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SYSTEMS PHASE

CHAPTER 8
STORES CERTIFICATION

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USAF TEST PILOT SCHOOL
EDWARDS AFB, CA

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8.1 INTRODUCTION

8.1.1 BACKGROUND

8.1.1.1 GENERAL

The compatibility with and separation of expendable stores from aircraft is a problem which has plagued engineers since the earliest days of flying. It gained early recognition in World War I. Since that time, regardless of the size or speed of the aircraft, or whether the stores were carried internally or externally, weapons compatibility and store separation have been continuous problems, despite the staggering advances in technology during the past fifty years. Not until the advent of high-speed jet aircraft, however, have the problems become of significant magnitude. The speed and complexities of modern fighter-bomber aircraft have made the solution of aircraft/store compatibility problems a necessity from both tactical and flight safety standpoints.

In the years following World War II, United States defense strategy emphasized the nuclear deterrent. In the early 1960's, the strategy suddenly shifted to limited conventional war while maintaining the massive nuclear retaliation capability. Almost overnight the "instant fighter-bomber aircraft" emerged.

It was created by devising equipment to allow the already existing nuclear strike aircraft to carry as many conventional bombs as possible. This hybrid aircraft was capable of enormous destruction - more than most heavy bombers of the past. To perform their assigned multiple missions, however, expensive and complex equipment was added--with accompanying weight. The end result of this spiral has been the appearance of today's multimillion dollar fighter bombers, some of which are as large as World War II heavy bombers.

The emphasis in the past decades on conventional munitions has produced a large family of new weapons, each designed to provide a certain tactical effect, or to "kill" a particular target. They were, for budgetary and logistic reasons, usually required to fit and be employed on all current aircraft, rather than to mate with a specific aircraft. In the US today, there are over 100 different conventional munitions in the inventory.

Although the development of US fighter aircraft over the past 30 years has been impressive, only lately (F-16XL, F-15E) has attention been given to the carriage of external stores in the aircraft design stage. Fighter aircraft today were designed around their "clean" aircraft performance, with stores added later on an "as much as possible" basis. The F-16, the workhorse of our tactical weapons delivery forces, was originally designed as a point defense dogfighter. Many weapons suspension racks and other airborne armament equipment in use today were designed years ago to meet the crash requirement for a limited war capability. The multiple and triple ejector rack (MER, TER) concept was conceived over 25 years ago to pack as many bombs on an existing aircraft as possible. The pressing situation at the time did not permit in-depth examination of potential problems such as store carriage and separation. This situation has led to aircraft performance and stability problems, dangerous store separation, reduced weapon accuracy, and a monumental testing workload to certify weapons for use with each aircraft. Some aircraft, such as the F-4, A-7, or F-16 have several external pylons, each capable of carrying different types of bomb racks (such as MERs or TERs). Each rack, in turn, can carry many different numbers and types of stores. With over 100 types of weapons, and dozens of racks and pods, possible loadings combinations on the aircraft can be in the millions. Internal stores carriage such as in the B-1B, B-2, YF-22, and YF-23 will not alleviate all problems. Stores still have to move smoothly from bomb bay to target, not an easy task. To cope with the unacceptable large testing workload generated by this situation, the US Air Force created project "SEEK EAGLE" in which aircraft/store compatibility is recognized as a distinctly separate requirement, and only certain stores are designated for certification on specific aircraft. To further reduce the scope of the problem, the tactical forces are asked to identify individual aircraft/store loading configurations they feel are necessary, and only those loadings are certified. The 3246 TESTW/TY at Eglin Air Force Base (AFB) is the Air Force in-house agency whose mission is store certification testing.

Store certification is the determination of the extent of specific aircraft/store compatibility and the formal publication of all information necessary for appropriate carriage, employment, and jettison of a store on a specified aircraft (aircraft series) in the applicable technical manuals and flight operation manuals (or interim supplements or revisions thereto).

The determination of compatibility of a particular store with a specific aircraft is an involved process. On present day aircraft with multiple external store stations and multiple store carriage at many of these stations, loading configurations can lead to serious weight and balance, stability, structural, or flutter problems. Keeping track of the approved and the not approved (and reasons for nonapproval) configurations is a monumental task for even one type aircraft. In determining the compatibility of a store with an aircraft, many areas must be examined and many tasks performed which cut across almost every engineering and testing discipline. The upcoming sections basically follow the guidance provided in MIL-STD-1763, Aircraft/Stores Certification Procedures, (Ref 1) for certification of stores. This standard calls out the range of tests that should be considered for every aircraft/store combination and often identifies other standards or specifications required to complete testing. It is recommended you review the latest version of the standards and specifications prior to start of analysis and flight testing. Some of the most important of these are discussed below.

8.1.1.2 PREFLIGHT ANALYSES

These include the necessary tasks and analyses which must be performed prior to flight testing the store. First, the specific loading configurations of interest are identified, and station loading capabilities and physical clearances are checked analytically. Once physical compatibility has been confirmed, analysis is begun to determine if acceptable operational carriage and employment envelopes can be established. Establishing a captive carriage envelope involves determining if any adverse stability and control, structural loading or flutter problems are caused by the carriage of the store on the aircraft. Similarly, establishing an employment envelope involves determining if any adverse store separation or jettison problems exist. Once these envelopes have been established, a flight test plan is then formulated which identifies the minimum flight test demonstration points that are required to clear the entire operational envelope. These analyses often require considerable amounts of computer and wind tunnel test time and sometimes involve the conduct of ground vibration and other structural tests prior to allowing the store to be flown.

8.1.1.3 FIT AND FUNCTION TESTS

Prior to actually flying the store on the aircraft, a physical and electrical compatibility fit test is conducted. Procedures for accomplishing this test are contained in MIL-STD-1289, Ground Fit and Compatibility Tests of Airborne Stores, (Ref 2); however, in general, the store is fitted on the aircraft in the desired loading configuration (or configurations) to insure adequate clearances exist between all parts of the store, the aircraft, the ground, and other stores. If the store has electrical connections, the physical mating of all plugs as well as pin functions are checked. It is at this time also that procedures for loading the store on the aircraft are verified and arming wire or lanyard hook-ups are determined.

8.1.3.4 FLUTTER TESTS

Prior to flying any aircraft/store configuration, a mathematical flutter analysis is made to determine whether any instabilities will be encountered within the expected captive flight envelope for the configuration. Unfortunately, even though we have developed complex sophisticated aircraft analytical flutter models, this mathematical analysis often tells us only that a problem may exist. If this occurs, flights with a specially instrumented flutter aircraft must be performed to confirm or reject the analysis prior to proceeding further. It should be stressed, however, that after some flight experience has been gained on a particular aircraft, it may be possible to develop an analytical flutter prediction capability which, through tests, has shown a high enough degree of reliability to preclude further flight tests.

8.1.1.5 CAPTIVE STRUCTURAL INTEGRITY TESTS

One discovery, very important to the field of aircraft/stores compatibility, was made as a direct result of US participation in the Southeast Asia conflict. Many times stores were loaded on aircraft in Vietnam and flown, but not dropped, due to lack of a target or other operational reasons and were still attached upon the aircraft's return to base. Stores sometimes made as many as three or four flights before being dropped. In addition, many missions to Northern Vietnam required one or more inflight refueling enroute. In these cases, the store might be subjected to as much as two or three hours of maneuvering flight (some of it highly evasive) prior to being released. As a result, failures of the stores themselves were being experienced--fins cracked, fuzes failed, arming wires became loose, etc. To simulate these conditions in the initial aircraft/store compatibility testing, a specific captive flight test was introduced. This qualitative flight test, usually using uninstrumented aircraft, usually consists of one sortie for fighter type aircraft if inflight refueling is available. However, some aircraft without the fuel capacity and refueling capability require two sorties. If two sorties are required, stores are not downloaded or otherwise disturbed between sorties so that an accumulative effect of maneuvering and vibration may be assessed. During these flights, the store (loaded on the aircraft in the desired operational configuration, including other stores such as fuel tanks if necessary) is subjected to various maneuvers (such as pushovers, pullups, stick pulses, rolling pullouts etc.) at various speeds and load factors up to the maximum predicted allowable. The minimum total flight time for the two sorties should be the time equivalent to fly aircraft's combat radius plus 50% (minimum of 1.5 hours). Testers should carefully note this is a typical minimum, and some aircraft/store combinations may require more to really represent the operational environment (i.e., training stores which are flown hundreds of hours or GBU-10's on the F-111F for approximately 10 hours on their way to Libya). Of this total time, at least 30 minutes should be performed at 0.9 Mach (or the maximum allowable airspeed--whichever is lower) at the lowest practical altitude commensurate with the weather and safety of flight (500 to 1000 feet above sea level is recommended).

8.1.1.6 STABILITY AND CONTROL TESTS

The handling qualities of an aircraft with stores may be qualitatively analyzed during a Captive Flight Profile (CFP) flown in accordance with (IAW) MIL-HDBK-244, A Guide to Aircraft/Stores Compatibility, (Ref 3). This handbook outlines specific tasks to be completed during the mission to evaluate the stability and control characteristics of a specific aircraft/store configuration. These maneuvers are usually performed in conjunction with the store loads portion of the CFP. The results of these missions help identify any configurations having undesirable handling qualities not previously identified.

If analysis predicts questionable handing qualities with a new store configuration, traditional stability and control flight test may be scheduled on an instrumented aircraft.

8.1.1.7 WEAPON SEPARATION TESTS

Separation testing involves releasing (employing) stores loaded on the aircraft in realistic operational configurations at various airspeeds, altitudes (level flight and dives), and release modes (single/pair/ripple) in sufficient quantity to demonstrate that an operational envelope may be cleared.

These separations must demonstrate the store can be safely released from the aircraft without excessive disturbances store-to-aircraft or store-to-store collisions and with sufficient repeatability to allow accurate delivery.

Since this part of the flight test program presents the greatest cost and hazards to flight safety, preflight analyses should be used to the maximum extent to reduce the amount of actual flight testing required. To do this, the analyses must be verified early in the flight testing. In 1966 when we first began attacking aircraft/stores compatibility with a planned program, little constructive information or technology on store separation existed. The existing information was woefully fragmented in the engineering departments of many different aircraft manufacturers. Because of the rapid buildup of the conventional weapon inventory, there was a serious lack of manpower and facilities available (or able) to accomplish the necessary preflight analyses and wind tunnel tests prior to flight tests. For that reason, most flight tests were run in what is called the "brute force" method. Based on whatever information we had, an initial flight test point was determined analytically. Store releases were made at this point and subsequently in increments of increasing (or decreasing) speed, usually 25 to 50 knots, until the maximum predicted envelope was demonstrated. Level flight was completed prior to dive angles. Single drops were made prior to ripple releases. Onboard and photochase motion pictures were taken of each release, and decisions to proceed to the next point were based exclusively on a qualitative analysis of this film. Today, as a result of experience and newly-developed technology, we are able to reduce the number of actual test flights on any given aircraft/store combination to about 1/4 of what they were in 1966. Today's methods involve the use of any of a number of analytical and wind tunnel techniques to define the predicted safe separation envelope of the store. A minimum number of flight demonstration points are then selected from this analysis, and store releases are made at these points while recording the stores' separation trajectory through the use of high-speed motion picture cameras. This quantitative store separation data is then reduced utilizing a photoimaging process, and a direct comparison is made between the flight test and predicted separation trajectories.

8.1.1.8 ELECTROMAGNETIC COMPATIBILITY TESTS (EMC)

EMC testing involves determining if any electrical or electronic equipment on the aircraft, other stores, ground support equipment, or enemy ground installations might produce an electrical potential in the weapon causing an explosion, abnormal operation, or other undesirable side effect. This also includes any effects Electronic Countermeasures ECM pods may have on other stores, the aircraft or its systems. It consists of testing for both Electromagnetic Interference (EMI) and for Hazards of Electromagnetic Radiation to Ordnance (HERO).

8.1.1.9 BOMB BALLISTICS TESTS

The flow field near the aircraft and ejector rack can materially affect the initial trajectory of a new store immediately after release, thereby having a substantial effect, known as separation effects, on its ground impact point. Once the store is clear of the aircraft the freestream ballistic will be constant for a given airspeed, G, dive angle, and Mach number. Because of separation effects, releasing a number of stores on an instrumented range may be required to establish accurate bombing tables for each different type of aircraft.

8.1.1.10 SYSTEM ACCURACY TESTS

A final step necessary with new aircraft or weapons is the quantification of overall system accuracy or effectiveness. This information is necessary for tactical or strategic planners and will be obtained from releasing a number of stores from an instrumented aircraft on an instrumented range.

8.1.2 DEFINITIONS

8.1.2.1 STANDARDIZATION OF TERMINOLOGY

It has been learned through experience that one of the biggest problems in the field of aircraft/stores compatibility is the inability to properly communicate to others problems or implications of areas of concern. This is caused primarily by a lack of awareness and a commonly understood language.

The following standardized definitions are provided to assist in the breaking down of this communications barrier. These definitions should be used to the maximum extent possible by all involved in the aircraft/stores compatibility field.

1. Aircraft: Any vehicle designed to be supported by air, being borne up either by the dynamic action of the air upon the surfaces of the vehicle, or by its own buoyancy. The term includes fixed and movable wing airplanes, helicopters, gliders, and airships but excludes air-launched missiles, target drones, and flying bombs.

2. Aircraft/Store Compatibility: The ability of an aircraft, stores, and related suspension equipment to coexist without unacceptable effect of one on the aerodynamic, structural or functional characteristics of the others under all flight and ground conditions expected for the aircraft/store combination. A particular store may be compatible with an aircraft in a specific configuration although not necessarily so with all pylons (or stations) or under all conditions.

3. Carriage: The conveying of a store or suspension equipment by an aircraft under all flight and ground conditions including taxi, takeoff, and landing. The store or suspension equipment may be located either externally or internally to the aircraft. Carriage shall include time in flight up to the point of complete separation of the store or suspension equipment from the aircraft. Types of carriage include:

   a. Symmetrical Carriage: A loading arrangement of identical stores on either side of a dividing line or plane (usually the longitudinal axis) as related to a given aircraft suspension equipment or weapons bay.

   b. Asymmetrical Carriage: The carriage of stores arranged without symmetry. This term applies to the carriage of stores unlike in shape, physical properties, or number with reference to the plane of symmetry.

Note: The term "asymmetrical" shall apply to the arrangement or loading of stores or suspension equipment on an aircraft, as contrasted with the term "unsymmetrical," which shall apply to an aircraft maneuver wherein the aerodynamic loading is unequally distributed on each side of the symmetry of the aircraft, as in a roll.

c. Conformal (or Tangential) Carriage: The concept of packaging stores to conform as closely as practical to the external aircraft lines to reduce drag and obtain the best overall dynamic shape. Stores are generally carried in arrays, mounted tangentially to some portion of the aircraft, usually the bottom of the fuselage. It includes those arrangements made possible by weapon shapes configured for this purpose.

d. Mixed Load Carriage: The simultaneous carriage or loading of two or more unlike stores on a given aircraft.

e. Multiple Carriage: Carriage of more than one store on any given piece of suspension equipment such as bombs carried on a TER or MER.

f. Single Carriage : Carriage of only one store on any given station or pylon. This is also known as parent carriage.

g. Tandem Carriage: Carriage of more than one store on any given piece of suspension equipment where one store is behind the other.

4. Certificating Agency: The service office or organization having the responsibility for issuing the technical manuals and changes thereto which constitute store certification (i.e., NAVAIR aircraft System Program Office (SPO) or System Program Manager (SPM)).

5. Certification of a Store: The determination of the extent of specific store/aircraft compatibility and the formal publication of all information necessary for appropriate employment of a store on a specified aircraft (aircraft series) in the applicable technical manuals and flight operation manuals (or interim supplements or revisions thereto).

a. Baseline (Initial) Store Certification Program: The original or initial store certification configurations where store compatibility analysis and engineering support is normally performed by the aircraft contractor and aircraft Program Office (PO). Flight-testing is normally conducted at the Air Force Flight Test Center (AFFTC), while technical guidance is provided by 3246th TESTW/TY. This program is designed to evaluate system capability and provide the structural integrity, flutter, performance, and flying qualities data base.

b. Follow-On Store Certification Program: The remainder of the store certification program which continues throughout the operational life of the aircraft and which is not performed during the Baseline Program. This program is designed to satisfy operational needs and store compatibility analysis; testing is normally conducted at Eglin by the 3246th TESTW/TY and managed by the aircraft PO or Air Logistics Command MMS or MMA divisions.

6. Certification Data Package (CDP): A CDP for a store is the primary data package used to insure stores are physically, mechanically, electromagnetically, environmentally, structurally, and aerodynamically compatible with USAF aircraft systems, and the supporting technical orders can be written. The CDP is comprised of the Compatibility Source Data Package (CSDP), Weapon Source Data Package (WSDP), and the Standard Source Data Package (SSDP).

a. Compatibility Source Data Package : A CSDP is the primary resource used to determine if a requested flight clearance can be granted. In addition, it is used to obtain the specific engineering data, test data, and computer simulations required to provide inputs to the WSDP. The CSDP is composed of the following:

(1) Physical Description
(2) Mass Properties
(3) Functional Description
(4) Interface Control Drawings
(5) Aerodynamic Characteristics
(6) Structural Analysis
(7) Electromagnetic Compatibility Interference Data
(8) Environmental Analyses and Qualification Tests

b. Weapons Source Data Package (WSDP): A WSDP is the primary resource used to develop ballistic and safe escape data for nonnuclear stores. It is used as source data for the Aircraft-34 TO. HQ USAF Program Management Directive (PMD) 5019 defines the type of data required for the WSDP, while MIL-M-38784, Technical Manual General Style and Format Requirements, defines the format. The WSDP can be a complex, expensive data package requiring a considerable amount of analysis and testing (both ground and flight) to develop. A WSDP is typically composed of the following:

(1) Front Matter
(2) Description
(3) Normal Aircrew Procedures
(4) Emergency Aircrew Procedures

(5) Supplemental Data
(6) Planning Procedures and Sample Problem
(7) Planning Charts and Ballistic Tables

c. Standard Source Data Package (SSDP): A SSDP is the primary resource used to develop loading procedures for nonnuclear stores. It is used as source data for the Aircraft-33 TO. It contains a description of the munition and how it functions. It also provides step-by-step instructions for store preparation and loading. SSDP contents are specified in MIL-M-38784, and the munition loading procedures are verified IAW TO 00-5-1, and TAC/AFSC/AFLCR 8-13. A SSDP is typically composed of the following:

(1) Munitions Description Data
(2) Support Equipment Description
(3) Bomb Fuzes
(4) Emergency Procedures
(5) Specific Safety Requirements
(6) Munitions Preparation
(7) Loading
(8) Fuzing
(9) Post Loading
(10) Cartridge Installation
(11) Post Loading Inspection
(12) Delayed Flight or Alert Procedures
(13) Prior to Launch Procedures

7. Critical Conditions: A combination of pertinent operational parameters expected to be encountered by an aircraft, store, suspension, equipment, or combinations thereof; upon which the design or operational limits of the aforesaid vehicles devices or portions thereof are based. Usually, this is the fastest speed and highest/lowest load factor desired for employment of the weapon.

8. Developmental Test and Evaluation (DT&E): Is Test and Evaluation (T&E) conducted throughout various phases of the acquisition process to ensure the acquisition and fielding of an effective and supportable system by assisting in the engineering design and development and verifying attainment of technical performance specifications, objectives, and supportability. It includes components, subsystems, preplanned product improvement changes, hardware-software integration and related software, as well as qualification and production acceptance testing. T&E of compatibility and interoperability with existing or planned equipment and systems

is emphasized.

9. Employment: The use of a store for the purpose and in a manner for which it was designed such as releasing a bomb, launching a missile, firing a gun, or dispensing a submunition.

a. Release: The intentional separation of a store, such as an "iron bomb," from its suspension equipment for purposes of employment of the store.

b. Launch: The intentional separation of a self-propelled store; such as a missile, rocket, or target-drone for purposes of employment of the store.

c. Fire: The operation of a gun, gun pod, or similar weapon, so as to cause a bullet or projectile to leave through the barrel.

d. Dispense: The intentional separation from an airborne dispenser of devices, weapons, submunitions, liquids, gases, or other matter, for purposes of employment of the items being dispensed.

10. Failure Mode: The malfunction of weapon components which must operate normally to ensure acceptable separation i.e., autopilot guidance, fin employment, etc.

11. Flight Clearance: An authorization for flight, after necessary testing and appropriate engineering analysis has been made, which an aircraft/store combination would not pose an unacceptable risk for a specific limited purpose such as DT&E or initial operational test and evaluation (IOT&E). The flight clearance will identify, as appropriate, the loading configuration, carriage, jettison, and employment limitations, information needed to make drag and stability computations, cartridge orifice combinations or settings, loading procedures, store mass and physical properties, and any additional information affecting personnel, flight safety, or mission accomplishment. Flight Clearances remain valid for a specified finite period of time for a specific user or group of users.

12. Free Flight (of a Store): The movement or motion of a store through the air after separation from an aircraft.

13. G-Jump: The change in normal load factor resulting from store release, due to the combined effects of ejection force, dynamic response, and instantaneous aircraft gross weight decrease. The G-jump effect is most apparent when several large stores are released simultaneously or a large number of smaller stores are released with a very small ripple interval. The amount of G-jump can, at times, be large enough to cause overstress of the aircraft or other stores not being released. In dive-toss delivery, G-jump of up to 3.5G (in addition to the maneuver load factor) are not

uncommon.

14. Hung Store: Any store (or stores) which does not completely separate from the aircraft when actuated for employment or jettison.

15. Interval: The elapsed time between the separation of a store and the separation of the next store.

16. Nonnuclear Stores Characteristic Data Bank: A centrally located compilation of store mass and physical properties.

17. Operational Test and Evaluation (OT&E): Is the field test under realistic conditions of any item (or key component) of weapons, equipment, or munitions for the key purpose of determining the effectiveness and suitability of the weapons, equipment, or munitions for use in combat by typical military users; and evaluation of the results of such tests. OT&E may, for large systems, be broken into Initial, Qualification, and Final phases to ensure all test objectives are met.

18. Safe Escape Analyses: Analyses are required on all munition systems which, by their functional design, could be delivered in profiles potentially hazardous to the aircraft due to munition fragmentation. These analyses will consider munitions which function according to their design specifications as well as potential failure modes identified by the munition SPO Non-Nuclear Munitions Safety Group, or the operational user. For the USAF, analyses will be conducted in accordance with methodology documented in the Advanced Safe Escape Program (ASEP) Analyst Manual. The munition fragmentation characteristics will be determined by firings in a static test arena. These arena test firings will be conducted IAW the Joint Munitions Effectiveness Manual (JMEM), Test Procedures for High Explosive Munitions (THG1A1-3-7).

