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ASSESSMENT OF THE FLIGHT TEST METHODOLOGY AND SEPARATION CHARACTERISTICS OF THE AGM-154A JOINT STANDOFF WEAPON (JSOW) ON THE F/A-18C/D HORNET

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Daniel Keith Hinson

May 2006

DEDICATION

The man in the cockpit is often the most visible component of a tremendous team working tirelessly toward a common goal. In combat, the pilot's very life depends upon the skill and dedication of the crews that maintain and load the aircraft. In flight test, that team includes a cadre of highly skilled engineers and technicians from both industry and government, many of whom are all but invisible to the population of the country they protect. This thesis is dedicated to the men and women of the Joint Standoff Weapon (JSOW) Integrated Test Team who developed and cleared this revolutionary weapon for its continuing use in combat, and to those men and women across the country who continue to serve "behind the scenes" to make this country strong enough to carry the torch of freedom across the globe.



Figure 1

JSOW First Launch Aircrew and Ground Support Personnel, 13 December 1994

ACKNOWLEDGEMENTS

Separation testing of the AGM-154A Joint Standoff Weapon was a collaborative effort of countless personnel from Texas Instruments (TI), who developed the weapon, McDonnell Douglas Aerospace (MDA) Corporation, who developed the F/A-18, and the Naval Air Systems Command (NAVAIR), whose ranks included myriad government and contract program management and test personnel. The core test team at the Naval Strike Aircraft Test Squadron (now VX-23) consisted of the author (Project Officer), Mr. Mike Griffith (Project Engineer), Mr. Myles Landon and Mr. Skip Adams. Primary reference materials for this thesis included the test plans written and amended by both the author and Mr. Mike Griffith, and so it is appropriate to first acknowledge his efforts in the collaborative development of those documents, and to thank him for the benefit of his engineering expertise and flight test experience throughout the entire test and evaluation of the JSOW on the F/A-18.

Data reduction for this project was complex and extensive. Many members of the Integrated Test Team had some responsibility for analyzing and formatting collected data for presentation, but TI and MDA had the bulk of the responsibility for reducing electronic data into a useful format, which was critical for progression of the JSOW separation flight test and extraordinarily useful for reference in the development of this thesis. Myriad technical drawings and data analysis from a vast collection of post- and inter-flight reports were used throughout this thesis. Documents referenced were all property of the United States Government. Source information has been annotated on figures and tables, where appropriate. JSOW project photographs used in this document were taken by Mr. Vernon Pugh.

Finally, as the development of this thesis was an effort managed during the “after-hours” time of a full-time job, no list of acknowledgements would be complete without mention of my wife, Sarah, who enabled me to devote the time required by herself shouldering my portion of child-raising and house-keeping responsibilities. She was the key element in allowing me to finally convert 60 pounds of 11 year old documents and memories into a finished product.

ABSTRACT

Flight clearance for carriage and release of a weapon on board an aircraft is a complex process, and involves myriad tests in order to first establish a flight envelope within which separation testing may commence. Though the author was also integrally involved in the air worthiness testing that immediately preceded AGM-154A Joint Standoff Weapon (JSOW) separation and launch testing on the F/A-18 Hornet, this thesis will focus exclusively on those latter elements.

Developmental testing to establish safe separation for jettison and launch envelopes included fit checks, ground jettison tests, in-flight jettison tests from both outboard and inboard aircraft weapons stations and initial launch testing to establish the starting point for follow-on weapons systems testing. These tests began in early 1994, with the first JSOW jettison flight event happening on 8 March 1994 and the first launch on 13 December 1994. Though the test program is now dated, the analysis of the methodology successfully used in this program is as pertinent today as it was in 1994. Test methods discussed in this document remain the standard for ordnance separation testing, and review of how those methods were applied to the Joint Standoff Weapon test program ten years ago may still provide valuable insight to any organization attempting to discern the safest, most cost-effective method for conducting ordnance separation testing in modern test programs. The purpose of this thesis is to clearly document and assess the iterative flight test methodology used throughout the JSOW test program, and to also document in detail and draw conclusions based upon the results of the jettison and launch separation flight test program.

The desired F/A-18C/D launch envelope to be cleared in this case was 0.60 to 0.95 Mach, +10 to -45 degrees pitch angle and 200 ft AGL to 30,000 ft MSL. Separation testing consisted of both jettison and launch testing. As launch releases were predicted to exhibit better separation characteristics, the test matrix built up from the most benign to the most severe jettison condition, thereby clearing the launch envelope along the way. Once jettison testing was completed, a demonstration of the launch release at the most severe jettison condition was to be conducted to verify JSOW safe separation characteristics in the launch mode. Initial wind tunnel analysis predicted that at the most critical separation condition, the separating store would not only violate the safe release condition requirement of 6 inches clearance, but it would actually impact the fuel tank during separation.

Test methodology was fairly straight-forward – proceed through the flight test matrix until the edge of the envelope, as indicated by unsatisfactory jettison characteristics, was determined, then proceed with launch testing with active control surfaces until unsatisfactory separation characteristics or the full desired envelope were attained. In contrast, data collection, reduction and analysis techniques were extensive and

complex. As each JSOW test point necessarily expended a valuable (and expensive) test asset, it was hoped that by investing in a robust separation model based initially upon wind tunnel analysis, and by updating that model with separation data derived from photogrammetric analysis and on-board aircraft and weapon telemetry data during separation, the fidelity of that separation model could be improved and validated adequately such that some planned separation test points could be skipped. The data collection effort included photogrammetric targeting of launch aircraft and weapons, on-board high speed cameras, on-board aircraft and weapon telemetry of multiple parameters, and ground and chase aircraft video.

A total of 15 flights expending 12 JSOW test vehicles were required to clear the jettison envelope for the outboard station between 8 March 1994 and 12 October 1994. Three more flights expending three additional JSOW test vehicles were required to clear the inboard jettison envelope between 18 October 1994 and 1 December 1994. JSOW positional data derived from aircraft and weapon telemetry and photogrammetric analysis were successfully used to update and validate the JSOW separation mode, which enabled the omission of five test points. Separation characteristics were satisfactory for each of the 15 JSOW jettison test points. Separation characteristics of the JSOW in the launch mode matched predictions and met all requirements of the specification for release, thus clearing the flight envelope for follow-on functional testing of the weapon in-flight.

Conclusions are drawn upon the applicability and effectiveness of the flight test methodology, and upon the separation characteristics of the JSOW from the F/A-18 throughout the separation test program. For the high profile JSOW test program, the iterative modeling and simulation used throughout separation testing was extremely effective at improving overall test safety and efficient use of extremely expensive test assets. For future test programs that may benefit from the extensive lessons learned with iterative modeling and simulation using multiple data sources in this test program, the author recommends consideration of methodology similar to that used for AGM-154A JSOW. The author also emphatically recommends use of the Integrated Test Team concept for future test programs, wherever feasible. Finally, the author makes specific recommendations as pertains to the jettison and launch envelopes of the AGM-154A JSOW when released from the F/A-18C/D aircraft.

PREFACE

Development of the AGM-154A Joint Standoff Weapon (JSOW) ushered in a new generation of weapons used in strike warfare, the Global Positioning System (GPS) guided weapons. But development of a new weapon is only part of the effort required in development of a functional airborne weapon system, and integration of that weapon onto the aircraft that will employ it in combat is a significant endeavor. The U.S. Navy F/A-18C Hornet was selected as the first aircraft to integrate the AGM-154A JSOW, and by November of 1993, the weapon was ready for air worthiness flight testing. After the flight envelope was defined through air worthiness flight testing, weapon separation testing could proceed. The purpose of the JSOW separation flight test program was simply to clear the weapon for jettison and follow-on flight testing to eventually establish the full launch envelope required for combat employment. Though much of the same data used for evaluation of suitable employment envelopes are necessarily included in this thesis, the primary purpose of this document is to describe how the use of a unique, iterative flight test methodology enabled safe, cost-effective clearance of those jettison and launch envelopes.

Success of the JSOW program hinged on the extraordinary efforts of hundreds of dedicated individuals from industry, from the Naval Air Systems Command (who sponsored the program) and from the Integrated Test Team. The author's role in the Integrated Test Team was that of Project Officer, specifically responsible for co-leadership (with a Project Engineer, Mr. Mike Griffith) of the Developmental Testing Phase IIA portion of the overall test program, wherein the weapon system jettison and initial launch envelopes were established. The author also personally piloted the flight tests for first jettison, all envelope end-point tests and the first JSOW launch – expending a total of six JSOW test vehicles in the process.

Much of the material forming the basis for the beginnings of this thesis was adapted from the author's original work as part of the test team that created the test plans under which the Joint Standoff Weapon was tested. Specifically, sections from those test plans were used as a starting point for Test Aircraft and Test Weapon Descriptions, Scope and Method of Tests, though they were adjusted, combined and added to, where required, to fit the context of this document. The remaining chapters of this document, including Chronology, Results and Discussion, Conclusions and Recommendations, and the Epilogue represent the efforts of the author alone. Interpretation of photographic evidence since transferred to videotape was conducted and reported upon by the author, though photogrammetric and telemetry data analysis was conducted as indicated for each source listed. Views and opinions discussed in this thesis are these of the author alone, and do not necessarily represent the official position of the United States Navy.

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NOMENCLATURE

deg	degree
ft	feet
fps	feet per second
g	normal force of gravity (also “G”)
HP	pressure altitude
IMN	indicated Mach number
in	inch
KCAS	knots calibrated airspeed
KTAS	knots true airspeed
msec	millisecond
NM	nautical mile
s	second
sec	second
VAC	volts, alternating current
VDC	volts, direct current

Acronyms and Abbreviations

ACPS	armament control processor set
ADF	automatic direction finding
ADM	advanced development model
A/G	air-to-ground (F/A-18 weapon system master mode)
AGL	above ground level
AGM	air to ground missile (designation, as in AGM-154A or AGM-188)
AID	air inflated decelerator
AIM	air intercept missile (designation, as in AIM-7)
AIWS	Advanced Interdiction Weapon System
AMAC	armament monitor and control
AOA	angle of attack
AOC	active oscillation control (an F/A-18 flight control computer subroutine)
ASIM	Aircraft Stores Interface Manual
ATA	autonomous target acquisition
ATACS	automated tactical manual supplement
ATP	air transport pilot (FAA pilot certification)

AWT	air worthiness testing
BIT	built in test
BLU	bomb live unit (designation, as in BLU-97 or BLU-108)
BROACH	bomb royal ordnance augmenting charge
BRU	bomb rack unit (designation, as in BRU-32)
CAD	cartridge actuated device
CATM	captive air training missile (designation, as in CATM-7)
CBU	cluster bomb unit (designation, as in CBU-87)
CCU	cartridge unit (designation, as in CCU-45/B)
CEB	combined effects bomblet
CF	captive flight
CG	center of gravity
CTR	Chesapeake Test Range (now Atlantic Test Range, Patuxent River, MD)
CV	conventionally powered fixed-wing aircraft capable aircraft carrier
CVN	nuclear powered fixed-wing aircraft capable aircraft carrier
DC	direct current
DDI	digital display indicator
DOF	degree of freedom (as in 6-DOF, six degree of freedom)
DR	dress rehearsal (flight)
DT	developmental test
DT-IIA	developmental test phase IIA
DT-IIB	developmental test phase IIB
FF	free flight
FOD	foreign object damage
FPA	flight path angle
FRP	full rate production
FTEG	Flight Test and Engineering Group (Patuxent River, MD)
FTS	flight termination system
GEU	guidance electronics unit
GPS	global positioning system
HARM	High Speed Anti-Radiation Missile (designated AGM-88)
HUD	head’s up display
HPC	Harpoon missile version C (designated AGM-84C)
IBIT	initiated built in test
IM	insensitive munition
IMU	inertial measurement unit

IOC	initial operational capability
JDAM	Joint Direct Attack Munition
JSOW	Joint Standoff Weapon
LBA	limits of the basic aircraft
LEX	leading edge extension
LOS	line of sight
MDA	McDonnell Douglas Aerospace Corporation
MMD	minimum miss distance
MSL	mean sea level
MUX	multiplex (as in multiplex bus)
NATC	Naval Air Test Center (as in NATCINST, which references an NATC instruction)
NATOPS	Naval Air Training and Operating Procedures Standardization
NAVAIR	Naval Air Systems Command (also NAVAIRSYSCOM)
NAWCAD	Naval Air Warfare Center Aircraft Division (Patuxent River, MD)
NAWCWD	Naval Air Warfare Center Weapons Division (China Lake, CA)
NORM	normal (as in a switch position)
NZ	normal force, z axis (measured in units g)
OFP	operational flight program
ORIDE	override
OSW	Operation Southern Watch
OT	operational test
PCM	pulse code modulation
PEO(T)	Program Executive Officer, Tactical Aircraft Programs (NAVAIR, Patuxent River, MD)
PMA-201	Program Manager, Conventional Weapons (NAVAIR, Patuxent River, MD)
RAD	ram air decelerator
RC	release consent
RCO	range control officer
SDF	six degree of freedom (synonymous with 6-DOF, but used by MDA versus TI)
SEC	source error correction
SERGRAD	selectively retained graduate (Navy aviation flight training instructor pilot program)
SQIDS	super quick installation data system
SMP	stores management panel
SMS	stores management set
SPINS	special instructions
STV	structural test vehicle
SUU	support unit (designation, as in SUU-63 pylon)

TACMAN	tactical manual
TI	Texas Instruments
TIK	telemetry instrumentation kit
TM	telemetry
UHF	ultra high frequency
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
USNTPS	United States Naval Test Pilot School (Patuxent River, MD)
USS	United States ship
VDC1	volts, direct current, F/A-18 electrical bus number 1
VDC2	volts, direct current, F/A-18 electrical bus number 2
VMC	visual meteorological conditions
VX	Navy designation for fixed wing, experimental squadron (as VX-23)
ZRF	zero retention force (solenoid)

CHAPTER I
INTRODUCTION AND GENERAL INFORMATION

Introduction

The test program and events discussed in following paragraphs occurred more than ten years ago. Not surprisingly, some of the organizational names have changed since then. Most notably, McDonnell Douglas Aerospace has become part of the Boeing Company, Texas Instruments has become part of the Raytheon Company, and the Navy Flight Test and Engineering Group has become the Test Wing Atlantic, while the subordinate Strike Aircraft Test Directorate became the Naval Strike Aircraft Test Squadron and finally Experimental Test Squadron (VX) 23. For consistency with the period referenced, the names of each organization have been left unchanged. Though the test program is now dated, the analysis of the methodology successfully used in this program is as pertinent today as it was in 1994. Test methods discussed in this document remain the standard for ordnance separation testing, and review of how those methods were applied to the Joint Standoff Weapon test program ten years ago may still provide valuable insight to any organization attempting to discern the safest, most cost-effective method for conducting ordnance separation testing in modern test programs. The purpose of this thesis is to clearly document and assess the iterative flight test methodology used throughout the JSOW test program, and to also document in detail and draw conclusions based upon the results of the jettison and launch separation flight test program, overall.

Background Information

In the early 1990s, the AGM-154A Joint Standoff Weapon (JSOW) was the "next generation" standoff weapon, and was developed by Texas Instruments (TI). The tactical glide weapon was to be launched from both existing and future United States Navy (USN), United States Marine Corps (USMC) and United States Air Force (USAF) aircraft. It was to provide a surface attack weapon capability against a wide spectrum of land and sea targets during day or night, and under all-weather conditions. The Navy was the lead service for JSOW, and had selected the F/A-18C/D as the initial JSOW integration launch platform. The Advanced Interdiction Weapon System (which became JSOW) System Specification, reference 1, required that it could be carried throughout the full subsonic aircraft envelope and supersonic dash capability on the F/A-18 with minimum restrictions. The System Specification also required a launch envelope of 0.60 to 0.95 IMN, +10 to -45degrees pitch angle (and 15 degrees roll) and release altitudes from 200 ft AGL to 30,000 ft MSL. The JSOW integrated test team consisted of (at the time) Navy Flight Test and Engineering Group (FTEG), McDonnell Douglas Aerospace (MDA) and TI personnel. JSOW Air

Worthiness Testing began at Patuxent River in November 1993. MDA completed flutter, Active Oscillation Control (AOC), captive loads and adjacent store ejection testing in March 1994. The Navy completed F/A-18 flying quality and performance, noise and vibration and carrier suitability flight testing of the JSOW in July 1994. Jettison testing of the JSOW was required in order to establish a safe separation envelope for the weapon, and began in March 1994 with outboard jettison of the JSOW with and without an adjacent fuel tank. Testing of separation characteristics from the inboard stations was added to the original separation test plan in October 1994, and launch (defined as active control fins and wing deployment) testing began with the first launch in December 1994.

Purpose of the Test Program

The overall purpose of store compatibility testing aboard an aircraft is to ensure the weapon system's compatibility across the spectrum of aerodynamic interface, electric interface, safe separation, carrier suitability, cockpit controls and displays, and the capability to be employed in its designed modes of operation. Necessarily, a flight envelope must first be established prior to separation testing. Once at least a preliminary flight envelope has been established, safe separation testing may commence. In the case of the AGM-154A JSOW, the complex weapon system had a jettison mode in which its control fins were inactive and wings did not deploy. Because the jettison mode was predicted to be the most critical mode for separation characteristics, separation testing proceeded in this mode until a suitable separation envelope could be established, whereupon launch (active control fins and wing deployment) separation testing could commence. The purpose of JSOW program flight testing was to first establish and recommend a jettison release envelope, then establish and recommend a launch release envelope for the JSOW on F/A-18C/D fleet aircraft. Specific objectives to be completed during the first launch further included: verification of correct operation of the JSOW in a captive environment, demonstration of safe separation of a JSOW launched from an F/A-18 aircraft, demonstration of safe wing deployment following JSOW launch, demonstration of safe controlled free-flight capability of a JSOW, collection of JSOW free-flight aerodynamic missile data, verification and effectiveness evaluation of the Flight Termination System (FTS), and demonstration of JSOW structural integrity before and after command destruct.

CHAPTER II
DESCRIPTION OF TEST AIRCRAFT AND MODIFICATIONS

Description of the F/A-18C/D Aircraft and Components

F/A-18C/D Aircraft General Information

The F/A-18C/D Hornet (figure 2) was a single (F/A-18C) or dual seat (F/A-18D), dual-engine, supersonic fighter attack aircraft originally built by MDA (now a wholly owned subsidiary of Boeing). The aircraft was intended for the all-weather intercept, identify, destroy and ground attack missions. Designed to be powered by two General Electric F404-GE-400 or F404-GE-402 turbofan engines with afterburner, flight test aircraft were powered by F404-GE-400 engines. Distinguishing aircraft features included a pressurized cockpit enclosed by an electrically operated clam shell canopy, a variable camber mid-fuselage wing with fuselage mounted leading edge extensions (LEXs), and twin vertical stabilizers, which were angled 20 degrees outboard and located well forward of the slab-type horizontal stabilators. Flight control was accomplished via a four-channel dual computer flight control system, and all flight control surfaces were hydraulically operated. The speed brake was mounted on the top side of the aft fuselage between the vertical stabilizers. The aircraft was configured with nine external weapon stations (numbered sequentially from the left wingtip to the right), five of which were designed to be capable of carrying and releasing air-to-ground ordnance. The stations known as the outboard stations were numbered 2 and 8, while the inboard stations (closest to the fuselage) were numbered 3 and 7. Stations 4, 5, and 6 were not capable of carrying the AGM-154A Joint Standoff Weapon. An integrated Stores Management Set (SMS) computer with a MIL-STD-1553 data bus was used for armament system control.



Figure 2
The F/A-18C Hornet

The SMS software loads used during these tests included Operational Flight Program (OFP) 89A and 91C. Weapon codes for each station were entered into the Stores Management Panel (SMP), figure 3. Since software integration (which required an F/A-18C) was not critical for the initial phases of flight testing, an earlier series F/A-18A was used for the first few flights of the separation test program. The test aircraft, Bureau Numbers 161925 (F/A-18A number 87 (A87), side number 106) and 163476 (F/A-18C number 37 (C37), side number 101) were representative of fleet aircraft for the purposes of this evaluation. A more detailed description of the F/A-18 aircraft is presented in the F/A-18 NATOPS Flight Manual, reference 2.

BRU-32 Ejector Rack

The F/A-18 aircraft utilized the BRU-32 as its parent rack. BRU-32 bomb ejector racks were designed to be used to suspend single stores, multiple bomb racks and missile launchers using either 14 or 30 inch suspension hooks. Features of the bomb rack included safety interlocks and automatic sway bracing. Sensing switches were used to indicate to the armament computer that a store or suspension unit was loaded. The primary ejector unit used two CCU-45/B cartridge actuated devices (CADs) to generate the required gas pressure for normal release or for select and emergency jettison of a single store or rack-launcher. Independent ignition wiring went to each cartridge, and firing of any one cartridge was designed to sympathetically fire the other cartridge. The auxiliary release system in the unit used on Mk 19 MOD 0 CAD, which was designed to open the hooks only should be the select and emergency jettison modes fail. Two zero retention force (ZRF) solenoid electromechanical arming units were provided for "nose" and "tail" fuze arming of mechanically fuzed bombs. A Mk 39 receptacle which mated with the Mk 122 switch assembly was provided for electrical fuzing functions. The Aircraft Stores Interface Manual (ASIM) for Suspension Equipment, reference 3, provides more detailed information about the BRU-32 ejector rack. More information about the CCU-45/B can be found in NAVAIR publication NA 11-100-1.3, reference 4.

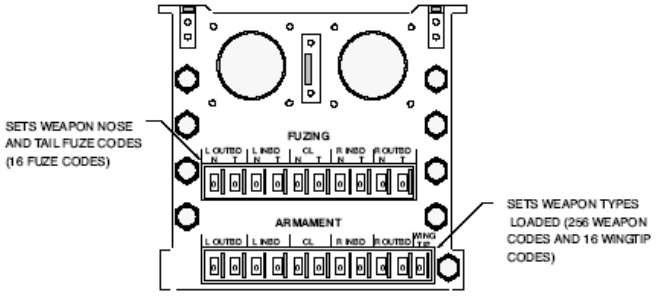


Figure 3

F/A-18 Stores Management Panel

Source: *Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13C System Configuration Set (13C SCS),* NAWCWD, China Lake, July 1998.

Aircraft Flight Test Modifications

Camera Systems

Standard Ordnance Separation Flight Test Cameras. Both flight test aircraft were equipped with externally mounted 16 mm cameras to provide adequate release coverage. Capable of operating at selectable speeds, all external cameras used throughout this test were set to 200 frames per second. Controls for the cameras were pushbutton type, located on the left console and instrument panel of the test aircraft. Standard cameras could be mounted on the wingtip stations (1 and 9), the fuselage stations (4 and 6) and under the tailhook on the aft belly of the aircraft (looking forward). A wing video camera replaced the AIM-7 antenna on the port wing of F/A-18 C37 (side number 101) between stations 2 and 3, and provided a downward view of the JSOW as it separated. The camera locations for both aircraft are presented in appendix A (figure A-7).

Nose Camera. The nose camera was internally mounted in place of the Automatic Direction Finding (ADF) antenna and flush deck plate with part of the gun system removed to provide internal space for the camera unit. The camera was equipped with a 90 degree lens protected by a metal fairing. Source Error Correction (SEC) calibration flights were conducted to determine the errors caused to the pitot-static system by the fairing, and the resultant air data corrections were incorporated into the flight tests.

Pylon Camera. A pylon camera was installed in the station 2 SUU-63 pylon and provided a downward view of the store during release. The camera was installed in the pylon where the encoder-decoder was normally installed and the encoder-decoder was moved to the Armament Monitor and Control (AMAC) compartment.

Photogrammetric Targets. To enable photogrammetric analysis post-flight, each test aircraft had to be configured with photogrammetric targets. These targets would form the reference against which relative JSOW position during separation would be derived through analysis of high speed film. A more detailed discussion regarding the use of photogrammetric analysis is contained in Method of Test. Figures A-1 and A-2 (located in appendix A) indicate JSOW and launch aircraft photogrammetric targeting schemes.

Aircraft Electrical Systems

IR COOL Switch. Electrical integration for this test was not per the standard F/A-18 Armament System, so a number of changes were incorporated to provide the capability to directly control voltage and firing

signal to the JSOW Structural Test Vehicle (STV) under test. A jumper was installed in the Armament Control Processor Set (ACPS) to enable the IR COOL switch, depicted in figure A-3, to be used to control 28 VDC1 to the JSOW STV. Toggling the IR COOL switch twice (from ORIDE to NORM) was required to put the JSOW STV-F into the simulation mode, when appropriate.

Select Jettison Configuration Changes. For normal weapon release operations, release consent signal from depression of the release consent button on the flight control stick would be the aircrew signal to the armament computer for weapon release. For JSOW flight tests, that release consent signal was used to irreversibly initiate the thermal batteries within the JSOW STV, which were used to power the test instrumentation and telemetry kit inside the test vehicle. As the normal release consent switch was therefore not available to command release, weapon release for each JSOW STV was commanded by actuation of the normal F/A-18 selective jettison functionality. As indicated in figure A-3, the selective jettison push button is on the same side of the cockpit as the emergency jettison push button, a characteristic which contributes to the occasional unintentional jettison of all aircraft stores via inadvertent actuation of the emergency jettison push button instead of the selective jettison push button. In order to avoid that expensive mistake during the JSOW test program, the emergency jettison push button was covered with a plastic avionics connector dust cap (connected to the emergency jettison push button by a rubber band) immediately before each live jettison. So that emergency jettison was available if required for the remainder of the flight, that cover was removed immediately following each live jettison, and removed from the cockpit after each flight (to prevent the potential for introduction of uncontrolled foreign object damage (FOD) material into the cockpit and aircraft).

