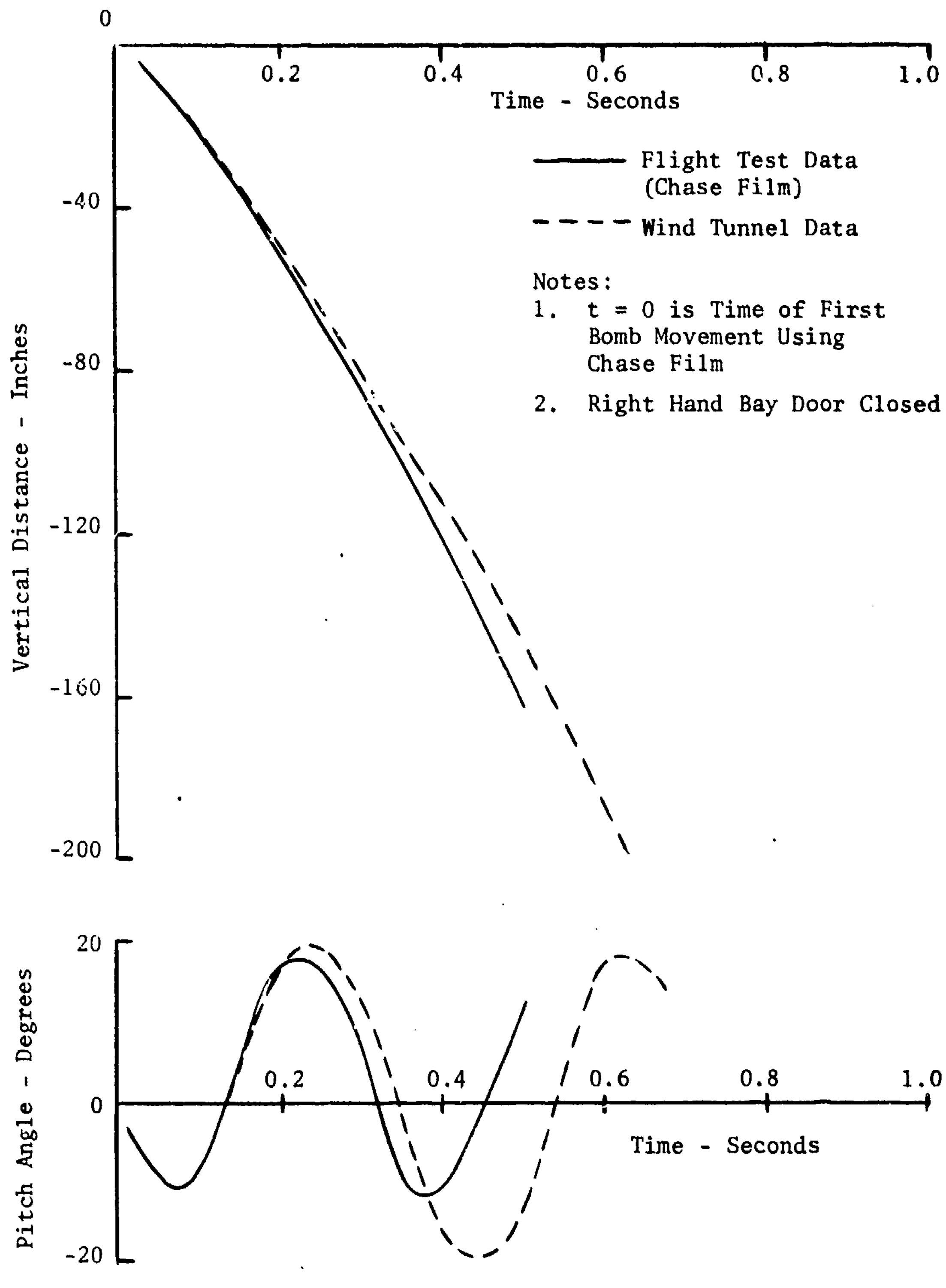


Figure 25. Single Release of M117M6 from Bay Position 2 at 0.95 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
27 August 1971 F-111E No. 4 Weapon Bay Position 4
Mach = 0.95   Altitude = 2000 Feet

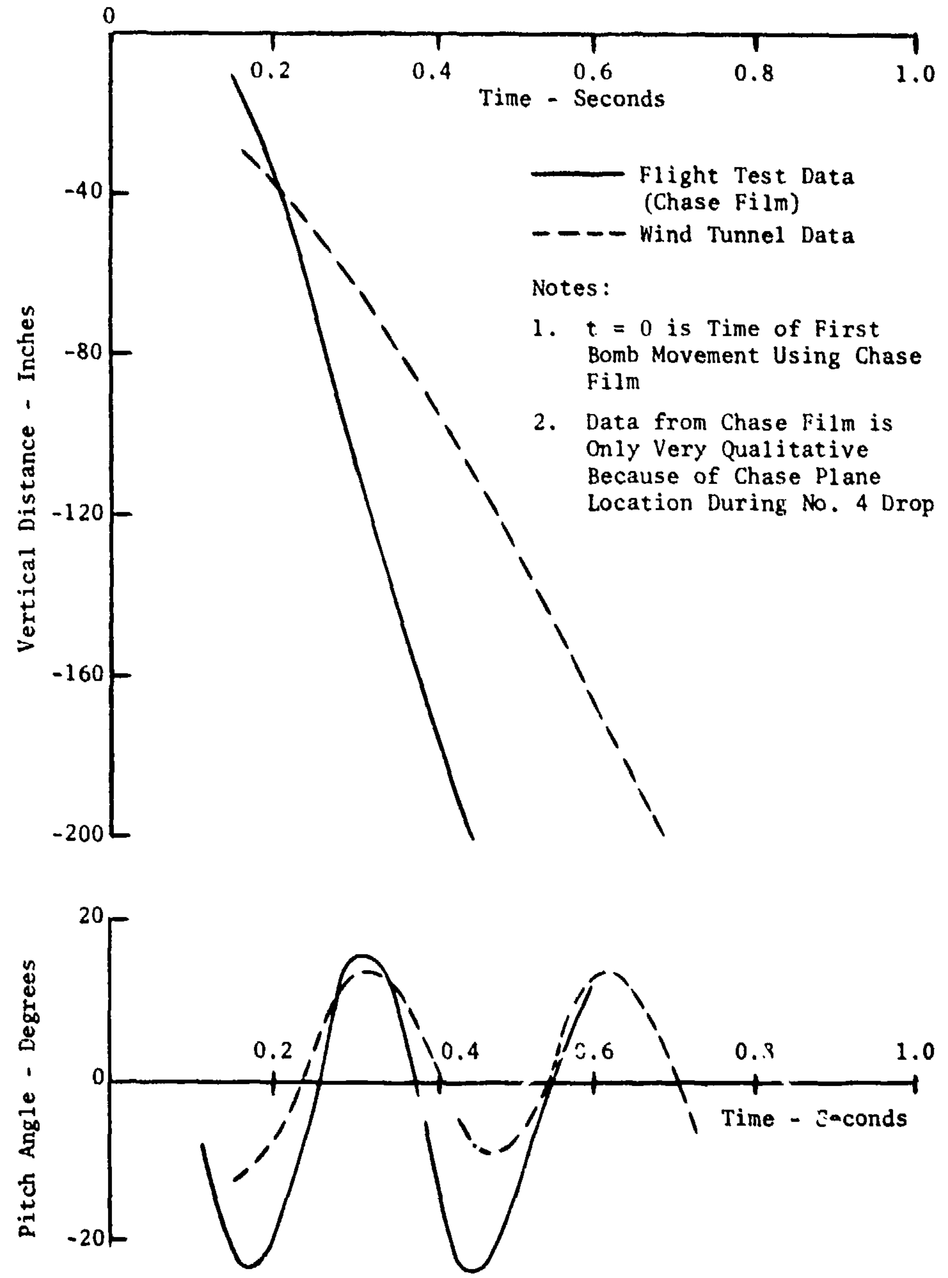


Figure 26. Single Release of M117M6 from Bay Position 4 at 0.95 Mach

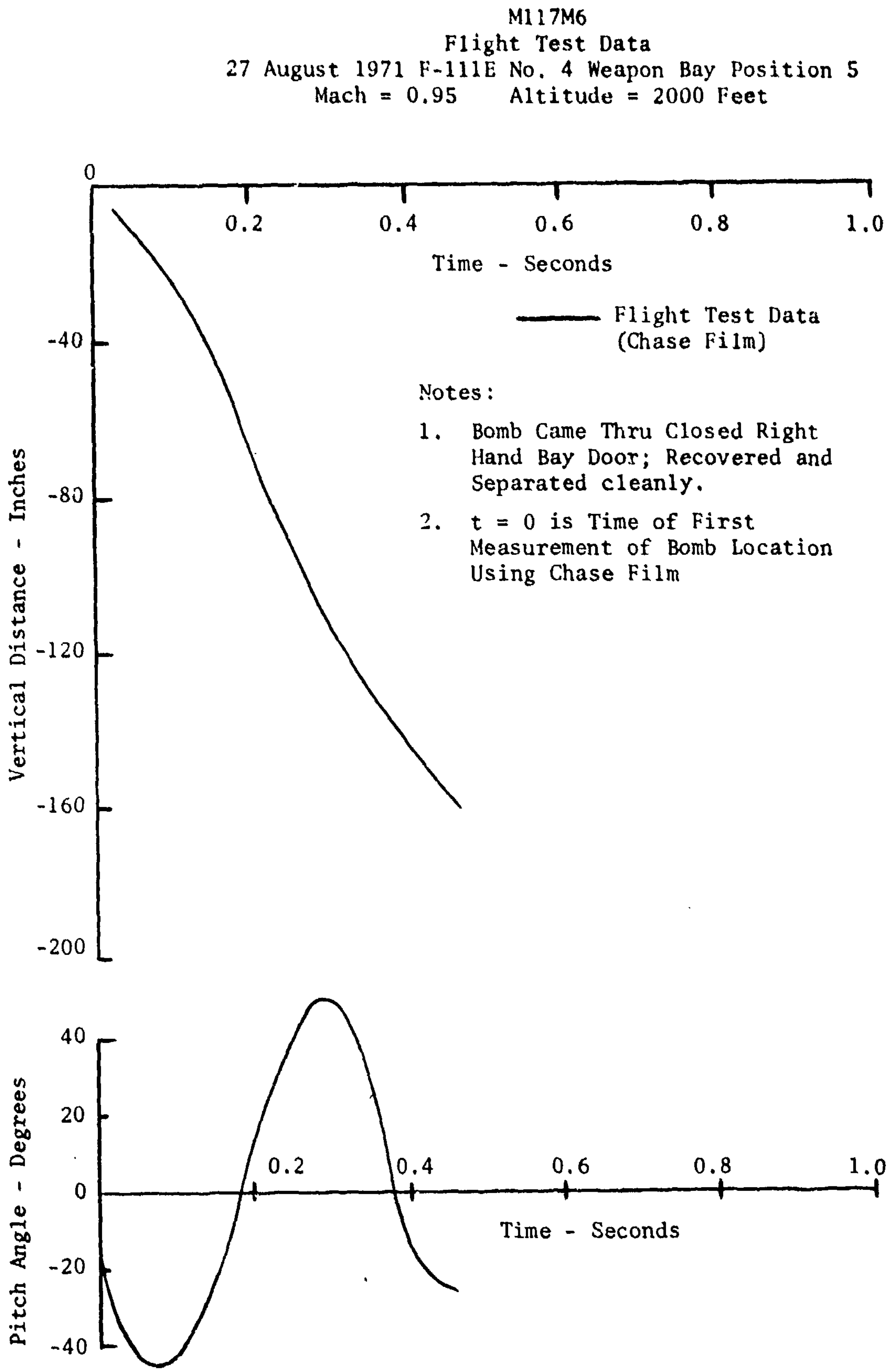


Figure 27. Single Release of M117M6 from Bay Position 5 at 0.95 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
2 June 1972 F-111E No. 4 Weapon Bay Position 1
Mach = 0.80   Altitude = 2000 Feet

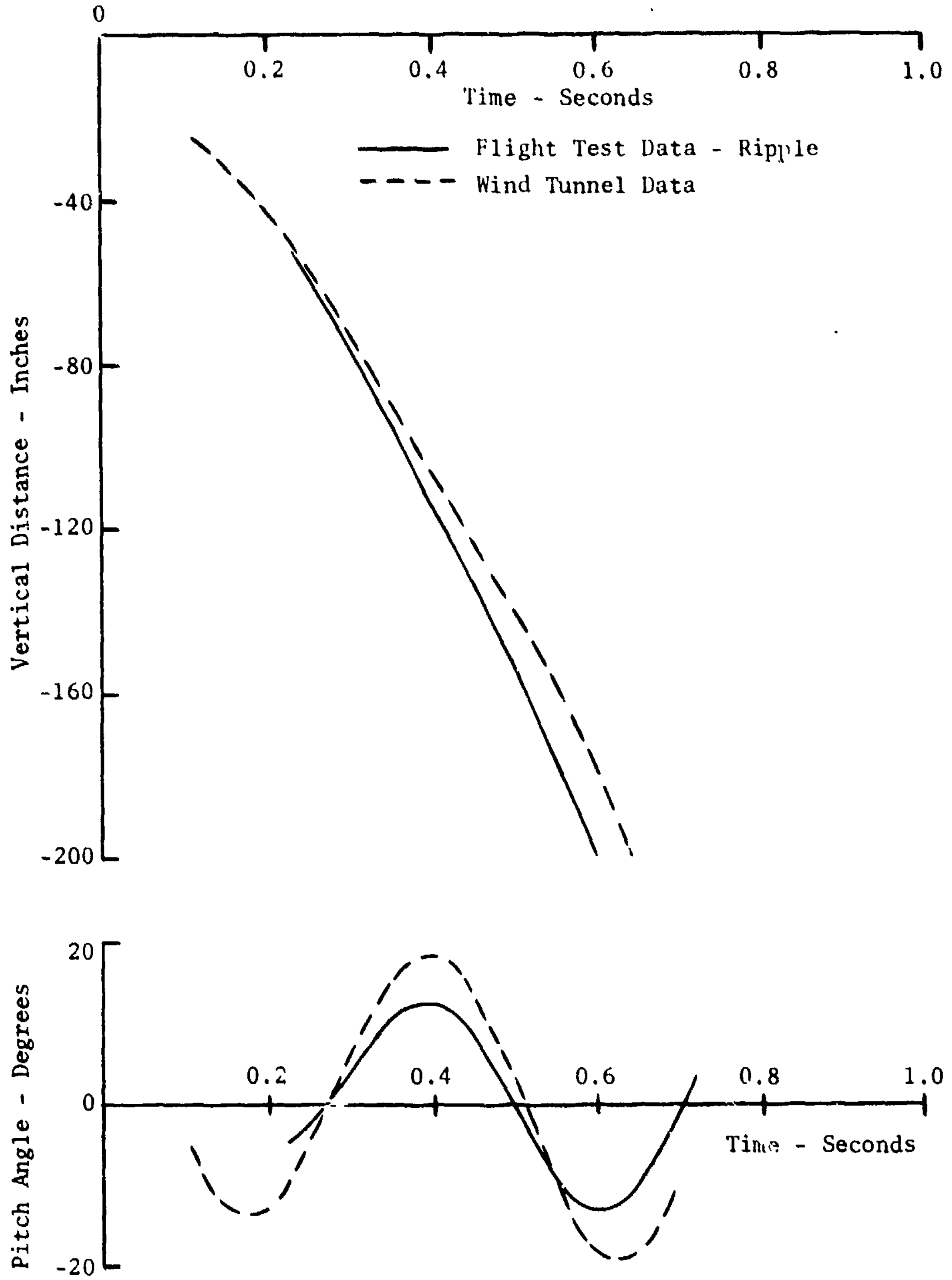


Figure 28. Ripple Release of M117M6 from Bay Position 1 at 0.8 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
2 June 1972 F-111E No. 4 Weapon Bay Position 2
Mach = 0.80   Altitude = 2000 Feet

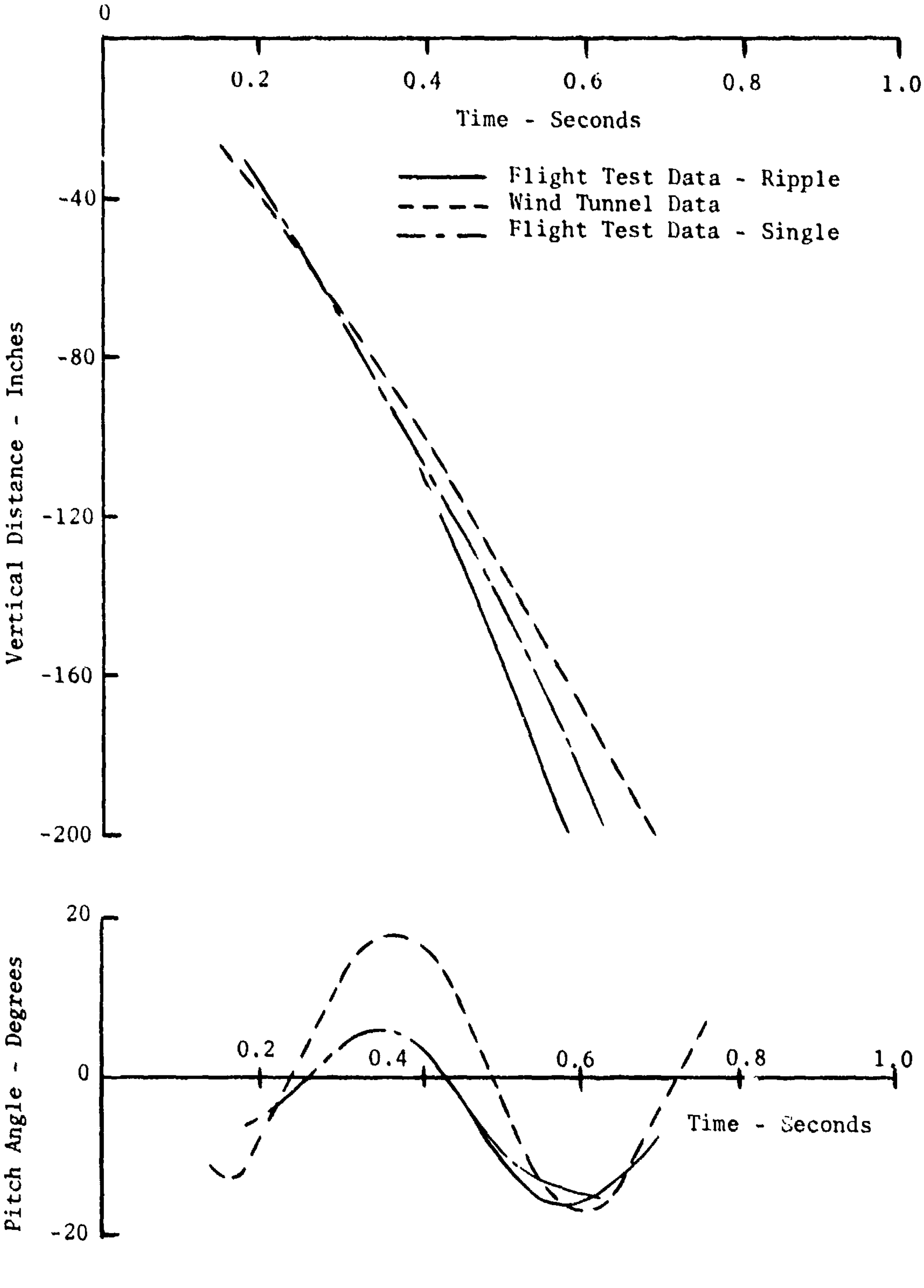


Figure 29. Ripple Release of M117M6 from Bay Position 2 at 0.8 Mach

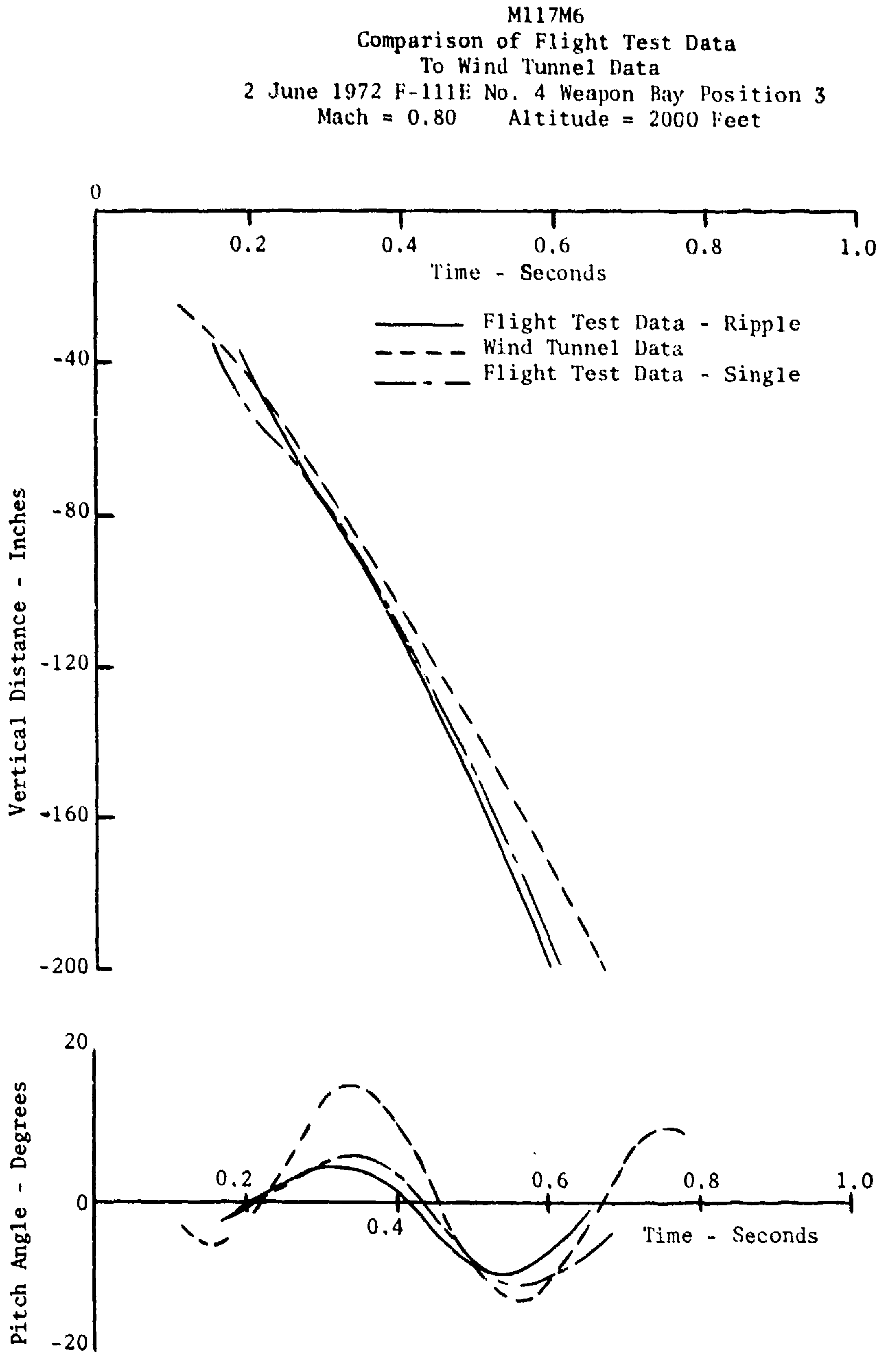


Figure 30. Ripple Release of M117M6 from Bay Position 3 at 0.8 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
2 June 1972 F-111E No. 4 Weapon Bay Position 4
Mach = 0.80 Altitude = 2000 Feet

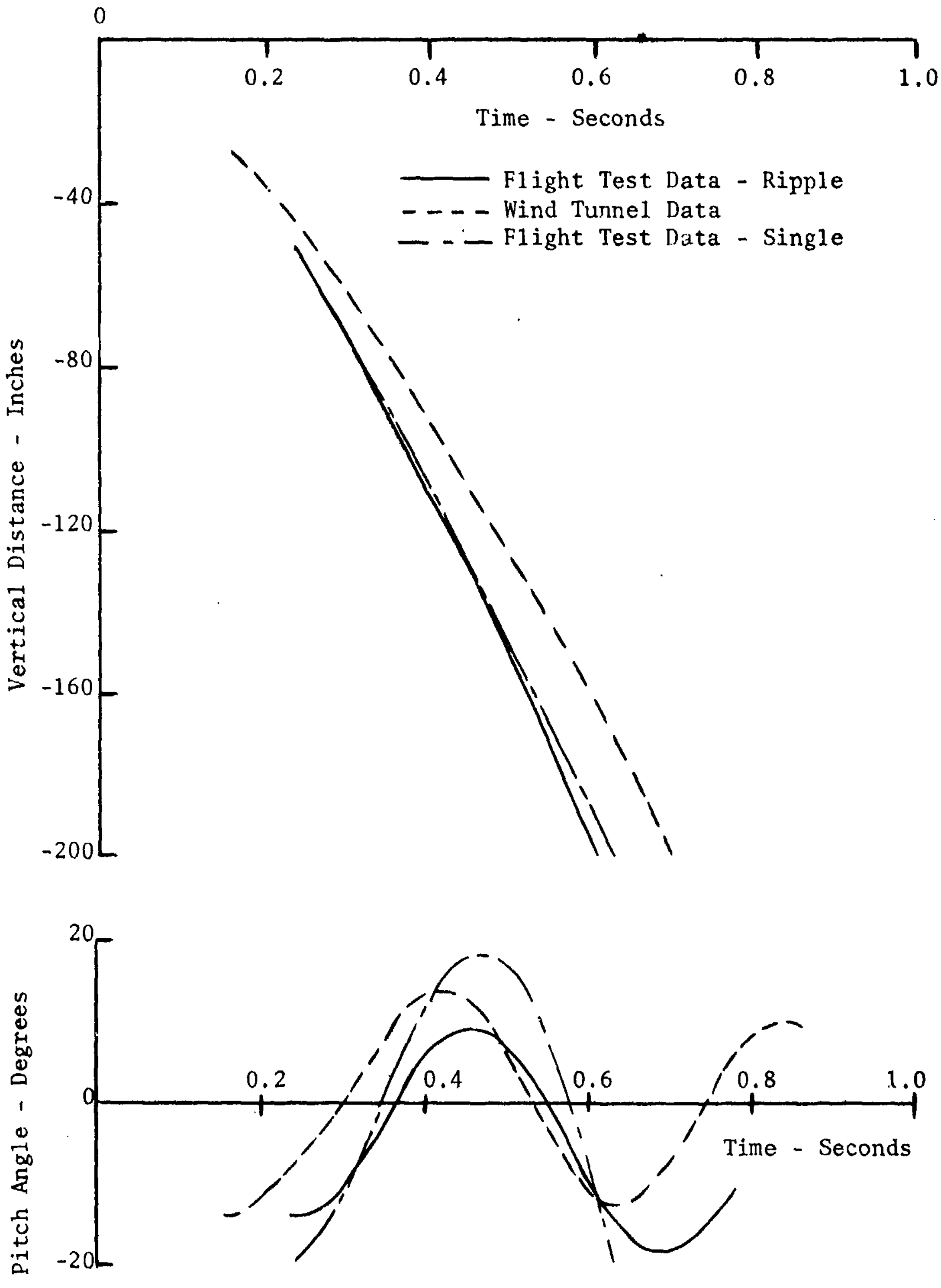


Figure 31. Ripple Release of M117M6 from Bay Position 4 at 0.8 Mach

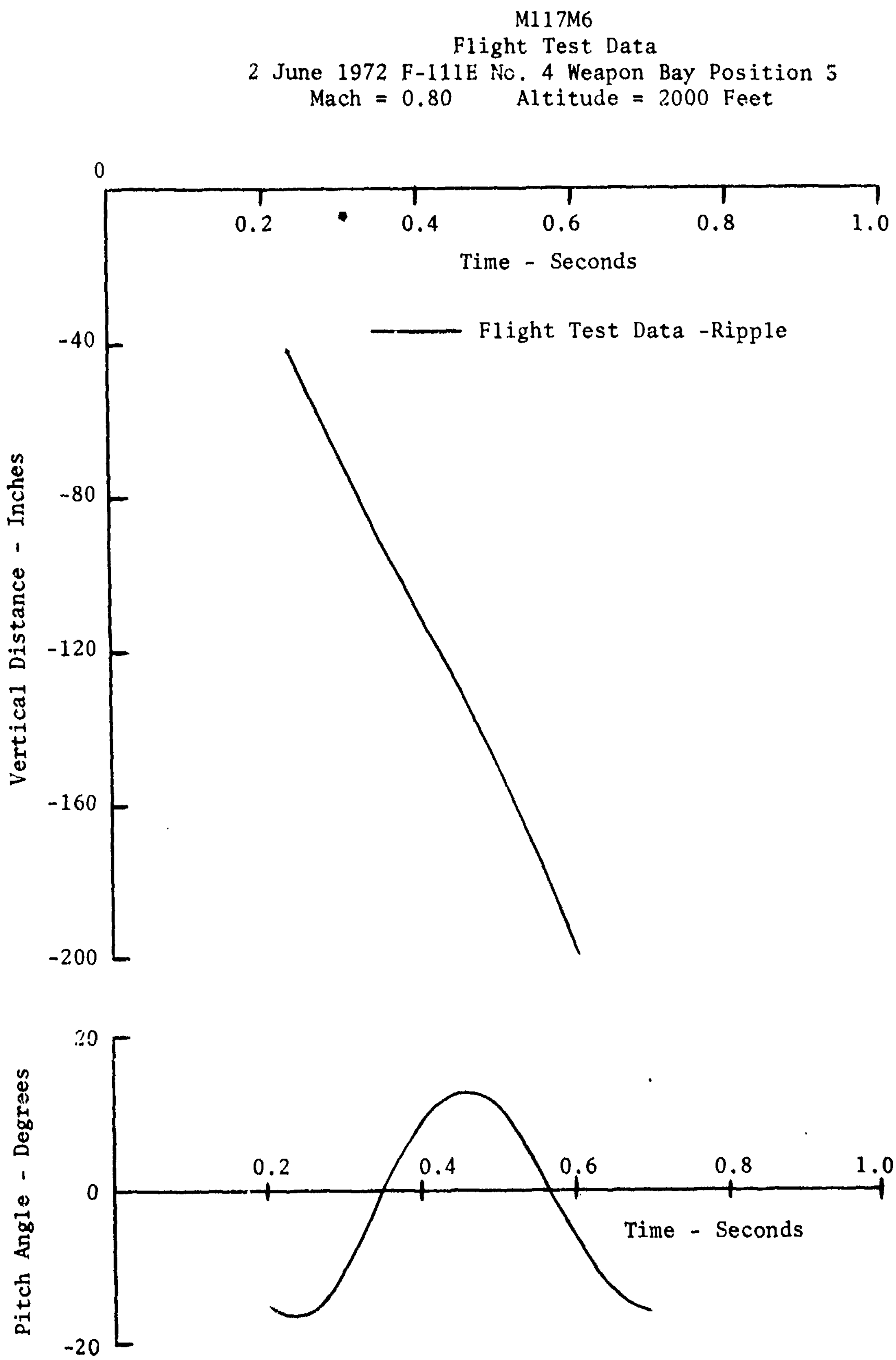


Figure 32. Ripple Release of M117M6 from Bay Position 5 at 0.8 Mach

CHASE SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Fourth Drop - 2 June 1972
Ripple Release of Five -100 ms.

RELEASE CONDITIONS
Mach = .80
2000 Feet

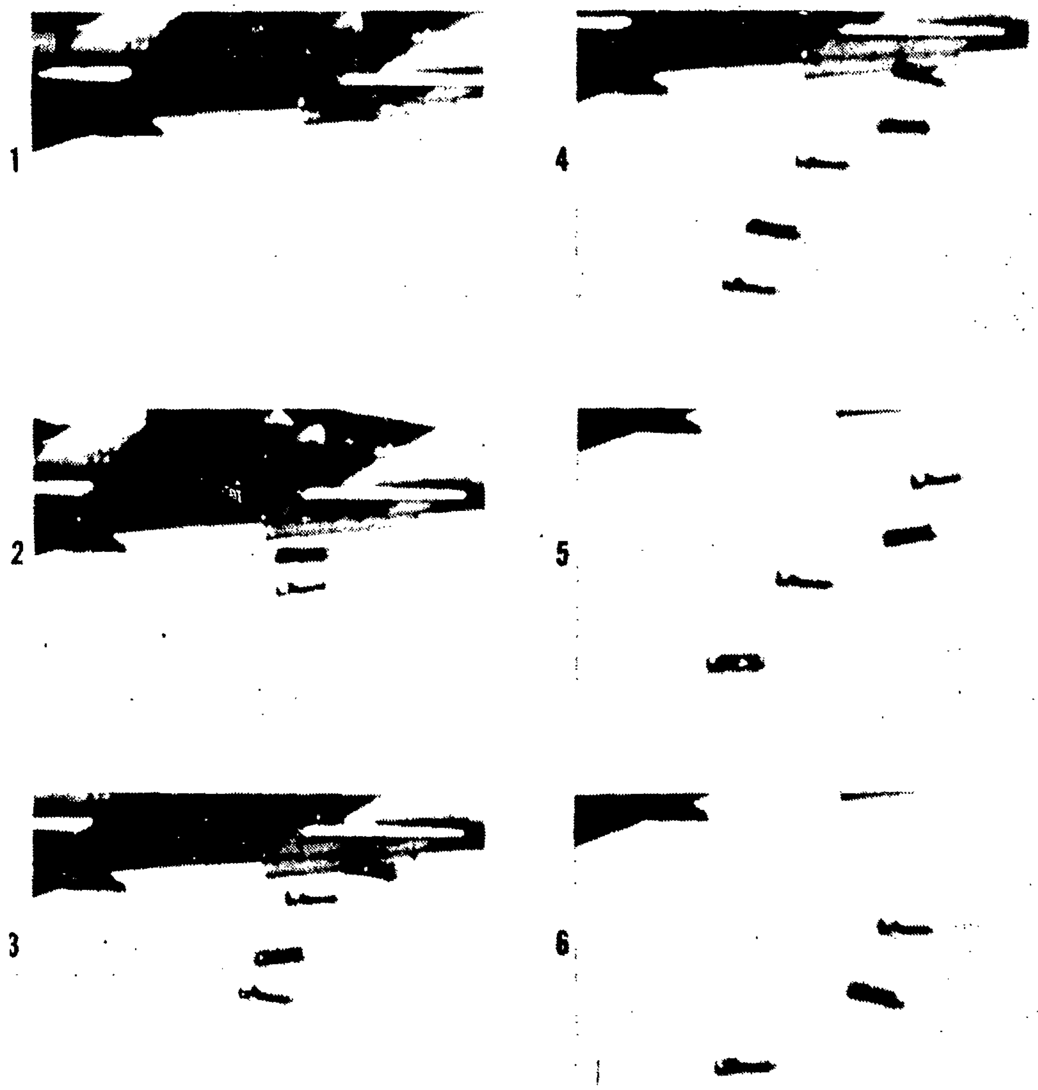


Figure 33. Chase Sequence of Ripple of Five M117M6 at 0.8 Mach

Mission 8

This was planned to be the second ripple drop with a 100-millisecond interval between weapon drops. The planned Mach was 0.95 and the altitude was 2000 feet. This mission was conducted as planned on 27 February 1973. Tabulated data were obtained for all positions, except No. 1 which was obscured by a glare at the time the weapon was separating. Figures 34, 35, 36 and 37 present the flight test data from this ripple drop. Wind tunnel data are also presented for comparison for Figures 34, 35 and 36. Figure 34 also presents the flight test data from the single drop at this same Mach-altitude condition. These figures show close agreement between wind tunnel and flight test data, and Figure 34 shows close agreement between ripple and single drop flight test data.

Figure 38 shows selected photographs from the ground coverage film which indicate the weapon separation characteristics at this condition.

Mission 9

This drop was made as planned at 0.6 Mach with one weapon dropped at 2,000 feet and one at 20,000 feet. These weapons were dropped from only the two forward positions on 28 February 1973. These drops were made to determine the bluff bomb separation characteristics at a low dynamic pressure and a high angle-of-attack.

Tabulated data were obtained for both drops and are presented in Figures 39 and 40. Both weapons had satisfactory separation characteristics. Selected sequence photographs from the wing tip camera for the first drop is shown by Figure 41 and indicates how the weapon separates from the aircraft.

Mission 10

Following the successful ripple drop at 0.8 and 0.95 Mach at 100 milliseconds, a 0.95 drop was planned at 50 milliseconds between weapons. This mission was conducted on 22 March 1973 at 0.965 Mach and 1950 feet altitude. A review of the motion pictures of this drop indicated that all five weapons separated satisfactorily.

The wing tip film from this flight was not good enough to obtain weapon separation data, and the chase film was not adequate to analyze. Figure 42 shows selected sequence photographs from the wing tip camera. These photographs indicate how cleanly the weapons separate from the aircraft.

Mission 11

This drop was planned to be single drops of all five weapons at Mach 1.2 and 2000 feet altitude. The first three positions were dropped essentially as planned on 5 April 1973. After the third weapon was dropped the weapon bay doors would not close so the remaining two weapons were dropped on the same

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
27 Feb 1973 F-111E No. 4 Weapon Bay Position 2
Mach = 0.95   Altitude = 2000 Feet

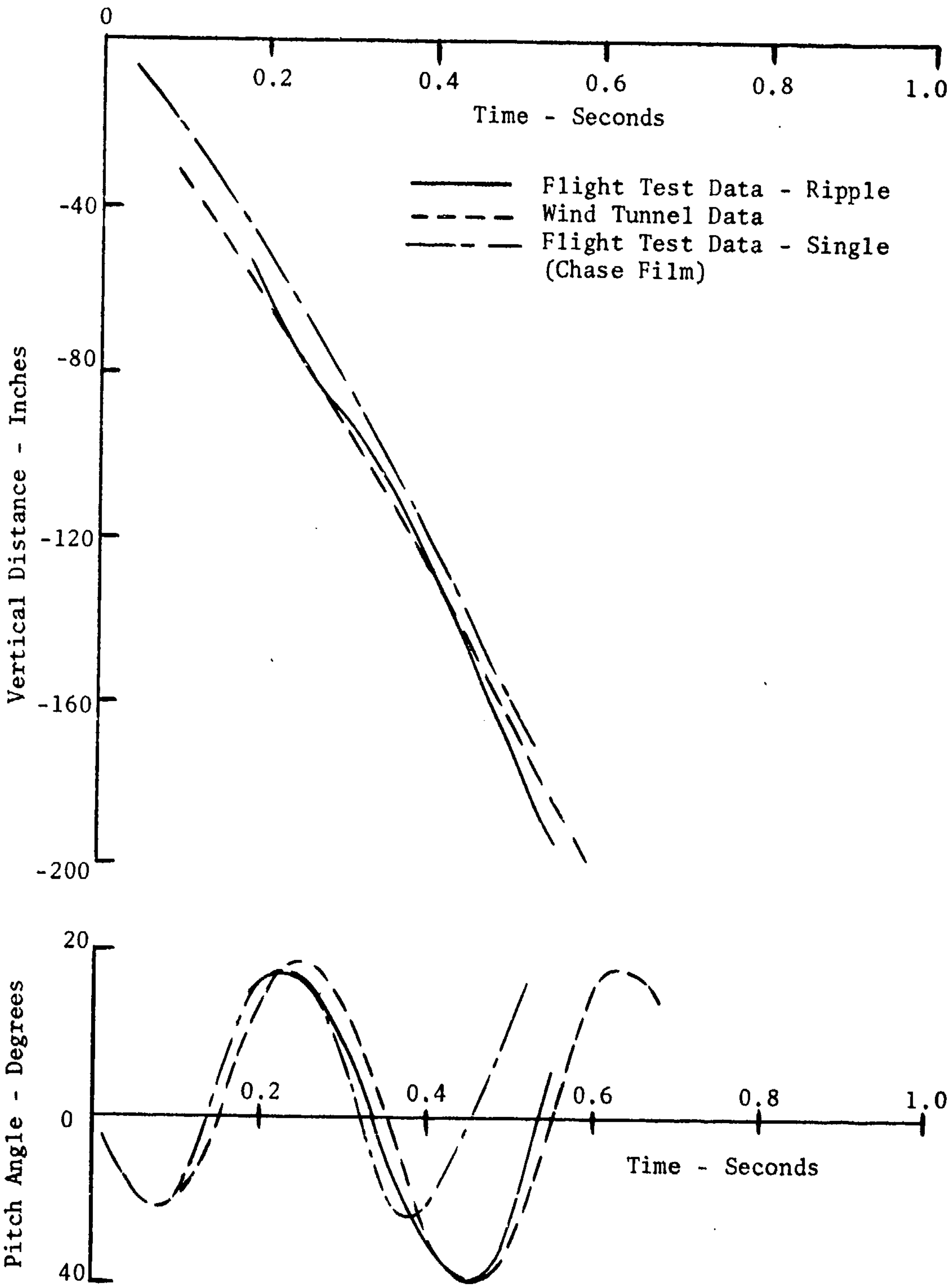


Figure 34. Ripple Release of M117M6 from Bay Position 2 at 0.95 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
Feb 1973 F-111E No. 4 Weapon Bay Position 3
Mach = 0.95   Altitude = 2000 Feet

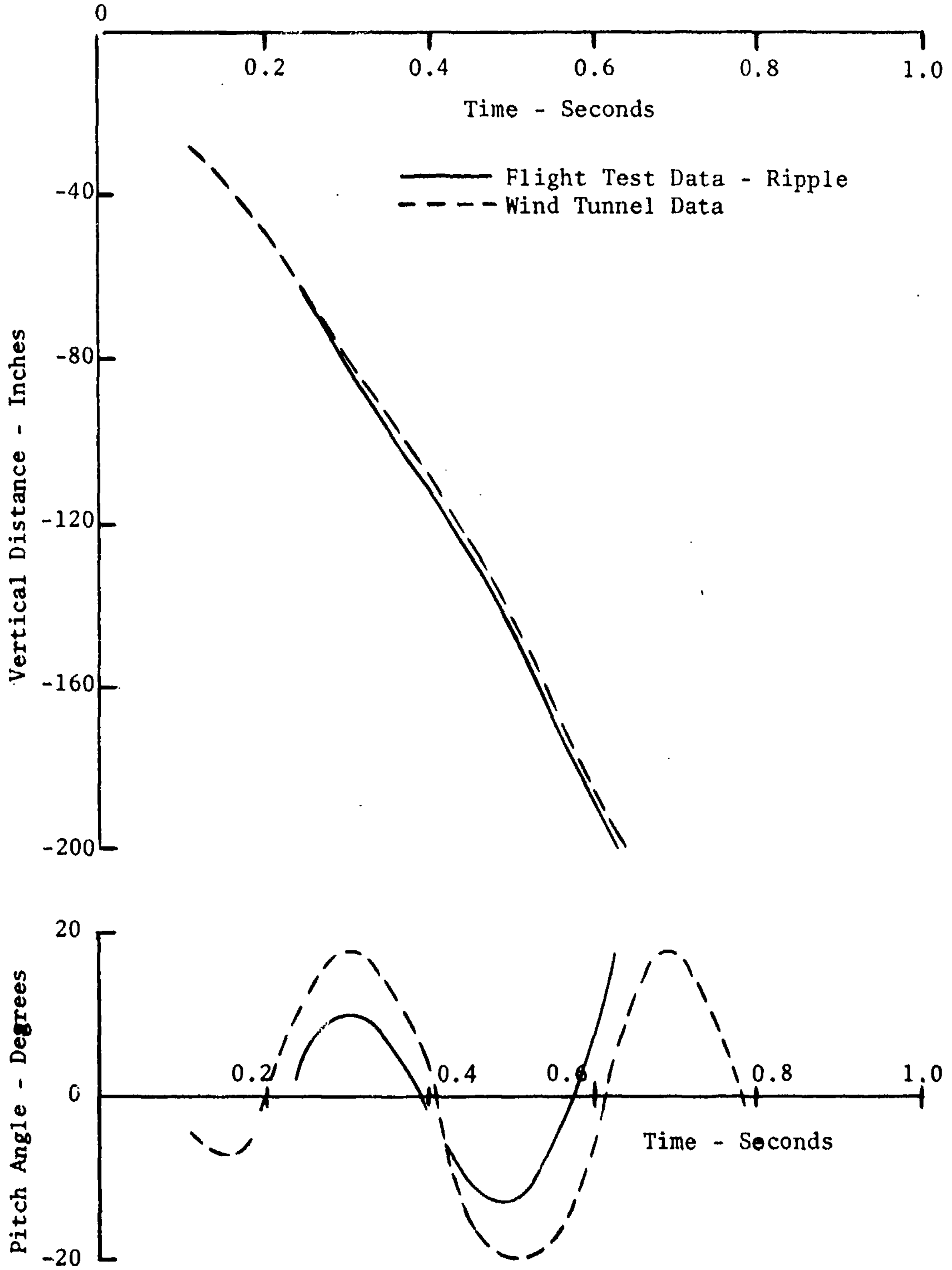


Figure 35. Ripple Release of M117M6 from Bay Position 3 at 0.95 Mach

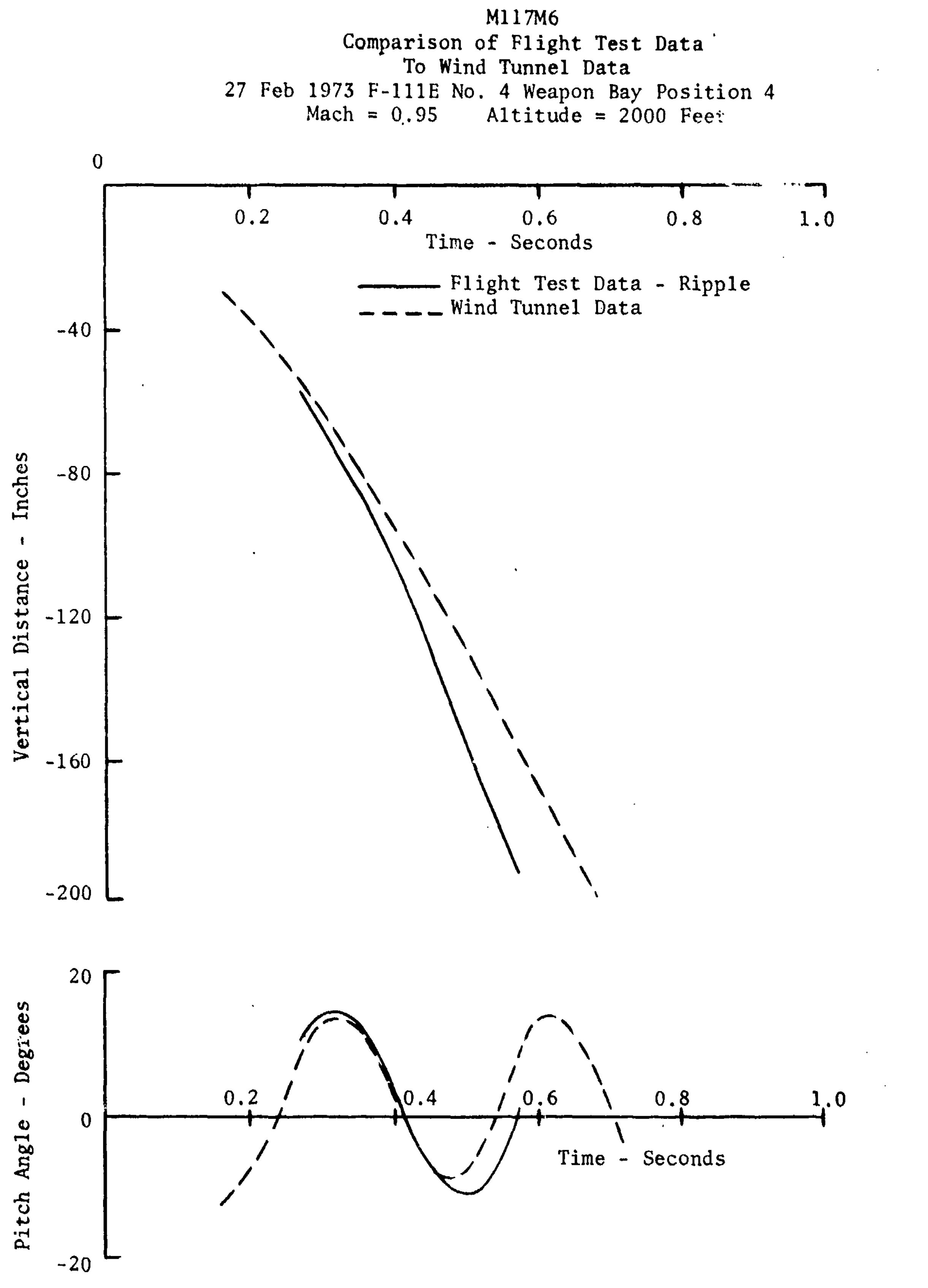


Figure 36. Ripple Release of M117M6 from Bay Position 4 at 0.95 Mach

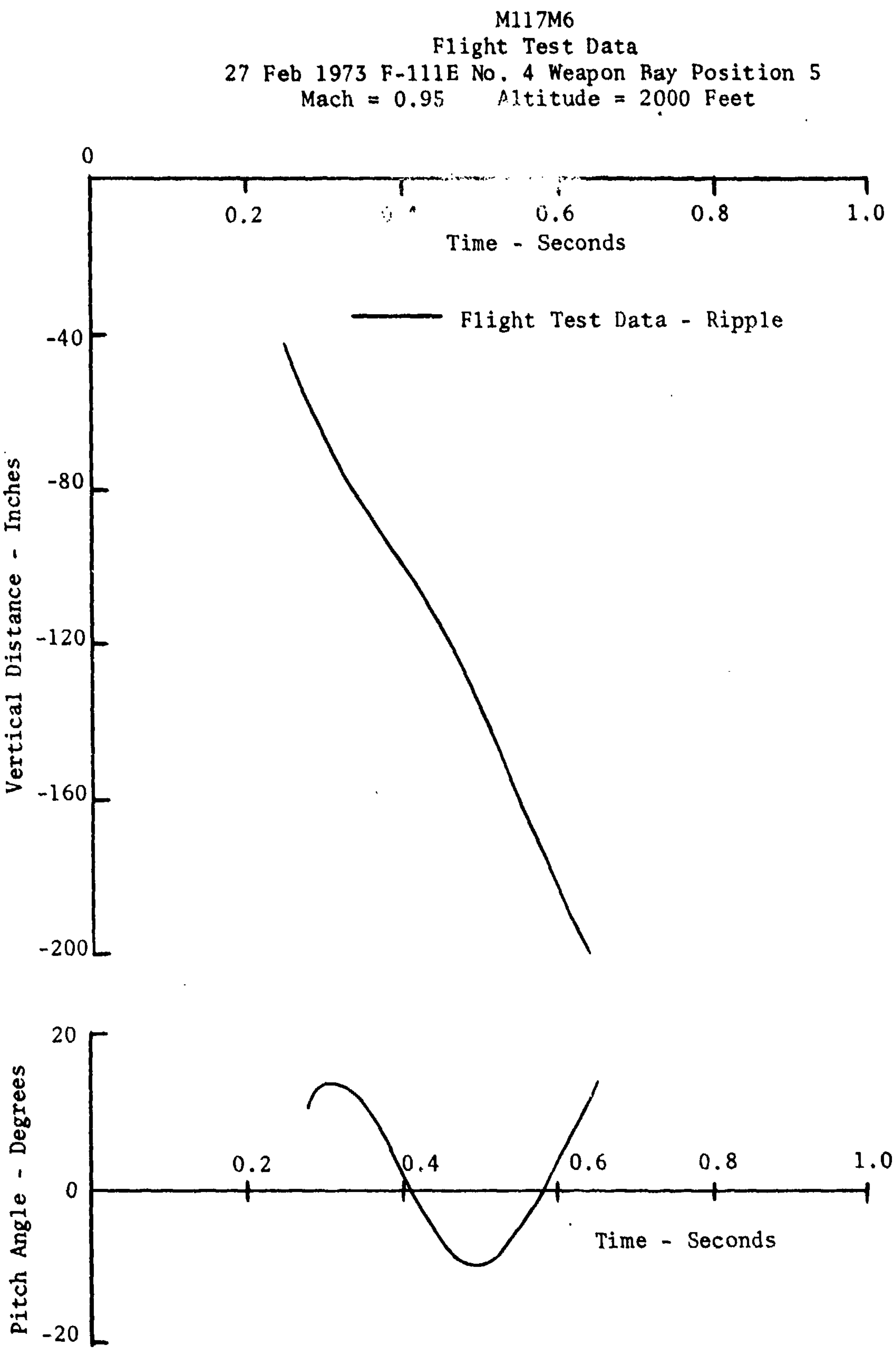


Figure 37. Ripple Release of M117M6 from Bay Position 5 at 0.95 Mach

GROUND SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Fifth Drop - 27 February 1973
Ripple Release of Five -100 ms.