19. Separation: The terminating of all physical contact between a store or suspension equipment, or portions thereof, and an aircraft; or between a store, or portions thereof; and suspension equipment. This shall include the parting of items or submunitions from a dispenser.

a. Safe Separation: The parting of a store, submunition, suspension equipment, or portions thereof, from an aircraft without exceeding the design limits of the store or the aircraft or anything carried thereon, and without damage to, contact with, or unacceptable adverse effects on the aircraft, suspension equipment, or other stores (both released and unreleased).

b. Acceptable Separation: Acceptable store separations are those which meet not only the "safe" separation criteria, but also meet pertinent operational criteria. For instance, guided weapons as a minimum must remain within control limitations consistent with mission effectiveness. Conventional weapons (bombs) shall not experience excessive angular excursions which induce ballistic disperions that adversely affect weapons effectiveness or cause bomb-to-bomb collisions.

c. Pairs: The simultaneous separation of stores from two separate stations on an aircraft.

d. Ripple (or Train): The separation of two or more stores or submunitions one after the other in a given sequence at a specified interval.

e. Ejection: Separation of a store with the assistance of a force imparted from a device, either external or internal to the store.

f. Selective Jettison: The intentional separation of stores or suspension equipment, or portions thereof (such as expended rocket pods), no longer required for the performance of the mission in which the aircraft is engaged.

g. Emergency Jettison: The intentional simultaneous, or nearly simultaneous, separation of all stores or suspension equipment from the aircraft in a preset, programmed sequence and normally in the safe condition.

20. Significant Change: Any change in store characteristics which results in any of the following:

a. Any change to external aerodynamic shape

b. Any change in arming wire/lanyard routing system

c. Any change affecting the electromagnetic radiation environment

d. Any change in suspension lug location

e. A one-half inch or greater shift of store center of gravity excluding any allowable tolerance

f. A five percent or greater change of store weight

g. A ten percent or greater change in pitch or yaw movement of inertia

h. Any change in store electrical/electronic connectors or characteristics

i. Any change in store safing or arming design

j. New store nomenclature

k. Any change in basic store structural characteristics

l. Any change in environmental tolerance

m. Any change in functional concept

n. Any change in ballistic or propulsion characteristics

o. Any change in the warhead design influencing fragmentation characteristics

21. Store: Any device intended for internal or external carriage and mounted on

aircraft suspension and release equipment whether or not the item is intended to be separated in flight from the aircraft. Stores include missiles, bombs, nuclear weapons, mines, torpedoes, pyrotechnic devices, detachable fuel and spray tanks, line-source disseminators, dispensers, pods (refueling, thrust augmentation, gun, electronic-countermeasures, etc.), targets, cargo-drop containers and drones.

a. All-up Round: Any store which is completely assembled both mechanically and electrically and ready for installation on or in an aircraft for purposes of carriage and employment on a specific mission. An all-up store has all mission-necessary subassemblies (such as guidance and control units, fins, fairings, and fuzes) associated hardware and electrical cables installed and serviceable, as well as necessary preflight safety devices, and any adaptation equipment which is normally fixed to the store. An all-up store does not include items of suspension equipment (such as bomb racks or missile rails), externally mounted electrical cables which attach the store to the suspension equipment, or other items which are not separated with the store.

b. Submunition: Any item, device, or munition dispensed from or carried in dispensers or pods and intended for employment therefrom.

22. Suspension Equipment: All airborne devices used for carriage, suspension, employment, jettison of stores, such as racks, adapters, launchers, and pylons.

23. Technical Manuals: These manuals contain the approved data required for the loading carriage and employment of the store(s). Air Force Technical Orders (TOs) consist of the following types:

a. Aircraft - 1 TO - Flight Manual

b. Aircraft - 16 TO - Nuclear Weapons Loading Procedures

c. Aircraft - 25 TO - Nuclear Bombs Delivery Manual

d. Aircraft - 33 TO - Nonnuclear Munitions Loading Procedures

e. Aircraft - 34 TO - Nonnuclear Munitions Delivery Manual

f. Aircraft - 35 or Similar TO - Stores Installation and Removal Procedures

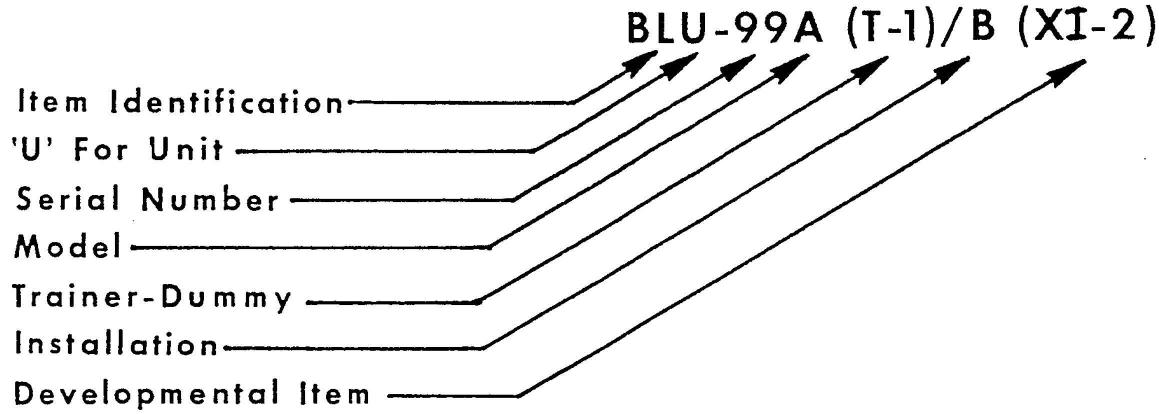
g. TO 11N-50-7 - Major Assembly Releases and Hold Orders for War Reserve Material.

8.1.3 STORE NOMENCLATURE

An effort has been made to standardize the method of designating munitions and related hardware. Under the "Air Force Munitions Type System" aeronautical units equipment are designated as shown in Table 1 and Table 2.

TABLE 1

I. AERONAUTICAL UNIT DESIGNATIONS



AERONAUTICAL ITEM IDENTIFICATION DESIGNATORS

AD CERTAIN ADAPTING ITEMS
BB EXPLOSIVE ITEMS
BD SIMULATED BOMBS
BL BOMBS & MINES
BR BOMB RACKS & SHACKLES
BS MUNITION STABILIZING & RETARDING DEVICES
CB END ITEM CLUSTER BOMBS
CC CARTRIDGES
CD CLUSTERED MUNITIONS (NOT END ITEMS)
CV MISCELLANEOUS CONTAINERS
DS TARGET DETECTING DEVICES
FM MUNITION FUZES
FS MUNITIONS FUZE SAFETY-ARMING DEVICE
FZ FUZE-RELATED ITEMS
GA AIRCRAFT GUN
GB GUIDED BOMBS
GF GUN-RELATED ITEMS
GP PODDED GUNS
GU MISCELLANEOUS GUNS
KA MUNITIONS CLUSTERING HARDWARE
KM KITS
LA AIRCRAFT INSTALLED LAUNCHERS
LK AMMUNITION LINKS
LM GROUND BASED LAUNCHERS
LU AMMUNITION LINKS
MA MISCELLANEOUS ARMAMENT ITEMS
MD MISCELLANEOUS SIMULATED MUNITIONS
MH MUNITIONS HANDLING EQUIPMENT
MJ MUNITIONS COUNTERMEASURES
ML MISCELLANEOUS MUNITIONS
MT MOUNTS
PA MUNITIONS DISPENSING DEVICES, EXTERNAL
PD LEAFLET DISPENSER
PG AMMUNITION
PW INTERNAL DISPENSER

RD DUMMY ROCKETS
RL ROCKETS
SA GUN-BOMB-ROCKET SIGHTS
SU STORES SUSPENSION & RELEASE ITEMS
TM MISCELLANEOUS TANKS
TT TEST ITEMS
WD WARHEADS
WT TRAINING WARHEADS

DUMMY AND TRAINER DESIGNATORS

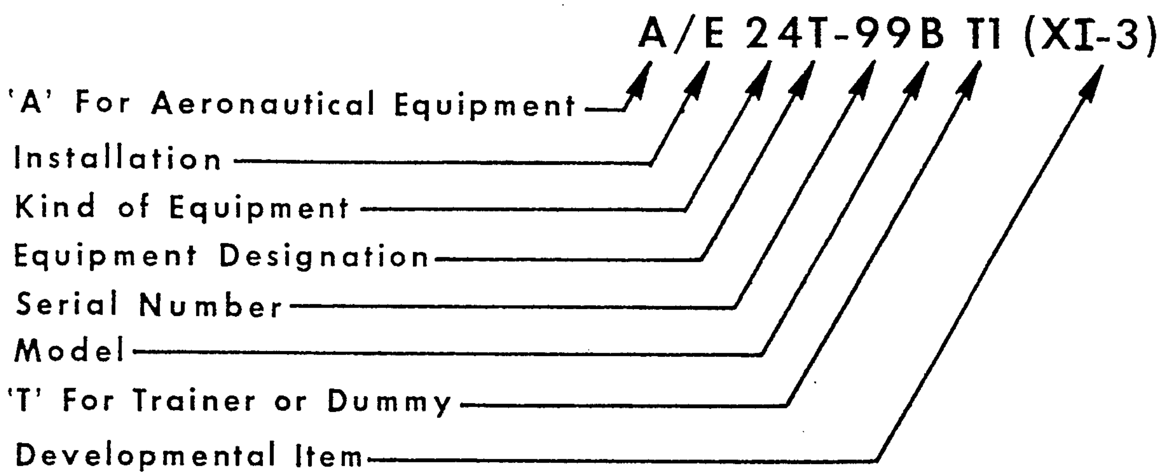
D DUMMY (COMPLETELY INERT)
T TRAINING (NOT COMPLETELY INERT)

INSTALLATION DESIGNATORS

A AIRCRAFT OR MISSILE, INSTALLED IN OR ON VEHICLE, NONMISSION EXPENDABLE
B AIRCRAFT OR MISSILE TRANSPORTED BUT NOT INSTALLED IN OR ON VEHICLE, MISSION EXPENDABLE
E GROUND, NOT FIXED
F GROUND, FIXED
M GROUND, SELF-CONTAINED, MOVABLE, INCLUDES VEHICLE BUT NOT SELF-PROPELLED
N AIRCRAFT OR MISSILE TRANSPORTED, BUT NOT INSTALLED IN OR ON VEHICLE, NONMISSION EXPENDABLE
S GROUND, SELF-PROPELLED, INCLUDES VEHICLE

TABLE II

II. AERONAUTICAL EQUIPMENT DESIGNATIONS



KIND OF AERONAUTICAL EQUIPMENT DESIGNATORS

23	CHEMICAL	36	OPTI-MECHANICAL
24	ELECTRICAL	37	ELECTROMECHANICAL
25	EXPLOSIVE	38	INFRARED
29	MATERIALS, RIGID	45	BIOLOGICAL
32	MECHANICAL	49	GUNNERY
35	OPTICAL	99	MISCELLANEOUS

AERONAUTICAL EQUIPMENT IDENTIFICATION DESIGNATORS

A AIRCRAFT OR MISSILE SUPPORT
B FIRE CONTROL OR BOMBING
D DETECTION
E DESTRUCTION
K MUNITIONS HANDLING
P PROTECTION
T TEST
U SPECIAL, MULTIPLE PURPOSE, MISCELLANEOUS
X IDENTIFICATION
Y DISSEMINATION

8.1.4 REFERENCES

The following references should be reviewed prior to involvement in a store certification process:

1. MIL-STD-1763, Aircraft/Stores Certification Procedures.

2. MIL-STD-1289, Ground Fit and Compatibility Tests of Airborne Stores, Procedures for.

3. MIL-HDBK-244, A Guide to Aircraft/Stores Compatibility.

4. AF Regulation 80-54, Aircraft/Stores Certification Program (SEEK EAGLE).

5. AOP-12, Aircraft Stores Interface Manual (ASIM).

6. T.O. 1-1M-34 Flight Manual Aircrew Weapons Delivery Manual (Non-Nuclear), Standard Volume, A-7, A-10, F-4, F-15, F-16, F/FB-111.

A much more detailed list of government specifications, standards, handbooks and other publications available is located in Reference 1.

8.2 CERTIFICATION ANALYSES

8.2.1 INTRODUCTION

The certification analyses phase encompasses the entire certification process. This phase begins with a data research and continues concurrent with ground and flight testing.

The easiest way to certify a store is by analogy on the basis of similarity. If the aerodynamic structural mass and operational characteristics of the store to be certified are sufficiently similar to those of a store already certified in the desired loading configuration on the designated (or similar) aircraft, it may be possible to certify the store partly or entirely by analogy. Where certification cannot be justified on the basis of similarity, analyses of existing aircraft and store data must be performed to evaluate compatibility. Such analyses may themselves provide enough information to allow certification, or they may point out the need for additional data to be acquired by the performance of specific tests. The analysis of this additional test data would then form the basis for a certification recommendation.

8.2.2 DATA RESEARCH

Prior to entering into any aircraft/store certification program, all existing data suitable for compatibility analyses should be reviewed to minimize requirements for additional analyses and testing. Before planning or performing any new tests, data research should be completed to: (a) provide a preliminary evaluation of compatibility for each store installation, (b) to assess the sufficiency of existing data, and (c) to identify what additional data are needed. It is recommended the aircraft SPO/SPM, Store SPO or item manager, and 3246th TESTW/TY be contacted in an attempt to acquire all the necessary information. Information acquired during research should include data for the aircraft and store together with certification information for similar aircraft/store installations. If sufficient data are acquired in this research, many tasks normally required in a complete certification program will be reduced or eliminated. The data must be organized systematically to permit correlation of data availability and suitability with certification requirements. Such data will normally consist of the following types:

1. Aircraft data
2. Store installation data
3. Store data
4. Operational data (for the store and for the aircraft/store as a weapon system)
5. Similar store installation data

8.2.3 PHYSICAL COMPATIBILITY REVIEW

It is important to establish early that the store can be installed satisfactorily at the specified locations in the desired numbers with all components interfacing properly. For a preliminary check, drawings and descriptions of the installations may be used to evaluate physical compatibility. The review necessary to accomplish this objective is described in paragraph 6.1.5.2 of MIL-HDBK-244. The data required to conduct an analytical fit check can be found in AOP-12 Aircraft Stores Interface Manual (ASIM) and the CDP submitted by the organization having engineering responsibility for the item.

A review of this data is made to assure mechanical and electrical connections and attachments between the store, suspension equipment and aircraft structure, the ground, and other installed stores are adequate. Test procedures to be used are found in MIL-STD-1289. Any store installation which does not satisfy the clearance requirements of MIL-STD-1289 should not be analyzed further unless a deviation has been approved by the agency having engineering responsibility on the specific aircraft in question. In addition to the above requirements, adequate clearance should exist so runway or carrier pendant cables will not strike the aircraft, installed stores, or suspension equipment during cable bounce caused by nose or main gear roll-over.

8.2.4 ENGINEERING ANALYSES

Where store similarity and physical compatibility reviews do not in themselves provide sufficient basis for certification, additional engineering analyses must be performed. The engineering analyses typically required to determine store/airplane compatibility should include but not be limited to, the following:

1. Operational compatibility
2. Store functional limitations
3. Carriage limitations
4. Separation limitations
5. Ballistic accuracy

Compatibility involves the establishing of estimated flight envelope limits for carrying, employing, and jettisoning of a store or group of stores intended for tactical employment. Analytical methods coupled with empirical data are used prior to flight test to predict critical areas, conditions, parameters, and to reduce the scope of both ground and flight test programs.

8.2.4.1 STRUCTURAL ANALYSIS

Prior to certification of a store on any aircraft, a thorough analysis of the strength of both the store itself and the store/aircraft/suspension equipment combination must be made. This analysis should consider the structural integrity of the store alone, the structural loading effects of the store on the aircraft and suspension equipment, and the effects of the aircraft and suspension equipment on the store. Additionally the analysis should be performed in accordance with MIL-A-8591, General Design for Airborne Stores, Suspension Equipment and Aircraft/Store Interface (Carriage phase) for all conditions throughout the desired aircraft/store operational envelope including takeoff (catapults, if applicable) carriage, separation, and landing (arrested landing if applicable).

8.2.4.2 AERODYNAMIC ANALYSIS

Adding an external store or group of stores to an aircraft often has a significant effect on the flying qualities and performance of the carrying aircraft. Airloads due to maneuver and gust requirements of the MIL-A-8860, Airplane Strength and Rigidity series specifications are of particular interest in developing the aerodynamic and structural performance of the aircraft. In addition to the obvious weight and center-of-gravity changes, the basic airflow over the aircraft lifting and control surfaces can be significantly altered. Depending on how and where the stores are installed on the aircraft, mutual interference effects can cause an increase in drag much larger than the combined free stream drag of all individual components. Asymmetric loads can require large deflections of aircraft controls for aerodynamic trim which add significantly to the total drag. This additional trim requirement can also reduce the available control authority below acceptance limits for maneuvering flight and arrested landings. Airloads, temperatures, and pressure or density gradients in the captive flow environment can be more severe than the store will tolerate and still function properly. Therefore, analyses for certification must consider the various ways in which stores change the aerodynamics of the aircraft and ways the captive environment affects the store and its separation trajectory.

1. Store Airloads Effects:

Incremental effects of stores on vehicle aerodynamics, including control effectiveness and variations in center-of-gravity location shall be included in analyses of the aircraft flying qualities. The analyses shall include takeoff and landing configurations where store effects on high-lift systems may be significant. Where control or lifting surfaces are adjacent to or in the wake of external stores both the steady state aerodynamics and fluctuating airloads must be evaluated. Large loadings of wing-mounted stores decrease roll response by increasing roll inertia. Therefore, control effectiveness of the aircraft with stores must be analyzed to assure adequate control authority is available with all loadings. If the aircraft with stores can reach flight conditions where the flying qualities are unsatisfactory, restrictions must be imposed as part of the certification results.

2. Stores Loading Effects:

Asymmetric loadings may be the most critical test of flying qualities even though these loadings may be realistically encountered only briefly during employment of the stores. Some store installations which induce large aerodynamic forces and moments may be carried acceptably in a symmetric arrangement and be unacceptable when loaded asymmetrically. Certification analyses must determine the airplane has sufficient control authority to balance the unsymmetric aerodynamic forces and moments created by all asymmetric loadings and still have adequate stability and control characteristics to perform the required mission throughout the required envelope including takeoff/landing with crosswinds. If the airplane flight characteristics are unacceptable with specific asymmetric loadings, this information shall be included in the certification document so the loading can be avoided even briefly during employment.

3. Store Drag Effects:

External stores affect aircraft performance in three important ways. Aerodynamic drag is normally increased by the added external bodies and the mutual flow interference. The added weight requires more lift of the aircraft which increases the induced drag. Also, aerodynamic trim usually has a drag penalty. Therefore, performance calculations for the various store loadings shall be used to assure adequate takeoff, landing and maneuvering performance is available and to evaluate performance penalties produced by the stores. Asymmetric loadings must be considered for any part of the flight envelope where such loadings are realistic because trim drag can be large.

4. Store Environmental Effects:

Most stores have airload, temperature or other environmental limitations. Aerodynamic interference from the aircraft and adjacent stores normally produces a flow environment more severe than experienced by the store in free flight. The aerodynamic analysis must provide captive airloads and pressure distributions for the structural and separation analyses. Some stores are sensitive to pressure or density gradients and these must be defined. Most stores have temperature limitations because of components such as warheads, electronics fuses or domes. These limits are often dependent on more than absolute temperature alone and are a function of the time spent at specific temperatures. Stores spend most of the time in the aircraft environment rather than in free flight so both captive and launch temperatures must be investigated. The aerodynamic heating analyses must show all weapon components will not be exposed to temperatures outside qualification limits during world-wide operational employment.

5. Store Operational Data:

To insure aircraft safety of flight and to inform the pilot of store effects on aircraft stability and control, aircraft flight manuals (or tactical manuals) should contain either "stability index numbers" or maximum allowable center-of- gravity travel for each store or loading configuration. Effects of stores on aircraft mission performance should be represented in aircraft handbooks by "drag indices." Information should also be provided for restricted flight times at conditions that can exceed temperature allowables for the stores. All flight restrictions which are necessary to avoid unacceptable captive loads, flying qualities and aircraft performance shall be identified.

8.2.4.3 AEROELASTIC ANALYSES

Acceptable aeroelastic analysis approaches within industry vary considerably. Therefore the following paragraphs enumerate some of the current practices keeping in mind newer methods are continually being developed. Regardless of the approach, a methodical system of documentation must be established to record the results of the various analyses and tests associated with each takeoff configuration along with the applicable limit speed envelopes and flutter margins of safety. These records should be retained whether a particular takeoff configuration is cleared or not as they may be invaluable for evaluation of future configurations. These derived configurations should reasonably cover the entire range of aircraft and store use including store down-loadings, fuel expenditure and applicable limit speeds. Store down-loadings may need to include not only considerations for standard deployment sequences but also optional deployment, mixed stores, hung stores, and partial store expenditure such as from fuel tanks, rocket launchers, external gun pods, and various dispensers. Partially filled external fuel tanks may need special attention to determine possible adverse center-of-gravity shifts in climbs and dives or fuel sloshing effects. While these lists of derived configurations should be kept as brief as possible by utilizing the results of any previous evaluations, the lists usually will still be quite extensive.

1. <u>Inertial Similarity Comparisons</u>:

Experience has shown for a given aircraft with a given set of wing pylons and racks the inertial characteristics of external stores on the pylons usually (but not always) play a much more dominant role in the aeroelastic stability (except divergence) of the total system than either the stores stiffness or unsteady aerodynamics characteristics. More specifically, configurations for the given aircraft/pylons/racks with nearly similar pylon loadings expressed in values of center-of-gravity and radius of gyration, usually exhibit similar aeroelastic characteristics except for some instances such as those presented later in this paragraph. Comparing such values for new configurations with those of previously evaluated configurations may thus provide an exceptionally low-cost method for initial reviewing purposes. There are some severe limitations to this method however. First, finding another configuration with enough inertial similarity as well as known aeroelastic characteristics usually requires prior evaluation of a large number of configurations. Secondly, determining the allowable tolerances on similar configurations requires an extensive knowledge of the basic aeroelastic mechanisms involved and their associated sensitivities. Results of inertial parameter trend studies using either more formal analytical or wind tunnel methods may be interpolated to actual stores configurations as needed. Inertial similarity may not be sufficient when triple ejection racks (TERs), multiple ejection racks (MERs), multiple launcher rails or significantly flexible stores are involved because of the intervening stiffness effects. Likewise stores with large fin areas, large but lightweight stores, or stores mounted near the wing tips may have significant unsteady aerodynamics characteristics not accounted for when only considering inertial similarity.

2. Computer Analyses:

Formal aeroelastic analyses usually performed by a computer, remains the most flexible approach in evaluating carriage of external stores while retaining reasonable accuracy and economy. This approach also tends to better reveal the basic aeroelastic mechanisms and their sensitivities than any other approach. Such information may be especially important in determining optimum resolution of borderline situations. The following discussion shall specifically refer to flutter, the most common aeroelastic instability usually encountered, but much of the discussion is applicable to the other instabilities as well. Flutter analyses are performed with discrete sets of input modal data and calculated unsteady aerodynamics. Current unsteady aerodynamic theories cannot account for embedded shocks in flow but are usually sufficiently accurate up to a Mach number of 0.85 and beyond a Mach number of 1.2 especially for thin airfoils. Unfortunately, the transonic region in between is usually also the most flutter critical region should external stores be carried above 0.85 Mach number. For these cases, extensive transonic wind tunnel tests of flutter models are mandatory. This modal data consisting of natural frequencies, associated mode shapes, and generalized modal masses, may be obtained directly from ground vibration tests at considerable expense but for the most part are usually calculated instead for economy. Therefore, a modal analysis in general must precede each flutter analysis for each configuration being considered. The input data for the modal analysis consists of idealized distributed lumped masses and discrete stiffness in a geometric array to dynamically represent the complete aircraft/stores system with special emphasis placed on the wings pylons, racks and individual stores. Formulating this analytical model with sufficient accuracy remains one of the most difficult dynamics tasks as the parameters needed cannot be measured directly. Calculated stiffness distributions are especially subject to error. The results of static load-deflection ground tests are usually not sufficiently accurate for use in theoretical vibration analysis. The analytical model must be verified although indirectly by ground vibration tests performed on a few representative aircraft-with-stores configurations. Aircraft with high-gain augmented flight control systems such as the F-16 or B-2, require special analyses to predict possible aeroservoelastic instabilities caused by the interaction of the aeroelastic response with the augmented flight control system. Most analytical methods in use today are capable of identifying those configurations which are either good or bad from a flutter standpoint. Many times however, the analysis identifies the candidate configuration in the marginal area from a flutter standpoint. In these cases three alternatives exist: (1) do not certify the store, (2) perform an instrumented aircraft flight test (usually very costly and time consuming, or (3) change the store loading configuration to another one allowing positive analytical determination. The aeroelastic analysis is usually performed concurrently with the structural analysis and utilizes the data defined in that paragraph.