CHAPTER III
DESCRIPTION OF TEST WEAPON AND MODIFICATIONS

Description of the AGM-154A Joint Standoff Weapon (JSOW)

AGM-154A JSOW General Information

The baseline AGM-154A JSOW variant was the first of a series of weapons, designed to be a conventionally armed, air launched surface attack glide weapon providing an intermediate standoff capability. The baseline JSOW variant, depicted in figure 4, was 160 inches long and weighed 1065 pounds. The basic weapon consisted of an aerodynamically efficient airframe with spring loaded 14 and 30 inch suspension lugs, folding wings and six non-folding tail surfaces. Four of the tail fins were designed to become active after release (for in-flight control and separation stability), while the two horizontal tail fins remained fixed for separation stability. After release from the launch aircraft, the tactical JSOW was designed to deploy its wings and guide itself to the target by an integrated navigational system consisting of a ring laser gyro Inertial Measurement Unit (IMU) and Global Positioning System (GPS). JSOW on-board computers were designed to calculate trajectories using either a direct or pre-planned waypoint route to the target area, where the weapon was designed to command an airborne dispense of 145 BLU-97 Combined Effects Bomblet submunitions. Details of the BLU-97 submunitions are contained in appendix C. Future variants and upgrades of the JSOW were planned to include BLU-108 submunitions, a unitary warhead and a terminal guidance system. Figure A-4 depicts an exploded view of the AGM-154A JSOW.

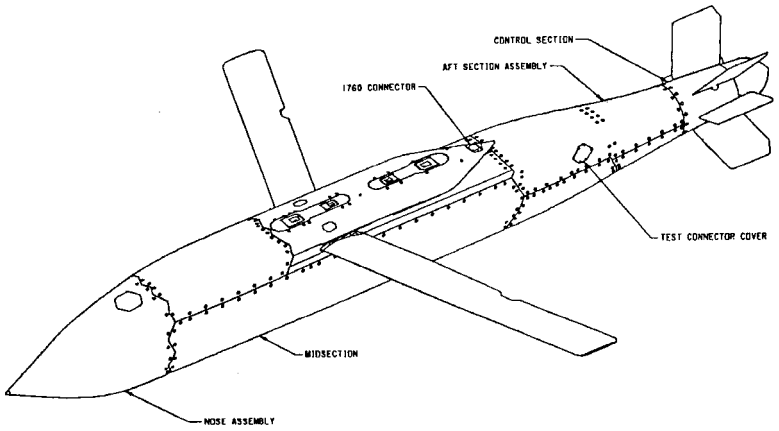


Figure 4

AGM-154A Joint Standoff Weapon (JSOW)

Source: Texas Instruments, *JSOW TRR F/A-18, AV-8B, A-6E, F-14 Fit Checks Meeting Minutes,* 4 October 1993.

Control Fins

The four moveable control fins were mounted to the control section at a 25 degree sweep angle and were locked in place at zero position for captive flight by two spring lock pins. Release of the control fin pins was automatically commanded by the Guidance Electronics Unit (GEU) when the JSOW batteries came on-line. Pyrotechnic devices (squibs) would detonate two gas generators to retract the locking pins. One gas generator would retract the two pins holding the two upper fins and one would release the two lower fins. The retracted pins would be held in place by spring clips to prevent the fins from relocking during flight. After activation of the gas generators, the GEU would perform a fin dither test to verify that all four fins had been unlocked. The test would command the fins to 2 degrees and then back to 0 degrees, where they were designed to remain until active control began after launch. Active control of the fins was designed to begin 39 to 52 msec after weapon release and was designed to initially zero out the angular motion caused by the flow field around the F/A-18 and JSOW. At 350 msec after release, the pitch control was designed to command the weapon to fly at 5.5 degrees angle of attack until just before wing deployment. The GEU would not initiate explicit path control until 350 msec after release. Control fins were locked in place for jettison tests, but were allowed to operate normally for the launch testing.

Wings

For a launch event, the wings were to be stowed and locked in the folded position until commanded to deploy after the JSOW was launched. While in the stowed position, the wing deployment driver was pinned and the system vented via a solenoid valve to prevent inadvertent deployment due to gas generator failure. Deployment of the wings was to be commanded after launch when vertical separation from the launch aircraft was greater than 30 feet, Mach number was less than 0.85 IMN and vertical acceleration of the weapon was less than 2.0 g. The weapon was designed to determine separation distance by assuming the aircraft continued flying the same flight path and velocity after release, calculate the new aircraft position, and compare it to the displacement (determined by the IMU) of the JSOW from the release point. When all wing deployment criteria had been met, the GEU would close the solenoid valve on the driver unit to prevent venting and fire the pyrotechnic devices (squibs) to detonate the gas generator. With the solenoid in the closed position, gas pressure would unseat the locking pin and drive the piston forward. The piston drove a single yoke assembly that was mechanically linked to both wings precluding inadvertent deployment of a single wing. When the piston reached the full open position (wings fully deployed), it would be locked in place by a spring loaded pin. Once open and locked, the wings could not be retracted. If a failure in the system prevented the piston from reaching the full open and locked position, aerodynamic forces would return the wings to a nearly stowed position. The JSOW was designed to begin flight path hold 2.1 seconds after the wings deployed (parallel to but below the launch aircraft flight path at release) to

assure that the launch aircraft was safely ahead in case a pull-up was commanded when the JSOW entered midcourse guidance. The axial displacement between host aircraft and the JSOW was to be greater than 150 feet for a maximum g pull-up command to be initiated. The detailed JSOW STV-F launch wing deployment timeline is provided as table B-1.

Weapon Flight Test Modifications

Structural Test Vehicle (STV) - C

Jettison testing was conducted with inert JSOW Structural Test Vehicles designated STV-Cs. The JSOW wings were to remain stowed after release, and the four moveable control fins would remain locked and unpowered throughout the jettison event. An internal nickel-cadmium battery (activated on the flight line prior to takeoff via an external switch) was designed to power the six degree of freedom instrumentation (6-DOF) package, strain gauges and telemetry system (TM) inside the test assets. The test vehicle's aerodynamic, mass, inertia and stiffness characteristics were representative of a fully operational vehicle, and each test asset was targeted to support photogrammetric analysis of each release. A representative JSOW STV-C target scheme is depicted in figure A-1.

Structural Test Vehicle (STV) - F

The launch test was accomplished with an inert JSOW Structural Test Vehicle designated STV-F. The STV-F was configured similar to the STV-C test vehicles used during the jettison program. The test vehicle's aerodynamic, mass, inertia and stiffness characteristics were representative of a fully operational vehicle. The STV-F was equipped with an Inertial Measurement Unit (IMU), a Global Positioning System (GPS) receiver, deployable wings, fully operational tail fins, a Flight Termination System (FTS) and a Test Instrumentation Kit (TIK) for real-time transmission of data. The STV-F instrumentation system, control activation system and flight termination system were to be powered by thermal batteries. The batteries would be activated after the test aircraft was airborne via depression of the weapon release button. The launch asset would also be targeted for photogrammetric analysis. The STV-F was representative of an All Up Round JSOW for the purposes of the separation evaluation.

Flight Termination System (FTS)

The flight termination system was a dual redundant system located just aft of the TIK assembly. It was powered by two thermal batteries, which were activated by the GEU during the weapon release sequence with release consent. Power could not be sent to the FTS via the three phase power from the aircraft. Each battery powered one flight termination receiver, one flight termination safe and arm device and one foil initiator. Two UHF antennas, one mounted on each side of the JSOW, were to provide input signals to the two receivers through use of a series of splitters and combiners. Either antenna was designed to provide input to both receivers. Each receiver would provide a signal to enable one of FTS safe and arm devices which would apply power to one explosive foil initiator and ignite the flight destruct cutting charge. This cutting charge ran just under the outer skin of the JSOW along the outside edge of the bulkhead behind the tray that held the TIK assembly. The two foil initiators were located on either end of the cutting charge and either one could ignite the cutting charge – severing the aft 42 inches of the JSOW. An illustration of JSOW STV-F components depicting the FTS is provided in figure A-5. A more detailed view of the TIK assembly is presented in figure A-6. A single ground test was conducted by TI prior to flight test in order to verify correct operation of the FTS.

CHAPTER IV
SCOPE OF TESTS

Tests and Test Conditions

Test and Test Conditions General Information

Separation testing of the JSOW consisted of jettison and launch releases. The jettison drops defined the safe release of the JSOW in the "dead-bird" mode, which means that the control fins did not activate and the wings did not deploy. Launch releases activated the control fins and deployed the wings. Active control of the fins was designed to begin within 52 msec after hook opening and was used initially to dampen the angular motion caused by the flow field around the F/A-18. No explicit course control was initiated until 350 msec after release. Launch releases should therefore have exhibited better separation characteristics than releases in the jettison mode. Because launch release characteristics were predicted to be better than the jettison release, the test matrix was to build up from the most benign to the most severe jettison condition (based upon wind tunnel predictions and previous F/A-18 separation testing), clearing the launch envelope along the way. Once jettison testing was complete, a demonstration of the launch release at the most severe jettison condition was to be conducted to verify the JSOW safe separation characteristics in the launch mode. If jettison testing was terminated prior to completing the test matrix, launch testing was to begin at the last safe jettison test point and continue until the test matrix was completed or safety of flight concerns terminated the test program.

Captive Carriage

A full air worthiness test program was conducted for JSOW concurrently with separation testing. In order to first establish a flight envelope in which separation testing could proceed, flutter, active oscillation control (AOC) and handling qualities testing were completed prior to the first jettison separation flight. Structural loads, noise and vibrations and carrier suitability flight testing was conducted in parallel with ongoing separation tests. If required, a captive carriage test matrix was to be planned and executed if the requirement arose.

Separation Tests

Test and Test Conditions - Jettison Test Flights. Fourteen jettison flights totaling approximately 14 flight hours and jettisoning 14 JSOW STV-Cs from parent stations 2 and 8 were initially planned. Three of the

14 test flights (and jettisons) were to be flown only if deemed necessary by the flight test team upon review of preceding test data. All jettison flights were conducted at the Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD using local restricted area R4005N, the Hooper Target complex. Jettison conditions and store loadings are presented in tables B-2 and B-3. The test matrix was designed to test the most benign jettison condition and loading (JSOW outboard, clean inboard station) then progress to the most critical condition and loading (JSOW outboard, fuel tank inboard). Previous F/A-18 testing had shown that releasing an outboard store next to an inboard fuel tank was the most critical separation loading (Holmes, 1993). Data gathered during F/A-18 wind tunnel testing showed that the presence of the fuel tank on the inboard station induced a large outboard yawing moment to the JSOW on the outboard station, which caused the tail of the JSOW to approach the aft end of the fuel tank. Selected JSOW trajectory predictions generated by MDA for the jettison mode are depicted as figures in appendix E. These predictions were considered "conservative" and were to be updated as 6-DOF and photogrammetric data was gathered during flight tests and included in the F/A-18 and JSOW 6-DOF model. Kinematic splash patterns for the JSOW released in the jettison mode were predicted for each test, verified on each flight and updated as required. Jettison altitude was to be adjusted as required to contain the splash points.

Test and Test Conditions - Launch Test Flights. Flight tests included two captive flights in the launch-flight weapon loading configuration, and one launch flight releasing a single JSOW STV-F. All flights were conducted in the Naval Air Warfare Center Weapons Division (NAWCWD), China Lake, CA test ranges. The three flights in support of the first launch test included 4.0 flight hours. Captive carriage flight one, designated CF-01, completed the following objectives: (1) verification of correct operation of the missile in a captive environment; (2) verification of the correct operation and transmission of the STV-F and aircraft telemetry systems with ground support; and (3) conduct practice runs of the launch profile. Captive carriage flight two (CF-02) was to be flown if adjustments to the JSOW software or instrumentation were required based upon the data collected during CF-01. Captive carriage flight three, designated DR-01 (DR – Dress Rehearsal), was conducted primarily to practice for the actual launch with special emphasis on the launch profile. One launch flight was conducted wherein a single JSOW STV-F was launched from the aircraft station 2 parent rack. The launch test was constructed with the objectives of verifying operation of the JSOW control system and Flight Termination System (FTS) and demonstrating that a controlled separation was more benign than a jettison in similar conditions. Subsequent launches were to be conducted to evaluate release characteristics at the end points defined by the jettison program, but were not a part of the test program covered by this report (those tests were categorized under Developmental Testing Phase IIB, or DT-IIB). JSOW STV-F launch conditions are presented in table 1.

Table 1

JSOW STV-F Launch Conditions

Parameter	Jettison
Airspeed (KCAS / IMN)	575 / 0.95
Altitude (ft MSL / AGL)	5,000 / 2,600
Flight Path Angle (deg)	Level
Normal Acceleration (g)	+0.7 to +1.0

Table 2

JSOW Launch and Jettison Flight Test Envelope

Parameter	Carriage	Jettison
Airspeed (KCAS / IMN)	635 / 1.3	575 / 0.95
Altitude (ft MSL)	LBA	4,000 to 6,000
Normal Acceleration (g)	-2.0 to +6.0	+0.7 to +1.0

Test Envelope

All test flights and test parameters were conducted within the limits of the F/A-18 NATOPS Flight Manual, reference 2, and as outlined in the NAVAIRSYSCOM flight clearances. Specific limitations for carriage and release events are presented as table 2.

Flight Clearance

Flight clearances obtained from NAVAIRSYSCOM (AIR-530) authorizing FTEG to conduct weapon jettison and launch testing are listed as references 5, 6 and 7. As part of the JSOW test team, the AIR-5301 JSOW representative was included in the decision making process when progressing through the test matrix and when changes were made to the test matrix. Final concurrence from the AIR-5301 representative for each test point was obtained at the JSOW test flight readiness review conference and review prior to each test flight. The JSOW test flight readiness review conference and subsequent test flight reviews consisted of appropriate personnel from SA80, NAVAIR, TI and MDA. NATOPS and TACMAN limits were observed for all areas not specifically covered by the flight clearance.

Test Loading

Test loading was a normal single-seat aircraft, including full internal fuel at start. Individual flight test loadings are shown in table B-2. Values for aircraft gross weight and center of gravity (CG) position were calculated by test squadron personnel prior to each test flight.

Test Configuration

All tests were conducted with flaps in AUTO, landing gear UP, speedbrake IN and thrust as required to reach test point conditions.

Test Standards

Jettison Test Flight Standards

Jettison tests were evaluated in accordance with MIL-STD-1763A, Guide to Aircraft/Stores Certification Procedures, reference 8. The test points were considered valid if the tolerances in table 3 were met. Flight tests not meeting these tolerances were to be repeated at the discretion of the separation test team. Aircraft Head's Up Display (HUD) tape, onboard records and telemetry data were used to monitor release parameters. The pilot also recorded level release data on kneeboard cards. Targeted flight parameters were adjusted as required to correct for the effects of the nose camera on the pitot-static system.

Table 3

JSOW Jettison Test Point Tolerances

Parameter	Tolerance
Airspeed (KCAS)	± 10
Mach (IMN)	± 0.01
Altitude (ft)	± 500 ft (level jettison) + 1000 / -500 ft (dive jettison)
Flight Path Angle (deg)	± 3
Normal Acceleration (g)	± 0.1

Launch Test Flight Standards

As the launch test incorporated multiple objectives, there were different test standards for each objective. Launch separation tests were also evaluated in accordance with MIL-STD-1763A, reference 8. The primary safe separation objective was to obtain data for the comparison of launch separation characteristics with known separation characteristics, determined via previous testing at airspeed intervals sufficient enough to enable comparison of launch data from any airspeed within the jettison envelope. Accordingly, the tolerances required to meet this test objective were relaxed. The launch test point was to be considered valid if the tolerances in table 4 were met. Test objectives which pertained to the free flight and performance of the missile varied according to flight phase, and are presented in table 5 as well as in the STV-F launch detailed timeline, figure D-1. Flight tests not meeting these tolerances were to be repeated at the discretion of the separation test team. Aircraft HUD tape, onboard records and telemetry data were used to monitor release parameters. The pilot recorded level release data on kneeboard cards. Targeted flight parameters were adjusted to correct for the effects of the nose camera on the pitot-static system.

Table 4

JSOW Launch Test Point Tolerances

Parameter	Tolerance
Airspeed (KCAS)	± 25
Mach (IMN)	± 0.02
Altitude (ft)	± 500 ft
Flight Path Angle (deg)	± 3
Normal Acceleration (g)	± 0.2

Table 5

JSOW Free Flight Test Tolerances

Parameter	Flight Phase			
	JSOW Power ON	Self-Leveling	Release Consent	JSOW Launch
Latitude (NM)	± 1.0	n/a	± 0.5	± 0.5
Longitude (NM)	± 1.0	n/a	± 0.5	± 0.5
Altitude (ft MSL)	n/a	n/a	± 250	± 250
Groundspeed	n/a	± 10 knots	± 50 knots	± 50 knots
Airspeed (KCAS)	n/a	± 10	n/a	n/a
Airspeed (KTAS)	n/a	n/a	± 10	± 10
Pitch Angle (deg)	n/a	± 5 of trim	± 5 of trim	± 5 of trim
Roll Angle (deg)	n/a	± 5 of zero	± 5 of zero	± 5 of zero
Ground Track	n/a	n/a	± 4 deg	± 4 deg
Crab Angle (deg)	n/a	n/a	≤ 5	≤ 5

CHAPTER V
METHOD OF TESTS

Test Method and Procedures

Test Method and Procedures General Information

All test procedures were conducted in accordance with the NATCINST 8600.1A, Standardized Armament Test Manual, reference 9. All test points were conducted under Visual Meteorological Conditions (VMC) within the limits of the flight clearances (references 5, 6 and 7), NATOPS Flight manual (reference 2) and F/A-18 Tactical Manual, Volume IV (reference 10). Film of flight tests was reviewed by project engineers prior to subsequent flight testing in order to identify adverse trends in jettison characteristics and determine whether photogrammetric analysis or photogrammetric analysis with updates to the F/A-18 and JSOW six degree of freedom (6-DOF) model was required. TI held a test flight readiness review conference prior to the start of the test program, and additional test flight reviews for each subsequent test flight.

Modeling and Simulation

Substantial investment in modeling and simulation was made throughout the JSOW program. Before separation testing ever began, wind tunnel analysis and simulation was used to generate 6-DOF separation models for both Texas Instruments (TI) and McDonnell Douglas Aerospace (MDA). As flight testing progressed, multiple data sources were used to compute actual JSOW position information relative to the launch aircraft, and that position data was compared to predicted values in order to refine the 6-DOF separation model. Both TI and MDA performed separation analysis and separation model updates independently, in order to increase fidelity of the overall prediction. Only MDA performed analysis of photogrammetric data when required, though that additional high-fidelity positional information was provided to both companies. This iterative process was expensive and time consuming, but the decision was made to use this methodology in order to first decrease the risk of unanticipated unsatisfactory separation characteristics (weapon to aircraft impact), then to provide the potential to regain test program savings by making more aggressive steps in separation flight testing (reducing the total expenditure and analysis of very expensive flight test assets). As photogrammetric analysis took up to 30 days to complete for each separation, that method was used only for the most critical separation cases. Representative diagrams of TI and MDA separation predictions and analysis used throughout the JSOW separation flight test program are presented in figures E-1 through E-13.

Photogrammetry

Photogrammetry is a technique of measuring positional data from photographic media. Simply put, with the location of specific points (photogrammetric targets) and the relative location of applicable cameras known, position information can be determined by analysis of distances between those specific points, in comparison. Only one camera is required for analysis in two dimensions, but at least two cameras are required for analysis in three dimensions. The photographic media used for JSOW flight testing photogrammetry were the on-board high-speed cameras, located on numerous weapon stations as well as internal to the launch station pylon itself (downward looking). As the critical data in question were JSOW positions relative to aircraft and aircraft components (pylon, external fuel tank, etc.), both the weapon and aircraft had to be configured with photogrammetric targets. Five types of photogrammetric targets were used for these tests, including circular outside with circle inside, bow tie, hour-glass, triangular and circle outside with bow tie inside. Precise photogrammetric target placement data (location and orientation) were recorded for each JSOW test vehicle in the targeting process. Both launch aircraft, suspension equipment and external fuel tanks were precisely targeted prior to testing. Figures A-1 and A-2 indicate JSOW and launch aircraft photogrammetric targeting schemes.

Test Method and Procedures for Jettison Tests

Jettison of inert JSOW STV-Cs in the jettison mode were conducted in R4005N at the Hooper Target complex under positive control of Chesapeake Test Range (CTR) and in accordance with the guidelines of NATCINST 3710.21 Safety and Test Operations Manual Chesapeake Test Range, reference 11. The jettison test matrix is presented in table B-3. A diving entry to wings level could be used, as required, to achieve the desired release airspeed for straight and level data points. Successful completion of JSOW ground instrumentation test was conducted prior to first flight. Normal F/A-18 selective jettison procedures, contained in the F/A-18 NATOPS manual, reference 2, were used with exception of a cap placed over the emergency jettison button, figure A-3, in-flight during pre-release checks and removed after jettison event to preclude inadvertent actuation.

Test Method and Procedures for Launch Tests

Electrical Integration

The STV-F was entered into the Stores Management Panel (SMP) as a tactical Harpoon, code 62, and appeared on the aircraft stores page as “HPC” (figure 5). Aircraft active oscillation control was not enabled

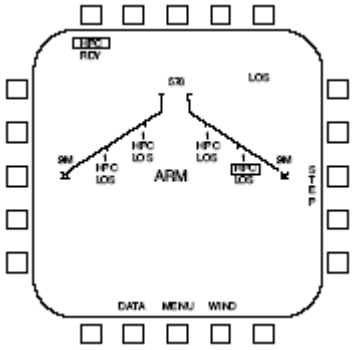


Figure 5

Harpoon Selected (Boxed) On Cockpit Digital Display Indicator (DDI)

Source: *Operation of the F/A-18 Avionic Subsystem for Aircraft with the 13C System Configuration Set (13C SCS),* NAWCWD, China Lake, July 1998.

by the Harpoon store code, and was not required for the JSOW. Electrical integration made use of the Harpoon Line of Sight (LOS) mode and display symbology. Removal of the A-14 card from the pylon encoder-decoder was required for this test in order to force the aircraft armament computers into the LOS mode. Launch release of the STV-F required the LOS mode so that the necessary voltages could be provided to the JSOW, and so that the Release Consent (RC) signal could be used to initiate the internal batteries. Upon application of the RC signal, the aircraft required a response from the Harpoon that the STV-F could not supply, and so the aircraft would "fail" the store and remove all applied power. The STV-F's batteries were designed to achieve output within 1.6 seconds of RC, whereas the aircraft mission computers would take 4 seconds to fail the store. The station jettison capability for the STV-F station would not be inhibited regardless of A-14 card status, and was used to release the store following telemetry verification that the store power change over had occurred. A locally manufactured subset of the MIL-STD-1760 cable was used to electrically interface the aircraft and the STV-F.

Test Method and Procedures - Captive Flight Tests (CF-01, CF-02 and DR-01)

Captive flights (CF-01 and CF-02) were conducted in order to evaluate and verify that JSOW and China Lake Range systems were fully operational prior to committing to launch a valuable JSOW STV-F test asset. The maneuvers included commanding the loaded STV-F to a "Simulated Launch" (Sim Launch) condition, and multiple practice runs of the launch profile. During the Sim Launch phase of the captive flights, the pilot commanded the store into the simulated launch mode by repetitive selection of the IR COOL switch at the simulated launch point, then simulated the free flight profile of the weapon by manually flying a specific altitude and airspeed profile. Test engineers at China Lake monitored control

inputs from the JSOW GEU to verify correct response of control software during maneuvers. The STV-F used aircraft three-phase and #1 28 VDC power for the Sim Launch mode, but at no time initiated any of its thermal batteries. Consequently, it was impossible for the control fins or wings to actuate or deploy while in this mode and still on the aircraft. At completion of each profile, the pilot secured power to the store, and the maneuver could have been repeated. The Sim Launch test was designed specifically to verify that the weapon Guidance and Control software was functioning as designed, and could have been repeated in additional flights if required to adjust and re-evaluate the missile. The dress rehearsal flight (DR-01) also included Sim Launch profiles. It was conducted primarily to practice for the actual launch, but also to verify via telemetry signals that the FTS was operating as designed.

Test Method and Procedures - Launch (FF-01)

Launch of an inert JSOW STV-F was conducted in the China Lake G-range complex under positive control of Pacific Ranges and Facilities, Land Range personnel and in accordance with the guidelines of the Naval Weapons Center Range Safety Manual, reference 12. The detailed launch timeline and procedures are depicted in figure D-1. The launch aircraft flew a very rigid profile while directly controlling voltages to the weapon through systematic actuation of specific switches in sequence. The aircraft autopilot and automatic throttle controller was used to the maximum extent possible during this test, limited only by turbulence in the launch area. A release consent (RC) signal was sent to the weapon to activate its thermal batteries, thereby committing the missile to release within 60 seconds on that run. Launch was accomplished via normal F/A-18 selective jettison procedures, with exception of a cap placed over the emergency jettison button in-flight during pre-release checks and removed after jettison event to preclude inadvertent actuation (as with jettison tests). Failure to release the weapon on that run after initiation of the thermal batteries would abort the test, and the aircraft would have had to return to base. Following successful launch of the missile, the launch aircraft cleared to the right by rolling right and pulling, an automatic lead change occurred, and the chase aircraft continued to follow the weapon while the launch aircraft crossed to the other side of the chase and loosely followed the formation. The test run was complete following activation of the missile FTS.