RELEASE CONDITIONS
Mach = .95
2000 Feet

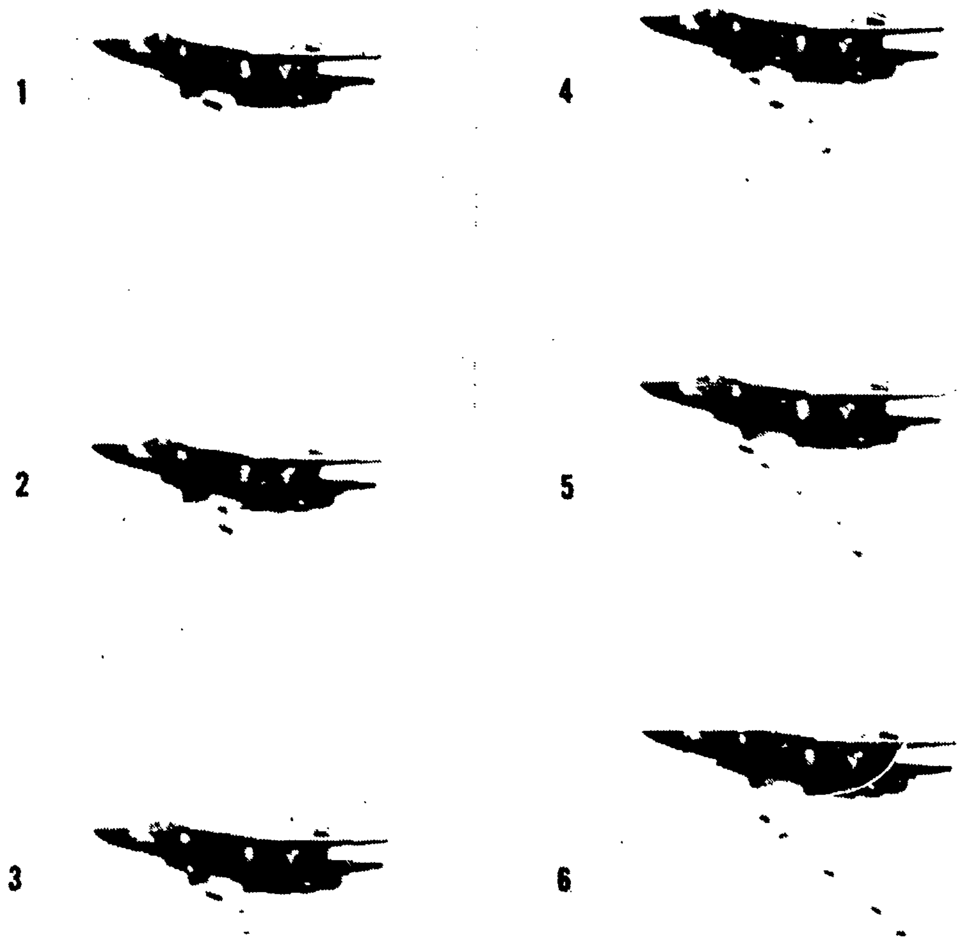


Figure 38. Ground Sequence of Ripple of Five M117M6 at 0.95 Mach

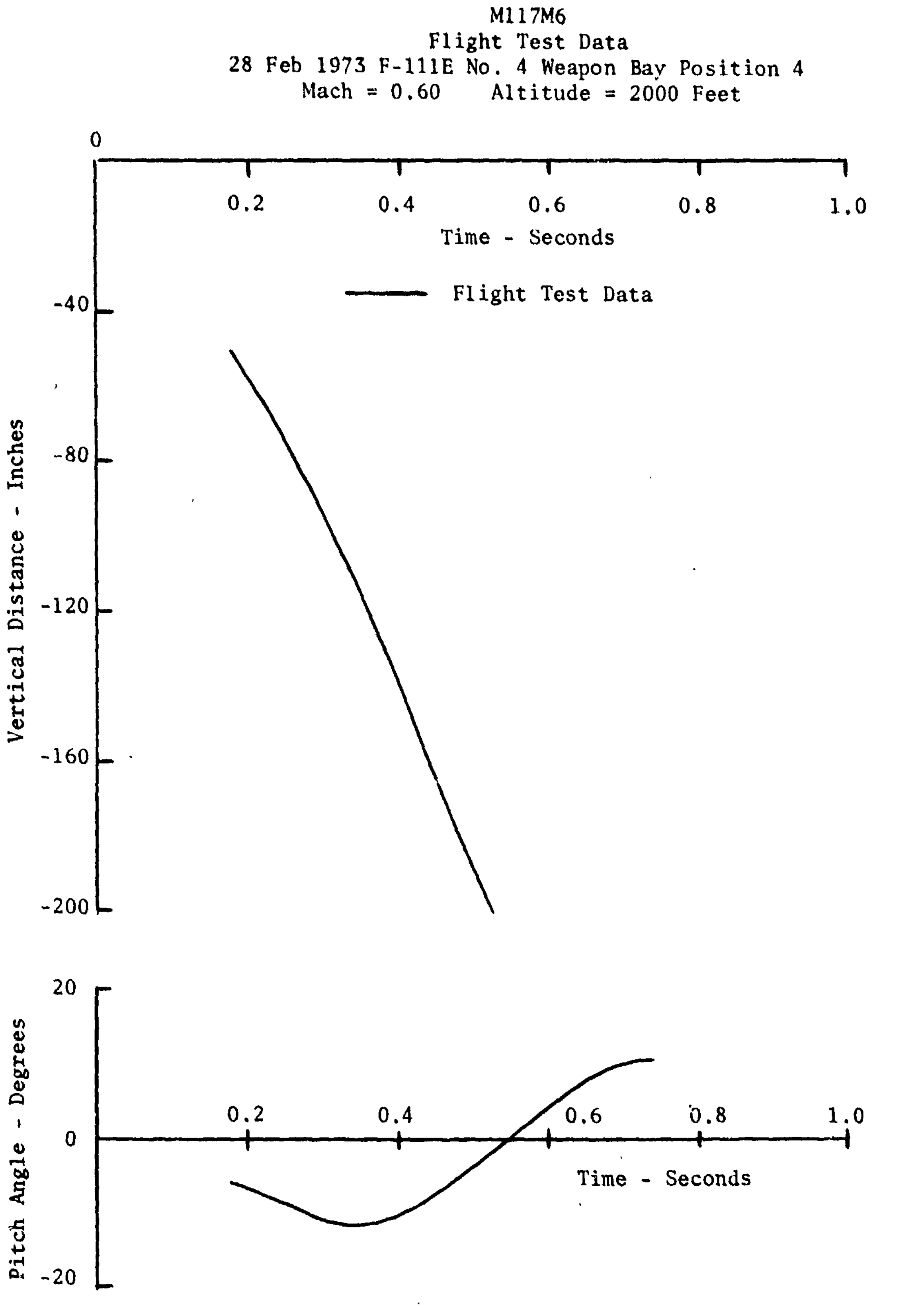


Figure 39. Single Release of M117M6 from Bay Position 4 at 0.6 Mach

M117M6
Flight Test Data
28 Feb 1973 F-111E No. 4 Weapon Bay Position 5
Mach = 0.60   Altitude = 20,000 Feet

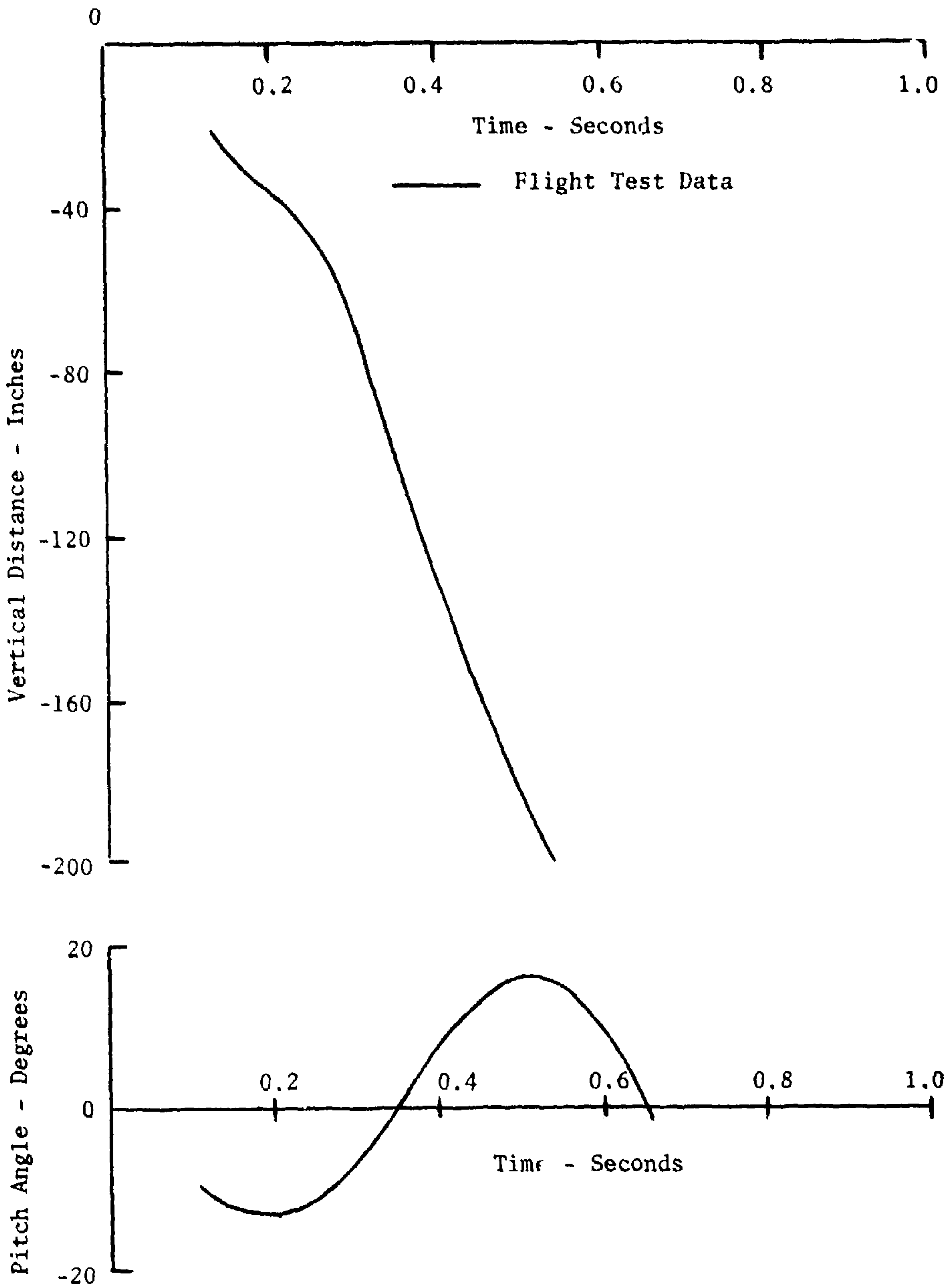


Figure 40. Single Release of M117M6 from Bay Position 5 at 0.6 Mach

WING TIP SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Sixth Drop - 28 February 1973
Single Release - Position 4

RELEASE CONDITIONS
Mach = .60
2000 Feet

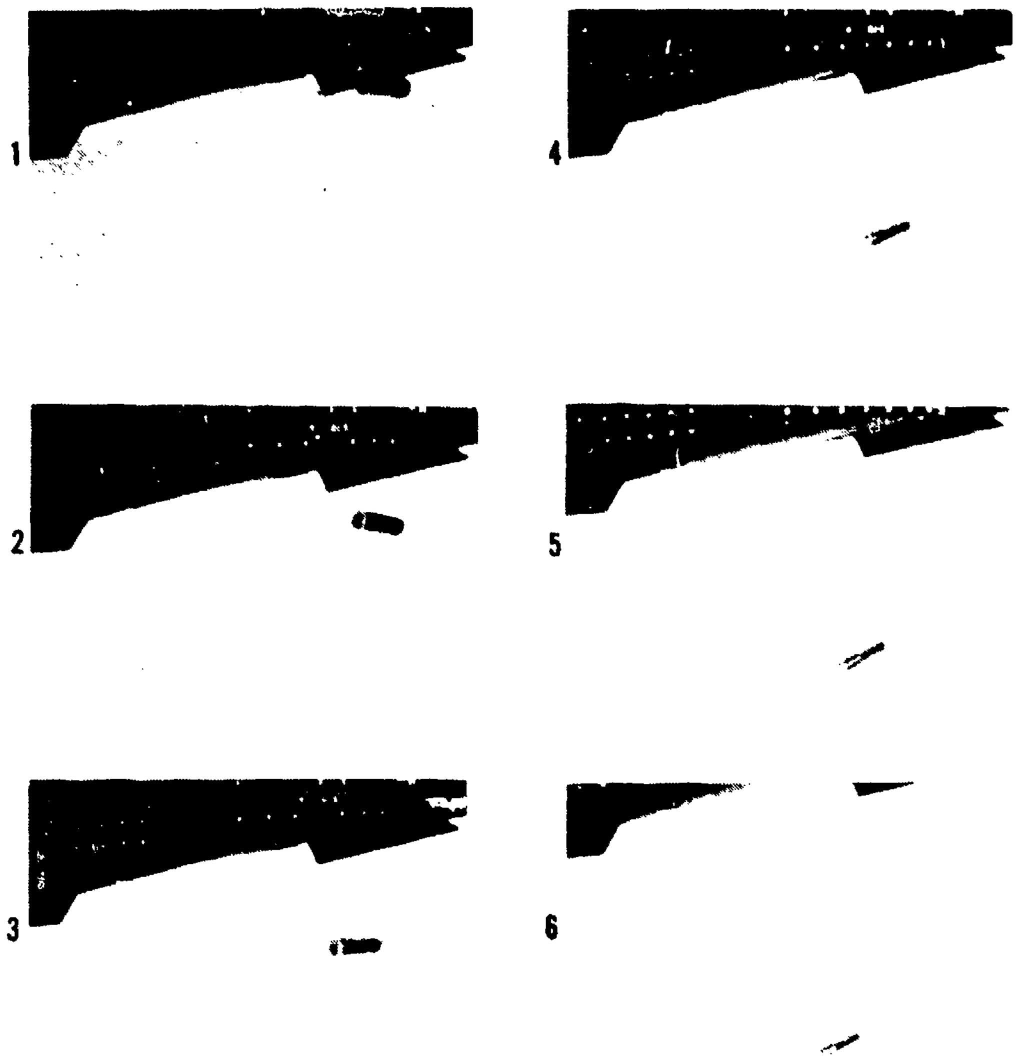


Figure 41. Wing Tip Sequence of M117M6 from Bay Position 4 at 0.6 Mach

WING TIP SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Seventh Drop - 22 March 1973
Ripple Release of Five -50 ms.

RELEASE CONDITIONS
Mach = .96
2000 Feet

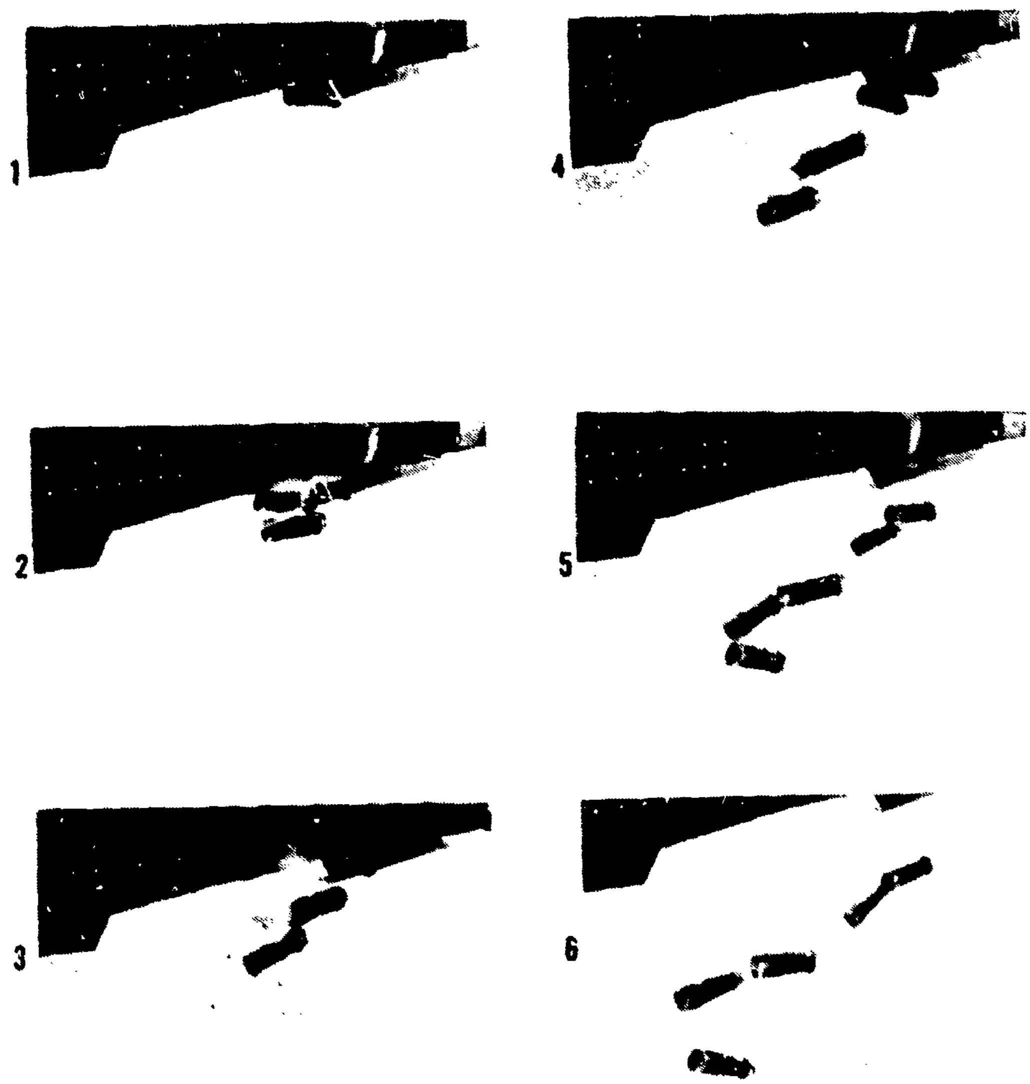


Figure 42. Wing Tip Sequence of Ripple of Five M117M6 at 0.96 Mach

pass at about 0.57 Mach and 2000 feet altitude. Post-flight inspection revealed that an improperly installed aircraft hydraulic line on the aft weapon bay bulkhead broke due to the turbulent air flow in the bay on the first three weapon drops. This broken hydraulic line caused loss of the hydraulic system which supplies power for the weapon bay door opening and closing operation.

Separation data on these weapon drops could not be obtained. The chase plane was too far away and the film quality not adequate to analyze. Figure 43 shows selected sequence photographs from the chase plane for the first weapon dropped. This figure shows that the weapon separates cleanly from the aircraft and it also shows that the bluff bomb trails behind the aircraft very quickly at this flight condition.

Mission 12

This drop was a ripple drop at 1.2 Mach and 2000 feet with 100 milliseconds between weapons. The mission was conducted on 10 April 1973. A review of the film from this drop indicated that all weapons separated satisfactorily. Onboard film data were obtained from weapons dropped from weapon bay positions 1, 2 and 3 only (Figures 44, 45 and 46). Figure 47 shows weapon separation sequence pictures from a ground camera. Figure 48 shows selected sequence photographs from the onboard cameras. This camera is forward of the bay and is looking aft. These photographs show how cleanly the weapon separates from the aircraft at the high speed condition.

Mission 13

Single drops were planned for all five positions at 1.6 Mach and 22,000 feet altitude. This mission was conducted on 30 July 1973. The first weapon was released from the number 2 position due to an incorrect set-up of the release system in the cockpit where the number 1 position was skipped from the release sequence. On successive passes, weapons were released from positions 3, 4 and 5. The released weapons from positions 3 and 4 had excessive vapor around the bodies during separation and thus no data were obtainable from the film of these drops.

The separation data from the weapons released from positions 2 and 5 are shown in Figure 49 and 50. In Figure 49 all data correlated well with wind tunnel data values of the same conditions. However, in Figure 50 the pitch and yaw angles for position 5 were fairly representative but flight test data did not agree with wind tunnel data as well as position 2 agreement. The reason was that the data was only 0.15 second in duration, which is too short a period of time to obtain good correlation. Figure 51 shows sequence pictures of the position 5 release from on-board motion picture film.

CHASE SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Eighth Drop - 5 April 1973
Single Release - Position 1

RELEASE CONDITIONS
Mach = 1.14
1500 Feet

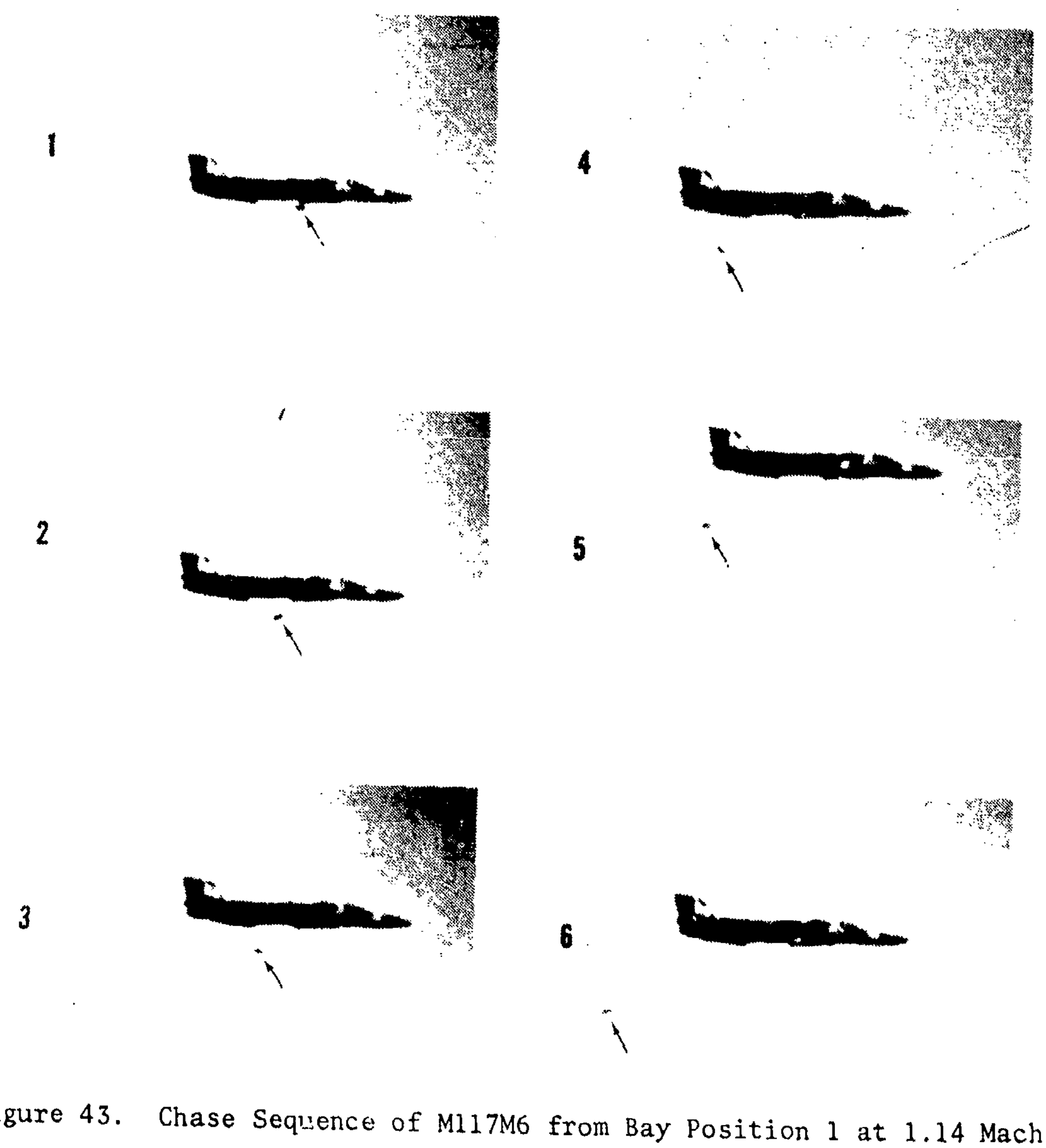


Figure 43. Chase Sequence of M117M6 from Bay Position 1 at 1.14 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
10 April 1973 F-111E No. 4 Weapon Bay Position 1
Mach = 1.20 Altitude = 2000 Feet

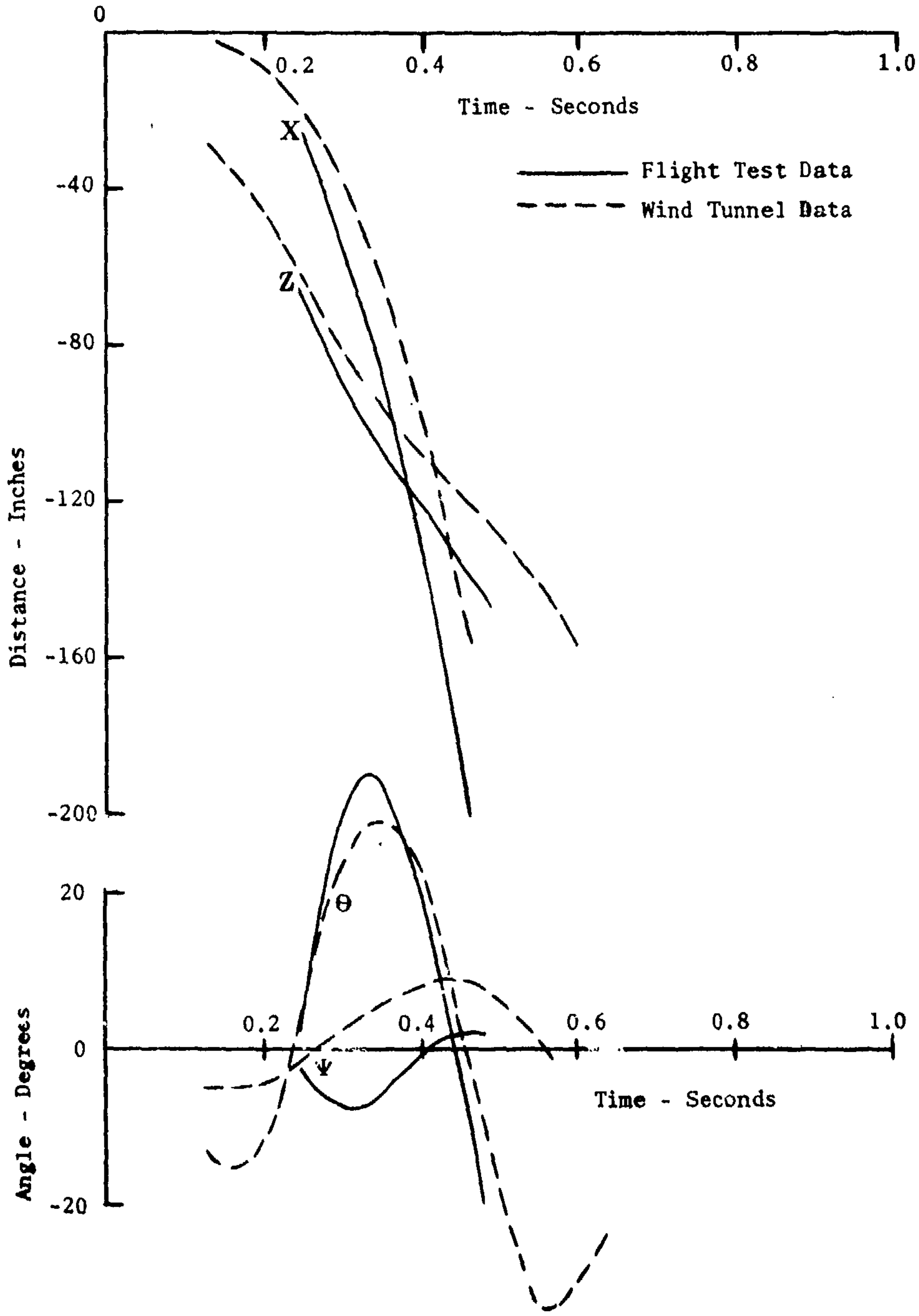


Figure 44. Ripple Release of M117M6 from Bay Position 1 at 1.2 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
10 April 1973 F-111E No. 4 Weapon Bay Position 2
Mach = 1.20 Altitude = 2000 Feet

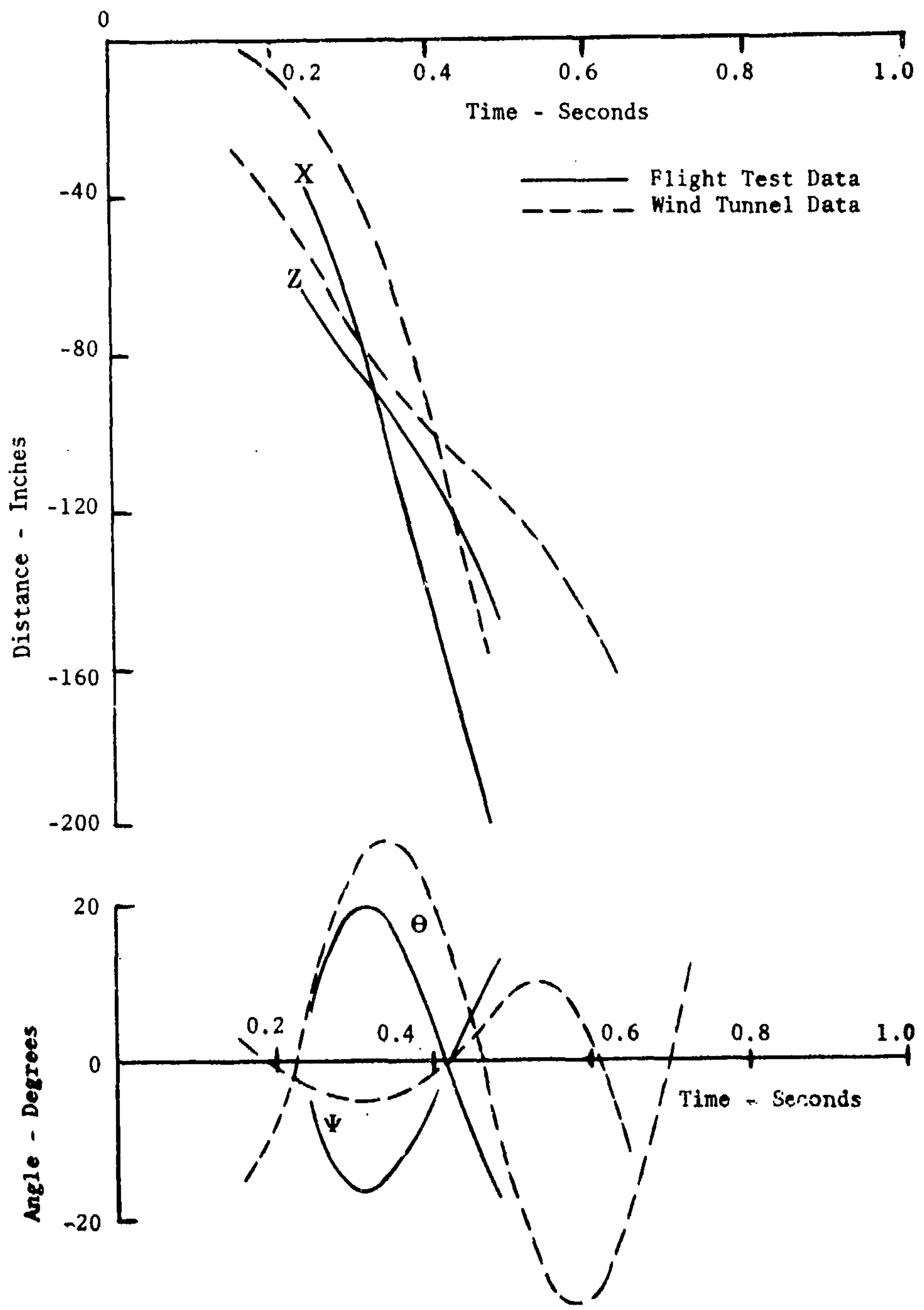


Figure 45. Ripple Release of M117M6 from Bay Position 2 at 1.2 Mach

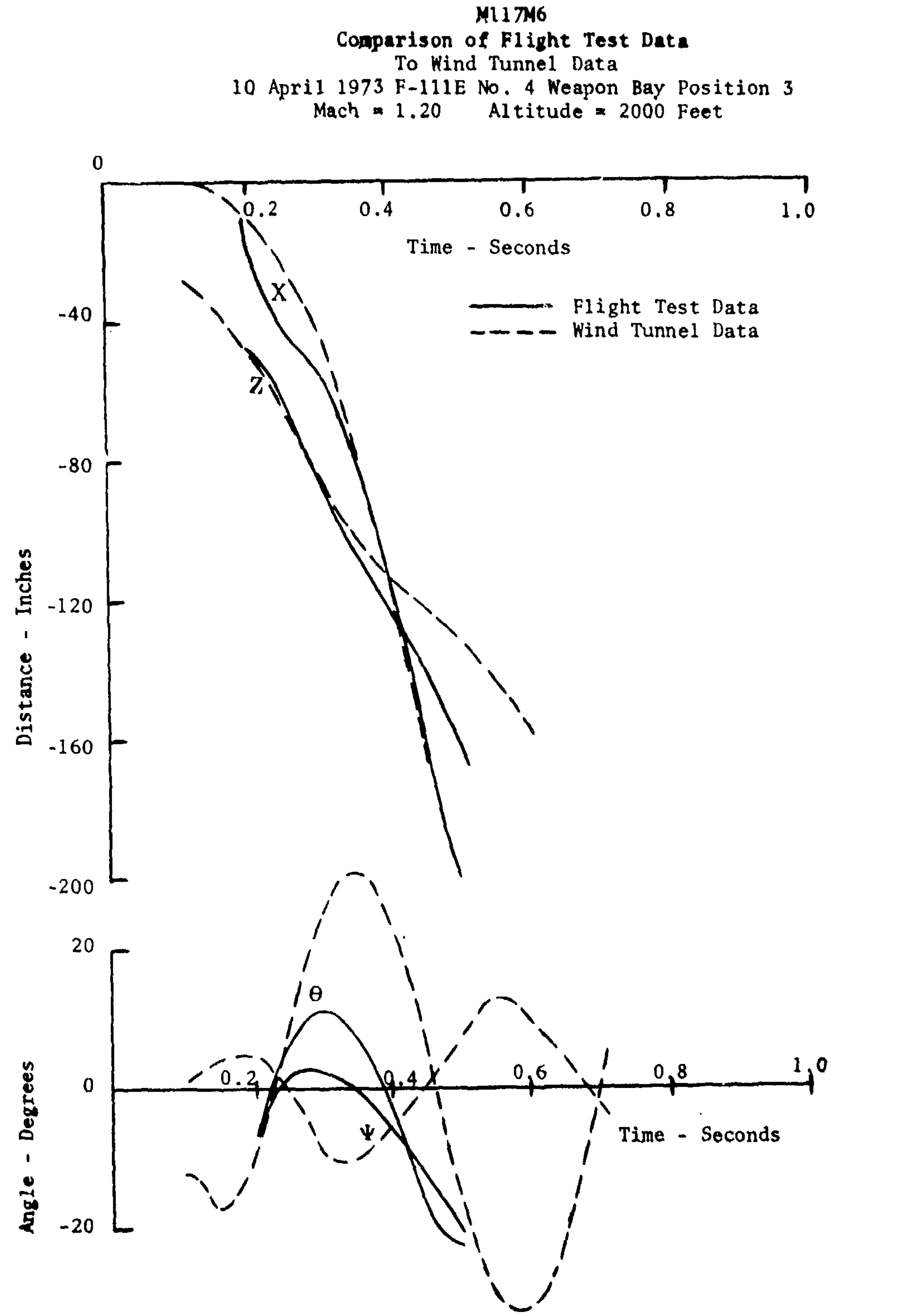


Figure 46. Ripple Release of M117M6 from Bay Position 3 at 1.2 Mach

GROUND SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Ninth Drop - 10 April 1973
Ripple Release of Five -100 ms.

RELEASE CONDITIONS
Mach = 1.20
2000 Feet

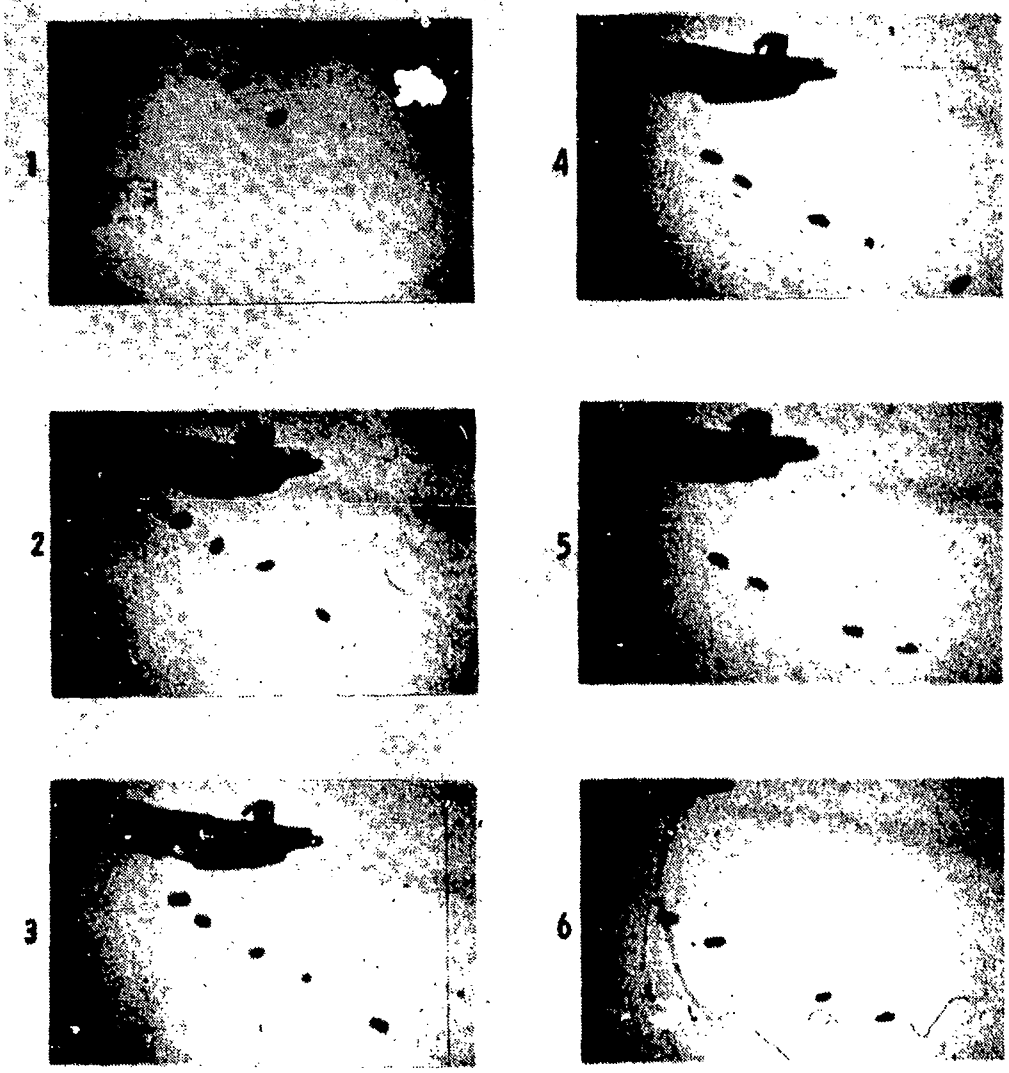


Figure 47. Ground Sequence of Ripple of Five M117M6 at 1.2 Mach

FORWARD-BOTTOM SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Ninth Drop - 10 April 1973
Ripple Release of Five -100 ms.

RELEASE CONDITIONS
Mach = 1.20
2000 Feet

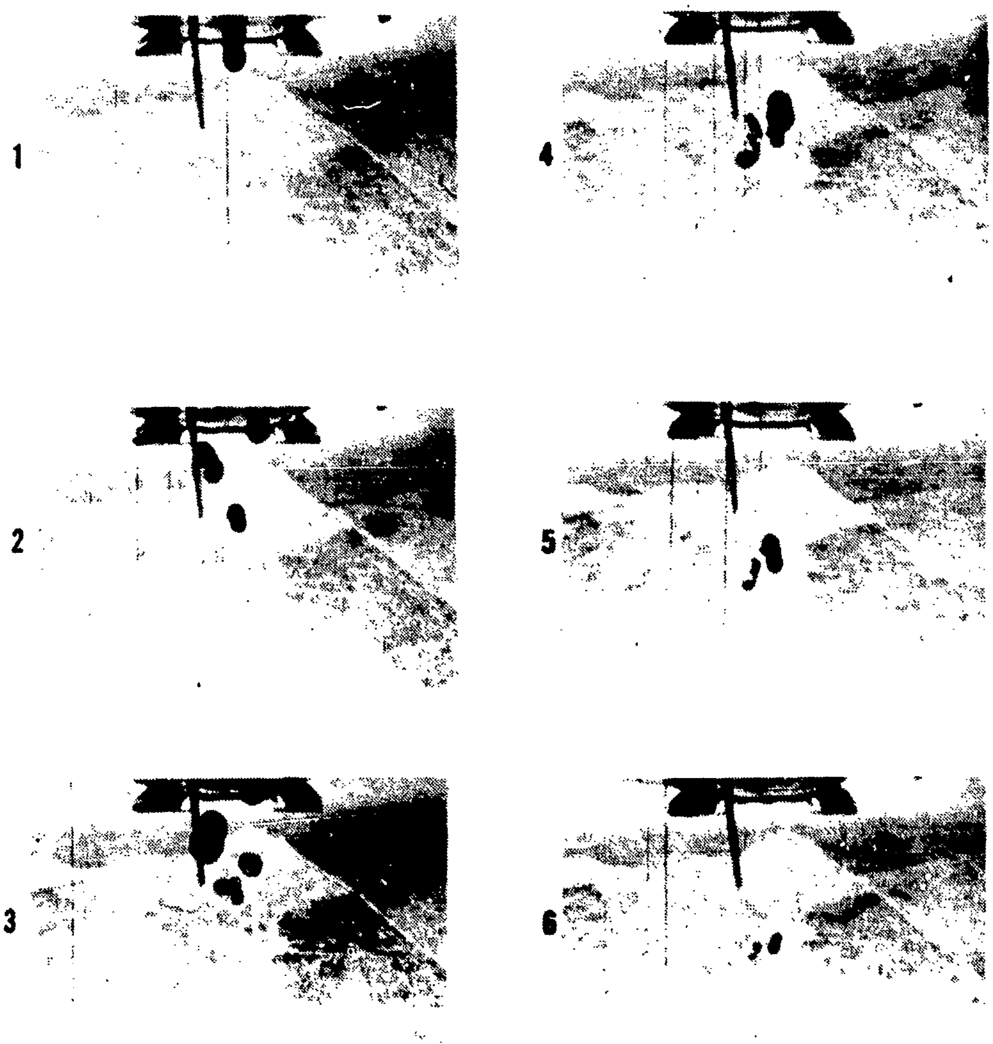


Figure 48. Onboard Sequence of Ripple of Five M117M6 at 1.2 Mach

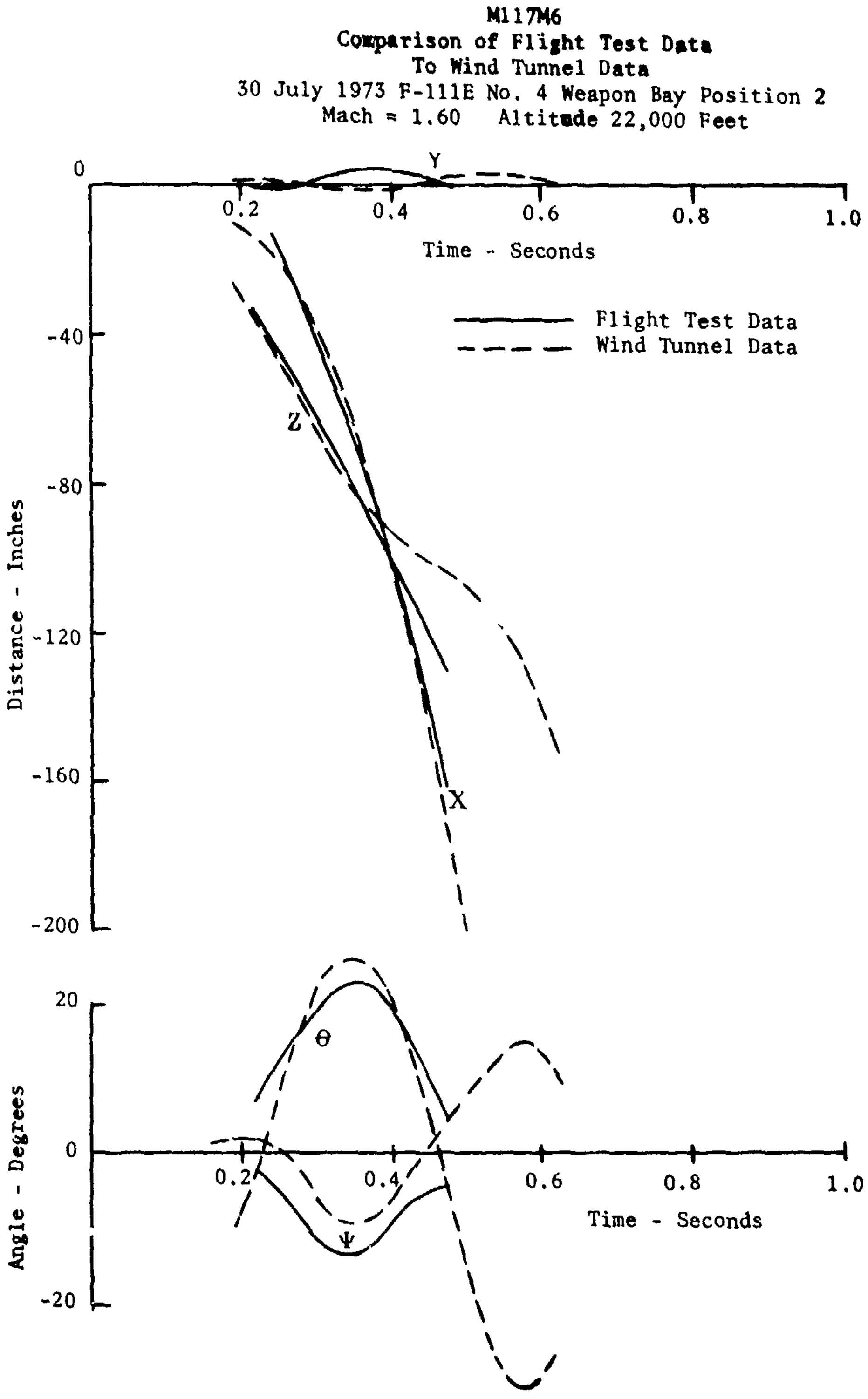


Figure 49. Single Release of M117M6 from Bay Position 2 at 1.6 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
30 July 1973 F-111E No. 4 Weapon Bay Position 5
Mach = 1.60 Altitude = 22,000 Feet

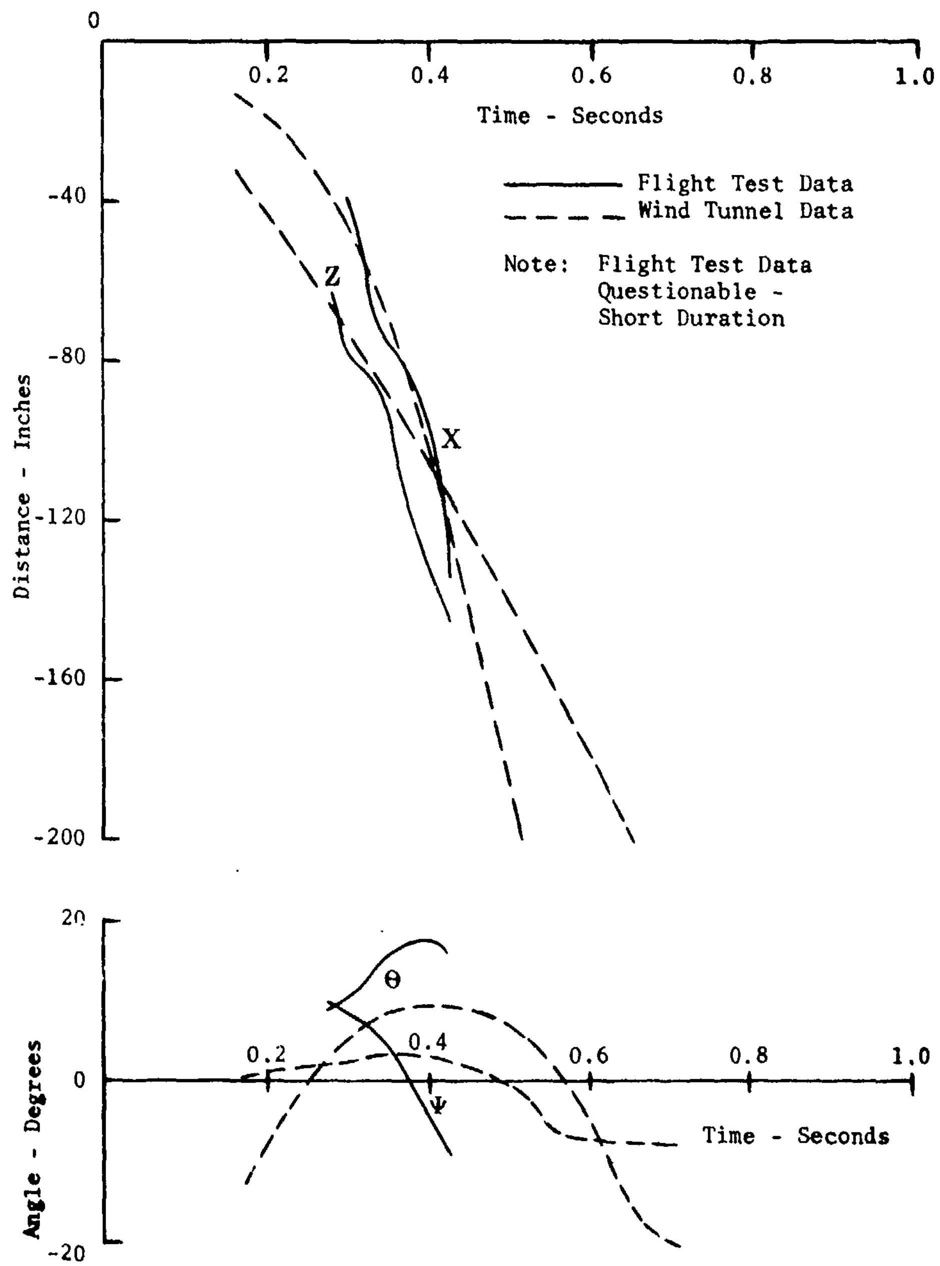


Figure 50. Single Release of M117M6 from Bay Position 5 at 1.6 Mach

FORWARD BOTTOM SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Tenth Drop - 30 July 1973
Single Release - Position 5

RELEASE CONDITIONS
Mach = 1.6
22,000 Feet

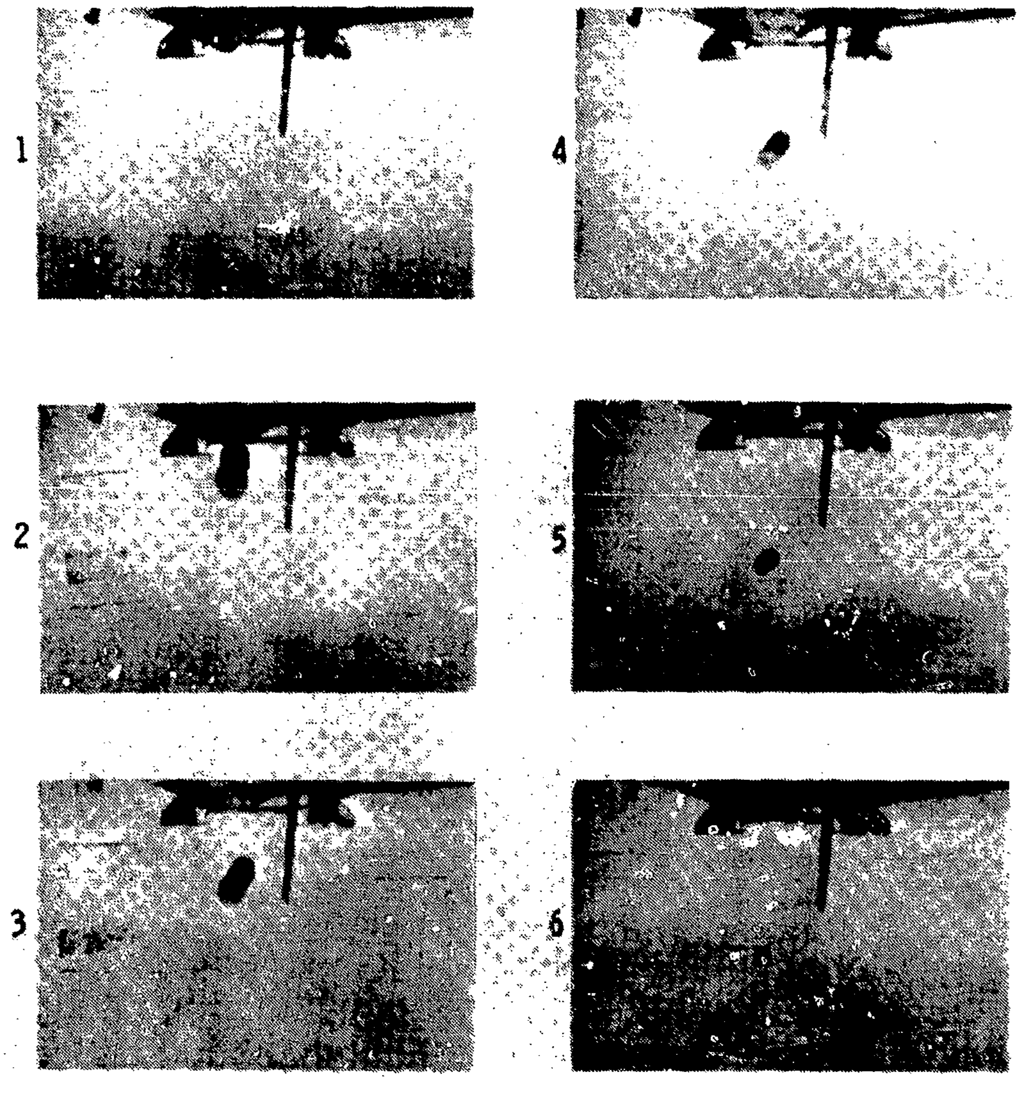


Figure 51. Onboard Sequence of M117M6 from Bay Position 5 at 1.6 Mach

Mission 14

Single drops were planned for all five weapons at a condition of Mach 1.80 and 26,000 feet altitude. This mission was conducted on 1 August 1973. As on the previous test, the weapon from number 2 position was released first since the number 1 position weapon was skipped due to an incorrect set-up in the F-111 cockpit. Tabulated data were obtained from t'e film of the weapons released from position 2, 3 and 4, but vapor obscured the markings of the weapon at number 5 position. Therefore, only plotted data from the three drops are found in Figures 52, 53 and 54.

The separation data from the weapon released from position 2 agreed well with wind tunnel data of the same conditions as is shown in Figure 52. The pitch angle was displaced somewhat in time, but was of the same relative magnitude.