8.2.4.4 SEPARATION ANALYSIS

One of the most important preflight analyses is determining the separation characteristics of a store. Store separation characteristics are important because they affect aircraft safety and weapon delivery accuracy. Also safety hazards associated with flight testing are increased due to the mass of the stores being released, the uncertain accuracy of the predictions, and the opportunities for inflicting serious aircraft damage because of the relatively large numbers of stores released at or near the boundaries of the acceptable flight envelope. Experience has shown proper use of predictive methods for store separation will enhance the safety of store delivery and jettison during flight testing and subsequent operational employment. Aircraft/store certification flight test programs can be considerably reduced, both in scope and in cost by reducing full scale flight tests based on a comprehensive analysis and positive correlation of predictions with the flight test data.

1. <u>Method Selection</u>:

Predicting accurate store separation trajectories on today's high speed aircraft under the varying conditions of altitude, Mach number, dive angle, load factor, and other factors related to the delivery (particularly when multiple carriage of stores is involved) is an extremely difficult task, requiring a skilled and experienced analyst. Several techniques are available for store separation analysis, and these are documented throughout scientific literature. Some are purely analytical in nature, utilizing theoretical aerodynamics and complex mathematical manipulation and analyst interpretations. Others utilize wind tunnel testing of small scale models of the store and aircraft, while still others involve a combination of theoretical and wind tunnel data utilizing a high speed digital computer for data reduction. Each of these techniques has advantages and disadvantages or limitations. No one technique will suffice for all cases. Rather, the analyst must examine the particular case and select the technique that, in his opinion, offers the most advantages for his particular situation. Most purely theoretical techniques available today suffer severe degradation when applied to transonic store separation or where multiple carriage is involved. Conversely, most pure wind tunnel techniques are expensive (much less than flight test however) and are generally limited to the specific cases and simulated flight conditions tested. Wind tunnel tests also have trouble with multiple store releases at small ripple intervals or during jettison. For these reasons, most analysts today employ hybrid methods which reduce costs while retaining wide applicability. Such a hybrid method would be the "grid" technique or the "flow angularity" technique described in Section 8.3.2.4.

One popular analysis method is a pure analytic technique called Computation Fluid Dynamics (CFD). Actually, CFD is not one specific techique or software package, but the overall name for an industry-wide set of techniques to program high-speed computers to model complex aerodynamics. It is another tool to be used by the separation analyst, and does not replace wind tunnel or other test methods. Computer models of the wing, aircraft and store are created, and a three-dimensional "air flow" is generated. The computer is used to "solve" the aerodynamic flow pattern around the aircraft/store combination and predict the position of the store just as it separates from the aircraft. New predictions of aerodynamic flow (and thus, forces and moments) are made based on the weapon's new position, and another prediction made. Predictions are repeated until a three-dimensional plot is created of the weapon's separation. This method has the advantage of having no sting effects, and is much cheaper than wind tunnel time. Load factors and angles of attack can be simulated without the hardware restrictions wind tunnels may have. Development of CFD techniques is continuing at the Arnold Engineering Development Center (AEDC), the Air Force Development Test Center (AFDTC), and the Naval Weapons Center.

2. Existing Data Review:

As a first step in store separation analysis, all available flight test and predicted data pertaining to the separation characteristics of the store in question either from the aircraft being examined or others with similar installations should be accumulated and screened for completeness of flight envelope coverage and for trends. If existing data covers the store's separation characteristics from the proper aircraft throughout the desired flight envelope, delivery conditions (speed, dive angle load factors etc.), delivery configuration, and mode (single, pair ripple etc.), little or no additional testing may be required to allow certification. If this is not the case, however, additional data must be obtained in accordance with the method of store separation prediction chosen.

3. Separation Envelopes:

Analysis of store separation should consider three separate aspects each with its own specific requirements. Store employment covers separating the store from the aircraft in its normal operational mode. It should cover separations at all speeds up to the maximum allowable in level and maneuvering flight both in the single release mode and in multiple release (ripple) mode down to the minimum allowable interval. Particular attention should be given to releases of stores in high dive angles (60° or greater) at the attendant low "G" (cosine of the dive angle). Such separations can be and often are extremely dangerous, particularly for unstable or low density stores. It should also be kept in mind proper store employment denotes not only safe separation from the aircraft but also requires the separation be relatively unperturbed so as not to adversely affect delivery accuracy.

4. Separation Reactions:

Analyzing the launch transient phase of store separation is extremely difficult. It generally involves guided stores such as electro-optical guided bombs which contain autopilot and guidance systems that are active during store separation to avoid target breaklock, or radical store movements caused by release perturbations. When operating normally, such weapons do not pose a danger to the release aircraft, either in a jettison mode (autopilot or guidance not active) or during release with active controls. If every component functions properly, separation will be completely safe and unperturbed. However, control failure or spurious guidance signals causing abnormal control deflections at release can cause high-energy collisions with the aircraft. Because of these possibilities, a reliability analysis of the store guidance and control system will be performed and the results of possible failures identified and examined for probability of occurrence and effect on store separation. Although no specific pass-fail criteria can be used in all cases, probabilities of failure of a single component causing an impact on the aircraft shall be kept in the realm of 1×10^{-6}. If this cannot be done, store redesign should be effected prior to flight.

5. Jettison Criteria:

Jettison of a store (or a store/suspension equipment combination) involves the releasing of items from the aircraft during emergencies (emergency jettison) or as normal operation after expenditure of cargo or submunitions (selective jettison). Examples of these would be fuel tanks, gun pods, dispensers, multiple bomb racks complete with some or all of its weapons etc. The primary concern of any jettison is to separate the item or items from the aircraft safely without collision. Obviously, there is no requirement for accurate delivery. This phase of store separation is by far the most dangerous to the releasing aircraft since many items jettisoned are aerodynamically unstable, usually of low density and their separation behavior is generally erratic and unrepeatable. If at all possible,the jettison envelope of a store shall be close to the full authorized carriage flight envelope including takeoff and landing speeds, etc. Jettisons are, however, commonly limited to level flight (plus and minus a reasonable "G" tolerance). Jettison envelopes limited to a single speed or those specifying a very narrow speed or altitude band shall be avoided if at all possible.

8.2.4.5 ENVIRONMENTAL ANALYSIS

The store suspension equipment and any affected aircraft components should or will be environmentally qualified to limits specified in their respective specifications. Generally these limits will be determined by the test methods delineated in MIL-STD-810, Environmental Test Methods and Engineering Guidelines, or each of the specified environments. If MIL-STD-810 has not or will not be used then the limits or specifics of determining the limits must be known or determined for each applicable environment.

1. Store Life-Span Considerations:

The initial environmental analyses should compare the natural and induced environment of the aircraft/store combination(s) in which the store and store suspension and release equipment must operate to that which has been or will be qualified. Of primary importance for these stores and equipment during this initial analysis is the operational or mission life-span. For some stores, this life-span could be a one-time flight, while with other stores such as fuel tanks, Electronic Countermeasures (ECM) pods, air-to-air and air-to-ground missiles, the life-span could be greater than the using aircraft.

2. Synergistic and Mutual Interactions Effects:

The next step is an analysis of the environmental capability of the aircraft/store/suspension equipment wherein the synergistic environmental effects and mutual interactions between onboard systems and the proposed store, store suspension equipment and store carriage locations are considered. It should be cautioned that there may also be some unique environments produced by either the aircraft or the store that could adversely affect the aircraft/store compatibility. The following are the synergistic and interactive environmental conditions which need be considered:

a. The radiation patterns of all aircraft electromagnetic emitters (radios, radar etc.) need be plotted and analyzed to determine the effect on any store or store combination. Conversely, the effects the store/store combination has on the aircraft emitter performance needs to be investigated.

b. When employing a store having an electronic emitter, the aircraft/store combination needs to be analyzed to determine what effect the radiation may have on the aircraft electronic components (especially flight control computers, armament and communications) and on the other aircraft stores. Also, the aircraft/store combinations influence on the emitter needs to be analyzed to ascertain proper functioning.

c. The aircraft vents and drains need to be investigated to determine if the material discharged will have an effect on any store which may be placed in the path of the material.

d. During store release or launch an array of miscellaneous debris could be released and includes such items as arming wire clips or lanyards, frangible nose cones, lens covers, rocket motor plugs, and dispenser caps, plugs etc. Analysis should be made to insure this debris will not damage the aircraft or other equipment carried in the aircraft either by insuring it does not impact the aircraft or is not ingested in the engine, or it is designed so impact or ingestion will not do damage.

e. An analysis of the effects of adjacent gun firing either from an internal gun or a gun pod. Gun pod installations require the same analysis as the installation of an internal gun. A high cyclic rate gun creates an extremely hostile environment and all of the adverse by-products of gunfire (muzzle blast, gun gas, vibration, shock, etc.) need to be analyzed to determine their effect on the aircraft and adjacent stores.

f. An analysis of the potential damage or detrimental effects from debris kicked up from the flight deck or runway by the nose or main gear wheels. Water, slush, sand, pebbles and stones are the more common debris be considered. This problem can worsen for aircraft operating from unprepared fields.

g. An analysis of turbulent boundary layer effects, shock wave impingement and flow changes caused by adjacent stores, pylons, and aircraft surfaces. For aircraft with bomb bays, the cavity effects of the weapons bays should be analyzed.

h. An analysis of the synergistic effects from combinations of induced environments. Examples are combinations of two or more of the following: aerodynamic heating, altitude variations, humidity, shock wave, dynamic pressure, vibration, and acoustics.

8.2.4.6 STORE PROPULSION ANALYSIS

There is a need to analyze the effects of gas and other by-products produced by thrust-augmented stores. This analysis is concerned with two major effects of these stores, namely the impingement of the expended gas and suspended foreign material (plume) on the aircraft surfaces or other stores and the ingestion of this plume by the aircraft engine(s). Rockets, air-to-air and air-to-ground missiles are the principle thrust-augmented stores, although any store, chaff/flare dispenser, or suspension and release device utilizing a system that expends gas or other foreign material during deployment of stores should be reviewed for potential impact of the expended by-products. Initially, an analysis or investigation should be made to evaluate the location of these thrust-augmented stores with regard minimizing impingement and engine ingestion problems. Reduction of ingestion by the engine(s) has the greater priority. Location or relocation of the stores to attain these goals should be accomplished if at all possible. Aside from the exhaust gas plume of the thrust-augmented stores, other foreign material such as clips, chaff, frangible nose cones, and lens coverings can also be expended during operational employment of these stores. Although undesirable, some very limited amounts of chaff and other frangible material may be tolerated by some engines but must be carefully evaluated by the respective engine authority.

1. Engine Ingestion:

Primarily this analysis is intended to address the gas plume and any foreign material suspended within this plume. Ideally, aircraft jet engines should not ingest any of these gases or other by-products. However, due to the limitation of store locations on some aircraft engine(s), ingestion of some of these plume gases will occur under many of the flight conditions desired for the store(s) employment. The engine ingestion analysis must include an estimate of the maximum or most critical amount of gas that would be ingested for those flight conditions under which the store(s) would be employed. The flight conditions (i.e., speed, altitude, and maneuvers) that would create these conditions must be determined by suitable analysis or preferably, empirical data from flight tests on similar installations under similar conditions. The permissible quantity and characteristics of ingested gas is a function of the engine, engine controls and sensors, altitude, ambient air conditions at altitude and aircraft velocity. In conjunction with the quantity of gas that will be ingested, the chemical composition of the gas plume and associated temperature, pressure, density and air dilution, plus any foreign material within the exhaust gases (alumina) and shock wave must be evaluated for detrimental engine effects. Flameout, overspeed, and non-self-recoverable surge stalls are detrimental effects that can result if the ingested gas variables are of sufficient severity. The ingested gas/smoke should not exceed the ingestion sensitivity limits of the respective engine(s). The sensitivity characteristics and their limits must be known. If not, only qualitative judgments can be made. There are several alternatives aside from relocation of the stores that may be acceptable if there are adverse effects to the engine(s) from gas ingestion. These are:

a. Stall/surge improvement devices (compressor bleed, variable geometry) can be actuated.

b. Engines can be scheduled for continuous ignition.

c. To a limited extent, evasive maneuvers or alterations of the flight path can be accomplished.

d. Engine automatic restart procedures can be incorporated.

e. Employment of the store can be restricted to acceptable engine limits only.

If none of the above or other satisfactory alternatives are acceptable, the store or store configuration must be rejected.

2. Gas Plume Impingement:

After store location has been satisfied with respect to the engine ingestion problems, an analysis must be made of the impingement effects of the gas plume on the aircraft or on other stores. Factors that must be considered for the gas plume are residue buildup and its chemical composition, corrosion, blast overpressure, shock wave, thermal effects, and the erosion due to the velocity of the exhaust by-products. In considering these factors, the added effects of the natural environments, i.e., humidity, rain, salt spray, solar heat, etc., must also be considered. These factors must be considered synergistically as well as individually.

3. Target Acquisition Analysis For Guided Weapons:

Installation of a guided weapon on a relatively flexible aeroelastic structure results in dynamic coupling motion between the weapon and the aircraft. The resultant pointing error signals can induce violent corrective movements of the weapon control system which could prevent target acquisition by the weapon's target seeker systems.

4. Gun Gas Analysis:

Previous paragraphs addressed an analysis of the effects of the hostile environment generated by gunfire. In addition to this hostile environment, the gunfire also generates large volumes of gas. It is generated at a rapid rate and is a direct function of the propellant per round, the firing rate, and the burst length. With the abundant air available in flight, the resulting gas air mixture becomes flammable and explosive over a broad range. The limits of the explosive mixture when combined in an enclosure are referred to as the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL). These limits must be determined to identify any limitations in burst length or firing rate or the need to change the gas vent system design.

5. Thermal Analysis:

The purpose of the thermal analysis is to determine the critical components of the store, the response of these components to anticipated flight and atmospheric conditions, and finally to provide a means by which parametric sensitivity studies can be made for determining the important variables for duplication in subsequent ground and flight test facilities. The results of these analyses provide preliminary data for the full range of flight and atmospheric conditions.

8.2.4.7 BALLISTIC ANALYSIS

1. Store Behavior:

Analysis of the ballistic behavior of a store in the presence of separation effects often presents a difficult problem, but one that must be solved if ballistic accuracy requirements are to be met. Ballistic analysis in the evaluation of aircraft/store compatibility should be coordinated with the aerodynamic and separation analyses discussed in Aerodynamic Analysis and Separation Analysis, respectively.

2. Store Accuracy:

Ballistic accuracy may be assessed for two store flight regimes. The first is independent of the releasing aircraft and occurs after separation disturbances have decayed and is specific for each weapon type. The other is for the entire store flight trajectory and is characteristic of the weapon, the releasing aircraft, and the release conditions. This trajectory is used when determining the system accuracy of the aircraft/weapon system.

3. Ballistics Validation:

Undisturbed trajectories may be analyzed to determine both a ballistic drag coefficient compatible with a single point (particle) math model that best represents the ballistic performance of the store and an estimate of the ballistic dispersion in milliradians (mils) Circular Error Probable (CEP), in a plane normal to the trajectory. This CEP should be less than an allowable maximum compatible with the probability of kill envelope desired for the worst anticipated delivery system. In many instances, e.g., when evaluating compatibility of an existing store on a new aircraft, ballistics and CEP of the store independent of the aircraft will be known before the compatibility flight tests begin. If this is not the case, it will be necessary to conduct and analyze drops to establish aircraft independent ballistics before any ballistic conclusions can be drawn from the compatibility drops. If such drops are required, MIL-B-81006, Bombs, Freefall, Demonstration of Dispersion Requirements for, should be employed to minimize the number of drops required to demonstrate that dispersion requirements are met.

4. Ballistics Assessment:

Assessment of ballistic accuracy for the store/aircraft delivery system requires a much larger envelope of release conditions and configurations (normally using the operational employment tactics and delivery modes) than is required to establish aircraft-independent ballistics. Maximum ballistic CEP values for each weapon/aircraft combination should be assigned based on the probability of target kill envelope desired, overall system accuracy, and the ratio of ballistic error to overall delivery system error (it would be unrealistic to assign a low CEP for an inaccurate delivery system). Separation effects can sometimes double the CEP. Free flight drop tests will determine what limitations must be placed on aircraft release envelopes, store loading configurations and other parameters to meet CEP degradation criteria.

8.2.5 HUMAN FACTORS REVIEW

At all times during the analyses and review cycles, everyone in the certification process must assess the affect the aircraft/store combination has on the performance of the combat mission, including loading, checkout, preflight, cockpit selections, takeoff, ingress, target acquisition, engagement, escape maneuvers, egress, landing, Integrated Combat Turn (ICT) capability, downloading, etc. Everyone needs to ask, is there a better/quicker/cheaper/more logical way of doing tasks as necessary to deliver the store safely, and successfully, and with desired effect.

8.2.6 RESULTS OF ENGINEERING ANALYSES

Upon completion of the engineering analyses, if the desired degree of aircraft/store compatibility has been determined and acceptable flight operating limitations established, the combination may be certified with no additional effort. In the event compatibility cannot be determined by analysis of the data provided, the requesting activity shall be advised as to the additional data analysis or testing required for the determination, the estimated costs of the tests or analyses required, and the approximate time required for completion.

8.3 CERTIFICATION TESTING/GROUND TESTS

8.3.1 INTRODUCTION

Store certification tests are for the most part conducted for two reasons. The first is to validate the results of the analysis. If the validation can be made early in the test program by comparison of predictions to test results and the test results prove favorable, the test program can often be significantly shortened. The second reason for testing is to provide data where no quantitative prediction can be made. In either case, after the test, the data must be examined either qualitatively or quantitatively, to determine the acceptability of the degree of compatibility exhibited by the aircraft/store configuration being examined. Where there are deficiencies in the existing data, tests are planned to provide experimental data for use in the certification analysis. Ground and flight tests should be planned to provide quantitative data, or verify analyses through physical tests at points throughout the desired aircraft/store operational envelope. Test requirements must be explicit and must be prepared in accordance with physical limitations of the aircraft/store combination insofar as these limitations are known, and must reflect the mission requirements as specified by the using agency. The specific test requirements are dependent upon the required operational conditions and upon previous experience with both the store and the aircraft. Often during testing of aircraft/store configurations, the extreme test conditions must be approached incrementally, and the locus of the test results plotted concurrently. This is particularly critical in determining buffet boundaries and flutter limits.

Certification testing must include tests to evaluate the aircraft, stores suspension equipment and in some cases, ground handling equipment. These tests are intended to evaluate the total aircraft/stores/suspension equipment combination, not the individual components except as each component relates to the overall combination. Evaluation of the aircraft, except for its ability to carry and employ stores, is not part of this certification procedure. In general, certification testing can include any or all of the following:

1. Wind tunnel tests
2. Environmental tests
3. Static and fatigue tests
4. Ground vibration tests
5. Fit and function tests
6. Flight tests
7. Shipboard suitability tests

When determining the extent of testing necessary, the mission requirements for the aircraft/stores/suspension equipment involved shall be ascertained from the using agency. To ensure appropriate testing is provided for, operational objectives such as speed, altitude and acceleration for carriage, employment and jettison must be specified. Also, factors such as range, delivery modes, loading configurations, and mission profile must be identified.

Both ground test and flight test data are usually necessary for certification. Much of the ground testing must be completed before flight tests begin for reasons of safety and as a means to reduce flight tests costs. Modeling flight configurations in wind tunnel tests is particularly useful because simulating the flight environment under laboratory conditions in the wind tunnel avoids many risks inherent to flying near operational boundaries. Aerodynamic effects of stores on aircraft, captive environment for the stores, store separation characteristics, store aerodynamics, and flutter tendencies are factors which are generally investigated in a wind tunnel. These data will not completely eliminate the requirement for flight investigations of the aerodynamic parameters. However, the quantity of flight testing is greatly reduced by defining areas of the operational envelope critical to certification. Performance of the tests themselves is usually carried out in a specific sequence. Store fit tests should be performed prior to any flight testing. Captive flight testing, if approved, should be performed prior to any store employment or jettison testing. Single store separations in level flight should precede any tests in multiple or ripple modes or in dives angles. Sequential testing of this type is done to maximize the safety of the test aircraft and crew.

8.3.2 WIND TUNNEL TESTS

Many of the aerodynamic and aeroelastic questions relative to aircraft/stores compatibility can be investigated in the wind tunnel to reduce the risk and complexities of flight test. Scaled models of the aircraft and stores are supported on fixed mounting in a controlled airstream under laboratory conditions. Aerodynamic forces and moments are obtained without the inertia loads experienced in flight; data obtained from the wind tunnel provide information of aircraft and store aerodynamics, airloads, flow environment, and store separation trajectories. The configuration, instrumentation, speed and attitude options for testing in the wind tunnel permit an evaluation of the aerodynamic and aeroelastic influence of aircraft stores and suspension equipment on each other. It is very important for the engineers to ensure models are scaled properly, the Reynolds number is scaled, and shockwave reflections and interference is accounted for. However, test data for scaled models are not sufficient for certification purposes without proper interpretation and some flight test verification. Discussions of the wind tunnel tests needed for certification studies are separated in four categories:

1. Effects of Aircraft on Captive Store(s)
2. Effects of Captive Stores on Aircraft
3. Aeroelastic Effects
4. Separation Tests

8.3.2.1 WIND TUNNEL TESTS - AIRCRAFT EFFECTS ON CAPTIVE STORES/SUSPENSION EQUIPMENT

The purpose of this test is to define the aerodynamic influence of the parent aircraft on the store/suspension equipment. The data required are the aerodynamic forces and moments acting on the captive store suspension equipment as a function of Mach number, aircraft orientation, altitude and configuration characteristics, usually disregarding aeroelastic effects.

There are generally two predominant methods for measuring captive store loads in wind tunnels: internal balance method and dual-sting or captive trajectory system (CTS) method. The internal balance method, sometimes called "rigid loads" or "metric model" method, incorporates a strain gage balance mounted completely within the store or store plus pylon. This method provides very accurate configuration simulation for small scale models because no external supports are required for store mounting.

The dual-sting technique or CTS is another method to obtain captive loads. This technique uses completely separate stings or struts to support the aircraft and the store. This technique is used primarily to predict store separation trajectories but can also give representative captive loads. The forces and moments acting on the store in the presence of the aircraft are measured using a strain gage balance mounted within the store.