Instrumentation and Data Requirements

As previously noted, both flight test aircraft were equipped with externally-mounted 16 mm cameras to provide adequate release coverage; however, F/A-18 A87 (side number 106) was not configured with a nose camera. Consequently, flights using A87 were restricted to those jettison test points listed in table B-3 for which a fuel tank was not loaded on the inboard station and sufficient camera coverage could be

obtained without a nose camera. All test points with a fuel tank loaded on the inboard station and the launch test used F/A-18 C37 (side number 101), which had an internally mounted nose camera. For some of the jettison flights and the launch flight, a pylon camera was also installed in the station 2 SUU-63 pylon, and it provided a downward view of the store during release. Cameras operated at 200 frames per second for all release flights. In addition to externally mounted cameras, ground tracking cine-theodolites and photo chase supplied qualitative data during jettison and launch flights. Additional video coverage was provided using a trideck Super-8 recording system (aircraft C37) which could record HUD, over the shoulder and wing camera video all at the same time. F/A-18 A87 was equipped with a Nose Instrumentation Pallet System and MDA Instrument Data System, capable of transmitting flight parameters as well as recording them on-board. F/A-18 C37 was equipped with a Super Quick Installation Data System (SQIDS) that included an internally mounted X-band beacon for position tracking. The SQIDS was a continuous recording system capable of selecting up to 2,000 sixteen bit words from the MIL-STD-1553 bus or recording the individual busses in their entirety (MUX-All). MUX-All data was programmed for separation and launch flights using F/A-18 C37. The digital signals were encoded and inserted into a fixed format Pulse Code Modulation (PCM) word stream. Data was recorded by onboard recorders and transmitted to a ground station via telemetry from both the weapon and the aircraft. The data cards for each flight were annotated with the required test conditions and requirements for switch actuation. The F/A-18 aircraft onboard HUD video tape recorder was reviewed to determine actual release conditions, although the "event marker" was not present at release (not available for jettison events). For level release, pilots also attempted to record release parameters on kneeboard cards. Critical parameters for these flights were: normal acceleration, altitude, calibrated airspeed, flight path angle and IMN.

Chase Aircraft

Chase Aircraft for Jettison Flights

A photo-chase aircraft was used when available, but was only required for the first jettison test and all flights releasing JSOW next to a fuel tank. During the jettison event, the chase aircraft was positioned to allow optimum coverage of weapon separation characteristics, but in no case closer than 200 feet from the separation aircraft, or within a 60 degree cone of the separation aircraft's longitudinal axis.

Chase Aircraft for Launch Flights

A photo-chase aircraft was used for the launch flight and one of the captive flights (CF-02), in order to familiarize the pilot with the planned weapon free-flight profile. The chase aircraft was positioned to allow

optimum photo-coverage of weapon separation characteristics, but in no case closer than 200 ft laterally from the separation aircraft or within 60 degrees of the JSOW's tail. As the JSOW STV-F was equipped with an FTS, particular caution had to be used by the chase pilot (the chase aircraft was to remain level or slightly stepped up on the missile) throughout the JSOW time of flight. If the JSOW began to deviate from its programmed flight, the chase pilot would have been notified to increase separation prior to activation of the FTS.

CHAPTER VI
CHRONOLOGY

Clearance of the Flight Envelope

Air Worthiness Testing (AWT) included the following test programs: flutter; active oscillation control (AOC); handling qualities; loads; adjacent store eject (effects on JSOW when adjacent store is released); noise and vibrations; and carrier suitability. The purpose of flutter testing was to substantiate that the aircraft with stores was free of any aeroelastic instability and had satisfactory damping characteristics within the prescribed flight envelope. A total of 12 flights for 13.8 hours were conducted in a single configuration (wingtip missiles off) from 19 November 1993 through 9 December 1993. An undesirable flight characteristic was observed at one the flutter test point conditions, resulting in a flight envelope restriction for that configuration. To provide data in determining the requirement for and effectiveness of the F/A-18 Active Oscillation Controller when carrying the JSOW within the prescribed envelope, a total of 6 flights for 6.8 hours were conducted in a single configuration (wingtip missiles on) from 17 December 1993 through 22 December 1993. It was determined that AOC flight control mode was not required.

In order to evaluate the influence of the stores and suspension equipment on the handling qualities of the aircraft, a total of 7 flights for 13.3 hours were conducted in two configurations from 11 January 1994 through 1 February 1994. There were no flight restrictions as a result of handling qualities tests. In-flight loads testing was conducted in order to obtain in-flight measured data for use in verifying the structural integrity of the store and aircraft-store combinations. A total of 10 flights for 9.6 hours were conducted in two configurations from 16 February 1994 through 1 March 1994, resulting in no flight restrictions. Adjacent store eject testing was conducted to measure the dynamic response of the JSOW when mounted on the F/A-18 during adjacent store ejection and determine the store and store interface environment and loads. A total of 8 flights for 6.5 hours were conducted in two configurations from 24 March 1994 through 8 April 1994, resulting in no flight restrictions.

Noise and vibrations testing was conducted to measure and define the vibration and acoustic environment of the JSOW throughout the F/A-18 air-to-ground envelope, and to determine if the aircraft, store and suspension equipment could withstand the actual flight environment to validate the design specification levels. A total of 14 flights for 13.8 hours were conducted in two configurations from 28 April 1994 through 17 May 1994. Carrier suitability testing was conducted to test the store under the dynamic conditions of actual catapult and arrested landings. No restrictions resulted from 13 flights for 31.1 hours in three configurations from 14 June 1994 through July 1994.

Fit Tests

Preliminary aircraft and stores interface (fit) tests were performed 25 August 1992 through 3 September 1992 to support the final design of the Joint Standoff Weapon. Fit testing of the weapon configuration that would be used to support air worthiness testing was conducted on the F/A-18 at the Naval Air Warfare Center Aircraft Division, Patuxent River, MD on 5 October 1993. There were no conflicts or minimum clearance violations for the weapon loads required by the JSOW Specification Guide. It was determined that the JSOW met the clearance requirements of MIL-STD-1289A as well as MIL-STD-1289B, reference 13, for the loads specified, and was suitable for flight testing on the F/A-18 aircraft.

Ground (Pit) Jettison

Ground ejection tests were conducted to determine end stroke velocity, evaluate separation trajectory and attitude rates, verify camera field of view, demonstrate the folding lug design, verify the STV-C Test Instrumentation Kit (TIK) operation during the ejection event, and to collect data to evaluate structural response to the ejection event. Ground ejection tests were completed in January 1994.

Jettison STV-C

The F/A-18 JSOW Flight Test Event Matrix is presented as table B-3. Outboard station jettison testing were the first separation tests completed for JSOW, starting with the first jettison on 8 March 1994 at a target airspeed of 400 KCAS. Photogrammetric analysis was time consuming (approximately a month long effort for each event), so the next jettison test event did not occur until 7 April 1994. In order to optimize the overall schedule, separation testing on the outboard station with an adjacent inboard external fuel tank commenced prior to reaching the end point test with the outboard station (clean inboard), which occurred on 23 May 1994. As the worst case separation involved JSOW jettison adjacent to the inboard fuel tank, photogrammetric analysis was required for each of the test points building up to the end point test for level flight, which took place on 1 September 1994. With the 575 KCAS level point established, the final end point test for 575 KCAS and 45 degree dive occurred on 12 October 1994.

Inboard station testing was added to the flight test matrix via test plan amendment in October 1994, and flight tests for that station commenced on 18 October 1994. Capitalizing on a well-validated and correlating separation model, inboard station testing proceed rapidly – skipping three test points in total and completing testing at 575 KCAS on 1 December 1994.

Launch STV-F

The schedule for the first JSOW launch was accelerated late in 1994 by the Conventional Weapons Program Manager (PMA-201). A combination of Developmental Test (DT) Phase IIA testing and DT-IIB testing, the first launch combined test objectives from offices at both Patuxent River, MD and China Lake, CA. Since the test required the instrumented and photographic capabilities of the aircraft that had been used in all other separation testing, that F/A-18 (C37, bureau number 163476) was flown to China Lake, CA on 5 December 1994. After a local area familiarization flight using another aircraft, JSOW captive flight tests CF-01 and CF-02 were flown on 6 and 8 December 1994. First free-flight launch test (FF-01) occurred on 13 December 1994.

CHAPTER VII
RESULTS AND DISCUSSION

Results and Discussion - Introduction

Results and Discussion General Information

Often in store separation testing, on-board high-speed cameras, ground-based and chase aircraft video recording are the only data sources available. These data may resolve into essentially a binary decision – the store continued moving away from the aircraft, or not; or the store impacted the aircraft during release, or not. If the separation test vehicles are inexpensive and available, if the separation store is similar to previously cleared stores, or if the total release envelope desired is conservative relative to the anticipated store separation characteristics, then this approach with respect to data sources may be acceptable. In the case of the Joint Standoff Weapon, however, this was not the case. The separation test vehicles were expensive and manufactured specifically for each test. The separation store was completely unique as compared to existing cleared weapons. And the desired flight envelope relative to the anticipated separation characteristics was aggressive – in fact, the separating store was initially predicted to impact the aircraft at the test end point. Consequently, it was appropriate to invest heavily in modeling and simulation in support of the JSOW test program, include multiple parameter telemetry data systems on-board both the aircraft and the separation test vehicles, and target both aircraft and store for photogrammetric post-flight analysis. At the end of separation testing, however, the data eventually resolve into a binary decision – the separation characteristics at end-point test conditions were either satisfactory, or not. Therefore, the effort expended on data collection, analysis, modeling and simulation becomes an effort to safely reach end-point test conditions. The following paragraphs in this section articulate that effort, in detail.

Summary of Data Sources

Multiple data sources were integrated to provide the best possible prediction for the next test. The pilot and flight test engineer post-test "daily" flight reports were used to capture information pertaining to aircraft configuration, flight test conditions, preliminary test point data, weather, etc. Photographic data consisted of ground-based video of the aircraft and post-release weapon to impact, on-board high-speed cameras and video as noted in figure A-7, and photo-chase aircraft still photographs and video. Review of photographic data provided a cross-check for flight parameter data streams (direction of roll rate, for instance), overall separation characteristics and a general understanding of store separation characteristics that is much more difficult to acquire from tabular numbers of position data. Photographic data were the best source for

determining whether or not the separating store was close to violating minimum separation criteria, but more detailed analysis had to be conducted when that review of photographic data showed a critical condition or trend. Reconstruction of JSOW position data based upon six degree of freedom (6-DOF) telemetry signals and aircraft parameters was conducted after each flight to corroborate photographic data, provide quantification of how close the store was to violating separation clearance minimums, and improve fidelity of the separation models. As photogrammetric analysis was more expensive and time consuming, it was used sparingly to support the most critical separation test points. Photogrammetric analysis provided an independent source of JSOW position data, and was generally considered the most accurate analysis of all data sources.

Predictive Analysis

To expand upon the use of modeling and simulation discussion earlier in this document, both Texas Instruments and McDonnell Douglas Aerospace created separation models based initially upon wind tunnel analysis. In addition to the obvious objective of the weapon separating safely during each separation flight test, another objective was the continuous update to the fidelity of each separation model based upon position data gained both from 6-DOF sensor data broadcast and recorded by both aircraft and weapon. Photogrammetric analysis was also used when deemed necessary based upon criticality of the dependent flight test point versus the delay incurred within the total flight test program. The most current, updated analysis and predictions for the next separation test points were presented at test readiness reviews scheduled between critical test flights. Selected representative MDA wind tunnel analysis-based predictions for JSOW separation are presented as figures E-1 through E-8. TI separation predictions are presented as figure E-9 and E-13, and are inclusive of data gained from all jettison tests up to those points.

Results and Discussion - Jettison

JSOW STV-C Outboard Jettison in Sequence with Analysis

Separation flight testing of the AGM-154A JSOW began with testing of jettison from the outboard station, without the presence of an inboard station external fuel tank, which was the most critical adjacent store for separation. Tests were initially planned for 14 events, sequentially progressing from lower airspeed and no external fuel tank, level flight conditions to 575 KCAS and adjacent external fuel tank, 45 degree dive conditions. In the course of flight testing and data analysis, it was determined that jettison events number 7 and 9 (425 and 475 KCAS, respectively) could be safely skipped. For the remainder of the jettison test events from the outboard station, those tests were conducted with the gear UP and flaps AUTO, and in the

test loadings indicated in table B-2, loadings 1 and 2. Flight test aircraft, date of test, aircrew and jettison test point parameters are as listed in table B-3. Myriad predictions and post-flight analyses were available before and after each flight test. Only selected representative samples of those products are presented within this document. Analysis of applicable flight test data sources for each jettison test are presented in the following paragraphs. As post-flight analysis from each test necessarily included the recommendation to proceed to the next test point in sequence (or skip a test point enroute), that recommendation is assumed in following paragraphs unless otherwise indicated. All tests met the separation characteristics requirements of the Specification, reference 8, unless otherwise indicated. Except where noted to the contrary, test point parameters were achieved within established tolerances.

Jettison Event 1. This test event was the first release of a Joint Standoff Weapon from the F/A-18. Conducted at 401 KCAS, separation for this was predicted to be benign, with only slight nose down pitch attitude and very little roll or yaw predicted as the store fell away from the aircraft (depicted in table E-1 and figure E-1). Six degree of freedom separation data for the first second after jettison is presented as table E-2. Review of photo and video sources indicate that the JSOW STV-C separated cleanly from the host aircraft, pitched slightly nose down and translated slightly outboard after jettison. Post-flight data analysis indicated a need to update the BRU-32 Bomb Rack ejector force model, the ejector friction and the JSOW mechanical bending model in the 6-DOF (TI) and SDF (MDA) models (TI, 31 March 1994), but flight test results otherwise compared favorably with both TI and MDA predicted values. An unexpected lug bounce was obvious in the high-speed film, and this issue was resolved over the course of the flight test program – it did not affect separation characteristics. JSOW separation for jettison event 1 is depicted in figures A-8 through A-10.

Jettison Event 2. The second JSOW jettison event was conducted at 445 KCAS. Review of photo and video sources indicate that the JSOW STV-C separated cleanly from the host aircraft, pitched down and moved slightly outboard after jettison. Slight outboard yaw was noted from the pylon camera, but it was quickly damped. Flight test results compared favorably with both TI and MDA predicted values.

Jettison Event 3. JSOW jettison event three was conducted at 497 KCAS. The store once again separated cleanly from the host aircraft, but left roll and outboard (left) yaw rates appeared more significant for this release as the store fell away below the aircraft. Six degree of freedom separation data for the first second after jettison is presented as table E-3. Otherwise unremarkable, flight test results compared favorably with both TI and MDA predicted values.

Jettison Event 4. The first attempt to jettison at 550 KCAS resulted in a hung store, due to a maintenance malfunction with the BRU-32 rack. Jettison was not attempted and that mission was aborted. The second

attempt at jettison was successful at 550 KCAS. The STV-C separated cleanly, pitched nose down and maintained positive movement away from the aircraft. A slight outboard yaw was also observed. Flight test results compared favorably with both TI and MDA predicted values.

Jettison Event 5. This event was the final jettison from the outboard station with no adjacent store on the inboard station. It was conducted at 578 KCAS, and again, the JSOW STV-C separated cleanly, pitched nose down and maintained positive movement away from the aircraft. Left yaw developed steadily to less than 10 deg total yaw during the first 10 ft of fall, but the separation overall was smooth and predictable. Roll rate after jettison was slight and left. Pylon film indicated the roll direction reverse during the fall to impact. Vertical acceleration recorded real-time from the JSOW STV-C Test Instrumentation Kit (TIK) was approximately 6.9 g (2 g lower than previous jettisons), most likely attributable to a defective cartridge actuating device (CAD). Initial predicted separation characteristics for this event, shown in figure E-2, were much more dramatic in yaw than noted during the flight test.

Jettison Event 6. Jettison event 6 was the first in the presence of an inboard station external fuel tank. Conducted at 399 KCAS, separation for this was predicted to be characterized by a notable left yaw generated as the store fell away from the aircraft, as depicted in E-3. Six degree of freedom separation data for the first second after jettison are presented as table E-4, and indicate a peak outboard yaw of 16.04 deg occurring at 0.60 sec after jettison. Review of photo and video sources indicate that the JSOW STV-C separated cleanly from the host aircraft, pitched slightly nose down, yawed slightly left and translated outboard after jettison. Initial MDA predicted minimum miss distance (MMD) for this event was 22.41 inches (table E-1), revised before flight to 23.0 inches by TI, and to 22.8 inches by MDA. Actual MMD for this jettison was computed post-flight to be 23.0 inches (TI) and 21.2 inches (MDA). Flight test results compared favorably overall with both TI and MDA revised values.

Jettison Event 8. Due to fidelity of TI and MDA predictive models and confidence of the test team that separation characteristics were adequately estimated by those models, the 425 KCAS jettison event 7 was skipped. Jettison event 8 was conducted at 450 KCAS. It was anticipated that the magnitude of the outboard yaw generated by proximity to the inboard external fuel tank would be increased, thereby decreasing the MMR predicted for this event. Nonetheless, separation was predicted to be safe for the test conditions. Review of photo and video sources indicate that the JSOW STV-C separated cleanly from the host aircraft, pitched slightly nose down, yawed significantly left and translated rapidly outboard after jettison. From the keel camera, the tail of the store appeared to track diagonally down and inboard as the nose tracked outboard and significantly nose down, generating a nose down, left yaw separation. Six degree of freedom separation data for the first second after jettison is presented as table E-5, and indicates a peak outboard yaw of 25.04 deg occurring at 0.60 sec after jettison. Also noted in table E-5, roll angle was

much more oscillatory for this jettison. Initial MDA predicted MMD for this event was 19.60 inches (table E-1), revised before flight to 20.0 inches by TI, and to 21.0 inches by MDA. Actual MMD for this jettison was computed post-flight to be 18.5 inches by both TI and MDA. Flight test results compared favorably overall with both TI and MDA revised values.

Jettison Event 10. Retaining the same confidence in predictability that enable skipping of jettison event 7, the 475 KCAS jettison event 9 was skipped and jettison event 10 was targeted for 500 KCAS. Actual airspeed at release, however, was less than the allowable tolerance at 487 KCAS. Consequently, a test plan amendment was required to use that point as valid, and the option to omit jettison event 11 was no longer available. Here again, it was anticipated that the magnitude of the outboard yaw generated by proximity to the inboard external fuel tank would continue to increase, further decreasing the MMR predicted for this event. Separation was still predicted to be safe for the test conditions. Review of photo and video sources indicate that the JSOW STV-C separated from the host aircraft, pitched significantly nose down, yawed significantly left and translated rapidly outboard after jettison. From one of the wing cameras, the tail appears to hang vertically and track slowly toward the rear section of the external fuel tank as the JSOW nose tracked steadily downward, increasing the separation pitch angle. Though in most camera views the JSOW appears to depart stable flight, the pylon camera clearly indicates the significant pitch is eventually damped before water impact. Initial MDA predicted MMD for this event was 13.72 inches (table E-1), revised before flight to 16.0 inches by TI, and to 19.0 inches by MDA. Actual MMD for this jettison was computed post-flight to be 13.0 inches (TI) and 15.5 inches (MDA). Flight test results compared favorably overall with both TI and MDA revised values.

Jettison Event 11. Jettison event 11 was conducted at 528 KCAS. Predicted separation characteristics were to follow the developing trend in JSOW separation adjacent to an external fuel tank, and pitch dramatically nose down with rapid onset of a rapid outboard yaw rate. Photo data indicated that separation characteristics were much the same as noted during jettison event 10, excepting that apparent rates were increased. The JSOW STV-C exhibited a dramatic yaw excursion within 10 ft below the aircraft, as confirmed by the data presented in table E-6, where 6-DOF separation data for the first 0.80 second after jettison is presented. Peak outboard yaw of 95.54 deg apparently occurred at 0.60 sec after jettison. However, the nose camera film indicates that the store yaw direction reversed shortly after jettison, and departed stable flight passing approximately 90 deg yaw in the opposite direction. Peak recorded pitch angle reached 45.19 deg (nose down), also at 0.60 sec after jettison. Roll angle was characteristically oscillatory for this jettison. Initial MDA predicted MMD for this event remained unchanged at 11.27 inches (table E-1), though TI predicted MMD of 14.0 inches. Actual MMD for this jettison was computed post-flight to be 14.0 inches (TI) and 11.1 inches (MDA). Flight test results compared favorably overall with both TI and MDA revised values.

Jettison Event 12. Separation characteristics for the 551 KCAS jettison event 12 were even more dramatic than discovered during the preceding jettison. The JSOW STV-C pitched down and yawed outboard immediately and significantly upon release, and rapidly tracked outboard of the aircraft. Yaw angle was in excess of 90 degrees within 10 ft of the aircraft, as indicated by 6-DOF separation data presented as table E-7. Peak outboard yaw of 98.32 deg occurred at 0.60 sec after jettison, and was accompanied by a pitch angle of 43.75 deg nose down 9.55 ft below the launch aircraft. Figure A-11 dramatically depicts JSOW separation characteristics at jettison event 12 flight conditions in the JSOW jettison mode. Review of photographic data reveals that the JSOW tail appears to float across toward the external fuel tank while the JSOW nose tracks rapidly down and outboard, before the entirety of the store suddenly tracks rapidly outboard. Initial MDA predicted MMD for this event was 8.95 inches (table E-1), revised before flight to 15.5 inches by TI, and to 10.0 inches by MDA. Actual MMD for this jettison was computed post-flight to be 16.0 inches (TI) and 7.8 inches (MDA). TI post-flight analysis for JSOW jettison event 12 is presented as figure E-9. Photographic evidence of this separation tends to favor the MDA conclusion with respect to miss distance.

Jettison Event 13. Per table E-1, the separating store was initially predicted to impact the external fuel tank during jettison at the target test airspeed of 575 KCAS. Accordingly, all preceding test points were necessarily considered build-up to this and the next endpoint jettison tests. During the first attempt to reach test conditions, however, it was discovered that the aircraft lacked sufficient power in level flight to overcome the additional drag induced by carriage of multiple on-board cameras. As a result, the bomb used to counterbalance the JSOW was down-loaded, and the flight successfully reattempted on the following day. Jettison event 13 was completed at 573 KCAS. Separation characteristics predictions are presented in figure E-4, which represents MDA analysis based upon initial wind tunnel data (with none of the recurring MDA SDF model corrections added), and in figure E-10, which conveys the updated 6-DOF model analysis completed by TI prior to each flight. MDA MMD prediction based upon combined integrated telemetry, SDF prediction and photogrammetric analysis is presented in figure E-14. Review of photo and video sources indicate that separation of the JSOW STV-C at 573 KCAS was similar to the preceding 551 KCAS test point, but even more extreme. Again, the store pitched down and yawed outboard immediately and significantly upon release, and rapidly tracked outboard of the aircraft. Yaw angle was in excess of 90 degrees within 10 ft of the aircraft, as indicated by 6-DOF separation data presented as table E-8. Peak outboard yaw of 103.30 deg occurred at 0.60 sec after jettison, and was accompanied by a pitch angle of 58.90 deg nose down 9.67 ft below the launch aircraft. Pitch angle continued to diverge past 65 deg nose down as the store departed stable flight. Wing video confirmed that the JSOW STV-C clearly missed the external fuel tank, but the minimum miss distance appeared to approach the 6 inch minimum allowed. Initial MDA predicted MMD for this event was 0.00 (contact) in

(table E-1), revised before flight to 7.5 inches by TI, and to 5.4 inches by MDA. TI post-flight analysis for JSOW jettison event 13 is presented as figure E-11. MDA combined post-flight analysis for integrated telemetry, the MDA SDF model and photogrammetric analysis is shown in figure E-15. Actual MMD for this jettison was computed post-flight to be 7.8 inches (TI) and 8.0 inches (MDA). Actual separation MMD was better than predicted for this test event.

Jettison Event 14. This jettison event, conducted at 583 KCAS in a 45 deg dive, was the endpoint test for the JSOW separation test program. Here again, the separating store was initially predicted to impact the external fuel tank during jettison at the target test airspeed of 575 KCAS (table E-1). The initial MDA separation characteristics prediction is presented in figure E-5 (with none of the recurring MDA SDF model corrections added). Revised MMD estimates were 3.3 inches by TI, and 2.3 inches by MDA. Review of photo and video sources indicate that this separation was almost identical to the preceding. The separating JSOW STV-C rapidly yawed outboard and pitched nose down while the tail approached the external fuel tank. Computed MMD was not available for this report, but comparison of photo and video indicate separation comparable to jettison event 13, and therefore on the order of 8 inches MMD. Again, separation was better than predicted for this test.

JSOW STV-C Inboard Jettison in Sequence with Analysis

Separation flight testing of JSOW from the inboard station was initially planned for six events, sequentially progressing from lower airspeed and no adjacent HARM conditions to 575 KCAS and adjacent HARM conditions. In the course of flight testing and data analysis, it was determined that jettison events number 15, 16 and 18 (400, 425 and 525 KCAS, respectively) could be safely skipped. For the remainder of the jettison test events from the inboard station, those tests were conducted with the gear UP and flaps AUTO, and in the test loadings indicated in table B-2, loadings 3 and 4. Flight test aircraft, date of test, aircrew and jettison test point parameters are as listed in table B-3. Analysis of applicable flight test data sources for each jettison test are presented in the following paragraphs. All tests met the separation characteristics requirements of the Specification, reference 8, and all test point parameters were achieved within established tolerances.