On the second release from position 3 the flight test data shown in Figure 53 again agreed fairly well with wind tunnel data, although the pitch angle was somewhat lower in magnitude. The yaw angle was of greater magnitude than the wind tunnel data for the same condition.

The third drop from position 4 shown in Figure 54 was similar to the second drop. Pitch angle was similar, but the maximum value was lower, and the yaw angle was greater in magnitude than the wind tunnel data for the same condition. The effect on separation of the presence of the position 1 weapon is not known; however, there is probably some effect on pitch and yaw. The overall relative comparison between flight test data and wind tunnel data was quite good. Figure 55 shows sequence pictures from the on-board motion picture camera from the left wing tip of the position 2 weapon separation.

Mission 15

A ripple release was planned for Mach 1.60 at 19,000 feet altitude at 100-millisecond intervals and was successfully accomplished on 22 August 1973. Tabulated data could not be reduced from this drop, although the motion picture film from the drop showed satisfactory weapon separation. The sequence pictures of Figure 56 from on-board motion picture camera film indicate the satisfactory separation of the five weapons at 100-millisecond intervals.

Mission 16

On 29 August 1973 a ripple release of five M117M6 weapons with live fuzes was made at Mach 0.9 and 2000 feet AGL. The test was successful. The weapons were recovered after the test and it was determined the fuzes operated correctly with some set to fire and some safe. No tabulated data were obtained. The ground sequence pictures of Figure 57 show the separation of the five weapons.

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
1 August 1973 F-111E No. 4 Weapon Bay Position 2
Mach = 1.80   Altitude = 26,000 Feet

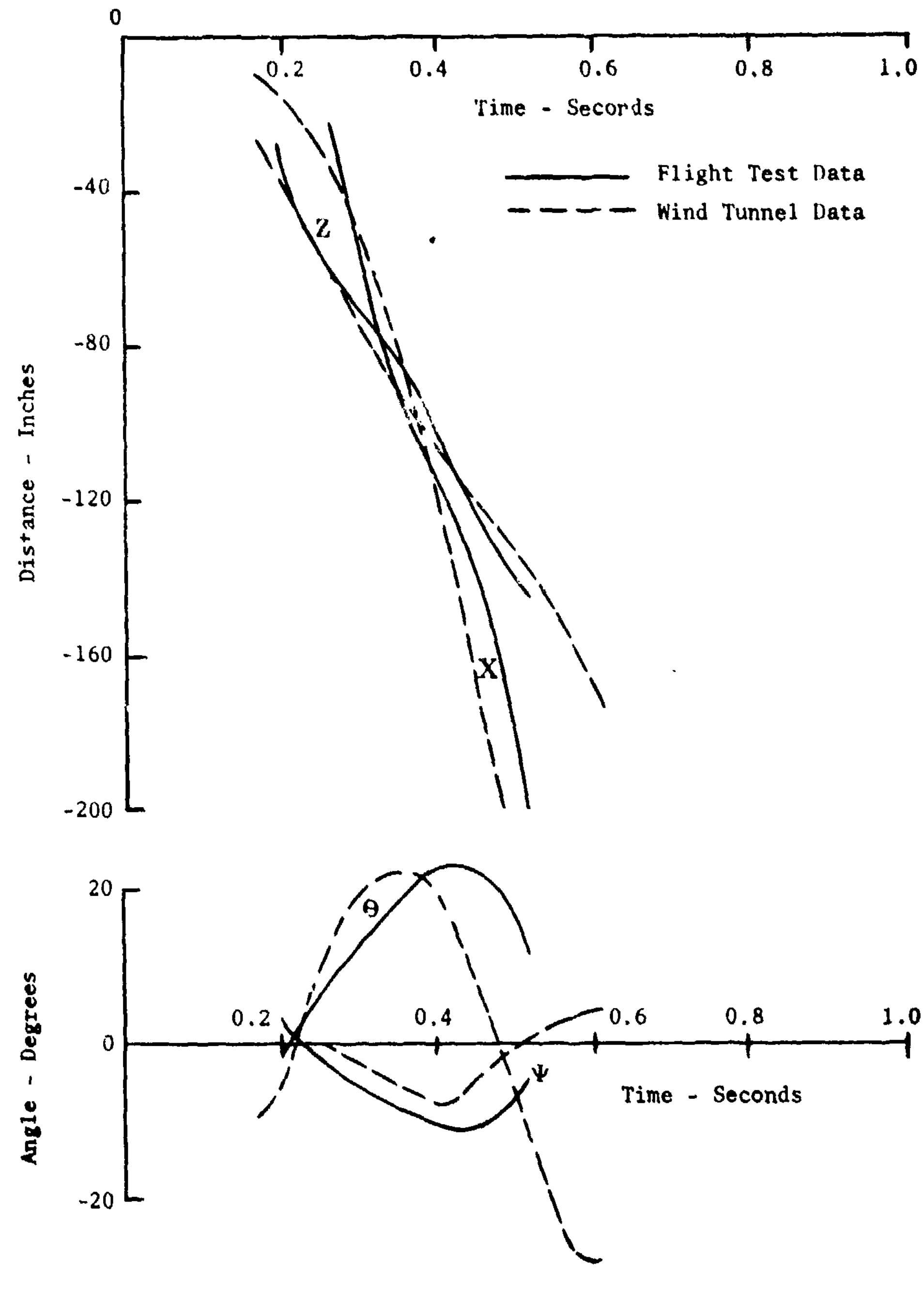


Figure 52. Single Release of M117M6 from Bay Position 2 at 1.8 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
1 August 1973 F-111E No. 4 Weapon Bay Position 3
Mach = 1.80 Altitude = 26,000 Feet

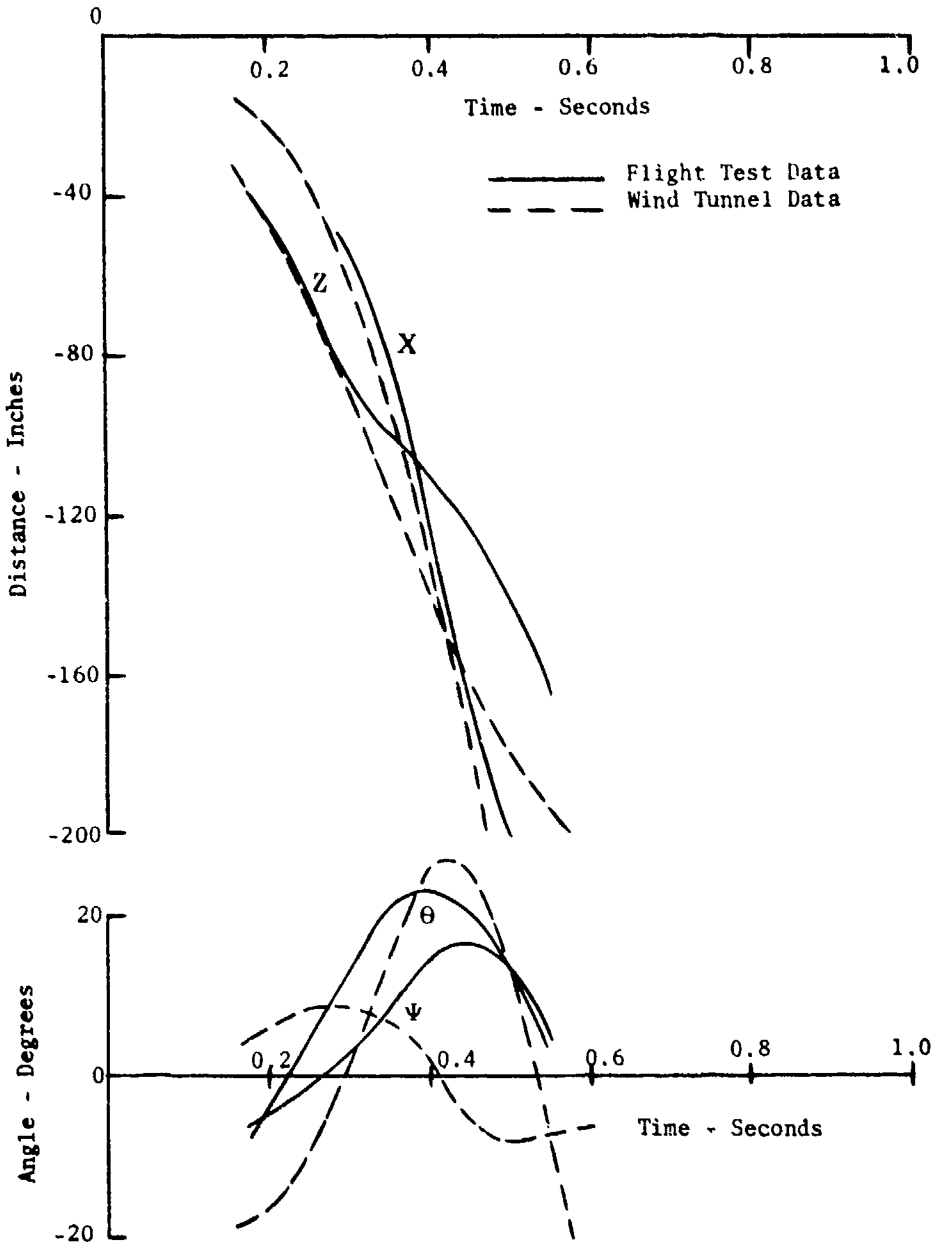


Figure 53. Single Release of M117M6 from Bay Position 3 at 1.8 Mach

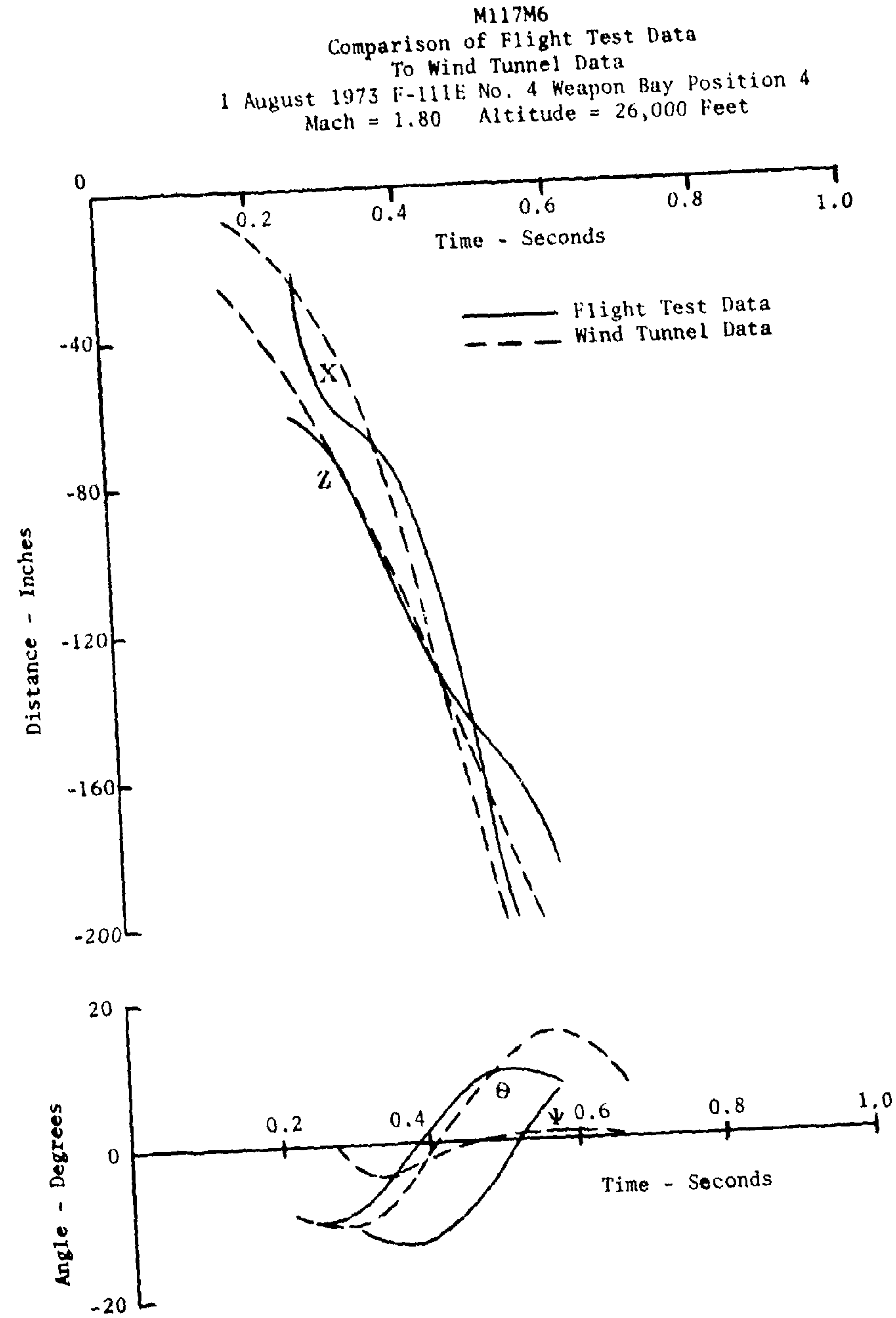


Figure 54. Single Release of M117M6 from Bay Position 4 at 1.8 Mach

LEFT WING TIP SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Eleventh Drop - 1 August 1973
Single Release - Position 2

RELEASE CONDITIONS
Mach = 1.8
26,000 Feet

1

2

3

4

5

6

Figure 55. Onboard Sequence of M117M6 from Bay Position 2 at 1.8 Mach

FORWARD BOTTOM SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Twelfth Drop - 22 August 1973
Ripple Release of Five-100 MS

RELEASE CONDITIONS
Mach = 1.6
19,000 Feet

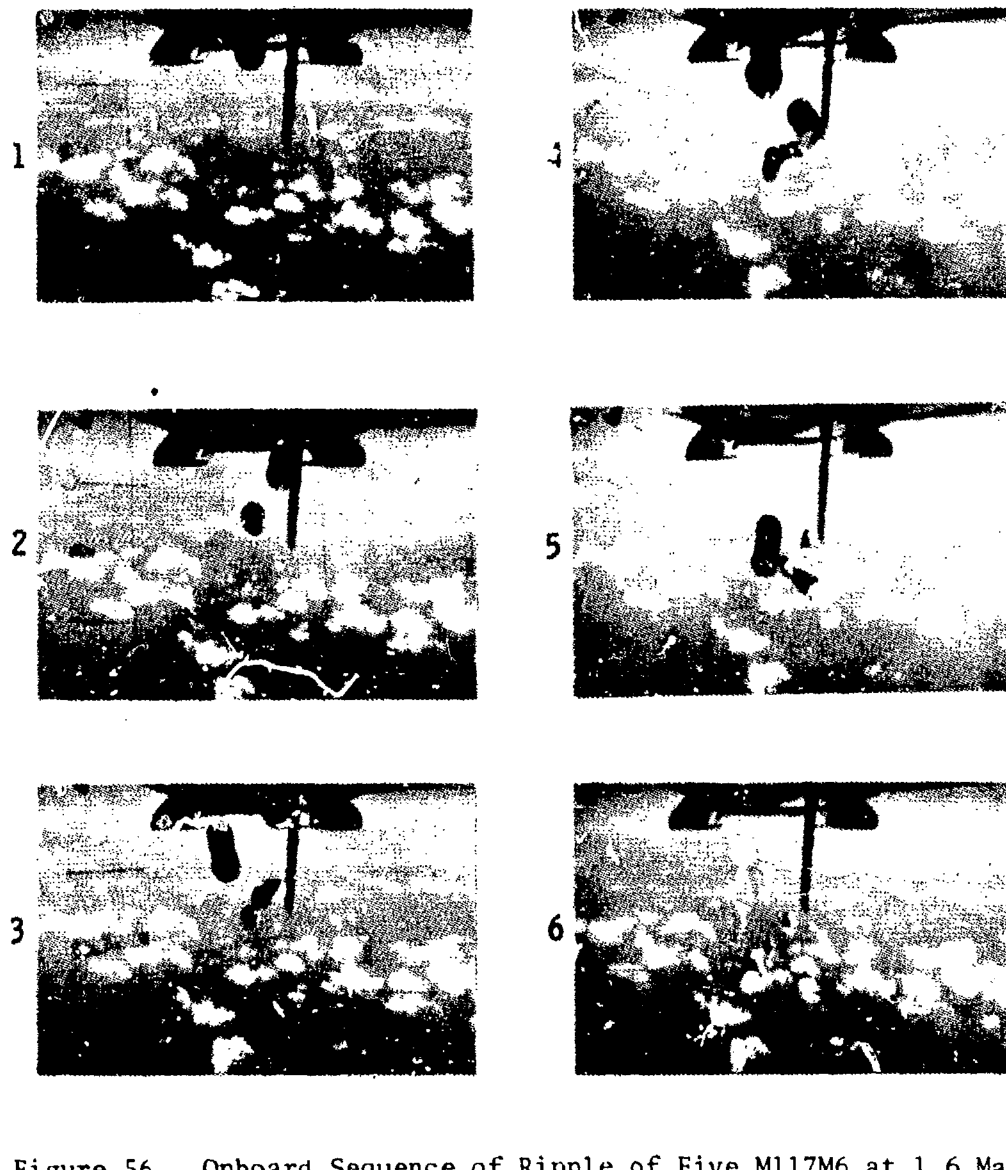


Figure 56. Onboard Sequence of Ripple of Five M117M6 at 1.6 Mach

GROUND SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Thirteenth Drop - 29 August 1973
Ripple Release of Five-100 MS
Test of "Live" Fuses

RELEASE CONDITIONS
Mach = .90
2000 Feet

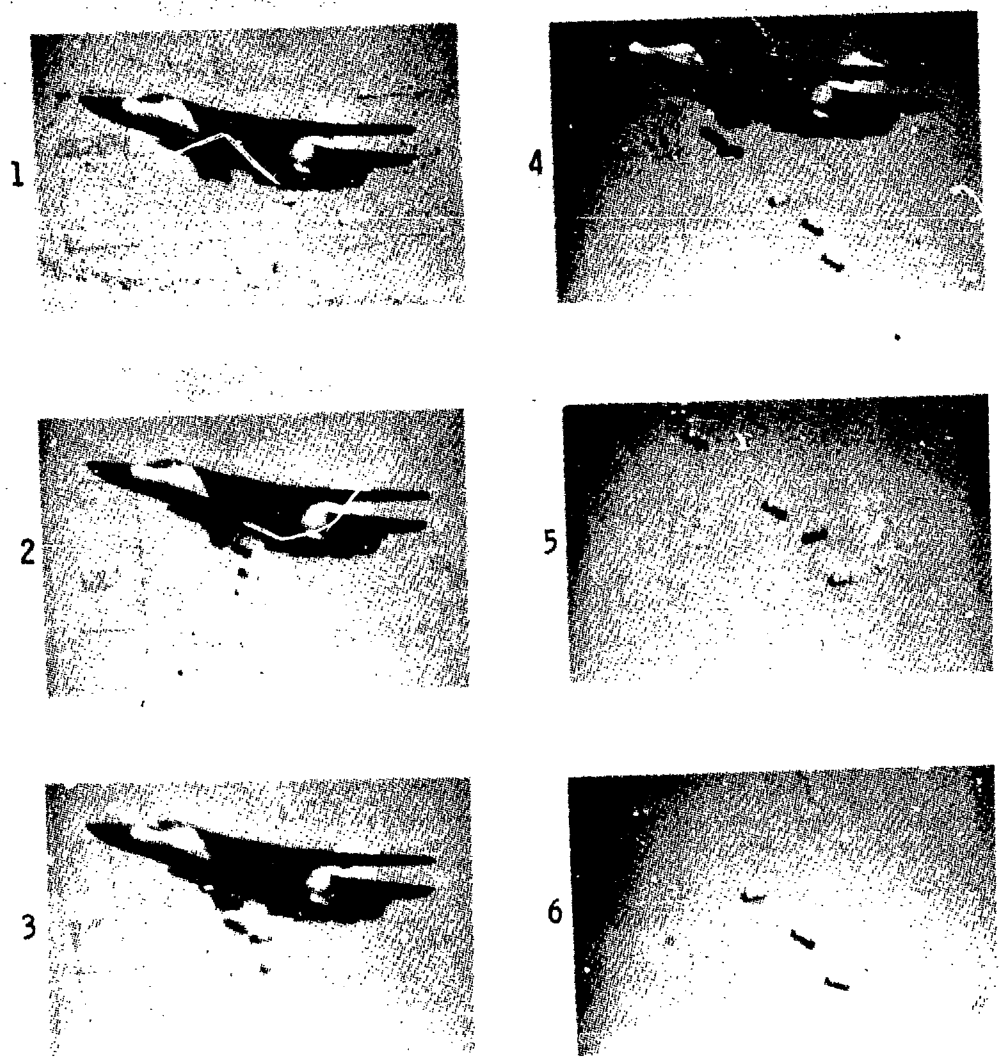


Figure 57. Ground Sequence of Ripple of Five M117M6 at 0.9 Mach

Mission 17

On 30 August 1973, five weapons with live fuzes and live warheads were released at 100-millisecond ripple mode from 2000 feet AGL and Mach 0.95. No tabulated data from this weapon separation were received. Figure 58 shows separation of the weapons. The ground film (Figure 59) shows the impact and cloud pattern of the five weapons and shows that all five weapons detonated.

Mission 18

On 1 November 1973, a single M117M6 was released from weapon bay position 1 at Mach 1.88, 720 KCAS and 32,050 feet altitude. The test was made primarily for ballistics data and was satisfactory. No tabulated separation data were obtained. Figure 60 shows sequence pictures from on-board film of weapon separation.

Mission 19

On 2 November 1973, another single ballistics drop was made at Mach 1.955, 740 KCAS at 32,275 feet altitude from weapon bay position 2. The on-board film showed satisfactory weapon separation as seen in Figure 61 sequence pictures from the wing tip camera. The weapon markings were not sufficiently visible to obtain tabulated weapon separation data.

Mission 20

On 6 November 1973, a single ballistics drop was made at Mach 1.93, 750 KCAS and 31,430 feet altitude from weapon bay position 3. A marginal amount of tabulated separation data were obtained from wing tip camera film (Figure 62). Sequence pictures from the wing tip motion picture camera are shown in Figure 63 indicating satisfactory weapon separation.

Mission 21

On 13 November 1973, a single ballistics drop was made at Mach 1.255 and 5150 feet altitude from weapon bay position 1. No tabulated separation data were obtained. The sequence pictures from the forward underside on-board camera film of Figure 64 show satisfactory separation.

Mission 22

On 14 December 1973, a single ballistics drop was made at Mach 1.25 and 5840 feet altitude from weapon bay position 2. No tabulated separation data were obtained. Figure 65 shows sequence pictures of clean separation of this weapon from the F-111E weapon bay. As with the previous four weapon tests, this drop was for ballistic data as well as for separation information.

CHASE SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Fourteenth Drop - 30 August 1973
Ripple Release of Five-100 MS
Test of "Live" Weapons

RELEASE CONDITIONS
Mach = .95
2000 Feet

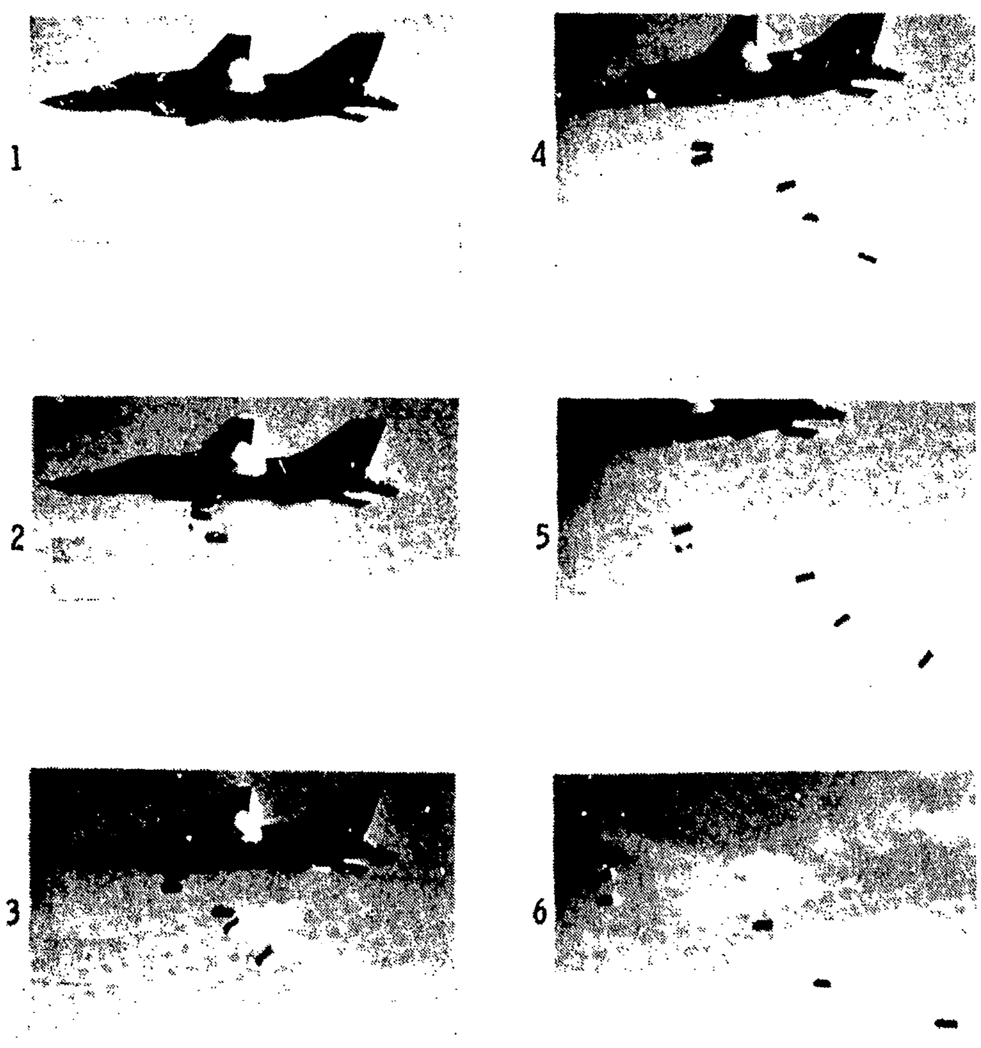


Figure 58. Chase Sequence of Ripple of Five M117M6 at 0.95 Mach

GROUND SEQUENCE PICTURES OF
"LIVE" WEAPON IMPACT PATTERN

AIRCRAFT F-111E NO. 4
Fourteenth Drop - 30 August 1973
Ripple Release at Five-100 MS

RELEASE CONDITIONS
Mach = .95
2000 Feet

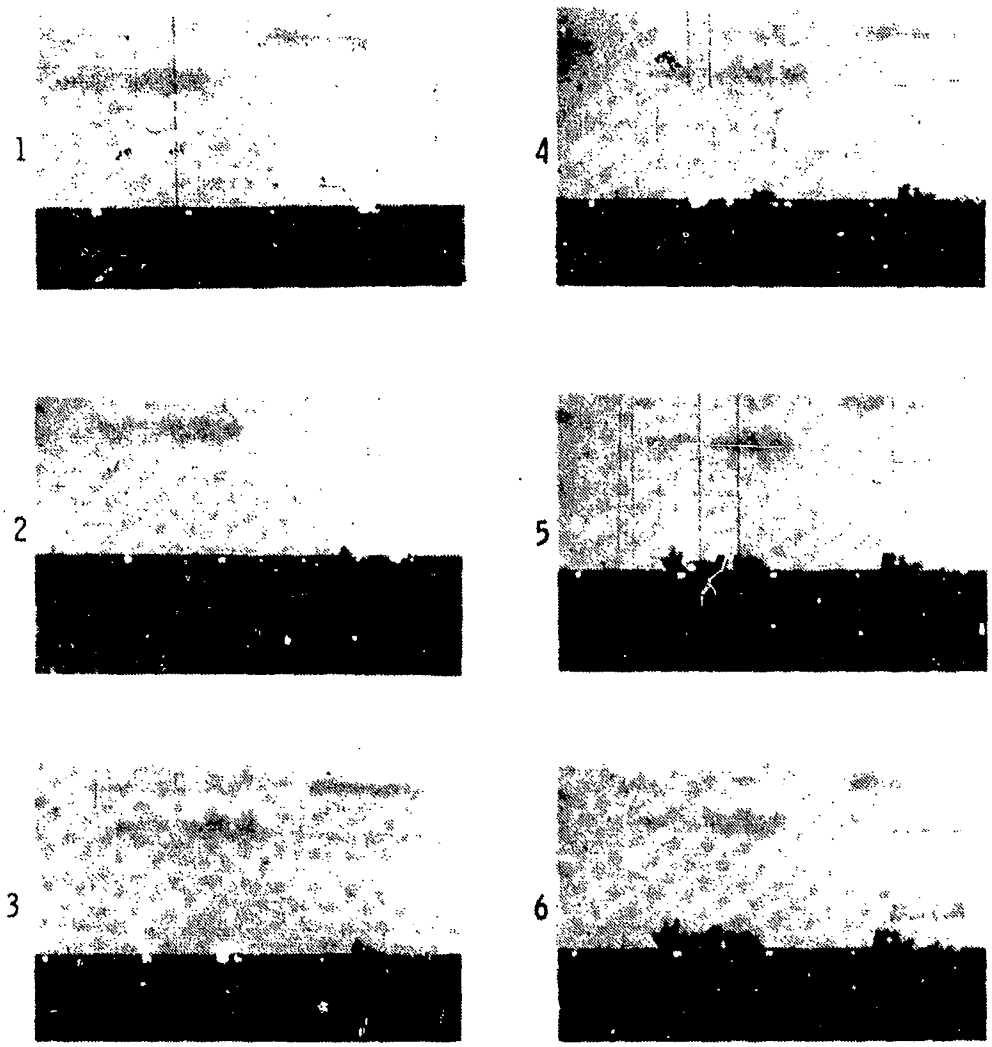


Figure 59. Ground Impact Sequence of Live M117M6

FORWARD BOTTOM SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Fifteenth Drop - 1 November 1973
Ballistics Release - Position 1

RELEASE CONDITIONS
Mach = 1.88
32,050 Feet

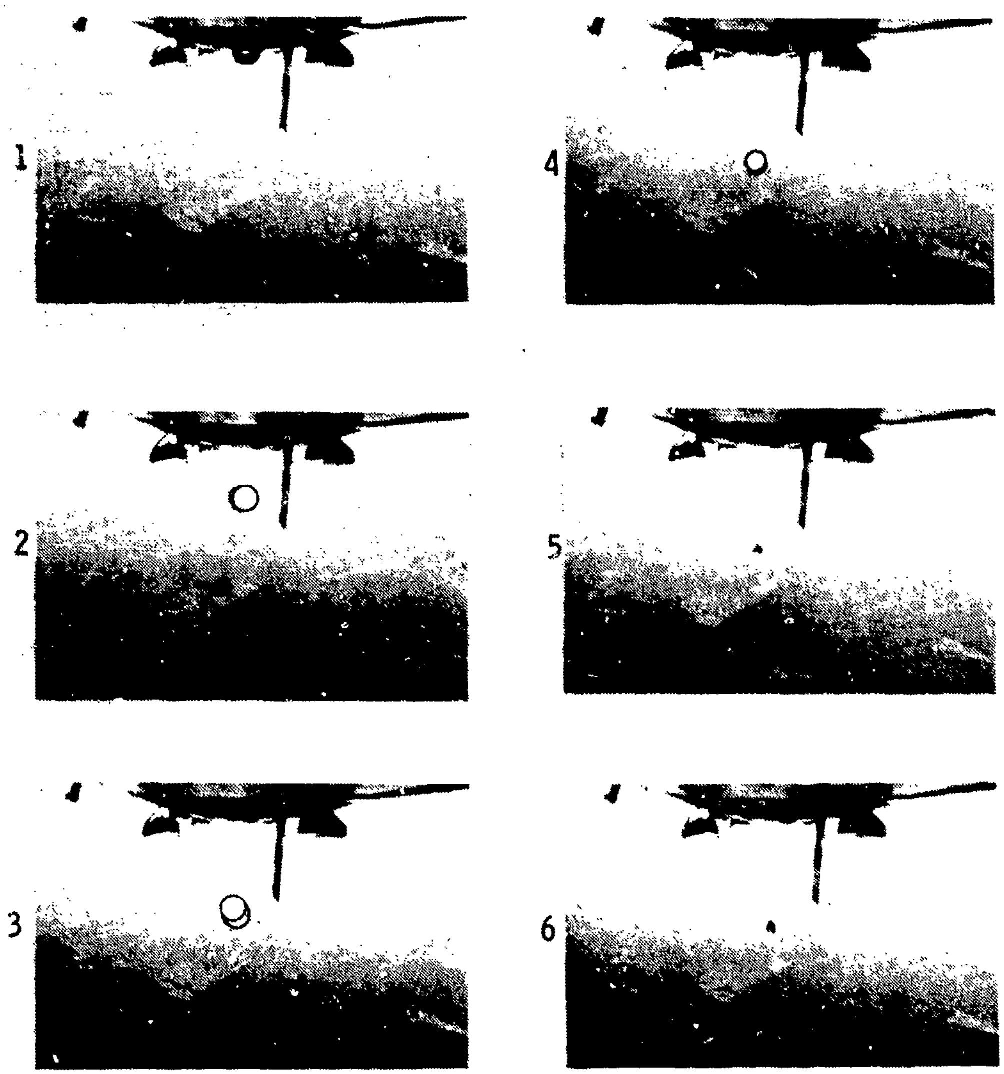


Figure 60. Onboard Sequence of M117M6 from Bay Position 1 at 1.88 Mach

RIGHT WING TIP SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Sixteenth Drop - 2 November 1973
Ballistics Release - Position 2

RELEASE CONDITIONS
Mach = 1.955
32,275 Feet

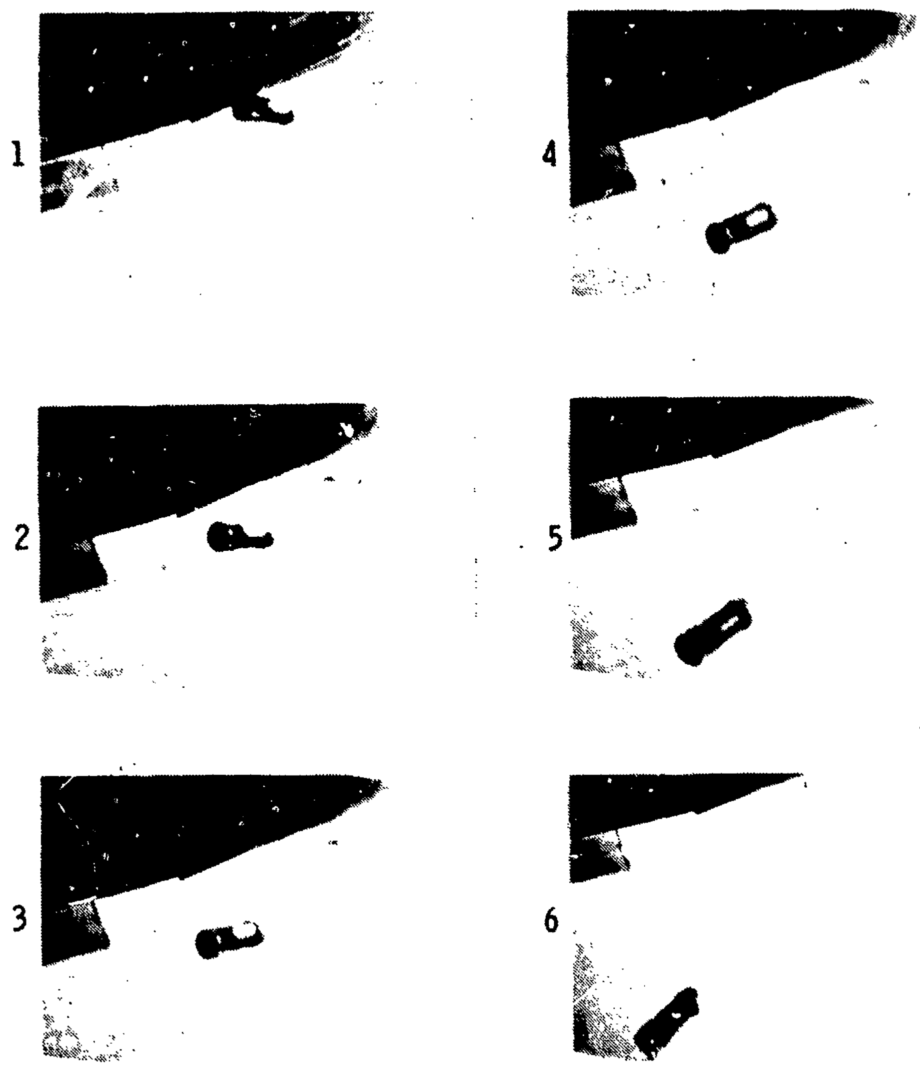


Figure 61. Onboard Sequence of M117M6 from Bay Position 2 at 1.96 Mach

M117M6
Comparison of Flight Test Data
To Wind Tunnel Data
6 November 1973 F-111E No. 4 Weapon Bay Position 3
Mach = 1.93 Altitude = 31,430 Feet

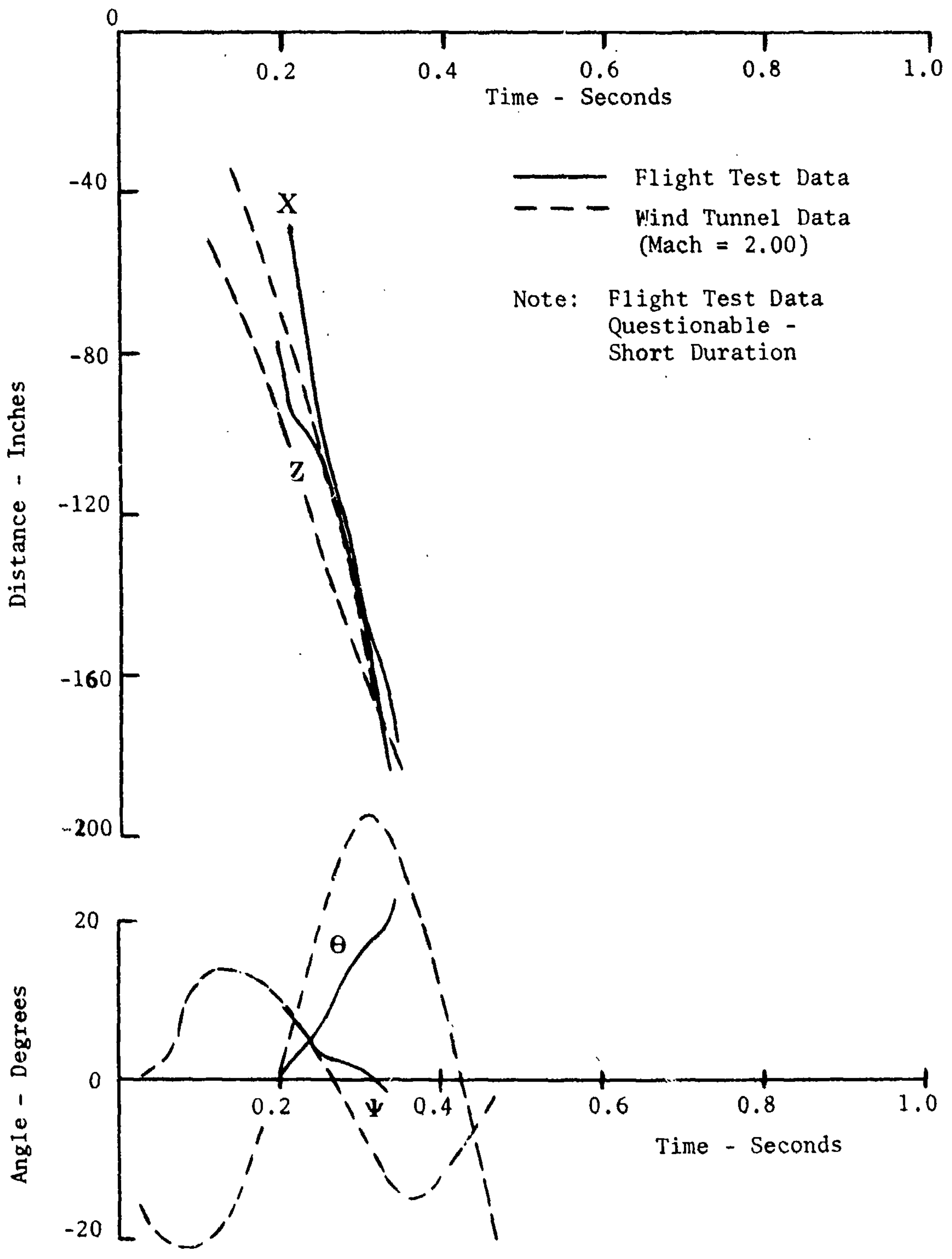


Figure 62. Single Release of M117M6 from Bay Position 3 at 1.93 Mach

RIGHT WING TIP SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Seventeenth Drop - 6 November 1973
Ballistics Release - Position 3

RELEASE CONDITIONS
Mach - 1.93
31,430 Feet

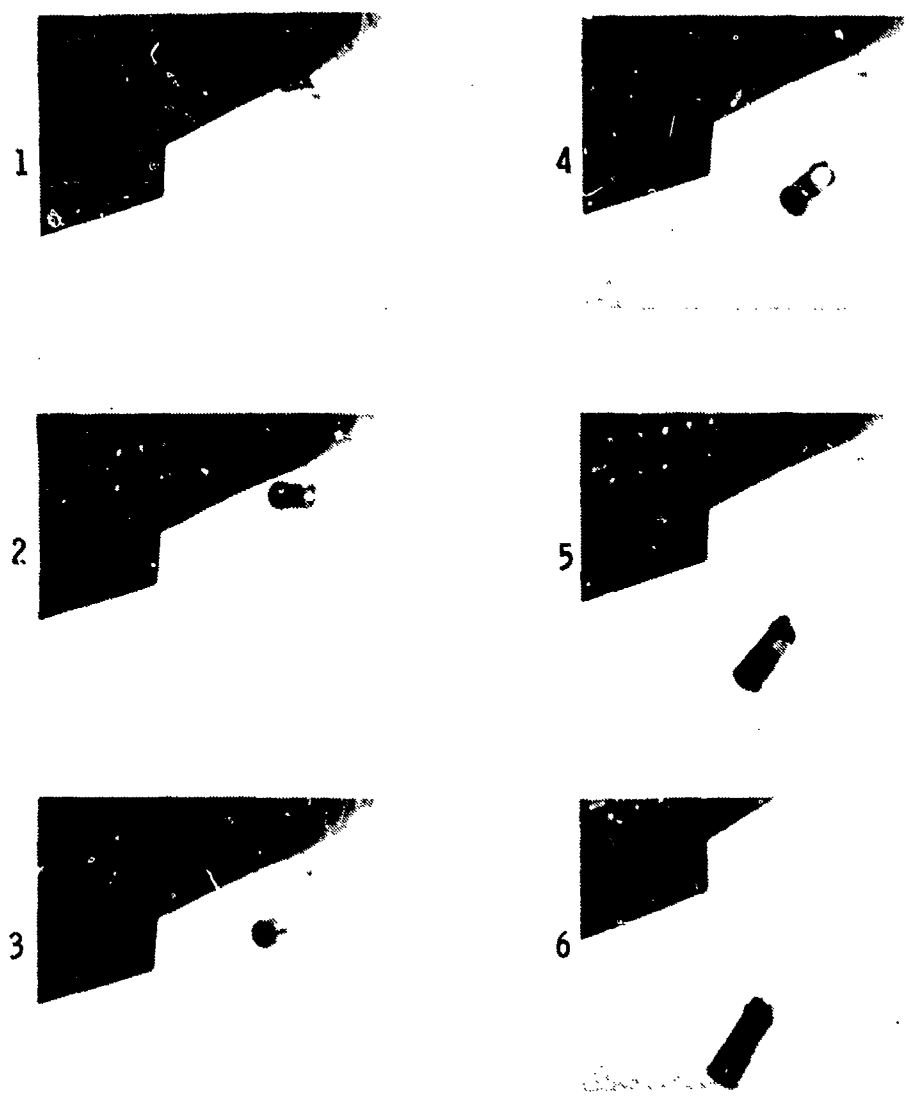


Figure 63. Onboard Sequence of M117M6 from Bay Position 3 at 1.93 Mach

FORWARD BOTTOM SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Eighteenth Drop - 13 November 1973
Ballistics Release - Position 1

RELEASE CONDITIONS
Mach = 1.255
5150 Feet

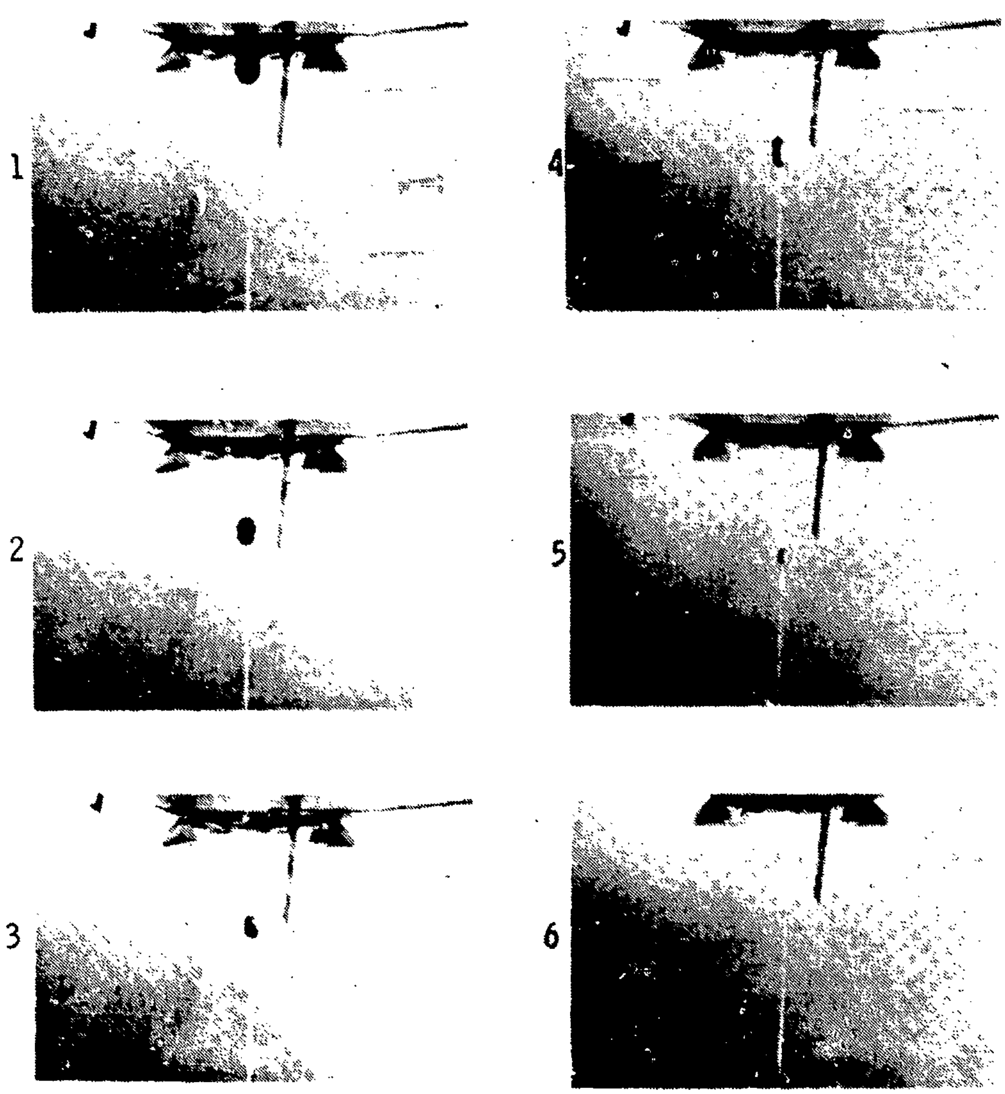


Figure 64. Onboard Sequence of M117M6 from Bay Position 1 at 1.26 Mach

FORWARD BOTTOM SEQUENCE PICTURES

AIRCRAFT F-111E NO. 4
Nineteenth Drop - 14 December 1973
Ballistics Release - Position 2

RELEASE CONDITIONS
Mach = 1.25
5840 Feet

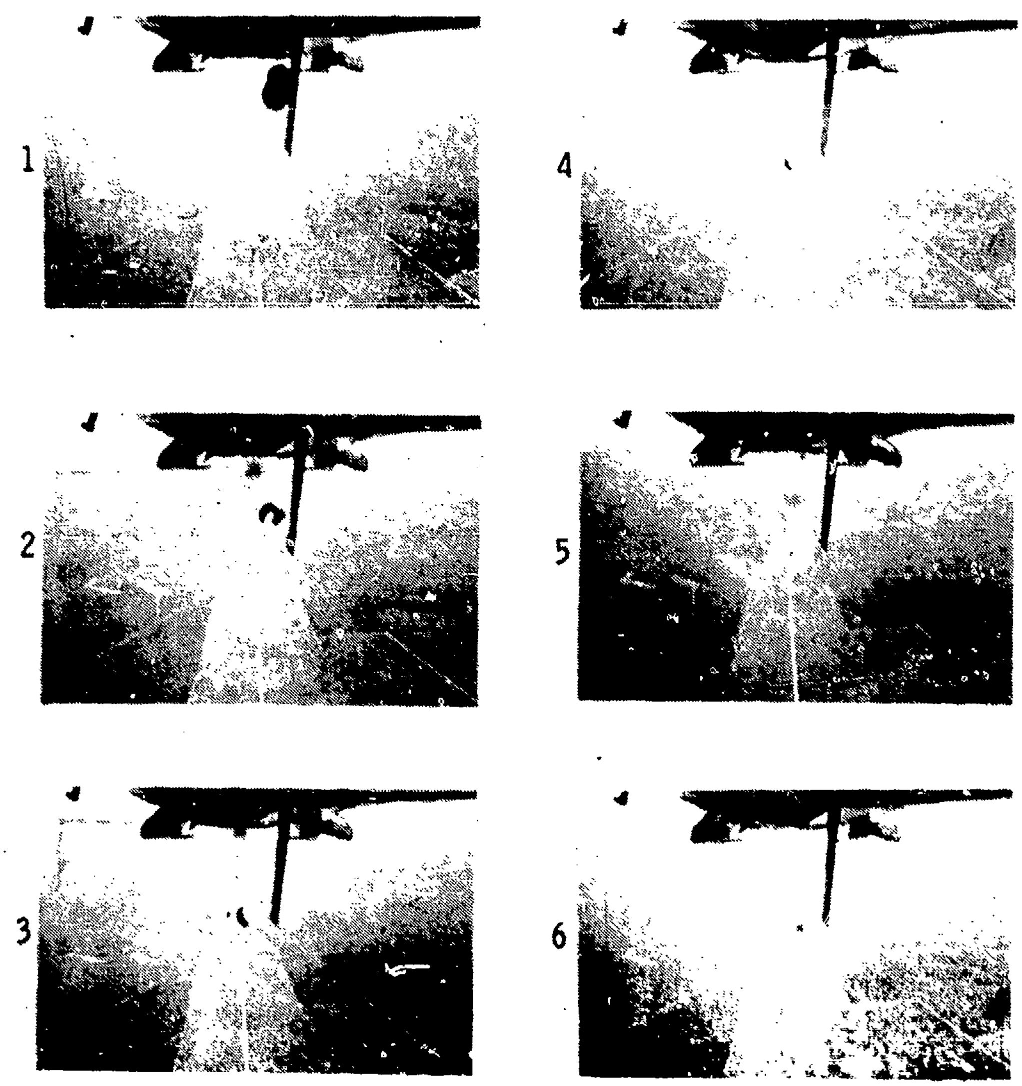


Figure 65. Onboard Sequence of M117M6 from Bay Position 2 at 1.25 Mach

The flight test data show several characteristics of the bluff bombs. The separation characteristics are excellent throughout the Mach range tested. Most bombs separated with small (about 10 to 20 degrees) initial nose down pitch displacement. Wind tunnel separation data correlate very well with flight test data in vertical, horizontal, and pitch displacement and to a lesser extent in yaw displacement. Separations were generally unaffected by release mode, sequence, or position in the bay. Even though the weapons are loaded in the bay close to each other and the aircraft walls, there was no known incident of their hitting the aircraft or each other (not including the BLU-58/B incident discussed earlier). The stores do trail aft of the aircraft more quickly with increasing airspeed. The benefits of the low lift characteristics are evident during several high speed releases where the initial pitch displacement of the bomb was nose up but the bomb did not show any floating or flying tendencies. Even though the bombs are stable, they were occasionally observed to oscillate all the way to the ground. Also, several were observed to initiate oscillating during flight. These phenomena suggest the dynamic stability of the M117M6 is less than desired.

Of the total of 76 inert bombs released, 44 were recovered after impact. Of these, only one was found to be split open, only a few exhibited bulging, but many were missing the nose and/or tail caps. All live fuzes and live bombs dropped functioned as intended.

4. Weapon Drag Analysis

Due to contract phasing, a preliminary weapon drag analysis, based upon the first 21 M117M6 weapon drops at release speeds of 0.58 Mach to 1.20 Mach, was conducted. These constitute the first set of missions shown in Table 3. Ground camera film was converted to Time Space Position Information (TSPI) by ADTC. The TSPI and corresponding weather data were then used by General Dynamics as reference data to determine the weapon ballistic drag. All TSPI data indicating end point smoothing or extrapolation were excluded from the analysis. Only data indicating midpoint smoothing were used for the ballistic drag analysis. Four to 10 drag data points were used from each of the 21 TSPI reference weapon drops for a total of 183 drag data points. Linear and parabolic drag curves were determined from the drag data points using polynomial regression curve fitting techniques. Both curves generated approximately the same value within the range of the reference data points. However, when the curves were projected to the higher release Mach numbers, the linear drag curve gave a better representation of the expected drag curve trend. The linear ballistic drag curve is shown in Figure 66.