Large scale model simulation is desirable from the standpoint of model detail duplication and Reynolds number simulation. However, the larger the model--the higher the costs associated with fabrication and with tunnel operation. If the model scale is too small, the result may be reduced Reynolds number simulation (i.e., laminar/turbulent flow regions) and reduced geometric simulation accuracy. In addition, if testing in the transonic flow regime, extreme care should be used to ensure accuracy of test conditions (i.e., Mach number and angle of attack) as well as repeatability. Local shocks, flow separation, etc., are very sensitive to flow conditions. Flow visualization is always desirable to verify shock reflection cancellation.

A limitation of the internal balance method is the inability to accomplish "rapid" model changes. Since a rigid structural member must be provided for mounting the balance, changes of store location can take considerable tunnel time. Configuration changes during testing are expensive and inefficient. Many balances can be used at each store location on the parent aircraft especially for MER/TER configurations, but these small balance(s) are very expensive. This is usually a non-recurring cost. Regardless of these limitations, this method does provide the most representative technique to acquire captive loads.

The CTS technique limitations are primarily its inability to accurately simulate the captive store geometry. Due to the usually small size or scale of the store models to be tested, the external shape of the afterbody is sometimes modified to accommodate the sting support. Physical interference caused by the sting can also limit the configuration which may be tested. In addition, a gap (touchwire gap) is needed between the store and the aircraft to avoid extraneous balance output thus improperly positioning the store with respect to the aircraft. Although the displacements introduced by the technique are usually small, large errors in captive loads can result, particularly when using small scale models. This method does, however, provide a rapid means to obtain store loads more efficiently when testing many store attitudes or positions than the internal balance method.

8.3.2.2 WIND TUNNEL TESTS - CAPTIVE STORES/SUSPENSION EQUIPMENT EFFECTS ON AIRCRAFT

The purpose of this test is to evaluate the influence of stores/suspension equipment on the aerodynamic characteristics of the aircraft. The user's primary objectives usually involve determining the aircraft performance or stability and control effects due to the addition of store/suspension equipment. These effects can cause the aircraft performance and stability and control characteristics to change due to increases in aircraft total drag, coupled with shifts in aircraft center of gravity and neutral point. The purpose of a performance/stability and control wind tunnel test is to obtain aerodynamic coefficients necessary to estimate performance and stability and control characteristics of an aircraft with carriage of external stores.

To accomplish this, the aircraft aerodynamic forces and moments with and without stores should be measured. In certain instances, pressure distributions on the aircraft surface may be required.

When considering weapons bays, the aero-acoustic environment of both the store(s) and the cavity must be considered. Extremely high resonant peaks and high overall turbulence can cause structural fatigue and vibration as well as avionics malfunctions.

There are two general categories of tunnel installations. One method of installation is an internally mounted force and moment balance. The second category is a force and moment balance external to the parent aircraft model. The model may be required to be instrumented. The strain gauge balances, ranging from 1 to 6 components (normal, side and axial forces, and pitch, yaw and roll moments) such that the loads measuring capability is matched to the aircraft wind tunnel loads. With the majority of the modern tunnel facilities, the balance is interconnected with a computer for rapid data sampling, recording and reduction to aerodynamic forces and moments. The aero-acoustic environments are usually determined with the aid of high dynamic response pressure transducers.

To avoid or reduce the magnitude of the inherent errors in aircraft/store force testing, only incremental coefficients should be used in analyses when possible. Usually, an aircraft baseline configuration is chosen to provide reference aerodynamic coefficients. A typical baseline configuration is the aircraft configuration without the store in question. With this method, the aerodynamic coefficients of the full-up configuration are compared to those of the baseline configuration. This comparison provides incremental coefficients due only to the store in question. The degradations to aircraft performance/stability and control due to carriage of an external store can be calculated with the incremental coefficients. The process of using only incremental coefficients eliminates many of the inherent errors of wind tunnel force tests. When performing pressure tests, static and dynamic, the procedure differs somewhat from force testing in that incremental pressure effects are not measured from a baseline, but the absolute values are used and are frequently compared to the baseline, or stores-off configuration, pressure levels. Integrated pressure data can be compared to force data results.

8.3.2.3 WIND TUNNEL TEST - AEROELASTIC EFFECTS

Wind tunnel tests are performed on dynamically scaled models of the aircraft-with-stores to experimentally determine the airspeed, frequency, and model shape of potential aeroelastic instabilities caused by the addition of external stores. For this purpose, flexible lightweight models of the aircraft-with-stores are used in which the geometric shape, mass and stiffness distributions are closely represented in miniature. These models, with proper construction and instrumentation, simulate any aeroelastic instability, and are generally referred to as flutter models. These tests are performed either in lieu of or to verify analytical predictions of aeroelastic instabilities such as flutter. For verification tests, the models are usually tested at increasing tunnel speeds until an instability occurs or the tunnel limits are reached. Tests conducted in lieu of analyses are often performed only up to 1.15 limit speeds, unless an instability should first occur, in order to reduce the risk of model destruction. Extensive flutter model tests may be conducted in low-speed wind tunnels with reasonable economy and assurance of accurate results especially when compressibility and Mach number effects are known to be insignificant. These models are dynamically scaled so the lower dynamic pressures and airspeeds experienced in the low-speed tunnel represent proportionally much greater values for the aircraft. When compressibility effects may become important (usually above Mach numbers of about 0.75), limited verification tests may also be conducted in transonic facilities with flutter models matching aircraft Mach numbers in addition to being scaled for other dynamic and aeroelastic properties. However, transonic flutter model testing is an order of magnitude more difficult, time consuming, and more expensive than low-speed testing.

Special purpose flutter model tests may be appropriate especially when analytical approaches are lacking. One such type of test is to determine the effect of partially filled fuel tanks on flutter. Another type of test may very efficiently use a remotely controlled variable-inertia flutter model to conduct broad ranging parametric studies of the inertia effects on flutter. Wing-tip mounted stores pose special analytical problems which may be resolved by wind tunnel testing. Tests using half-span flutter models may sometimes be used to reduce costs and increase testing efficiency or to avoid the inevitable small structural asymmetries of full-span models. However, half-span models simulate only symmetric aeroelastic instabilities and thus possible antisymmetric or asymmetric instabilities must be investigated in other ways, such as full-span flutter models.

Test equipment and instrumentation are usually kept as simple and reliable as possible. Wing root and mid-span strain gages are installed relative to the elastic axes to separate wing torsional and vertical bending motions using 4-arm bridge circuits. Wing tip accelerometers may also be installed. The pylons may also be strain-gauged to detect pylon pitch and yaw motions. The outputs of these transducers are recorded on strip charts and sometimes magnetic tape along with instantaneous tunnel conditions. Selected strain gauge channels are also displayed on oscilloscopes as Lisajous figures to display the dynamic coupling of bending and torsion at the onset of an instability. Two or three motion picture cameras are installed to film the occurrence of any aeroelastic instabilities.

After model installation in the tunnel, a brief vibration test may be performed to insure proper installation and model condition and to check instrumentation operation. The various loading configurations are then tunnel tested in a predetermined sequence based on the technical logic involved and best efficiency in changing configurations. For each test, the tunnel speed is slowly increased while the model is periodically excited until an instability occurs or the test or tunnel limits are reached. Because blow-down tunnels have short test times, their tunnel airspeeds and dynamic pressures must be increased at relatively very rapid rates, which is a disadvantage. When an instability occurs, high-speed movie cameras are activated and the tunnel is slowed down as quickly as possible to prevent extensive model damage.

During the tests, continuously running oscillographs and oscilloscopes are monitored for signs of an impending instability. When the onset of an instability occurs, the instantaneous tunnel airspeed dynamic pressure and other tunnel conditions are recorded. Other dynamics information such as flutter frequencies are determined from the oscillograph records. More modern testing methods now being developed should be able to trace model response frequencies and damping in near real time during testing. Such procedures could significantly reduce testing time while improving model safety and test data comprehensiveness.

8.3.2.4 WIND TUNNEL SEPARATION TESTS

The purpose of store separation testing is to gather sufficient data to assure acceptable separation. This is accomplished through wind tunnel testing and analysis of the resulting data. Aerodynamic data is taken on the store while in the aircraft flow field or on the flow field generated by the aircraft. The analysis is used to establish limit bounds for flight tests, to detect problem areas, and find preproduction fixes.

There are essentially four major wind tunnel testing techniques used today to predict store separation trajectories. They are the Captive Trajectory System (CTS), grid, flow angularity, and freedrop. Each has its advantages and disadvantages which are detailed in MIL-STD-1763 and the best method or combination of methods depends upon the individual problem. The first three of these techniques can best be employed by using the automated CTS rig, but off-line methods can be used if necessary. The CTS is generally considered the most accurate of the prediction methods and is often used as a baseline for comparison of other techniques. Grid and flow angularity techniques make use of the automation of the CTS rig for data acquisition; however, different types of data are acquired and in both cases the store trajectories are run at a later time rather than on-line as part of the wind tunnel test. The following paragraphs will briefly describe the four methods mentioned above.

1. Captive Trajectory System (CTS):

There are five known active CTS facilities in the United States. Two of these are located at the Arnold Engineering Development Center (AEDC) and are used with the four-foot (1.2 m) transonic wind tunnel (4T) and the AEDC Von Karmen Facility (VKF) supersonic tunnels A, B, and C. The third active US government CTS system is located at the David Taylor Naval Ship Research and Development Center

(DTNSRDC). The installation is in the 7 x 10 foot (2.1 x 3.0 m) transonic wind tunnel. The other two active systems located in the US are used in the Vought Aeronautics Company four-foot (1.2 m) high speed wind tunnel and the Calspan Corporation eight-foot (2.4 m) transonic wind tunnel.

The Aircraft Research Association, Ltd., (A.R.A.), Bedford, England, and the Office National d'Etudes et de Recherches Aerospatiales (ONERA), Paris, France have both developed excellent facilities. The A.R.A. system, referred to as a two-sting rig, is installed in their 9 x 8 foot (2.7 x 2.4 m) transonic wind tunnel (Figure 1). The ONERA CTS rig is installed in the ONERA 1.76 x 1.75 m transonic/supersonic wind tunnel (S2).

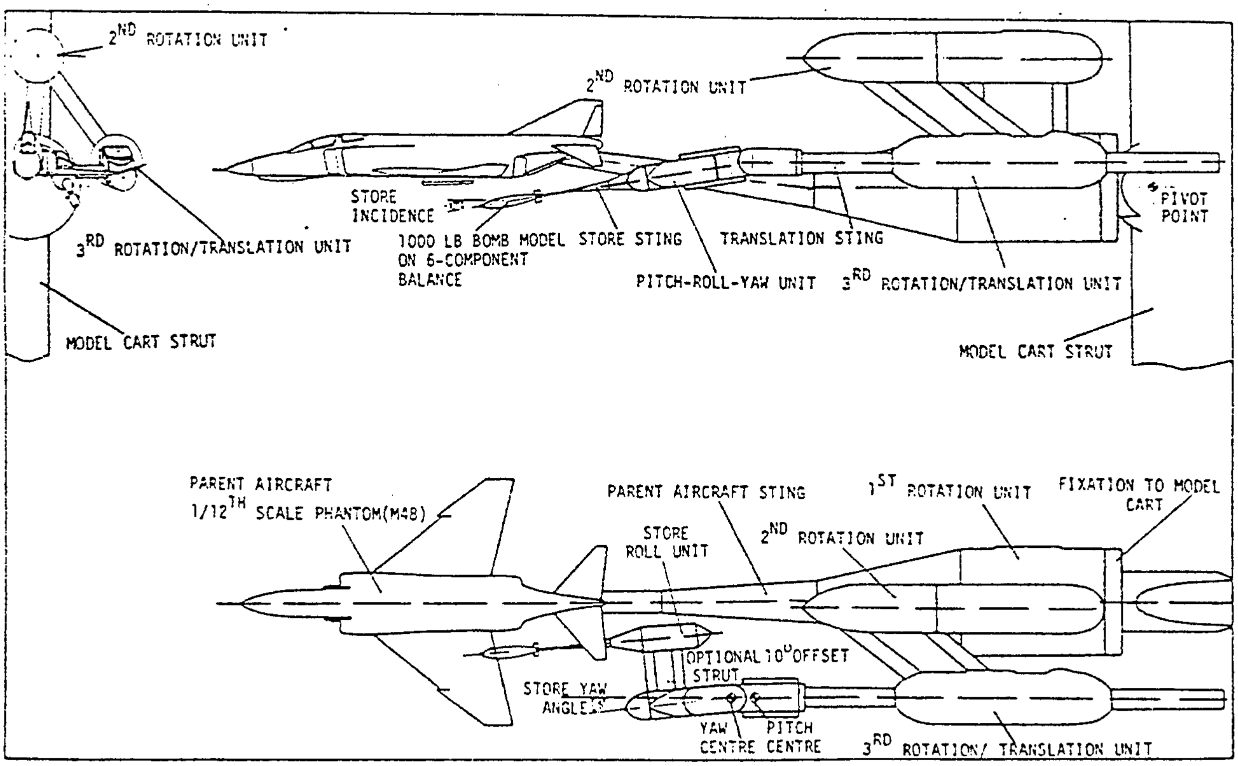


FIGURE 1. TWO-STING RIG - A.R.A.
9 X 8 ft. TRANSONIC WIND TUNNEL

The principle of the CTS is basically the same for all wind tunnels having this capability. The following describes the AEDC 4T system, which is typical.

The store model, containing an internal six-component strain gage balance, is mounted on a store model support system or CTS rig which is free to move in six-degrees-of-freedom. The aircraft model is supported at the desired attitude by the tunnels main support system. After the tunnel is stabilized at the desired flight conditions, the store is moved to the carriage position and the aerodynamic forces and moments are measured. A digital computer combines the measured aerodynamic data with the store mass, inertia, center of gravity, bomb rack ejection forces, etc., and solves the equations of motion to predict the next position of the store relative to the aircraft model at a small increment in time. Through a closed-loop system, the computer then commands the rig to translate and rotate the store CTS to achieve the computed position. The process is automatically repeated to obtain the stores trajectory. The time required to complete a trajectory encompassing one second of actual flight time is less than five minutes.

2. Grid:

In this technique the grid data is normally obtained in the wind tunnel using a CTS rig. Ideally, the CTS is programmed to automatically traverse the store model through a given volume in the vicinity of the carriage station of interest and the aerodynamic loads on the store are measured at discrete points. The store may also be pitched yawed and rolled at these discrete points. The data is then incorporated in a six-degree-of-freedom trajectory program, and the aerodynamic forces and moments for the Euler equations of motion are retrieved according to the store's position and attitude relative to the aircraft.

For a given configuration, the aerodynamic loads acting on the store in the vicinity of the aircraft are functions of Mach number and aircraft attitude as well as the store vertical, lateral, and longitudinal positions and pitch, yaw, and roll attitude. To acquire a comprehensive set of grid data accounting for all of these variables requires an extremely lengthy wind tunnel test program as well as a computer program requiring a large amount of storage and run time. Previous testing concluded the interference coefficients varied considerably more with vertical displacement than with lateral or longitudinal displacement, and rotations in pitch, yaw, and roll at various points in the grid have less significant effects on interference. This suggests investigation into the use of a "limited grid" where data is taken in only as a function of vertical displacement (and, of course, Mach number and aircraft attitude). The elimination of lateral and longitudinal data points at various store attitudes considerably reduces the required wind tunnel time and data handling requirements. Experience has proven this approach quite accurate for many store separation problems and data from one store may be applicable to analogous stores. A notable exception is the F-15E, which has many store carriage positions on the fuselage conformal tanks, and comprehensive grids are required for sufficient accuracy in trajectory prediction.

The USAF conducted a program to further investigate the validity of the "limited grid." Wind tunnel tests were conducted in the AEDC 4T with both F-111 and F-15 aircraft models. In addition to vertical displacement, the aerodynamic interference coefficients were obtained for six stores at various lateral and longitudinal displacements and store pitch, yaw, and roll attitudes. The aerodynamic interference coefficients were obtained by subtracting the free stream coefficients from the total coefficients measured in the aircraft interference flow field. For example, the interference pitching moment coefficient is obtained as follows:

$$C_{M_{INT}} = C_{M_{TOTAL}} - C_{M_{FREE\ STREAM}} \quad (8.1)$$

Examination of the data has shown that after vertical displacement, the interference coefficients are most sensitive to store pitch attitude and relatively insensitive to yaw and roll attitudes as well as lateral and longitudinal displacements.

3. Flow Angularity:

In this technique flow angularity data is collected in the wind tunnel using a velocity probe often attached to a CTS rig rather than a store model for direct measurement of the aerodynamic forces and moments. The CTS is programmed to automatically traverse the probe through a given volume, or plane, in the vicinity of the carriage station of interest and measure the change in local angle of attack and sideslip ($\Delta\alpha$, $\Delta\beta$) at selected points. Once the flow angularity data is obtained it can be used to calculate the interference aerodynamics using free stream body buildup data for the weapon. Using the pitching moment as an example:

$$C_{m_\alpha} = C_{m_{\alpha B}} + C_{m_{\alpha F}} \quad (8.2)$$

Where $C_{m_{\alpha B}}$ and $C_{m_{\alpha F}}$ are the free stream pitching moment coefficient slopes of the body and fin respectively.

The interference pitching moment coefficient is calculated by:

$$C_{M_{INT}} = C_{m_{\alpha B}} \Delta\alpha_B + C_{m_{\alpha F}} \Delta\alpha_F \quad (8.3)$$

Where $\Delta\alpha_B$ and $\Delta\alpha_F$ are $\Delta\alpha$ values at the center-of-pressure of the body and fins of the store. The other coefficients are calculated in the same manner.

The flow angularity data is used in a six-degree-of-freedom digital computer program for trajectory calculations. New interference coefficients are calculated due to changes in $\Delta\alpha$ and $\Delta\beta$ as the store translates and rotates within the volume containing the interference data. They are combined with the free stream coefficients to obtain the total aerodynamic forces and moments acting on the store at each point in the trajectory.

$$C_{M_{TOTAL}} = C_{M_{INT}} + C_{M_{FREE\ STREAM}} \tag{8.4}$$

The aerodynamic forces are then combined with the physical forces such as store mass, ejection force, etc., and the Euler equations of motion are integrated with respect to time to obtain a point by point trajectory.

There are basically two approaches to the flow angularity technique. In the first approach, the flow angularities are obtained with the store whose trajectory is to be calculated installed in the carriage position.

In the second approach, the flow angularities are obtained without the store whose trajectory is to be calculated. The initial store loads are calculated using the flow angularities measured along a line where the centerline of the store would be located if it were installed.

Neither approach can measure the exact interference flow field, however, the first order effects of the flow field are collected and both techniques are useful tools in weapon design studies. In spite of the lack of technical rigor, correlation with other techniques such as CTS and full scale flight testing has generally been good in both cases. Figure 2 shows the comparison between the first approach and CTS. The trajectories are for a M-117 bomb which is a high density, aerodynamically stable store. The simulated release was from a bottom station of the inboard wing station of the F-4 TER. Figure 3 shows the comparison between the second approach, CTS, and full scale flight tests.

A joint Air Force Armament Laboratories/Engineering Development Center research program has been established to investigate the feasibility of using a laser Doppler velocimeter to measure the transonic flow field about an aircraft wing and multiple stores. The main advantages of this potential technique are the large increase in the rate of data acquisition and the space where data may be acquired is not restricted due to physical interference of the probe and sting support with the aircraft and store models. Also, there is no question as to the effects of probe interference. An excellent set of data was obtained for the longitudinal and vertical components of flow velocity.

It was planned that a pylon would be constructed of a non-reflective clear plastic which will permit measurements of both sides of the pylon.

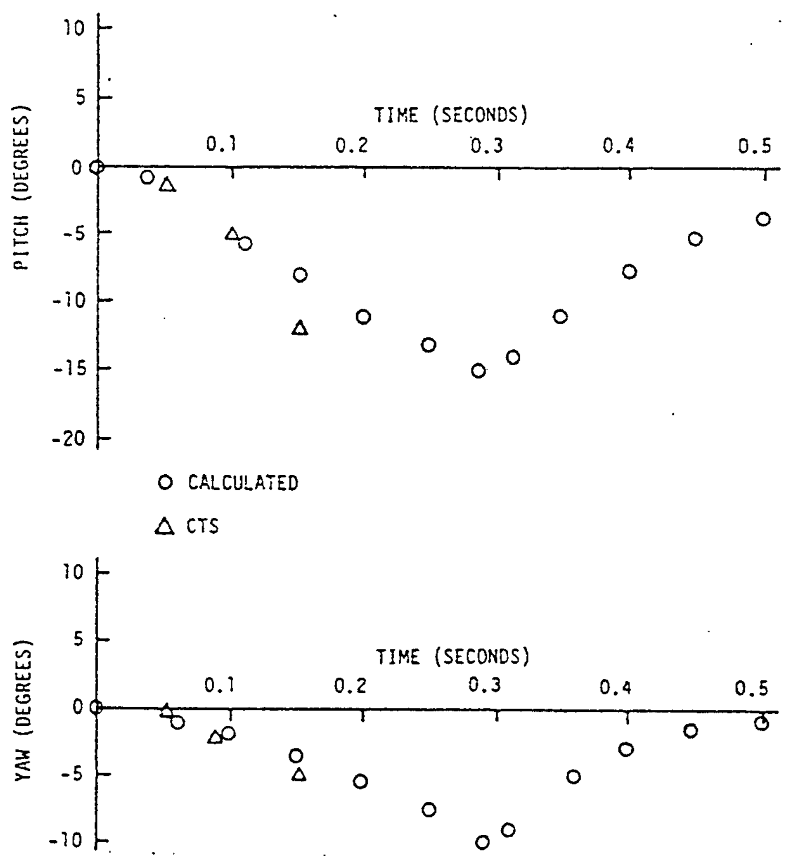


FIGURE 2. PITCH AND YAW TIME HISTORIES OF A SUU-51/B DISPENSER EJECTED FROM THE BOTTOM TER STATION (ALTITUDE 5,000 FEET AND MACH 0.82)

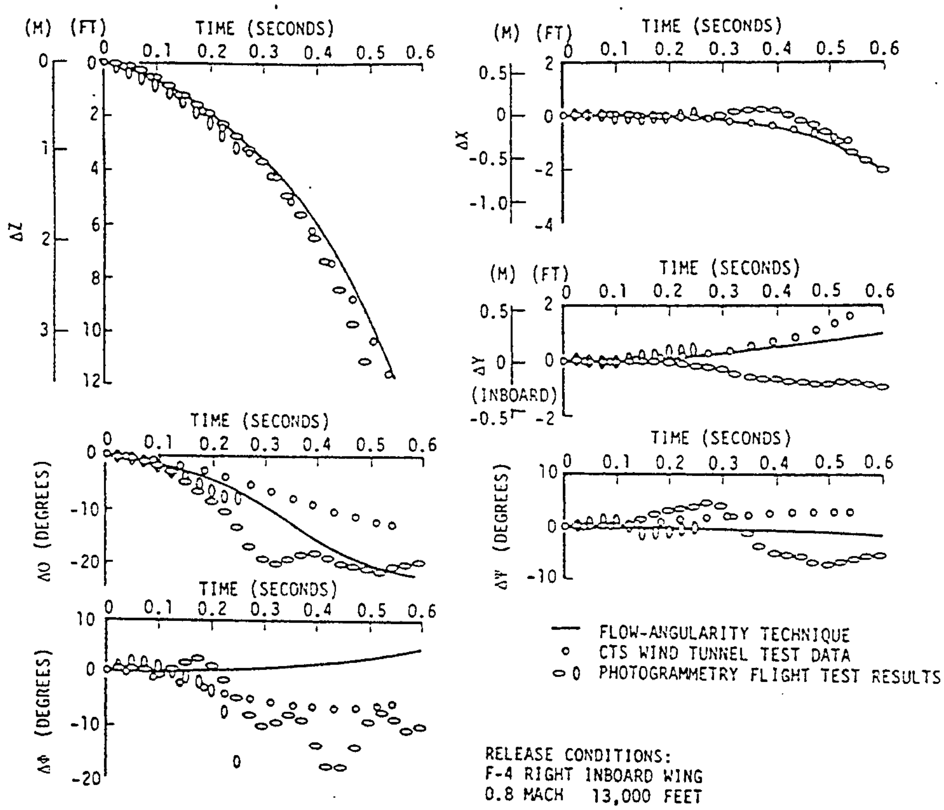


FIGURE 3. CORRELATION OF FLOW ANGULARITY, CTS, AND FLIGHT TEST

4. Freedrop:

Freedrop studies are made by releasing or ejecting dynamically scaled store models from a parent aircraft installed in the wind tunnel. The separation characteristics are determined from either high speed motion pictures or multiple exposure (strobe) still photographs taken from two or three (ideally orthogonal) locations. The bomb rack ejection forces are generally simulated by small pistons driven by coil or leaf springs, pneumatic pistons, or small solid propellant charges (e.g., in the UK).