Jettison Event 17. This test event was the first release of a Joint Standoff Weapon from the inboard station of the F/A-18. Conducted at 504 KCAS, separation for this was predicted to be benign, with only moderate nose down pitch attitude and very little roll or yaw predicted as the store fell away from the aircraft (depicted in figure E-6). Six degree of freedom separation data for the first 0.8 second after jettison is presented as table E-9. Review of photo and video sources indicate that the JSOW STV-C separated cleanly from the host aircraft, pitched nose down and separated vertically after jettison. TI post-flight

analysis for JSOW jettison event 17 is presented as figure E-12. Flight test results matched fairly closely with both TI and MDA predicted values, but the critical parameter for inboard separation, pitch, was less than anticipated. The TI maximum pitch angle of 24.4 deg nose down was predicted at 0.40 sec following jettison, and the MDA prediction conveyed a maximum pitch angle of 28.4 deg nose down 0.5 sec after jettison. Flight test indicated a maximum pitch angle of 21.7 deg nose down occurred at 0.40 sec after jettison, resulting in revision to the 6-DOF and SDF separation models for the inboard station. This revision was critical, as initial MDA wind tunnel analysis predicted a store to pylon impact at 575 KCAS (jettison event 20).

Jettison Event 19. Due to fidelity of TI and MDA predictive models and confidence of the test team that separation characteristics were adequately estimated by those models, the 525 KCAS jettison event 18 was skipped. Jettison event 19 was conducted at 550 KCAS. It was anticipated that the magnitude of the initial nose down pitch would be moderately increased (to approximately 33 deg), thereby decreasing the minimum miss distance (JSOW tail to pylon) predicted for this event. Nonetheless, separation was predicted to be safe for the test conditions. Review of photo and video sources indicate that the JSOW STV-C separated cleanly from the host aircraft, but the tail appeared to hang in place until a significant nose down pitch attitude had been reached, whereupon the store continued to separate from the launch aircraft. Very little roll or yaw was noted throughout the separation. Flight test results matched closely with both TI and MDA revised models.

Jettison Event 20. Jettison event 20 was the final jettison event in the JSOW separation test program. It established the endpoint for the inboard station at a test airspeed of 579 KCAS. Though it was anticipated that the presence of an AGM-88 High Speed Anti-Radiation Missile (HARM) on the outboard station would have virtually no effect on the resulting trajectory of a JSOW released from the inboard pylon, that test loading was used to prove the analysis. Initial MDA wind tunnel analysis indicated that a JSOW to pylon collision would occur at 0.95 IMN and 575 KCAS due to the large post-jettison nose down pitch, as indicated in figure E-7. Analysis of jettison event 17 indicated that the nose down pitch separation characteristic was much less pronounced than expected, and both the TI and MDA models (6-DOF and SDF) were updated to reflect this new information. Figures E-8 and E-13 depict revised expectations for the jettison test event per MDA and TI, respectively. As with the preceding test, review of photo and video sources indicate that the JSOW STV-C separated cleanly from the host aircraft. The store tracked down approximately 6 inches with the ejector stroke, whereupon the JSOW nosed down to approximately 30 deg pitch attitude and continued movement vertically away from the launch aircraft. No appreciable lateral movement either toward the outboard HARM or the fuselage station CATM-7 missile was noted. Flight test results matched closely with both TI and MDA revised models.

Results and Discussion - Launch

JSOW STV-F Launch General Information

As the first JSOW launch was accelerated from the original schedule, the program decision was made to reduce risk by conducting the first launch not at the "most severe jettison condition" as originally planned, but at a lower airspeed and without the adjacent inboard station fuel tank. Consequently, the captive flight test and first launch conditions were targeted for 500 KCAS in loading 5 as depicted in table B-2. All launch related tests were conducted with the gear UP and flaps AUTO. The launch test marked the transition point for the JSOW program from DT-IIA to DT-IIB. The integrated test team included several members that would continue on into DT-IIB at China Lake, as the program transitioned. Indicative of this team approach, CF-01 (a DT-IIA mission) was flown on a China Lake aircraft by local test aircrew. CF-02 and the subsequent launch flight was conducted on a Patuxent River aircraft with a Patuxent River pilot, supporting not only the stated DT-IIA objectives, but also a number of DT-IIB flight test objectives. Flight test aircraft, date of test, aircrew and launch test point parameters are as listed in table B-3. All test point parameters were achieved within established tolerances.

JSOW STV-F Captive Flight Events (CF-01 and CF-02)

Captive flight testing of the first JSOW STV-F was conducted in order to thoroughly test systems as much as possible in preparation for the launch test event. Conduct of these flight enabled refinement of launch procedures, familiarity with communications and range procedures, and verification of JSOW STV-F system functionality (specifically telemetry (TM) systems). TM checkout consisted of JSOW three-phase power application, completion of the weapon initiated built-in-test (IBIT), and a single set of maneuvers conducted on the downwind leg of the practice run. A target area TM checkout to explore each axis of the JSOW instrumentation was completed as a by-product of the Sim Launch operations. Sim Launch was effected by cycling the IR COOL switch from OFF to ORIDE in a specific sequence. Data were recorded from aircraft as well as weapon TM on the ground, and from aircraft systems onto the on-board parameter recording system. Cameras were turned on to verify operation at approximately 10 seconds prior to Sim Launch on the first run, and secured after they had run out. Control of the STV-F Sim Launch mode via modified procedures was effective. Though a few issues were discovered concerning reliable receipt of aircraft TM and sensing of FTS activation radio tones, the captive carriage flights were highly successful overall, and all critical systems were verified for proper operation or identified for resolution prior to launch. As a result, the decision was made to combine flight objectives of DR-01 into the practice runs for FF-01, and if successful, accelerate the first launch even further.

JSOW STV-F Captive Flight Event (DR-01)

The "Dress Rehearsal" event (DR-01) comprised the normal launch communication and procedures plus flight through the expected JSOW flight path (practice for the chase aircraft as well as JSOW TM verification) as well as another practice run up to the launch point to confirm aircraft TM operational status. The first run was overall successful, with the exception of a TM dropout at the jettison point. The decision was made to repeat this run to ensure that the TM dropout was a one-time occurrence and not related to the flight profile. TM was satisfactory for the entirety of the second run, thereby completing the test objective of DR-01 to "verify correct operation of the JSOW in a captive environment."

JSOW STV-F Free Flight Launch Event (FF-01)

This test event was the first launch of a Joint Standoff Weapon from the F/A-18. Conducted at 505 KCAS, separation for this was predicted to be benign, with the slight nose down pitch attitude and minimal roll and yaw noted for the comparable jettison condition countered by the flight controls as the store fell away from the aircraft. Following sequentially after DR-01, two runs with intent to launch were aborted prior to the final successful launch. The first live run was aborted due to a temporary communication failure in the FTS structure (Van 2). The second live run was aborted due to poor weapon leveling performance caused by a commanded course correction late in the delivery. Aircraft autopilot and auto-throttle systems were used to aid in stabilizing test point parameters, despite moderate turbulence at test altitude. Release consent was used to initiate the STV-F batteries, and once all systems were "GO", the normal aircraft Select Jettison procedures were used to release the weapon. Review of photo and video sources indicate that the STV-F separated cleanly from the host aircraft, activated tail control fins approximately 1 ft below the pylon, and apparently controlled motion in pitch, roll and yaw to virtually zero. Comparison of STV-F controlled separation to STV-C jettison event 3 separation reveals that peak jettison pitch of 17.0 deg nose down was reduced to 5.5 deg (starting point on pylon was 3 deg nose down), peak jettison yaw of 4.8 deg outboard was reduced to 1.2 deg, and peak jettison roll of 3.0 deg right was reduced to 1.0 deg. Wing deployment occurred as designed 2.5 sec after launch, and JSOW course corrections were evident 7.0 sec after launch. The JSOW STV-F appeared to be stable throughout time of flight, until FTS activation severed the tail after 2 min and 54 sec of flight. The weapon main body was found with wings still intact, and the mid-section along with the TIK was for the most part intact as well. The control section was found intact approximately 1,000 ft south of the main body. The JSOW STV-F Free Flight Launch Event (FF-01) successfully met each of its DT-IIA and DT-IIB flight test objectives. Separation and free-flight for the first launch event are depicted in figures A-12 and A-13. Launch separation characteristics met the requirements of the Specification, reference 8.

CHAPTER VIII
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

General Conclusions

The general objective of AGM-154A JSOW separation flight testing was to clear the F/A-18A/B/C/D envelope for jettison and launch out to the limits of the systems specification (reference 1), 0.60 to 0.95 IMN, +10 to -45degrees pitch angle (and 15 degrees roll) and release altitudes from 200 ft AGL to 30,000 ft MSL. As amplified by specific conclusions noted in following paragraphs, AGM-154A JSOW separation characteristic in the jettison mode were satisfactory throughout the entire envelope. Launch testing in DT-IIA was truncated at 500 KCAS with no adjacent store, versus the full envelope originally envisioned. Separation characteristics for launch were satisfactory throughout the envelope tested. Overall, jettison and launch separation characteristics of the AGM-154A Joint Standoff Weapon were satisfactory for the Ground Attack mission.

Effectiveness of Methodology

Because a sizable program investment was made into multiple redundant data sources, modeling and simulation, it is reasonable to comment upon the effectiveness and impact of that investment. Specifically, the value of the methodology whereby data from on-board telemetry systems and post-flight photogrammetric analysis was fed back into 6-DOF (TI) and SDF (MDA) wind-tunnel analysis based models to predict separation characteristics is hereby addressed. First and foremost, that iterative process was shown to be invaluable toward increasing the fidelity of both models, and increasing test team confidence in safe execution of the next test in sequence. Though rigorous discussion of cost-effectiveness is beyond the scope of this document, it was shown that the cost associated with the iterative modeling process was more than compensated in cost and schedule by the omission of five JSOW STV-C test points, two of which would have required post-flight photogrammetric analysis. Furthermore, had test tolerances for jettison test event 10 not been exceeded (low airspeed), the potential was there to skip the next point in sequence (and that post-flight photogrammetric analysis), as well. For the high profile JSOW test program, the iterative modeling and simulation used throughout separation testing was extremely effective at improving overall test safety and efficient use of extremely expensive test assets.

AGM-154A JSOW Jettison Envelope

Outboard Stations (2 and 8), Jettison Mode. Jettison separation characteristics of the AGM-154A JSOW were thoroughly evaluated from the outboard station of an F/A-18C with and without the presence of the worst-case adjacent inboard store (the external fuel tank). Though store separation clearly was approaching minimum allowable at worst-case conditions, characteristics noted were satisfactory up to test limits of 575 KCAS and 0.95 IMN and -45degrees pitch angle. Jettison of this store only requires safe separation from the aircraft, as functional weapon employment is no longer viable in that mode. Therefore, the unstable characteristics demonstrated at high speeds following safe separation from the aircraft are not relevant to this specific conclusion. Jettison separation characteristics of the AGM-154A JSOW from the outboard stations (2 and 8) with and without the presence of an adjacent external fuel tank were satisfactory for the Ground Attack mission.

Inboard Stations (3 and 7), Jettison Mode. Jettison separation characteristics of the AGM-154A JSOW were evaluated from the inboard station of an F/A-18C with and without the presence of the worst-case adjacent outboard store (the High-Speed Anti-Radiation Missile, or HARM). Though the significant nose down pitch angle observed at high speed was a concern regarding potential JSOW tail impact to pylon, characteristics noted were satisfactory up to test limits of 575 KCAS and 0.95 IMN in level flight. Jettison separation characteristics from the inboard station in any condition other than level were not determined and cannot be extrapolated from these tests. Jettison separation characteristics of the AGM-154A JSOW from the inboard stations (3 and 7) with and without the presence of an adjacent outboard HARM were satisfactory for the Ground Attack mission.

AGM-154A JSOW Launch Envelope

Separation characteristics of the AGM-154A JSOW in normal launch mode were evaluated from the outboard station of an F/A-18C without any adjacent inboard store. Separation characteristics noted were, as predicted, better than jettison at comparable conditions, and were satisfactory up to test limits of 500 KCAS and 0.82 IMN in level flight. Separation characteristics of the AGM-154A JSOW in normal launch mode from the outboard stations (2 and 8) without the presence of any adjacent store were satisfactory for the Ground Attack mission.

JSOW STV-F Readiness For Follow-On Testing (DT-IIB)

Launch Envelope Limitations. Separation characteristics of the AGM-154A JSOW in normal launch mode were *only* evaluated from the outboard station of an F/A-18C without any adjacent inboard store, and *only*

up to test limits of 500 KCAS and 0.82 IMN in level flight. Test methodology was planned to demonstrate better separation characteristics of the JSOW launch mode than the JSOW jettison mode at the worst-case conditions, confirmed in this document as 575 KCAS and 0.95 IMN in the presence of an adjacent external fuel tank. In so doing, the entire launch envelope would have been cleared to match the jettison envelope tested. As overall JSOW program requirements dictated a change in test design, the total envelope cleared for launch was necessarily reduced to those conditions tested, and that part of the launch envelope inclusive of an adjacent external fuel tank and up to 575 KCAS and 0.95 IMN remains to be demonstrated in DT-IIB prior to fleet clearance.

Wing Deployment. Wing deployment characteristics of the JSOW STV-F in normal launch mode were evaluated following separation testing during the first JSOW STV-F launch. Wing deployment characteristics noted were satisfactory up to test launch limits of 500 KCAS and 0.82 IMN in level flight. Wing deployment characteristics of the JSOW STV-F in normal launch mode were satisfactory for continued development in DT-IIB.

Free Flight Characteristics. Free flight characteristics of the JSOW STV-F were evaluated following separation testing during the first JSOW STV-F launch. Free flight characteristics noted were satisfactory from test launch limits of 500 KCAS and 0.82 IMN in level flight to activation of the Flight Termination System. Free flight characteristics of the JSOW STV-F were satisfactory for continued development in DT-IIB.

Flight Termination System (FTS). The FTS of the JSOW STV-F was evaluated following separation testing during the first JSOW STV-F launch. FTS characteristics noted were satisfactory, as activation of that system immediately terminated free flight of the weapon upon ground-initiated signal. The JSOW STV-F FTS was satisfactory for continued development in DT-IIB.

Structural Integrity. Structural integrity of the JSOW STV-F was evaluated during and following separation testing of the first JSOW STV-F launch. Structural integrity was found to be robust throughout the separation event, wing deployment, free flight, FTS activation and ground impact. The JSOW STV-F structural integrity was satisfactory for continued development in DT-IIB.

Specification Conformance

The AGM-154A JSOW jettison and launch separation characteristics met all requirements of the MIL-STD-1763A specification, reference 8, against which it was tested. Wing deployment and free flight characteristics as well as FTS performance and structural integrity were not compared to any specification.

Recommendations

General Recommendation

The author recommends flight clearance for the AGM-154A Joint Standoff Weapon from F/A-18C/D aircraft in the jettison and launch modes subject to the limitations of specific recommendations.

Specific Recommendations

1. For future test programs that may benefit from the extensive lessons learned with iterative modeling and simulation using multiple data sources in this test program, the author recommends consideration of methodology similar to that used for AGM-154A JSOW. Furthermore, if high-speed photography is to be used for a test program, the author recommends the relatively inexpensive option of targeting separating stores for potential photogrammetric analysis.

2. The JSOW program clearly benefited from the close interaction of an Integrated Test Team composed of knowledgeable industry and government representatives across a spectrum of disciplines. The author emphatically recommends use of the Integrated Test Team concept for future test programs, wherever feasible.

3. For JSOW jettison from F/A-18C/D outboard stations (2 and 8) with or without adjacent Tactical Manual authorized inboard station stores, the author recommends flight clearance up to 575 KCAS and 0.95 IMN, +10 to -45degrees pitch angle (up to 15 degrees roll) and all release altitudes.

4. For JSOW jettison from F/A-18C/D inboard stations (3 and 7) with or without adjacent Tactical Manual authorized fuselage station and outboard station stores, the author recommends flight clearance up to 575 KCAS and 0.95 IMN, level flight (up to 15 degrees roll) and all release altitudes.

5. For JSOW launch from F/A-18C/D outboard stations (2 and 8) without adjacent inboard station stores, the author recommends flight clearance up to 500 KCAS and 0.82 IMN, level flight (up to 15 degrees roll) and all release altitudes without restriction.

6. For JSOW launch from F/A-18C/D outboard stations (2 and 8) without adjacent inboard station stores, the author recommends flight clearance up to 575 KCAS and 0.95 IMN, +10 to -45degrees pitch angle (up

to 15 degrees roll) and all release altitudes, restricted to DT-IIB testing with a qualified test pilot until satisfactory separation characteristics in the launch mode have been demonstrated during that test phase.

7. For JSOW launch from F/A-18C/D outboard stations (2 and 8) with adjacent Tactical Manual authorized inboard station stores, the author recommends flight clearance up to 575 KCAS and 0.95 IMN, +10 to -45degrees pitch angle (up to 15 degrees roll) and all release altitudes, restricted to DT-IIB testing with a qualified test pilot until satisfactory separation characteristics in the launch mode have been demonstrated during that test phase.

8. For JSOW launch from F/A-18C/D inboard stations (3 and 7) with or without adjacent Tactical Manual authorized fuselage station and outboard station stores, the author recommends flight clearance up to 500 KCAS and 0.82 IMN, level flight (up to 15 degrees roll) and all release altitudes without restriction.

9. For JSOW launch from F/A-18C/D inboard stations (3 and 7) with or without adjacent Tactical Manual authorized fuselage station and outboard station stores, the author recommends flight clearance up to 575 KCAS and 0.95 IMN, level flight (up to 15 degrees roll) and all release altitudes, restricted to DT-IIB testing with a qualified test pilot until satisfactory separation characteristics in the launch mode have been demonstrated during that test phase (from any condition more critical than jettison event 20).

10. For JSOW jettison or launch from F/A-18C/D inboard stations (3 and 7) with or without adjacent Tactical Manual authorized fuselage station and outboard station stores, up to the full envelope of 575 KCAS and 0.95 IMN, +10 to -45degrees pitch angle (up to 15 degrees roll) and all release altitudes, the author recommends additional flight testing.

11. Considering launch envelope restrictions, JSOW wing deployment and free flight characteristics, FTS performance and JSOW apparent structural integrity to ground impact, the author recommends transition of the test program into DT-IIB.

CHAPTER IX
EPILOGUE

Continued Development of the AGM-154A JSOW

Following successful completion of the first JSOW launch on 13 December 2004, the Conventional Weapons Program Manager (PMA-201) for JSOW had this to say (NAWCWD, 1995):

> "My congratulations to the entire JSOW TEAM. Our successful flight of STV-F1 on December 13th marks the culmination of lots of hard work to meet a challenge to fly before the Christmas holidays. You all did it! JSOW has spread its wings!
> Very Respectfully, J.V. Chenevey (The Proud PMA of JSOW)"

At the completion of DT-IIA, much was yet to be done to make JSOW fully operational. The DT-IIB phase of flight testing commenced immediately upon completion of the first launch, and the first Advanced Development Model (ADM) version of JSOW was launched on 15 March 1995 (TI, 17 March 1995). Following ten out of eleven successful launches, DT-IIB was completed in December of 1995. Operational Testing (OT) commenced in February 1997, and following 42 for 44 successful launch tests, OT completed later that same year. As a result of fleet demand, JSOW test articles were deployed aboard USS Nimitz in 1997, and those test articles were transferred ship-to-ship to remain in the combat theater until replaced with production models. In December of 1998, the Raytheon Company (now the parent company of Texas Instruments) was awarded the Full Rate Production (FRP) contract for the first lot of JSOW. As a result of another urgent fleet request following Operation Desert Fox in December of 1998, the initial JSOW production units were shipped from storage to the USS Vinson, deployed in support of Operation Southern Watch (OSW) (Global Security, 2005). On the 21st of January 1999, the Program Executive Officer for Tactical Aviation (PEO(T)) released the message declaring Initial Operational Capability (IOC) for the AGM-154A Joint Standoff Weapon. On the 25th of January, just four days later, three JSOW were launched in combat at anti-aircraft defense sites in Iraq that had been threatening coalition aircraft (News Review, 17 February 1999).

Combat Employment

By spring of 2000, 62 AGM-154A JSOW had been used in combat, 51 of which had been launched at Iraqi targets in support of Operation Southern Watch. Another 11 JSOW were launched at targets in 1999 during Operation Allied Force, and achieved a 100 percent success rate as those weapons performed precisely as designed and hit their intended aimpoint (Tester, 28 September 2000). In a February 2001

OSW strike, a JSOW guidance problem surfaced related to the wind correction algorithm, as 26 of 28 JSOW missed their intended aimpoints (Arkin, 2001). That problem has since been corrected. Throughout Operation Enduring Freedom and Operation Iraqi Freedom, the AGM-154A JSOW was again the weapon of choice. To date, over 400 of these weapons have been launched in combat, and have provided the lethality from standoff critical to survivability in modern warfare (Global Security, 2005).

Evolution of JSOW

When JSOW became a "joint" program in 1992, development was planned for two additional variants of the Joint Standoff Weapon, the AGM-154B and the AGM-154C. The AGM-154B was designed to carry six BLU-108 submunitions that in turn were designed to dispense four projectiles capable of detecting and attacking infrared targets. After much development effort, the United States Air Force (USAF) cancelled the AGM-154B program in favor of a variant of the Wind Corrected Munitions Dispenser (Aviation Week, 2003). The AGM-154C was developed solely for use by the United States Navy. This JSOW variant was designed to include a unitary warhead and an imaging infrared seeker with Autonomous Target Acquisition (ATA) technology. The Navy selected the BAE Systems BROACH (Bomb Royal Ordnance Augmenting Charge) warhead for the AGM-154C (Tester, 11 June 1998), and development for this warhead proceeded in parallel to the unitary JSOW. First flight of the AGM-154C JSOW occurred late in 2001, the FRP contract was awarded in December 2004 and IOC was declared in February 2005. Continued evolution of the AGM-154 JSOW includes plans for integration of a weapon data link and production of a lower cost unitary variant containing the 500 pound BLU-111 warhead (designated the AGM-154A-1). The USAF withdrew from the "joint" JSOW program in the fall of 2003, effectively increasing the unit cost for Navy acquisition (NAVAIR, 21 December 2005). As a result, the Navy and industry teamed to pursue lower cost variants, since designated as Block II and Block III JSOW. The Block III weapon will include data link to enable the engagement of moving targets. Over 2,000 JSOW have been delivered to date, and the weapon capability has been integrated on F/A-18C/D, F/A-18E/F, F-16, F-15E, B-52, B-1B and B-2 aircraft. It will be integrated on the Joint Strike Fighter (F-35), as well (Tester, 1 December 2005).

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APPENDICES

APPENDIX A: FIGURES



Figure A-1

Author and Plane Captain with Photogrammetric Targets Depicted



Figure A-2

Photogrammetric Targets on Aircraft and JSOW STV-F Pre-Launch

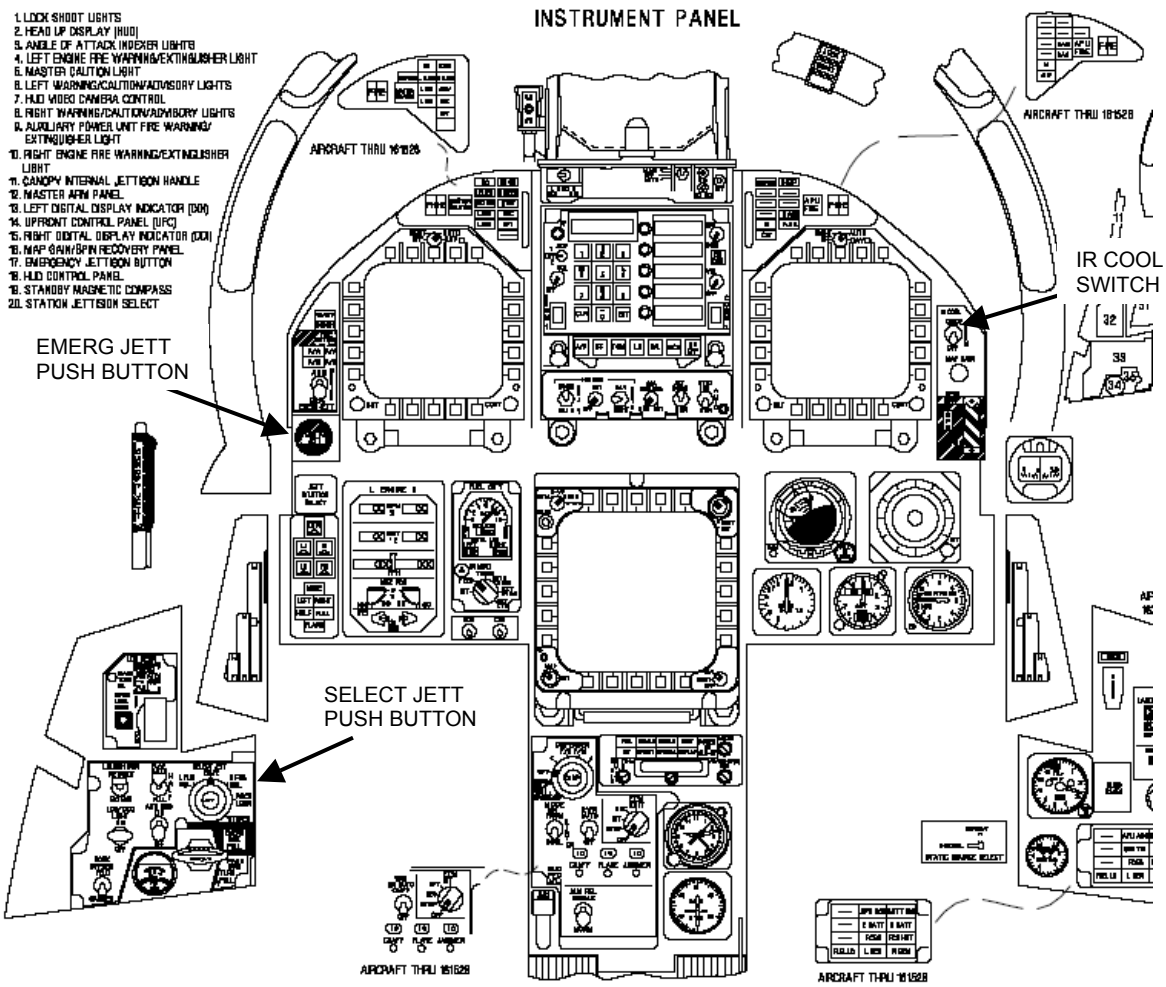


Figure A-3

F/A-18A Cockpit Indicating IR COOL Switch, Emergency Jettison and Select Jettison Push Buttons

Source: NAVAIR A1-F18AC-NFM-00, *NATOPS Flight Manual F/A-18A/B/C/D Aircraft,* 15 January 1991.