The apparent drag variation from bomb to bomb is larger for the M117M6 than for most free-fall weapons. The RMS error of this drag variation from the nominal drag curve is 18 percent. This wide drag variation is attributable to (1) less than desired dynamic stability and (2) weapon interaction. Review of ground tracking camera film revealed that some of the

TABLE 3. M117M6 TIME SPACE POSITION INFORMATION

	Flight Date	TSPI Drops Available	Comments
EARLY PHASE	24 Mar 1971	2	Single releases
	25 Mar 1971	3	Single releases
	2 Jun 1972	5	100 ms ripple release
	27 Feb 1973	5	100 ms ripple release
	28 Feb 1973	2	Single releases
	22 Mar 1973	5	50ms ripple release
	5 Apr 1973	4	Single releases
	10 Apr 1973	5	100 ms ripple release
LATE PHASE	1 Nov 1973	1	Single release
	2 Nov 1973	1	Single release
	6 Nov 1973	1	Single release
	13 Nov 1973	1	Single release
	14 Dec 1973	1	Single release
	TOTAL	36	

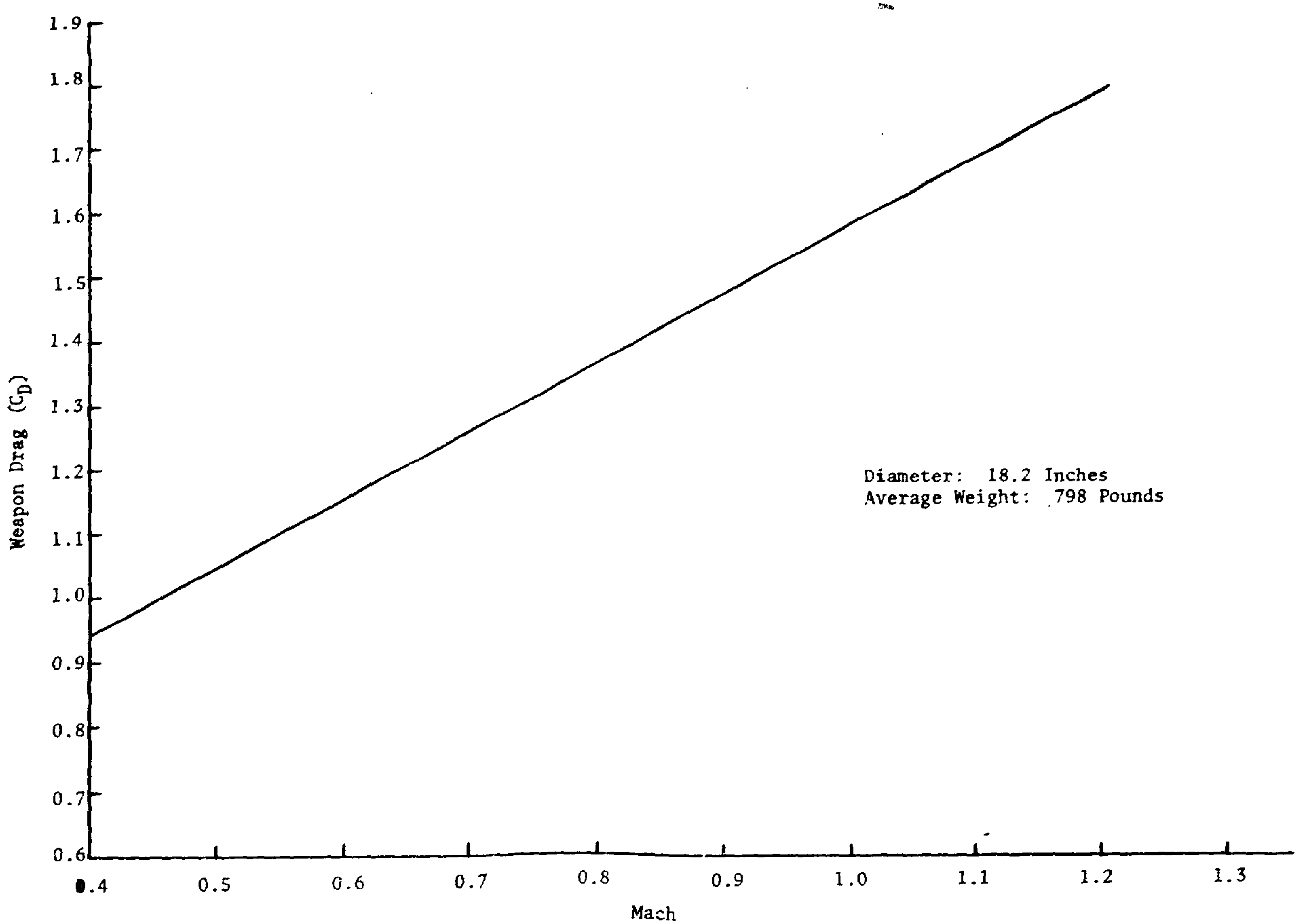


Figure 66. M117M6 Ballistic Drag Curve, Average Weight 798 Pounds

weapons oscillated. Also, the oscillations would apparently increase as the weapon would deaccelerate through 0.78 and 0.66 Mach numbers. Individual weapon drag data for two of the four ripple release flights indicated a strong trend for the weapon drag to vary as a function of weapon release sequence. The first weapon released would have approximately 30 percent more drag than the last weapon released. This trend was present for the entire weapon trajectory.

The validity of the linear ballistic drag curve was determined by using the curve to compute the weapon trajectory based on TSPI weapon conditions approximately 2 seconds after actual weapon release. Picking up the weapon trajectory 2 seconds after release will avoid any perturbations in the initial part of the trajectory due to release timing and/or interaction between aircraft flow field and weapon (ballistic separation effects). Table 4 shows the bomb range comparison between the actual TSPI range and the computer predicted range using the derived ballistic drag curve. Of the first 31 weapon drops, only 27 trajectory comparisons are shown due to the short tracking time of the TSPI data for four weapon drops. This trajectory comparison yielded an RMS error of 58 feet.

The first weapon drop on 25 March 1971, the second weapon drop on 28 February 1973, and the third weapon drop on 22 March 1973 had excessive trajectory range error; therefore, these three weapon drops were excluded from all analysis.

The weapon ballistic drag data (1107 data points) were later analyzed for the five additional weapon drops. The two weapons dropped at 5000 feet altitude followed the linear drag curve previously developed. The three weapons dropped at altitudes above 30,000 feet indicated a weapon drag substantially below the weapon drag of the low altitude weapon drops. A compromise drag curve was obtained combining the old drag curve with the three weapons dropped above 30,000 feet altitude. To retain the integrity of the analysis of the subsonic weapon drops, the new drag curve is the same as the old drag curve up to 0.96 Mach. At 0.96 Mach, the new drag curve becomes a constant value to represent the weapon drag trend of the high altitude supersonic weapon drops. The new drag curve is shown in Figure 67. Bomb to bomb drag variation was again noted as discussed previously.

The TSPI drag data for the three high altitude supersonic weapon drops indicated a relatively smooth trend in the supersonic region. As the weapon traversed the transonic region, a small increase in weapon drag was observed and the weapon drag became slightly erratic.

5. Weapon Ballistic Separation Effects

It is desirable to try to match the flight test TSPI data to the ballistic data generated using the derived drag curve (Figure 67) and the free stream store ejection velocity (12 feet per second) to account for the effects of the aircraft flow field and initial bomb perturbations on total

TABLE 4. M117M6 BASIC BALLISTICS CHECK

Flight Date	Weapon No.	TSPI Range (Feet)	Computed Range (Feet)	Difference (Feet)
24 Mar 1971	1	5746	5695	+51
	2	6141	6077	+64
25 Mar 1971	1	7814	8261	-447*
	2	8521	8437	+84
	3	8616	8513	+103
2 Jun 1972	1**	--	--	--
	2**	--	--	--
	3	907	912	-5
	4	2022	2036	-14
	5	5064	5060	+4
27 Feb 1973	1	1235	1220	+15
	2	932	924	+8
	3	4778	4772	+6
	4	3640	3538	+102
	5	3328	3267	+61
28 Feb 1973	1	4350	4236	+114
	2	14336	12782	+1584*
22 Mar 1973	1**	--	--	--
	2	3696	3691	+5
	3	5627	5886	-259*
	4	2914	3046	-132
	5	1478	1507	-29
5 Apr 1973	1	5343	5413	-70
	2	5148	5165	-17
	3	5908	5875	+33
	4	3774	3744	+30
10 Apr 1973	1**	--	--	--
	2	788	797	-9
	3	5651	5705	-54
	4	1645	1633	+12
	5	759	756	+3
		N (Number of data points)		24
		X (Bias)		+15
		RMS		58

* Excessive error, not representative of majority of data, not used in analysis

**Trajectory too short to be used in basic ballistics check

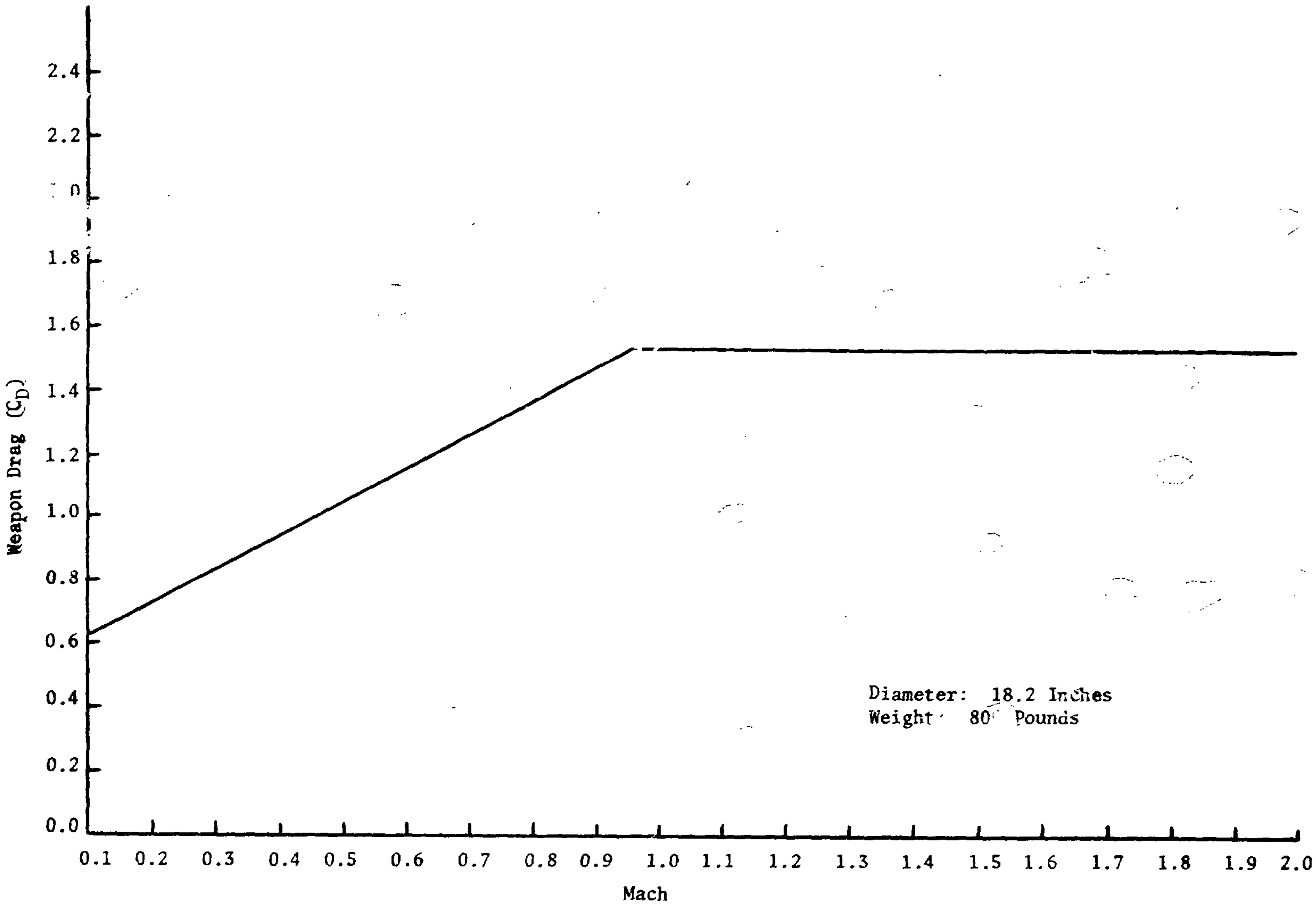


Figure 67. M117M6 Ballistic Drag Curve, Weight 800 Pounds

downrange travel. Initial separation velocities (separation effects along and perpendicular to the flight path must be assumed to be acting in addition to weapon drag and ejection velocity). The differences between TSPI data and ballistic data generated using drag and ejection velocity were computed and used to determine the separation effects needed to make the two the same. The desired velocity adjustments are shown in Table 5.

The TSPI data yielded 36 weapon releases but of those only 31 are considered valid. The first release on 25 March 1971, the second release on 28 February 1973, the third release on 22 March 1973, and the releases made on 1 November 1973 and 14 December 1973 were all considered to exhibit trajectory range error. Therefore, these five drops were excluded from these analyses.

Table 5 values for velocity adjustments along and perpendicular to the flight path were used to determine the character of the separation effects. Using curve fitting techniques, acceptable data fits were obtained with the curves shown in Figures 68 and 69. The vertical velocity adjustment was found to correlate well with dynamic pressure and the longitudinal velocity adjustment was found to correlate well with Mach Number.

The improvement in bomb range due to application of the separation effects was verified by recomputing the predicted bomb range using the weapon release conditions as modified by the values calculated from the ballistic separation effects curves. The results of the computer predicted bomb ranges improved from an RMS error of 366 feet without separation effects to an RMS error of 150 feet with separation effects. The results are shown in Table 6.

The overall RMS bomb range error of 150 feet is larger than most free-fall weapons; however, for low altitude bombing (200 to 500 feet) with short times-of-fall of 2.5 to 6.0 seconds, the weapon dispersion is decreased to an acceptable value. Out of the 36 weapon drops in this analysis, eight weapons had valid TSPI tracking times within the range of 2.5 to 6 seconds. An analysis of these eight drops yielded a reduction of the RMS weapon dispersion value to 67 feet. This value compares favorably to the weapon dispersion value of 76 feet for the M117 retarded weapon. The results of the M117M6 low altitude weapon drop analysis are summarized in Table 7.

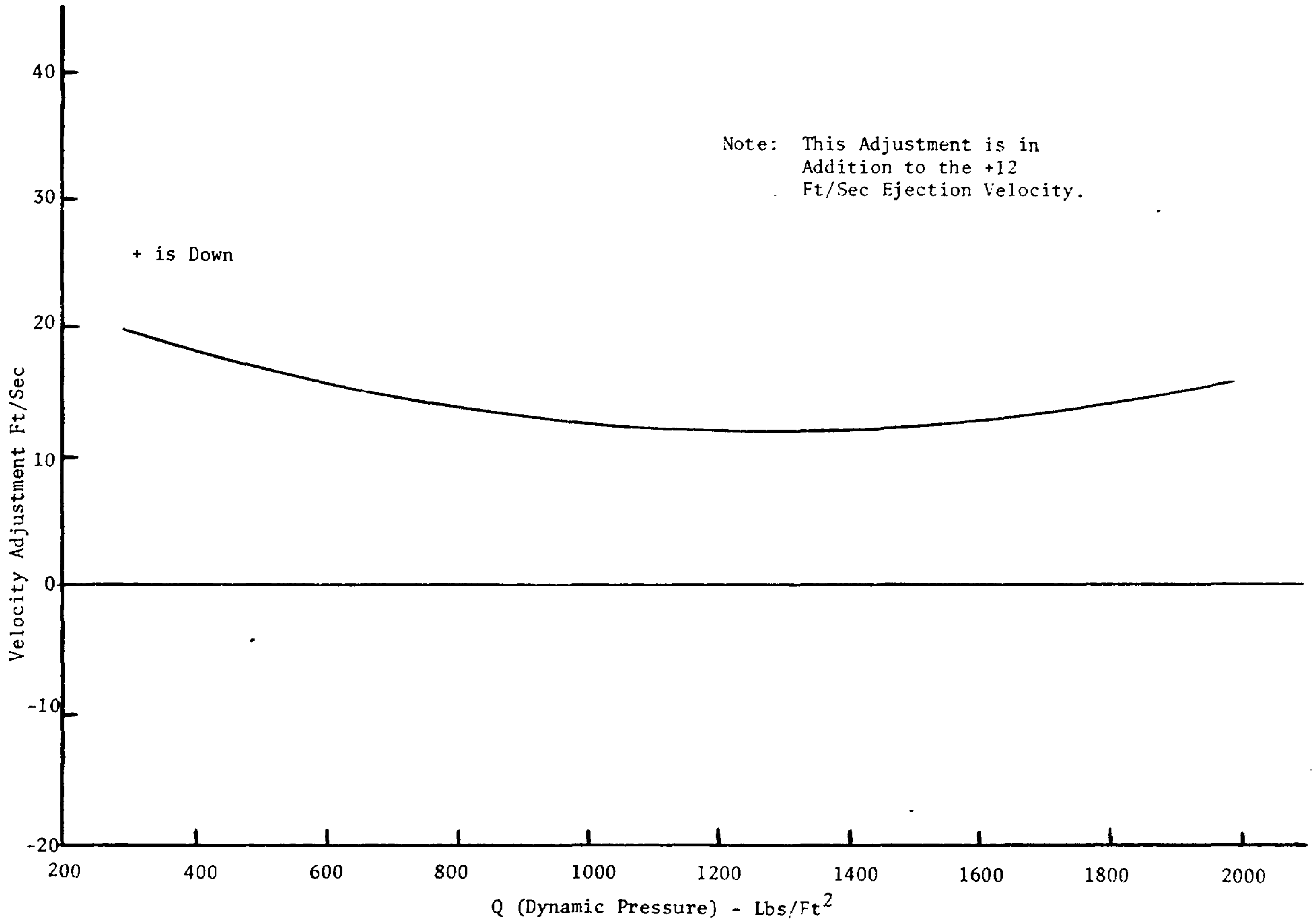


Figure 68. Separation Effects, Velocity Adjustment Perpendicular to Flight Vector

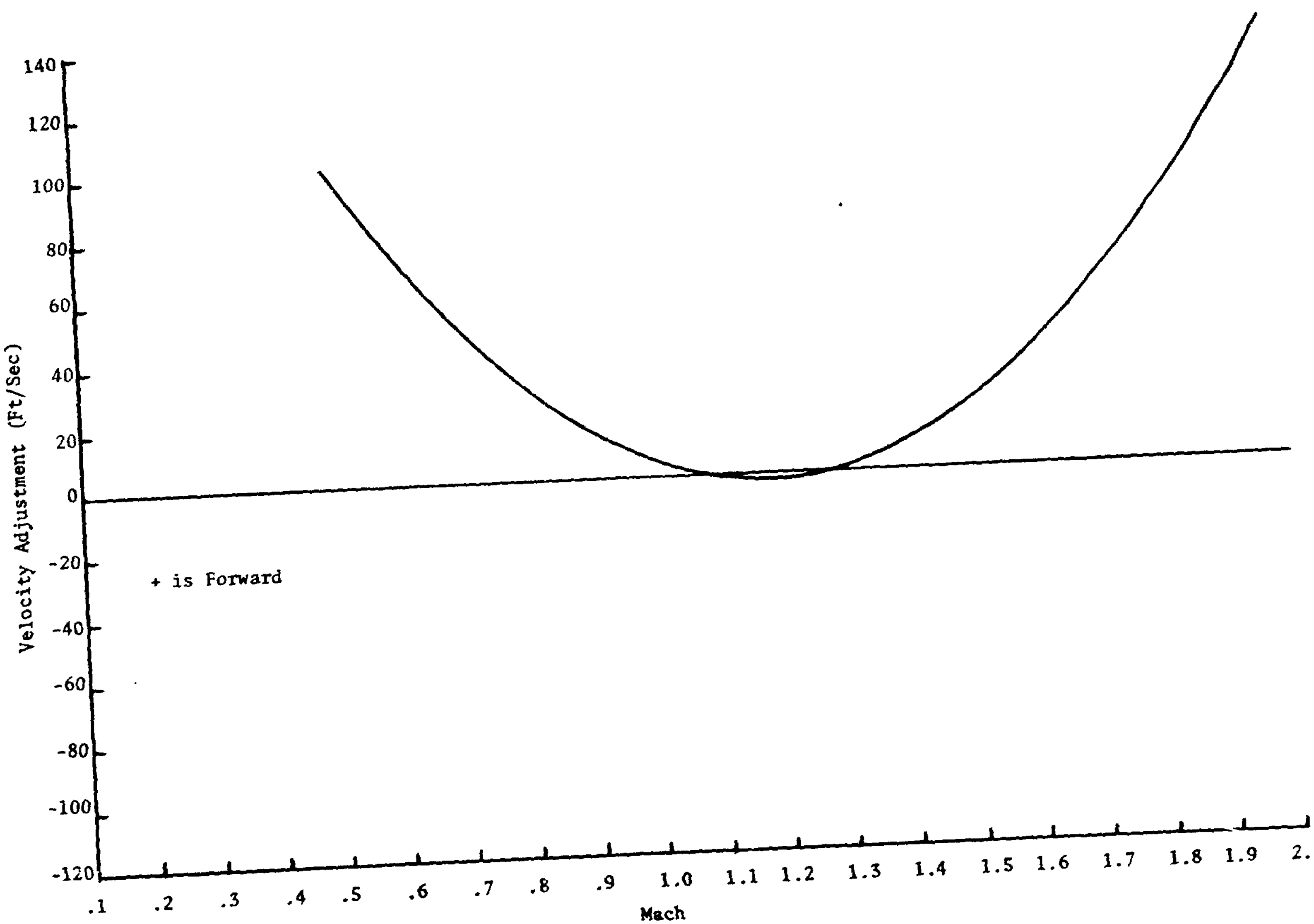


Figure 69. Separation Effects, Velocity Adjustment Along Flight Vector

TABLE 5. DESIRED VALUES FOR M117M6 BALLISTICS SEPARATION EFFECTS

Flight Date	Weapon No.	Mach No.	Velocity Adjustment Along Flight Vector Ft/Sec	Q (Dynamic Pressure) Lbs/Ft^2	Velocity Adjustment Perpendicular to Flight Vector* Ft/Sec
24 Mar 1971	1	0.81	29.7	892	4.4
	2	0.80	55.5	879	15.5
25 Mar 1971	1	0.90	-103.9**	1037	-0.9*
	2	0.89	46.8	1009	22.1
	3	0.89	60.1	1004	18.5
2 Jun 1972	1	0.80	9.9	882	13.1
	2	0.80	13.6	883	13.7
	3	0.80	28.9	884	12.9
	4	0.80	[illegible]3.1	885	16.6
	5	0.80	34.5	886	14.4
27 Feb 1973	1	0.95	-8.5	1234	7.8
	2	0.95	-7.8	1234	10.8
	3	0.95	31.9	1234	9.4
	4	0.95	99.2	1233	13.3
	5	0.95	60.8	1233	7.0
28 Feb 1973	1	0.60	58.9	507	16.7
	2	0.61	173.1**	249	124.0**
22 Mar 1973	1	0.96	-10.4	1255	20.7
	2	0.96	43.1	1255	6.9
	3	0.96	-77.0**	1255	-1.8**
	4	0.96	-42.5	1255	15.4
	5	0.96	49.2	1256	11.0
5 Apr 1973	1	1.14	3.4	1815	14.0
	2	1.15	-11.6	1830	14.1
	3	1.15	27.6	1801	13.9
	4	.58	27.1	462	13.4
10 Apr 1973	1	1.20	-96.9	1970	15.5
	2	1.20	-48.6	1968	15.5
	3	1.20	-84.4	1968	15.5
	4	1.20	1.7	1967	15.5
	5	1.20	-19.4	1966	15.4
1 Nov 1973	1	1.86	8.4**	1380	11.9
2 Nov 1973	1	1.93	132.2	1482	12.2
6 Nov 1973	1	1.92	121.3	1538	12.4
13 Nov 1973	1	1.27	11.7	1963	15.4
14 Dec 1973	1	1.26	-98.7**	1868	14.5

*This is in addition to a free-stream ejection velocity of 12 ft/sec.

**Determined to be non-representative, not used in analysis.

TABLE 6. M117M6 BOMB RANGE PREDICTIONS WITH AND WITHOUT SPEARATION EFFECTS

Flight Date	Weapon No.	TSPI T_F Sec.	TSPI Range Feet	Predicted Without Separation Effects - Range Feet	Difference (TSPI-w/o S.E.) Feet	Predicted With Separation Effects - Range Feet	Difference (TSPI-w/S.E.) Feet
24 Mar 1971	1	10.0	6633	6545	88	6511	122
	2	10.6	7022	6945	77	6922	100
25 Mar 1971	1	16.0	8756	9328	-572*	9286	-530*
	2	16.0	9453	9412	41	9382	71
	3	16.0	9552	9407	145	9373	179
2 Jun 1972	1	1.4	1197	1441	-244	1228	-31
	2	1.8	1511	1766	-255	1558	-47
	3	3.2	2585	2755	-170	2598	-13
	4	4.8	3710	3858	-148	3769	-59
	5	10.4	6743	6757	-14	6887	-144
27 Feb 1973	1	3.8	3297	3468	-171	3269	28
	2	3.4	2986	3213	-227	3011	-25
	3	10.8	7637	7615	22	7505	132
	4	6.8	5598	5445	153	5293	305
	5	6.4	5277	5175	102	5015	262
28 Feb 1973	1	10.0	5683	5530	153	5761	-78
	2	41.4	15554	13814	1740*	14743	811*
22 Mar 1973	1	2.2	2072	2561	-489	2312	-240
	2	7.0	5646	5605	41	5435	211
	3	11.4	7565	7895	-330*	7776	-211*
	4	6.2	4844	5263	-419	5087	-243
	5	3.8	3451	3550	-99	3326	125
5 Apr 1973	1	9.7	7548	7725	-177	7529	19
	2	9.4	7362	7605	-243	7403	-41
	3	10.8	8116	8178	-62	7994	122
	4	9.7	4987	4967	20	5245	-258
10 Apr 1973	1	1.7	1812	2224	-412	1972	-160
	2	3.0	3022	3409	-387	3135	-113
	3	10.3	7631	8164	-533	7970	-339
	4	3.6	3680	3949	-269	3675	5
	5	2.8	2989	3310	-321	3034	-45
1 Nov 1973	1	62.4	31580	31589	-9*	32466	-886*
2 Nov 1973	1	60.6	33878	32688	1190	33849	29
6 Nov 1973	1	62.0	32981	31937	1044	32922	59
13 Nov 1973	1	20.2	13255	13340	-85	13195	60
14 Dec 1973	1	21.2	12559	13190	-631*	13067	-508*
N (Number of data points)					31		31
$\overline{X}$ (Bias)					-53		0
RMS					366		150

*Determined to be non-representative; not used in analysis.

TABLE 7. M117M6 LOW ALTITUDE WEAPON DROPS

Flight Date	Weapon No.	Time-of-Fall Seconds	Range Error Feet
2 Jun 1972	3	3.2	-13
	4	4.8	-59
27 Feb 1973	1	3.8	28
	2	3.4	-25
22 Mar 1973	5	3.8	125
10 Apr 1973	2	3.0	-113
	4	3.6	5
	5	2.8	-45
N (Number of data points)			8
$\bar{X}$ (Bias)			-12
RMS			67

SECTION III

CONCLUSIONS

1. This flight test program demonstrated safe subsonic and supersonic weapon separation characteristics for the bluff bomb configuration M117M6 from the F-111 weapon bay. The flight testing was accomplished at supersonic speeds to Mach 1.96 and 32,000 feet altitude. Clean weapon separation was demonstrated for single and ripple drops at all speeds tested.

2. Ground tracking camera film revealed that some of the weapons oscillated during their trajectory. This indicates that the dynamic stability for the M117M6 weapon configuration was lower than desired.

3. Review of the data indicated wide variations in weapon drag due to apparent weapon oscillations.

4. A possible trend indicating that weapon drag may vary as a function of release sequence in a ripple release has been noted when comparing the apparent weapon drag for each weapon in the ripple release sequence.

5. The overall weapon dispersion is greater than was desired or expected. This may be due in part to the dynamic stability and drag problems of the weapon. For low altitude releases, weapon dispersion is in the range of inventory retarded weapons and may be acceptable.

6. The high altitude supersonic weapon drops indicate a relatively smooth weapon drag trend in the supersonic region. As the weapon traversed the transonic region, a small increase in weapon drag was observed and the weapon drag became slightly erratic.

7. The weapon drops above 30,000 feet indicated a weapon drag substantially below the weapon drag indicated by the low altitude weapon drops.

8. The modification kit to the M117 provides a means of obtaining a bluff bomb using present munitions in inventory and saving time and money over developing a totally new bomb.

APPENDIX A

STRUCTURAL DESIGN OF BLUFF BOMB KITS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The structural adequacy of the M117 bluff shaped bomb conversion has been verified by analysis. Inertia and airloads for ejection and free fall have been investigated. Ultimate stress levels are well below allowable limits.

SECTION I

INTRODUCTION

High density munitions are desirable for internal carriage and high speed bomb drops. In order to use existing munitions, a kit has been designed to convert M117 bombs to a high density bluff shaped configuration.

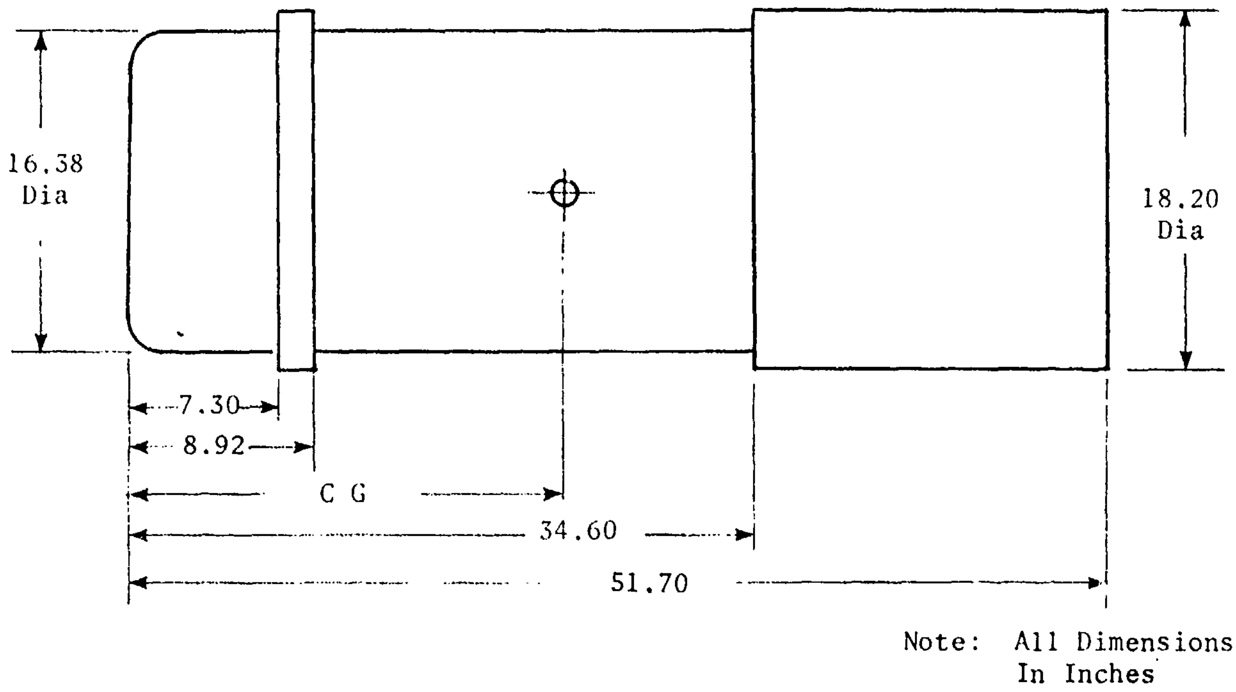
The purpose of this report is to present the design loads and the stress analysis for the cast aluminum bluff shaped conversion kit.

SECTION II

M117 BLUFF SHAPED CONFIGURATION

The bomb weighs approximately 834 pounds with the cg about 8.2 inches aft of the forward 14-inch suspension lug. Figure A-1 shows the weight distribution and overall dimensions of the M117 bluff shape.

The kit consists of a cast aluminum nose and a tail assembly. The tail assembly is a one piece aluminum casting with a seal riveted to the forward flange. The nose and tail are attached to the bomb case with the forward and aft closure plugs as shown in Figure A-2.



WEIGHT DISTRIBUTION

Nose Assembly	37 Pounds
M117 Bomb	769 Pounds
Tail Assembly	21 Pounds
Fuzes	7.5 Pounds
	834.5 Pounds

CG = 21.6 Inches

Figure A-1. M117M Bluff Shaped Dimensions and Weight Distribution

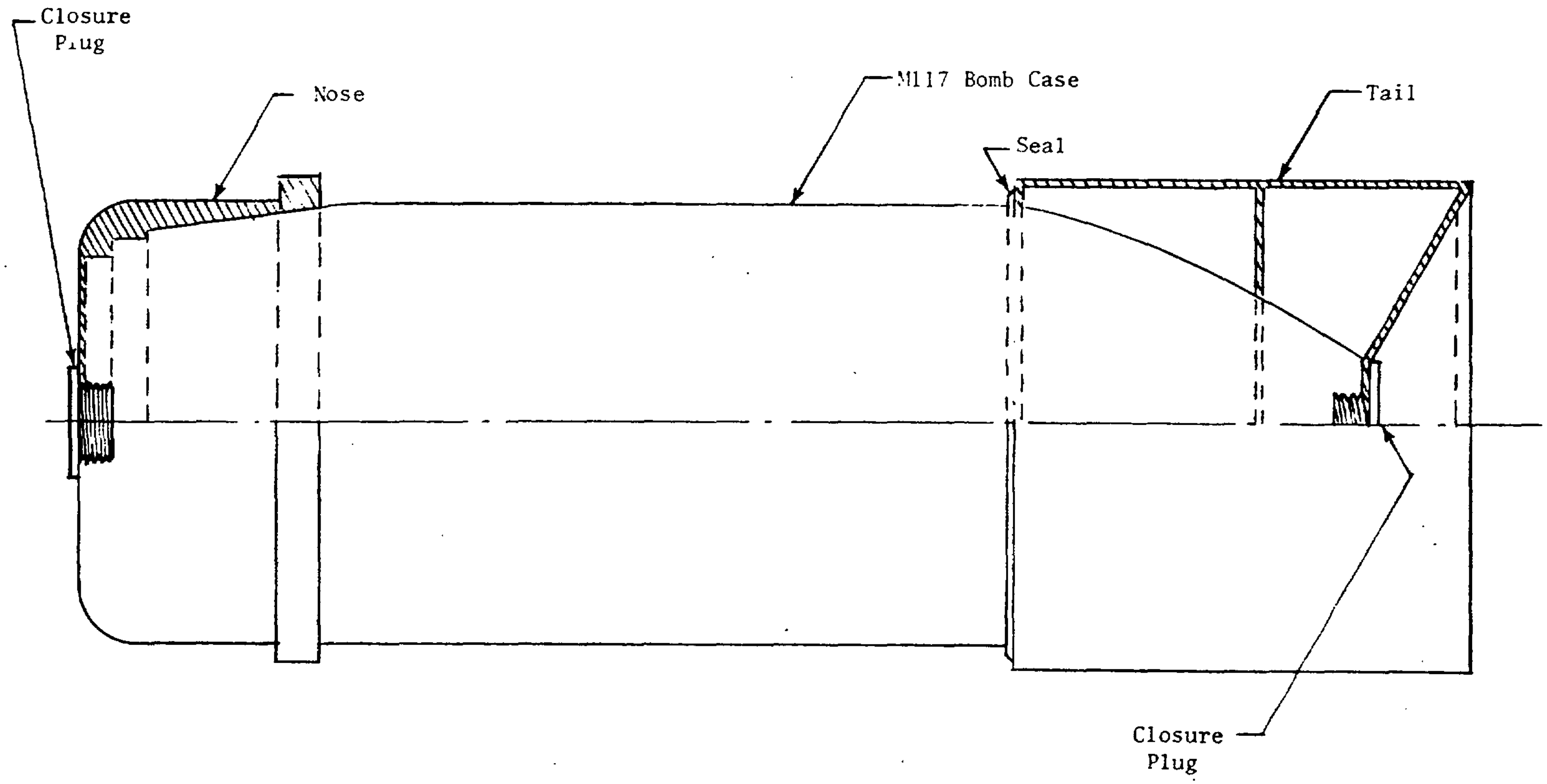


Figure A-2. M117 Bluff Shaped Kits Aluminum Cast Parts

SECTION III

DESIGN LOADS AND CRITERIA

3.1 Introduction

The purpose of this section is to present the design loads on the M117 bluff shaped weapons and the rationale employed in their computations. The scope of the analysis has been to determine loads acting on the weapon ejector area and loads for design of the conversion kit hardware.

3.2 Criteria

Design loads are based on the release and jettison flight envelope and aircraft position, rate and acceleration parameter values presented in Figure A-3.

3.3 Design Loads

3.3.1 Ejection Force

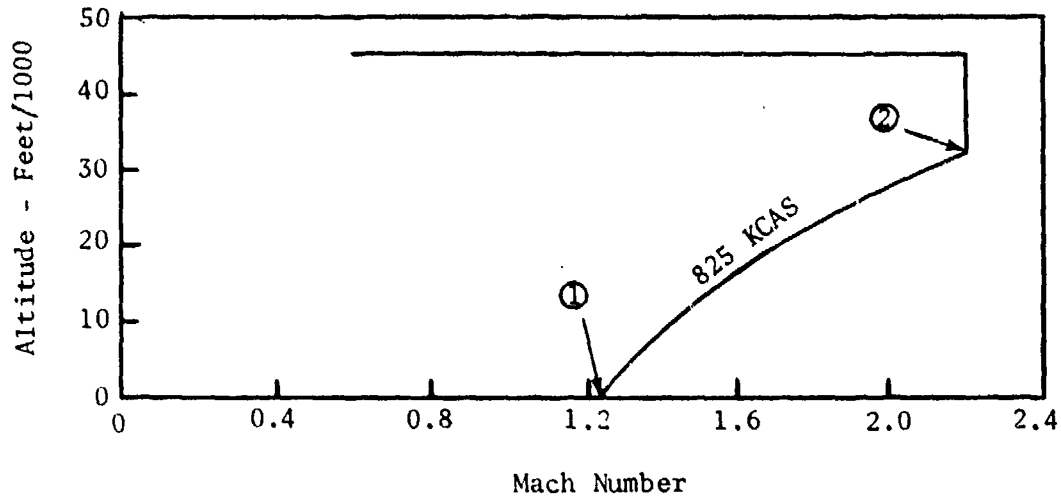
Release or jettison from the MAU-12 rack is obtained by firing a combination of one ARD-863-1 and one ARD-446-1 cartridge. The ejection forces acting on the ejector area of the M117 bluff shaped weapons are presented in Table A-1. The peak force at 70°F is based on a peak-to-mean ratio derived from test results (Reference 1). The peak force at 160°F includes effects of variation in cartridge charge and elevated temperature. The charge variation is based on a standard deviation of 0.06, with a dispersion of plus three standard deviation from the mean used for calculation of forces. Effects of elevated temperatures were derived from a statistical analysis of results from tests conducted with ARD 446-1 cartridges (Reference 2). Based on this analysis, a factor of 1.1 was determined which, when combined with the charge variation factor of 1.18, is estimated to provide coverage of approximately three standard deviations about the mean for ejection foot forces at elevated temperatures up to 160°F. Therefore, a factor of 1.3 (i.e., 1.18 x 1.1) was used to calculate peak ejector

---

References:

1. Smith, P. D., and Young, M. A., Qualification and Performance Report of the MAU-12A/A and MAU-12 B/A Rack, WL TR 64-177, 1965.

2. ARD-446-1 Cartridge, Olin Mathieson Chemical Corporation, 1960.



The weapon can be released within the following:

Normal acceleration = +0.5 to +4.0g
Pitch angle = -20 to +45 degrees
Roll angle = $\pm$5 degrees
Roll rate = zero

Figure A-3. M117 Bluff Shaped Weapon Release and Jettison Envelope

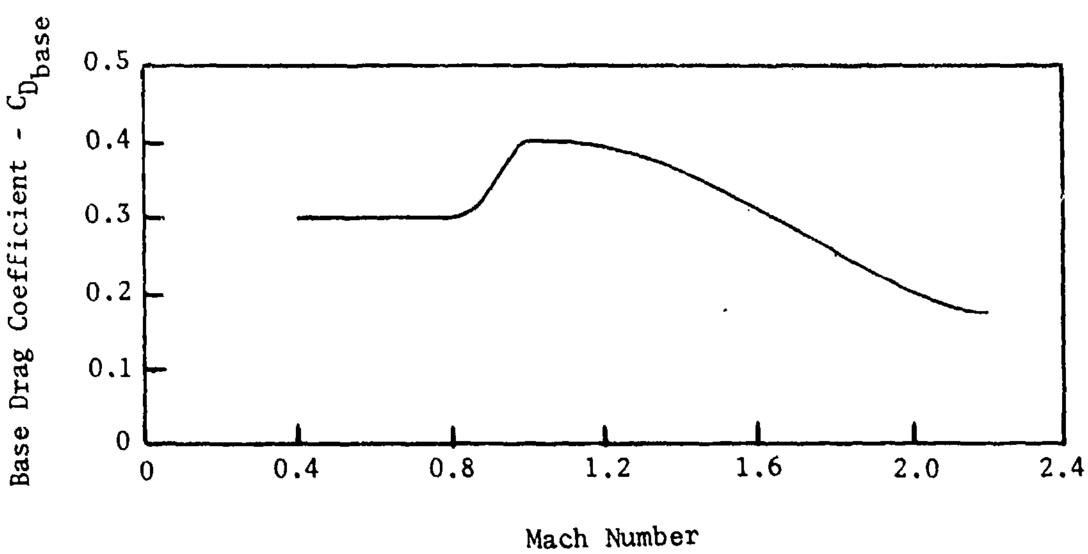


Figure A-4. M117 Bluff Shaped Weapon Base Drag

TABLE A-1. EJECTION LOADS ON M117 BLUFF SHAPED WEAPONS

Weight	Avg Force 70°F	Peak Force 70°F	Peak Force 160°F	Force Distribution	
				Fwd Ejector	Aft Ejector
←	$(10)^{-3}$ Lbs		→		
0.800	6.064	12.50	16.23	70 → 30%	30 → 70%
1.000	6.835	13.00	16.87	70 → 30%	30 → 70%

forces based on combined effects of charge variation and elevated temperatures.

3.3.2 Inertia Loads

The maximum inertia loads occur during release or jettison when the weapon is subjected to forces imposed by the ejectors. Table A-2 contains the necessary input into the following equations from which inertia forces can be computed.

Pitching Acceleration:

$$\ddot{\theta} cg_{store} = \frac{T_{total} L_1 - T_f L + M_{cg_{pl}}}{I_o}$$

Inertia Load Factor:

$$n_{z_{cg_{store}}} = -n_{z_{cg_{A/P}}} + \frac{\ddot{\theta} cg_{A/P} (FS_{cg_{store}} - FS_{cg_{A/P}})}{g} + \frac{T_{total}}{GW_{store}}$$

Sign Convention:

+ Linear acceleration is upward

+ Angular acceleration is nose up

+ Load (forces) acts upward

+ Moment acts nose up

3.3.3 Free Fall Airloads

It was assumed that the most critical airloads will occur along the 825 KCAS constant compressible dynamic pressure, q_c, line (see Figure A-3). With the weapon at a specified angle of attack, all component airloads will be constant along this 825 KCAS line with the exception of the aft bulkhead of the tail assembly where the base drag varies as a function of the Mach-altitude combination. Increasing the altitude along the constant q_c line results in a decrease in base drag but an increase in stagnation temperature. Points 1 and 2 on Figure A-3 were selected for the tail assembly aft bulkhead design conditions because they represent maximized base drag and stagnation temperature, respectively. Point 2 was selected for design of all other component parts in order to provide coverage for combined effects of high load/temperature conditions.

Pressure distributions applied on the component parts are not correlated to weapon total forces and moments but are empirically determined

TABLE A-2. INERTIA LOAD DATA

Parameter	Symbol	Magnitude
Normal Acceleration	$n_{z_{cg_{A/P}}}$	+0.5 to +4.0g
Pitching Acceleration	$\ddot{\theta}_{cg_{A/P}}$	$\pm 4.0\ ^{Rad}/Sec^2$
Pre-Launch Pitching Moment for Positive $\ddot{\theta}_{cg_{A/P}}$	$M_{cg_{pl}}$	-30100 In-Lb
Pre-Launch Pitching Moment for Negative $\ddot{\theta}_{cg_{A/P}}$	$M_{cg_{pl}}$	29500 In-Lb
Total Ejector Force = $T_{forward} + T_{aft}$	T_{total}	See Table A-1
Forward Ejector Force	T_f	See Table A-1
Length Between Weapon Ejectors	L	20 In.
Length Between Weapon cg and Aft Ejector	L_1	7.85 In.
Pitching Moment of Inertia	I_o	507 In-Lb/Sec^2
Gross Weight	GW	800 Lb
Fuselage Station of A/P cg	$FS_{cg_{A/P}}$	530 In.
Fuselage Station of Store cg (2 Fwd 3 Aft)	$FS_{cg_{store}}$	357.0 In. (Fwd) 421.0 In. (Aft)

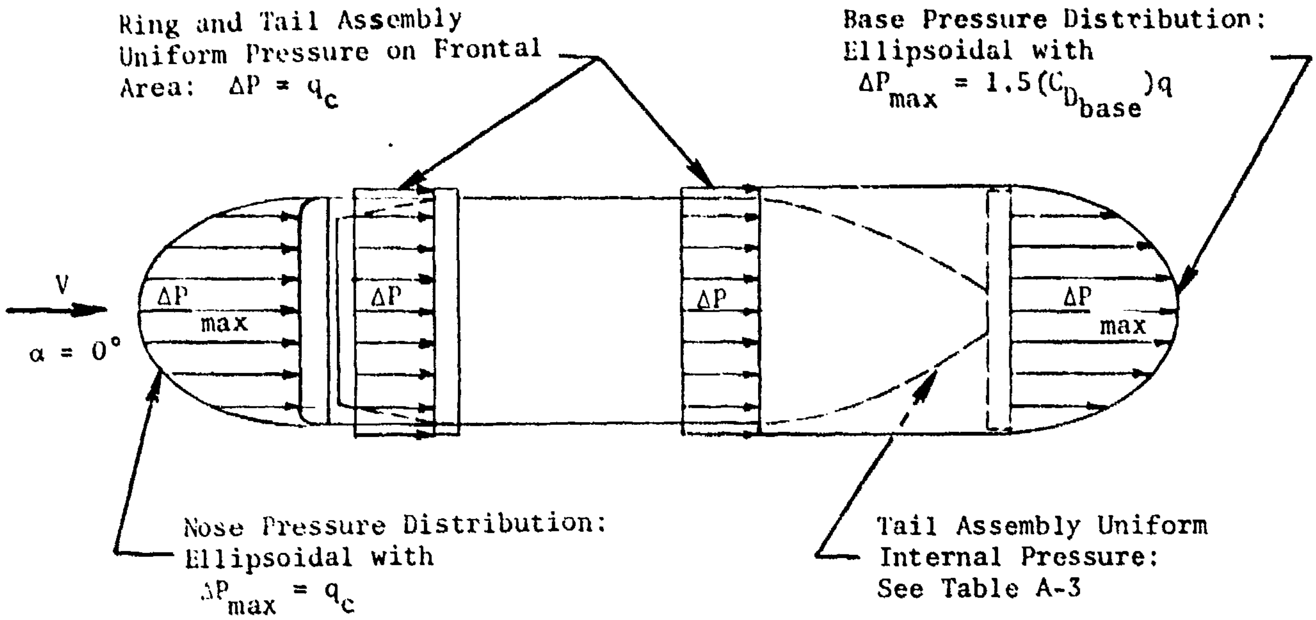
distribution shapes to provide reasonably conservative coverage of expected maximum aerodynamic forces. Manufacturing tolerances can result in an annular gap between the forward ring of the tail assembly and the warhead casing. The design provides for a flexible seal at this gap; however, airloads were calculated assuming a pressure leakage through the seal into the interior of the tail assembly. This internal pressure was estimated considering effects of energy loss in the local boundary layer at the opening.

Three cases were chosen for evaluation of design airloads. These three cases position the weapon in four different angles of attack as shown in the following case descriptions. The q_c values and stagnation temperatures applicable to these cases are summarized in Table A-3. Base drag coefficient, CD_{base}, is presented in Figure A-4 as a function of Mach Number. All pressures (surface loads) are increased by a factor of 1.5 to generate ultimate design pressures.