The static aerodynamic forces and moments will be properly scaled if the flow field and model geometry are similar to full scale. The accelerations of the scaled store will be similar if the forces and moments, mass, center of gravity, and moment of inertia are scaled.

Three scaling laws termed "heavy," "light," and "Froude" are commonly in use. Again, the best technique depends upon the problem, personal preference, and wind tunnel facilities available. The object is to preserve the proper ratios of mass, length and time in order that the store model will transcribe the same linear and angular path with respect to the store aircraft model as the full scale store would with the aircraft.

a. Heavy Scaling: In this method the free stream Mach number is duplicated and the proper aircraft flow field is preserved. It also preserves the ratio of the static aerodynamic forces to gravity forces (store weight) at the time of release. The dynamic derivatives (C_{m_q}, C_{m_α}) are not properly scaled, and the angular motions are undamped; however, these are often less important than the gravitational forces. The requirement to maintain the proper ratio of static aerodynamic forces to gravity often makes it difficult or impossible to obtain sufficiently dense materials. In this case "mass deficient" models are used, and the bomb rack ejection force is increased to assist the model in passing through the correct flow field as it separates the aircraft.

b. Light Scaling: In this method, the free stream Mach number is also duplicated; the aerodynamic forces are properly scaled; but the proper ratio of station aerodynamic forces to gravity forces is not preserved. The gravitational force is deficient by the ratio of the model to aircraft characteristic length. Angular motion is properly simulated; however, linear accelerations are incorrect; and the store model does not properly traverse the aircraft flow field. Unfortunately, there are no practical means available to scale the gravitational force; therefore, erroneous store separation characteristics can result from the technique.

c. Froude Scaling: In this method the Froude number is duplicated, and all dynamic similarities are preserved. The free stream Mach number, however, cannot be duplicated and the technique is generally limited to the incompressible case.

d. Model Similitude: The majority of USAF store separation testing has been conducted in the AEDC 4T wind tunnel which is relatively inexpensive when compared to some of the larger wind tunnels. However, the four-foot (1.2 m) square test section of 4T has dictated the use of aircraft models which are usually no larger than 1/20 scale. This small scale has made it difficult to adequately model the details of the full scale bomb rack and pylon hardware to include sway braces, sway brace bolts, vents and gaps within multiple racks, etc. As a result, the majority of 1/20 scale suspension hardware has been modeled without these details, and it was assumed their effects were insignificant.

However, when information from the UK indicated rack and pylon details may be important, a comprehensive wind tunnel test program was conducted in 4T to systematically evaluate the effects of rack details on carriage position store airloads. Wind tunnel tests were conducted with a 1/20 scale F-4 model, with three MK-83 bombs installed on both TERs. Significant differences were noted in the detailed and plain TERs and the detailed TER shows much better agreement with full scale flight tests. At least for the configuration and flight conditions investigated it was shown that attention to model detail is more important than scale effects, and accurate store airloads may be obtained with small scale models. This important conclusion supports the use of small scale models in the smaller, less expensive wind tunnels which potentially will save millions of dollars of wind tunnel test resources.

8.3.3 ENVIRONMENTAL TESTS

8.3.3.1 GROUND VIBRATION TEST

The primary purpose of the Ground Vibrational Test is to experimentally determine the frequency, damping, and mode shape of the important modes of the aircraft store/suspension equipment combination. These data are to be used to help substantiate/derive theoretical flutter calculations and analyses. In the current update to MIL-STD-1763, a new store ground vibration test will be incorporated to subject the store (and pylon/launcher) to MIL-STD-810 requirements for store/pylon/launcher structural integrity.

8.3.3.2 HERO TESTS

Hazards of Electromagnetic Radiation to Ordnance (HERO) tests are designed to measure the level of electromagnetic (EM) energy which can be induced into ordnance circuits and dissipated in the most susceptible explosive components of the store, usually the electroexplosive devices (EEDs). The tests are structured to reproduce the electromagnetic environment normally encountered during the sequence from loading to delivery. The US Navy requires testing in the environment from shipping configuration through delivery, where other services might choose only the flight environment. The test data is analyzed in context with the evaluation criteria to yield a meaningful assessment of the potential effects of the EM energy. These effects are treated as two categories: (1) hazards in which spurious initiation of an EED might result in injury to personnel or damage to material; and (2) reliability degradation in which spurious initiation of an EED might result in dudding or degradation of ordnance. These tests are usually performed by the store SPO and are made available to the aircraft test agency.

8.3.3.3 ELECTROMAGNETIC COMPATIBILITY (EMC) TESTS

EMC certification tests and analyses are performed to determine the extent of unintentional interaction, if any, between aircraft avionics systems and store electronic systems, as well as the effect of each store on all other stores in the proposed configuration. The effect of all unintentional interactions on flight safety and mission success must be determined and documented.

8.3.3.4 AEROACOUSTIC TESTS

Acoustic ground tests are performed to determine the ability of the store configuration(s) and related suspension equipment to withstand or, if applicable, to operate in the acoustic environments generated.

1. Acoustic tests simulate the aeroacoustically excited vibration environment and supply functional information on system equipment and structural integrity. These tests may also verify adequacy of component vibration test levels if necessary. Acoustic tests are performed in test chambers capable of generating desired sound pressure levels and spectra, wind tunnels and free jet flow facilities.

2. The acoustic chamber test for assembled stores/suspension equipment is performed to determine if a complete store/suspension system will successfully withstand its expected aeroacoustic environment and will not malfunction in flight. This test compliments conventional sinusoidal and random vibration tests which simulate structural airborne vibrations. For stores/suspension equipment, carried both internally and externally, the test chamber noise levels should be taken to the maximum levels the stores will operationally experience or can withstand.

8.3.3.5 TEMPERATURE EXTREMES AND THERMAL TESTS

These thermal tests are for the purpose of determining the compatibility of the test article in the thermal environment of captive carriage. Thermal-structural testing is covered in MIL-STD-1763.

Aerodynamic heating, ambient temperature variations and other thermal sources can alter or modify the functioning characteristics or cause carriage limitations on the store/suspension equipment being investigated. Thermal test conditions as determined in the analysis requirements may be used, if captive carriage conditions are not available.

8.3.3.6 GUN GROUND FIRING TESTS

The integration and qualification of a gun or gun system with an air vehicle for operational use must be accomplished without unnecessary risks to life and material. As such, ground gun firing tests are conducted to determine, verify, evaluate and certify the safety, compatibility and performance requirements of the gun system with the air vehicle prior to flight tests.

The gunfire induced environments and their effects that must be considered during the ground tests are:

1. Muzzle blast and overpressures.

2. Effectiveness of muzzle and blast deflectors.

3. Recoil and counter recoil loads.

4. Vibration and acoustic frequencies and amplitudes.

5. Effectiveness of the ventilation/purge system to prevent accumulation and pocketing of explosive gun gas mixtures.

6. Gun gas impingement and residue buildup on the air vehicle surfaces.

7. Proper operation of the gun system in various attitudes simulating actual flight conditions.

8. Evaluation of the accuracy of the gun.

9. Evaluation of the performance parameters of the total gun system and its associated components, i.e., gun, drive, ammunition feed and storage system, spent case/unfired round storage or ejection system.

10. Evaluation of other aircraft systems exposed or affected by the gun fire environment.

8.3.3.7 ROCKET/MISSILE FIRING TESTS

Aircraft rockets/missiles and associated launching equipment are ground tested and evaluated to verify safe operating characteristics, establish compatibility, and to establish baseline data prior to flight tests. In addition, ground tests:

1. Provide data on the operation of the rocket/missile launchers and associated intervalometers.

2. Determine rocket/missile plume blast and temperature characteristics.

3. Determine structural effects upon launching aircraft.

4. Determine effects of a rocket/missile/launching equipment malfunction on the launching aircraft. For this test, malfunctions are limited to those which are considered probable during the operational life of the item or those having historically been problems with the particular item being tested.

8.3.3.8 FIT AND FUNCTION TESTS

Fit and function testing is an item of major importance in aircraft/store compatibility testing and is a prerequisite to, as well as an integral part of, captive carriage and separation tests. In addition to normal safety-of-flight objectives, generation and verification of assembly, loading, rigging, and checkout procedures are major objectives of fit and function tests. Documentation of configurations and procedures should be maintained for use during tests and to serve as a baseline for smooth transition to operational usage. These tests should be performed IAW MIL-STD-1289, Procedure for Ground Fit and Compatibility of Airborne Stores. It is extremely important the fit and function tests be conducted with test items (aircraft, pylons, racks, launchers, and the particular store(s)) which accurately represent the items requiring certification.

Fit tests are the loading on the aircraft of the stores in the configurations which are to be certified. These tests investigate the compatibility of the physical, mechanical and electrical interface between the store and its surroundings to permit satisfactory loading, servicing, carriage and deployment. It ascertains whether proper store alignment with respect to the aircraft can be accomplished. It also shows whether the required electromechanical connections (lanyards, arming wires, umbilical wires, hoses) can be made and electrical components can be adequately powered and operated correctly. It verifies the store can be loaded onto the aircraft using the loading procedures specified as a portion of the test.

Clearances between the store and its surroundings must be verified as sufficient to allow all aspects of the loading procedure to be accomplished, to permit aircraft and munition servicing, and to allow for deployment. Measurements of store-to-store, store-to-aircraft, and store-to-ground clearances are required for all operational settings of movable aircraft parts and for the most severe aircraft attitude in accordance with MIL-STD-1289. Verification of the efficiency and correctness of the loading procedures is required. Any deviation or modification of the test articles or equipment from the standard or norm must be reported.

Representative production aircraft, stores, suspension equipment, and loading equipment must be utilized. Modification peculiarities of any of these items would require verifying the modification does not limit the applicability of the test results. Only equipment which is available to aircraft and armament personnel or which is being introduced as part of the support equipment for the aircraft/store combination being certified should be used. Devices with sufficient accuracy to perform the measurements required by MIL-STD-1289 must be provided. Any special tools or handling equipment should be identified in the final report. The loading checklist shall be prepared in advance of the test. Any deviations to MIL-STD-1289 are to be waived only by the certifying agency or in the case of flight testing, by the agency having the flight clearance responsibility. In any case, all test requests, modifications, and exceptions are to be documented in a test report. The aircraft, pylon, launcher, and store wiring diagrams applicable to the test should be included in the final report to assist in post-test reviews.

The test shall be judged successful if the store is able to be safely loaded, serviced, carried, deployed, and unloaded without interfering with the operation of the aircraft or other stores being carried, and if the test fulfills the requirements of MIL-STD-1289.

8.3.3.9 STATIC EJECTION TESTS

The purpose of static ejection tests is to determine reactive force loads, store velocities, separation characteristics of the store configurations to be released from the racks, and to ensure correct operation of the store arming control system. Such characteristics will include the acceleration, velocity, and attitude (pitch, yaw, and roll) of the store as it leaves the influence of the ejector rack (end of piston stroke) and the dynamics imparted to the store by the ejector(s). A minimum distance of 3 feet from the end of piston travel or the distance required to operate the store arming lanyard system should be used for determining these characteristics. The orifice(s) settings, the location of the respective ejector(s), or other means of controlling these ejection characteristics may be adjusted to obtain acceptable and the most favorable ejection characteristics. Such tests should be performed on the aircraft to approximate aircraft elasticity, or on a test rig, if the aircraft is unavailable or if static ejection could produce unacceptable damage to the aircraft. Aerodynamic forces and moments may be simulated by the use of externally applied loads.

8.3.3.10 AIRCRAFT/STORE/SUSPENSION EQUIPMENT STRUCTURAL INTEGRITY GROUND TESTS

The purpose of the structural integrity ground testing is to verify store/suspension equipment structural integrity and compatibility by testing the aircraft/store/suspension equipment combination to the most critical flight conditions. The applicable design conditions called out in the vehicle/aircraft specification requirements and in MIL-A-8591, Airborne Stores, Suspension Equipment, and Aircraft/Store Interface (Carriage phase): General Design for, shall be met. Sufficient strength shall be provided to meet the applicable yield and ultimate design conditions.

8.4 FLIGHT TESTS

8.4.1 INTRODUCTION

The final and most important step in the store certification process is flight test. The purpose of flight test is to verify the results of the analytical studies and ground tests and to demonstrate the safe and acceptable carriage and employment of critical aircraft store configurations/conditions. Quantitative captive carriage flight tests are broken down into the same areas as the ground tests: (1) inflight loads and structural integrity; (2) flutter; (3) environmental; (4) flying qualities; and (5) performance and drag. A qualitative captive compatibility carriage test is also flown. Separation tests are broken down into the following areas: (1) employment (including release, launch, dispense, and gun fire tests); (2) jettison and (3) ballistics. Another important part of the certification process is weapon system accuracy. Flight tests are conducted to determine the effectiveness of an aircraft/store combination against a specific target when the store is employed under prescribed conditions. Weapon system accuracy testing will be addressed in Section V.

8.4.2 CAPTIVE CARRIAGE FLIGHT TESTS

8.4.2.1 LOADS AND STRUCTURAL INTEGRITY FLIGHT TESTS

These tests are conducted to obtain inflight qualitative or quantitative data for use in verifying the structural integrity of the store and aircraft/stores combinations. The structural integrity of the aircraft/stores combination can be qualitatively demonstrated for critical loading conditions by performing flights to such conditions without damage to, or failure of the aircraft, store, or suspension equipment. During quantitative flight tests a flight load survey is made to measure inflight loads to substantiate the structural design loads and analyses. Also, dynamic response tests are conducted to measure the elastic response characteristics of the aircraft structure to dynamic loads for substantiating the dynamic loads analysis. Loads flight test should be flown in aircraft instrumented with strain guages and telemetry. Fly-by-wire aircraft such as the F-16 may be equipped with cockpit selectable G limiters to simplify the flight test manuevers. Loads should be measured to positive, negative and unsymmetric manuever limits. The testing shall be performed in the following three phases:

1. Ground operating loads tests:

These tests shall include all ground operating conditions required for the particular type of store or aircraft/store combination which are indicated to be critical or near critical by analytical calculations. These tests shall be performed after successful completion of the ultimate static tests for all ground loading conditions.

2. Initial phase flight tests to 80% limitations:

Eighty percent of the design limit load on any primary structural component of the store or aircraft/store shall not be exceeded during this phase of the test program.

3. Final phase flight tests to 100% limitation:

The final phase flight tests shall be performed after completion of the initial phase flight tests and the ultimate load static tests and with specific approval of the certificating authority. Buildup maneuvers shall be flown as necessary to insure the 100% design limit load is not exceeded.

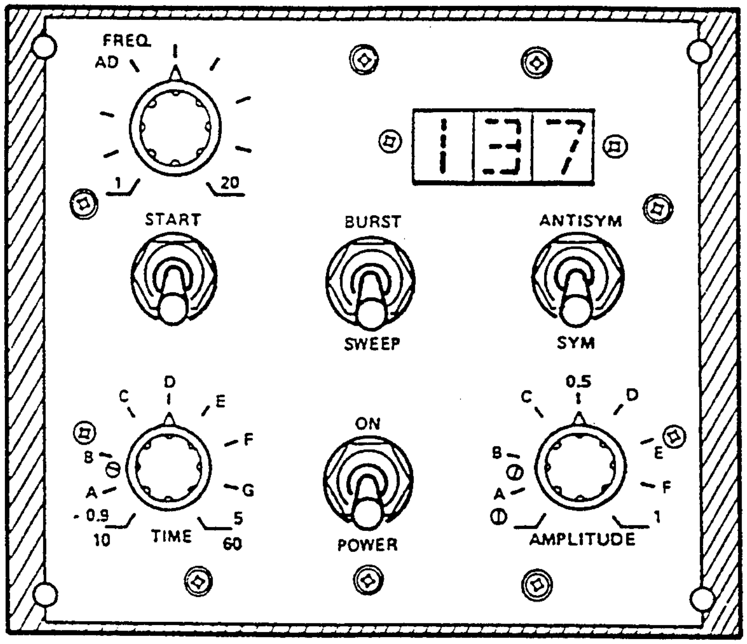
8.4.2.2 FLUTTER FLIGHT TEST

The purpose of flutter flight test is to substantiate that the aircraft with stores is free of any aeroelastic instability and has satisfactory damping characteristics within the prescribed flight envelope. A given take-off configuration may be considered certifiable for operational use, from a flutter standpoint, when the most critical condition of stores down-loading, hung stores, and aircraft conditions has been flight demonstrated to be free of any aeroelastic instability throughout its appropriate operational flight envelope. No less than three percent structural response total damping (including aeroelastic as well as structural damping) and no predicted occurrence of an aeroelastic instability up to 1.15 limit speeds is permissible. Extrapolation to 1.15 limit speed from flight test data will be required. For aircraft with augmented flight controls, the test configuration must be flutter flight tested both with the augmentation system on and off (the latter at test speeds for which the aircraft can be safely flown). Before any stores configuration can be flutter flight tested on a given aircraft, the configuration must be shown by validated analysis and/or wind tunnel tests to be the most critical combination and have at least a 15% flutter safety margin on the limit speeds. The flutter flight tests must be performed on a similar but dynamically instrumented test aircraft and the tests must be performed in a careful, methodical manner to detect the earliest indications of any possible aeroelastic instability. In spite of these precautions and technical advances in testing and analysis, flutter flight testing remains among the most dangerous kinds of flight testing and requires the utmost vigilance and expertise to avoid encountering an actual aeroelastic instability in flight.

Test data comes from accelerometers or strain gauges. The test data required are the structural response frequencies, amplitudes, and damping of the wings, pylons, and stores along with changes in these values with increasing dynamic pressure and Mach number. Sometimes data is also required from the tail, fuselage, or other aircraft or store appendage so gradual or sudden decreases in damping, usually with increases in amplitudes and the coalescing of two or more response frequencies, generally indicate approaching flutter.

The aircraft used for the flutter flight tests must be similar to those in operational use and be equipped with all standard items having appreciable mass and aerodynamic loading. The fuel loading should be such that the most flutter critical loading is attained through usage or transfer at about the time the maximum speed at the lowest altitude is reached. Stores such as bombs, rockets, missiles etc., should have their warheads replaced by inert ballast for safety. Since many stores have appreciable manufactured mass variations, all flight test stores should be carefully mass ballasted to their design or worst case values in weight, center-of-gravity location, and pitch, roll and yaw inertias.

The test aircraft should be equipped with a structural excitation system which can adequately excite the modes of interest, unless analyses can show stick raps of the flight controls can provide adequate excitation. Stick raps can usually excite structural modes only up to about 8-12 Hz for most fighter aircraft. This may be adequate only if the lower frequency wing and store modes are involved in the predicted instabilities. However, this doesn't provide enough energy into most systems to excite all the modes required for a valid evaluation (this was shown during F-111 flutter flight testing). Various excitation systems have been used with success such as flight control computer inputs (F-16), oscillating tip vanes, rotating or oscillating masses, aerodynamic excitation systems on stores, and small wing-tip pyrotechnic charges. Reliance upon atmospheric turbulence for excitation and rotating and oscillating masses in the upper frequencies have generally been less successful. The cockpit panel used to control F-16 flight control computer flutter excitation is presented in Figure 4. The panel has controls for frequency, amplitude, time duration, and phasing (symmetric or unsymmetric) of flaperon excitation.



Control Settings		
Time (sec)		Amplitude (deg)
Burst 0.9 to 5.0	Sweep 10 to 60	
		Pos 0 = 0.050
Pos A = 1.40	Pos A = 16.0	Pos A = 0.125
Pos B = 1.90	Pos B = 22.5	Pos B = 0.250
Pos C = 2.45	Pos C = 28.5	Pos C = 0.375
Pos D = 2.95	Pos D = 35.0	Pos 0.5 = 0.500
Pos E = 3.45	Pos E = 41.0	Pos D = 0.625
Pos F = 3.95	Pos F = 47.5	Pos E = 0.750
Pos G = 4.50	Pos G = 54.5	Pos F = 0.875
		Pos 1 = 1.000

FIGURE 4. F-16 FLUTTER EXCITATION CONTROL PANEL AND AVAILABLE SETTINGS

Dynamics instrumentation may include four-arm bridge strain gage circuits at the wing roots, mid-span, and on the pylons on both sides of the aircraft. These gages are oriented to the local elastic axes in order to separate bending and torsional structural motion and symmetric and antisymmetrical modes. However, a more common flutter instrumentation is store and wing tip accelerometers, as well as control surface position indicators. Either an FM-FM (frequency modulated) or PCM (pulse code modulated) telemetry system is needed to transmit the test data signals to the ground for analysis during flight. Sample rates for PCM systems should be at least five times the highest structural resonance frequency of interest. An onboard magnetic tape recorder is also highly desirable for post flight analysis and as a backup system. Older ground stations are equipped with oscillograph recorders and oscilloscopes for observing the test data. Modern test methods require a frequency analyzer for near-real-time analysis of the test data using Fast-Fourier and Laplace transform algorithm methods. It is essential a direct radio voice link be established between the test pilot(s) and the dynamics test engineer(s) conducting the test.

Flutter flight tests of external store configurations may initially be conducted simultaneously with other structural integrity flight tests in a gradual expansion of the cleared flight envelope. However, the other structural flight tests are usually only concerned with a few specific loading configurations and thereafter, flight tests may be more dedicated to flutter and possibly to stores separation.