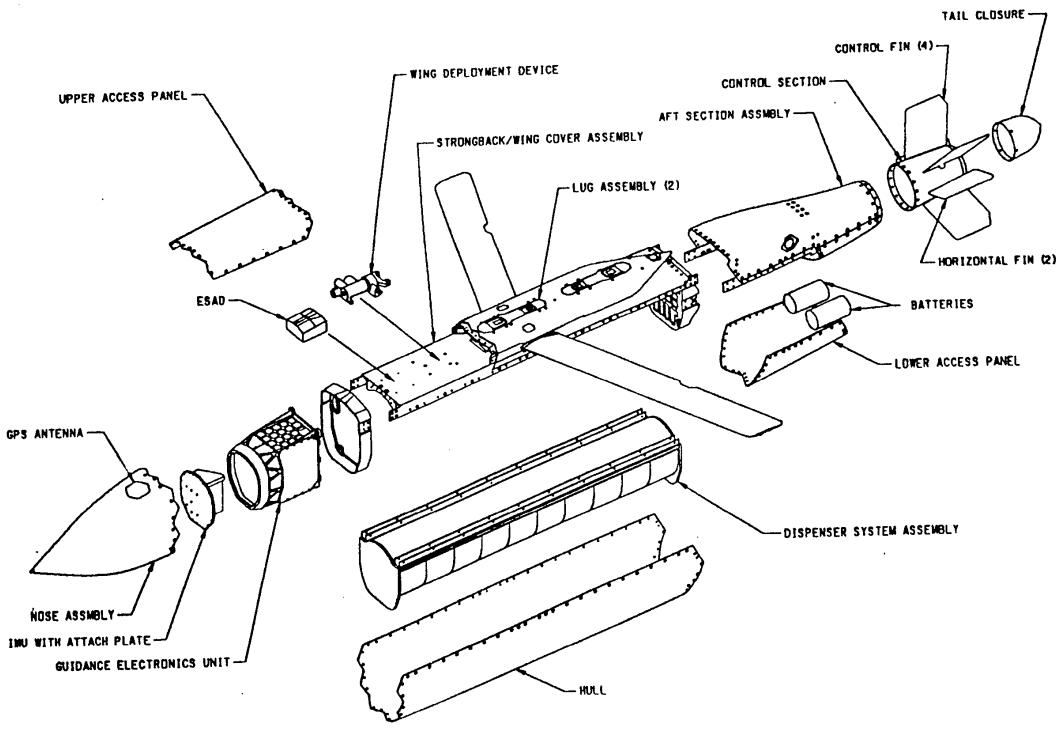


Figure A-4

AGM-154A JSOW Exploded View

Source: Texas Instruments, *JSOW TRR F/A-18, AV-8B, A-6E, F-14 Fit Checks Meeting Minutes,* 4 October 1993.

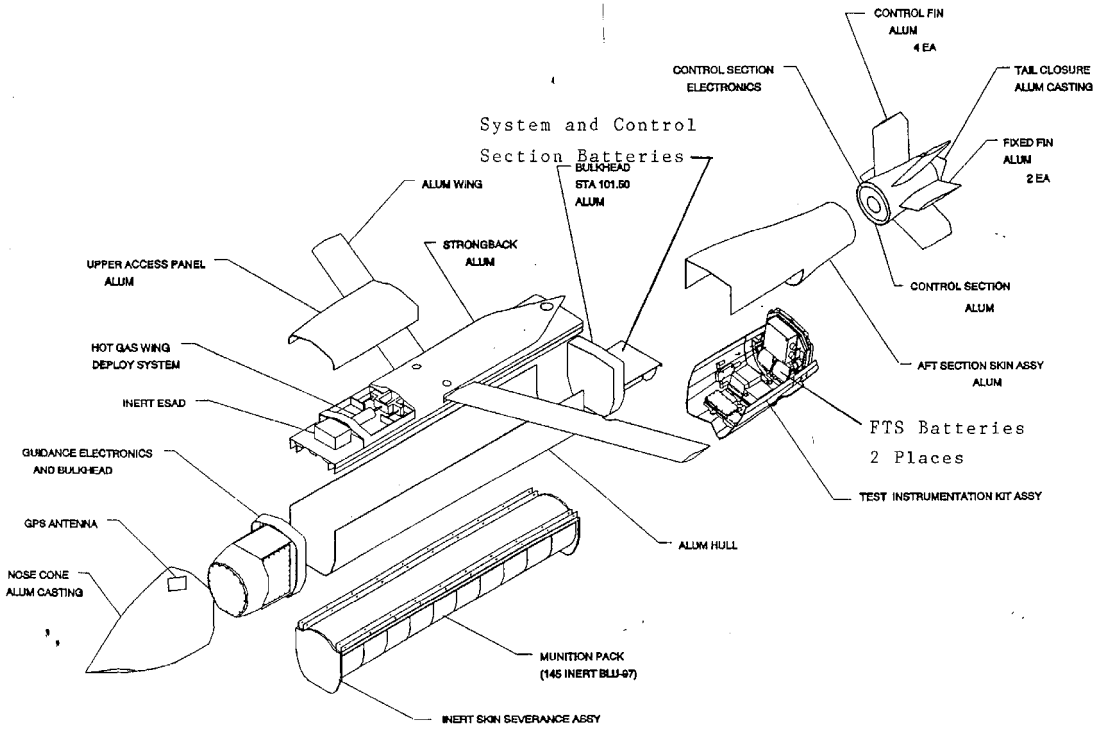


Figure A-5

JSOW STV-F Components

Source: Adapted from LT D. Hinson, Mr. M. Griffith, NAWCAD T&E Engineering / Aircraft Test Wing Atlantic Project Test Plan 1689, 9 September 1994.

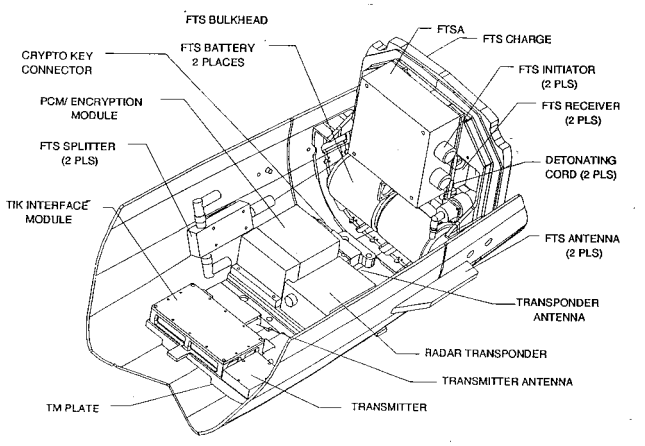


Figure A-6

JSOW STV-F TIK Mechanical Layout

Source: Adapted from LT D. Hinson, Mr. M. Griffith, NAWCAD T&E Engineering / Aircraft Test Wing Atlantic Project Test Plan 1689, 9 September 1994.

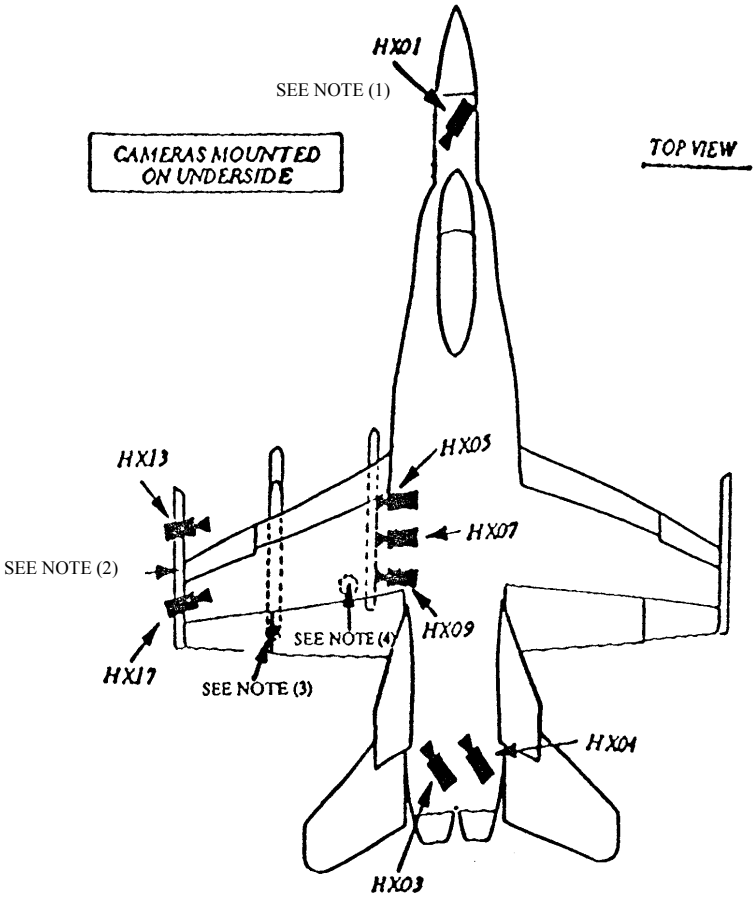


Figure A-7

F/A-18 JSOW Test Camera Configuration

Notes: (1) Nose camera No. HX01 applies to F/A-18C BuNo 163476 (#101) only.

(2) Port wing tip camera configuration in accordance with local flight clearance restrictions and configuration requirements (third camera optional).

(3) Downward looking 1-PL camera with 90 degree lens mounted in aft section of station 2 pylon (pylon S/N LEY-122).

(4) Downward looking SEKAI video camera with 90 degree lens mounted in port wing Sparrow radar cavity of F/A-18C BuNo 163476 (#101) only.

Source: Adapted from LT D. Hinson, Mr. M. Griffith, NAWCAD FTEG Project Test Plan 1571, 10 February 1994.



Figure A-8

JSOW Jettison 1-1



Figure A-9

JSOW Jettison 1-2



Figure A-10

JSOW Jettison 1-3



Figure A-11

JSOW Jettison Event 12



Figure A-12

JSOW STV-F Launch



Figure A-13

JSOW STV-F Free Flight

APPENDIX B: TABLES

Table B-1

Detailed JSOW STV-F Launch Wing Deployment Timeline

Event	Time (sec)
Release Consent	-20.000
Actuator Battery	-18.400
Control Fins Lock Release	-17.400
Control Fins to 2 deg	-17.200
Control Fins to Zero	-17.000
Final Go / No-Go	-5.000
Hooks Open	0.000
Umbilical Separation	0.039
First Command to Control Section (Worst Case)	0.052
Start Pitch Accelerator Control	0.350
Begin Ramp to Wings Deployed Angle of Attack Limits (30 ft Vertical Separation)	1.210
Start Yaw Acceleration Control	1.500
Start Wing Deployment	1.560
Start Flight Path Hold Parallel to Host Aircraft Path at Release	2.100
Begin Outboard Skid	2.100
Full Wing Deployment	2.800 (earliest) 3.560 (latest)
Start Roll Integrator	4.135
Lateral Avoidance Distance Achieved, Begin Max L/D Pull-Up	5.281
Flight Termination System Minimum Arm Time	7.000
Complete Outboard Skid	7.300
Pull-Up through Host Aircraft Plane of Flight, Begin Bank-to-Turn Control	7.882

Source: Adapted from LT D. Hinson, Mr. M. Griffith, NAWCAD T&E Engineering / Aircraft Test Wing Atlantic Project Test Plan 1689, 9 September 1994.

Table B-2

F/A-18 JSOW Flight Test Loadings

LOAD	AIRCRAFT STATION NUMBER									REMARKS
	1	2[1]	3[1]	4	5	6	7	8	9	
1	2 CAM	JSOW STV-C	EMPTY PYLON	2 CAM	FUEL TANK	EMPTY	EMPTY PYLON	MK 82[3]	BALLAST	2 TAIL CAM BuNo 163476 had 3 CAM Stations 1 and 4
2[2]	3 CAM	JSOW STV-C	EMPTY FUEL TANK	3 CAM	EMPTY PYLON	EMPTY	EMPTY FUEL TANK	MK 82	BALLAST	NOSE CAM, 2 TAIL CAM, Video at AIM-7 Wing Antenna Location
3	3 CAM	EMPTY PYLON	JSOW STV-C	CATM-7[4]	EMPTY FUEL TANK	EMPTY	MK 83[3]	EMPTY PYLON	BALLAST	NOSE CAM, 2 TAIL CAM, Video at AIM-7 Wing Antenna Location
4	EMPTY	AGM-88 [5] HARM	JSOW STV-C	CATM-7	EMPTY FUEL TANK	EMPTY	MK 83	MK 83	EMPTY	NOSE CAM, 2 TAIL CAM, Video at AIM-7 Wing Antenna Location
5	3 CAM	JSOW STV-F	EMPTY PYLON	3 CAM	FUEL TANK	EMPTY	EMPTY PYLON	MK 83	BALLAST	NOSE CAM, 2 TAIL CAM, Video at AIM-7 Wing Antenna Location

Notes: (1) Stations 2 and 3 pylons contained a the pylon camera when JSOW installed for release on that station.
(2) Empty Fuel Tank station 7 downloaded in order to make release conditions for flight event 13.
(3) MK 82 represents and inert 500 lb bomb assembly. MK 83 represents an inert 1,000 lb bomb assembly.
(4) CATM-7 represents a captive (inert) 500 lb AIM-7 air-to-air missile.
(5) AGM-88 HARM represents a captive (inert) 1,000 lb High Speed Anti-Radiation Missile.
(6) Flight test cameras are indicated by "CAM", where appropriate. The Nose Camera and Wing Video loadings were only installed on aircraft bureau number 163476.

Table B-3

F/A-18 JSOW Flight Test Event Matrix

TEST EVENT	LOAD	EVT NO.	BUNO	DATE	PILOT	RELEASE CONDITIONS					REMARKS
						ALT (ft HP)	AIRSPEED (KCAS)	ACCEL (g)	FPA (deg)	IMN	
JETTISON	1	1	161925	8 MAR 94	Hinson	5,012	401	1.0	0	0.66	First JSOW Jettison
JETTISON	1	2	161925	7 APR 94	Rader	4,984	445	1.0	0	0.73	
JETTISON	1	3	161925	14 APR 94	Thomas	4,992	497	1.1	0	0.81	
JETTISON	1	4	161925	26 APR 94	Reuter	N/A	N/A	N/A	N/A	N/A	In-Flight ABORT
JETTISON	1	4	161925	28 APR 94	Bouchard	4,964	550	1.03	0	0.90	
JETTISON	2	6	163476	18 MAY 94	Reuter	5,088	399	0.97	0	0.66	
JETTISON	1	5	163476	23 MAY 94	Everett	5,268	578	1.1	0	0.95	
JETTISON	2	7	N/A	SKIP	N/A	5,000	425	1.0	0	0.70	Planned Conditions – Point Skipped
JETTISON	2	8	163476	31 MAY 94	Hinson	5,096	450	0.98	0	0.74	
JETTISON	2	9	N/A	SKIP	N/A	5,000	475	1.0	0	0.78	Planned Conditions – Point Skipped
JETTISON	2	10	163476	20 JUN 94	Sturckow	5,116	487	1.17	0	0.80	Missed 500 KCAS Test Point (Low)
JETTISON	2	11	163476	15 JUL 94	Mortenson	5,084	528	1.03	0	0.86	
JETTISON	2	12	163476	8 AUG 94	Hinson	5,140	551	1.0	0	0.90	
JETTISON	2	13	163476	31 AUG 94	Everett	N/A	N/A	N/A	N/A	N/A	Target Release Conditions Not Attained
JETTISON	2[(1)]	13	163476	1 SEP 94	Everett	5,310	573	1.0	0	0.94	
CAPTIVE	2	14	163476	12 OCT 94	Hinson	N/A	N/A	N/A	N/A	N/A	Practice Flight for 45 degree Jettison
JETTISON	2	14	163476	12 OCT 94	Hinson	6,025	583	0.7	-44	0.96	Endpoint for Outboard Jettison
JETTISON	3	16[(2)]	N/A	SKIP	N/A	5,000	450	1.0	0	0.74	Planned Conditions – Point Skipped
JETTISON	3	17	163476	18 OCT 94	Traven	5,095	504	1.0	0	0.82	First Inboard Station Release
JETTISON	3	18	N/A	SKIP	N/A	5,000	525	1.0	0	0.86	Planned Conditions – Point Skipped
JETTISON	3	19	163476	2 NOV 94	Heins	5,060	550	1.0	0	0.90	
JETTISON	4	20	163476	1 DEC 94	Hinson	5,360	579	1.0	+1	0.95	Endpoint for Inboard Station
CAPTIVE	-	CF-01	114	6 DEC 94	Lee	N/A	N/A	N/A	N/A	N/A	Wpns Test Sqdn China Lake Aircraft
CAPTIVE	5	CF-02	163476	8 DEC 94	Hinson	N/A	N/A	N/A	N/A	N/A	
LAUNCH	5	FF-01[(3)]	163476	13 DEC 94	Hinson	5,142[(4)]	505	1.0	0	0.82	First Launch of JSOW

Notes: (1) Station 7 External Fuel Tank was down-loaded in order to reduce drag to make this test point achievable.
(2) Test Event 15 (425 KCAS inboard station jettison) was deleted before signature on the test plan amendment for the inboard station.
(3) Test evaluation included a "Dress Rehearsal" (DR-01).
(4) Altitude reported in ft MSL for this test.

APPENDIX C: BLU-97 COMBINED EFFECTS BOMBLET (CEB)

The BLU-97 shown in figure C-1 was originally produced by AEROJET for the CBU-87 Combined Effects Munition (CEM) cluster bomb. Under the JSOW contract, AEROJET transitioned the BLU-97 to an insensitive munition, designated the IM BLU-97A/B CEB. Each BLU-97 bomblet was a cylinder 2.51 inches in diameter and 6.65 inches in length (before dispense), and weighed 3.5 pounds. Once the submunition was dispensed from the CBU-87, the spider assembly was designed to catch the airflow which shifted it rearward, withdrawing the Air Inflated Decelerator (AID) cup, also shown in figure C-1. This action was designed to release the AID ballute and allow the spring loaded stand-off tube to extend forward by the compressed conical stand-off spring. The JSOW variant of the BLU-97 used a Ram Air Decelerator (RAD) instead of the AID. As the AID was inflated by the air stream, it was designed to orient and stabilize the submunition for proper target impact with the target or terrain, the stand-off tube was designed to slide rearward over the bomb body and support collar and strike the firing pin which impacts the piezoelectric crystal which initiates the explosive train. As a backup, the BLU-97 had a secondary omnidirectional firing mechanism which would fire the submunition from any impact angle due to gravity forces. An escapement device was designed to delay the arming sequence for one half to one second for safe separation purposes during dispense. The bomblet had three kill mechanisms; a downward firing conical copper shaped charge, fragments produced when the blast of the bomblet's main charge burst the scored-steel bomb case, and a zirconium sponge ring which was designed to provide incendiary fire starting capability on all surfaces.

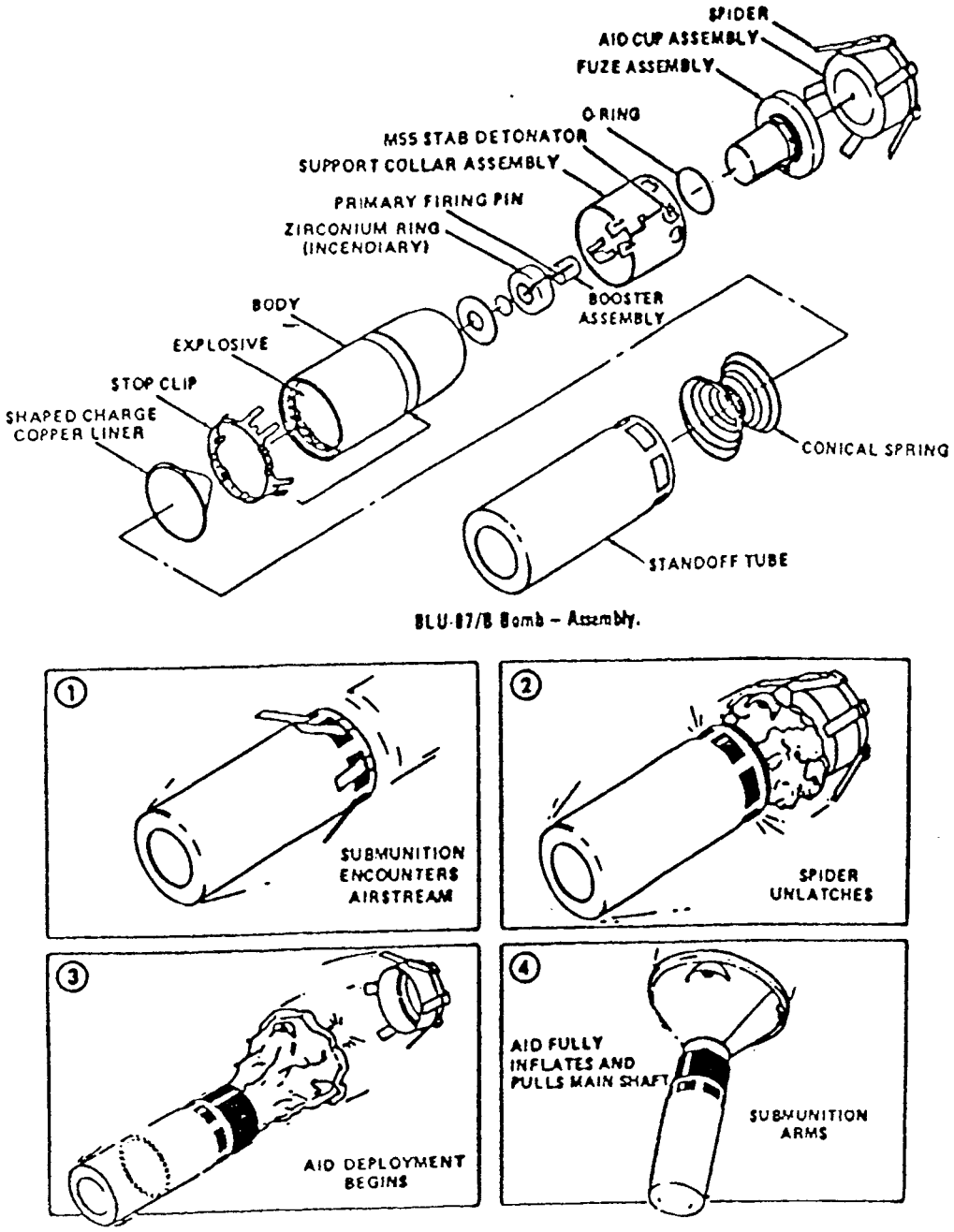
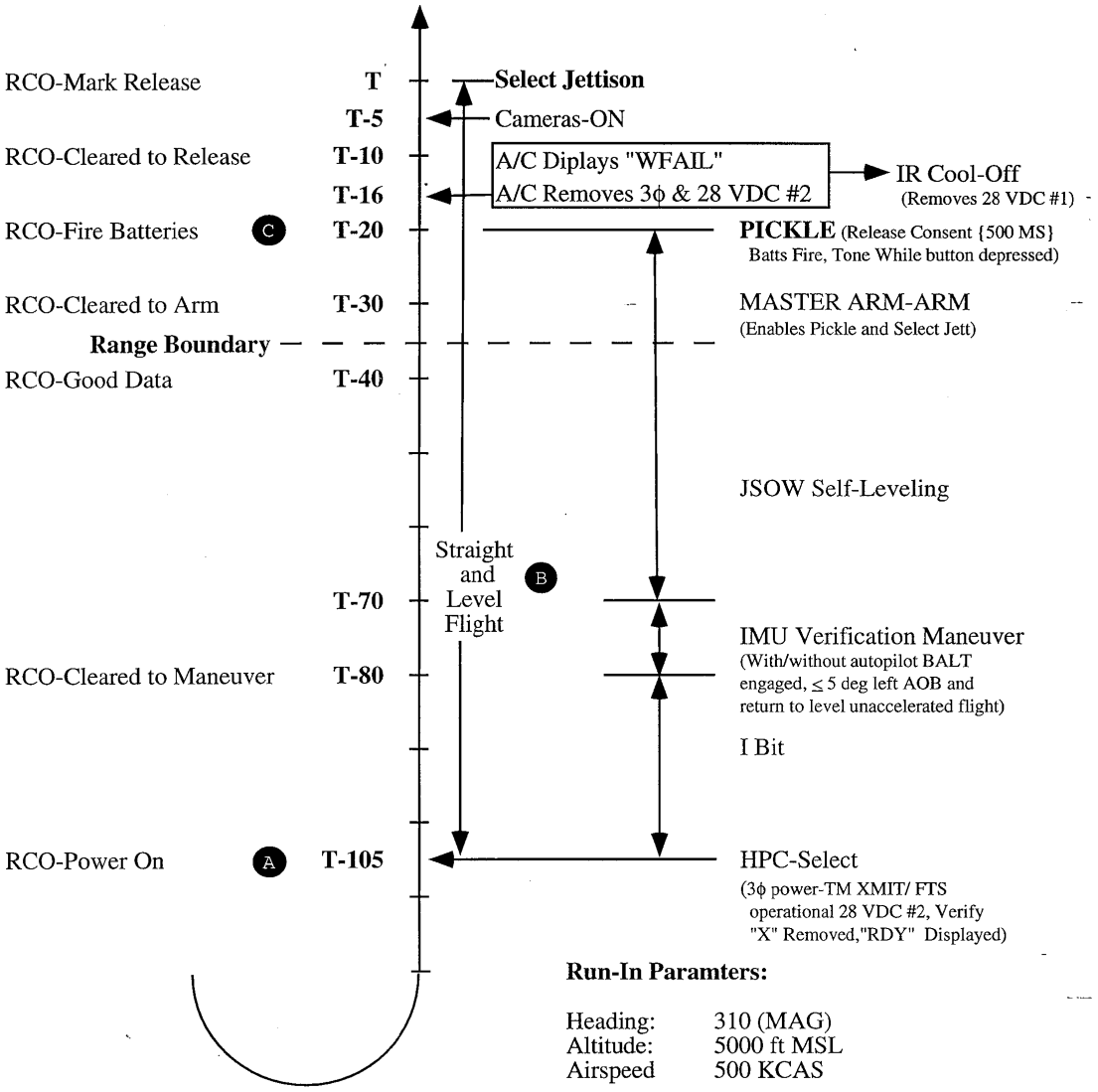


Figure C-1

BLU-97 Assembly and Operating Sequence

Source: Adapted from LT D. Hinson, Mr. M. Griffith, NAWCAD FTEG Project Test Plan 1571, 10 February 1994.