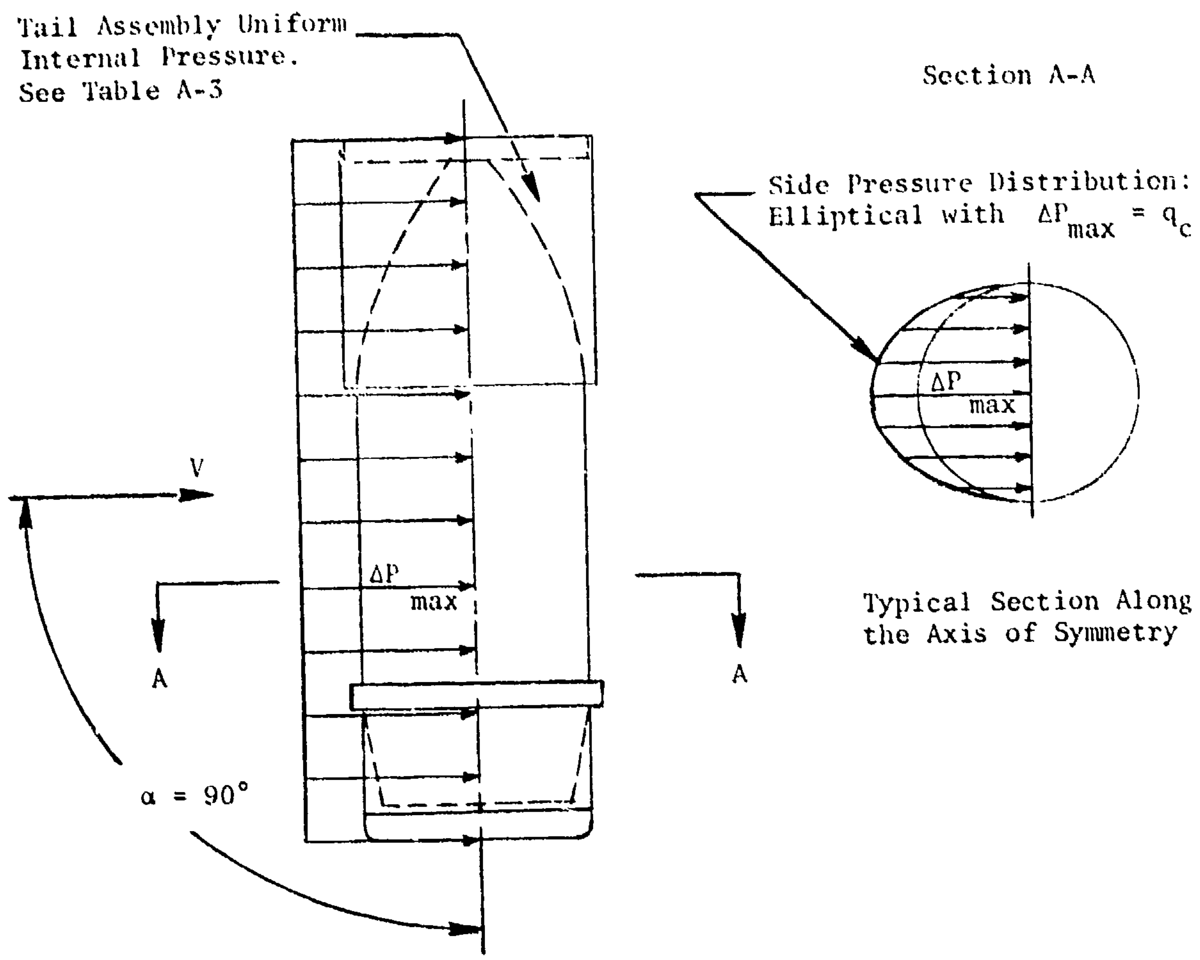
TABLE A-3. DESIGN AIRLOAD PRESSURES AND TEMPERATURES

Mach Number	Altitude	Incompressible Dynamic Pressure	Compressible Dynamic Pressure	Tail Assembly Uniform Internal Pressure	Stagnation Temperature (Hot Day)
	Feet/1000	-q - psi	$-q_c$ - psi	-psi	$-T_{total}$ - °F
1.25	0	16.07	22.8	5.40	279
2.20	32	13.49	22.8	4.20	406

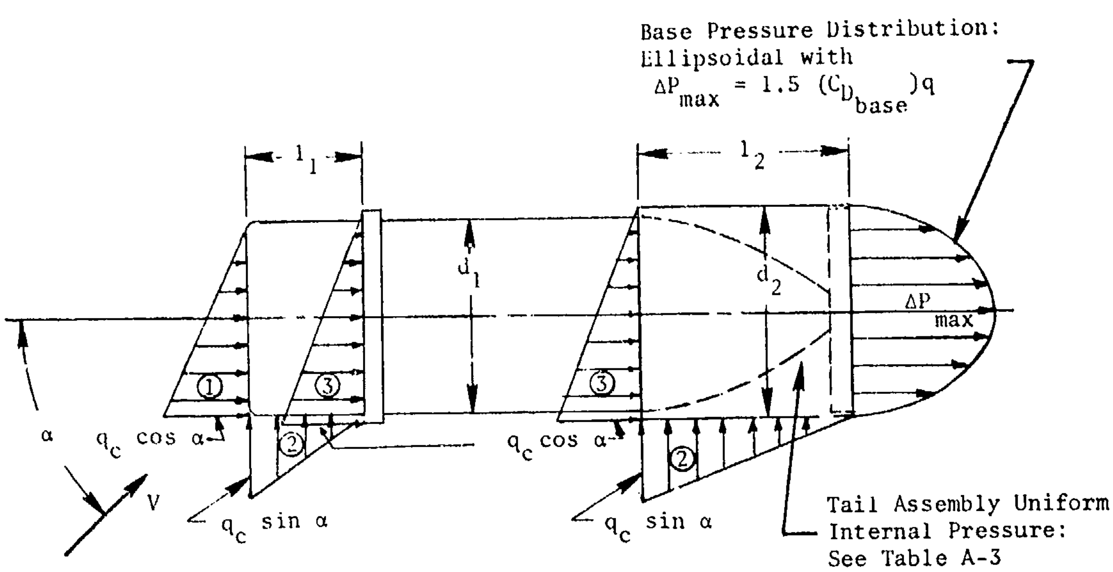
CASE 1: ANGLE OF ATTACK = 0°



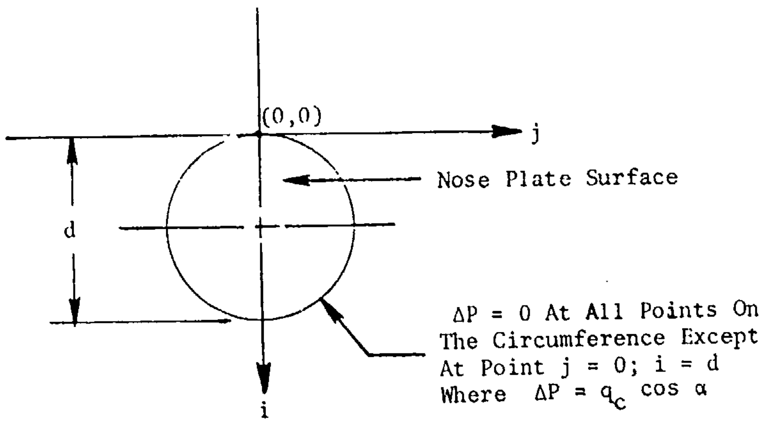
CASE 2: ANGLE OF ATTACK = 90°



CASE 3: ANGLE OF ATTACK = 45° or 60°



DISTRIBUTION 1



Pressure normal to the surface at any point i, j may be calculated from:

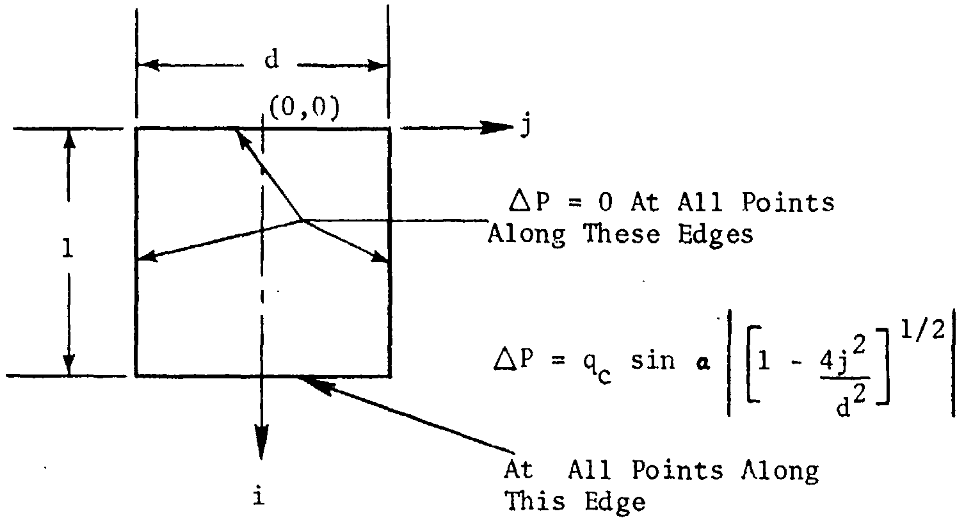
$$\Delta P(i,j) = \left(\frac{q_c \cos \alpha}{d}\right) \left| \left(i^2 - \frac{j^2\, i}{d-i}\right)^{1/2} \right|$$

where: $d = d_1$

$0 \lessgtr i \lessgtr d$

$-d/2 \lessgtr j \lessgtr d/2$

DISTRIBUTION ②



Pressure normal to the projected area at any point i, j may be calculated from:

$$\Delta P(i,j) = \left(\frac{i(q_c \sin \alpha)}{l}\right) \left| \left(1 - \frac{4j^2}{d^2}\right)^{1/2} \right|$$

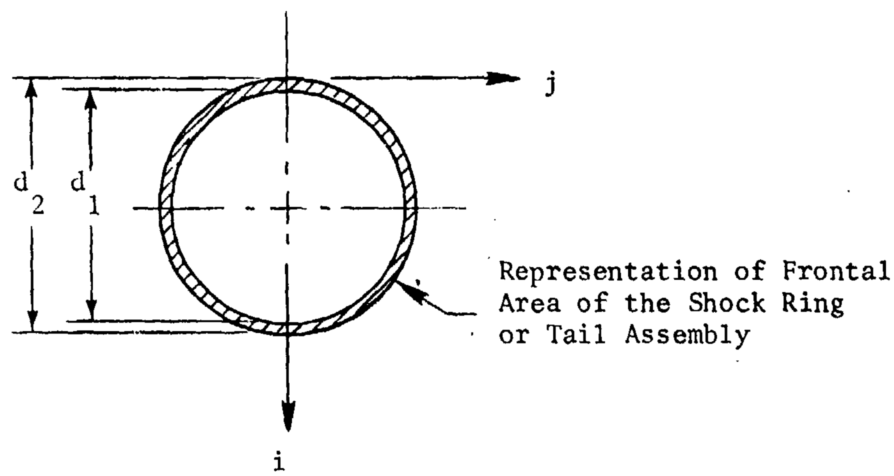
where: $l = l_1$ or l_2

$d = d_1$ or d_2

$0 \lesseqgtr i \lesseqgtr l$

$-d/2 \lesseqgtr j \lesseqgtr d/2$

DISTRIBUTION 3



Pressure normal to the surface at any point i, j may be calculated from:

$$\Delta P(i,j) = \frac{(q_c \cos \alpha)\, i}{d}$$

where: $d = d_2$

$0 \lessgtr i \lessgtr d$

j must be on the shaded area

SECTION IV

STRESS ANALYSIS OF NOSE AND ROUND TAIL

4.1 Discussion

The M117 bluff shaped conversion kit is composed of an aluminum nose casting and a cast aluminum tail assembly. Details of the kit are shown in Figure A-2 and are analyzed on the following pages.

Loads on the nose and tail assemblies are primarily airload. The two critical load conditions are given in subsection 4.2. Inertia load from ejection is negligible for the aluminum nose and tail castings.

Parts are cast 356-T6 aluminum. The structural temperature of Case 2, 406°F, was used for design temperature. Material allowables at temperature are shown in the detail stress analysis.

4.2 Applied Loads

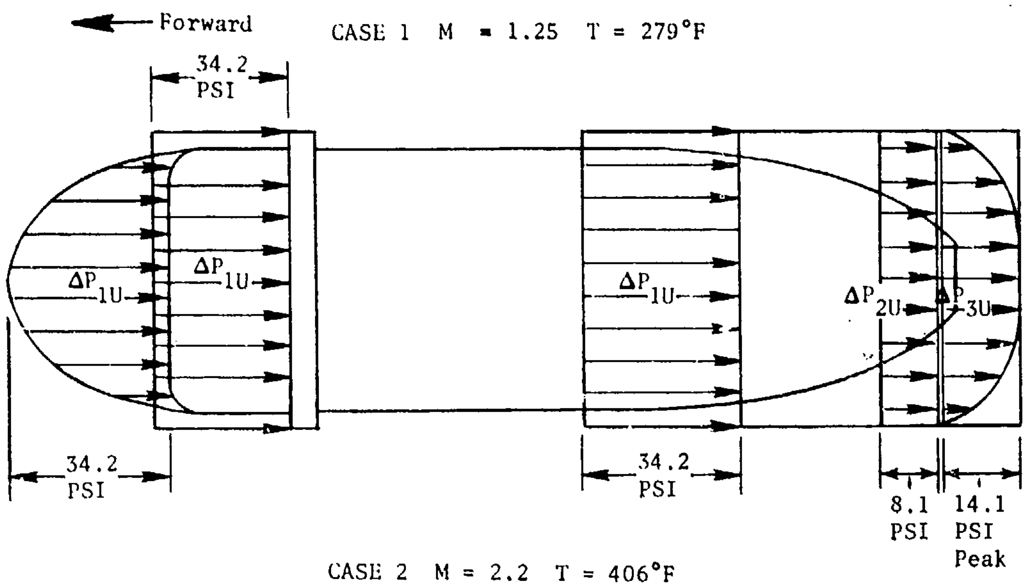
$$M = 1.25 \text{ @ SL} \quad \begin{cases} C_D = 0.39,\ \Delta P_2 = 5.4 \text{ PSI} \\ q = 16.07 \text{ PSI},\ q_c = 22.8 \text{ PSI} \end{cases}$$

$\Delta P_{3U} = 1.5\ C_D q(1.5) \quad \Delta P_3 = 14.1$ PSI (ULT)

$\Delta P_{1U} = 1.5 q_c = 34.2$ PSI (ULT)

$\Delta P_{2U} = 1.5\ \ P_2 = 8.1$ PSI (ULT)

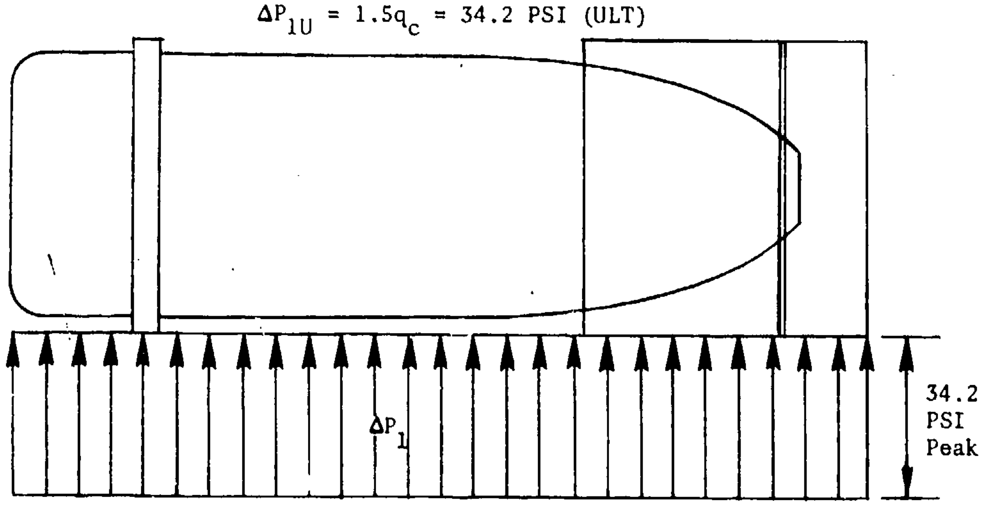
CASE 1 M = 1.25 T = 279°F



CASE 2 M = 2.2 T = 406°F

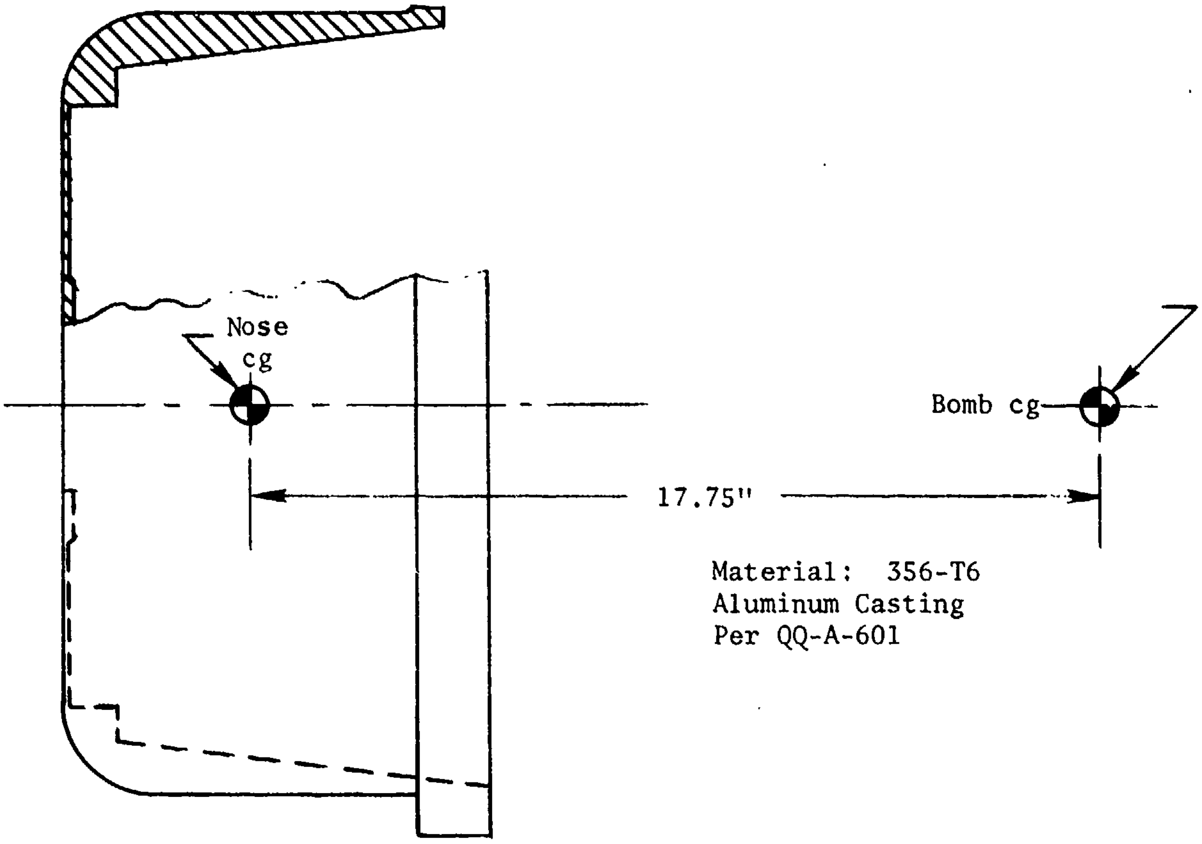
M = 2.2 @ 32,000 Feet $q_c = 22.8$ PSI

$\Delta P_{1U} = 1.5 q_c = 34.2$ PSI (ULT)



4.3 Stress Analysis

Nose Casting



Material: 356-T6
Aluminum Casting
Per QQ-A-601

Max g Loading

$$n_{Z_{CG_{store}}} = n_{Z_{CG_{A/P}}} + \frac{\ddot{\theta}_{CG_{A/P}} (FS_{CG} - FS_{CG_{A/P}})}{g} + \frac{T_{total}}{GW_{store}}$$

$$\ddot{\theta}_{CG_{store}} = \frac{T_{total}\, L_1 - T_f L + M_{CG_{pl}}}{I_o}$$

$n_{Z_{CG_{store}}} = 20.9g$ LIM

$\ddot{\theta}_{CG_{store}} = -256$ Rad/Sec^2 LIM

$d = 17.75$ inches

$FS_{CG} = 421$ inches

$GW_{store} = 800$ pounds

Nose Casting

$$n_{Z_{CG_{nose}}} = n_{Z_{CG_{store}}} - \frac{\ddot{\theta}_{CG_{store}} d}{g}$$

$$n_{Z_{CG_{nose}}} = 20.9 - \frac{(-256)(17.75)}{386}$$

$$n_{Z_{CG_{nose}}} = 32.7g \text{ LIM}$$

$$n_{Z_{CG_{nose}}} = 49.05g \text{ ULT}$$

Nose Assembly Weight = 37.3 pounds

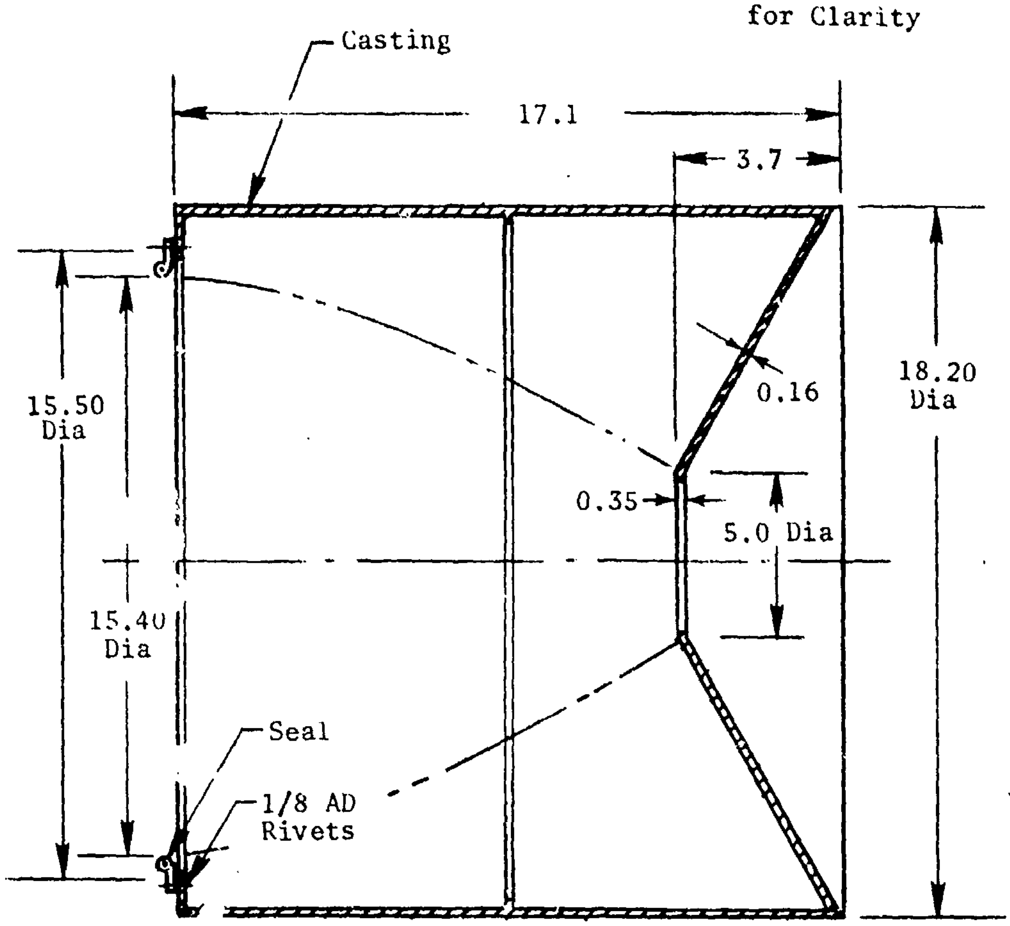
P = (49.05)(37.3) = 1830 pounds

P is reacted in bearing on the forward and aft rings. The bearing stress is small.

Round Tail Assembly

Skins are 0.12 In. Except as Noted

Near Skin Not Shown for Clarity



Note: All dimensions in inches

The tail assembly is a one piece 356 T6 aluminum casting to which a seal is attached with 1/8 inch AD rivets. The forward flange with seal is designed by maximum dynamic pressure. Maximum pressure on the skins is from a side condition. The bulkhead is critical for maximum aft airload on the assembly.

Round Tail Assembly

Material: 356-T6 Aluminum Casting Per QQ-A-601

RT	At 406°F
$E = 10.3 \times 10^6$ PSI	$E = (10.3 \times 10^6)(0.86) = 8.86 \times 10^6$ PSI
$F_{tu} = 30 \times 10^3$ PSI	$F_{tu} = (30 \times 10^3)(0.68)(0.75)^* = 15{,}300$ PSI
$F_{su} = 25 \times 10^3$ PSI	$F_{su} = (25 \times 10^3)(0.68)(0.75)^* = 12{,}750$ PSI
$\mu = 0.33$	

Check Cylinder for Buckling

(Reference 4, Page 318, Case 31, External Pressure on a Cylinder)

Peak Pressure = 34.2 PSI ULT

Allowable External Pressure

$$\Delta P_{ALL} = 0.807 \frac{Et^2}{lr} \sqrt[4]{\left(\frac{1}{1-\mu^2}\right)^3 \frac{t^2}{r^2}}$$

t = 0.12 inches, l = 17.1 inches, r = 9.1 inches

$$\Delta P_{ALL} = \frac{(0.807)(8.86 \times 10^6)(0.12)^2}{(17.1)(9.1)} \sqrt[4]{\left(\frac{1}{1-0.33^2}\right)^3 \left(\frac{0.12}{9.1}\right)^2}$$

$$\Delta P_{ALL} = 82.8 \text{ PSI}$$

$$MS = \frac{82.8}{34.2} - 1 = +1.42$$

*Casting Factor (Reference 3, Page 380)

References:

3. Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5A, February 1966.

4. Formulas for Stress and Strain, McGraw-Hill Book Co, 1954.

Round Tail Assembly

Bulkhead

$\Delta P_{AVG} = 8.1 + 2/3\ (14.1) = 17.5$ psi (From Case 1)

Check as a Cone Under Uniform Pressure

$F_{tu} = 15{,}300$ psi

$$r_{AVG} = \frac{2.5 + 9.0}{2}$$

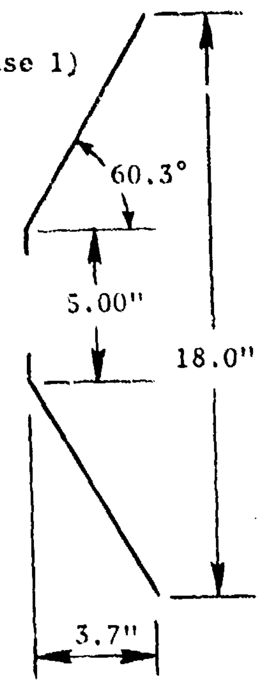
$r_{AVG} = 5.75$ inches

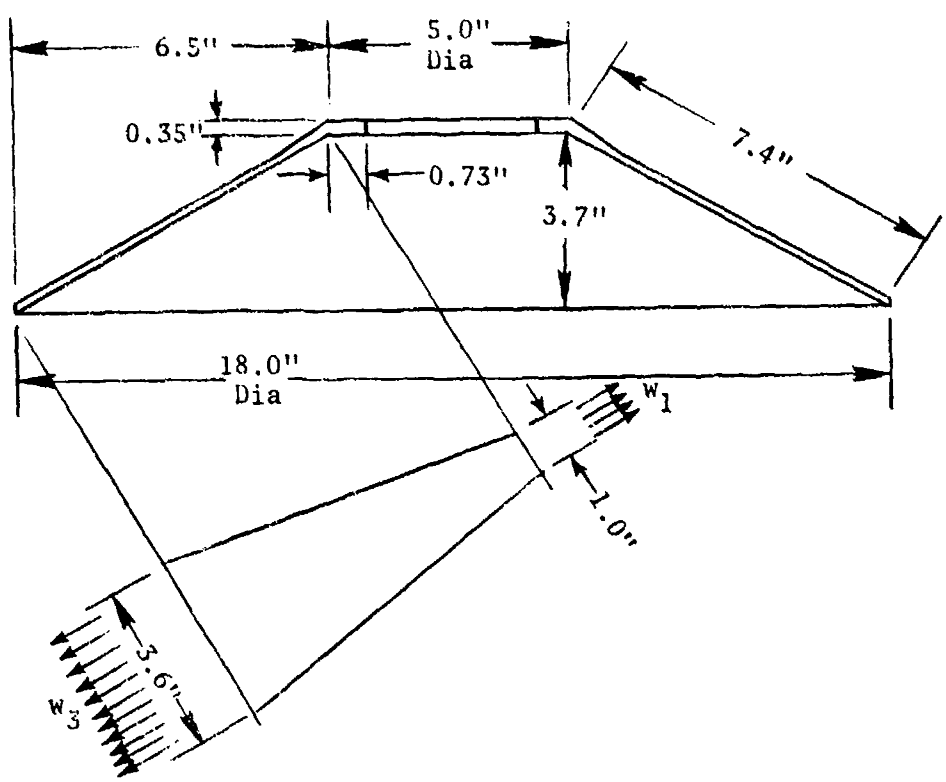
$$f_{MAX} = \frac{PR}{t \cos \alpha}$$ (Reference 4, Page 269, Case 3)

$$f_{MAX} = \frac{(17.5)(5.75)}{(0.16)(\cos 60.3°)}$$

$f_{MAX} = 1270$ psi

Not Critical





Round Tail Assembly

Bulkhead (Continued)

Total Load on Bulkhead

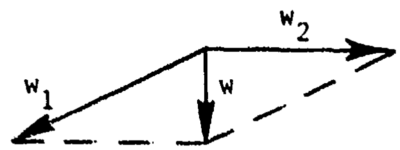
P = Load on Forward Ring + Load on Bulkhead

$P = \pi/4\ (18.2^2 - 15.4^2)(34.2\text{ psi}) + \pi/4\ (18.2^2 - 5.0^2)(17.5\text{ psi})$

P = 6733 Lb Ult

Running Load on 5.0 Inche Diameter

$w = \dfrac{P}{\pi D} = \dfrac{6733}{\pi(5.0)} = 429\text{ Lb/In.}$

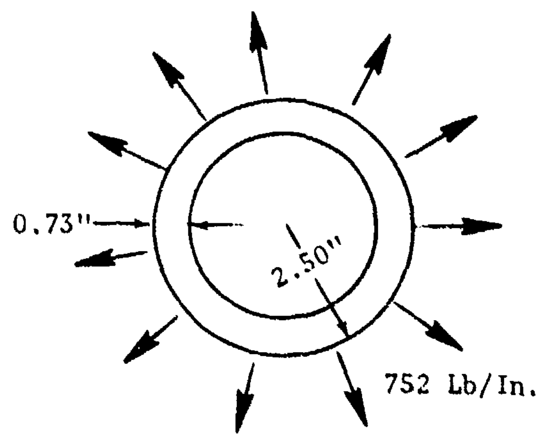


Putting Load in Plane of Web

$w_1 = 429 \times \dfrac{7.4}{3.7} = 858\text{ Lb/In.}$

$w_2 = 429 \times \dfrac{6.5}{3.7} = 754\text{ Lb/In.}$

Hoop Stress on 0.73-inch Wide Flange



$f_h = \dfrac{w_2 R}{b\ t} = \dfrac{754(2.5)}{(0.73)(0.35)} = 7380\text{ psi}$

$F_{tu} = 15{,}300\text{ psi}$

$MS = \dfrac{15{,}300}{7380} - 1 = +1.07$

Tension Stress

$f_t = \dfrac{w_2}{t} = \dfrac{754}{0.35} = 2150\text{ psi}$

Round Tail Assembly

Bulkhead (Concluded)

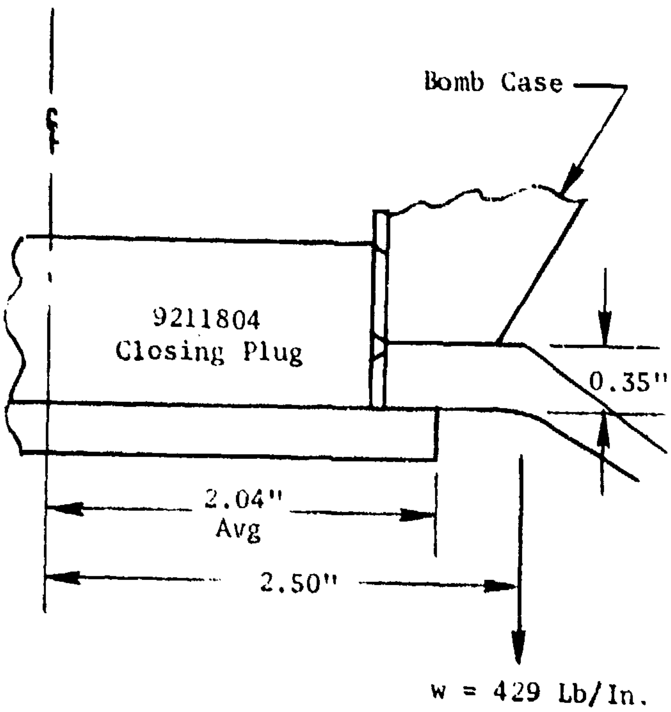
Bending Stress

$M = 429\ (2.50 - 2.04)$

$M = 198$ In-Lb/In.

$f_b = \frac{6M}{t^2} = \frac{6(198)}{0.35^2}$

$f_b = 9700$ psi



Shear Stress

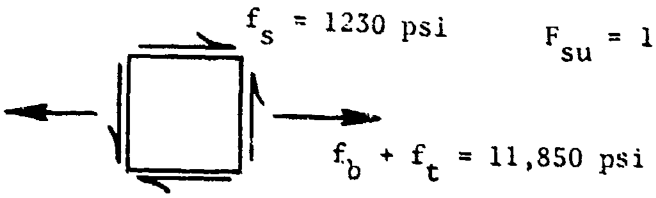
$f_s = \frac{w}{t} = \frac{429}{0.35}$

$f_s = 1230$ psi

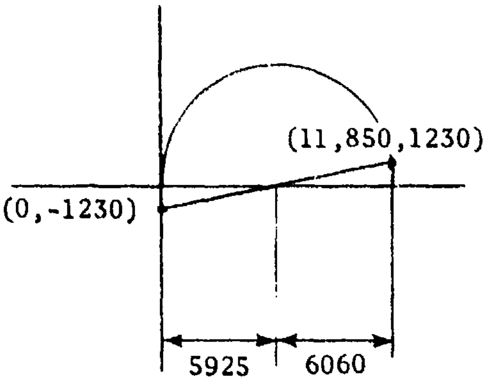
Principal Stresses

$F_{tu} = 15{,}300$ psi

$F_{su} = 12{,}750$ psi



Using Mohr's Circle:



$C = \frac{11{,}850}{2} = 5925$ psi

$\tau_{max} = \sqrt{(5925)^2 + (1230)^2} = 6060$ psi

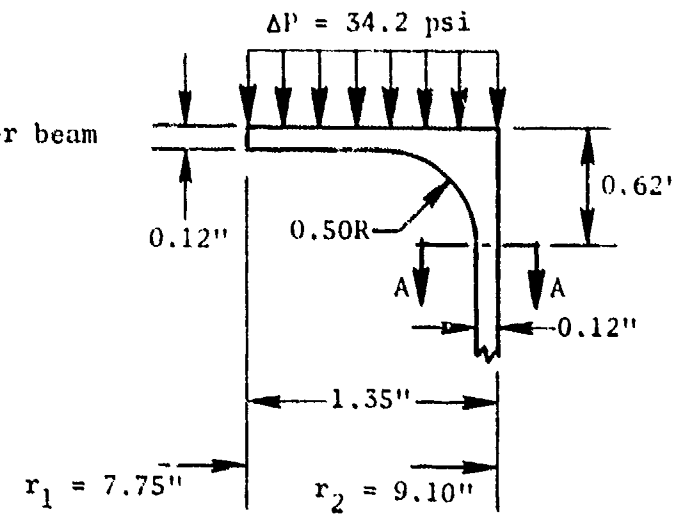
$MS = \frac{12{,}750}{6060} - 1 = +1.10$

$\delta_{max} = 5925 + 6060 = 11{,}985$ psi

$MS = \frac{15{,}300}{11{,}985} = +0.28$

Round Tail Assembly

Forward Lip



Assume a one-inch-wide cantilever beam

$$M_{max} = \frac{\Delta P\ (r_2 - r_1)^2}{2}$$

$$M_{max} = \frac{(34.2)(1.35)^2}{2}$$

$$M_{max} = 31.2 \text{ In-Lb/In.}$$

Check Cylinder with Uniform Radial Moment

(Reference 4, Page 271, Case 11)

$$M_x = M_{max}\, e^{-\lambda x}\, (\cos \lambda x + \sin \lambda x) \quad \text{where } \lambda \text{ is defined as}$$

$$\lambda = \sqrt[4]{\frac{3(1 - \nu^2)}{a^2 t^2}} = \left(\frac{3(1 - 0.3^2)}{(9.1)^2 (0.12)^2}\right)^{1/4} = 1.23$$

Section A-A

$$x = 0.62''$$

$$M_x = (31.2)\, e^{-(1.23)(0.62)} \left[\cos\ (1.23)(0.62) + \sin\ (1.23)(0.62)\right]$$

$$M_x = 20.6 \text{ In-Lb/In.}$$

$$f_b = \frac{6M_x}{t^2} = \frac{6(20.6)}{(0.12)^2}$$

$$f_b = 8580 \text{ psi}$$

$$F_{tu} = 15{,}300 \text{ psi} \qquad MS = \frac{15{,}300}{8580} - 1 = +0.78$$

SECTION V

STRESS ANALYSIS OF THE FIN TAIL CASTING

5.1 Discussion

A fin tail casting has been designed for the M117 bluff shaped conversion kit. Details are shown and analyzed on the following pages.

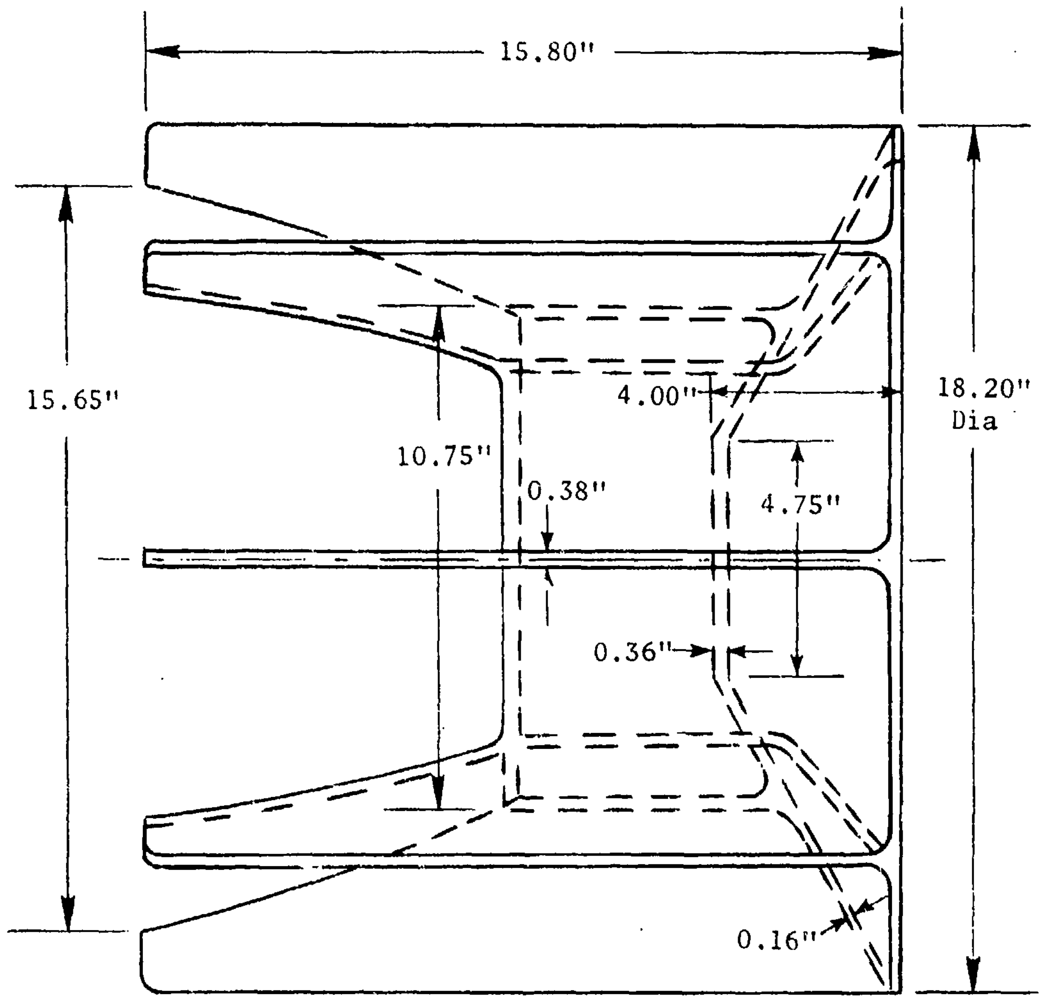
The fin tail configuration improves lateral stability to the extent that the 90° angle of attack condition used for the round tail configuration becomes an unrealistic design requirement. The fin tail casting is analyzed for maximum drag and for 60° maximum angle of attack as shown in subsection 6.2.

In Section IV, the very conservative assumption was made that the structural temperatures would be equal to the stagnation temperature. However, for the fin tailed design, this assumption leads to undue penalties, and was therefore modified to more realistic considerations.

The bluff shaped bombs are carried in the F-111 weapons bay which is air conditioned. Maximum temperature is 160°F. Maximum load and maximum temperature on the bomb will not occur longer than 5 seconds after ejection. This short duration of maximum temperature will not heat the casting appreciably above 160°F, which is selected as the design structural temperature.

The fin tail is cast from 356-T6 aluminum. The material allowables at 160°F are shown in the detail stress analysis.

Fin Tail Casting



Material: 356-T6 aluminum casting per QQ-A-601

$F_{tu} = 30 \times 10^3$ psi @ R.T. $F_{tu} = (30 \times 10^3)(0.95)(0.75)^* = 21,400$ psi

(Reference 3, Page 380)

The fin tail assembly is a one piece 356-T6 aluminum casting. The fins and skins are designed by a 60° side pressure condition. The bulkhead is critical for maximum aft airload on the assembly and a 60° side pressure condition.

*Casting Factor

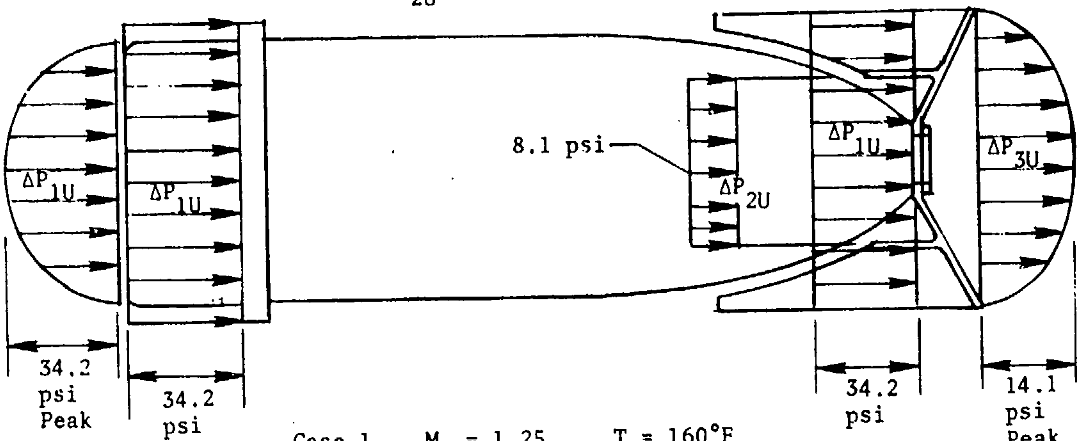
5.2 Applied Loads

$M = 1.25$ @ SL $\begin{cases} C_D = 0.39 & \Delta P_2 = 5.4 \text{ psi} \\ q = 16.07 & q_c = 22.8 \text{ psi} \end{cases}$

$\alpha = 0°$ $\quad \Delta P_{3U} = 1.5\ C_D q\ (1.5) = 14.1$ psi (Ult)

$\Delta P_{1U} = 1.5\ q_c = 34.2$ psi (Ult)

$\Delta P_{2U} = 1.5(5.4) = 8.1$ psi (Ult)



Case 1 $\quad M_o = 1.25 \quad T = 160°F$

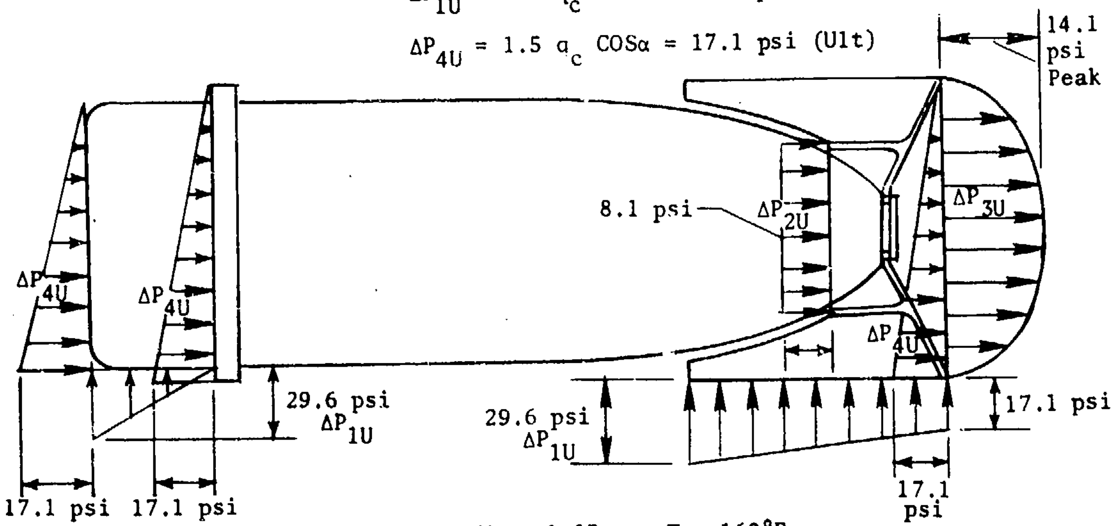
$M = 1.25$ @ SL $\begin{cases} C_D = 0.39 & \Delta P_2 = 5.4 \text{ psi} \\ q = 16.07 & q_c = 22.8 \text{ psi} \end{cases}$

$\alpha = 60°$ $\quad \Delta P_{3U} = 1.5\ C_D q\ (1.5) = 14.1$ psi

$\Delta P_{2U} = 1.5(5.4) = 8.1$ psi (Ult)

$\Delta P_{1U} = 1.5\ q_c\ \mathrm{SIN}\alpha = 29.6$ psi (Ult)

$\Delta P_{4U} = 1.5\ q_c\ \mathrm{COS}\alpha = 17.1$ psi (Ult)

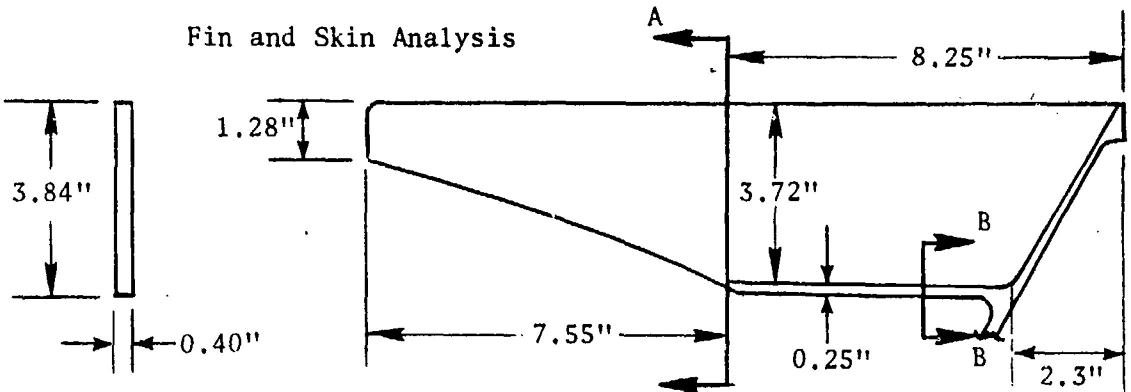


Case 3 $\quad M_o = 1.25 \quad T = 160°F$

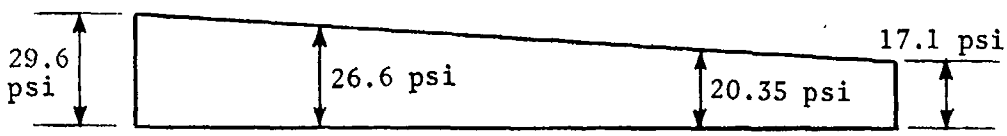
5.3 Stress Analysis

Fin Tail Casting

Fin and Skin Analysis



Section A-A



Airload Distribution

Bending at Section A-A

$$M = \frac{(1.28)(7.55)^2(26.6)}{2} + \frac{(2.56)(7.55)^2(26.6)}{6}$$

$$M = 1620 \text{ In-Lb}$$

$$f_b = \frac{6M}{bt^2} = \frac{6(1620)}{(3.84)(0.40)^2} = 15{,}800 \text{ psi}$$

$$F_{tu} = 21{,}400 \text{ psi}$$

$$F_{bu} = 1.25\ F_{tu} = 26{,}700 \text{ psi} \qquad MS = \frac{F_{bu}}{f_b} - 1 = +0.69$$

(Reference 3, Page 424)

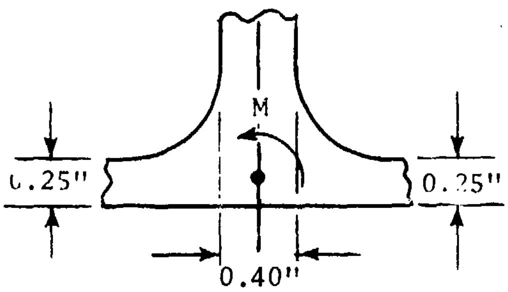
Fin Tail Casting

Fin and Skin Analysis (Concluded)

Bending of Skin at Section B-B

Conservatively assume that the fin is not attached to the bulkhead and is attached only to the skin for analysis of the skin.

Assume the total fin load, P, is concentrated at 1.86 inches from skin to calculate moment, M.



Section B-B

$$P = (1.28)(7.55)(26.6) + \frac{(2.56)(7.55)(26.6)}{2} + (3.72)(5.95)(20.35)$$

$$+ \frac{(2.3)(3.72)}{2}(20.35)$$

$P = 1050$ Lb

$M = 1.86\ P = (1.86)(1050) = 1953$ In-Lb

$$f_b = \frac{6M}{b\ 2t^2} = \frac{6(1953)}{(5.95)(2)(0.25)^2}$$

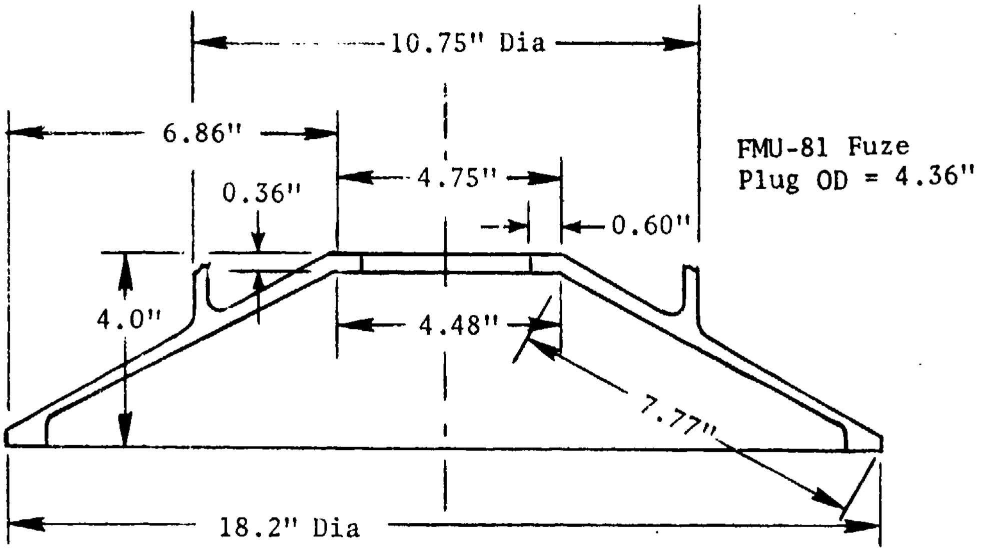
$f_b = 15{,}800$ psi

$f_{bu} = 26{,}700$ psi

$$MS = \frac{F_{bu}}{f_b} - 1 = +0.69$$

Fin Tail Casting

Bulkhead Analysis



Total Load on Bulkhead (Case 1)

$$P = \pi/4\ (18.2^2 - 10.75^2)(34.2\ \text{psi}) + \pi/4\ (18.2^2 - 4.36^2)(14.1\ \text{psi})(2/3)$$

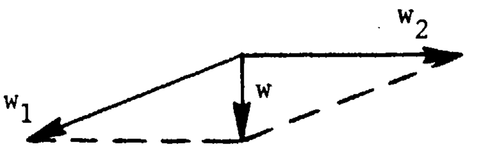
$$+\ \pi/4\ (10.75^2 - 4.75^2)(8.1\ \text{psi})$$

$P = 8690$ Lb

Running Load on 4.48 Inch Diameter

$$w = \frac{P}{\pi D} = \frac{8690}{\pi(4.48)} = 620\ \text{Lb/In}$$

Putting Load in Plane of Web



$$w_1 = 620\ \frac{7.77}{3.64} = 1320\ \text{Lb/In}$$

$$w_2 = 620\ \frac{6.86}{3.64} = 1170\ \text{Lb/In}$$

Fin Tail Casting

Bulkhead Analysis (Concluded)

Hoop Stress on 0.60 Wide Flange

$$f_{t_h} = \frac{w_2 R}{b\ t} = \frac{(1170)(2.37)}{(0.60)(0.36)}$$

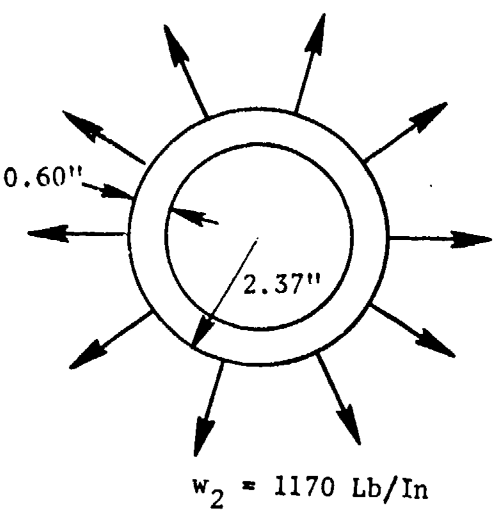
$$f_{t_h} = 12{,}900 \text{ psi}$$

$$F_{tu} = 21{,}400 \text{ psi}$$

$$F_{su} = (25{,}000)(0.95)(0.75)^* = 17{,}800 \text{ psi}$$

(Reference 3, Page 380)

$$MS = \frac{F_{tu}}{f_{t_h}} - 1 = +0.66$$



Tension Stress

$$f_t = \frac{w_2}{t} = \frac{1170}{0.36} = 3250 \text{ psi}$$

Bending Stress

$$M = (620)(2.24 - 2.18)$$

$$M = 37.2 \text{ In-Lb/In}$$

$$f_b = \frac{6M}{t^2} = \frac{6(37.2)}{(0.36)^2}$$

$$f_b = 1720 \text{ psi}$$

Shear Stress

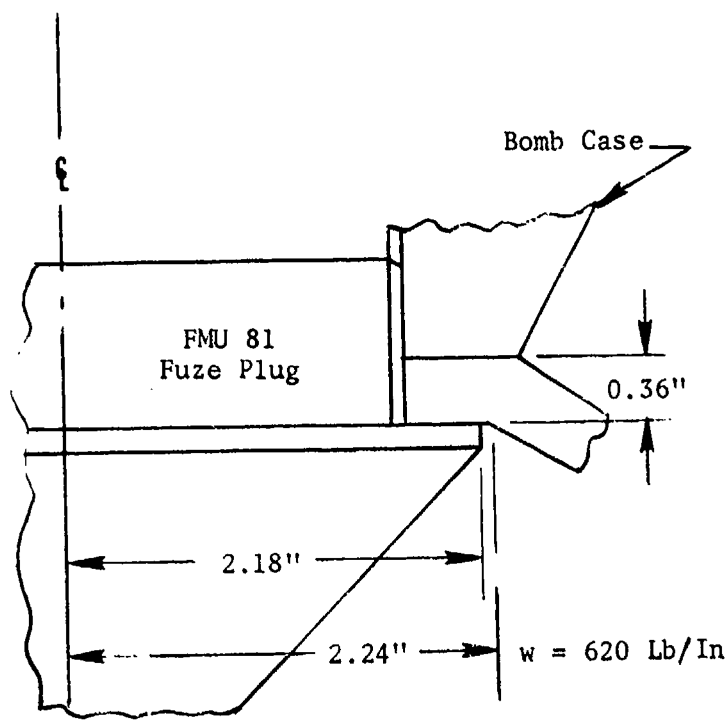
$$f_s = \frac{w}{t} = \frac{620}{0.36}$$

$$f_s = 1720 \text{ psi}$$

$$R_t = \frac{f_t}{F_{tu}} = 0.15$$

$$R_b = \frac{f_b}{F_{tu}} = 0.08$$

$$R_s = \frac{fs}{F_{su}} = 0.10$$

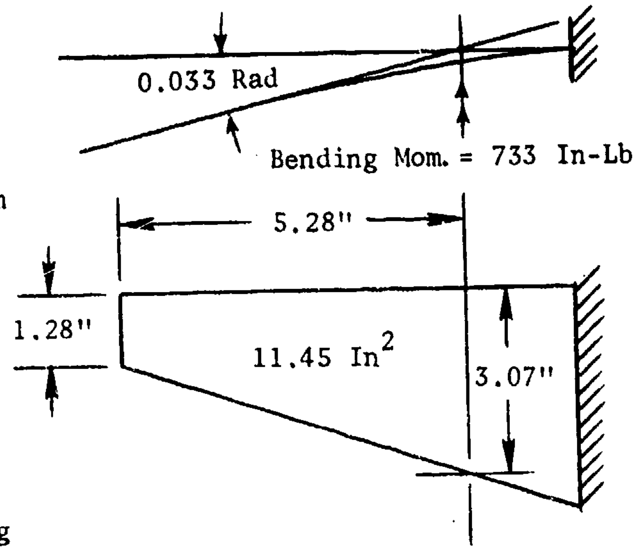


$$MS = \frac{1}{\sqrt{(R_t + R_b)^2 + R_s^2}} - 1 = +3.00$$

*Casting Factor

5.4 Bomb Fin Divergence Check

If the structural spring rate of the fin is greater than the aerodynamic spring rate, divergence will not occur.



Using the loads and moments from the fin stress analysis, the slope of the fin at the tip under load is calculated to be 0.033 radius. A tangent line at the tip crosses the zero deflection axis at 5.28 inches from the tip. The corresponding bending moment at 5.28 inches is 733 In-Lb.