Flutter flight tests are flown with test data taken at predetermined test points in a prescribed order of ascending criticality, generally beginning at low dynamic pressure and increasing to high dynamic pressure. A sample of plotted test data for one aircraft store combination is presented in Figure 5. At each test point, defined by Mach number and altitude, the aircraft-with-stores is structurally excited and data, recording and excitation and structural response, is telemetered to the ground station for immediate analysis. The test pilot must not be allowed to proceed to the next test point until granted clearance by the dynamics test engineers from the ground station. The test points are chosen at increasing Mach numbers up to limit speed, usually in 0.05 Mach number increments or less, at constant altitude. Initially, two or three altitudes tested in descending order may be chosen, but with experience, only the most critical altitude (usually the lowest possible altitude still permitting safe flight) may need to be flown. For aircraft with augmented flight controls, test data is taken at each test point with the system on and off for speeds at which the unaugmented aircraft can be safely flown. The most critical test points, usually at the highest attainable Mach number at the lowest permissible altitude, are flown last. These test points can usually be reached only by diving the aircraft from a higher altitude at full throttle and then pulling out of the dive at the prescribed test altitude. These test points are especially dangerous because they have the highest possibility of flutter occurrence while the aircraft has the least favorable attitude for a quick recovery. Often times flutter characteristics improve when the aircraft goes supersonic, and some flutter engineers might argue the transonic Mach region is the most critical (up 0.90 Mach).

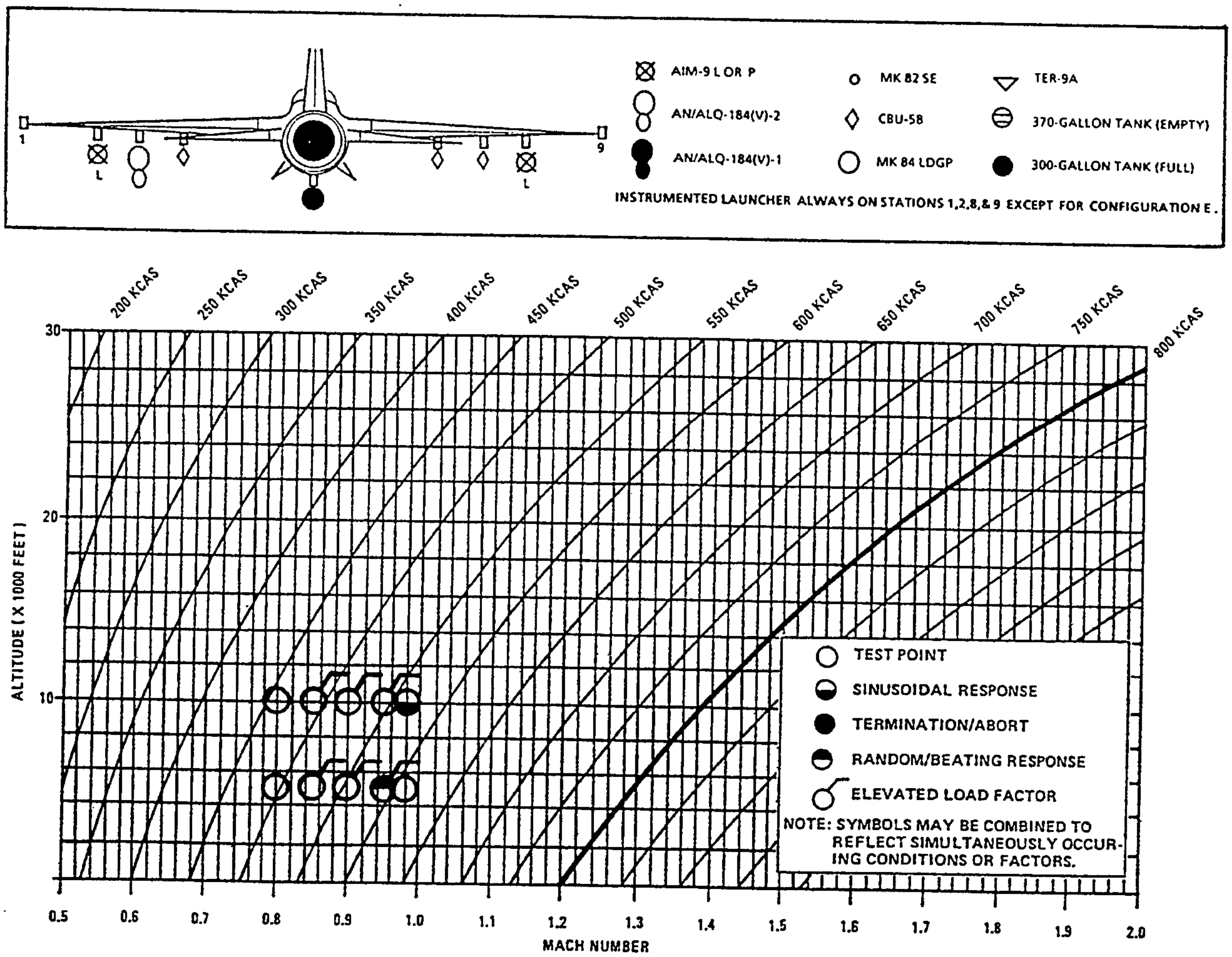


FIGURE 5. SAMPLE PLOTTED FLUTTER TEST DATA FOR ONE AIRCRAFT/STORE COMBINATION

Should the onset of flutter occur, the pilot may have no more than two or three seconds (sometimes even less) to make recovery actions before major structural damage or aircraft destruction occurs. Therefore, the most effective emergency procedures for recovery from flutter must be carefully planned in advance and the test pilot briefed before each test flight. Flutter may sometimes be stopped by immediately reducing airspeed to at least that of the last test point. This may be done by simultaneously deploying the speed brakes (if so equipped) and pulling up into a steep climb. However, a pull-up that is too suddenly applied may impose excessively large "G" loads on the wing and pylons on top of the very high dynamic loads caused by the wildly oscillating stores and wings. Reducing engine throttle is usually ineffective because the engine response is too slow. Jettison of some of the external stores may be used to arrive at a stable condition. This must be carefully planned in advance since separation characteristics of oscillating stores, especially at high speeds can also be unpredictable and hazardous. Therefore, the pilot must be intimately familiar with all possible emergency procedures.

Immediate but qualitative assessments of the test aircraft's aeroelastic stability can be interpreted from the oscillograph's continuous recordings of the dynamics instrumentation outputs. Lissajous figures on the oscilloscope, portraying bending-torsion strain gage outputs, can instantly show modal coupling tendencies. New methods using digital computers and time-series analysis methods including Fast-Fourier and Laplace transform algorithms, can extract response frequencies and associated damping from accelerometer outputs within a minute after the structure has been excited. Other data reduction methods are also being developed such as Randomoec and Zimmerman's technique, which may also give quick analysis results with an acceptable degree of reliability, provided the test aircraft can be adequately excited. Additionally, a post flight analysis of the tape-recorded flight test data may be performed at a more leisurely pace with higher degree of accuracy, if required. Correlation of the flight test data with available flutter analyses and wind tunnel flutter model tests is very important. In particular, frequency and damping trends determined from the flight test data should agree favorably with the preflight evaluations in order to properly identify the most critical store combinations. If flutter was actually encountered in flight, the resulting flight test data could be exceptionally valuable in making direct flutter speed and flutter frequency comparisons with analytical and wind tunnel test results. However, because the risks are so great, no one should ever intentionally seek actual flutter or other instabilities during flutter flight tests.

8.4.2.3 ENVIRONMENTAL FLIGHT TESTS

The purpose of the environmental flight tests is to determine if the aircraft/store and suspension equipment can withstand the actual flight environment, to validate the design specification levels and to substantiate the predicted/test levels.

1. Vibration Tests:

Captive flight vibration measurements on a store are made as a part of the store certification process for a number of reasons. These reasons include:

a. To determine if the store has been designed and tested to vibration conditions typical of service;

b. To establish test levels for equipment to be mounted within the store;

c. To establish test levels for the store itself; and

d. To investigate the effects of changes in the carrying aircraft (or the tactics of the carrying aircraft) on the reliability of the store.

Since these purposes all relate to test or design specifications, the aim of a vibration measurement program should be to generate data for the broadest possible use.

The vibration measurement program shall explore the limits of the dynamic pressure/Mach number envelope for the aircraft/store combination and maneuver conditions. Sources of vibration for externally carried stores on jet aircraft include aerodynamic boundary layer turbulence, buffet, maneuvers, and aircraft induced vibration (i.e. engine). As an illustration of one vibration flight test technique, the envelope for an F-4 aircraft is presented in Figure 6, along with a description of the flight profile necessary to explore the boundaries of the envelope. Maneuver conditions characteristic of the aircraft's tactical mission with the store onboard shall be flown (windup turns, high buffet turns, etc.). If the aircraft has speed brakes or guns, these conditions shall be involved in the vibration measurement program. The effects of dynamic pressure and Mach number on these tactical conditions shall be explored (e.g., gunfire at both high and low dynamic pressures).

2. <u>Thermal Tests</u>:

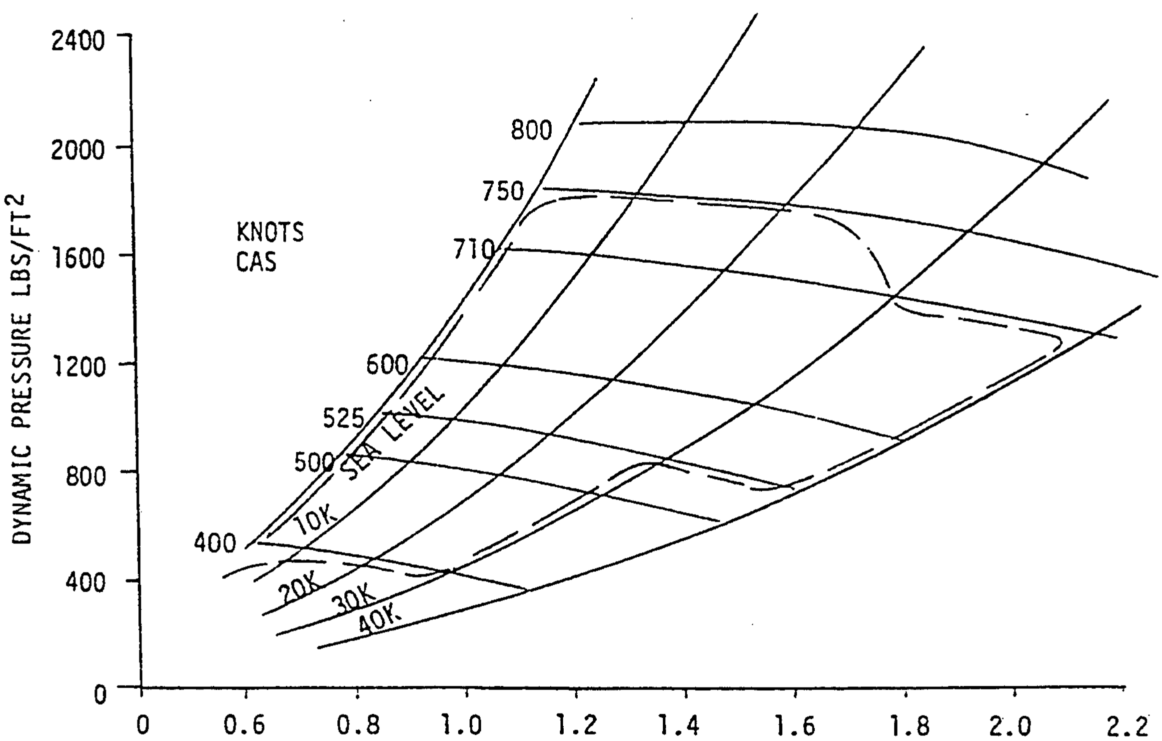
The purpose of the thermal flight test is to determine if the test article/subsystems can withstand the actual thermal environment of flight. Flight test results are also used to correlate with ground test and analytic results to improve/verify theory and test techniques.

The article tested shall have the same physical and thermal properties as the proposed store, insofar as possible. Explosive or hazardous materials shall be simulated by non-explosive or non-hazardous materials having similar physical and thermal properties. The effects of differences in thermal properties of the test article and the actual article shall be analyzed and documented.

Test article instrumentation should consist of heat transfer rate gauges for monitoring the store external wall heat transfer rate distribution. Thermocouple or thermistors should be used for measuring external wall and internal component temperature.

a. Store wall heat transfer rate gauges and temperature sensors should be located such that representative temperature and heating distributions are obtained. Also, detection of hot spots caused by shock impingement of internal component thermocouples or thermistors should be in and around the critical components, i.e., those with temperature restrictions.

b. Phase change paint is also advantageous in flight test by providing flow field visualization. The paints, which melt and flow at predetermined temperatures, can be photographed after the flight test to give a permanent record of the store flow field. Test points (Mach number, altitude, ambient temperature) should be chosen within the flight envelope which yield representative and extreme conditions on the test article. In addition, adjacent store configurations may be chosen to determine possible interference heating.



1. Climb to 30,000 feet at 400 KCAS.
2. Accelerate to 525 KCAS.
3. Climb to 40,000 feet at 525 KCAS.
5. Dive to 30,000 feet at 710 KCAS.
6. Continue dive to sea level accelerating to 750 KCAS.
7. Level out and decelerate to 400 KCAS.

FIGURE 6. FLIGHT PROFILE EXPLORING THE MACH AND DYNAMIC PRESSURE LIMITS OF THE F-4 AIRCRAFT

3. Aeroacoustic Tests:

Aeroacoustic flight tests are performed to determine the actual flight acoustic environment and determine the ability of the store configurations and related suspension equipment to withstand or, if applicable, to operate in the flight environment. The flight data is required to validate the acoustic specification levels and/or to substantiate the predicted/test levels.

The data required are the sound pressure density spectra at various surface locations on the test articles and those data necessary to verify critical components are functioning within the limits of their respective specifications. The response data may include but not be limited to, vibration characteristics, acceleration levels, power levels, and visual inspections.

The flight test article shall be full scale and configured in the operational aircraft/store carriage configuration. Any additional modification to the test article altering the flow field characteristics could change the aeroacoustic levels experienced thus provide invalid test results. The test article shall be mounted on its mission flight suspension equipment.

The article shall be tested to the extreme limits of the captive flight envelope. However, for test articles in weapons bays, data need only be taken at the maximum flight conditions where the bay doors are cleared to open. These test conditions shall concentrate in the highest dynamic pressure environment. Flight test conditions may also be selected to duplicate the ground test conditions, if different from above.

8.4.2.4 FLYING QUALITIES FLIGHT TESTS

Flying qualities tests demonstrate that the aircraft meets the requirements for the flying qualities of aircraft. Also, qualitative and quantitative information is obtained to determine full operational potential of the aircraft. These tests establish the limits within which the aircraft can be safely operated and ensure the aircraft meets the goal of its design mission, as related to flying qualities, with any particular store or stores combination. The results of these tests also provide an accurate description of flight characteristics for inclusion in the aircraft flight manual.

Flying qualities tests shall consist of quantitative flight test measurements demonstrating compliance with MIL-STD-1797, Flying Qualities of Piloted Aircraft, within the boundaries of the operating flight envelope, as well as demonstrating satisfactory flight characteristics within the maximum speed and maneuver envelope of the aircraft for that configuration. MIL-HDBK-244 describes maneuvers required for flying qualities captive flight tests.

The test article shall consist of aircraft/stores configurations under consideration which analysis and previously conducted ground tests, including wind tunnel if applicable, has shown to be critical as an operational configuration.

The test equipment for quantitative flight tests shall consist of an instrumented aircraft equipped with necessary gauges, accelerometers, telemetry capability, and provisions for recording aircraft flight conditions. Qualitative flight tests may be flown on non-instrumented aircraft.

The test shall be performed to evaluate the longitudinal, lateral, and directional stability and control of the aircraft at critical flight conditions and configurations (degraded mode flying qualities should also be considered) for:

1. Taxi and ground handling characteristics.

2. Takeoff characteristics including crosswinds.

3. Climb cruise maneuvering and descent characteristics, including effects of speed brake, power, and configuration changes.

4. Subsonic, transonic, supersonic, and hypersonic characteristics (as applicable) including trim and stability changes.

5. Buffet onset and intensity, vibration, stall characteristics, spin, and departure characteristics.

6. Low speed characteristics with and without high lift devices, carrier approved characteristics (for carrier type aircraft) including stalls, wave-offs, and crosswind landings.

7. Air refueling operations.

8. Operationally representative tracking maneuvers.

Normally, a stability and control flight test would be accomplished only in such cases where abnormal or undesirable aerodynamic trends show up during the analysis of the wind tunnel data. In this case an instrumented aircraft would be used to obtain quantitative flight test data and establish the handling qualities suitability of the store configuration. In the majority of cases, a qualitative flight test demonstration will be accomplished prior to clearance of the carriage envelope. Upon successful completion of the flight test and demonstration of the carriage envelope, the aircraft/weapon configuration is cleared and certified for carriage within the appropriate carriage envelope.

8.4.2.5 PERFORMANCE AND DRAG FLIGHT TESTS

Performance and drag tests are required to determine what, if any, degradation in mission performance is caused by the carriage of external stores. Store loadings selected to be flown should be compatible with the anticipated operational requirements and yield a sufficient range of aerodynamic drag in order to be representative of all loadings. Results of these tests should be compared with analytical and wind tunnel data. In the event the drag of any tested loading is unusually excessive, alternate, lower drag loadings should be selected where practical and tested.

The selected test points must be sufficient to allow accurate extrapolation to all conditions at which the store will be carried. The data must be such that a determination of the aircraft performance (acceleration, turn rate, climb rate, etc.) with various store loadings can be made throughout the envelope. The performance and drag of aircraft/store combinations will be judged acceptable if the system specifications are met with no degradation in mission performance, or if any discovered degradation is determined to be acceptable by the procuring agency.

8.4.2.6 STRUCTURAL INTEGRITY FLIGHT TESTS

One discovery very important to the field of aircraft/stores compatibility was made as a direct result of US participation in the Southeast Asia conflict. Many times stores were loaded externally on aircraft in Vietnam and flown but not dropped due to lack of a target or other operational reasons, and were still attached upon the aircraft's return to base. Stores sometimes made as many as three or four flights before being dropped. In addition, many missions to North Vietnam required one or more inflight refuelings enroute. In these cases, the store might be subjected to as much as two or three hours of maneuvering flight (some of it highly evasive) prior to being released. As a result, failures of the stores themselves were being experienced--fins cracked, fuzes failed, arming wires became loose, etc. To simulate these conditions in the initial aircraft/store compatibility testing, a specific captive flight test program was developed.

1. Qualitative Flight Tests:

Qualitative flight tests referred to as captive compatibility or endurance tests are flown on uninstrumented aircraft to:

a. Check the store loading configurations on the aircraft flying qualities and store failures induced by the aircraft.

b. Investigate the ability of the stores loaded in a specific aircraft/store configuration to withstand the ground and flight operational environment for periods of time longer than a single mission, including preparation for and return with all stores still on the aircraft.

2. Quantitative Flight Tests:

Generally, captive flight critical conditions are defined by those store loadings which could cause wing flutter, aircraft stability problems, or maximize loads in the aircraft pylon or wing structure. These conditions are usually derived analytically by grouping stores in terms of those of similar size, weight, or moments of inertia. Flight tests with instrumented aircraft are then used as necessary to verify the analytical predictions.

Normally, a structural flight test would be accomplished only in those cases where the store(s) is an unusual size/weight/shape or it is desired to extend the envelope beyond the present data bank. In this case, the area of investigation (i.e., aircraft, pylon, rack, store, etc.) is instrumented to obtain quantitative data. The data obtained would be compared with the calculated loads and a suitable carriage envelope established. In the majority of cases, a qualitative flight test demonstration is also accomplished prior to the certification of the aircraft/weapon configuration for carriage within the appropriate carriage envelope.

3. Store Loading Configurations:

To preclude store failures induced by the aircraft and to make a final qualitative check of the store loading configuration on the aircraft flying qualities, a representative number of combat store loadings should be flown on an uninstrumented aircraft. In addition, certain aircraft/store loading configurations may be judged by the testing agency to be analogous to other loadings of similar stores and, therefore, not require quantitative flight testing. Experience has shown, however, such analogous configurations should be flown on a spot-check basis prior to release for operational use.

4. Store Carriage for Sustained Periods:

One of the major purposes of the qualitative flight test is to investigate the ability of the stores loaded in a specific aircraft/store configuration to withstand the aircraft structural, aeroacoustical, vibrational environment for sustained periods, as would be the case on a combat mission with several inflight refuelings. To accomplish this part of the test, the specific aircraft/store configuration should be flown for a total time equivalent to the aircraft's mission radius plus 50% of the mission time, with the minimum being 1.5 hours. This would be 150% of the mission time on a particular serial number store in a specified store configuration. Of this total time, at least 30 minutes should be obtained in the region of highest vibrational loading, generally a high subsonic speed at the lowest practicable altitude. If more than one sortie is required to obtain the total flight time, stores should not be downloaded between sorties.

5. Examination Before and After Each Sortie:

Before and after each sortie, visually examine the aircraft/suspension equipment/store combination for damage, failure, cracks, looseness, popped rivets, etc. If significant discrepancies occur on the first sortie (major structural failure, extreme vibration or looseness, aircraft damage, fin bending, rivet popping, etc.), discontinue testing and decide whether to repeat the flight (after applicable correction is performed) or to suspend the test. If lesser discrepancies occur (arming wire slippage, etc.), continue with the second sortie without correction of the discrepancies. After the last sortie, examine the configuration both externally and internally (dismantling as necessary) for evidence of any discrepancies. Still photographs are desired if significant discrepancies are found after either flight.

6. Aircraft Configuration and Munitions:

The aircraft configuration will be indicated in the appropriate test method. Inert munitions are desired for all captive compatibility flights, with fuzes, boosters, and arming wires or lanyards installed.

7. Specified Envelopes:

Occasionally two envelopes for a particular aircraft/munition combination may be specified. The first or primary envelope gives the maximum allowable load factor with its corresponding airspeed or Mach limitations. The second or alternate envelope permits higher airspeeds or Mach but at a reduced load factor. In such cases, demonstrate both envelopes.

8.4.2.7 CAPTIVE COMPATIBILITY FLIGHT PROFILE (CFP)

The following flight test description summarizes CFP instructions in MIL-HDBK-244 and MIL-STD-1763. Those sources should be referenced for more detailed information.