APPENDIX D: JSOW LAUNCH DETAILED TIMELINE



Prior to Turn-in for Live Run:

1. IR Cool-ORIDE (28 VDC #1, 10 min. before Launch)
2. A/G Mode-Select (Verify Racks Unlock)
3. Records-ON
4. Tone-Select
5. Video-ON
6. Cap On Emergency Jettison Button
7. Verify Select Jettison Switches

Figure D-1

JSOW Launch Detailed Timeline

Notes:

(A) When aircraft power applied, aircraft flight parameters must agree with those stored in the Power-On message within the following limits:

(1) Time of Day: N/A

(2) Latitude: ± 1 NM

(3) Longitude: ± 1 NM

(B) During straight and level flight, aircraft must:

(1) Hold groundspeed to ± 10 knots change over 1 minute

(2) Hold airspeed to ± 10 KCAS at all times

(3) Hold pitch angle to ± 5 degrees of expected trim angle

(4) Hold roll angle to ± 5 degrees of zero

(C) When Release Consent is applied, aircraft flight parameters must agree with those stored in the Preplanned Release message within these limits:

(1) Altitude: ± 250 feet

(2) Latitude: ± 0.5 NM

(3) Longitude: ± 0.5 NM

(4) Airspeed: ± 10 KCAS

(5) Ground Speed: ± 50 knots

(6) Pitch: ± 5 degrees

(7) Roll: ± 5 degrees

(8) Ground Track: ± 4 degrees

(9) Aircraft Crab Angle: ≤ 5 degrees

Source: Adapted from LT D. Hinson, Mr. M. Griffith, NAWCAD T&E Engineering / Aircraft Test Wing Atlantic Project Test Plan 1689, 9 September 1994.

APPENDIX E: DATA AND ANALYSIS TABLES AND FIGURES

Table E-1

MDA JSOW Outboard Station Jettison Analysis Summary[1]

Outboard Pylon Jettison (Station 2 / 8) – Altitude 5,000 ft							
Configuration	Mach (IMN)	Nz (G)	AOA (deg)	Dive Angle (deg)	Minimum Miss Distance to Store (in)		Results
No Adjacent Store	0.66	1.0	2.19	0	JSOW / Pylon minimum miss distance of 1.59 in occurs at carriage		Safe Jettison
	0.74		1.82				
	0.82		1.50				
	0.90		1.33				
	0.95		1.13				Note (2)
Adjacent Inboard Station Fuel Tank	0.66	1.0	2.52	0	22.41	Tank	Safe Jettison
	0.70		2.33		21.81	Tank	
	0.74		2.16		19.60	Tank	
	0.78		1.99		16.76	Tank	
	0.82		1.76		13.72	Tank	
	0.86		1.58		11.27	Tank	
	0.90		1.42		8.95	Tank	Note (3)
	0.95		1.12		0.00	Tank	Notes (2) and (3)
	0.95	0.71	0.94	-45	0.00	Tank	Notes (2) and (3)
	0.80		1.60		9.79	Tank	Safe Jettison

Notes: (1) Table and wind tunnel analysis produced by MDA and provided to Government for JSOW Test Plan.
(2) Violates MIL-STD-1763A requirement "No portion of the separating store may penetrate a 6 inch boundary surrounding the aircraft, suspension equipment or adjacent stores."
(3) Violates MIL-STD-1763A requirement "Portions of the separating store inside of the 6 inch boundary upon release are prohibited from further encroachment."

Source: Adapted from M. J. Holmes III, K. A. Gordon, MDA *F/A-18 JSOW Launch / Jettison Wind Tunnel and Analysis Report,* MDC93B0191 of 15 December 1993, as incorporated into NAWCAD FTEG Project Test Plan 1571 of 10 February 1994.

Table E-2

JSOW Jettison Event-1, 6-DOF Post-Flight Data

Parameter[1]						
Time (sec)	x (ft)	y (ft)	z (ft)	Psi (deg)	Theta (deg)	Phi (deg)
0.00	0.00	0.00	0.00	0.00	-3.40	0.00
0.10	-0.07	-0.02	0.82	-0.38	-4.59	-0.05
0.20	-0.21	-0.08	2.26	-1.25	-7.18	1.93
0.30	-0.41	-0.19	4.10	-2.17	-10.01	3.24
0.40	-0.69	-0.39	6.36	-2.80	-12.45	3.01
0.50	-1.04	-0.68	9.10	-2.94	-14.20	.048
0.60	-1.50	-1.06	12.33	-2.49	-15.16	-4.36
0.70	-2.05	-1.52	16.05	-1.50	-15.30	-11.14
0.80	-2.71	-2.05	20.27	-0.17	-14.67	-19.33
0.90	-3.46	-2.60	24.94	1.23	-13.42	-28.24
1.00	-4.29	-3.15	30.05	2.44	-11.77	-37.09

Notes: (1) Psi, Theta, and Phi represent Yaw, Pitch and Roll angles, respectively. Sign convention is: +x is forward, +y is lateral right, +z is down; +Psi is nose right, +Theta is nose up, +Phi is right roll.

Source: Texas Instruments, *JSOW F/A-18 Aircraft Jettison #2 & #3 TRR Meeting Minutes,* 31 March 1994.

Table E-3

JSOW Jettison Event-3, 6-DOF Post-Flight Data

Parameter[1]						
Time (sec)	x (ft)	y (ft)	z (ft)	Psi (deg)	Theta (deg)	Phi (deg)
0.00	0.00	0.00	0.00	0.00	-3.00	0.00
0.10	-0.10	-0.03	0.89	-1.11	-5.25	0.72
0.20	-0.34	-0.15	2.51	-3.28	-9.84	2.01
0.30	-0.73	-0.45	4.64	-4.60	-14.12	-0.59
0.40	-1.31	-1.00	7.43	-3.83	-16.46	-9.86
0.50	-2.11	-1.76	10.91	-1.07	-15.92	-25.02
0.60	-3.10	-2.62	15.06	2.38	-13.09	-43.11
0.70	-4.25	-3.43	19.73	5.52	-9.11	-61.88
0.80	-5.52	-4.09	24.79	7.77	-5.01	-80.11
0.90	-6.92	-4.51	30.08	8.70	-1.73	-97.17
1.00	-8.45	-4.68	35.46	8.35	-0.16	-112.60

Notes: (1) Psi, Theta, and Phi represent Yaw, Pitch and Roll angles, respectively. Sign convention is: +x is forward, +y is lateral right, +z is down; +Psi is nose right, +Theta is nose up, +Phi is right roll.

Source: Texas Instruments, *JSOW F/A-18 Aircraft Jettison #4, #5 & #6 TRR Meeting Minutes,* 22 April 1994.

Table E-4

JSOW Jettison Event-6, 6-DOF Post-Flight Data

Parameter[1]						
Time (sec)	x (ft)	y (ft)	z (ft)	Psi (deg)	Theta (deg)	Phi (deg)
0.00	0.00	0.00	0.00	0.00	-3.00	0.00
0.10	0.01	0.04	0.79	-1.10	-4.71	0.18
0.20	-0.11	0.08	2.20	-4.12	-8.00	2.07
0.30	-0.26	0.01	4.02	-8.09	-11.78	4.01
0.40	-0.39	-0.34	6.36	-11.50	-14.27	2.07
0.50	-0.50	-1.11	9.34	-14.17	-13.40	-10.16
0.60	-0.60	-2.25	12.83	-16.04	-10.00	-26.22
0.70	-0.67	-3.62	16.57	-14.95	-5.96	-35.00
0.80	-0.72	-5.06	20.42	-10.48	-1.43	-29.47
0.90	-0.80	-6.46	24.38	-3.58	2.61	-13.38
1.00	-0.95	-7.75	28.48	3.03	4.55	2.88

Notes: (1) Psi, Theta, and Phi represent Yaw, Pitch and Roll angles, respectively. Sign convention is: +x is forward, +y is lateral right, +z is down; +Psi is nose right, +Theta is nose up, +Phi is right roll.

Source: Mr. Chris McLean, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #7 & #8 Test Readiness Data,* 31 May 1994.

Table E-5

JSOW Jettison Event-8, 6-DOF Post-Flight Data

Parameter[1]						
Time (sec)	x (ft)	y (ft)	z (ft)	Psi (deg)	Theta (deg)	Phi (deg)
0.00	0.00	0.00	0.00	0.00	-3.00	0.00
0.10	0.03	0.02	0.68	-1.42	-4.35	-1.00
0.20	0.00	0.04	1.95	-6.07	-8.51	0.02
0.30	-0.05	-0.16	3.75	-12.20	-13.42	0.03
0.40	-0.12	-0.92	6.33	-18.91	-15.08	-12.78
0.50	-0.19	-2.40	9.53	-23.61	-13.00	-37.07
0.60	-0.21	-4.53	12.63	-25.04	-10.72	-46.85
0.70	-0.20	-7.26	15.47	-21.76	-7.05	-36.54
0.80	-0.21	-10.36	18.38	-14.66	-2.92	-8.02
0.90	-0.29	-13.67	21.69	-6.21	1.45	30.88
1.00	-0.45	-17.22	25.40	2.44	5.46	77.57

Notes: (1) Psi, Theta, and Phi represent Yaw, Pitch and Roll angles, respectively. Sign convention is: +x is forward, +y is lateral right, +z is down; +Psi is nose right, +Theta is nose up, +Phi is right roll.

Source: Mr. Chris McLean, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #9 & #10 Test Readiness Data,* 10 June 1994.

Table E-6

JSOW Jettison Event-11, 6-DOF Post-Flight Data

Parameter[1]						
Time (sec)	x (ft)	y (ft)	z (ft)	Psi (deg)	Theta (deg)	Phi (deg)
0.00	0.00	0.00	0.00	0.00	-3.00	0.00
0.10	-0.05	0.05	0.72	-2.03	-5.20	-0.41
0.20	-0.38	-0.02	2.10	-10.50	-12.10	0.02
0.30	-0.81	-1.03	4.60	-25.30	-17.15	-7.91
0.40	-1.12	-4.68	7.80	-41.64	-26.68	-35.88
0.50	-1.10	-12.73	9.85	-65.40	-40.61	-29.26
0.60	-0.56	-25.68	11.16	-95.54	-45.19	9.04
0.70	0.47	-42.72	12.00	-92.63	-44.58	-15.21
0.80	1.90	-63.45	12.31	-58.06	-41.14	-50.22

Notes: (1) Psi, Theta, and Phi represent Yaw, Pitch and Roll angles, respectively. Sign convention is: +x is forward, +y is lateral right, +z is down; +Psi is nose right, +Theta is nose up, +Phi is right roll.

Source: Mr. Chris McLean, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #12 Test Readiness Data,* 8 August 1994.

Table E-7

JSOW Jettison Event-12, 6-DOF Post-Flight Data

Parameter[1]						
Time (sec)	x (ft)	y (ft)	z (ft)	Psi (deg)	Theta (deg)	Phi (deg)
0.00	0.00	0.00	0.00	0.00	-3.00	0.00
0.10	-0.04	0.02	0.74	-2.60	-5.84	-1.49
0.20	-0.35	-0.12	2.37	-14.00	-12.33	-4.46
0.30	-0.85	-1.63	5.21	-30.26	-17.07	-20.46
0.40	-1.42	-6.42	7.63	-43.16	-29.19	-40.03
0.50	-1.80	-16.06	8.83	-72.41	-39.14	-6.97
0.60	-1.98	-30.78	9.55	-98.32	-43.75	9.11
0.70	-1.89	-49.69	9.81	-84.97	-48.72	-32.39
0.80	-1.59	-72.37	9.04	-41.66	-42.76	-62.82

Notes: (1) Psi, Theta, and Phi represent Yaw, Pitch and Roll angles, respectively. Sign convention is: +x is forward, +y is lateral right, +z is down; +Psi is nose right, +Theta is nose up, +Phi is right roll.

Source: Mr. Chris McLean, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #13 Test Readiness Review,* 30 August 1994.

Table E-8

JSOW Jettison Event-13, 6-DOF Post-Flight Data

Parameter[1]						
Time (sec)	x (ft)	y (ft)	z (ft)	Psi (deg)	Theta (deg)	Phi (deg)
0.00	0.00	0.00	0.00	0.00	-3.00	0.00
0.10	-0.06	0.06	0.74	-3.01	-6.00	-1.16
0.20	-0.47	-0.14	2.44	-16.23	-12.08	-5.90
0.30	-1.25	-2.34	5.28	-34.10	-13.28	-22.86
0.40	-2.23	-8.40	7.03	-43.51	-23.28	-27.69
0.50	-3.22	-19.64	7.94	-64.66	-44.72	-0.52
0.60	-4.21	-36.46	9.67	-103.30	-58.90	31.64
0.70	-5.17	-57.98	11.72	-87.05	-65.37	-13.92

Notes: (1) Psi, Theta, and Phi represent Yaw, Pitch and Roll angles, respectively. Sign convention is: +x is forward, +y is lateral right, +z is down; +Psi is nose right, +Theta is nose up, +Phi is right roll.

Source: Mr. Dave Duggan, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #14 Test Readiness Review,* 7 October 1994.

Table E-9

JSOW Jettison Event-17, 6-DOF Post-Flight Data

Parameter[1]						
Time (sec)	x (ft)	y (ft)	z (ft)	Psi (deg)	Theta (deg)	Phi (deg)
0.00	0.00	0.00	0.00	0.00	-3.00	0.00
0.10	-0.02	0.05	0.84	-0.34	-5.04	-0.25
0.20	-0.24	0.08	2.40	-1.76	-11.59	-0.23
0.30	-0.54	-0.15	4.77	-1.23	-18.88	-6.06
0.40	-0.88	-0.73	8.22	4.52	-21.71	-14.35
0.50	-1.22	-1.27	12.80	10.93	-18.74	-21.26
0.60	-1.57	-1.31	18.35	10.35	-13.24	-26.89
0.70	-1.94	-0.97	24.59	6.13	-6.56	-26.30
0.80	-2.36	-0.40	31.23	1.34	0.38	-26.95

Notes: (1) Psi, Theta, and Phi represent Yaw, Pitch and Roll angles, respectively. Sign convention is: +x is forward, +y is lateral right, +z is down; +Psi is nose right, +Theta is nose up, +Phi is right roll.

Source: Mr. Chris McLean, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #18 or #19 Test Readiness Data,* 31 October 1994.

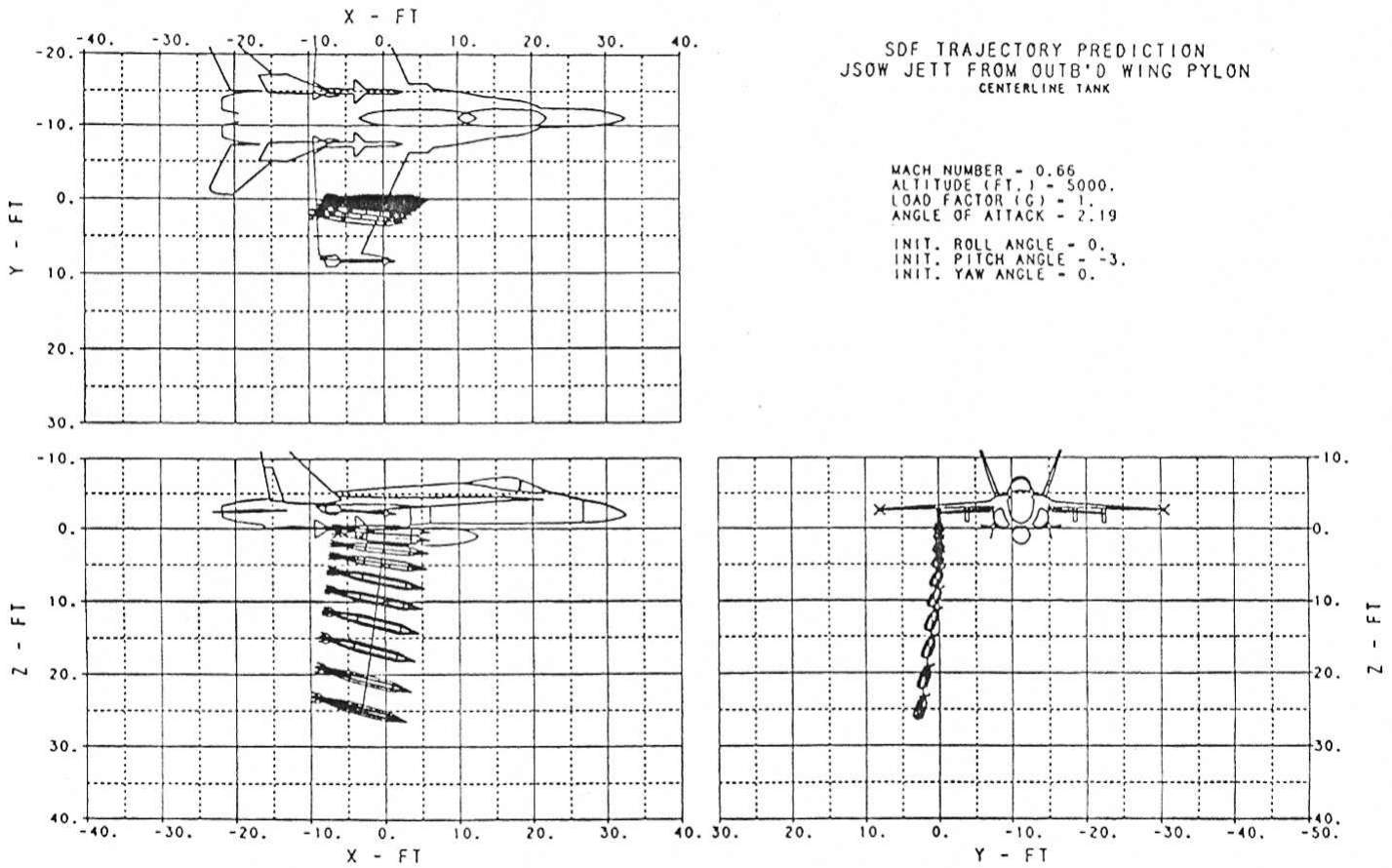


Figure E-1

MDA Wind Tunnel Analysis and Prediction, JSOW Jettison 1

Source: Adapted from M. J. Holmes III, K. A. Gordon, MDA *F/A-18 JSOW Launch / Jettison Wind Tunnel and Analysis Report,* MDC93B0191 of 15 December 1993, as incorporated into NAWCAD FTEG Project Test Plan 1571 of 10 February 1994.

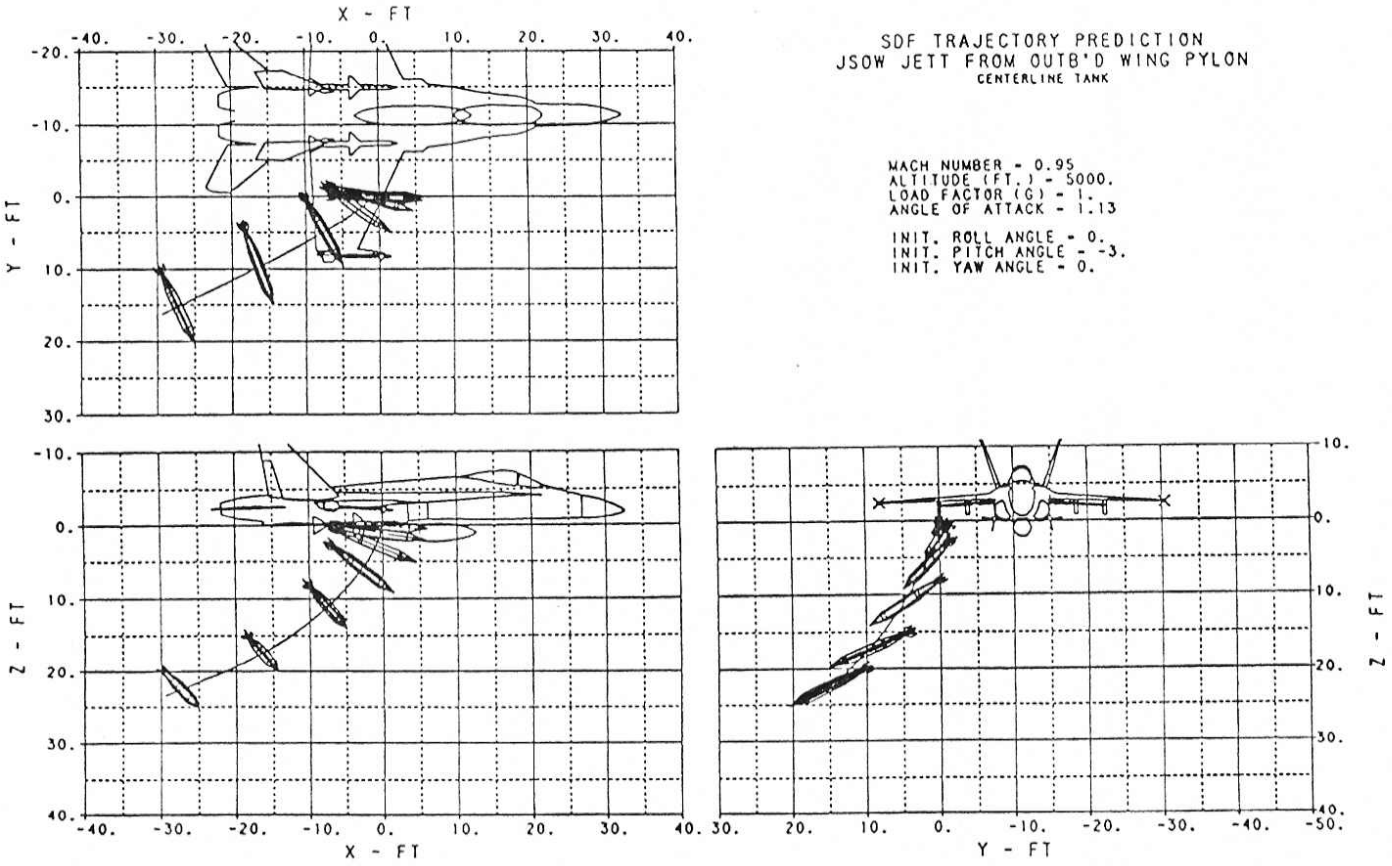


Figure E-2

MDA Wind Tunnel Analysis and Prediction, JSOW Jettison 5

Source: Adapted from M. J. Holmes III, K. A. Gordon, MDA *F/A-18 JSOW Launch / Jettison Wind Tunnel and Analysis Report,* MDC93B0191 of 15 December 1993, as incorporated into NAWCAD FTEG Project Test Plan 1571 of 10 February 1994.