Therefore, the structural spring rate is:

$$k_s = \frac{733 \text{ In-Lb}}{0.033 \text{ Rad}} = 22{,}000 \frac{\text{In-Lb}}{\text{Rad}}$$

The aerodynamic load as a function of angle of attack is

$$P = q \; S \; C_{L\alpha} \; \alpha$$

Assume this acts at r = 2.5 inches from the rotation point. Then the aerodynamic moment about the rotation point is:

$$M = Pr$$

and the aerodynamic spring rate is

$$k_A = \frac{Pr}{\alpha}$$

or

$$k_A = \frac{q \; S \; C_{L\alpha} \cancel{\alpha} \; r}{\cancel{\alpha}} = q \; S \; C_{L\alpha} \; r$$

for

$$M = 1.25 \text{ @ SL}$$

$$q \cong 2300 \text{ Lb/Ft}^2 = 16 \text{ Lb/In}^2$$

$$S = 11.45 \text{ In}^2$$

$$r = 2.5 \text{ In}$$

$$C_{L\alpha} = \frac{4}{\sqrt{M^2 - 1}} = \frac{4}{\sqrt{(1.25)^2 - 1}} = 5.4/\text{Rad}$$

then

$$k_A = (16 \frac{\text{Lb}}{\text{In}^2})(11.45 \text{ In}^2)(5.4/\text{Rad})(2.5 \text{ In}) = 2480 \frac{\text{In-Lb}}{\text{Rad}}$$

$\therefore$ No divergence since $k_A << k_S$

$(2480 << 22{,}000)$

SECTION VI

BLUFF BOMB KIT MASS CHARACTERISTICS DEMONSTRATION

A sample weighing procedure was established which demonstrated that a ± 5 percent weight tolerance on M117M6 modification kits was met. The results of these weighings are detailed below.

6.1 M117M Tail Assembly

Sample weighings of the round tail assembly produced values of:

(1) 17.81 pounds

(2) 16.97 pounds

(3) 17.54 pounds

Average Weight: 17.44 Pounds

A 5 percent tolerance would permit a maximum weight of 18.31 pounds and a minimum weight of 16.57 pounds. The three samples fell within tolerance.

6.2 M117M Nose Casting

Sample weighings of the nose casting produced values of:

(1) 32.59 pounds	(5) 32.00 pounds	(9) 31.00 pounds
(2) 32.75 pounds	(6) 31.00 pounds	(10) 31.00 pounds
(3) 33.00 pounds	(7) 31.00 pounds	(11) 31.00 pounds
(4) 32.00 pounds	(8) 31.00 pounds	

Average Weight: 31.67 Pounds

A 5 percent tolerance would permit a maximum weight of 33.25 pounds and a minimum weight of 30.09 pounds. All eleven samples fell within tolerance.

6.3 M117M6 Fin Tail

Sample weighings of the fin tail casting produced values of:

(1) 26.00 pounds	(4) 27.00 pounds	(7) 26.50 pounds
(2) 26.00 pounds	(5) 25.50 pounds	(8) 26.50 pounds
(3) 26.00 pounds	(6) 26.50 pounds	(9) 26.00 pounds

Average Weight: 26.22 Pounds

A 5 percent tolerance would permit a maximum weight of 27.53 pounds and a minimum weight of 24.91 pounds. All nine samples fell within tolerance.

6.4 M117M6 Kit Total

The average weight for an M117M6 kit is 57.89 pounds. A 5 percent tolerance would permit a maximum weight of 60.8 pounds and a minimum weight of 55.0 pounds.

If the maximum combination of weights for an M117M6 kit is taken, a weight of 60.00 pounds results; if the minimum weights are considered, a weight of 56.50 pounds results. Both of these weights are within 5 percent of an average kit weight of 57.89 pounds.

Based on the above results, the requirement to maintain a $\pm$ 5 percent tolerance on the bomb modification kits is being met.

SECTION VII

SUMMARY AND CONCLUSIONS

The M117 bluff shaped cast aluminum conversion kit has been checked for strength and is satisfactory for drops within specified limits of Section III. The minimum margin of safety is 28 percent on the aft bulkhead of the round tail casting. The fin tail casting has been checked for strength and is satisfactory for releases within limits of subsection 4.6. The minimum margin of safety is +66 percent on the aft bulkhead.

REFERENCES

1. Qualification and Performance Report of the MAU-12A/A and MAU-12B/A Rack, AFWL-TR-64-177, 1965.

2. ARD 446-1 Cartridge, Olin Mathieson Chemical Corporation, 1960.

3. Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5A, February 1966.

4. Formulas for Stress and Strain, McGraw-Hill Book Co, 1954.

APPENDIX B

STRUCTURAL DESIGN OF AFT WEAPONS BAY RACK AND SUPPORT STRUCTURE

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The aft weapons bay rack for the F-111 has been analyzed for steady state and ejection loads for a rack loading of three 1000-pound bluff shaped bombs. The rack structure and the fuselage backup structure is satisfactory for the full F-111 flight and bomb ejection envelope.

SECTION I

INTRODUCTION

A bomb rack with a capacity of three 1000-pound bombs has been designed for installation in the aft portion of the F-111 weapons bay. This rack increases the F-111 weapons bay capacity to five 1000-pound bluff shaped bombs.

The purpose of this report is to present the design loads and criteria and the stress analysis for the F-111 aft weapons bay rack.

SECTION II

AFT WEAPONS BAY RACK CONFIGURATION

The aft weapons bay rack is a steel framework accommodating three conventional MAU-12 ejector racks. The framework is attached to hardpoints in the F-111 weapons bay.

The framework consists of fittings and channel section beams machined from 4130 steel. Longitudinal beams on each side of each MAU-12 rack are bolted to lateral beams at fuselage stations 392 and 448. The forward lateral beam is attached to the four existing trapeze fittings at station 392. The aft lateral beam attaches to added fittings on the weapon bay wall at the station 448 cheek frames.

The aft weapons bay bomb rack is designed for installation in an F-111A/D/E aircraft. To expedite installation, the design permits all attachments to be made to the fuselage from outside the fuel tanks.

Figure B-1 shows the aft weapons bay rack installed in an F-111 weapons bay. Figure B-2 shows major rack details. Total weight of the aft weapons bay rack, including three MAU-12 racks but not including three bluff stores, is 960 pounds.

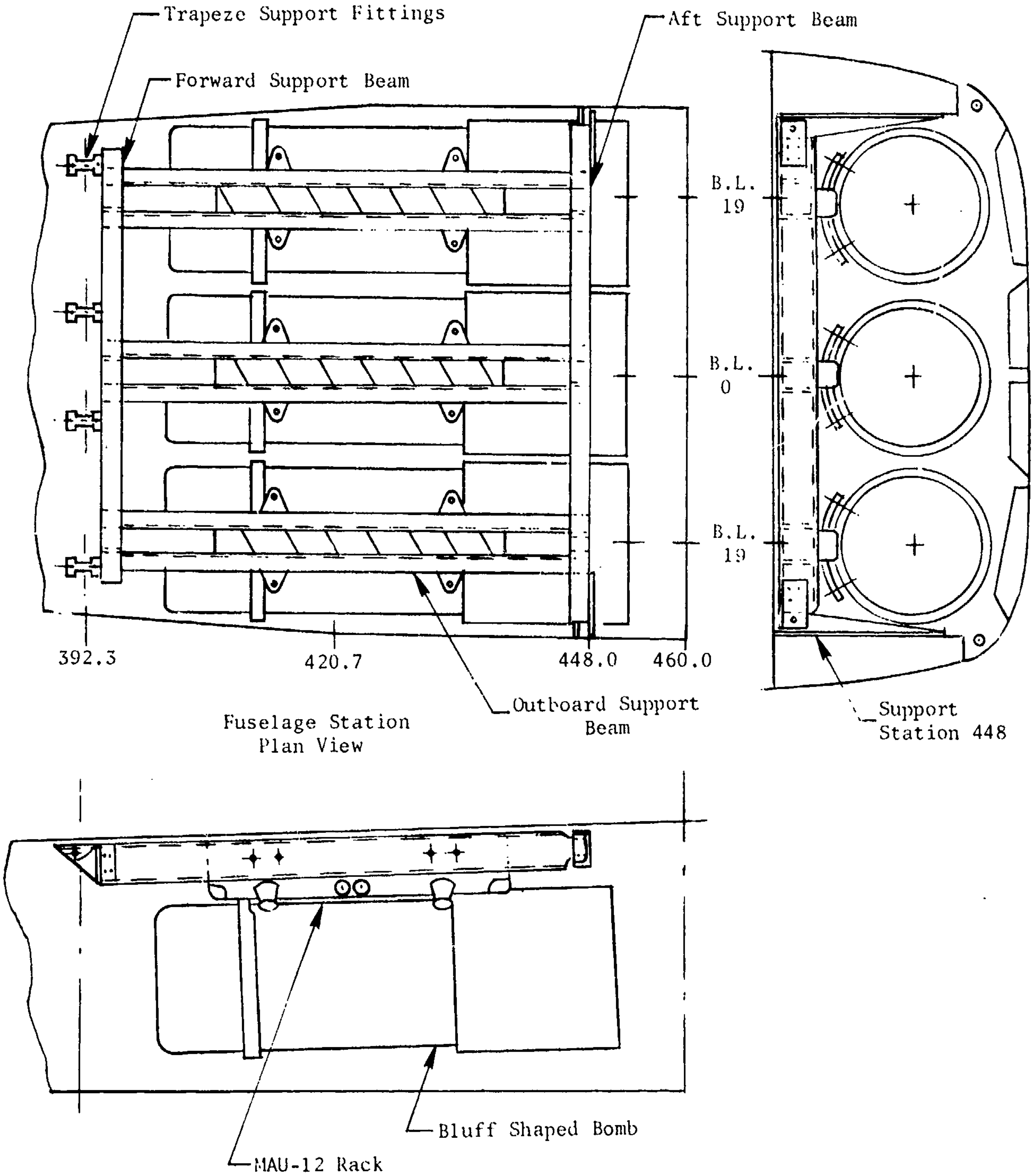


Figure B-1. Aft Weapons Bay Rack

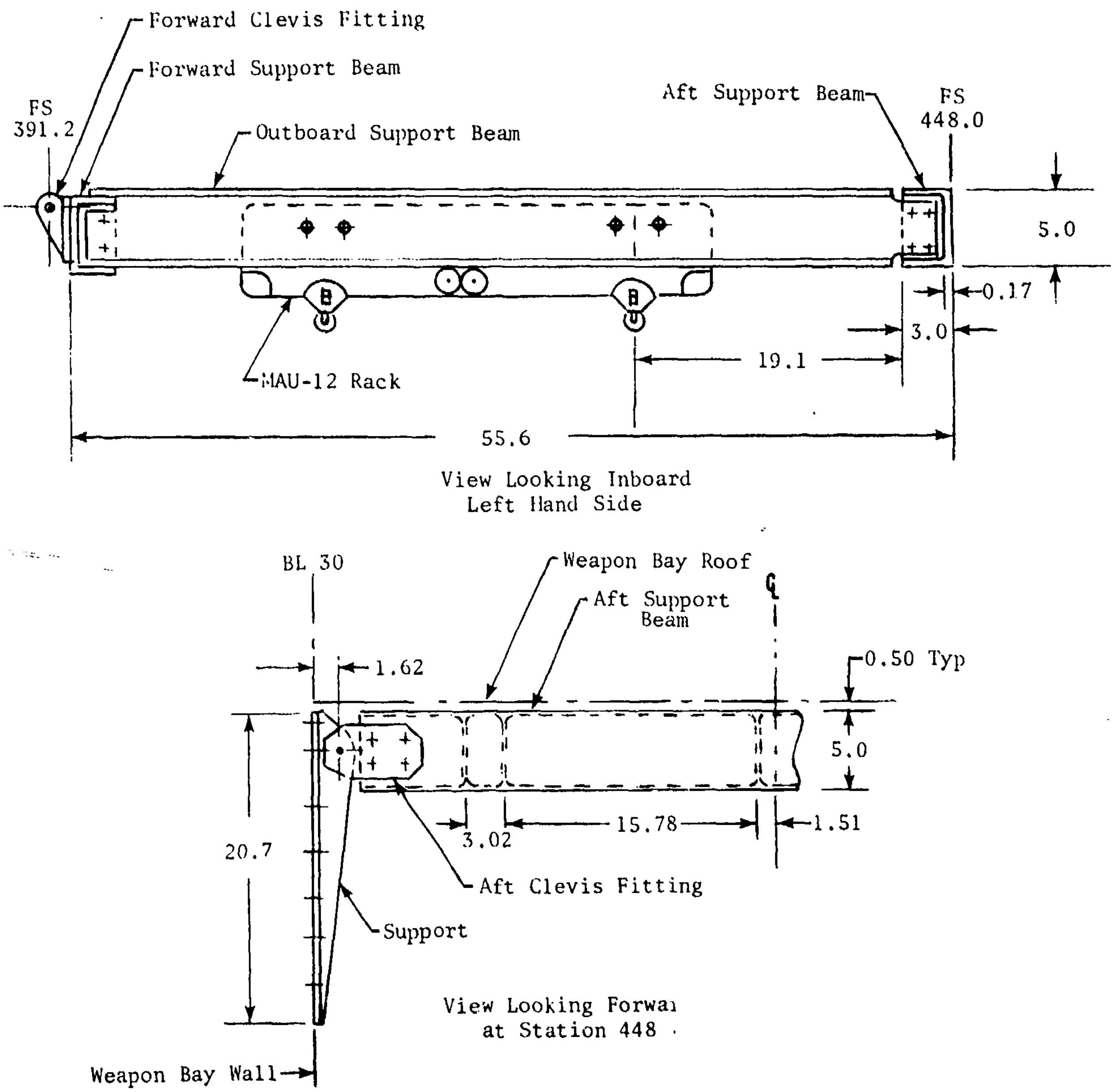


Figure B-2. Details of Aft Weapons Bay Rack

SECTION III

STRUCTURAL DESIGN CRITERIA AND LOADS

3.1 INTRODUCTION

Presented in this section are the M117 bluff shaped weapon loads applicable to the design and installation of the aft weapons bay rack.

3.2 CRITERIA

3.2.1 Flight Envelopes

With bay doors open, the level flight maximum speeds shall be limited by a straight line connecting 1.2 Mach at sea level to 2.2 Mach at 40,000 feet MSL. Weapons bay doors are considered to be closed at speeds above that up to a line connecting 1.37 Mach at sea level to 2.37 Mach at 40,000 feet MSL. Weapons can be released at all wing sweeps at all Mach-altitude conditions within the release envelope shown in Figure B-3 but within the basic wing sweep restrictions of the F-111 aircraft.

3.2.2 Flight Load Factors

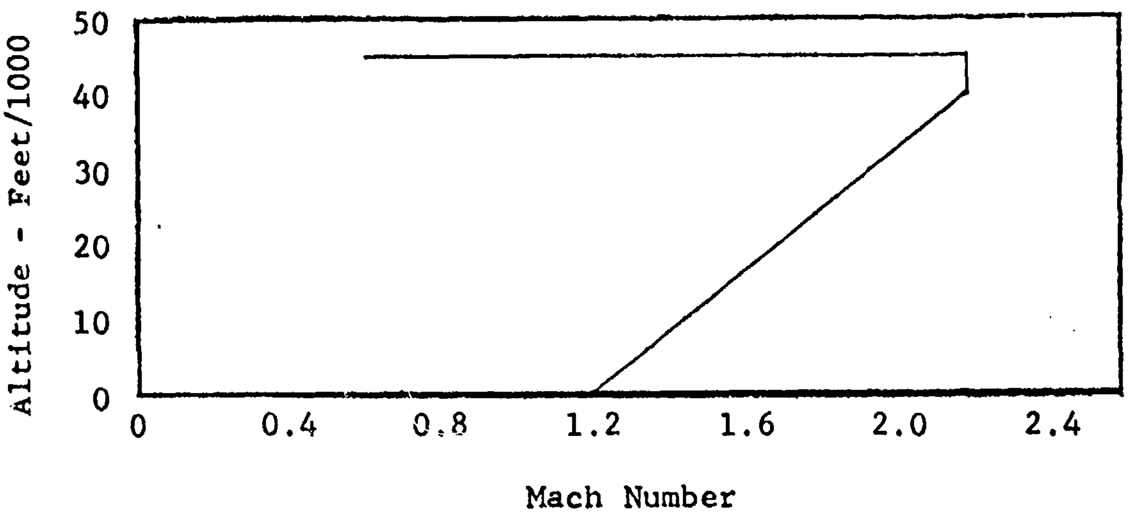
Limit maneuver load factor envelopes for weapons bay doors open or closed and during weapon ejection are presented in Figure B-4.

3.3 LOADS

3.3.1 Weapon Carriage Maneuvering Flight Loads

The weapon carriage structure design loads presented herein are based on having weapon bay doors open.

Maneuvers that resulted in maximum weapon inertia loads were chosen as design points. For symmetric flight, a maneuver that maximized vertical load factor (n_z) at the aircraft center of gravity and one that combined the effects of high normal load factor and pitching acceleration at the aircraft center of gravity were chosen. The flight condition commensurate with maximum adiabatic wall temperature was assumed. Lateral maneuvers were chosen to cover inertia loads resulting from the effects of (1) maximum rolling acceleration and (2) maximum positive n_z with high rolling acceleration. With the exception of the aerodynamic drag force, the steady state airloads calculated as acting on each store were relieving the inertia load and were of small magnitude; therefore, they were assumed to be zero. Unsteady airloads are included as dynamic moment increments in pitch and yaw at the weapon center of gravity. Loads resulting from lateral conditions are presented in Tables B-1 and B-2 and those from symmetric conditions are shown in Table B-3.



The weapon can be released within the following:
- Pitch angle = -20 to +45 degrees
- Roll angle = ±5 degrees
- Roll rate = zero

Figure B-3. M117 Bluff Shaped Weapon Release and Jettison Envelope

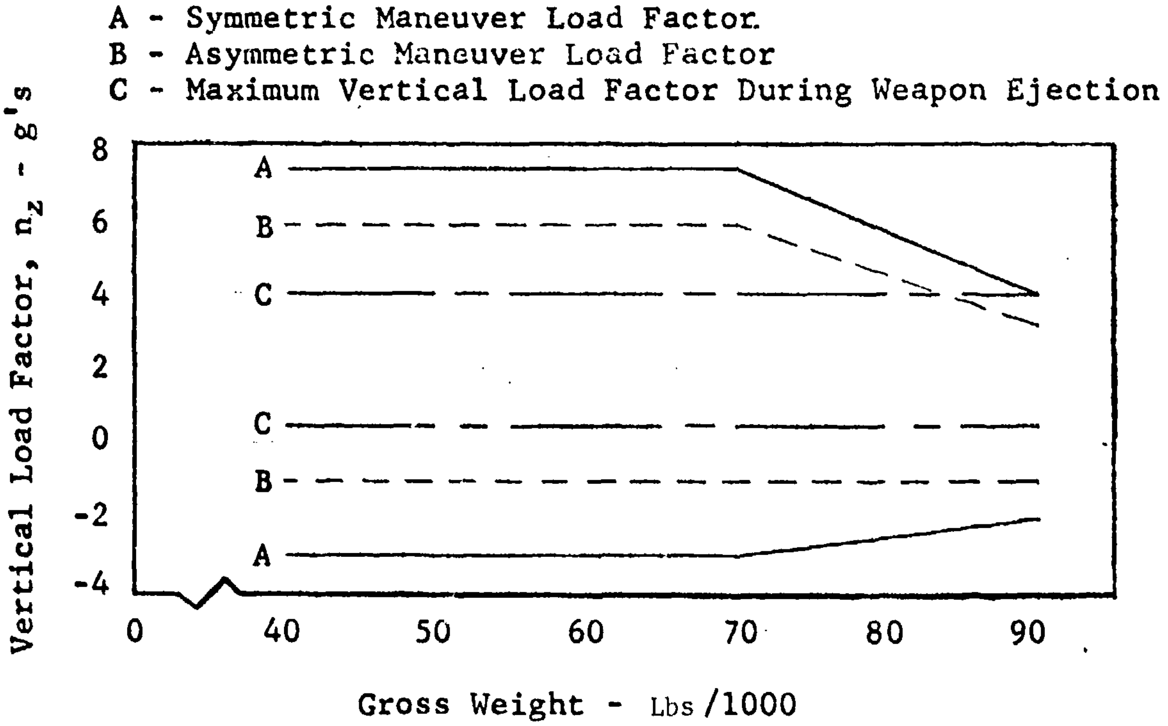


Figure B-4. Limit Maneuver Load Factors

TABLE B-1. BLUFF SHAPED M117M IN-THE-WEAPONS-BAY LOADS

LATERAL MANEUVER: MAXIMUM POSITIVE ROLLING ACCELERATION - CONDITION I

WEAPON	LOAD	F_X	F_Y	F_Z	M_X	M_Y	M_Z
		LB	LB	LB	IN-LB	IN-LB	IN-LB
LEFT	Inertia	±1500	2668	-494	-2520	1200	-600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	1585	0	0	0	0	0
	Net Limit	3085 / 85	2668	-494	-2520	28500 / -26100	26700 / -27900
CENTER	Inertia	±1500	2717	486	-2520	1200	-600
	Dynamic	0	0	0	0	±27300	[illegible]27300
	Airload	1585	0	0	0	0	0
	Net Limit	3085 / 85	2717	486	-2520	28500 / -26100	2[illegible]700 / [illegible]900
RIGHT	Inertia	±1500	2766	1466	-2520	1200	-600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	1585	0	0	0	0	0
	Net Limit	3085 / 85	2766	1466	-2520	28500 / -26100	26700 / -27900

TABLE B-1. BLUFF SHAPED M117M IN-THE-WEAPONS-BAY LOADS
LATERAL MANEUVER: MAXIMUM POSITIVE ROLLING ACCELERATION - CONDITION I (CONTINUED)

WEAPON	LOAD	F_X	F_Y	F_Z	M_X	M_Y	M_Z
		LB	LB	LB	IN-LB	IN-LB	IN-LB
LEFT	Inertia	±1500	-2766	1466	2520	1700	600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	1585	0	0	0	0	0
	Net Limit	3085 85	-2766	1466	2520	28500 -26100	27900 -26700
CENTER	Inertia	±1500	-2717	486	2520	1200	600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	1585	0	0	0	0	0
	Net Limit	3085 85	-2717	486	2520	28500 -26100	27900 -26700
RIGHT	Inertia	±1500	-2668	-494	2520	1200	600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	1585	0	0	0	0	0
	Net Limit	3085 85	-2668	-494	2520	28500 -26100	27900 -26700

TABLE B-1. BLUFF SHAPED M117M IN-THE-WEAPONS-BAY LOADS

LATERAL MANEUVER: MAXIMUM POSITIVE ROLLING ACCELERATION - CONDITION I (CONCLUDED)

FLIGHT CONDITION
AND MANEUVER RESPONSE: $M = 1.1$, $Alt = SL$, $q = 12.45\ Lb/In^2$, $n_x = \pm 1.5\ g$, $n_y = \pm 1.5g$, $n_z = -1.0g$, $cg = 0.268\ MAC$, $GW = 70{,}000\ Lb$, $\Lambda = 72.5°$, $\alpha = -1.4°$, $\beta = \pm 2°$, $\dot{\phi} = \pm 1\ RAD/SEC$, $\ddot{\phi} = \pm 20\ RAD/SEC^2$, $\ddot{\psi} = \pm 1\ RAD/SEC^2$, $\ddot{\theta} = +2\ RAD/SEC^2$

NOTES:

1. Positive loads are up, aft, right.
2. Positive moments are nose up, nose right, right wing down.
3. Adiabatic wall temperature = T_{AW} = 225°F (Hot Day).
4. All loads are limit.
5. Weapon Bay Doors are open.
6. Aft 3 weapons alone in the bay.
7. Specified loads are quoted at individual weapon cg and are to be summed in the most critical combination of loads for design of the rack assembly.

TABLE B-2. BLUFF SHAPED M117M IN-THE-WEAPONS-BAY LOADS

LATERAL MANEUVER: MAXIMUM VERTICAL LOAD FACTOR (MAXIMUM POSITIVE ROLLING ACCELERATION) - CONDITION II

WEAPON	LOAD	F_X	F_Y	F_Z	M_X	M_Y	M_Z
		LB	LB	LB	IN-LB	IN-LB	IN-LB
LEFT	Inertia	±1500	-1196	-6102	-1008	600	-600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	2170	0	0	0	0	0
	Net Limit	3670 / 670	-1196	-6102	-1008	27900 / -26700	26700 / -27900
CENTER	Inertia	±1500	-1147	-5711	-1008	600	-600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	2170	0	0	0	0	0
	Net Limit	3670 / 670	-1147	-5711	-1008	27900 / -26700	26700 / -27900
RIGHT	Inertia	±1500	-1098	-5320	-1008	600	-600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	2170	0	0	0	0	0
	Net Limit	3670 / 670	-1098	-5320	-1008	27900 / -26700	26700 / -27900

TABLE B-2. BLUFF SHAPED M117M IN-THE-WEAPONS-BAY LOADS

LATERAL MANEUVER: MAXIMUM VERTICAL LOAD FACTOR (MAXIMUM NEGATIVE ROLLING ACCELERATION) - CONDITION II (CONTINUED)

WEAPON	LOAD	F_X	F_Y	F_Z	M_X	M_Y	M_Z
		LB	LB	LB	IN-LB	IN-LB	IN-LB
LEFT	Inertia	±1500	1098	-5320	1008	600	600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	2170	0	0	0	0	0
	Net Limit	3670 670	1098	-5320	1008	27900 -26700	27900 -26700
CENTER	Inertia	±1500	1147	-5711	1008	600	600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	2170	0	0	0	0	0
	Net Limit	3670 670	1147	-5711	1008	27900 -26700	27900 -26700
RIGHT	Inertia	±1500	1196	-6102	1008	600	600
	Dynamic	0	0	0	0	±27300	±27300
	Airload	2170	0	0	0	0	0
	Net Limit	3670 670	1196	-6102	1008	27900 -26700	27900 -26700

TABLE B-2. BLUFF SHAPED M117M IN-THE-WEAPONS-BAY LOADS

LATERAL MANEUVER: MAXIMUM VERTICAL LOAD FACTOR

(MAXIMUM NEGATIVE ROLLING ACCELERATION) - CONDITION II (CONCLUDED)

FLIGHT CONDITION

AND MANUEVER RESPONSE: $M = 1.2$, Alt = SL, $q = 14.8$ Lb/In^2, $n_x = \pm 1.5g$, $n_y = \pm 1.5g$, $n_z = 5.86g$, $cg = 0.268$ MAC, GW = 70,000 Lb, $\Lambda = 72.5°$, $\alpha = 10.3°$, $\beta = +3.4°$, $\dot{\phi} = \pm 1$ RAD/SEC, $\ddot{\phi} = \pm 8$ RAD/SEC^2, $\ddot{\psi} = \pm 1$ RAD/SEC^2, $\ddot{\theta} = -1$ RAD/SEC^2

NOTES:

1. Positive loads are up, aft, right.
2. Positive moments are nose up, nose right, right wing down.
3. Adiabatic wall temperature = T_{AW} = 249°F (Hot Day).
4. All loads are limit.
5. Weapon Bay Doors are open.
6. Aft 3 weapons alone in the bay.
7. Specified loads are quoted at individual weapon cg and are to be summed in the most critical combination of loads for design of the rack assembly.

TABLE B-3. *BLUFF SHAPED M117M IN-THE-WEAPONS-BAY LOADS*
SYMMETRIC MANEUVERS

MANEUVER	CRITERIA	WEAPON	LOADS	F_X LB	F_Y LB	F_Z LB	M_X IN-LB	M_Y IN-LB	M_Z IN-LB	CONDITION
Balanced	Full	Each	Inertia	±1500	0	-7330	0	0	0	III
Symmetric	Flight	of the								
Maneuver	Envelope	Aft 3	Dynamic	0	0	0	0	±27300	±27300	
$\Lambda = 72.5^\circ$	$n_z = 7.33g$	Alone –								
$M = 2.2$	$n_x = \pm 1.5g$	Per Store	Airload	2010	0	0	0	0	0	
Alt = 40000'	$n_y = 0$									
$\alpha = 18.0^\circ$	$\ddot{\psi} = \dot{\phi} = \ddot{\theta} = 0$		Net Limit	$\frac{3510}{510}$	0	-7330	0	±27300	±27300	
GW = 70000 Lb	$\beta = 0$									
CG = 0.361 MAC	$T_{AW} = 270^\circ F$									
Unbalanced	Full	Each	Inertia	±1500	0	-4384	0	-2400	0	IV
Symmetric	Flight	of the								
Maneuver	Envelope	Aft 3	Dynamic	0	0	0	0	±27300	±27300	
$\Lambda = 72.5^\circ$	$n_z = 3.5g$	Alone –								
$M = 2.2$	$n_x = \pm 1.5g$	Per Store	Airload	1283	0	0	0	0	0	
Alt = 40000'	$n_y = 0$									
$\alpha = 12.3^\circ$	$\ddot{\psi} = \dot{\phi} = 0$		Net Limit	$\frac{2783}{-217}$	0	-4384	0	$\frac{-24900}{-29700}$	±27300	
GW = 70000 Lb	$\ddot{\theta} = 4\ \mathrm{Rad/Sec^2}$									
CG = 0.361 MAC	$\beta = 0$									
	$T_{AW} = 270^\circ F$									

NOTES:

1. Positive Loads are up, aft, right.
2. Positive moments are nose up, nose right, right wing down.
3. All loads are limit.
4. Weapon Bay Doors are open.
5. One complete set of loads is given for each of the above two conditions. For both conditions, the set of loads presented are those acting at the c g of each individual weapon of the aft three alone in the bay. These loads are to be summed in the most critical combination for design of the rack assembly.

3.3.2 Store Ejector Loads

Each of the three weapons is suspended on a MAU-12 rack and separation from the aircraft is accomplished by the simultaneous firing of two ejection cartridges (one ARD-863-1 and one ARD-446-1). The ejection forces acting on the ejector area of the M117 bluff shaped weapons are presented in Table B-4. The peak force at 70°F is based on a peak-to-mean ratio derived from test results (Reference 1). The peak force at 160°F includes effects of variation in cartridge charge in addition to the effects of elevated temperature. The charge variation is based on a standard deviation of 0.06, with a dispersion of plus 3 standard deviations from the mean used for calculation of forces. Effects of elevated temperatures were derived from a statistical analysis of results from tests conducted with ARD-446-1 cartridges (Reference 2). Based on this analysis a factor of 1.1 was determined which when combined with the charge variation factor of 1.18 is estimated to provide coverage of approximately 3 standard deviations about the mean for ejection foot forces at elevated temperatures up to 160°F. Therefore, a factor of 1.3 (i.e., 1.18 x 1.1) was used to calculate peak ejector forces based on combined effects of charge variation and elevated temperatures.

The total net steady state loads acting at the cg of each store, after the weapons bay doors are opened but before store ejection, can be determined from the data of Table B-5. These steady state loads are initial conditions for ejection and are to be used in the following equations for the total net loads acting on the racks during ejection.

For an ejected store station when one, two or three weapons are carried on the test installation rack:

Vertical:

$$\overline{F}_{Z_{1_F}} = F_{Z_{1_F}} + MF\ (T_F - F_{Z_{1_F}})$$

$$\overline{F}_{Z_{1_A}} = F_{Z_{1_A}} + MF\ (T_A - F_{Z_{1_A}})$$

References:

1. Qualification and Performance Report of the MAU-12A/A Rack, AFWL-TR-64-177, 1965.

2. ARD 446-1 Cartridge, Olin Mathieson Chemical Corporation, 1960.

TABLE B-4. EJECTION LOADS ON M117 BLUFF SHAPED WEAPONS

Weight	Avg Force 70° F	Peak Force 70° F	Peak Force 160° F	Force Distribution	
				Fwd Ejector	Aft Ejector
←	(10^{-3} Lbs		→		
0.800	6.064	12.50	16.23	70→30%	30→70%
1.000	6.835	13.00	16.87	70→30%	30→70%

TABLE B-5. EJECTION ENVELOPE NET LIMIT LOADS FOR 1000-POUND
M117 BLUFF SHAPED WEAPON - AFT THREE WEAPONS IN THE BAY

LOADS	CRITERIA	N_X	N_Y	N_Z	$\ddot{\theta}$	$\ddot{\psi}$	AXIAL FORCE	SIDE FORCE	NORMAL FORCE	ROLLING MOMENT	PITCHING MOMENT	YAWING MOMENT
		g's	g's	g's	RAD/SEC^2	RAD/SEC^2	LB	LB	LB	IN-LB	IN-LB	IN-LB
Inertia	Ejection	± 1.5	± 1.5	4.0	± 4	± 2	∓ 1500	∓ 1500	-4000	0	∓ 2500	∓ 1200
Unsteady Airload	Envelope	↓	↓	↓	↓	↓	0	0	0	0	∓ 27300	± 27300
Steady Airload	M = 2.2	↓	↓	↓	↓	↓	+1358	∓ 83	+200	0	-159	± 1338
Net Limit	Alt = 40000'	↓	↓	↓	↓	↓	-142 +2858	∓ 1583	-3300	0	-29959 +29641	± 27438

NOTES:

1. Positive loads are up, aft, right.
2. Positive moments are nose up, nose right, right wing down.
3. Adiabatic wall temperature = T_{AW} = 270°F.
4. All loads are pre-ejection and limit.
5. Weapon Bay Doors are open.
6. Specified loads are quoted at individual weapon c.g 's and are to be summed in the most critical combination of loads for design of the rack assembly.

Lateral:

$$\overline{F}_{Y_{1_F}} = F_{Y_{1_F}} + 1.3\ (-F_{Y_{1_F}})$$

$$\overline{F}_{Y_{1_A}} = F_{Y_{1_A}} + 1.3\ (-F_{Y_{1_A}})$$

For a non-ejected (adjacent) store station when two or three weapons are carried on the test installation rack:

Vertical:

$$\overline{F}_{Z_{2_F}} = F_{Z_{2_F}} + 0.15\ (T_F - \overline{F}_{Z_{1_F}})$$

$$\overline{F}_{Z_{2_A}} = F_{Z_{2_A}} + 0.15\ (T_A - F_{Z_{1_A}})$$

Lateral:

$$\overline{F}_{Y_{2_F}} = F_{Y_{2_F}} + 0.05\ (-F_{Y_{1_F}})$$

$$\overline{F}_{Y_{2_A}} = F_{Y_{2_A}} + 0.05\ (-F_{Y_{1_A}})$$

where:

$\overline{F}$ denotes total net force acting on the rack during store ejection

F denotes total net steady state (pre-ejection) force acting on the ejector rack

Z denotes vertical direction (+ = up)

Y denotes lateral direction (+ = right)

1 denotes ejected store station

2 denotes non-ejected (adjacent) store station

T denotes thruster force (Table B-4)

F subscript denotes forward store/rack attachment point

A subscript denotes aft store/rack attachment point

MF coefficient denotes dynamic magnification factor having values as follows:

1.35 for the test installation rack aft lateral beam, its support attachments, and all connections onto that beam

1.15 for the test installation rack remaining beams and connections.

The above equations are written in terms of net loads acting on the test installation rack as a function of the forward and aft thruster and store-rack interface initial conditions. The transfer of the total net steady state (pre-ejection) loads of Table B-5 from the store cg to the point being analyzed is necessary to obtain the F forces required for the above equations. The ejector forces and force distribution percentages of Table B-4 are to be used to determine T_F and T_A. Determination of the net steady state loads and phasing of the various load components in the above equations are to be assumed adverse.

SECTION IV

STRESS ANALYSIS

4.1 DISCUSSION

The aft weapons bay rack for the F-111 is a framework of longitudinal and lateral beams attached to the roof of the weapons bay. Three MAU-12 ejector racks are bolted to the framework as shown in Figure B-5.

The rack is designed for inertia loads combined with airload and for ejection loads combined with steady state loads. Loads at the bomb cg from Section III have been distributed and are shown in Tables B-6 and B-7. Critical loads for the rack are from ejection combined with airload and dynamic effects.

This analysis covers the rack details and the existing F-111 structure which supports the rack. Margins of safety are shown for the beams, the fittings, and the connecting joints. Analysis of the F-111 structure at station 448 is shown. The aircraft hardpoints at station 392 are designed for weapon bay gun loads and are not critical for rack loads.

All rack parts are machined from 4130 steel. Heat treat and allowables are shown with the detail stress analysis of each part. Sample calculations of reaction influence coefficients generated using unit loads are given in subsection 4.4.

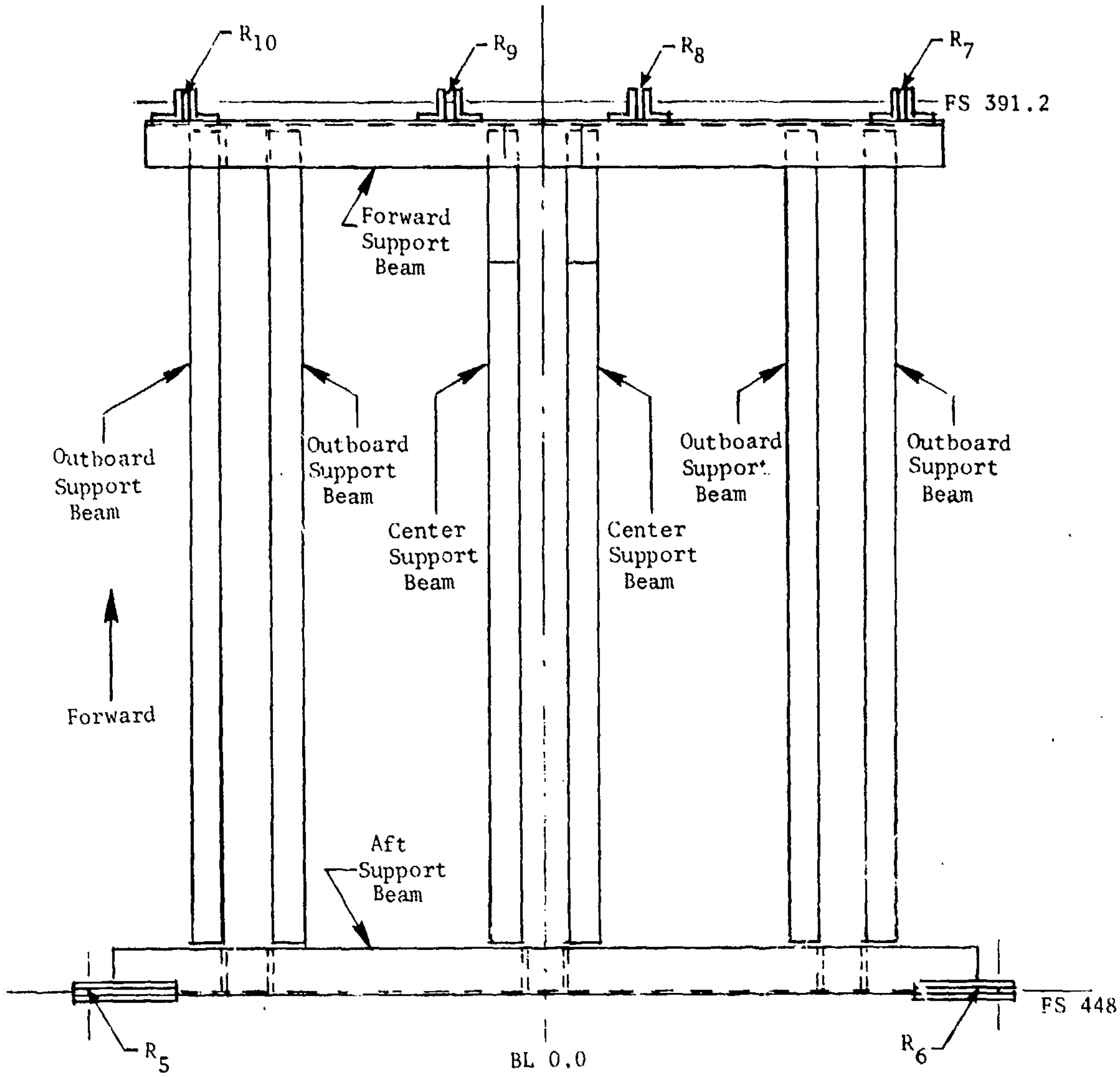


Figure B-5. Top View of Bomb Racks Structure Installation

TABLE B-6. CRITICAL LOADING CONDITIONS

Condition I A -	Ejection Loads for Center Bomb with 70 Percent Aft and 30 Percent Forward Distribution.
Condition I B -	Ejection Loads for Center Bomb with 30 Percent Aft and 70 Percent Forward Distribution.
Condition II A -	Ejection Loads for Left Bomb with 70 Percent Aft and 30 Percent Forward Distribution.
Condition II B -	Ejection Loads for Left Bomb with 30 Percent Aft and 70 Percent Forward Distribution.
Condition III A -	Ejection Loads for Right Bomb with 70 Percent Aft and 30 Percent Forward Distribution.
Condition III B -	Ejection Loads for Right Bomb with 30 Percent Aft and 70 Percent Forward Distribution.
Condition IV A Through IV D -	Pre-ejection Loads for Center Bomb.
Condition V A Through V D -	Pre-ejection Loads for Left Bomb.
Condition VI A Through VI D -	Pre-ejection Loads for Right Bomb.
Condition VII A Through VII D -	Flight Loads for Three Bombs With Maximum Positive Vertical Load Factor.

TABLE B-7. LOADS SUMMARY (ALL LOADS ARE ULTIMATE)

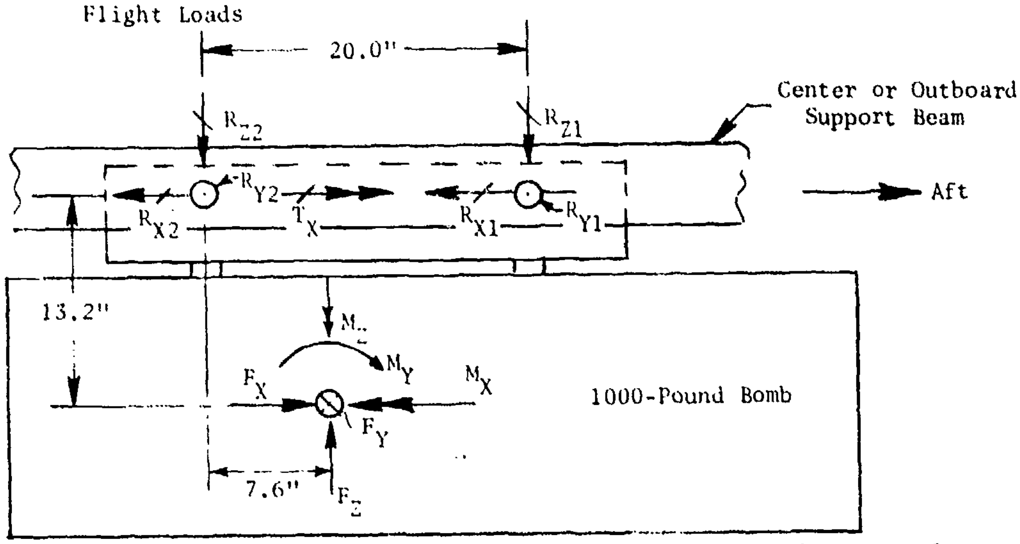
Loads/Condition No.	I A	I B	II A	II B	III A	III B	IV A	IV B	IV C	IV D	V A	V B	V C
F_x	--	--	--	--	--	--	-213	-213	4287	4287	-213	-213	4287
F_y	--	--	--	--	--	--	2375	2375	3275	2375	2375	2375	2375
F_z	--	--	--	--	--	--	-5700	-5700	-5700	-5700	-5700	-5700	-5700
M_x	--	--	--	--	--	--	0	0	0	0	0	0	0
M_y	--	--	--	--	--	--	-44,939	44,462	-44,939	44,462	-44,939	44,462	-44,939
M_z	--	--	--	--	--	--	-41,157	-41,157	-41,157	-41,157	-41,157	-41,157	-41,157
R_{z2}	7591	17,714	7591	17,714	7591	17,714	-5640	-1170	-8610	-4140	-5640	-1170	-8610
R_{z1}	17,714	7591	17,714	7591	17,714	7591	-60	-4530	2910	-1560	-60	-4530	2910
R_{x2}	0	0	0	0	0	0	-107	-107	2144	2144	-107	-107	2144
R_{x1}	0	0	0	0	0	0	-107	-107	2144	2144	-107	-107	2144
R_{y2}	0	0	0	0	0	0	-585	-585	-585	-585	-585	-585	-585
R_{y1}	0	0	0	0	0	0	2960	2960	2960	2960	2960	2960	2960
T_x	0	0	0	0	0	0	-31,350	-31,350	-31,350	-31,350	-31,350	-31,350	-31,350
R_{z3}	14,044	10,501	14,044	10,501	14,044	10,501	-1788	-3353	-749	-2313	-1788	-3353	-749
R_{z4}	11,261	14,804	11,261	14,804	11,261	14,804	-3912	-2348	-4952	-3387	-3912	-2348	-4952
R_{x4}	0	0	0	0	0	0	-213	-213	4287	4287	-213	-213	4287
R_{y3}	0	0	0	0	0	0	1772	1772	1772	1772	1772	1772	1772
R_{y4}	0	0	0	0	0	0	603	603	603	603	603	603	603
T_{x3}	0	0	0	0	0	0	-13,794	-13,794	-13,794	-13,794	-13,794	-13,794	-13,794
T_{x4}	0	0	0	0	0	0	-17,556	-17,556	-17,556	-17,556	-17,556	-17,556	-17,556
R_{z5}	7022	5251	11,657	8716	2387	1785	-1142	-1925	-623	-1405	-1732	-3031	-870
R_{z6}	7022	5251	2387	1785	11,657	8716	-646	-1428	-126	-908	-56	-322	121
R_{y5}	0	0	0	0	0	0	886	886	886	886	886	886	886
R_{y6}	0	0	0	0	0	0	886	886	886	886	886	886	886
R_{z7}	-833	-1095	113	148	8468	11,133	131	16	208	93	14	29	3
R_{z8}	6464	8497	-709	-933	3390	4456	-174	724	-771	127	-34	-133	31
R_{z9}	6464	8497	3390	4456	-709	-933	-4317	-3419	-4914	-4016	245	715	-69
R_{z10}	-833	-1095	8468	11,133	113	148	447	332	524	409	-4136	-2960	-4918
R_{x7}	0	0	0	0	0	0	16	16	-317	-317	-2	-2	43
R_{x8}	0	0	0	0	0	0	-122	-122	2461	2461	13	13	-270
R_{x9}	0	0	0	0	0	0	-122	-122	2461	2461	-64	-64	1290
R_{x10}	0	0	0	0	0	0	16	16	-317	-160	-160	-160	3224
R_{y7}	0	0	0	0	0	0	151	151	151	151	151	151	151
R_{y8}	0	0	0	0	0	0	151	151	151	151	151	151	151
R_{y9}	0	0	0	0	0	0	151	151	151	151	151	151	151
R_{y10}	0	0	0	0	0	0	151	151	151	151	151	151	151

TABLE B-7. LOADS SUMMARY (ALL LOADS ARE ULTIMATE) CONCLUDED

Loads/Condition No.	V D	VI A	VI B	VI C	VI D	VII A	VII B	VII C	VII D
F_x	4287	-213	-213	4287	4287	5265	5265	765	765
F_y	2375	2375	2375	2375	2375	0	0	0	0
F_z	-5700	-5700	-5700	-5700	-5700	-11,000	-11,000	-11,000	-11,000
M_x	0	0	0	0	0	0	0	0	0
M_y	44,462	-44,939	44,462	-44,939	44,462	40,950	-40,950	40,950	-40,950
M_z	-41,157	-41,157	-41,157	-41,157	-41,157	-40,950	-40,950	-40,950	-40,950
R_{z2}	-4140	-5640	-1170	-8610	-4140	-8247	-12,342	-5277	-9372
R_{z1}	-1560	-60	-4530	2910	-1560	-2753	1342	-5723	-1628
R_{x2}	2144	-107	-107	2144	2144	2633	2633	383	383
R_{x1}	2144	-107	-107	2144	2144	2633	2633	383	383
R_{y2}	-585	-585	-585	-585	-585	-2048	-2048	-2048	-2048
R_{y1}	2960	2960	2960	2960	2960	2048	2048	2048	2048
T_x	-31,350	-31,350	-31,350	-31,350	-31,350	0	0	0	0
R_{z3}	-2313	-1788	-3353	-749	-2313	-4374	-2940	-5413	-3980
R_{z4}	-3387	-3912	-2348	-4952	-3387	-6626	-8060	-5587	-7020
R_{x4}	4287	-213	-213	4287	4287	5265	5265	765	765
R_{y3}	1772	1772	1772	1772	1772	717	717	717	717
R_{y4}	603	603	603	603	603	-717	-717	-717	-717
T_{x3}	-13,794	-13,794	-13,794	-13,794	-13,794	0	0	0	0
T_{x4}	-17,556	-17,556	-17,556	-17,556	-17,556	0	0	0	0
R_{z5}	-2168	-552	-818	-376	-642	-6561	-4410	-8120	-5970
R_{z6}	-145	-1236	-2535	-373	-1671	-6561	-4410	-8120	-5970
R_{y5}	886	886	886	886	886	1076	1076	1076	1076
R_{y6}	886	886	886	886	886	-1076	-1076	-1076	-1076
R_{z7}	19	-1748	-572	-2530	-1353	-4559	-5545	-3844	-4830
R_{z8}	-68	-2600	-2129	-2913	-2442	-5380	-6545	-4537	-5700
R_{z9}	403	527	429	593	494	-5380	-6545	-4537	-5700
R_{z10}	-3741	-92	-76	-102	-86	-4559	-5545	-3844	-4830
R_{x7}	43	-160	-160	3224	3224	3622	3622	526	526
R_{x8}	-270	-64	-64	1290	1290	4275	4275	621	621
R_{x9}	1290	13	13	-270	-270	4275	4275	621	621
R_{x10}	3224	-2	-2	43	43	3622	3622	526	526
R_{y7}	151	151	151	151	151	-538	-538	-538	-538
R_{y8}	151	151	151	151	151	-538	-538	-538	-538
R_{y9}	151	151	151	151	151	-538	-538	-538	-538
R_{y10}	151	151	151	151	151	-538	-538	-538	-538

4.2 Loads Distribution

Flight Loads



Note: Loads at CG of bomb from Section III

View looking Inboard on Left Side

$R_{Z2} = -0.66\ F_X + 0.62\ F_Z + 0.05\ M_Y$

$R_{Z1} = 0.66\ F_X + 0.38\ F_Z - 0.05\ M_Y$

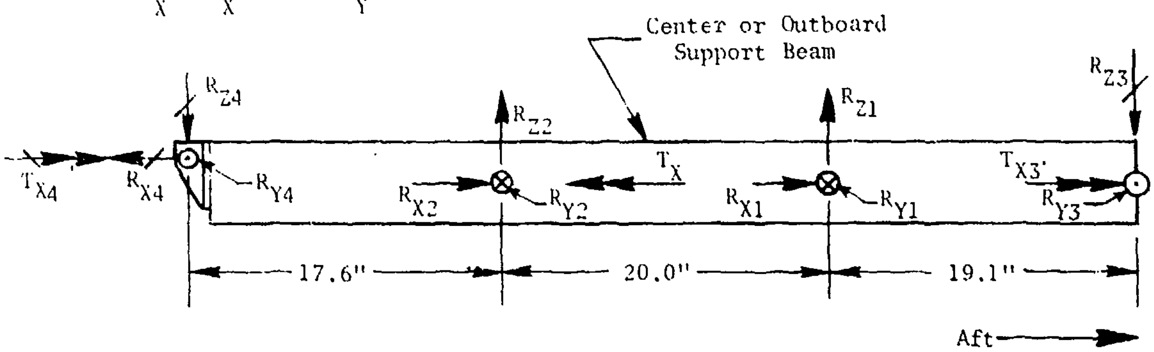
$R_{X2} = 0.50\ F_X$

$R_{X1} = 0.50\ F_X$

$R_{Y2} = 0.62\ F_Y + 0.05\ M_Z$

$R_{Y1} = 0.38\ F_Y - 0.05\ M_Z$

$T_X = M_X - 13.2\ F_Y$



View Looking Inboard on Left Side

Flight Loads (Continued)

$R_{Z3} = 0.31\ R_{Z2} + 0.66\ R_{Z1}$

$R_{Z4} = 0.69\ R_{Z2} + 0.34\ R_{Z1}$

$R_{X4} = R_{X2} + R_{X1}$

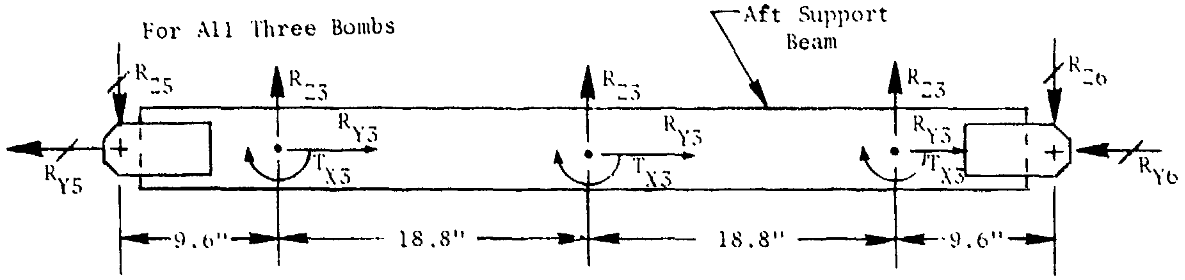
$R_{Y3} = 0.31\ R_{Y2} + 0.66\ R_{Y1}$

$R_{Y4} = 0.69\ R_{Y2} + 0.34\ R_{Y1}$

$T_{X3} = 0.44\ T_X$

$T_{X4} = 0.56\ T_X$

For All Three Bombs



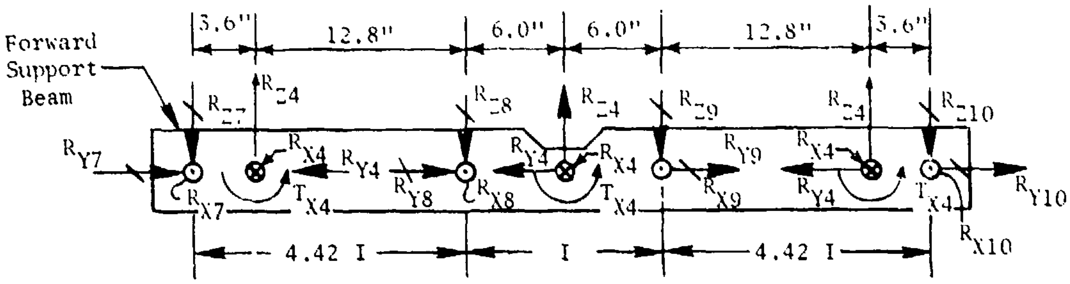
View Looking Forward at Aft Beam

$R_{Z5} = 1.5\ R_{Z3} + 0.053\ T_{X3}$

$R_{Z6} = 1.5\ R_{Z3} - 0.053\ T_{X3}$

$R_{Y5} = 1.5\ R_{Y3}$

$R_{Y6} = 1.5\ R_{Y3}$



Loads Were Distributed by Moment Distribution Method

View Looking Aft at Forward Beam

Flight Loads (Continued)