1. Part I/First Sortie (Structural Integrity and Handling):

The first sortie will be a check of the configuration for structural integrity and degradation of aircraft handling qualities by subjecting the aircraft/munition combination to maximum symmetrical and unsymmetrical load factors at maximum allowable airspeed. A series of increasing values will be employed to reach the maximum load factors and maximum airspeed specified. The first captive compatibility sortie should be performed as follows:

a. Stabilize aircraft at desired airspeed in level flight and trim to fly hands off.

b. Perform steady state sideslip analysis. Slowly increase rudder deflection (either direction - assuming symmetrical configuration) and apply necessary aileron deflection to maintain straight level flight. There is no need apply full rudder deflection - just enough to obtain necessary data. Note if rudder deflection (force) increases for increasing sideslip (this is an indication of positive static directional stability - C_{n_β}). Note increasing aileron deflection (stick force) in direction opposite rudder application. (This is an indication of positive dihedral effect C_{ℓ_β}).

c. Perform longitudinal dynamic short period motion analysis. Stabilize aircraft on airspeed and altitude and turn pitch damper off. Apply a pitch doublet to obtain about ±1 "G" pitch oscillation. Exercise extreme caution during this input, especially at high speed, as too large an input may create an oscillation that could overstress the aircraft. If the first attempt is too small, repeat using slightly larger input. After releasing control stick, observe and note the overshoots in pitch oscillation. Less than 7 overshoots is acceptable damping of longitudinal short period dynamic motion (oscillations should damp in 1 or 2 overshoots with pitch damper engaged). If oscillations continue, the aircraft/weapon configuration is apparently neutrally stable dynamically. If oscillations increase in amplitude, reengage pitch damper and quickly dampen motion with pilot inputs. Do no further investigation as the configuration is unsafe (dynamically unstable longitudinally).

d. Perform lateral-directional dynamics analysis. Stabilize aircraft airspeed and altitude and disengage roll and yaw dampers. With hands off stick control, apply a rudder doublet to induce Dutch Roll. Apply just enough rudder to induce motion. Do not rapidly apply full rudder. Observe if the resulting motion is damped. If motion continues undamped, the aircraft/weapon configuration is apparently neutrally stable dynamically. If oscillations increase in amplitude, reengage dampers and quickly dampen motion with pilot inputs, aborting mission as the configuration is unsafe (dynamically unstable laterally/directionally).

e. Investigate aircraft roll performance. Stabilize aircraft airspeed and altitude and disengage all dampers. Perform an aileron roll at maximum specified roll rate (limits provided on test mission card) by timing the roll through appropriate bank angles (not to exceed design limits). Approach maximum roll rate slowly, repeating the point until desired rate is attained. Note aircraft divergence from flight path. Measure roll performance in both direction if asymmetrically configured. Upon completion of roll, reengage dampers.

f. Investigate aircraft maneuvering stability characteristics. Normally a wind-up turn is performed to obtain an indication of the degree of dynamic longitudinal maneuvering stability that exists for that specific loading center of gravity position and flight condition. This is attained by measuring the amount of stick force required to pull incremental "G" up to the maximum + "G" limit authorized. Another purpose for performing the wind-up turn is to determine the positive structural integrity of the configuration, which is accomplished by attaining the maximum positive "G" authorized. Stabilize aircraft airspeed and altitude and insure dampers engaged. Roll into turn adding power as required to maintain constant airspeed as "G" is gradually increased to maximum attainable or munition limit "G," whichever occurs first. Limit your first test points to 80% of the limit load to avoid overshoots and other surprises. Maintain nearly a constant bank angle so as not to induce rolling "G" on the configuration (bank angle may be greater than 90°). Stick pull force should continue to increase with increasing "G." However, a lightening of stick pull force may occur. This is permissible provided the local F_s/G gradient doesn't deviate from the average gradient by more than 50 percent during the maneuver. If the stick (pull) force reverses such that it takes totally less pull force to achieve a higher incremental "G," then "stick reversal" has occurred. Consequently, the aircraft/store configuration should be considered unsafe to fly beyond that "G" limit at that particular center of gravity since "stick reversal" can rapidly lead to an aircraft and/or store overstress condition. With asymmetric store configurations, do initial windup turns away from heavy wing. Loss of lateral control should result in an upright roll of the aircraft.

g. Attain rolling "G" limits upon completion of maneuvering flight by relaxing "G" to the rolling limit (limits provided on test mission card), and roll the aircraft back to wings level attitude maintaining maximum roll rate. Adjust power to maintain airspeed. This maneuver will generally place the greatest stress on the aircraft/munition combination; thus the design "G" limits should not be exceeded.

h. Perform negative "G" limit structural integrity demonstration. Stabilize airspeed and altitude (hands off trim not required) and attain negative "G" limit (limits provided on test mission card) by pushover or inverted flight.

i. Evaluate speed stability during acceleration to next speed increment. Maintain level flight and note that stick force (push) increases slightly as airspeed is increased. Do not trim during the acceleration.

j. Repeat steps 1 through 9 at each speed increment specified by the test mission card. Use a build-up approach to speed increments. Start in the middle of the test envelope, subsonic at moderate altitude. Build out from there to slow speeds (see paragraph l below), and to high subsonic, then supersonic, and finally to the highest dynamic pressure (q) point where the Mach limit and calibrated airspeed limit intersect. See Figure 7 for an example test envelope.

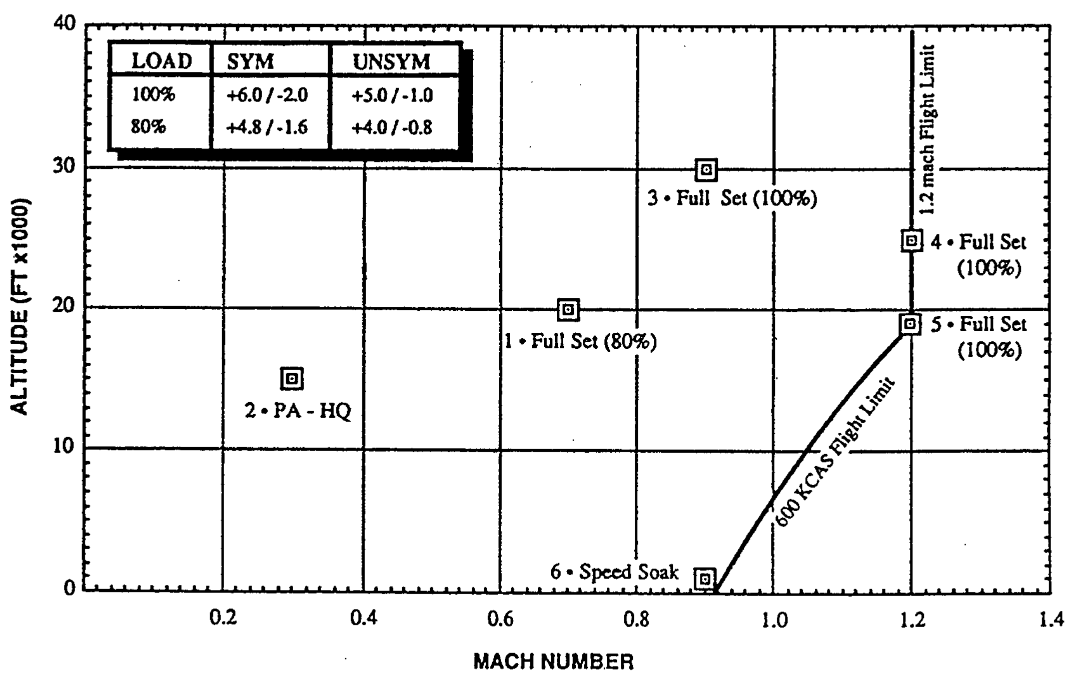


FIGURE 7. EXAMPLE CAPTIVE COMPATIBILITY PROFILE ENVELOPE

k. Upon completion of final, highest q test condition, evaluate trim change induced when speed brake is extended. Extend speed brake noting change in trim force required to maintain level flight. Excessive forces should be reflected in technical report.

l. Prior to landing, investigate slow speed general flying qualities with aircraft in landing configuration. Investigate trim changes when lowering gear and flaps while performing turns and while approaching stall warning. Keep in mind configuration may not normally be landed operationally.

2. Part II/Second Sortie (Vibration and Endurance):

The second sortie shall fly the configuration at 0.90 Mach or the maximum allowable airspeed (whichever is more restrictive) at the lowest practicable altitude commensurate with weather and safety considerations (1000 feet above mean sea level as maximum) for at least 30 minutes. Sorties can be combined if fuel allows or air refueling is available.

3. Flying Time:

Flying time is allocated as follows:

a. Part I plus Part II total (2 sorties) is 1.50 multiplied by the time equivalent to the aircraft mission radius with a minimum time of 1 hour and 30 minutes. The minimum time of 1 hour and 30 minutes is predicated on fighter type aircraft. For other aircraft types the minimum time may need to be altered.

b. Part II total of 30 minutes.

8.4.3 EMPLOYMENT FLIGHT TESTS

During these tests, part or all of the stores are released from the aircraft. Even though ground tests are widely used to predict employment characteristics, flight testing is normally considered mandatory to demonstrate as a minimum envelope extremes. Most certification agencies admit that due to their lack of confidence in simulation techniques, they would not base a certification recommendation solely on analytic or wind tunnel techniques. Also, many occasions will arise where employment analogies or simulations are not available and flight testing is the only available tool to determine safe employment envelopes.

Employment, as defined earlier, means to release, launch, fire, or dispense part or all of the selected stores from the aircraft. Employment in many cases is characteristically different from jettison. Jettison is the safe release of stores from the aircraft and is done simply to separate the stores from the aircraft for safety or performance reasons. During employment tests, the store is operated in its normal mode to accomplish an operational objective, as opposed to jettison which is usually accomplished in 1 "G" level flight. Employment testing is often accomplished throughout a large part of the aircraft flight envelope to demonstrate the store or store part will safely and satisfactorily separate from the aircraft. As a side benefit, through a well structured employment test, valuable parametric insight into basic aircraft/store employment characteristics can be obtained. It is easily conceivable that a store will be designed that could dispense as it separates from the aircraft, or otherwise combine more than one of the four types of employment modes. For such cases, several standard tests may have to be combined in a unique manner to properly evaluate safe employment.

8.4.3.1 RELEASE FLIGHT TESTS

Release tests are performed when, during normal employment, the entire store is released from its suspension equipment. Guided and unguided iron bombs and clusters, firebombs, and nuclear weapons are examples of weapons normally released during employment. Release tests are performed to demonstrate the store or the submunitions within a cluster bomb will safely and satisfactorily separate from the aircraft throughout the employment envelope. Missiles that release, then propel, are discussed under Launch. Cluster bombs that dispense submunitions after the cluster is released from the aircraft are discussed herein. Dispensers that remain on the aircraft while dispensing submunitions are discussed under Dispenser Tests.

Data are taken to ensure the stores released are representative of the inventory, to ensure the desired release conditions are demonstrated, to document the store release characteristics, and to allow comparison of flight release motion with that predicted during simulations. Data may be quantitative as measured by onboard film coverage or instrumentation or observation via chase camera coverage.

1. Test Preparation:

There are several steps in the planning process (these steps are often combined with preparation for fit, captive flight, and other employment and jettison tests):

a. Establish the desired or predicted release envelope. Quite often this might seem as simple as ascertaining operational requirements, but such requirements may be modified to clear all of a similar type of store to a common release envelope or to clear only a simple low cost portion of the operationally desired envelope. The user may accept a smaller envelope to field the weapon rapidly, returning to expand the weapon envelope later.

b. Generate a release test plan. Test plans should not be formulated until data from previous test and evaluation of the store in question and similar stores are fully reviewed. Then using that knowledge, along with the information gained through available analysis and simulation, a detailed test plan can be formulated. Typically, testing is started from the safest presumed condition (not necessarily the lowest speed) and the release envelope is expanded from there. Expansion may consist of higher and lower airspeeds and Mach numbers, higher and lower load factors, increasing dive angles (reducing G), increasing bank angle, reducing release intervals, proceeding from single carriage to multiple carriage, proceeding from single release to multiple release (including salvo), proceeding from preprogrammed or dummy vehicles to vehicles with active guidance systems, proceeding from low drag to high drag, and proceeding from protracted function times to minimum function times. Liquid filled stores may proceed from a non-sloshing dummy to an actual liquid fill. The test plans should include data requirements, range requirements, and details on all aspects of configurations and release conditions.

c. Evaluate separation failure modes. In formulating test plans, it is critical to ensure either store separation with unopened fins or worst case control settings is safe (not necessarily acceptable) or the likelihood of such a failure or setting is acceptably low (say once in every 10,000 releases). If such cannot be determined, then release tests of the store should not be initiated since a control system or fin opening system failure could easily result in a high energy aircraft/store collision.

d. Test stores should be identical to inventory stores except, in the interest of flight safety, they should be inert if at all possible. There may be cases where a simulant for the live fill cannot be found and therefore, inventory stores may be used. In cases where a large test program is planned, it may be cost effective to design an inert "blivet" of identical shape and mass properties but without complicated and costly internal mechanisms, electronics, or exotic materials. All test articles should have their critical physical and mass properties checked prior to their use in a flight test situation and specially painted if needed, to assist in data reduction. For some guided weapons, it may be desirable to have preprogrammed vehicles or other separation test vehicles to eliminate the possibility of, or evaluate the effects of control system failures or settings.

To ensure the test stores are representative of the inventory, the mass physical and operational characteristics of the inventory stores must be known and compared to the measured values of the test stores. Stores with measured values outside the tolerances of the inventory should not be used unless it can be determined through analysis or judgment that the out-of-tolerance parameter will not be expected to affect basic separation characteristics. Parameters of interest and their criticality are given in MIL-STD-1763, Test 271, Table 1.

e. To ensure the desired release conditions are achieved the test engineer must have detailed knowledge of the aircraft configuration and release flight conditions. Required aircraft configuration characteristics such as exact store location, lanyard routing, tacks used, flight control surface location, etc., are listed in MIL-STD-1763 Test 271, Table 2. Aircraft flight conditions at release should be very close to test conditions. MIL-STD-1763, Test 271, Table 3, lists flight condition data such as airspeed, altitude, angle of attack, load factor, etc., and desired tolerances. Often an instrumented aircraft is not available, and the test engineer must rely on a visual (by crewmember) or photographic (Heads Up Display (HUD) or over-the-shoulder camera) record of the flight conditions from aircraft instruments. If a visual record is the only available one, the crewmember should be provided with a flight card or form with prelabeled spaces to facilitate entry of data. Flight conditions at release may also be determined from tracking information (radar or photographic).

f. To document store release characteristics, it is essential to have onboard or chase high speed motion picture cameras or a video equivalent. It has been demonstrated over and over that the pilot of the release or chase aircraft cannot be expected to reliably visually ascertain store separation characteristics. Onboard cameras may be mounted internally, on adapters to the skin of the aircraft, carried in removable pods, carried on a beam with suspension lugs (i.e., a pod without skin), or for very low-speed aircraft, hand held by a crewmember. Cameras must be installed in such a way that their presence does not perturb the airflow sufficiently to affect store separation characteristics. "High speed" is defined herein as frame rates of 128-200 frames a second. Slower frame rates cannot sufficiently slow down the motion to allow checking of phenomena such as fin-to-fin contact, and frame rates faster than 200 frames per second usually restrict camera run time. Onboard cameras should be lensed and aimed such that separation motion is documented from the pylon/store interface until the store is well clear (approximately 20 feet) of the aircraft. Combinations of side viewing and rear viewing or side viewing and down viewing cameras may be needed to adequately record separation characteristics including store oscillations, functioning, store-to-store collisions, store passage through aircraft flow and shock fields, etc. Extreme wide-angle or fisheye lenses can provide useful information but the image is so distorted that linear and angular relationships are usually lost. Video tape systems used in addition to motion picture cameras can provide an instantaneous review of the release. Work is underway to develop high-speed, shuttered video systems which could replace film cameras, but nothing approaching the required 200 frames per second yet exists.

g. Chase camera coverage is often considered superfluous to on-board coverage, but there are many release situations for which chase coverage is superior. For example, store reactions well below the aircraft (i.e., through a shock wave), store functions such as retarder initiation, motor ignition, store trajectory changes due to long period store oscillations, and store-to-store collisions, crossovers, and drafting may be best documented through chase photography. Chase cameras are usually hand held since it is difficult to keep a hard-mounted camera on the chase aircraft aimed at the store. Chase cameras should be "high speed" in the same sense as onboard cameras. Ideally, for most release tests, the chase pilot should be positioned approximately side-by-side just slightly aft of and just slightly below the release aircraft. The photographer should be able to see the store (not be hidden by fuel tanks or other stores), and the resulting film should usually depict a pitch plane of the store separating. The chase aircraft should be close enough that the store is easily identifiable in the film but far enough away that other stores released simultaneously may be seen, as well as the aircraft tail area. Variations from test to test may necessitate different chase positions. Also, as single releases are made from one side of the aircraft, then the other, the chase aircraft must also be repositioned to get useful camera coverage.

h. Onboard and chase coverage are often not permissible for releases at high speeds, steep dive angles, or certain maneuvers. For such tests, it may be possible to use a ground camera to document separation characteristics. Ground cameras may also be useful to get store functions, drafting or store-to-store collisions. In general, however, ground cameras do not provide a close enough view to replace onboard or chase camera coverage.

i. Pilot comments on the response of the aircraft during and after store release provide subjective but valuable information. Comments related to the "feel" of the release, the resulting G-jump trim changes, oscillation and their ease of control, similarity to other stores and overall acceptability should be recorded immediately after the flight for the final report.

2. <u>Test Procedures</u>:

Test procedures should be contained in the detailed test plan. The plan should relate mandatory release sequences and missions. A number of techniques can be employed to combine tests and hence reduce the number of missions actually flown. For example, the assumption is often made that the airflow on one side of the aircraft is the mirror image of the flow on the opposite side of the aircraft. If loading configuration ground rules permit, two separate store configurations may be split in half and loaded half each on two different sides of the aircraft. Since normally the initial release from that configuration must be reviewed before the subsequent release from that configuration, concurrent testing with the two configurations could reduce the number of missions required by half. This type of testing may, under certain circumstances, even be employed with multiple carriage stores. Multiple racks normally have an inherent release sequence which means that a TER load of bombs released from one side of the aircraft is not the mirror image of a TER load of bombs released from the other side. But cases occur where the point of interest may be release of stores from the TER in the presence of some other store or missile. By partially reversing the release sequence of one TER, a mirror image situation can be created. In a pairs release, stores could be released from one wing with the adjacent store present and from the other wing with the adjacent store absent. With pairs release, the effects of the adjacent store is obvious. In the same manner, if there are two stores for which an analogy is hesitatingly assumed, pairs release can confirm or deny that analogy. When flying asymmetric configurations to reduce the overall number of flights required, attention must be paid to aircraft control surface deflections to achieve or maintain desired aircraft heading. Aircraft conditions may vary due to the asymmetric loading and give erroneous data.

a. Stores with fins that deploy after release (not retarders) should have the fin release wire hardwired to the aircraft to ensure the fins open. An arming solenoid should not be used for this function.

b. A practice that should be avoided is the use of the release or chase aircraft pilot to observe one release and then, based on his observation alone, clear a more rigorous release condition. Store motion is quick and will elude even a trained eye. Use of this procedure is especially dangerous in multiple releases, as the observer simply cannot be expected to see what 10 to 20 individual stores did for the second or so it takes them to be clear of the aircraft.

c. After each release mission, the amount of data review required will vary depending on the level of difficulty of the next release. It may, in many cases, be adequate to review the film to ensure no surprises or anomalies occurred. It is good practice to inspect the test aircraft suspension equipment and adjacent stores for signs of store contact. It may be necessary in some cases to have separation motion analytically determined from the film, and compare these data to simulations. It may become necessary to test fire the rack or function the stores release system on the ground to isolate interval or ejector problems. And it may also be necessary to review inflight release conditions in detail to determine if release problems were due to release at other than the desired condition.

d. After any release, it may be that safety of flight dictates a different subsequent release than the one planned. When making such changes, the entire test plan philosophy will probably have to be reviewed to ensure that insertion of a single new mission does not result in a wastefully small step to the originally planned subsequent mission.

e. The test pilot should be familiar with the normal aircraft response to release of stores of similar types. Such a person will be best able to evaluate the acceptability of release transients and verbalize the nature of those transients for subsequent reporting. The pilot and chase photographer shall be prebriefed on what to observe and expect during and after release.

f. Since any store released from an aircraft could possibly be hung or strike the aircraft, causing physical damage to the aircraft or aircraft loss, the test agency shall have well thought out contingency plans for such events. Hazard/safety review boards made up of engineering, operational, and safety personnel shall review all release tests prior to the first drop. The board shall ensure that the authority to release stores (flight clearance) has been provided by a competent agency.

g. The store must safely and satisfactorily separate from the aircraft throughout the desired release envelope, or the release envelope must be reduced to be commensurated with safe and satisfactory separation criteria. Separation criteria are provided in MIL-HDBK-244. In addition to separation characteristics of the store, the aircraft response must be evaluated. Responses such as G-jump trim changes and aircraft oscillations should not be objectionable. Evaluation of these responses is primarily a subjective judgment the test pilot must make aided by aircraft instruments denoting quantitative values achieved during the test.

3. Data Reduction Methods:

Once the store separation has been made, the quantitative photographic data must be reduced to a form similar to that of the predictions, so a direct comparison between predicted and inflight trajectories may be made. To do this, there is one technique currently employed by the US Air Force called "photo-imaging." It was initially developed by US Navy engineers at the Pacific Missile Test Center and Naval Weapons Center. It is capable of providing excellent data. The second technique, called "Chase," is used by the McDonnell Aircraft Company.

a. Photo-Imaging Data Reduction. This system utilizes an image matching technique to obtain spatial position and orientation of photographed objects with respect to recording cameras (see Figure 8). The system begins by projecting each frame of the onboard flight-gathered data film through an optical system into a high resolution video camera, and displaying the resulting image on a TV monitor located on an operator's console. A computer generated model of the store is fed through a video mixer, and the resulting image is simultaneously displayed on the same TV monitor as that from the data film. The operator can adjust the position and orientation of the computer generated store model through the use of a set of levers on the console. He adjusts the store model until the image of the store on the positioner is exactly superimposed, on the image of the store from the data film (a process similar to using a camera range finder). Once the two images are exactly aligned and superimposed, the operator can press a single button which transfers the encoded frame count and position data to computer memory. Each frame of the film is similarly reduced until a data file is generated. This data file is input to a computer program to solve the spatial relationships. The output from the photo-imaging technique is a set of tabular data and selected plots which accurately define the store separation trajectory to compare directly with the predictions. This technique produces extremely accurate data (2 inches for displacements and 2 degrees for angles). A photo-imaging system now exists at three US Navy testing locations and at Eglin AFB.

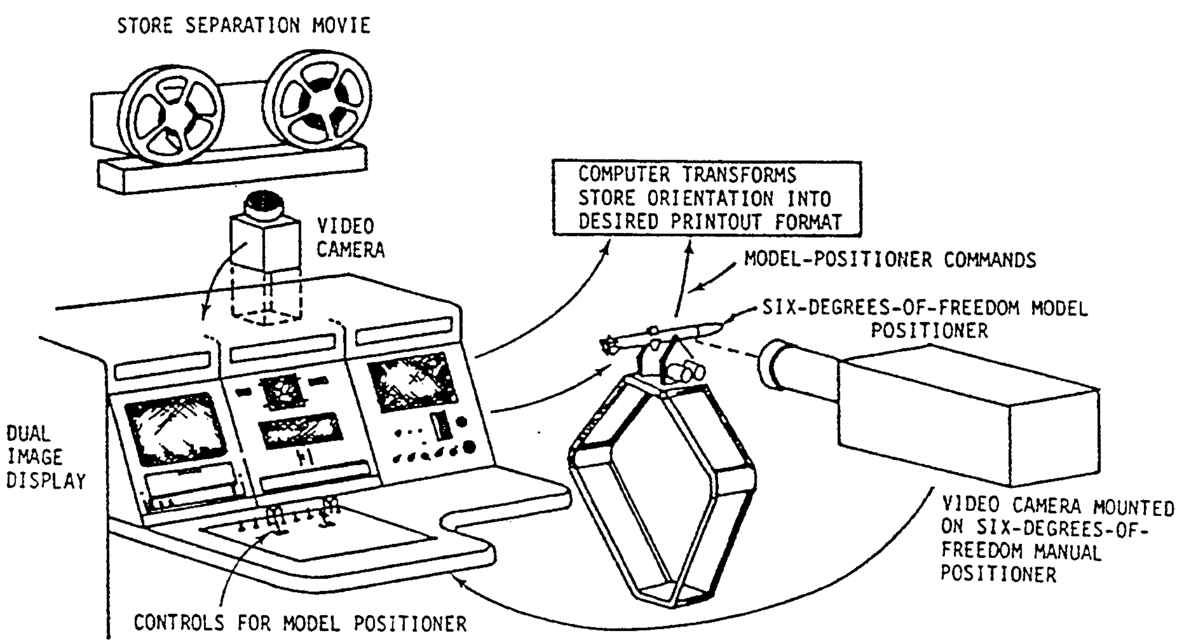


FIGURE 8. PHOTO-IMAGE SYSTEM USED FOR FLIGHT TEST DATA REDUCTION OF STORE SEPARATION

b. CHASE. A photogrammetric technique called CHASE has been developed by the McDonnell Aircraft Company and was used to support the F-15E program. CHASE is an analytical and software technique that yields six-degree-of-freedom data with an accuracy equal to or better than any other existing systems. The system is fast. A separation requires, on the average, only one hour on a film reader and two minutes on an average computer. Three important advantages are the system requires little preparation since the stores need no marking; no special equipment is required; and the results are independent of the camera position. This last advantage is responsible for the system name, CHASE, as the ultimate objective for future development in the quantitative reduction of film taken from a "chase" aircraft. Figure 9 depicts the CHASE concept.