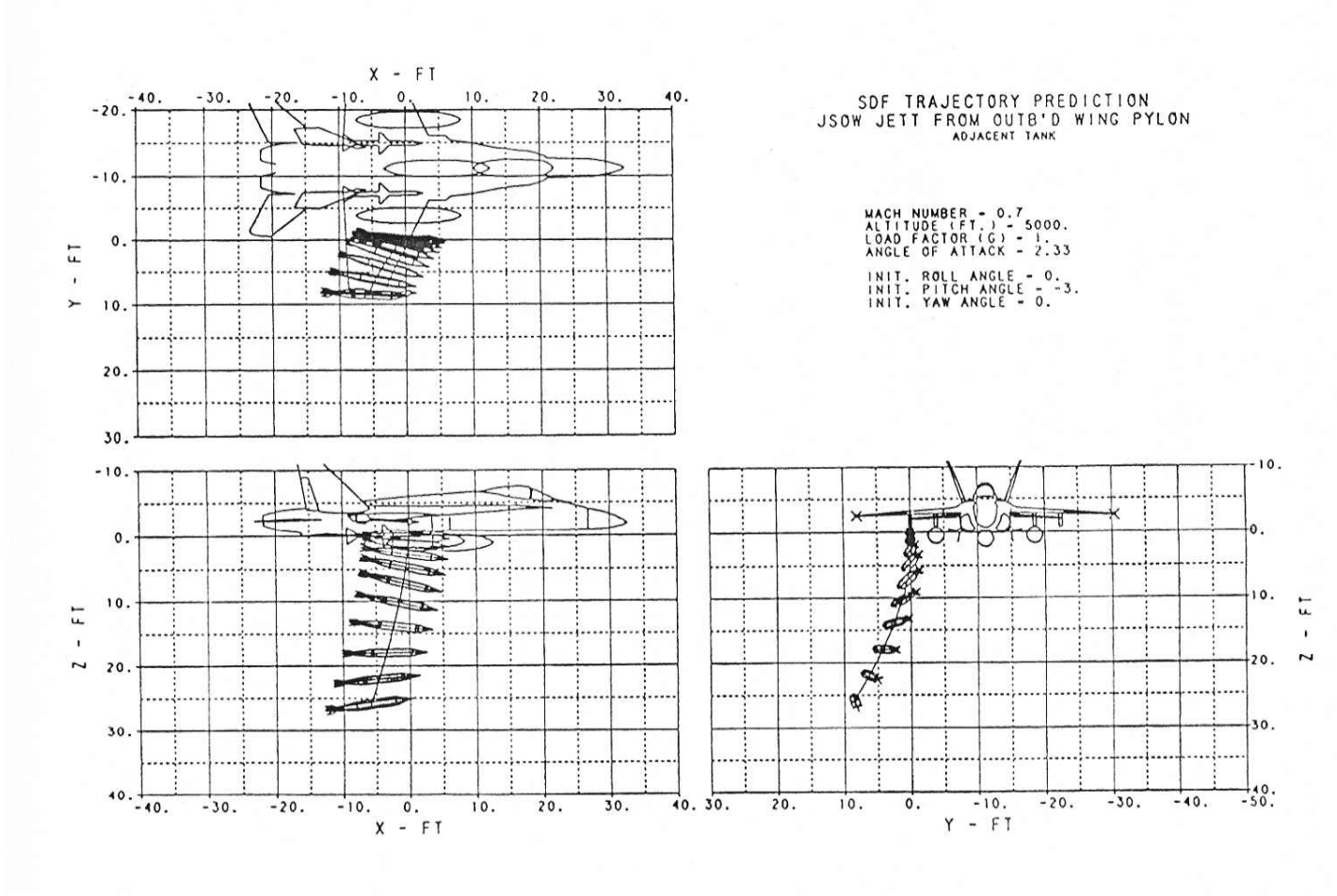


Figure E-3

MDA Wind Tunnel Analysis and Prediction, JSOW Jettison 6

Source: Adapted from M. J. Holmes III, K. A. Gordon, MDA *F/A-18 JSOW Launch / Jettison Wind Tunnel and Analysis Report,* MDC93B0191 of 15 December 1993, as incorporated into NAWCAD FTEG Project Test Plan 1571 of 10 February 1994.

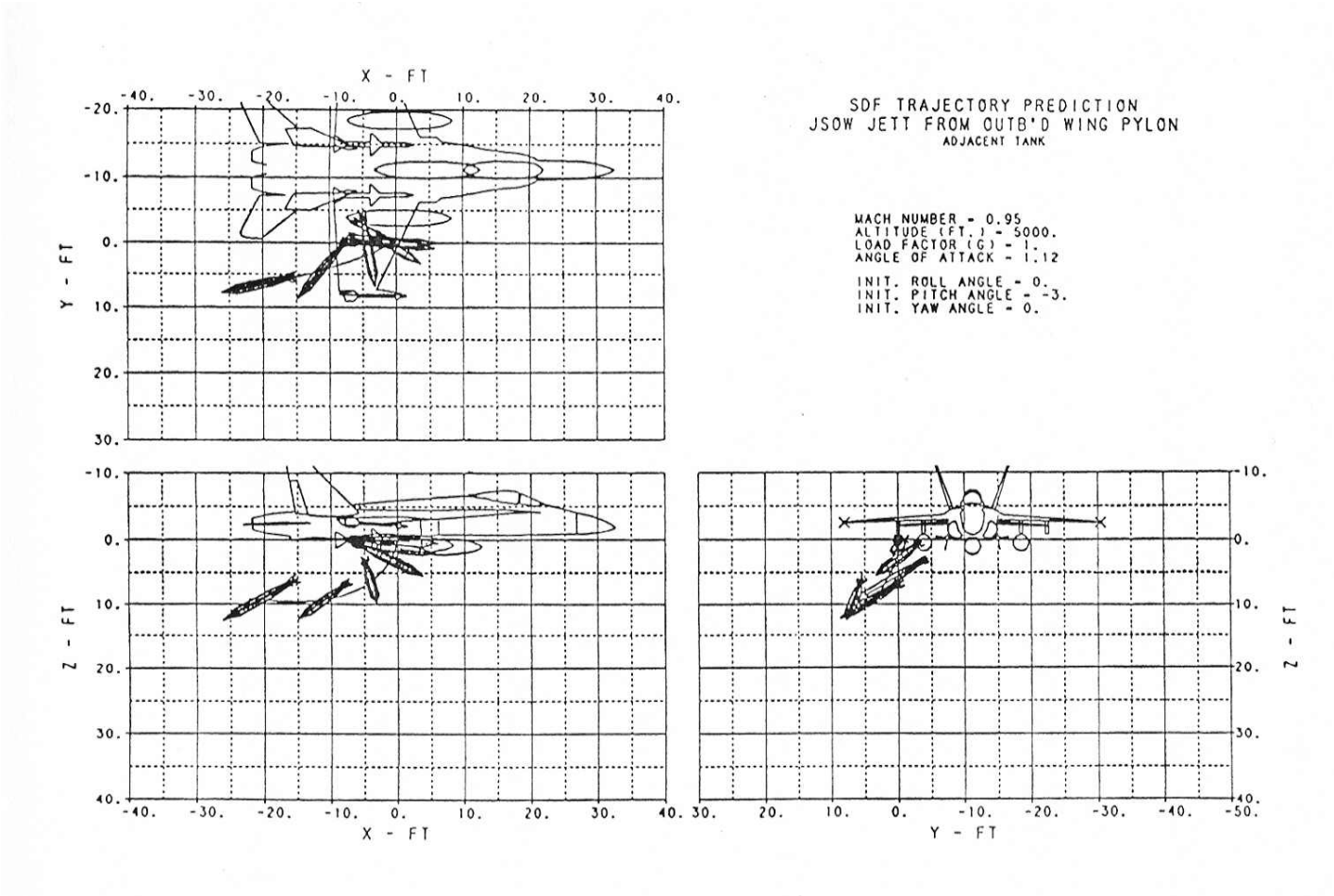


Figure E-4

MDA Wind Tunnel Analysis and Prediction, JSOW Jettison 13

Source: Adapted from M. J. Holmes III, K. A. Gordon, MDA *F/A-18 JSOW Launch / Jettison Wind Tunnel and Analysis Report,* MDC93B0191 of 15 December 1993, as incorporated into NAWCAD FTEG Project Test Plan 1571 of 10 February 1994.

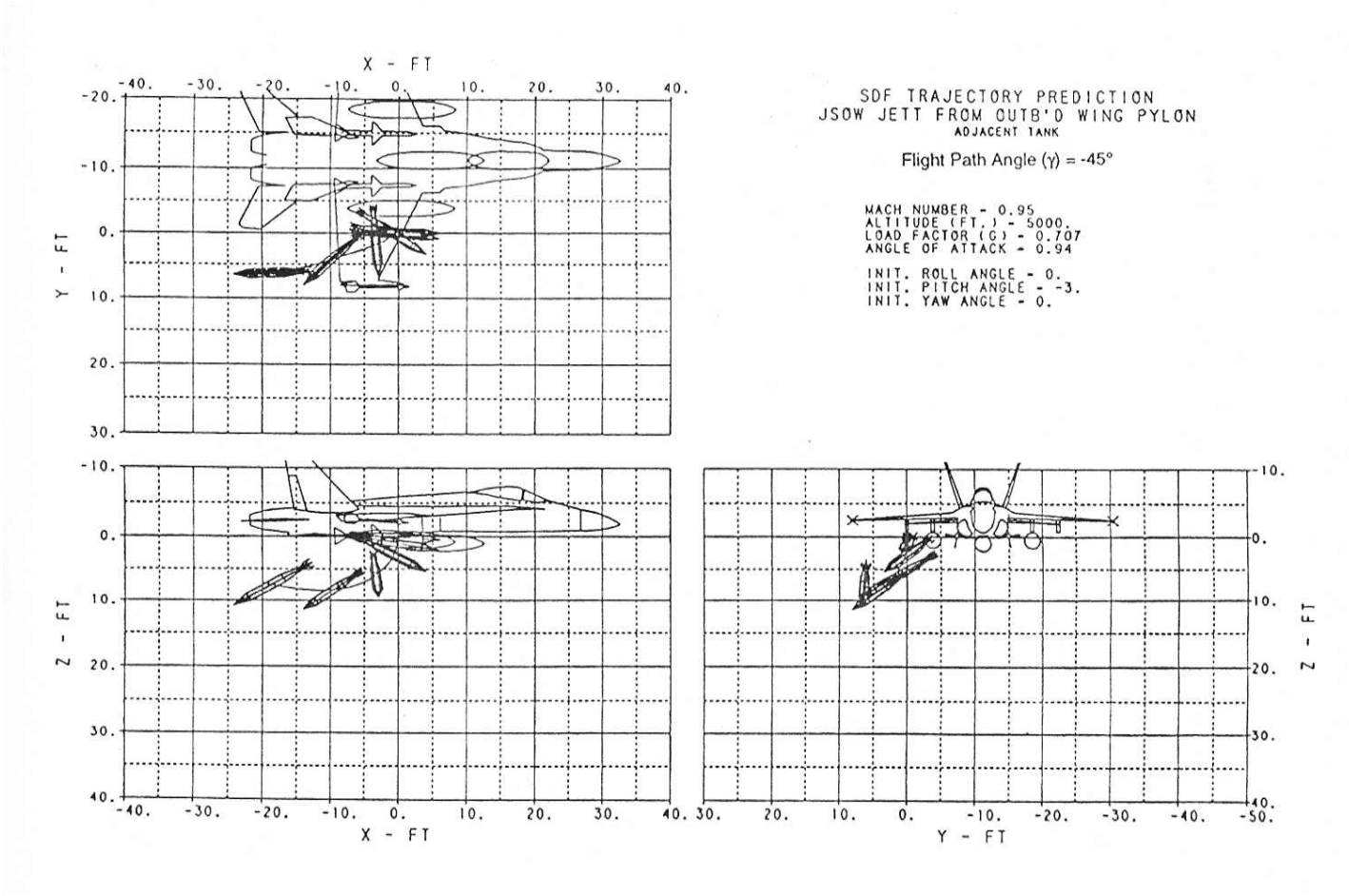


Figure E-5

MDA Wind Tunnel Analysis and Prediction, JSOW Jettison 14

Source: Adapted from M. J. Holmes III, K. A. Gordon, MDA *F/A-18 JSOW Launch / Jettison Wind Tunnel and Analysis Report,* MDC93B0191 of 15 December 1993, as incorporated into NAWCAD FTEG Project Test Plan 1571 of 10 February 1994.

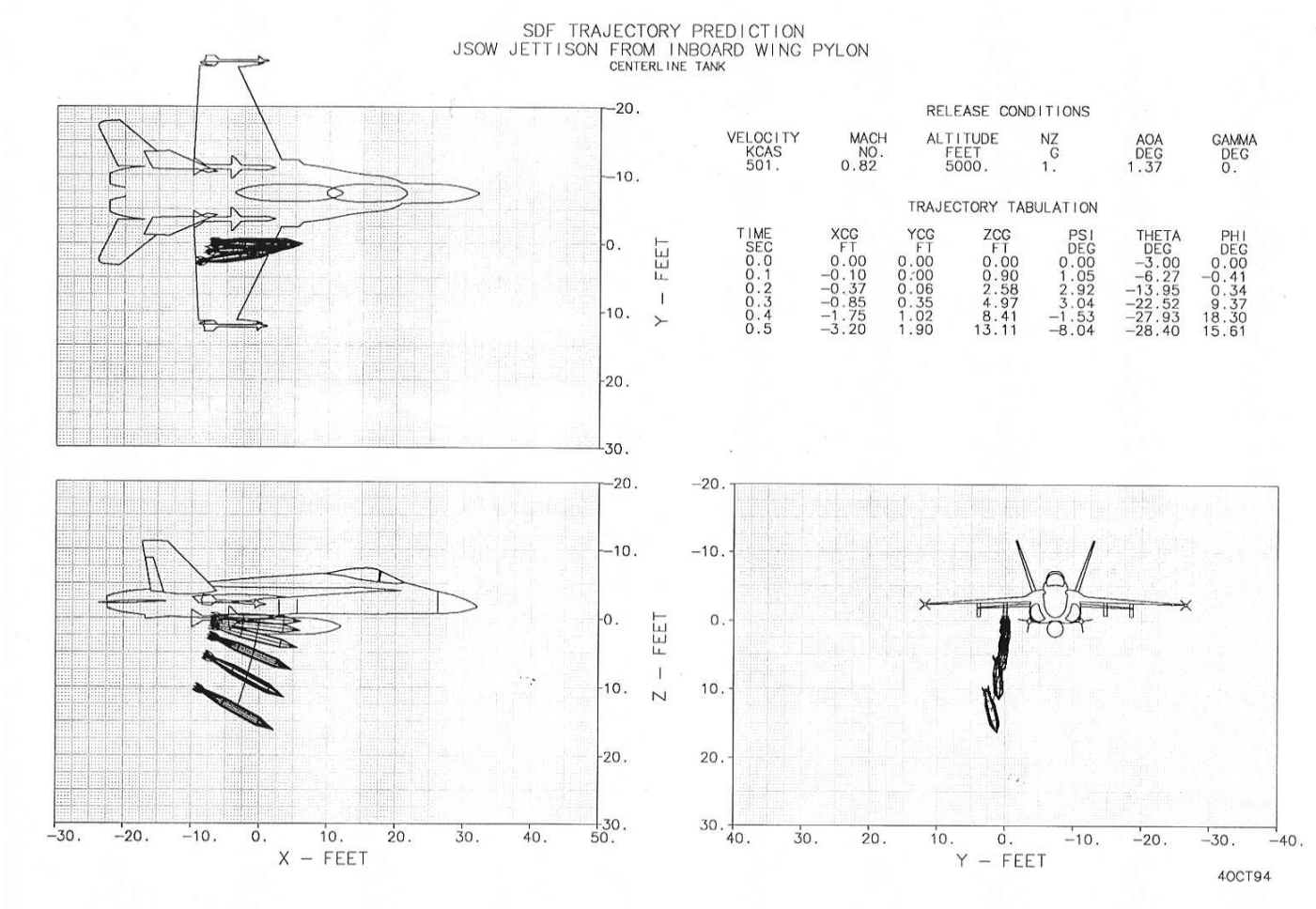


Figure E-6

MDA Wind Tunnel Analysis and Prediction, JSOW Jettison 17

Source: Adapted from M. J. Holmes III, K. A. Gordon, MDA as incorporated into NAWCAD FTEG Project Test Plan 1571 of 10 February 1994, Amendment 4 of 4 October 1994.

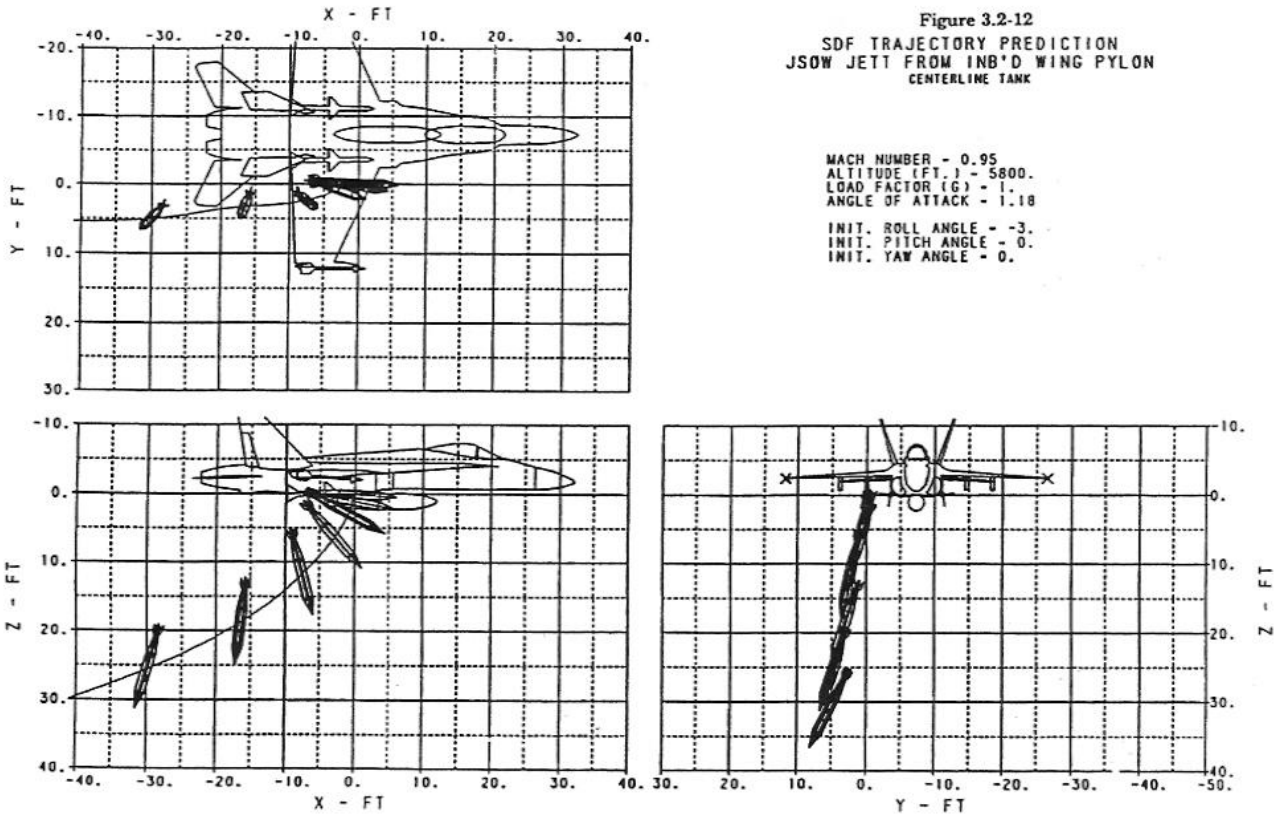


Figure E-7

MDA Wind Tunnel Analysis and Prediction, JSOW Jettison 20

Source: Adapted from M. J. Holmes III, K. A. Gordon, MDA *F/A-18 JSOW Launch / Jettison Wind Tunnel and Analysis Report,* MDC93B0191 of 15 December 1993, as incorporated into Texas Instruments *JSOW F/A-18 Aircraft Jettison #18 or #19 Test Readiness Data*, 31 October 1994.

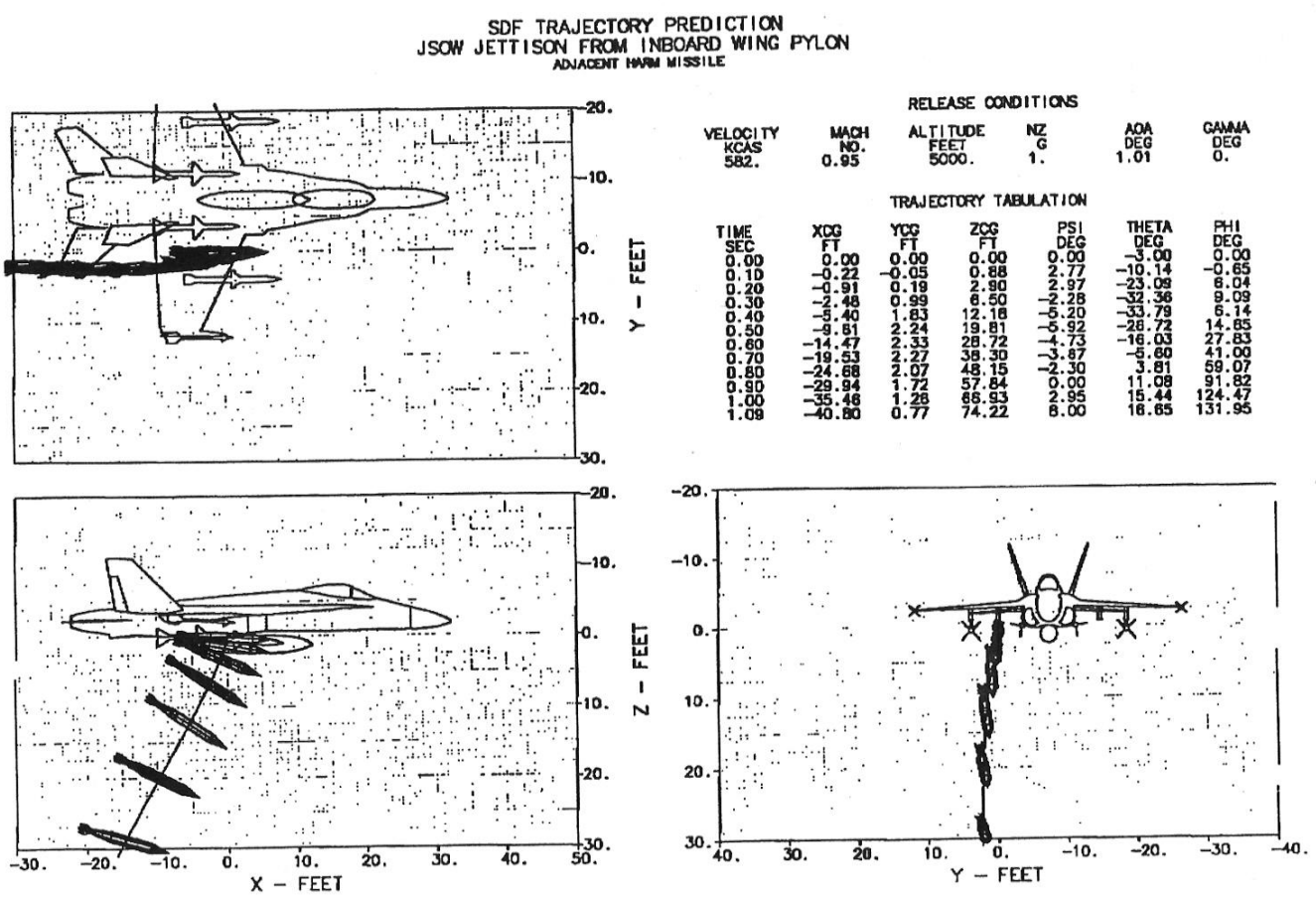


Figure E-8

MDA Revised Analysis and Prediction, JSOW Jettison 20

Source: Mr. Pierre Pondrom, MDA, as incorporated into Texas Instruments *JSOW F/A-18 Aircraft Jettison #18 or #19 Test Readiness Data*, 31 October 1994.

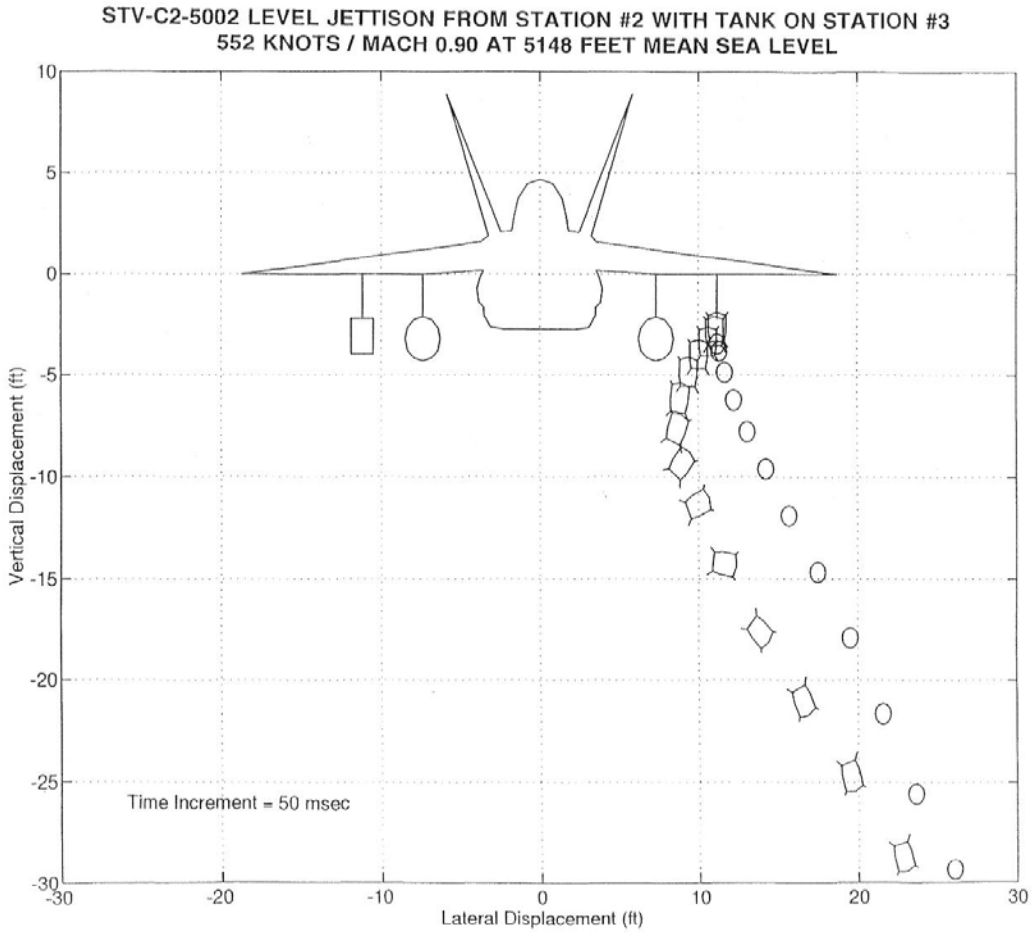


Figure E-9

TI Post-Flight Analysis of JSOW Jettison 12

Source: Mr. Chris McLean, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #13 Test Readiness Review,* 30 August 1994.