$R_{Z7} = 0.688\ R_{Z4} - 0.062\ T_{X4}$

$R_{Z8} = 0.812\ R_{Z4} - 0.021\ T_{X4}$

$R_{Z9} = 0.812\ R_{Z4} + 0.021\ T_{X4}$

$R_{Z10} = 0.688\ R_{Z4} + 0.062\ T_{X4}$

$R_{X7} = 0.688\ R_{X4}$

$R_{X8} = 0.812\ R_{X4}$

$R_{X9} = 0.812\ R_{X4}$

$R_{X10} = 0.688\ R_{X4}$

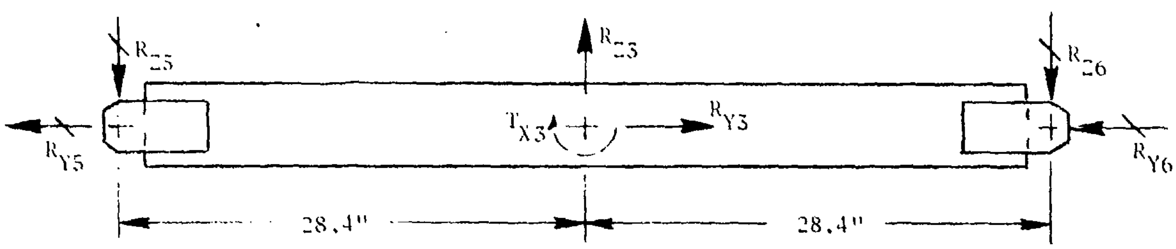
$R_{Y7} = 0.75\ R_{Y4}$

$R_{Y8} = 0.75\ R_{Y4}$

$R_{Y9} = 0.75\ R_{Y4}$

$R_{Y10} = 0.75\ R_{Y4}$

For Center Bomb Only



View Looking Forward at Aft Beam

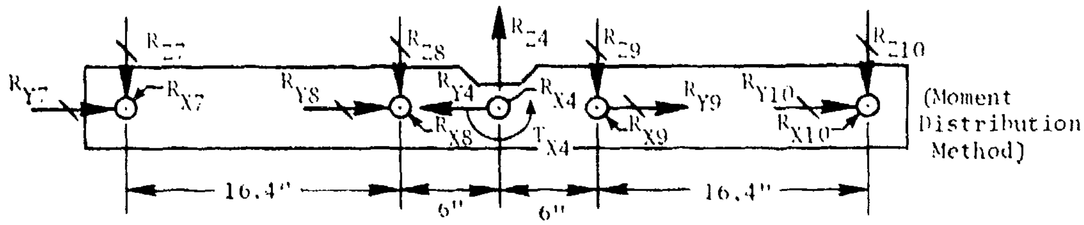
$R_{Z5} = 0.5\ R_{Z3} + 0.018\ T_{X3}$

$R_{Z6} = 0.5\ R_{Z3} - 0.018\ T_{X3}$

$R_{Y5} = 0.5\ R_{Y3}$

$R_{Y6} = 0.5\ R_{Y3}$

Flight Loads (Continued)



View Looking Aft at Forward Beam

$R_{Z7} = -0.074\ R_{Z4} + 0.009\ T_{X4}$

$R_{Z8} = 0.574\ R_{Z4} - 0.118\ T_{X4}$

$R_{Z9} = 0.574\ R_{Z4} + 0.118\ T_{X4}$

$R_{Z10} = -0.074\ R_{Z4} - 0.009\ T_{X4}$

$R_{X7} = -0.074\ R_{X4}$

$R_{X8} = 0.574\ R_{X4}$

$R_{X9} = 0.574\ R_{X4}$

$R_{X10} = -0.074\ R_{X4}$

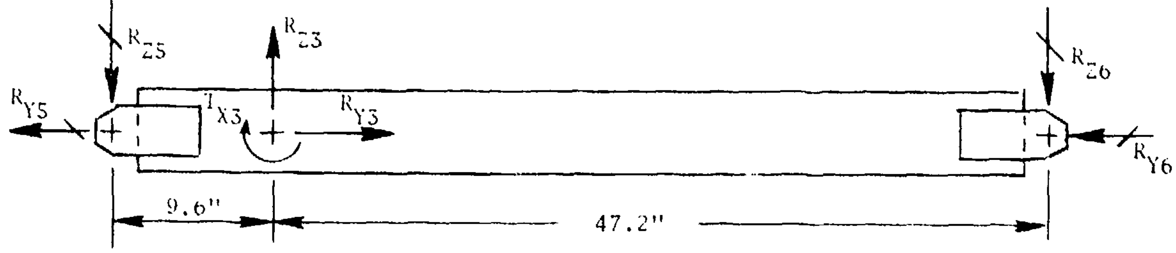
$R_{Y7} = 0.25\ R_{Y4}$

$R_{Y8} = 0.25\ R_{Y4}$

$R_{Y9} = 0.25\ R_{Y4}$

$R_{Y10} = 0.25\ R_{Y4}$

For Left Bomb Only



View Looking Forward at Aft Beam

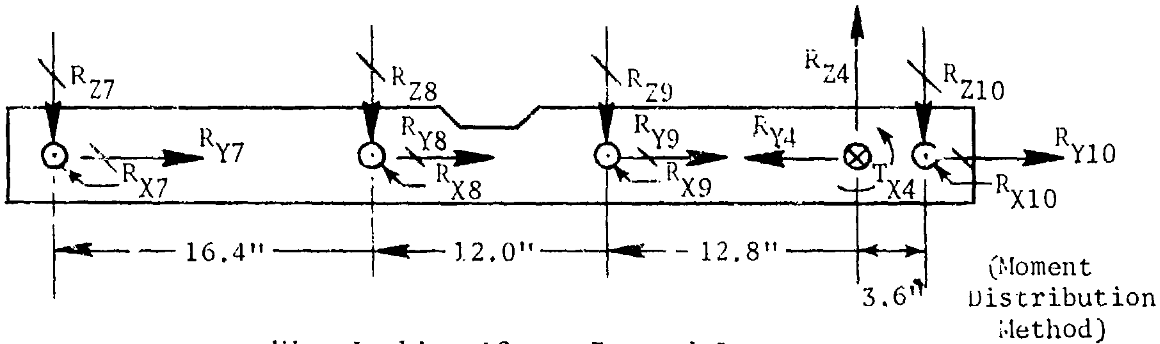
Flight Loads (Continued)

$R_{Z5} = 0.83\ R_{Z3} + 0.018\ T_{X3}$

$R_{Z6} = 0.17\ R_{Z3} - 0.018\ T_{X3}$

$R_{Y5} = 0.5\ R_{Y3}$

$R_{Y6} = 0.5\ R_{Y3}$



View Looking Aft at Forward Beam

$R_{Z7} = 0.010\ R_{Z4} - 0.003\ T_{X4}$

$R_{Z8} = -0.063\ R_{Z4} + 0.016\ T_{X4}$

$R_{Z9} = 0.301\ R_{Z4} - 0.081\ T_{X4}$

$R_{Z10} = 0.752\ R_{Z4} + 0.068\ T_{X4}$

$R_{X7} = 0.010\ R_{X4}$

$R_{X8} = -0.063\ R_{X4}$

$R_{X9} = 0.301\ R_{X4}$

$R_{X10} = 0.752\ R_{X4}$

$R_{Y7} = 0.25\ R_{Y4}$

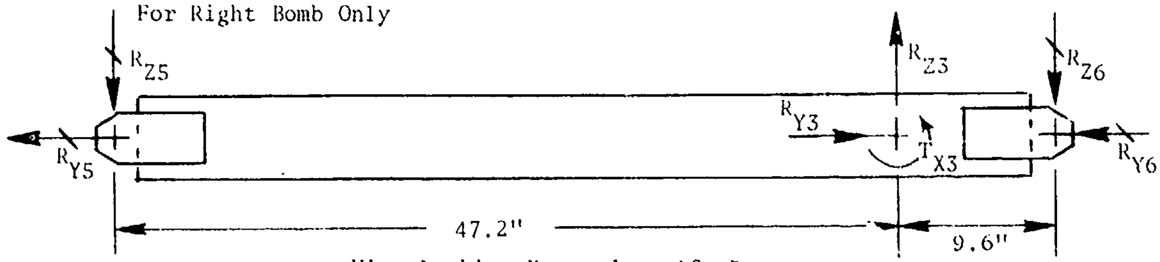
$R_{Y8} = 0.25\ R_{Y4}$

$R_{Y9} = 0.25\ R_{Y4}$

$R_{Y10} = 0.25\ R_{Y4}$

Flight Loads (Concluded)

For Right Bomb Only



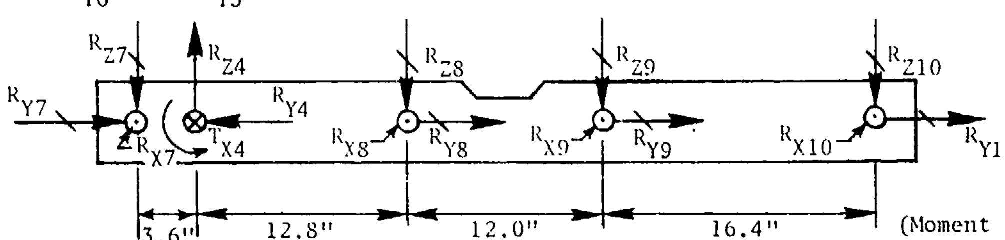
View Looking Forward at Aft Beam

$R_{Z5} = 0.17\ R_{Z3} + 0.018\ T_{X3}$

$R_{Z6} = 0.83\ R_{Z3} - 0.018\ T_{X3}$

$R_{Y5} = 0.5\ R_{Y3}$

$R_{Y6} = 0.5\ R_{Y3}$



(Moment Distribution Method)

View Looking Aft at Forward Beam

$R_{Z7} = 0.752\ R_{Z4} - 0.068\ T_{X4}$

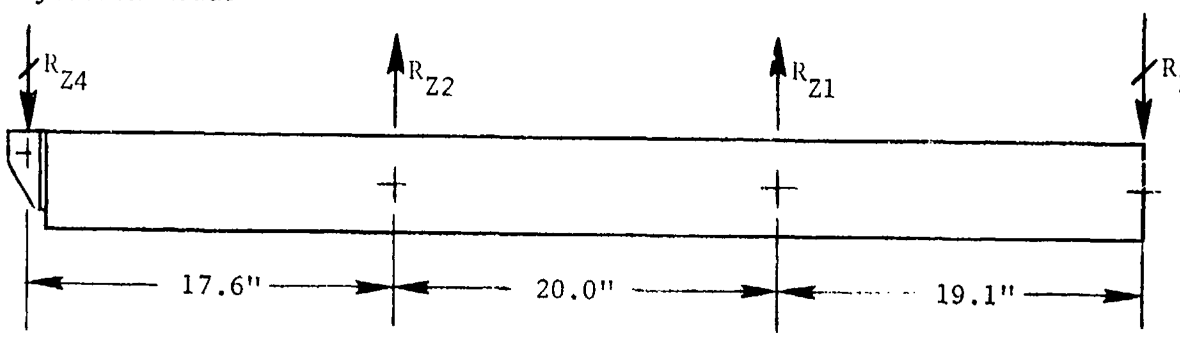
$R_{Z8} = 0.301\ R_{Z4} + 0.081\ T_{X4}$

$R_{Z9} = -0.063\ R_{Z4} - 0.016\ T_{X4}$

$R_{Z10} = 0.010\ R_{Z4} + 0.003\ T_{X4}$

$R_{X7} = 0.752\ R_{X4}$	$R_{Y7} = 0.25\ R_{Y4}$
$R_{X8} = 0.301\ R_{X4}$	$R_{Y8} = 0.25\ R_{Y4}$
$R_{X9} = -0.063\ R_{X4}$	$R_{Y9} = 0.25\ R_{Y4}$
$R_{X10} = 0.010\ R_{X4}$	$R_{Y10} = 0.25\ R_{Y4}$

Ejection Loads



View Looking Inboard on Left Side

P_{EJ} = Ejection Force

$R_{Z1} = C_1 \; P_{EJ}$

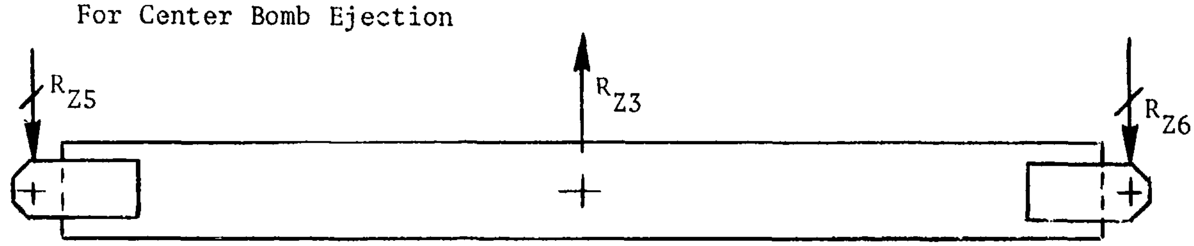
$R_{Z2} = C_2 \; P_{EJ}$

$C_1 + C_2 = 1$

$R_{Z3} = 0.31 \; R_{Z2} + 0.66 \; R_{Z1}$

$R_{Z4} = 0.69 \; R_{Z2} + 0.34 \; R_{Z1}$

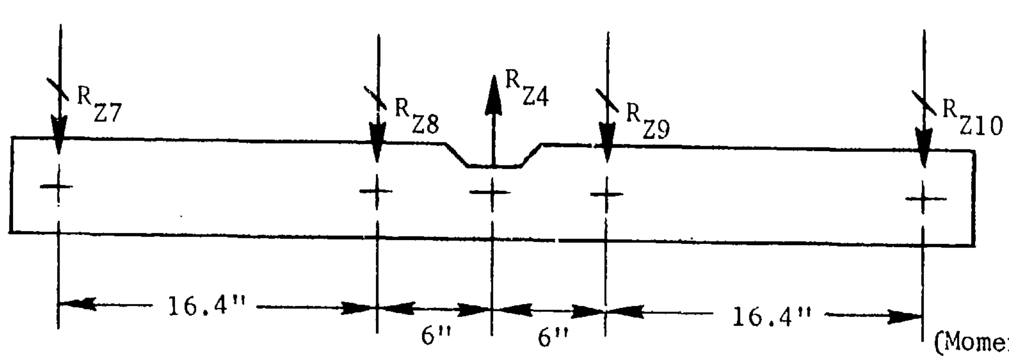
For Center Bomb Ejection



View Looking Forward at Aft Beam

$R_{Z5} = 0.5 \; R_{Z3}$

$R_{Z6} = 0.5 \; R_{Z3}$



(Moment Distribution Method)

Ejection Loads (Continued)

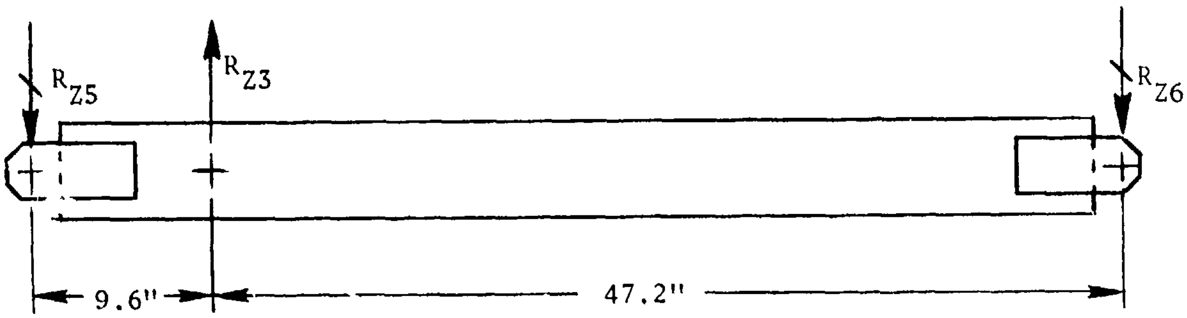
$R_{Z7} = -0.074\ R_{Z4}$

$R_{Z8} = 0.574\ R_{Z4}$

$R_{Z9} = 0.574\ R_{Z4}$

$R_{Z10} = -0.074\ R_{Z4}$

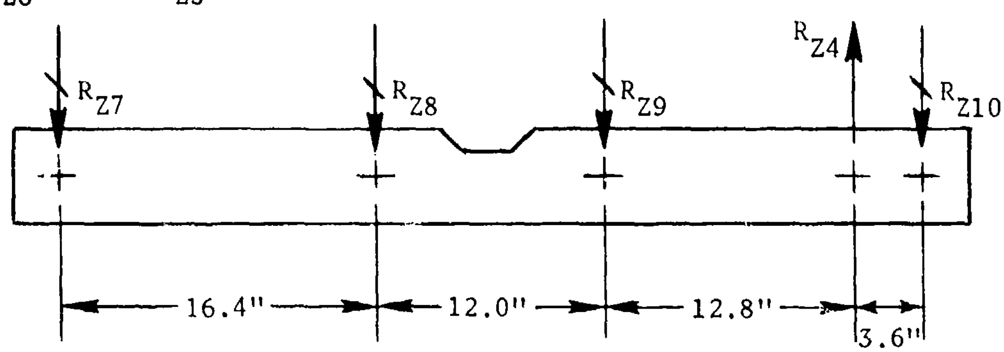
For Left Bomb Ejection



View Looking Forward at Aft Beam

$R_{Z5} = 0.83\ R_{Z3}$

$R_{Z6} = 0.17\ R_{Z3}$



View Looking Aft at Forward Beam

(Moment Distribution Method)

$R_{Z7} = 0.010\ R_{Z4}$

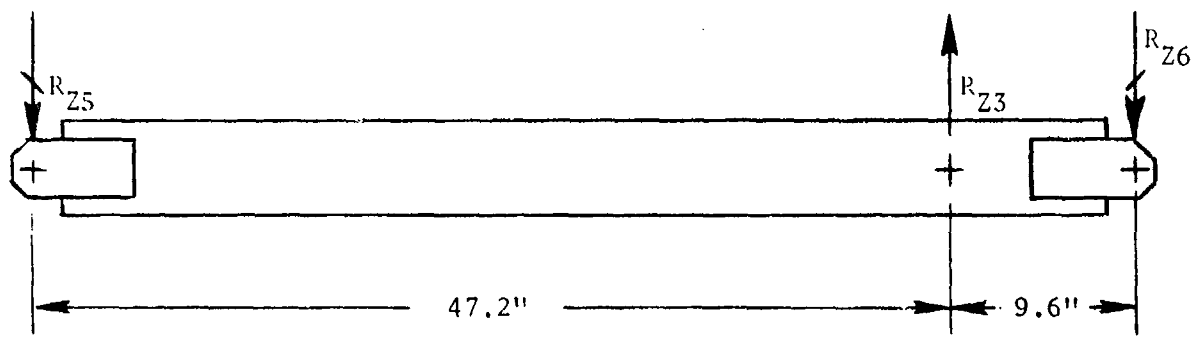
$R_{Z8} = -0.063\ R_{Z4}$

$R_{Z9} = 0.301\ R_{Z4}$

$R_{Z10} = 0.752\ R_{Z4}$

Ejection Loads (Concluded)

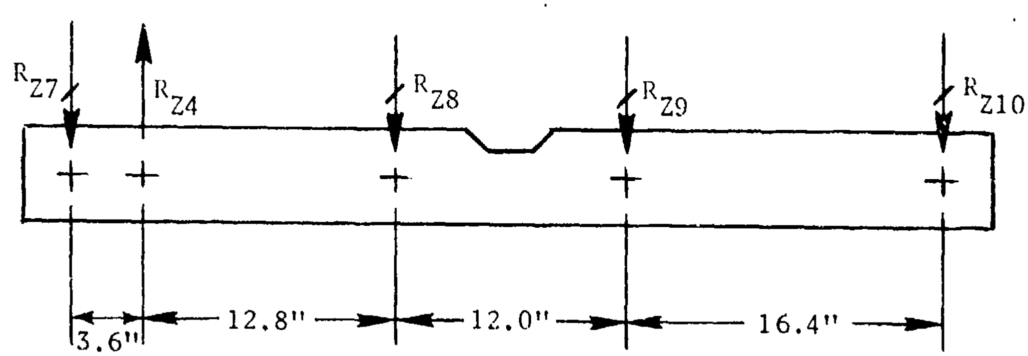
For Right Bomb Ejection



View Looking Forward at Aft Beam

$R_{Z5} = 0.17\ R_{Z3}$

$R_{Z6} = 0.83\ R_{Z3}$



(Moment Distribution Method)

$R_{Z7} = 0.752\ R_{Z4}$

$R_{Z8} = 0.301\ R_{Z4}$

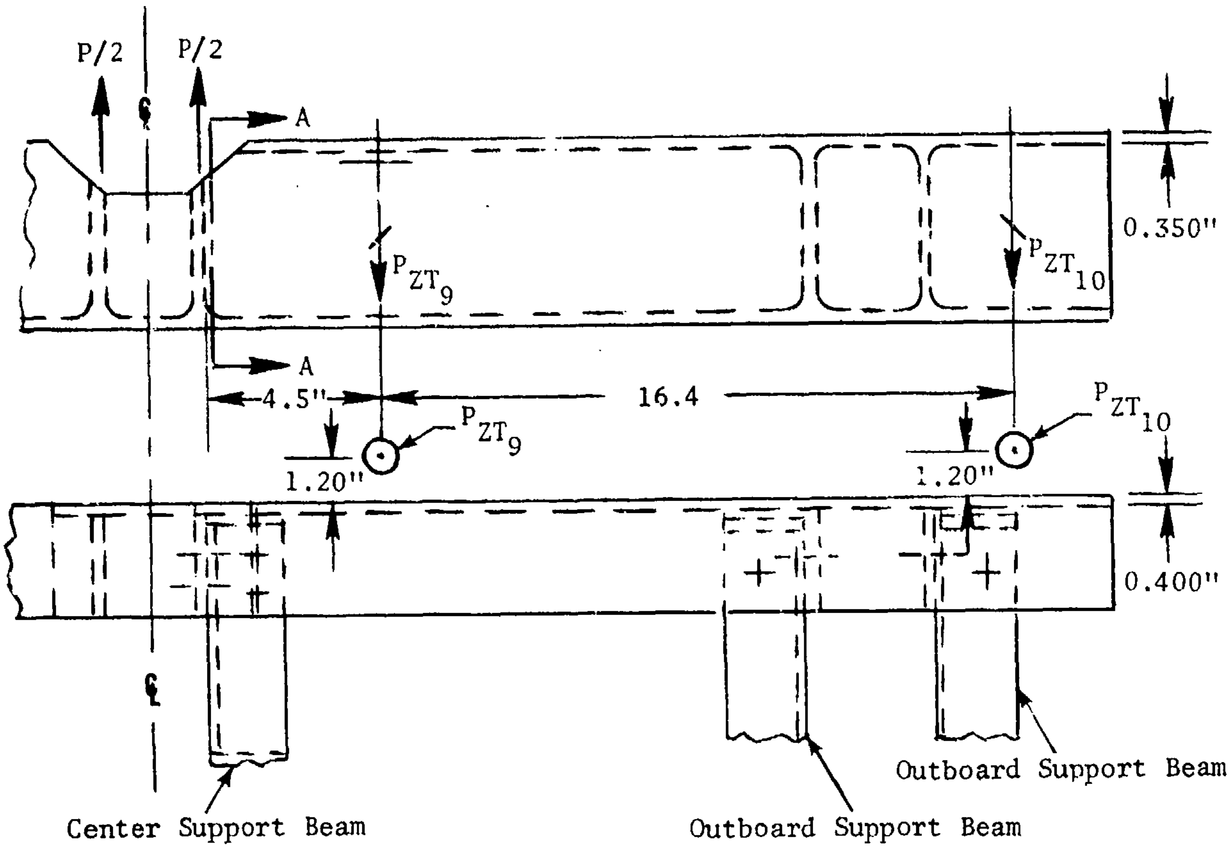
$R_{Z9} = -0.063\ R_{Z4}$

$R_{Z10} = 0.010\ R_{Z4}$

4.3 ANALYSIS

4.3.1 Rack Structure

Forward Support Beam



The forward beam supports the forward end of the outboard and center support beams and distributes the loads to the forward clevis fittings.

Material - 4130 per MIL-S-6758

F_{tu} = 90,000 psi @ room temperature

F_{su} = 55,000 psi @ room temperature

$$\left.\begin{aligned} F_{tu} &= (90{,}000)(0.97) = 87{,}300 \text{ psi} \\ F_{su} &= (55{,}000)(0.98) = 53{,}900 \text{ psi} \end{aligned}\right\} \text{@ } 270^\circ\text{F}$$

(Reference 3, page 100, 102, 104)

References

3. Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5A, February 1966.

Forward Support Beam (Continued)

Loading -

Condition No. IV C

$$R_{Z9} = -4914 \text{ pounds} = P_{Z9}$$

$$R_{Z10} = 524 \text{ pounds} = P_{Z10}$$

Condition No. I B

$$R_{Z9} = 8497 \text{ pounds} = T_9$$

$$R_{Z10} = -1095 \text{ pounds} = T_{10}$$

$$P_{ZT} = P_Z + 1.15\ (T - P_Z)$$

$$P_{ZT_9} = -4914 + 1.15\ (8497 + 4914)$$

$$P_{ZT_9} = 10{,}509 \text{ pounds}$$

$$P_{ZT_{10}} = 524 + 1.15\ (-1095 - 524)$$

$$P_{ZT_{10}} = -1338 \text{ pounds}$$

Section A-A - Critical Section

Bending

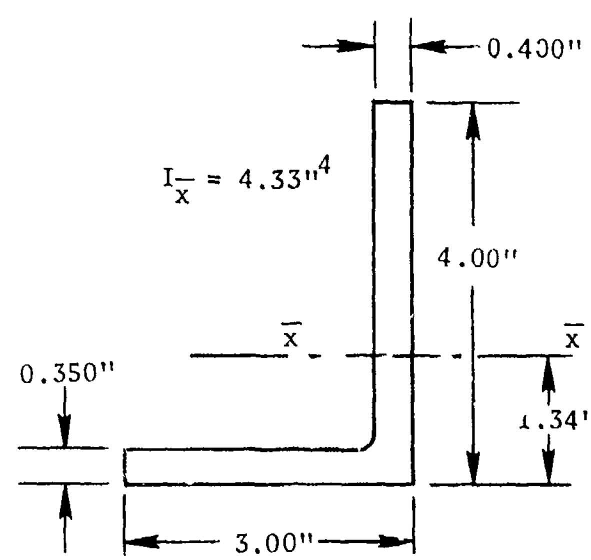
$$M = 4.5\ P_{ZT_9} + 20.9\ P_{ZT_{10}}$$

$$M = 19{,}326 \text{ in-lb}$$

$$f_b = \frac{Mc}{I} = \frac{(19{,}326)(2.66)}{4.33}$$

$$f_b = 11{,}872 \text{ psi}$$

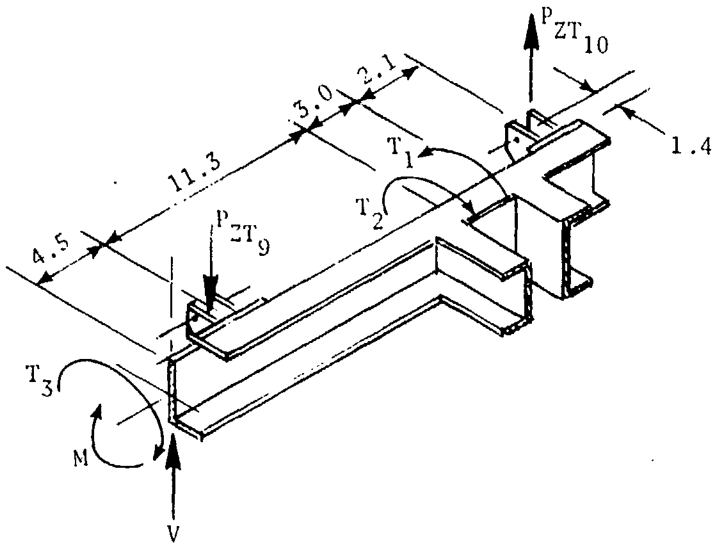
$$F_{tu} = 87{,}300 \text{ psi @ } 270°\text{F}$$



Section A-A

$$MS = \frac{87{,}300}{11{,}872} - 1 = \text{High}$$

Forward Support Beam (Continued)



Section A-A (Continued)

Torsion

$$T_1 = P_{ZT_{10}}(1.4) = -1338(1.4) = -1870 \text{ in-lb}$$

$$T_2 = \frac{4.5}{4.5 + 11.3}(P_{ZT_9})(1.4) = \frac{4.5}{15.8}(10{,}509)(1.4) = 4190 \text{ in-lb}$$

$$T_3 = \frac{11.3}{4.5 + 11.3}(P_{ZT_9})(1.4) = \frac{11.3}{15.8}(10{,}509)(1.4) = 10{,}520 \text{ in-lb}$$

$$f_{st} = \frac{T}{\alpha b t^2}, \quad b/t = \frac{7.00}{0.38} = 18.42, \ \alpha = 0.32 \quad \text{(Reference 4, page 331)}$$

$t = 0.38$ inches average

$$f_{st} = \frac{10{,}520}{0.32 \times 7 \times 0.38^2} = 32{,}500 \text{ psi}, \quad F_{su} = 53{,}900 \text{ psi @ } 270°\text{F}$$

$$R_{st} = \frac{F_{st}}{F_{su}} = 0.603$$

Shear

$$V = P_{ZT_9} + P_{ZT_{10}} = 9171 \text{ lb}$$

$$fs = \frac{VQ}{It}, \quad Q = 2.66(0.40)(1.33) = 1.415 \text{ in}^3$$

$$I = 4.33 \text{ in}^4$$

References

4. Peery, D. J., Aircraft Structures, McGraw-Hill Book Co., 1950.

Forward Support Beam (Concluded)

Section A-A (Concluded)

$$f_s = \frac{VQ}{It} = \frac{9171(1.415)}{4.33(0.40)} = 7492 \text{ psi}$$

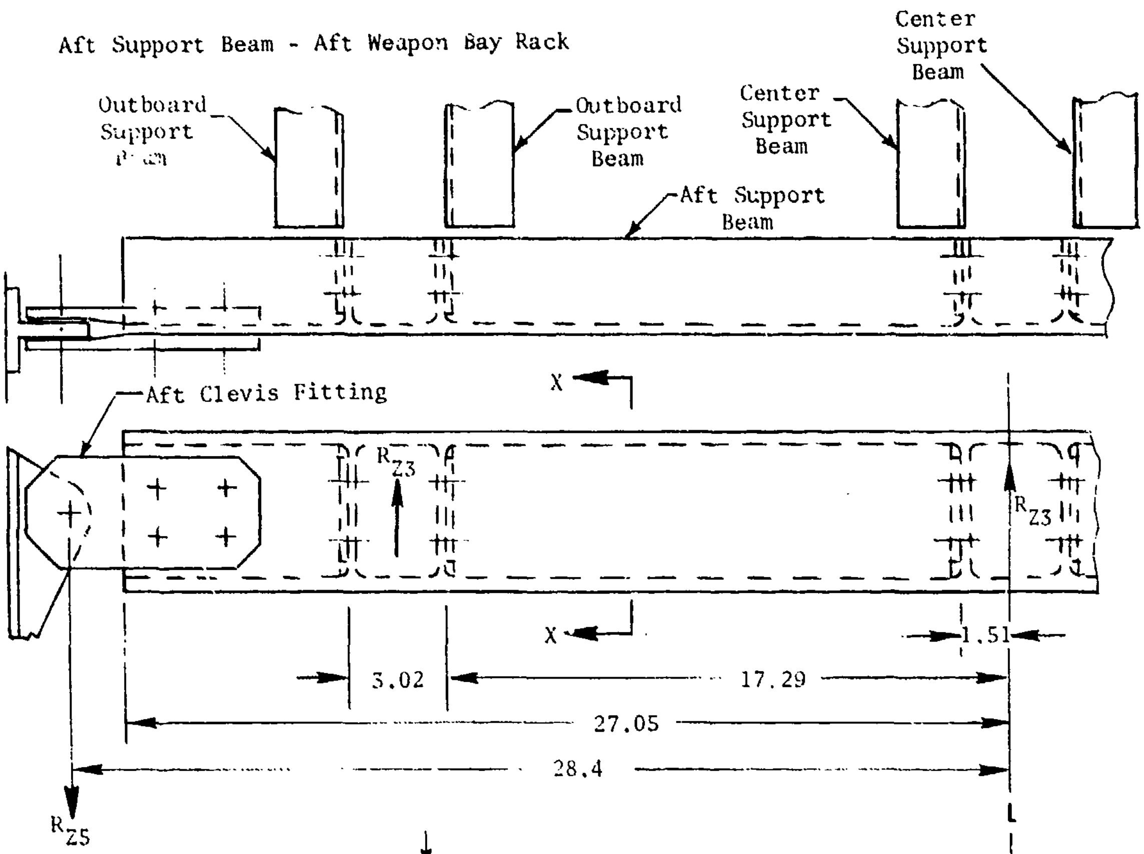
$$F_{su} = 53{,}900 \text{ psi @ } 270^\circ\text{F}$$

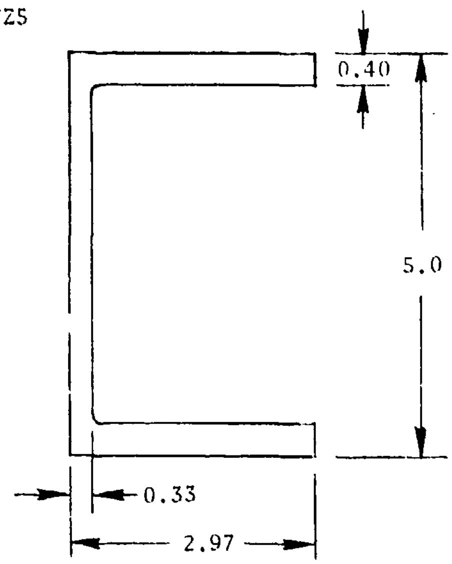
$$R_s = \frac{7492}{53{,}900} = 0.139$$

$$MS = \frac{1}{R_s + R_{st}} - 1 = \frac{1}{0.603 + 0.139} - 1 = +0.35$$

Section A-A is the minimum section with upper flange removed. The remainder of the beam is at lower stress levels.

Aft Support Beam - Aft Weapon Bay Rack





$A = 3.77 \text{ in}^2$

$I = 14.65 \text{ in}^4$

$Q = 3.47 \text{ in}^3$

Section X-X

$V_{MAX} = 16{,}800 \text{ lb}$

$$f_{s\ MAX} = \frac{VQ}{It} = \frac{16{,}800 \times 3.47}{14.65 \times 0.33} = 12{,}058 \text{ psi}$$ Not Critical

Aft Support Beam (Continued)

Maximum beam bending will occur when ejecting a bomb from the center rack while retaining bombs on the outboard racks. Steady state loads should be maximum down on the ejected bomb and minimum down on the retained bombs.

Ejection Condition IA R_{Z3} = 14,044 lb

Steady State Conditions IV B, V B, VI B, R_{Z3} = -3353 lb

(Maximum Load for Ejected Bomb) R_{Y3} = +1772 lb

Steady State Conditions IV C, V C, VI C, R_{Z3} = -749 lb

(Minimum Load for Retained Bombs) R_{Y3} = 1772 lb

T_{X3} = -13,794 in-lb

Ejected Store

$$F_Z = \begin{pmatrix} 1.35\ T \\ \text{Thrust} \end{pmatrix} - 0.35 \begin{pmatrix} F_Z \\ \text{Steady} \\ \text{State} \end{pmatrix} = 1.35(14{,}044) - 0.35(-3353)$$

$$= 20{,}175 \text{ lb}$$

$$F_Y = -0.3\ F_Y = -0.3(1772) = -530 \text{ lb}$$

Retained Stores

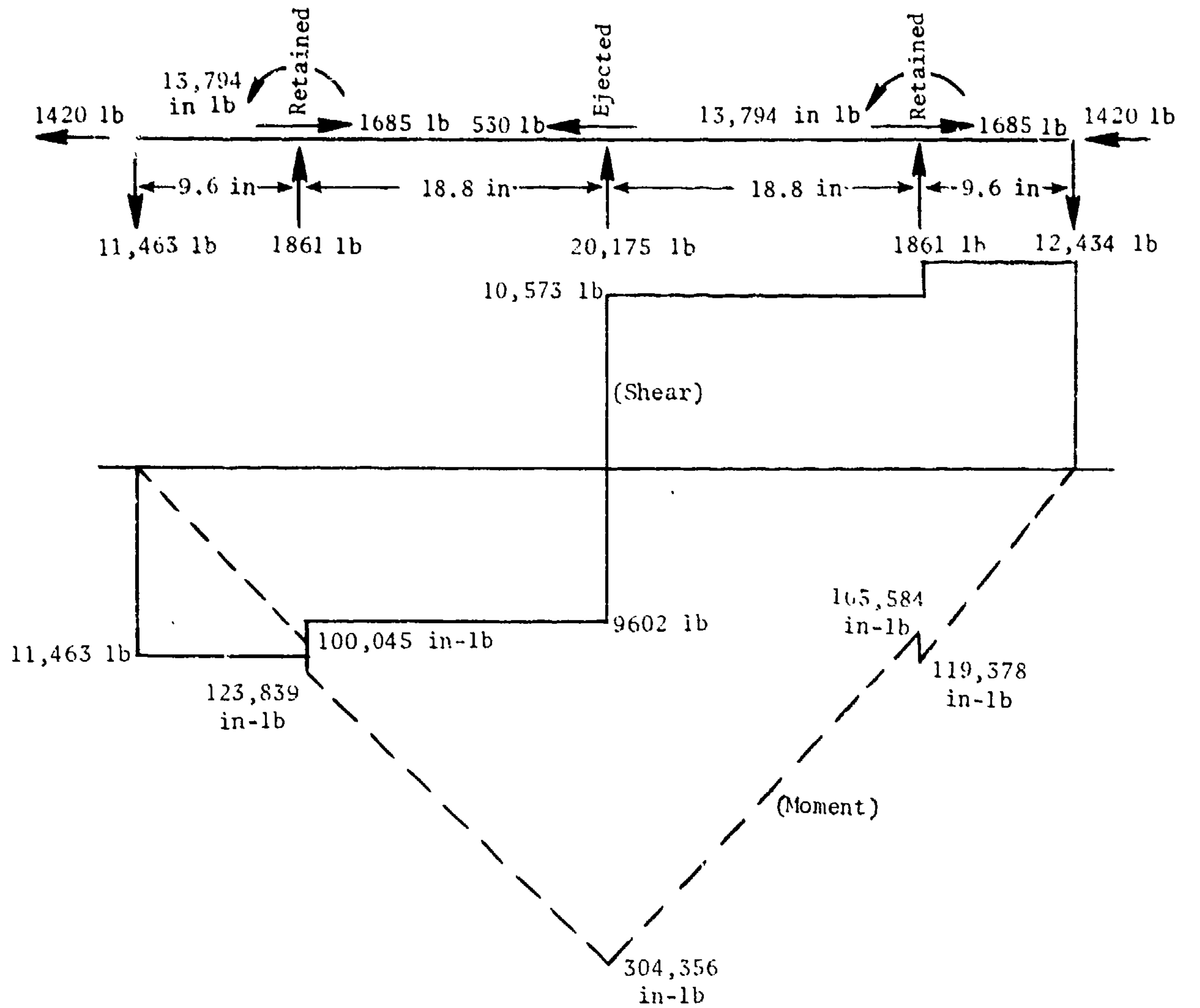
$$F_Z = \begin{pmatrix} F_Z \\ \text{Retained} \\ \text{Store} \end{pmatrix} + 0.15 \begin{pmatrix} T\text{-}F_Z \\ \text{Ejected} \\ \text{Store} \end{pmatrix} = -749 + 0.15\ (14{,}044 + 3353)$$

$$= 1861 \text{ lb}$$

$$F_Y = \begin{pmatrix} F_Y \\ \text{Retained} \end{pmatrix} + 0.05 \begin{pmatrix} -F_Y \\ \text{Ejected} \end{pmatrix} = 1772 + 0.05(-1772)$$

$$= 1685 \text{ lb}$$

Aft Support Beam (Concluded)



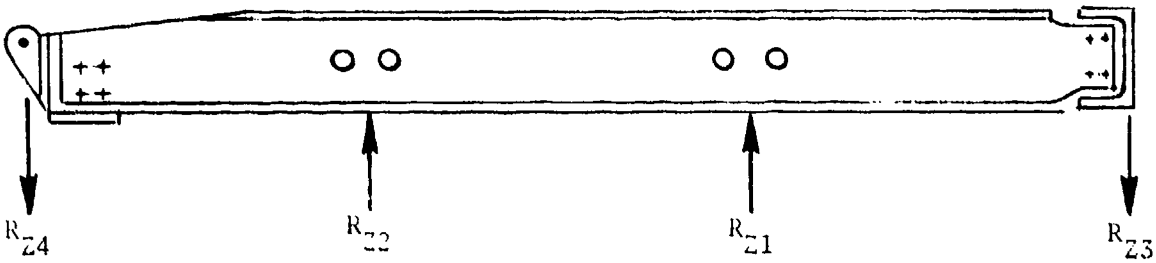
$$f_b = \frac{Mc}{I} = \frac{304{,}356 \times 2.5}{14.65} = 52{,}000 \text{ psi}$$

F_{cy} = 70,000 psi @ RT x 0.96 = 67,200 psi @ 270°F

(Reference 3)

$$MS = \frac{67.2}{52.0} - 1 = +0.29$$

Center and Outboard Support Beams



Critical beam loading is maximum ejection load up combined with maximum steady state load down. Loads are combined per equation

$$R_Z = 1.15\ R\ (\text{Thrust}) - 0.15\ R\ (\text{Steady State})$$

Condition I A + IV B

$$R_{Z4} = 1.15\ (11{,}261) - 0.15\ (-2348) = 13{,}302\ \text{lb}$$

$$R_{Z2} = 1.15\ (7591) - 0.15\ (-1170) = 8906\ \text{lb}$$

$$R_{Z1} = 1.15\ (17{,}714) - 0.15\ (-4530) = 21{,}080\ \text{lb}$$

$$R_{Z3} = 1.15\ (14{,}044) - 0.15\ (-3353) = 16{,}653\ \text{lb}$$

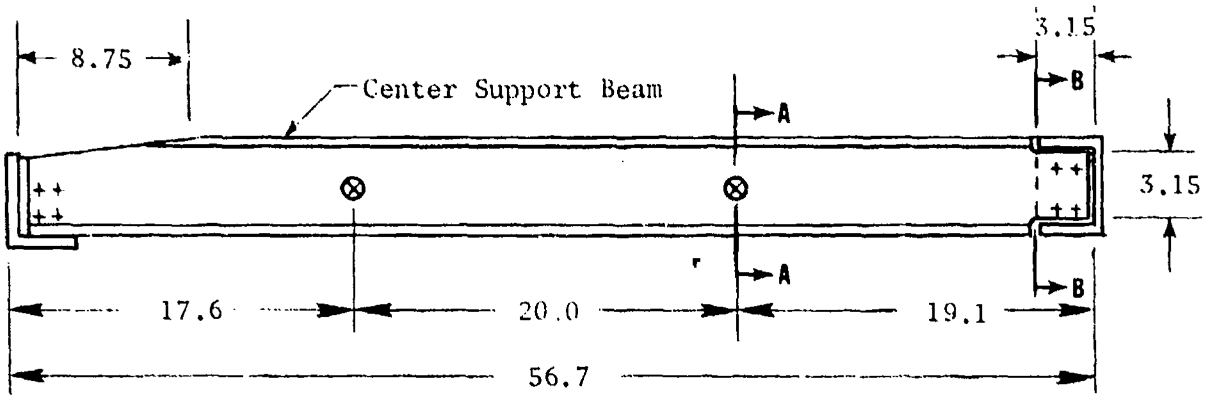
Condition I B + IV C

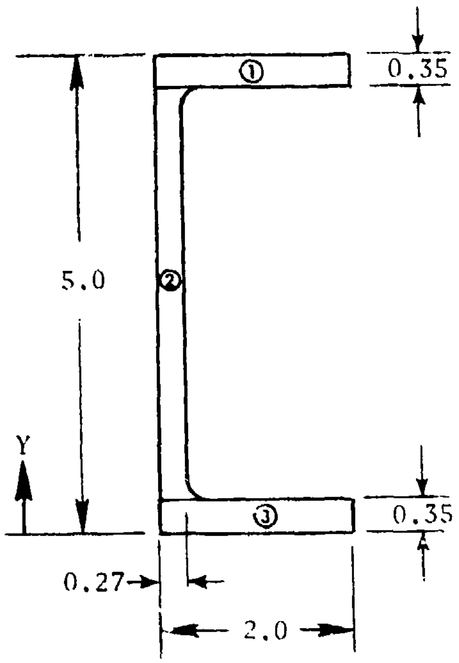
$$R_{Z4} - 1.15\ (14{,}804) - 0.15\ (-4952) = 17{,}785\ \text{lb}$$

$$R_{Z2} = 1.15\ (17{,}714) - 0.15\ (-8610) = 21{,}690\ \text{lb}$$

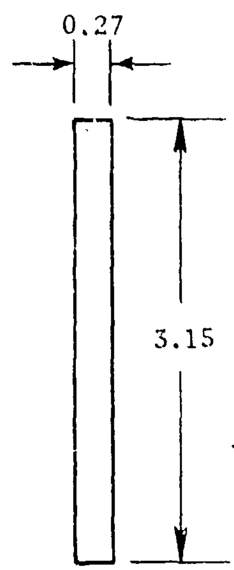
$$R_{Z1} = 1.15\ (7591) - 0.15\ (+2910) = 8292\ \text{lb}$$

$$R_{Z3} = 1.15\ (10{,}501) - 0.15\ (-749) = 12{,}212\ \text{lb}$$





Section A-A



Section B-B

Section Properties

$\Sigma A = 2.56 \text{ In}^2$ $\quad \Sigma I_o = 1.88 \text{ In}^4$

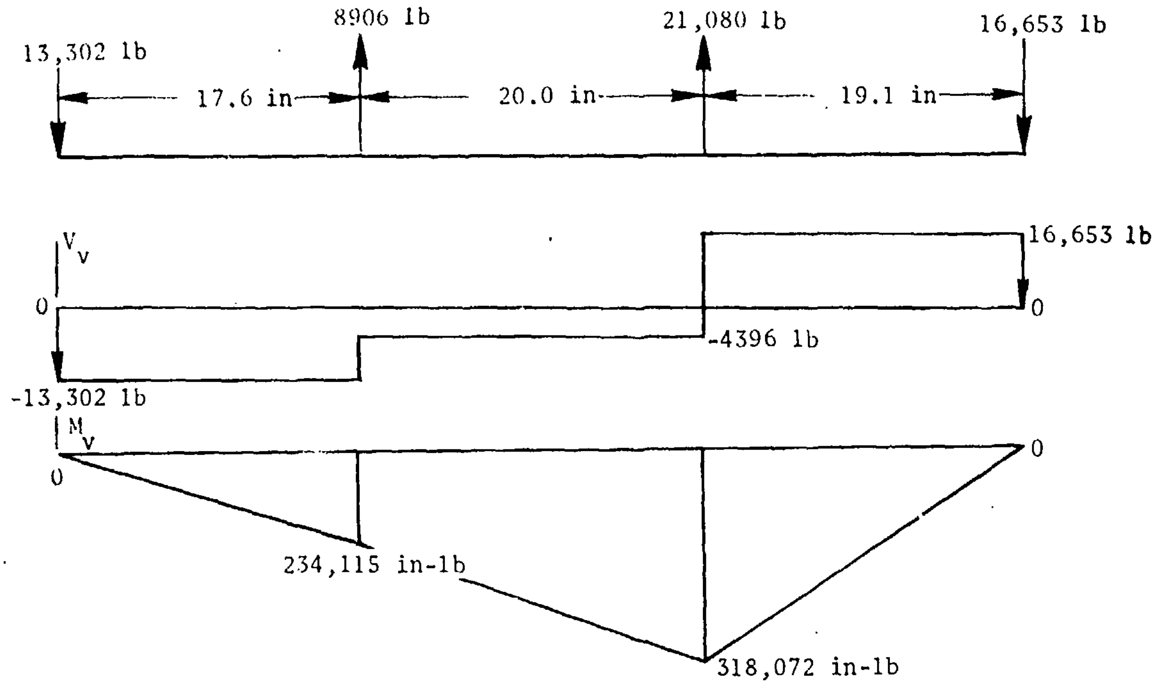
$\Sigma AY = 6.40 \text{ In}^3$ $\quad I_{NA} = 9.371 \text{ In}^4$

$\Sigma AY^2 = 23.60 \text{ In}^4$ $\quad \overline{Y} = 2.50 \text{ In}$

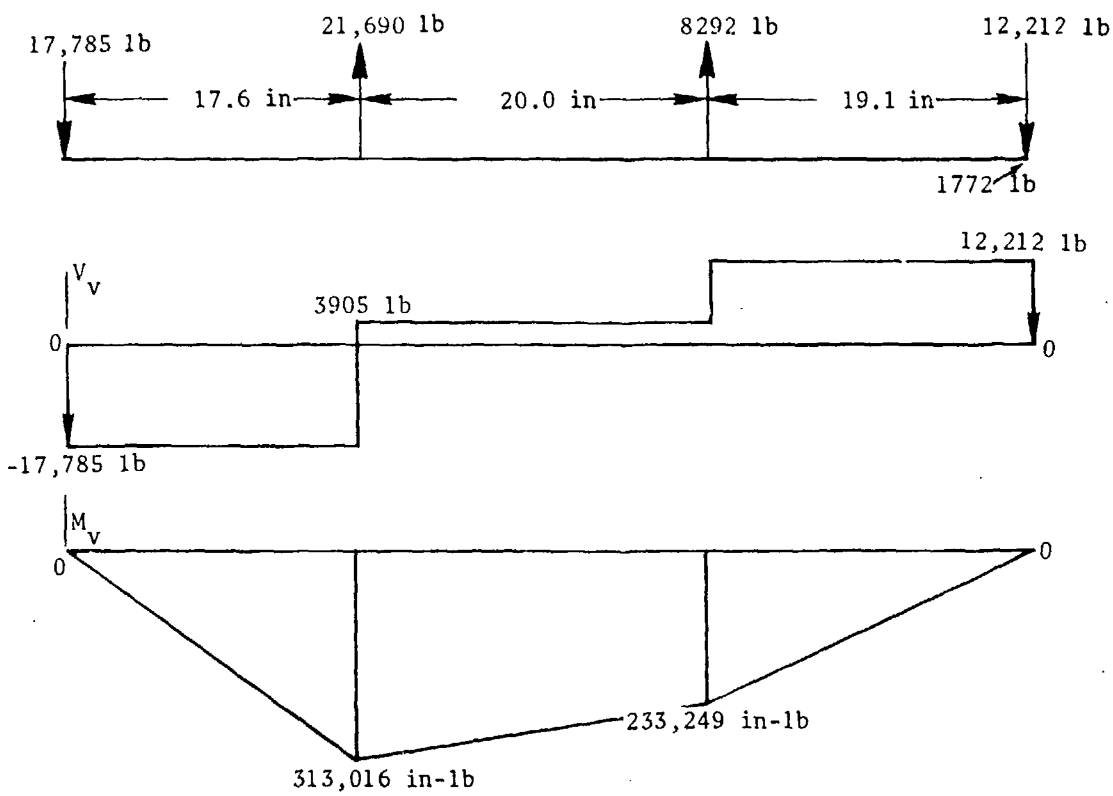
Section Properties

$I_{NA} = 0.703 \text{ In}^4$

Condition I A + IV B



Condition I B + IV C



Beam Analysis

Material Allowables:

4130 Steel per MIL-S-6758

F_{tu} = (90,000)(0.97) = 87,300 psi @ 270°F

F_{cy} = (70,000)(0.97) = 67,900 psi @ 270°F

F_{su} = (55,000)(0.97) = 53,350 psi @ 270°F

(Reference 3, Page 102)

Assume a 50 - 50 moment distribution. Maximum loads are from Condition I A and IV B.

$$M_{MAX} = (1/2)(318,072) = 159,036 \text{ in-lb}$$

Check Section A-A

$$f_t = \frac{Mc}{I} = \frac{(159,036)(2.50)}{9.371} = 42,400 \text{ psi}$$

$$MS = \frac{F_{tu}}{f_t} - 1 = \frac{87,300}{42,400} - 1 = +1.06$$

Check Section B-B

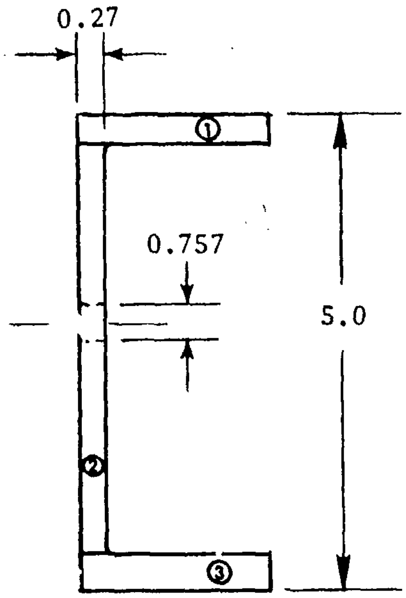
$$I = \frac{(0.27)(3.15)^3}{12} = 0.703 \text{ in}^4$$

$$M = (1/2)(16,653)(3.15) = 26,200 \text{ in-lb}$$

$$f_t = \frac{Mc}{I} = \frac{(26,200)(1.58)}{0.703} = 58,900 \text{ psi}$$

$$MS = \frac{F_{tu}}{f_t} - 1 = \frac{87,300}{58,900} - 1 = +0.48$$

Check Shear Stress: Use cross section area ② for effective area in shear.



$A_{②} = (5.0) - (0.757)(0.27) = 1.15 \text{ in}^2$

Using Condition [illegible] B and IV C:

$V_{V_{MAX}} = 17,785$ pounds

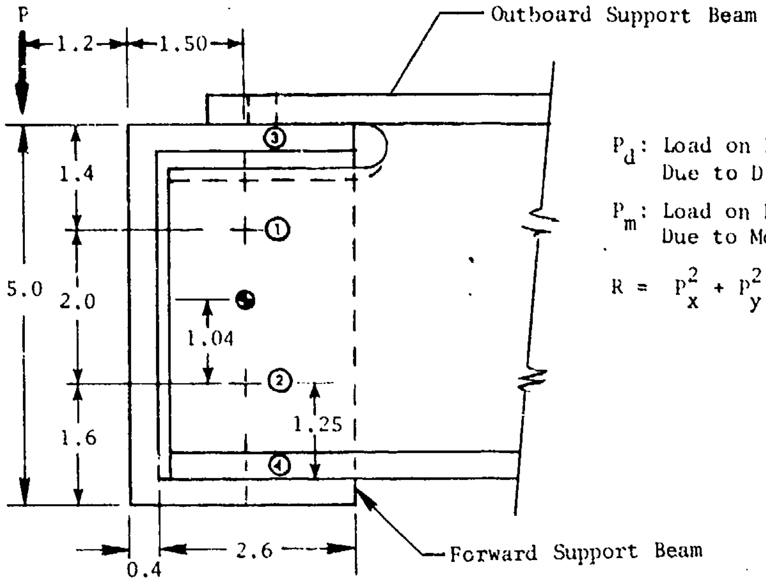
$f_s = \frac{VQ}{It} = \frac{3}{2}\frac{V}{A} = 3/2 \, \frac{(17,785)}{(1.15)} = 23,200$ psi

$F_{su} = (55,000)(0.97) = 53,350$ psi

$MS = \frac{F_{su}}{f_s} - 1 = +1.30$

Forward Joint (Side View)

$P = \frac{17,785}{2}$



P_d: Load on Fastener Due to Direct Load

P_m: Load on Fastener Due to Moment

$R = P_x^2 + P_y^2$

Bolts	x	y	x^2	y^2	Pdx	Pmx	Px	Pdy	Pmy	Py	R
1	0	0.96	0	0.92	0	-1801	-1801	4450	0	4450	4801
2	0	-1.04	0	1.08	0	+1951	+1951	4450	0	4450	4859
3	0	+2.36	0	5.57	0	-4427	-4427	--	0	--	4427
4	0	-2.29	0	5.24	0	+4296	+4296	--	0	--	4296
			0	12.81							

where

$M = (2.7)(8900) = 24,030$ in-lb

$$P_{mx} = \frac{-MyA}{\Sigma Ay^2 + \Sigma Ax^2} = \frac{-24,030y}{12.81} = -1876y$$

$$P_{my} = \frac{-MxA}{\Sigma Ax^2 + \Sigma Ay^2} = \frac{24,030x}{12.81} = 1876x$$

for 3/8" NAS676V Bolts:

P_{su} = 10,500 Pounds Single Shear

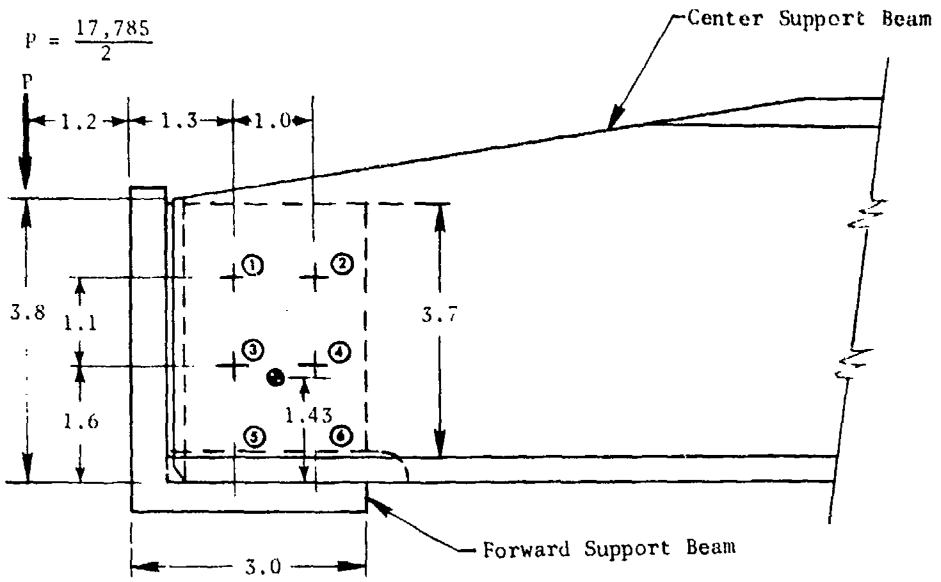
Reference NAS621

P_{su} = (10,500)(0.86) = 9030 Pounds @ 270°F

Reference 3, page 618)

$$MS = \frac{9030}{4858} - 1 = +0.86$$

Forward Joint



Bolt	x	y	x^2	y^2	Pdx	Pmx	Px	Pdy	Pmy	Py	R
1	-0.5	1.27	0.25	1.61	0	-4056	-4056	2225	-1597	628	4104
2	0.5	1.27	0.25	1.61	0	-4056	-4056	2225	1597	3822	5573
3	-0.5	0.17	0.25	0.03	0	-543	-543	2225	-1597	628	830
4	0.5	0.17	0.25	0.03	0	-543	-543	2225	1597	3822	3860
5	--	-1.43	--	2.04	0	4567	4567	--	--	--	4567
6	--	-1.43	--	2.04	0	4567	4567	--	--	--	4567
			1.00	7.36"^{2}							

M = (3.0)(8900) = 26,700 in-lb

$$P_{mx} = \frac{-MyA}{\Sigma x^2 A + \Sigma y^2 A} = \frac{-26,700}{8.36} y = -3194y$$

$$P_{my} = \frac{MxA}{\Sigma x^2 A + \Sigma y^2 A} = \frac{26,700}{8.36} x = 3194x$$

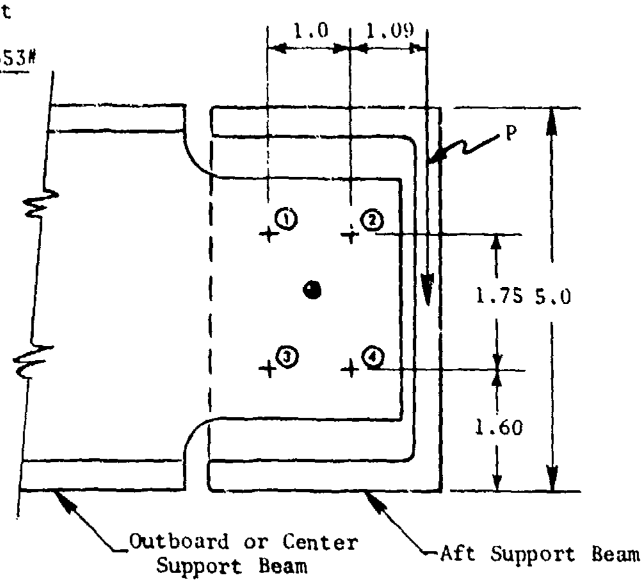
for 3/8" NAS676V Bolts: P_{su} = 10,500 pounds (Single Shear) Ref: NAS 621

P_{su} = (10,500)(0.86) = 9080 in-lb @ 270°F

(Reference 3, page 618)

$$MS = \frac{9080}{5573} - 1 = +0.63$$

Aft Joint



Rivet	x	y	x^2	y^2	Pdx	Pmx	Px	Pdy	Pmy	Py	R
1	-0.5	0.875	0.25	0.765	0	-2853	-2853	2082	-1630	452	2889
2	+0.5	0.875	0.25	0.765	0	-2853	-2853	2082	1630	3712	4682
3	-0.5	-0.875	0.25	0.765	0	2853	2853	2082	-1630	452	2889
4	+0.5	-0.875	0.25	0.765	0	2853	2853	2082	1630	3712	4682
			1.00	3.06							

where

$$M = (1.59)(8327) = 13{,}240 \text{ in-lb}$$

$$P_{mx} = \frac{-MyA}{\Sigma Ax^2 + \Sigma Ay^2} = -\frac{13{,}240y}{4.06} = -3261y \qquad P_{my} = \frac{MxA}{\Sigma Ax^2 + \Sigma Ay^2} = 3261x$$

for

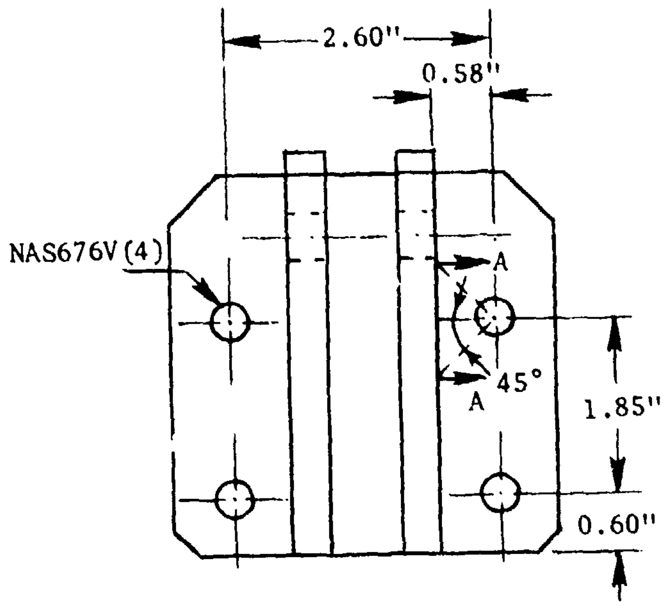
3/8" NAS676V bolts: P_{su} = 10,500 Pounds Reference NAS621

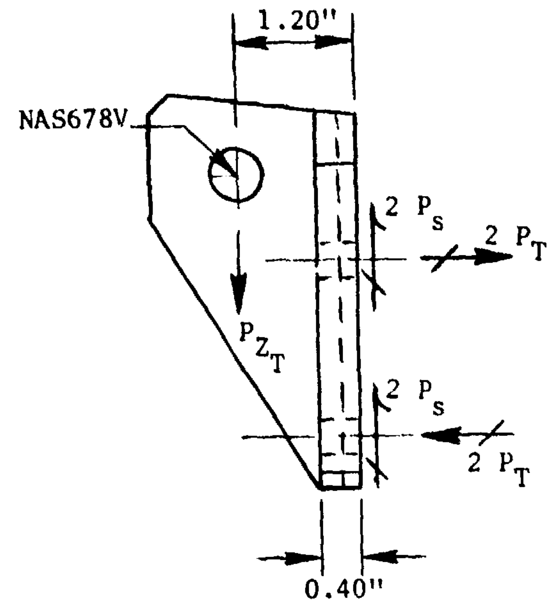
P_{su} = (10,500)(0.86) = 9030 Pounds @ 270°F (Reference 3, page 618)

$$MS = \frac{9030}{4682} - 1 = +0.93$$

4.3.2 Fittings

Forward Clevis Fitting





The forward clevis fittings function as connections between the forward support beam and the forward attach points. The maximum load occurs at the outboard fittings.

Material - 4130 Steel per MIL-S-6758

F_{tu} = 150,000 psi per MIL-H-6875

F_{tu} = (150,000)(0.97) = 145,500 psi @ 270°F

(Reference 3, page 102)

Forward Clevis Fitting (Continued)

Loading

Condition No. V C

$R_{Z10} = -4918 \text{ Pounds} = P_z$

Condition No. II B

$R_{Z10} = 11{,}133 \text{ Pounds} = T$

$P_{ZT} = P_Z + 1.15\ (T - P_Z)$

$P_{ZT} = -4918 + 1.15\ (11{,}133 + 4918)$

$P_{ZT} = 13{,}541 \text{ Pounds}$

$$P_T = \frac{(1.20)P_{ZT}}{2(1.85)} = \frac{(1.20)(13{,}541)}{2(1.85)}$$

$P_T = 4392 \text{ Pounds}$

Section A-A

$M = (0.58)P_T = (0.58)(4392)$

$M = 2547 \text{ in-lb}$

$$f_b = \frac{6M}{bt^2} = \frac{6(2547)}{(1.16)(0.40)^2}$$

$f_b = 82{,}338 \text{ psi}$

$f_{tu} = 145{,}500 \text{ psi}$

$$MS = \frac{F_{tu}}{f_b} - 1 = 0.77$$

Forward Clevis Fitting (Concluded)

Connection to Forward Support Beam

$P_s = P_{ZT}/4 = 13,541/4$

$P_s = 3385$ Pounds

$P_T = 4392$ Pounds

NAS676V

$P_{su} = 10,500$ Pounds Single Shear
Per NAS 621
$P_{tu} = 14,000$ Pounds

$P_{su} = (10,500)(0.86) = 9030$ Pounds
@ 270°F (Reference 3, Pages 617,618)
$P_{tu} = (14,000)(0.86) = 12,040$ Pounds

$R_s = \frac{P_s}{P_{su}} = 0.375$

$R_T = \frac{P_T}{P_{tu}} = 0.365$

$$MS = \frac{1}{(R_s^2 + R_T^2)^{1/2}} - 1 = +0.91$$

Connection to Attach Point

$P_s = P_{ZT} = 13,541$ Pounds

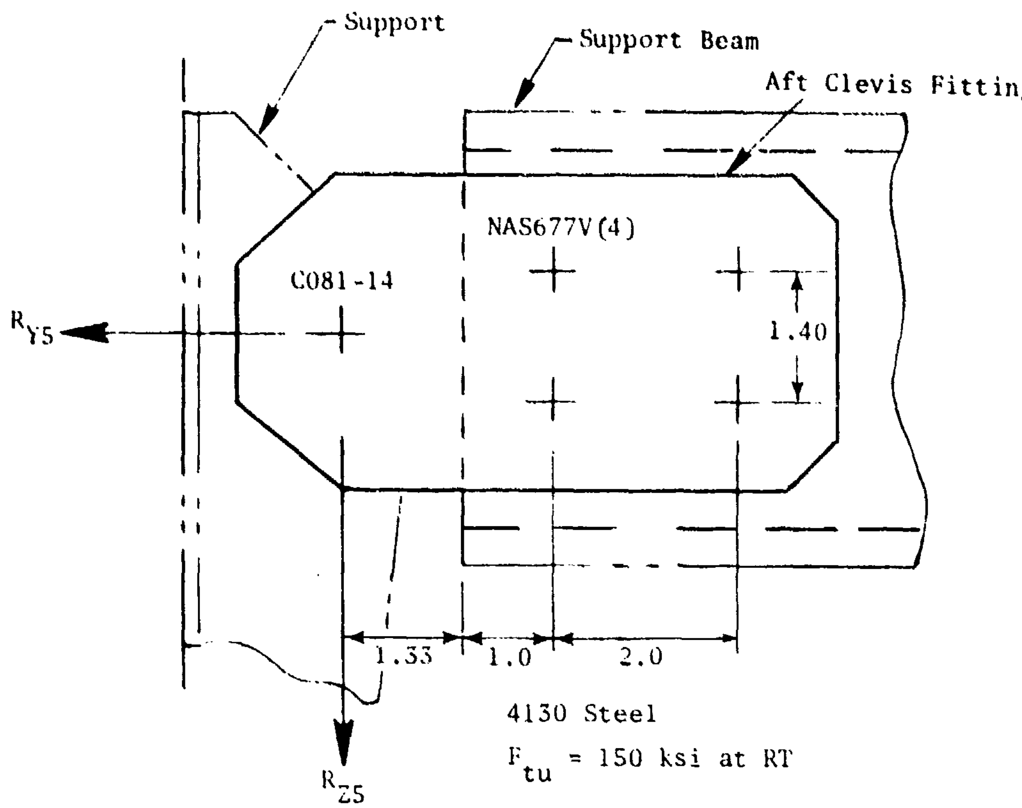
NAS 678V

$P_{su} = 37,300$ Pounds Double Shear Per NAS 621

$P_{su} = (37,300)(0.86) = 32,078$ Pounds (Reference 3, page 618)

$$MS = \frac{P_{su}}{P_s} - 1 = +1.37$$

Aft Clevis Fitting

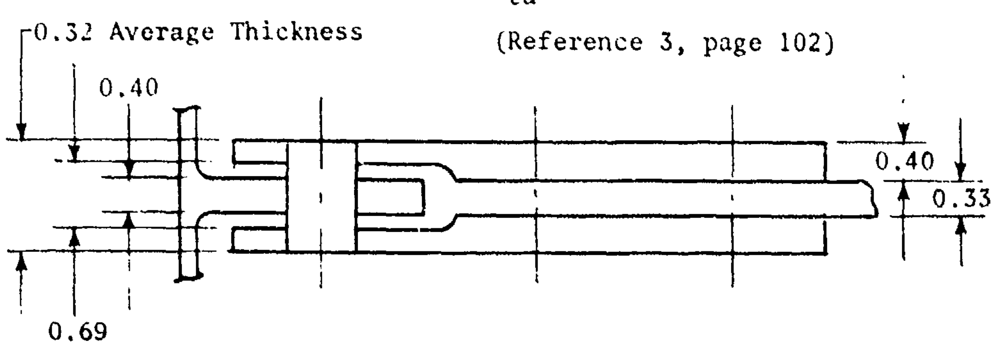


4130 Steel

F_{tu} = 150 ksi at RT

F_{tu} = 145.4 ksi at 270°F

(Reference 3, page 102)



Loads

Condition V B (Steady State) R_{Z5} = -3031 Lb

R_{Y5} = 886 Lb

Condition II A (Thrust) R_{Z5} = 11,657 Lb

R_{Z5} Total = 1.35(T) -0.35(S.S.)

= 1.35 x 11,657 - 0.35 x -3031

= 16,800 Lb

Aft Clevis Fitting (Continued)

Pin Bending

0.15 gap is left on each side of the C081-14 bolt to prevent the fitting from taking axial load.

$$b = \frac{F_1}{2} + \frac{t_2}{4} + g$$

t_1 = Outer Lug = 0.32 inch

t_2 = Center Lug = 0.40 inch

g = Gap = 0.15 inch

$$b = 0.16 + 0.10 + 0.15 = 0.41 \text{ inch}$$

$$M = \frac{Pb}{2} = 16{,}800 \times 0.205 = 3450 \text{ in-lb}$$

$$f_b = \frac{Mc}{I} = \frac{3450 \times 0.4375}{0.0288} = 52{,}500 \text{ psi bolt bending}$$

F_b of a 7/8-inch diameter C081-14 bolt is 220 ksi

$$MS = \frac{220 \times 1.7}{52.5} - 1 = \text{High}$$

where 1.7 = K for bending modulus of circular section

Lug Bearing

$$P_{bru} = K_{br} \times F_{tu} \times A_{br}$$

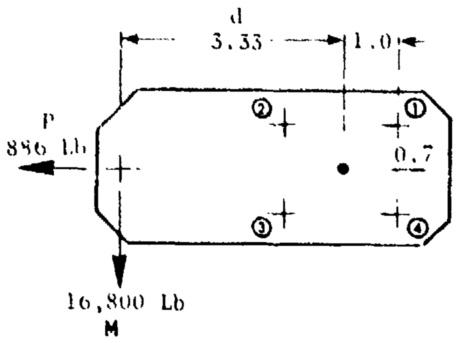
$$= 1.04 \times 145{,}500 \times 0.875 \times 0.32 \times 2 = 85{,}000 \text{ Lb}$$

$$MS = \frac{85{,}000}{16{,}800} - 1 = \text{High}$$

where K_{br} is a bearing factor.

Aft Clevis Fitting (Concluded)

Fastener Analysis



$$\Sigma X^2 + Y^2 = 4(1.0^2 + 0.7^2) = 5.96$$

$$P_d = P/4$$

$$P_m = \frac{Mu}{5.96}$$

$$R = \sqrt{Px^2 + Py^2}$$

No.	$\bar{x}$	$\bar{y}$	Pdx	Pmx	Px	Pdy	Pmy	Py	R
1	1.0	0.7	-222	-6560	-6782	-4200	+9380	+5180	8533
2	-1.0	0.7	-222	-6560	-6782	-4200	-9380	-13,580	15,179
3	-1.0	-0.7	-222	+6560	+6338	-4200	-9380	-13,580	14,986
4	1.0	-0.7	-222	+6560	+6338	-4200	+9380	+5180	8186

$R_{MAX} = 15{,}179$ Lb

$F_{bru} = 190$ ksi @ RT x 0.95 = 180 ksi @ 270°F (Reference 3)

$$f_{bru} = \frac{R_{max}}{A} = \frac{15{,}179}{0.33 \times 0.437} = 105{,}000 \text{ psi}$$

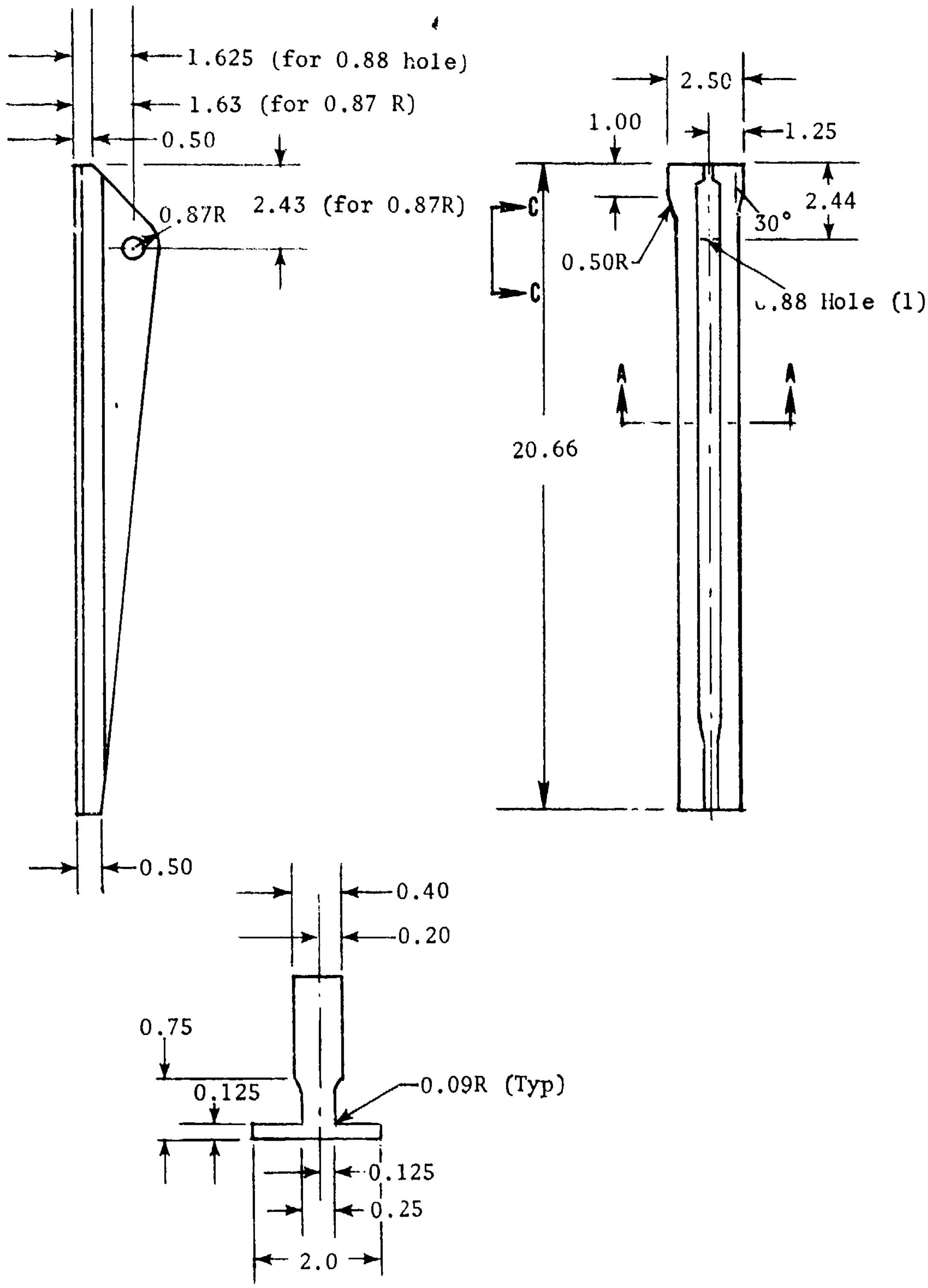
$$MS = \frac{180}{105} - 1 = +0.71$$

For a 7/16-inch-diameter 6AL-4V Titanium Bolt (NAS 677)

$P_s = 14{,}280$ Lb

$$MS = \frac{14{,}280}{\left(\frac{15{,}179}{2}\right)} - 1 = +0.88$$

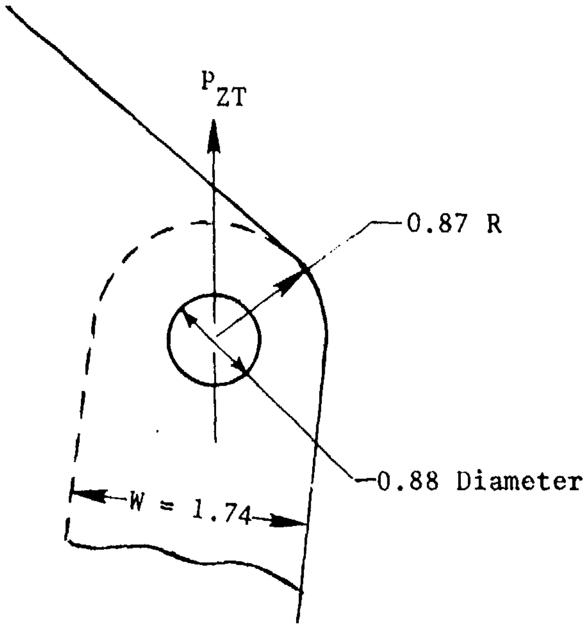
Support



Section A-A

Support

An analysis of the log located in the upper part of the beam (Section C-C) is made. An idealized lug is assumed.



Section C-C

Load Conditions:

$$P_{ZT} = P_Z + 1.35\ (T - P_2)$$

Condition II A gives R_{Z5}: $11{,}657 = T$

Condition V B gives R_{Z5} : $-3031 = P_Z$

(R_{Z5}, R_{Y5} are location points) R_{Y5}: $886 = P_Y$

(Reference ejection & inertia loads)

$$P_{ZT} = -3031 + 1.35\ (11{,}657 + 3031) = 16{,}800 \text{ Pounds}$$

Material

4130 heat treat steel @ 270° F (temperature factor, K = 0.97).

$$\left.\begin{aligned} F_{tu} &= (0.97)(150) = 145 \text{ ksi} \\ F_{ty} &= (0.97)(132) = 128 \text{ ksi} \\ E &= (0.97)(29 \times 10^6) = 28.13 \times 10^6 \text{ psi} \end{aligned}\right\} \text{(Reference 3, Page 100)}$$

Lug Check

P = 16,800 Pounds

Bearing - Tearout

$$P_{bru} = K_{bru}\ A_{br}\ F_{tu} = 0.82 \times 0.88 \times 0.40 \times 145{,}000 = 41{,}900 \text{ Lb}$$

where K_{bru} is a bearing factor $\quad MS = \frac{41{,}900}{16{,}800} -1 = +1.49$

Tension

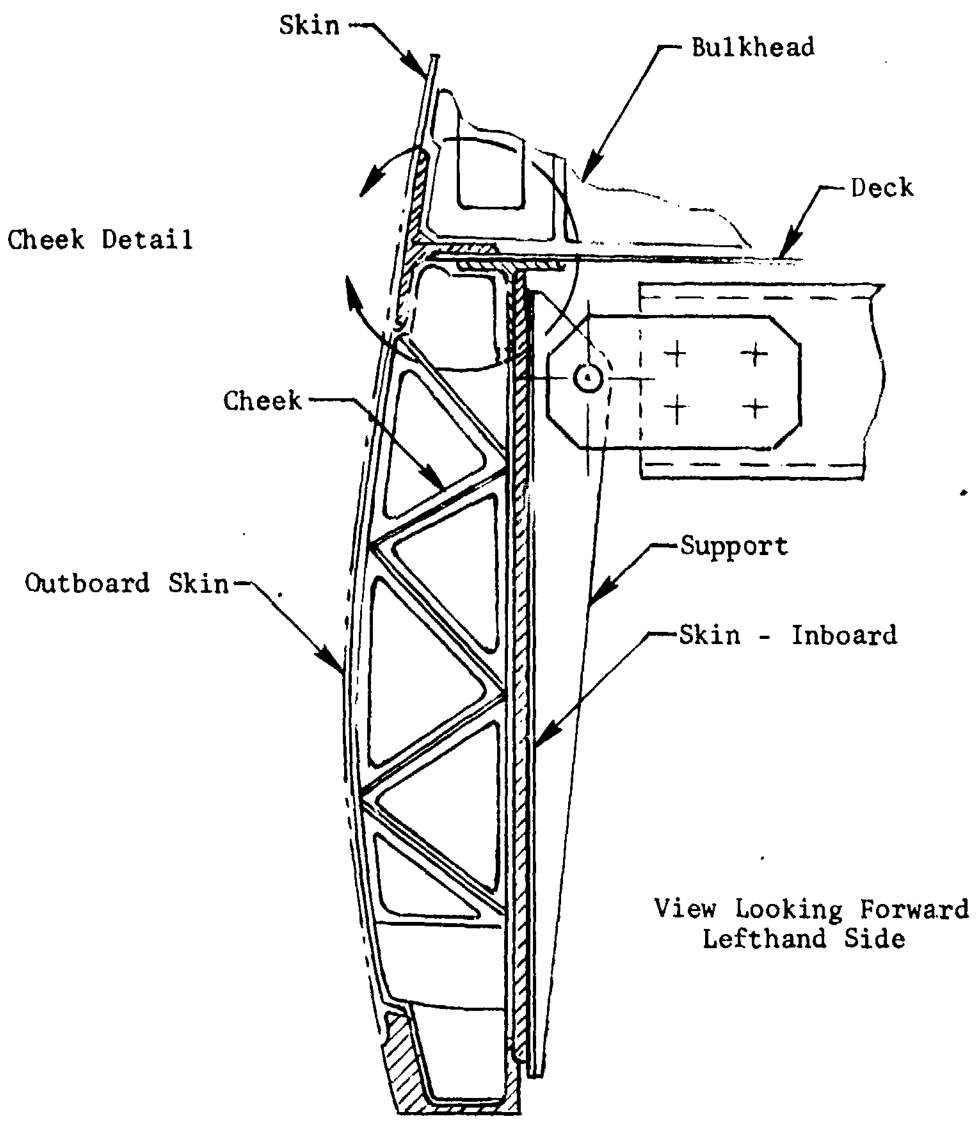
$$P_{tu} = K_t\ A_t\ F_{tu} = 0.93\ (1.74 - 0.88)(0.40)(145{,}000) = 46{,}400 \text{ Lb}$$

where K_t is a tension efficiency factor $\quad MS = \frac{46{,}400}{16{,}800} -1 = +1.76$

Shear Check

No shear check will be necessary because of the large number of fasteners on the rack support and the relatively small load.

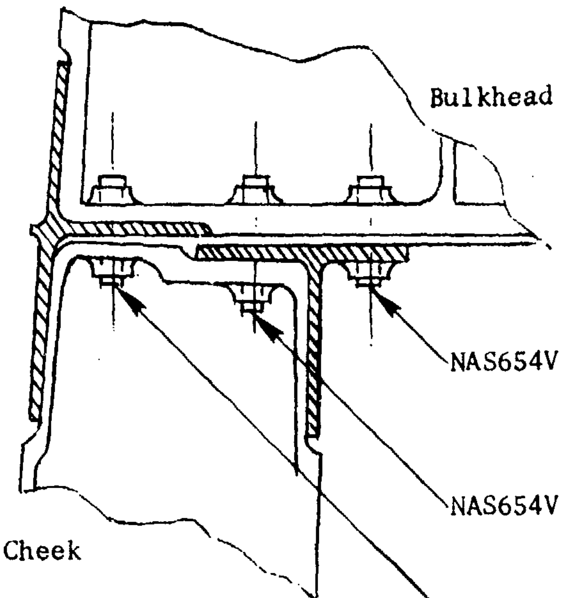
4.3.3 Fuselage Backup Structure - Aft Weapons Bay Rack



Cheek to bulkhead connecting bolts are the most critical items in the fuselage structure.

The four NAS654 bolts attaching the cheek to the bulkhead will be evaluated for down weapons load plus weapon bay door loads.

Support



Detail

The four bolts connecting the cheek to the bulkhead carry rack loads in addition to existing load from weapons bay doors. The two bolts from longeron to bulkhead are considered ineffective for rack loads.

$P_{7.33G}$ = 8120 Lb Ult   Condition VII C, R_{Z5}

P_{Rack} = 1760 Lb Ult   (1/4 of Rack Weight at 7.33 G)
9880 Lb Ult

Critical Bolt Load

1/4(9880) + 1/2(5185) = 5062 Lb

P_T, NAS654V = 5820 Lb

$$MS = \frac{5820}{5062} - 1 = +0.15$$

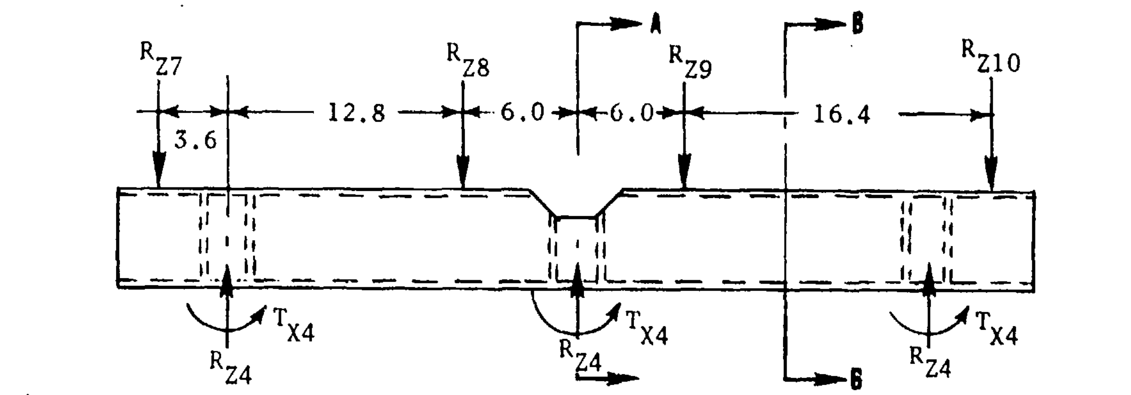
4.4 Sample Influence Coefficient Calculation

The beams to be evaluated are indeterminate members. In order to evaluate the structural adequacy of the members, they are converted to a series of determinate segments through use of the Hardy Cross iteration (Reference 4). A sample calculation is presented here using unit loads.

Forward Beam - Unit Loads

Drag Load (R_X) is distributed same as vertical load (R_Z)

Side Load (R_Y) is equally distributed to four supports



View Looking Aft at Forward Beam

Section A-A, $I = 3.14\ \text{In}^4$, $L = 12.0$ In.

Section B-B, $I = 13.90\ \text{In}^4$, $L = 16.4$ In.

$$\frac{I_{BB}}{I_{AA}} = \frac{13.90}{3.14} = \frac{4.42}{1.00}$$

Moment Distribution Factors

Section A-A, $I/L = \frac{1.0}{12.0} = 0.083$

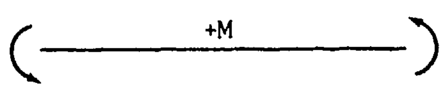
Section B-B, $I/L = \frac{4.42}{16.4} = 0.269$

$$\Sigma \frac{I}{L} = 0.352$$

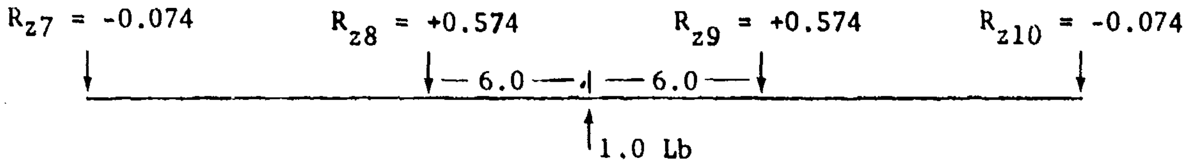
$$K_{AA} = \frac{0.083}{0.352} = 0.24$$

$$K_{BB} = \frac{0.269}{0.352} = 0.76$$

Fixed End Moment Sign Convention:



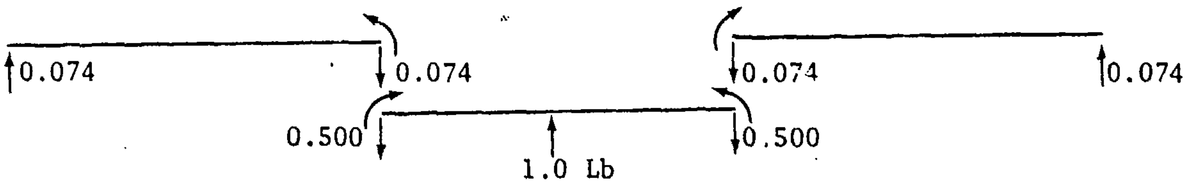
Vertical Load on Centerline Rack



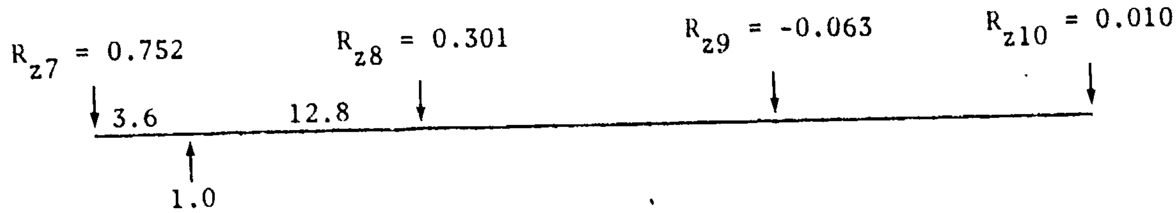
$$\text{Fixed End Moment} = \frac{Pab^2}{L^2} = \frac{1 \times 6 \times 36}{144} = 1.50 \text{ In-Lb}$$

$$a = b = 6.0 \text{ In}$$

1.0	0.76	0.24	0.24	0.76	1.0
0	0	-1.500	+1.500	0	0
0	1.140	0.360	-0.360	-1.140	0
0.570	0	-0.180	0.180	0	-0.570
-0.570	0.137	0.043	-0.043	-0.137	+0.570
0.068	-0.285	-0.021	0.021	0.285	-0.068
-0.068	0.232	0.073	-0.073	-0.232	0.068
0	1.224	-1.225	1.225	-1.225	0



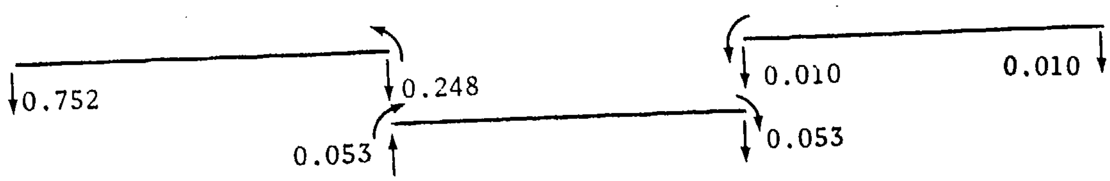
Vertical Load on Right Hand Rack



$$\text{Fixed End Moment} = \frac{Pab^2}{L^2} = \frac{1 \times 3.6 \times 12.8^2}{16.4^2} = 2.193 \text{ In-Lb}$$

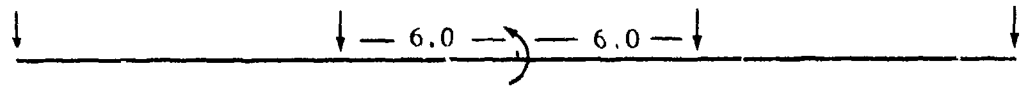
$$\text{Fixed End Moment} = \frac{Pa^2b}{L^2} = \frac{1 \times 3.6^2 \times 12.8}{16.4^2} = 0.617 \text{ In-Lb}$$

1.0	0.76	0.24	0.24	0.76	1.0
-2.193	+0.617	0	0	0	0
2.193	-0.469	-0.148	0	0	0
-0.234	1.096	0	-0.074	0	0
0.234	-0.833	-0.263	0.018	0.056	0
-0.416	0.117	0.009	-0.131	0	0.028
0.416	-0.096	-0.030	0.031	0.100	-0.028
-0.048	-0.208	0.015	-0.015	-0.014	0.050
0.048	-0.169	-0.054	0.007	0.022	-0.050
0	0.471	-0.471	-0.164	0.164	0



Torque on Centerline Rack

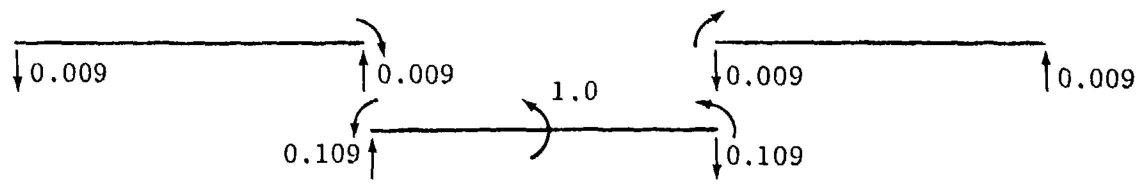
R_{z7} = +0.009 R_{z8} = -0.118 R_{z9} = +0.118 R_{z10} = -0.009



$$\text{Fixed End Moment} = \frac{mb}{L}\left(\frac{3a}{L} - 1\right) = \frac{1 \times 6}{12}\left(\frac{3 \times 6}{12} - 1\right) = 0.250 \text{ In-Lb}$$

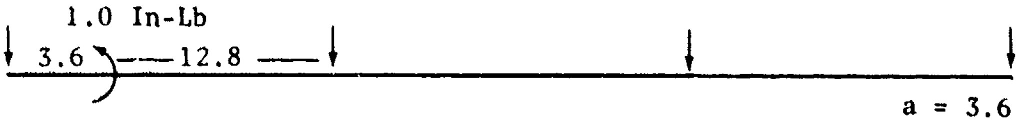
$a = b = 6.0$ In.

1.0	0.76	0.24	0.24	0.76	1.0
0	0	0.250	0.250	0	0
0	-0.190	-0.060	-0.060	-0.190	0
-0.095	0	-0.030	-0.030	0	-0.095
0.095	0.023	0.007	0.007	0.023	0.095
0.011	0.047	0.003	0.003	0.047	0.011
-0.011	-0.038	-0.012	-0.012	-0.038	-0.011
-0.019	-0.005	-0.006	-0.006	-0.005	-0.019
0.019	0.008	0.003	0.003	0.008	0.019
0	-0.155	0.155	0.155	-0.155	0



Torque on Right Hand Rack

$R_{z7} = -0.068$ $\quad R_{z8} = +0.081$ $\quad R_{z9} = -0.016$ $\quad R_{z10} = +0.003$



a = 3.6 In.
b = 12.8 In.

$$\text{Fixed End Moment} = \frac{mb}{L}\left(\frac{3a}{L} - 1\right) = \frac{1 \times 12.8}{16.4}\left(\frac{3 \times 3.6}{16.4} - 1\right) = -0.267$$

$$\text{Fixed End Moment} = -\frac{ma}{L}\left(\frac{3a}{L} - 1\right) = -\frac{-1 \times 3.6}{16.4}\left(\frac{3 \times 12.8}{16.4} - 1\right) = 0.292 \text{ In-Lb}$$

1.0	0.76	0.24	0.24	0.76	1.0
-0.267	0.292	0	0	0	0
0.267	-0.222	-0.070	0	0	0
-0.111	0.133	0	-0.035	0	0
0.111	-0.101	-0.032	0.008	0.027	0
-0.050	0.055	0.004	-0.016	0	0.013
0.050	-0.045	-0.014	0.004	0.012	-0.013
-0.022	0.025	0.002	-0.007	-0.006	-0.006
0.022	0.021	-0.007	0.003	0.010	0.006
0	0.116	-0.117	-0.043	0.043	0

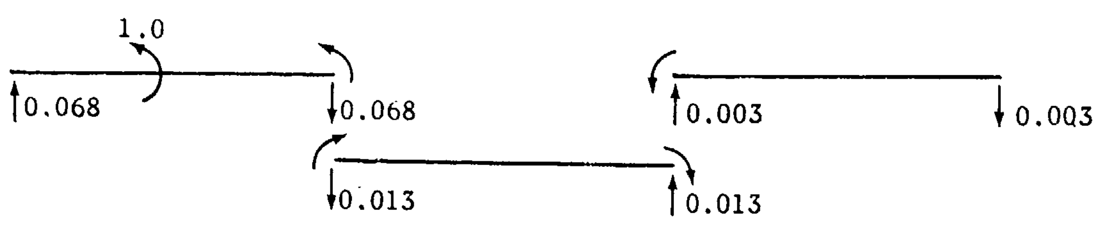


TABLE B-8. UNIT LOADS FORWARD BEAM - AFT WEAPONS BAY RACK

Condition	Reaction	R_{z4} LH	R_{z4} Center	R_{z4} RH	T_{x4} LH	T_{x4} Center	T_{x4} RH	Total Reaction R_{z4}	+ T_{x4}
3 Vert Loads	R_{z7}	0.752	-0.074	0.010	-0.068	0.009	-0.003	0.688	-0.062
3 Torques	R_{z8}	0.301	0.574	-0.063	0.081	-0.118	0.016	0.812	-0.021
	R_{z9}	-0.063	0.574	0.301	-0.016	0.118	-0.081	0.812	+0.021
	R_{z10}	0.010	-0.074	0.752	0.003	-0.009	0.068	0.688	+0.062
Centerline Load	R_{z7}	0	-0.074	0	0	0.009	0	-0.074	0.009
Centerline Torque	R_{z8}	0	0.574	0	0	-0.118	0	0.574	-0.118
	R_{z9}	0	0.574	0	0	0.118	0	0.574	0.118
	R_{z10}	0	-0.074	0	0	-0.009	0	-0.074	-0.009
Left Hand Rack	R_{z7}	0	0	0.010	0	0	-0.003	0.010	-0.003
Load and Torque	R_{z8}	0	0	-0.063	0	0	0.016	-0.063	0.016
	R_{z9}	0	0	0.301	0	0	-0.081	0.301	-0.081
	R_{z10}	0	0	0.752	0	0	0.068	0.752	0.068
Right Hand Rack	R_{z7}	0.752	0	0	-0.068	0	0	0.752	-0.068
Load and Torque	R_{z8}	0.301	0	0	0.081	0	0	0.301	0.081
	R_{z9}	-0.063	0	0	-0.016	0	0	-0.063	-0.016
	R_{z10}	0.010	0	0	0.003	0	0	0.010	0.003
Centerline Load	R_{z7}	0	-0.074	0	0	0	0	-0.074	0
	R_{z8}	0	0.574	0	0	0	0	0.574	0
	R_{z9}	0	0.574	0	0	0	0	0.574	0
	R_{z10}	0	-0.074	0	0	0	0	-0.074	0
Left Hand Rack	R_{z7}	0	0	0.010	0	0	0	0.010	0
Load	R_{z8}	0	0	-0.063	0	0	0	-0.063	0
	R_{z9}	0	0	0.301	0	0	0	0.301	0
	R_{z10}	0	0	0.752	0	0	0	0.752	0
Right Hand Rack	R_{z7}	0.752	0	0	0	0	0	0.752	0
Load	R_{z8}	0.301	0	0	0	0	0	0.301	0
	R_{z9}	-0.063	0	0	0	0	0	-0.063	0
	R_{z10}	0.010	0	0	0	0	0	0.010	0

SECTION V

SUMMARY AND CONCLUSIONS

The aft weapons bay rack with three 1000-pound bluff shaped bombs has been designed for the full F-111 flight envelope. Ejection is limited to +0.5g to +4.0g, the same as the existing limit for the F-111A. The minimum margin of safety is 29 percent for ejection loads on the aft support beam.

The fuselage backup structure is critical for the 7.33g flight condition. The minimum margin of safety is 15 percent on two bolts connecting the cheek to the bulkhead at station 448.

SECTION VI

PROOF TEST LOAD

Proof test load is 7.33g limit on the aft weapons bay rack including three MAU-12 ejector racks and three 1000-pound bombs.

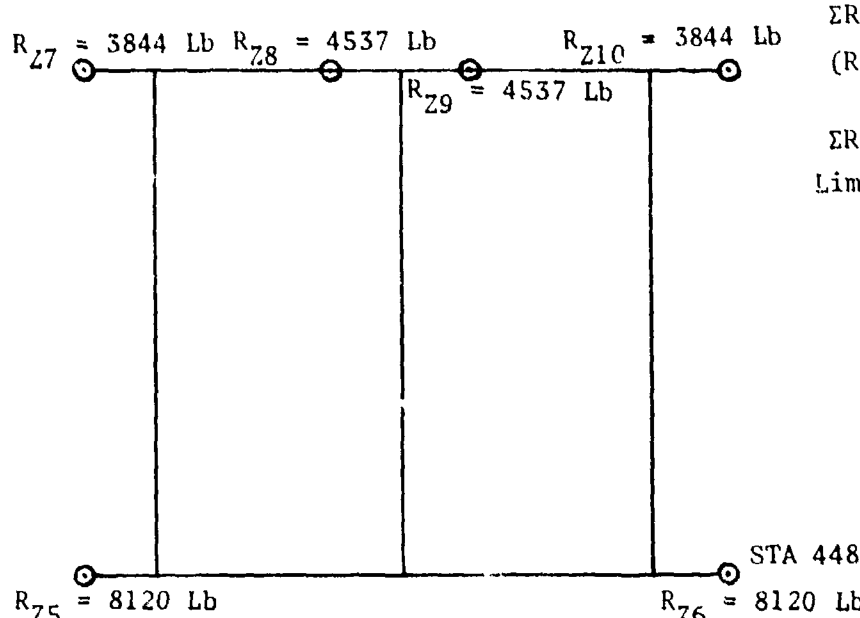
Load Due to Aft Weapons Bay Rack

$$P = 1 \times 400 \text{ Lb} \times 7.33g - 400^{*}\text{Lb} = 2530 \text{ Lb}$$

Load Due to 3 MAU-12 Ejector Racks

$$P = 3 \times 80 \text{ Lb} \times 7.33g = 1750 \text{ Lb}$$

Load Due to 3, 1000-Pound Bombs



Plan View

$\Sigma R_Z = 33{,}000$ Lb Ult
(Reference Condition VII C)

$$\Sigma R_{Z\,\text{Limit}} = \frac{33{,}000}{1.5} = 22{,}000 \text{ Lb}$$

Total Proof Test Load

$$P_{Total} = 2530 + 1750 + 22{,}000 = 26{,}280 \text{ Lb}$$

* Weight of Test Article

SUBSCRIPTS

a - Aerodynamic
Avg - Average
AW - Adiabatic Wall
b - Bending
br - Bearing
bru - Bearing Ultimate
bu - Bending Ultimate
c - Compression, Compressible
D - Drag
d - Due to Direct Load
h - Hoop
L - Lift
m - Due to Moment
NA - Neutral Axis
s - Shear, Structural
su - Shear Ultimate
t - Tensile
tu - Tensile Ultimate
U - Ultimate
v - Vertical
y - Yield
x, y, z - Orthogonal Axis
1, 2, 3, etc - Case in Point

LIST OF SYMBOLS AND ABBREVIATIONS

A - Area

all - Allowable

alt - Altitude

BHD - Bulkhead

b - Heigth

C - Coefficient

c - Distance to Moment Axis, Center Stress

cg - Center of Gravity

CL, ℄ - Centerline

D, d, dia - Diameter, Direct

e - Radius, Distance to Edge

E - Modulus of Elasticity

F - Force, Fahrenheit, Allowable Stress

f - Occurring Stress

FEM - Fixed End Moment

FS - Fuselage Station

FWD - Forward

g - Gravitational Acceleration

GW - Gross Weight

H - Horizontal

I - Moment of Inertia

K - Factor (Defined in Body)

k - Spring Rate

KCAS - Knots Calibrated Airspeed

L - Length

LIM - Limit

M - Moment, Mach Number

Max - Maximum

MS - Martin of Safety

MSL - Mean Sea Level

n - Normal Load Factor

P - Load

LIST OF SYMBOLS AND ABBREVIATIONS (CONCLUDED)

ΔP - Pressure

psi - Pounds per Square Inch

Q - Shear Volume

q - Dynamic Pressure

R - Reaction

rad - Radius

R - Resultant Load

RT - Room Temperature

S - Area

SL - Sea Level

T - Torque Reaction, Thrust (Ejector Force), Temperature

t - Thickness

ult - Ultimate

V - Velocity, Shear Load, Vertical

w - Running Load

x, y, z - Orthogonal Axes

$\overline{x}$ - Moment Axis Location

GREEK

α - Angle of Attack

β - Angle of Sideslip

Λ - Wing Sweep Angle

θ, $\dot{\theta}$, $\ddot{\theta}$ - Pitch Displacement, Velocity, Acceleration

ψ, $\dot{\psi}$, $\ddot{\psi}$ - Yaw Displacement, Velocity, Acceleration

ϕ, $\dot{\phi}$, $\ddot{\phi}$ - Roll Displacement, Velocity, Acceleration

δ - Total Stress

μ - Poisson's Ratio

τ - Shear Stress

Σ - Summation

ν - Specific Weight

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