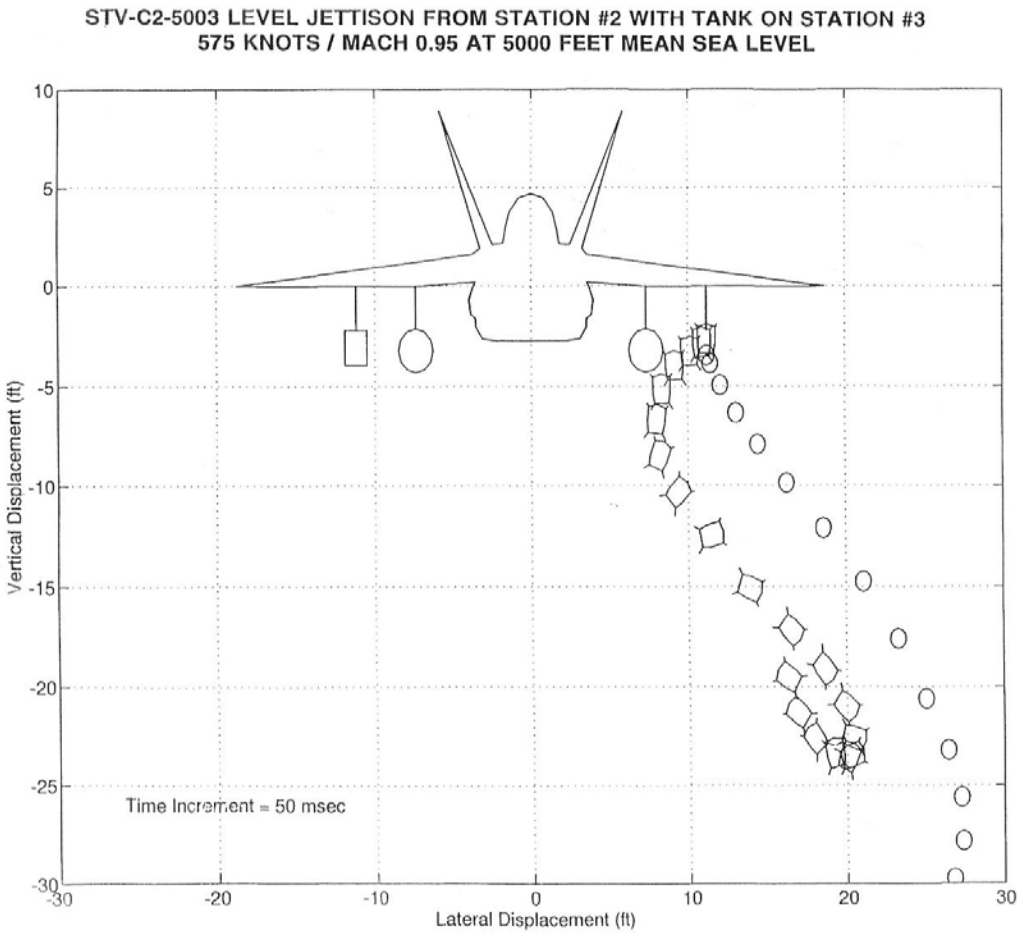


Figure E-10

TI Pre-Flight Prediction of JSOW Jettison 13

Source: Mr. Chris McLean, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #13 Test Readiness Review,* 30 August 1994.

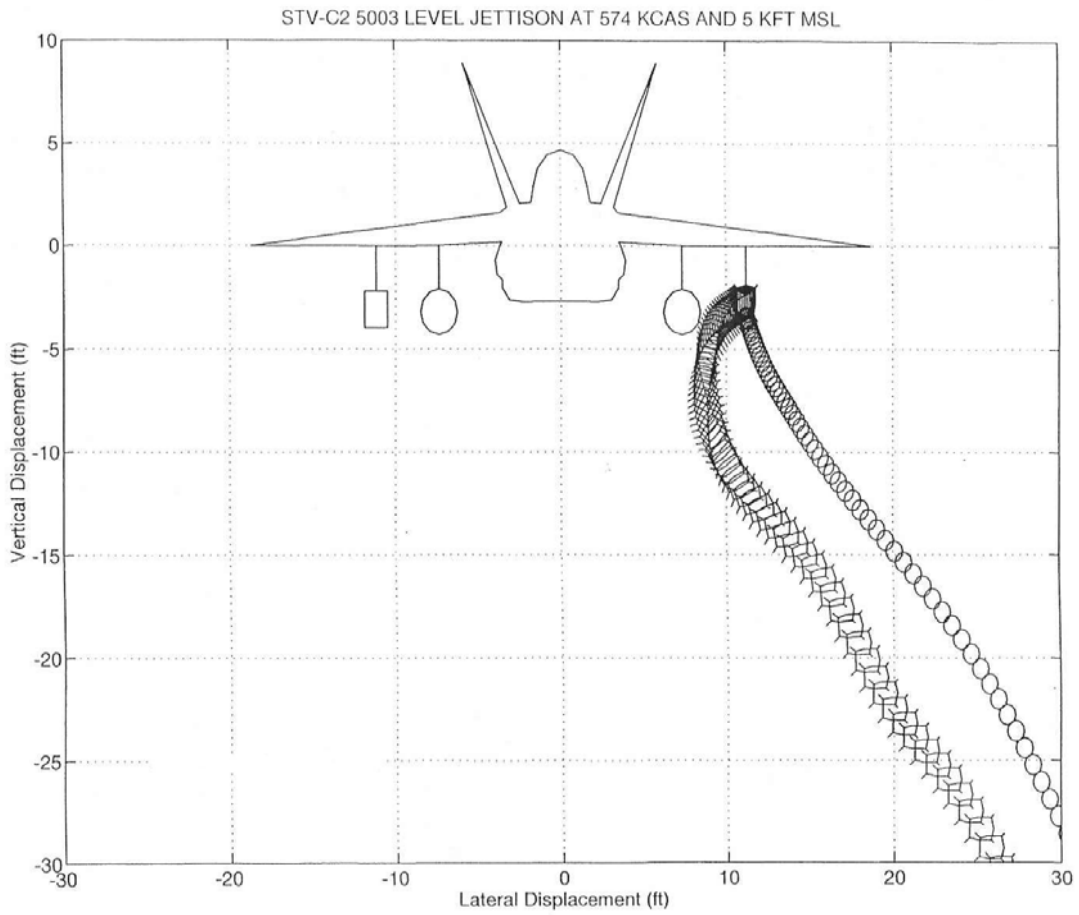


Figure E-11

TI Post-Flight Analysis of JSOW Jettison 13

Source: Mr. Dave Duggan, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #14 Test Readiness Review,* 7 October 1994.

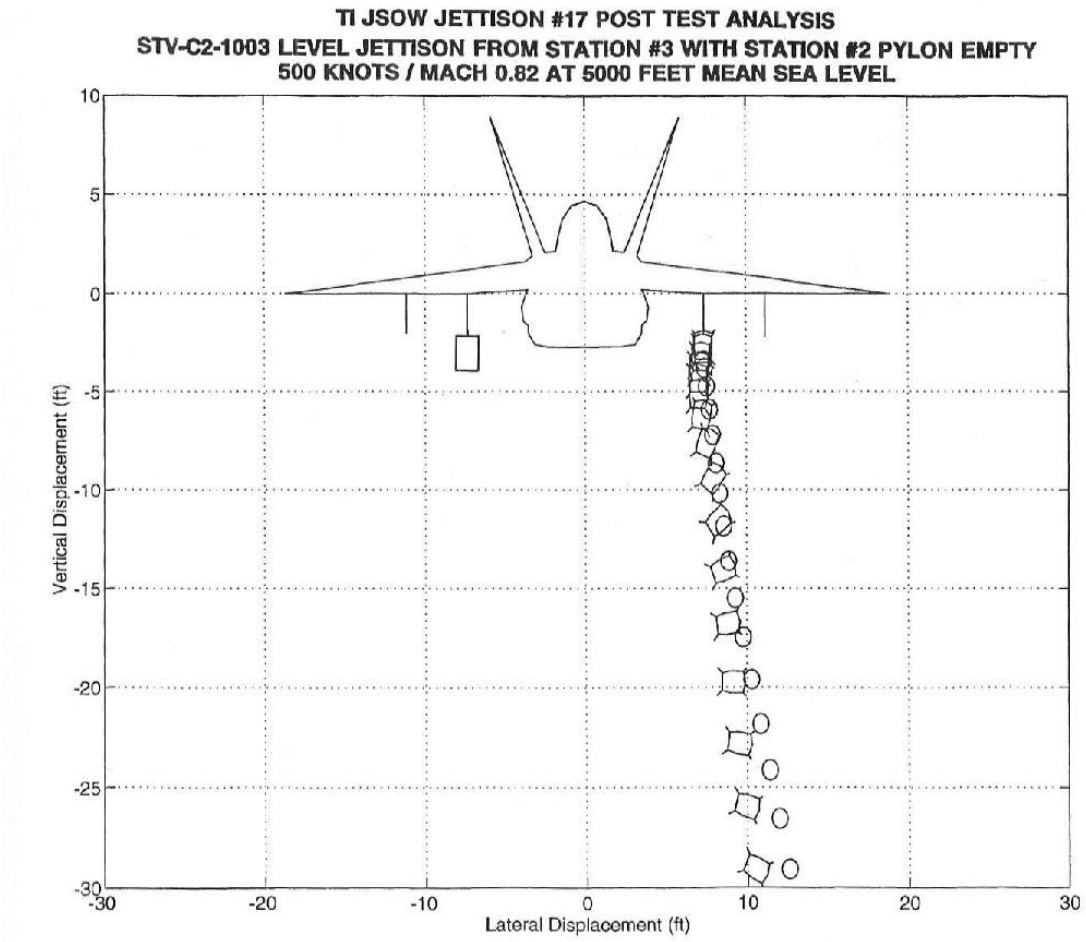


Figure E-12

TI Post-Flight Analysis of JSOW Jettison 17

Source: Mr. Chris McLean, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #18 or #19 Test Readiness Data,* 31 October 1994.

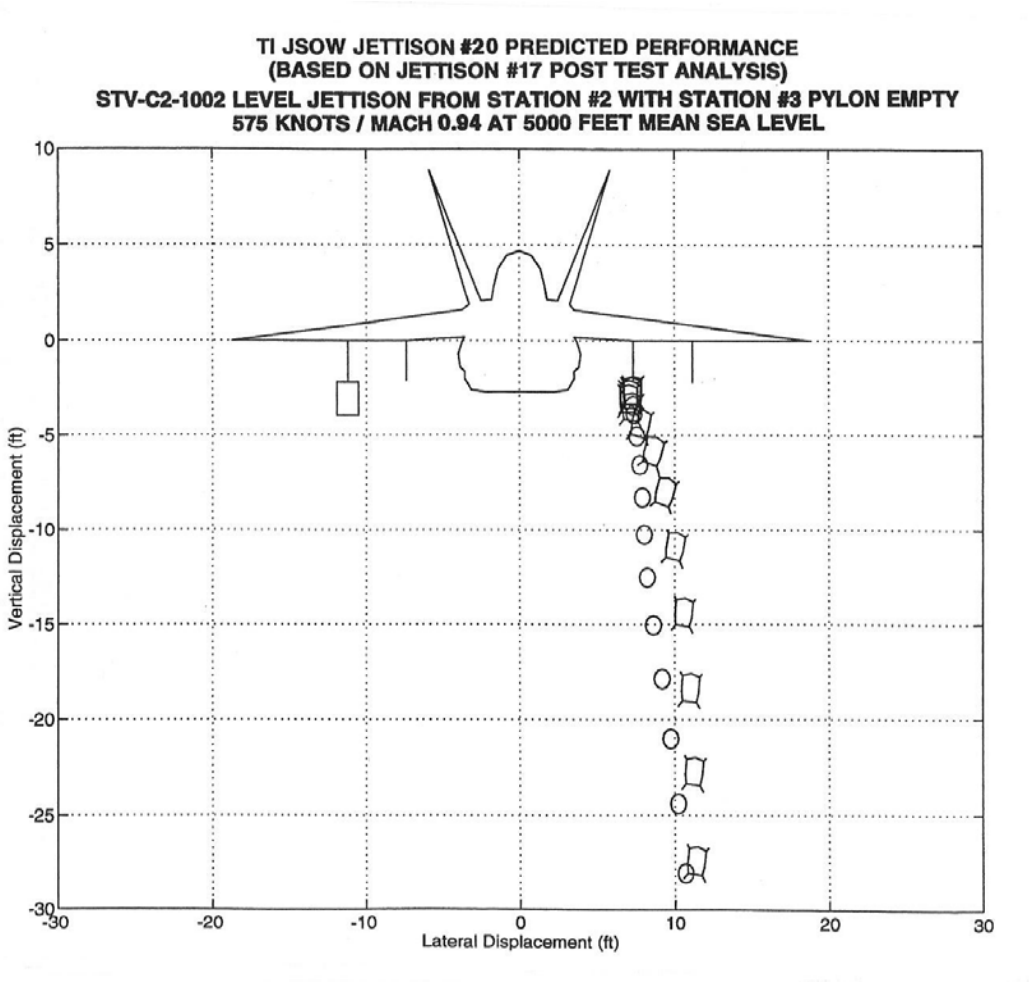


Figure E-13

TI Pre-Flight Prediction of JSOW Jettison 20

Source: Mr. Chris McLean, Texas Instruments, *JSOW F/A-18 Aircraft Jettison #18 or #19 Test Readiness Data,* 31 October 1994.

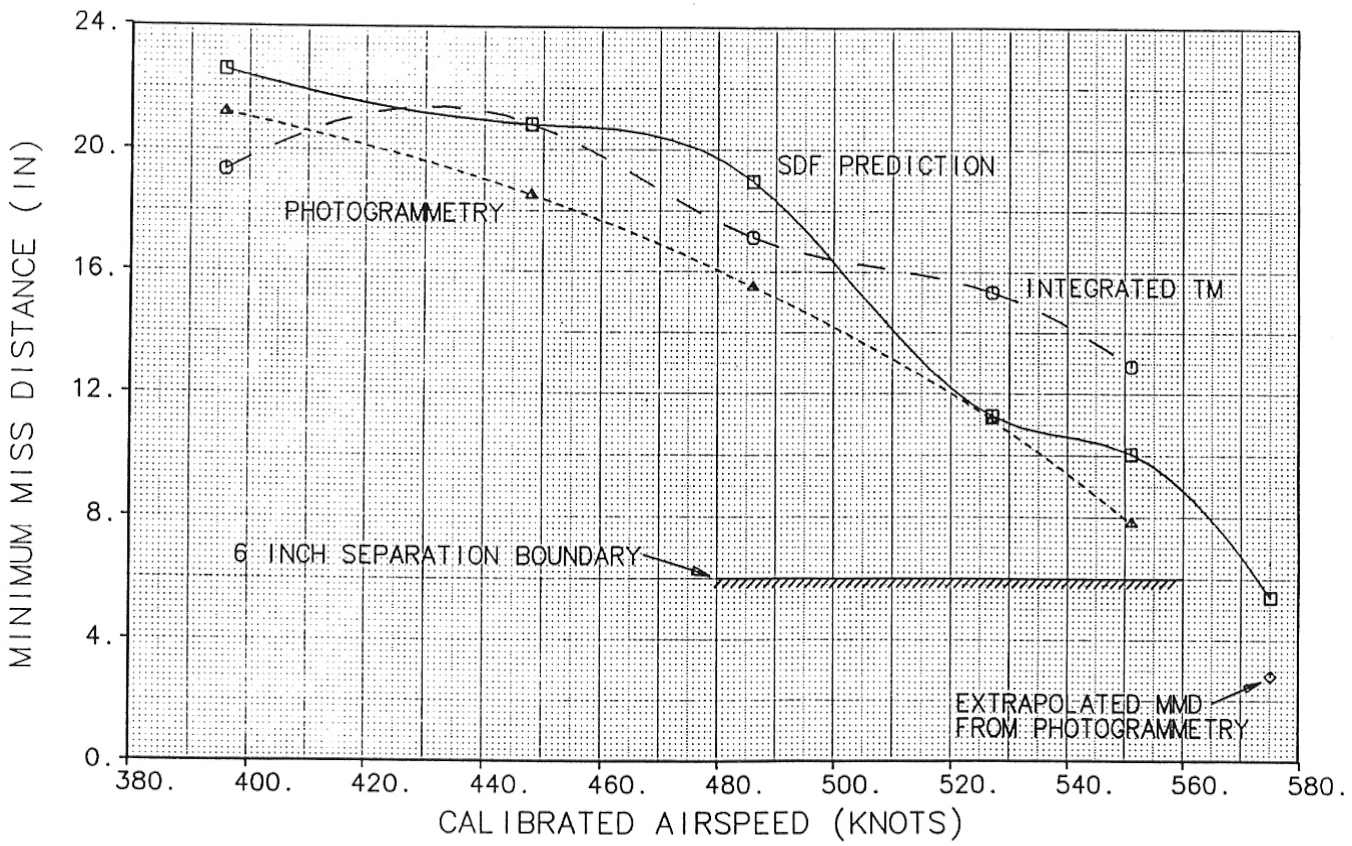


Figure E-14

MDA Combined Analysis and Prediction, JSOW Jettison 13

Source: Mr. M. J. Holmes III, MDA, as incorporated into Texas Instruments, *JSOW F/A-18 Aircraft Jettison #13 Test Readiness Review,* 30 August 1994.

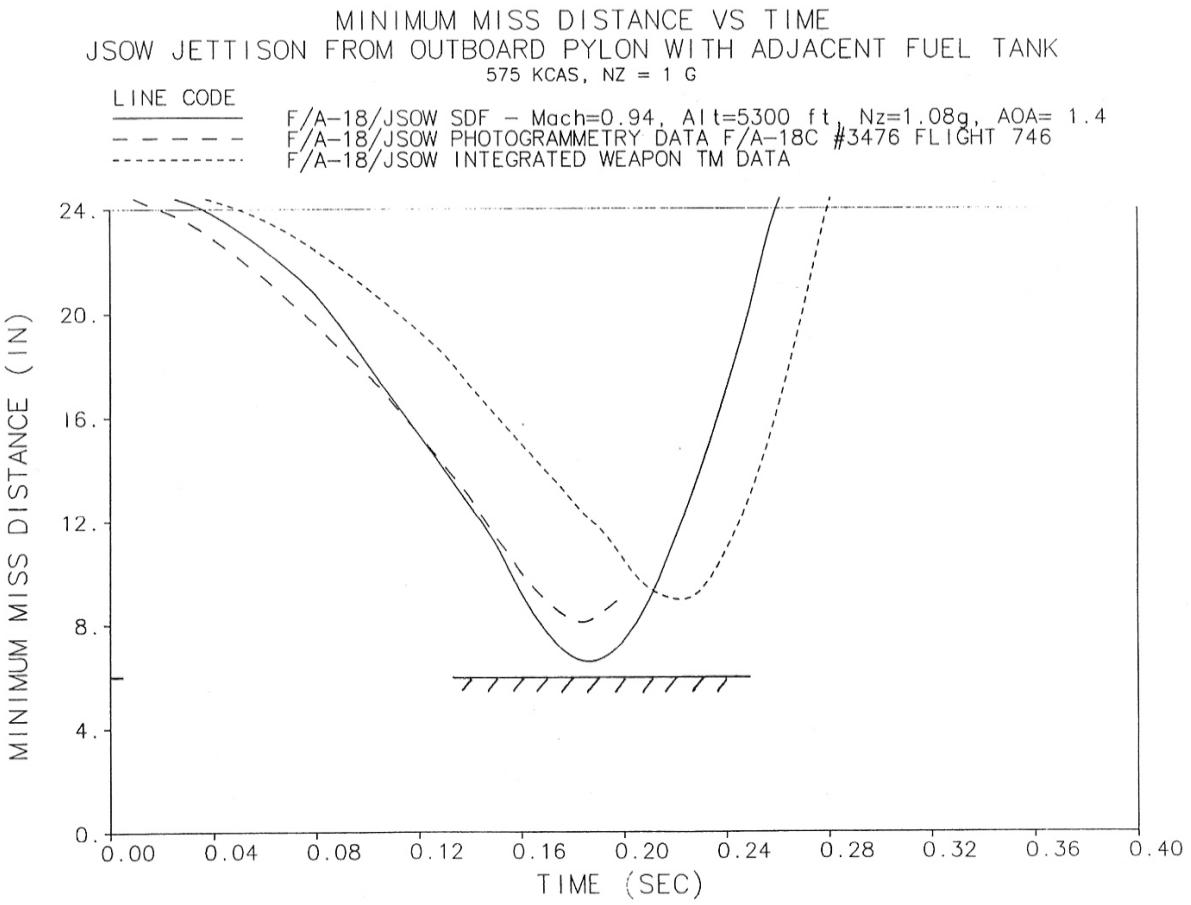


Figure E-15

MDA Combined Post-Flight Analysis, JSOW Jettison 13

Source: Mr. Pierre Pondrom, MDA, as incorporated into Texas Instruments, *JSOW F/A-18 Aircraft Jettison #14 Test Readiness Review,* 7 October 1994.

VITA

Born the son of an Army officer in San Antonio, TX, Commander Hinson is a native of Charleston, SC. He graduated from the University of South Carolina with a major in Chemistry and a member of Phi Beta Kappa, and was commissioned an Ensign in the United States Navy in May of 1985.

Flight training took him to Pensacola, FL, then on to Beeville, TX, for intermediate and advanced jet training in VT-26 and VT-25. Commander Hinson earned his Wings of Gold in January, 1987. As a Selectively Retained Graduate (SERGRAD) flight instructor, his first assignment was to train prospective Naval Flight Officers at VT-10 in Pensacola. In February, 1989, he was again ordered to flight training, this time as an F/A-18 Hornet Fleet Replacement Pilot at VFA-106 in Cecil Field, FL.

Commander Hinson's first fleet squadron was the VFA-15 "Valions", where he served as the Avionics and Armament Division Officer, Nuclear Weapons Training Officer, Personnel Officer, Administrative Officer and Command Security Manager from November, 1989 to June, 1992. In 1991, he deployed aboard USS Theodore Roosevelt (CVN 71) and flew combat missions in support of Operations Desert Shield, Desert Storm and Provide Comfort. He left the Valions in June of 1992 and reported as a member of the United States Naval Test Pilot School (USNTPS) 103rd class.

A distinguished graduate from USNTPS, Commander Hinson was assigned to the Strike Aircraft Test Directorate of the Naval Air Warfare Center Aircraft Division, Patuxent River, MD, from June, 1993 to June, 1995. As a test pilot for the Ordnance Department, he was the Project Officer for the Joint Standoff Weapon (JSOW), the Automated Tactical Manual Supplement (ATACS) and many other smaller programs. He also flew test flights in support of High Lateral Asymmetry Flying Qualities envelope expansion, Joint Direct Attack Munition (JDAM) Engineering and Manufacturing Development, and Automated Carrier Landing Systems certification on three aircraft carriers. He successfully launched the first free-flight JSOW at China Lake, CA, in December 1994, which marked the new era of GPS/INS-only guided munitions. Later in December of 1994, he was awarded the Captain "Axel" Hazelrigg Award for superior leadership.

Commander Hinson reported directly to the VFA-131 "Wildcats" in June of 1995 for duties as the Administrative Officer and Command Security Manager, Safety Officer and Operations Officer. While deployed aboard USS George Washington (CVN 73) for the first half of 1996, he flew missions in support of Operations Decisive Endeavor and Southern Watch. Following work-ups on USS John C. Stennis (CVN

74), he completed his department head tour in late November 1997, and reported to the Staff of USNTPS, again in Patuxent River, MD.

Commander Hinson held the positions of Senior Airborne Systems Curriculum Instructor and Operations Officer while at USNTPS, and was selected as the 1998 Instructor of the Year. Late in July of 2000, he reported to the Balkans Combined Air Operations Center, Vicenza, Italy, where he served as the C-5 Plans Cell Chief in charge of force beddown and allocation, theater aircrew special instructions (SPINS) and theater exercise coordination. This tour included travel to theater locations including Pristina, Kosovo; Sarajevo, Bosnia-Herzegovina; and Zagreb, Croatia.

Returning to the United States on the first of March, 2001, Commander Hinson moved to Virginia Beach, VA, reported to VFA-106 briefly for carrier qualification, and then reported to the CVW-7 Staff as the Operations Officer. Highlights of this tour include support for Operation Noble Eagle for homeland defense following the attack of September 11, 2001; combat operations in support of Operation Enduring Freedom while deployed in 2002 aboard USS John F. Kennedy (CV 67); and acting as the Officer-in-Charge of a three-F/A-18 fighter detachment to Azraq, Jordan – also while deployed to the North Arabian Sea. Following three months of training, he then reported to the "Outlaws" of Strike Fighter Weapons School, Pacific in October, 2002, for duty as the Executive Officer. He took command of the Strike Fighter Weapons School, Pacific in January 2004, and held the position until the sixth of May, 2005. CDR Hinson currently serves as the F/A-18 and EA-18G Program Manager Communication, Navigation, Identification and Landing Systems Deputy Integrated Program Team Lead within the Naval Air Systems Command, Naval Air Station Patuxent River, Maryland.

Qualified in all series of the F/A-18 and the T-34C, Commander Hinson has accumulated 4285 total flight hours in 65 different airplanes and helicopters, including over 2700 hours in the F/A-18 and over 500 carrier arrested landings. He also holds the civilian certification of Air Transport Pilot (ATP), and is an active member of the Navy's Acquisition Professional Community and the Society of Experimental Test Pilots. Personal decorations include the Meritorious Service Medal (three awards), Strike Flight Air Medal (four awards), Joint Service Commendation Medal, Navy Commendation Medal (five awards, two with combat distinguishing device), Navy Achievement Medal and numerous theater and campaign medals.