(1) In the field of view, information of three targets on the airplane is read from the film. These three targets are referred to as Boresight Targets. Their positions are converted into included angles between the lines of sight from the camera. These lines form a tetrahedron a rigid structure. The baseline dimensions of this tetrahedron are established using the aircraft stations of the boresight points. An iterative technique using the Laws-of-Cosines is used to locate the camera such that the projected radials make a best fit of the targets. When the coordinate sum of the successive radial errors is less than one inch, a solution has been established locating the camera. The orientation or look angle of the camera is computed using this camera location and the optical transfer functions. The camera location and orientation is computed for every frame that is processed. Each frame then is in itself a complete solution and is not dependent upon another camera, nor is it time dependent. It adjusts for the conditions that exist at that very precise moment.

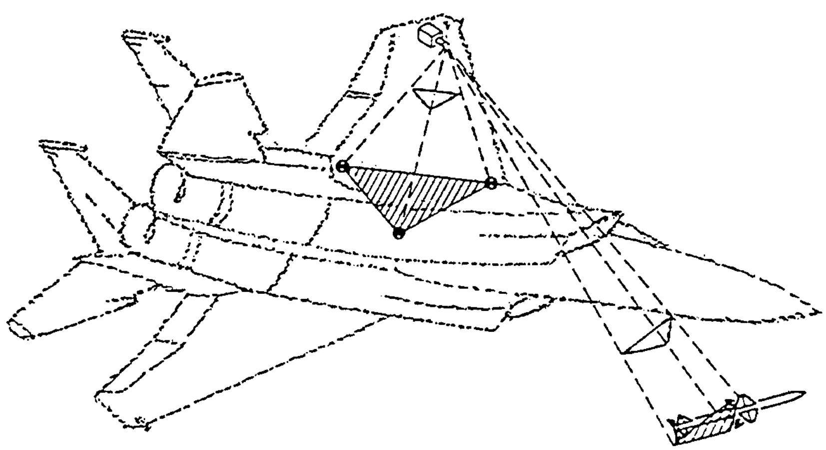


FIGURE 9. CHASE CONCEPT

(2) Using that same frame, three points are read on the store. Various features of the store having distinct outlines are used for these three points. Again, the included angles to those points define another tetrahedron. Using the location of these points for the baseline of that tetrahedron, the base is shifted around in the

same manner until there is a best fit for the radials. When the sum of the differences is less than 2.5mm, the location of the plane (the stores coordinate system in space) is established.

(3) At this point, the store is numerically reconstructed. From this numerical representation, the data as requested by the user, is precisely furnished. Discrete points on, in or outside the store and attitudes of a preferred coordinate system are presented, rather than the traditional nose, CG, tail. The analyst can now observe clearances of critical points. This is particularly beneficial for nonsymmetrical stores or those having protrusions.

The basis of the technique is that the Boresight Targets are precisely located on the aircraft. This makes it possible to accurately calculate the camera position relative to the aircraft at any one time. Accurate dimensional data on the store is contained in the software permitting accurate calculation of the store position relative to the camera at any one time. Therefore the position of the store relative to the aircraft may be calculated as a function of time and independent of camera position.

The real success of the CHASE system is the result of innovative mathematics in the software and the use of extensive information files on boresight, optical calibrations and aircraft instrumentation configuration. Vast improvements in optical calibration techniques for camera lenses were made during the development of CHASE. These improvements were probably the most significant single factor contributing to the success of CHASE.

c. Summary of Flight Test Data Reduction Methods. Both of the methods described above provide accurate, useful, quantitative data both in a tabular and a plotted format. All of them are inherently accurate enough to provide good, usable data. The degree of mathematical accuracy attained is not as important as how many of the error-causing factors are accounted for by the method and (more importantly) whether the factors are compensated for or corrected. Data reduction accuracies of 3 inches (5.1 cm) and 3 degrees can be absolutely accurate, but not if the effect on store separation of wing flexibility, for instance, is not properly accounted for. Of all the error-causing factors the ones which seem to be most important (and most difficult to correct for), are connected with the camera optics. Errors caused by lens/camera alignment calibration, internal manufacturing aberrations, and uncertain optical centers are among the most important. Although great care must be exercised in developing a data reduction method which properly accounts for as many of the error-causing factors as is possible, equal care must be used in insuring the method does not introduce other large errors due to the human factor. A method which requires an inordinate amount of human input and manipulation of data prior to and during computer reduction is extremely liable to errors, particularly if no built-in test features are incorporated.

8.4.3.2 LAUNCH FLIGHT TESTS

Launch tests are conducted when the store to be employed separates from the aircraft primarily through the propulsion of a motor, rather than gravity or an ejection cartridge. Air-to-air and air-to-ground missiles and rockets are examples. The store may be released and left to free fall for a short (approximately 1 second) time prior to motor ignition; this does not alter classification. Launch tests are conducted to demonstrate the store will safely and satisfactorily separate from the aircraft throughout the desired employment envelope.

Data requirements are essentially as specified for release tests with a few additions and exceptions. Onboard cameras that view forward will be needed. Data systems will have to monitor and record, in addition to previously specified parameters, effects of motor thrust, levels of motor thrust, motor ignition times, and impingement on aircraft engine operation, control responses, external surfaces (corrosion, combustion, product buildup, etc.), and in some cases, crew or crew support systems such as oxygen.

Test preparation consists of the same steps as for release tests. In addition, when evaluating possible effects on the aircraft engine, there are analytic techniques that can be used to predict flight conditions or motor ignition times that minimize or maximize engine effects. As with some released stores, the effects of separation failure modes such as autopilot failure or fin opening failures must be considered in formulating the test plan.

Test articles shall be of similar mass and physical characteristics to the inventory item. The warhead shall be replaced with an inert version or, if missile free-flight data are also being measured, the warhead may be replaced with a telemetered or recoverable instrumentation package. Guidance systems may be replaced with ballast, with a preprogrammed control system, or the actual system may be needed, depending on test requirements and autopilot logic. Control surface alignment and actuator bias are factors which must be monitored to ensure missile aerodynamic characteristics are correct for the test conditions and represent the actual item.

Procedures are the same as for release tests. After any launch test, where live rocket motors are used, the aircraft shall be inspected for blackening, buildup of combustion products, corrosion, pitting, damage from throat seal pieces, etc.

8.4.3.3 GUN FIRING FLIGHT TESTS

Gun firing tests are conducted to determine and evaluate the performance and verify the safety, reliability and maintainability of the aircraft/gun system combination throughout the operational envelope of the aircraft. This evaluation includes: the ammunition handling and loading/unloading methods; equipment and procedures; the installing and removal of the gun system; access for service, maintenance and safety and the safety features of the gun system for both ground and airborne operations.

Factors, characteristics, and effects generated by or for the gun system during gunfire must be determined as specified below. In some cases, the data may be qualitative rather than quantitative and are so indicated.

1. Quantitative determination of gun gas concentrations in the gun and ammunition compartments and any other compartment susceptible to accumulating gun gas will be determined at those flight conditions (combinations of speed, altitude, burst length, and maneuvers performed) analyzed as being the most critical.

2. Qualitative evaluation should be made by the pilot/crewmembers of any gun gas concentrations within the cockpit during firing bursts.

3. Engine ingestion of gun gas throughout the flight envelope and resulting temperature spikes, inlet pressure fluctuations or flameouts shall be noted. Temperature and pressure fluctuations shall be measured and will require corrective measures.

4. There should be measurement of vibrations and acoustic levels during gunfire within the cockpit and those aircraft compartments in the area of the gun and muzzle blast environment.

5. Blast overpressures and pattern on aircraft skin areas adjacent to the gun muzzle should be noted. Measurements shall be from twelve inches aft of the muzzle forward.

6. The recoil, counter-recoil and blast loads transmitted to the airframe during gunfire shall be measured under varying conditions of inertia, velocity and altitude. Structural adequacy will be determined from these actual measurements.

7. Qualitative evaluation including motion pictures of visibility during both night and day gunfiring. Such factors as flash, flame, smoke, or residue be evaluated for

corrective action deemed necessary. None of these are desired although all may not be totally eliminated.

8. Gun gas residue may accumulate on aircraft skin and windscreen or canopy. Corrosion effects and visibility determination shall be determined.

9. Gun control characteristics shall be measured. Time to start and come up to speed after trigger is actuated and time to stop after trigger release will be measured. If applicable, clearing times after gunfire burst, clearing gun jams, and reverse gun clearing cycles will be measured.

10. A safety evaluation of the complete gun system will be accomplished throughout the test. Safety features to prevent gunfire during ground operations, takeoff, landing and in flight shall be assessed.

11. Although separate reliability and maintainability tests may be employed, the gun system flight test program shall log the maintenance actions and record the stoppages, malfunctions and the reasons for inclusion into the reliability and maintainability programs.

12. Verify the aircraft gun systems imposes no limitation on burst length under any and all flight conditions. If the gun dictates burst limitations, verify the limiter will function in the event of system control failure.

13. Power required for control and operation of the gun system shall be measured. Such characteristics as DC/AC voltage, amps, hydraulic or pneumatic pressures and flow, etc., shall be measured.

14. Affects of gunfire and length of burst on aircraft stability, control, and handling shall be qualitatively determined. Inputs to the flight control system to offset these affects shall be evaluated.

15. Accuracy and accuracy retension will be determined in conjunction with the system employed on the aircraft. Both air-to-air and air-to-ground accuracies in accordance with the aircraft system specification requirements will be evaluated. Boresight retension shall be evaluated by frequent ground boresightings during the flight test program. Ground gun butt firing prior to and after flight qualification shall be conducted to verify gun sight to mean impact point relationship.

16. Aircraft flight conditions including airspeed, altitude, dive angle, angle of attack, normal acceleration, and flight control positions shall be recorded during firing.

The test article shall be the final aircraft/gun system configuration. All normal aircraft equipment shall be installed in functional condition. The performance characteristics of the installed engine(s) shall be established prior to the gun firing test in order to evaluate effects of gun gas ingestion and power extraction. The use of nonrepresentative equipment will jeopardize the results and thus the validity of the qualification program.

The gun system shall be fired throughout the aircraft envelope. Primary attention shall be directed in the primary use envelope. Firing shall be conducted at various engine power settings including idle. Testing shall include the maximum allowable burst lengths.

The measurement of physical effects of gunfire on structure and equipment will be accomplished using typical test equipment such as accelerometers, strain gages, microphones, thermocouples, etc. Maximum temperature of the structure and equipment can be obtained by temperature sensitive labels or other similar devices. Gun gas concentration in the gun bay shall be measured by continuous readout type instrumentation due to the transient nature of the data. Cockpit air samples shall be taken during the periods of highest gas concentration for laboratory evaluation. Accuracy data shall be obtained on a scorable range in conjunction with ground tracking of aircraft to establish the aircraft conditions during firing. Typical flight test instrumentation shall be used to establish aircraft flight and engine conditions for tests other than accuracy. Photochase, onboard camera and the gun sight camera shall be used to record the effects of gunfire.

8.4.3.4 DISPENSE FLIGHT TESTS

Dispense tests are conducted when, during normal employment, the payload of the store is freely or forcefully admitted into the airstream, but the basic store structure is retained with the aircraft. Submunitions, practice bombs, flares, chaff, liquid and dry agents, smoke, and sensors are examples of items that are normally dispensed from store. Dispensing can occur forward or sideward but is most commonly rearward or downward. Dispense tests are conducted to demonstrate that the material released including its packaging will safely and satisfactorily separate from the aircraft throughout the desired employment envelope. A cluster consists of a dispenser filled with material. Some clusters are released and open after release; some dispense the material while the dispenser itself remains attached to the aircraft. The latter type only is addressed in this section. The former are discussed under Release Tests.

The test agency must ensure that the physical mass and functional characteristics are representative of the inventory. For minuscule items such as chaff, or for powders or liquids, the actual material will probably have to be used. The physical characteristics of simulants, such as specific gravity and viscosity, must be carefully matched to the actual material being simulated.

1. As with other types of employment tests, it is important to record aircraft flight conditions at dispensing. Dispensing tests may require that the flight condition be maintained for several seconds. Thus, variations in flight altitude or velocity will be noted as this can distort impact pattern data. For dispensed items such as IR flares, decoys or chaff, it is likely that dispensing tests may occur during maneuvering flight and exact dispensing flight conditions will be difficult to ascertain without an instrumented aircraft.

2. Photographic documentation of dispensed material can pose problems as the material streaming out from behind the aircraft may be difficult to see by the chase photographer. As the material slows down relative to the aircraft, the photographer will have difficulty following it with the camera. Also, as the dispensed material spreads out, the photographer will have difficulty keeping it in frame. Finally for items forcibly dispensed at high exit velocities, a high camera frame rate may be required to satisfactorily slow down the motion for later analysis. Frame rates in excess of 200 per second may be required to capture such motion, but this shortens the time that film coverage is available.

3. Rearward and downward dispensed materials have been observed to strike or contaminate wing, fuselage, or tail surfaces. It is desirable to aim cameras to evaluate such events. It may also be necessary to dye or color-coat the dispensed items or to put some sort of witness card or coating on areas of potential contamination or impingement make detection of impact more positive.

4. Dispensers that forcibly downward eject items in varying intervals may excite structural frequencies at or near the natural structural frequencies of the aircraft wing. It may be necessary to instrument the aircraft with deflection or acceleration gauges to monitor wing response during dispensing tests.

The preparation of a dispense test will be similar to release tests outlined earlier. During formulation of the test plan there are additional factors that shall be considered when determining how to proceed through envelope demonstration. For submunitions of changing mass or shape such as flares or chaff, it may be necessary to initiate testing with a dummy of fixed shape and mass and then proceed to the actual item (which ultimately would have to be tested). For dispensers that forcibly downward eject submunitions of a variety of weights it may be desirable to test the heaviest last since the heavy item will probably generate the highest reaction force and the lowest separation velocity. For rearward dispensed items of various weights, it may be desirable to dispense the lightest last since it is more likely to be perturbed by the airflow about the aircraft and therefore more likely to strike the aircraft. The test planner should reflect on the effects of a failure of a dispenser ejection system to ensure that such a failure will not cause the item to strike the aircraft or to burn (such as a flare might) while within the dispenser.

The items or material dispensed shall not strike or narrowly miss (such that a repeat of the test might result in a hit) the aircraft. Items with fuzes, explosives, damageable electronics, or damageable external shape shall not bump into each other. Items that function (deploy chute or retarder) shall be in a proper orientation so as not to defeat that function. Dispensed items shall not disintegrate or fail structurally. Aircraft responses in the judgment of the test pilot shall be acceptable.

One special area of concern in dispense tests is the determination of hung or undispensed submunitions. Few aircraft have a competent stores management system to determine if the dispenser has completely expended its payload. Submunitions or items not dispensed can fall out at any time, but a common event is to have items fall from an ejecting dispenser when the aircraft touches down for landing. For safety of flight and landing it may be desirable to selectively jettison functioned dispensers as soon as permissible, although knowledge of dispenser reliability and failure modes may be lost. Jettison may also be desirable since empty dispensers often exhibit cavity resonances (acoustic vibrations) that will unduly vibrate the aircraft or slowly destroy the empty dispenser while still on the aircraft.

8.4.4 JETTISON FLIGHT TESTS

8.4.4.1 PURPOSE

Internal/external stores are jettisoned to rid the aircraft of their weight, drag, or other undesirable characteristics. Virtually any type of store may be jettisoned, but typical examples are fuel tanks and empty dispensers. Jettison may occur in an emergency to improve aircraft survivability or just to avoid the carriage of an item of questionable value and safety. Jettison of empty dispensers may be desirable to reduce acoustic vibrations generated by dispenser cavity resonances. Since the jettison of stores is not always a preplanned event, the speed limits to which a store may be jettisoned should be as wide as possible. Jettison is normally done in straight and level flight, but there are exceptions. Munitions are normally jettisoned safe.

1. There are two modes of jettison: selective and emergency. Selective jettison consists of the elimination of part of the stores and suspension equipment (usually excluding pylons). Emergency jettison constitutes the elimination of all stores and suspension equipment (including pylons on some aircraft) usually in a preset sequence. Under each of these cases, there may be an option to release just stores, then failing that, stores and suspension equipment, and on some aircraft, the pylons. Selection of the options may be made by the pilot or built into the stores management set.

2. Jettison of stores suspension equipment and if applicable, pylons are usually done forcefully. In jettison, missiles may be launched safe or allowed or to fall off their launcher, or on some aircraft, released as a missile/launcher combination. Jettison tests are also conducted to demonstrate that the store and/or suspension equipment will safely separate from the aircraft throughout the desired jettison envelope. Satisfactory separation is not a requirement, and cases arise where minor item-to-item or item-to-aircraft contact is acceptable.

8.4.4.2 JETTISON DATA REQUIREMENTS

Data are taken to ensure the items released represent the inventory, to ensure the desired jettison conditions are demonstrated, to document the item jettison characteristics, and to allow comparison of flight jettison motion with that predicted during simulation.

To ensure the test items represent the inventory it is desirable to measure the mass and physical characteristics of the item jettisoned. If this is a single store, proceed as in release tests. However, if a store/rack store/pylon or other configuration of items is to be jettisoned, the mass and physical characteristics of those combinations must be determined. The mass properties of individual pieces may have to be summed to estimate the mass properties of the combination; however, it is more desirable for actual measurements to be made. The mass and physical properties are of interest as well as the location of stores on the rack, if a rack jettison is planned. If fuel tanks are jettisoned it is desirable to note quantity and location (compartment) of fuel. It is also desirable to know fuel seepage rate, if fuel tends to slowly leak into other compartments of the tank. Finally, some fuel tanks, multiple ejector racks, and pylons have a pivot mechanism of some sort to control initial jettison motion of the item. These pivots employ various ways of adjusting the amount of rotation or translation allowed before release finally occurs. Details of these adjustments are critical to the orderly understanding of test results.

8.4.4.3 JETTISON TEST PREPARATION

Preparation is essentially similar to that of release tests. The desired jettison envelope usually consists of a speed range over 1 "G" level flight. The speed range shall be as broad as possible consistent with flight safety, so the operational pilot is not driven to unreasonable extremes or a single airspeed jettison. Desirable speed ranges encompass takeoff speed through maximum speed. For rotary wing aircraft, jettison shall be accomplished during autorotation.

1. For a single carriage stable stores, the employment (release) envelope may be virtually identical in airspeed to the desired jettison envelope. However, jettison is often accomplished at flight conditions where employment is not normally done, such as high altitude, low speed or low altitude, high speed, and hence, even for a single carriage store, the employment tests may not demonstrate the entire envelope desired for jettison. Test plans should reflect these differences.

2. The jettison test plan will probably not include all the variables in release tests, but consideration must be given to more than speed. Jettison sequence and interval between stations can be a large factor in determining whether jettisoned stores collide below the aircraft. For items of variable CG such as partially loaded dispensers, fuel tanks, and multiple ejector racks with hung stores or partial downloads, a careful analysis will have to be made to select representative cases and avoid testing all possible situations over the speed range.

3. Any store with folding fins that is jettisonable as a store shall have its fin release wire hardwire to the aircraft. An arming solenoid shall not be used for this function since, during jettison, the arming solenoids will not be activated and the fins will not open, resulting in a potentially dangerous separation.

8.4.4.4 JETTISON TEST ARTICLES

Normally multiple ejector racks, practice bomb racks, and pylons will be inventory items since small numbers are involved and it would be impractical to develop and procure a ballasted version. However, it may be possible to use condemned but structurally sound hardware to minimize lost equipment.

8.4.4.5 JETTISON TEST CONDITIONS

Test conditions shall be chosen to demonstrate safe separation throughout the entire jettison envelope. Critical test conditions for jettison may include maximum airspeed (maximum dynamic pressure), maximum Mach number, minimum "G," minimum release interval, maximum aircraft angle of attack, jettison during autorotation, or sideslip or others as specifically related to the test item.

8.4.4.6 JETTISON ACCEPTABLE CRITERIA

Separation shall be safe but need not be satisfactory. For unusual cases, minor store-to-store or store-to-aircraft collisions may be deemed acceptable if the envelope cleared is greatly expanded due to that acceptance. Aircraft response shall be noted, but unless severe, shall not prohibit jettison. Items jettisoned may break up or otherwise fail after release as long as such break up does not threaten the aircraft.

8.4.4.7 JETTISON TEST PROCEDURES

Procedures are as discussed in release tests. Items released in jettison tests often possess center-of-gravity, position, aerodynamic shape, or other characteristics that would be undesirable from a separation viewpoint. Separation predictions are often incorrect due to an inability to accurately predict aerodynamic or mass characteristics. Therefore, jettison tests shall be considered as high risk, and test personnel shall be appraised of the increased likelihood of the jettisoned item striking the aircraft.

8.4.5 BALLISTIC TESTS

8.4.5.1 PURPOSE

An integral part of the determination of compatibility of a munition with a specific aircraft is the insurance that the munitions when employed will traverse a repeatable trajectory to the target. A munition's ballistic accuracy and trajectory must be assessed, and release tables (or inputs to munition delivery computers) prepared to provide the aircraft flight crew with weapon release system settings and delivery instructions for various flight conditions.

8.4.5.2 BALLISTICS DATA REQUIREMENTS

1. Photographic Requirements:

Onboard and photochase aircraft motion picture film (200 frames/second) of the munition separation similar to that used during separation testing is sufficient.

2. Cinetheodolite Film Coverage:

Time-Space-Position Information (TSPI) of the aircraft and munition by cinetheodolites operating at 30 frames per second on 35mm black and white film should provide the following coverage:

a. The aircraft from a minimum of three seconds before release to as long after release as the aircraft appears on the film of the phototheodolites tracking the munition.

b. Of the munition from release to cluster opening, munition function or impact.

3. Radar Data Requirements:

Where conditions do not permit good phototheodolite coverage and the munition is large enough, a radar may attempt to provide TSPI coverage. The radar should track the aircraft and the munition as above, operating at 40 samples per second (sps). Radars such as the MSQ-77 and the FPS-16 with Automatic TV Tracking System are considered optimum for this purpose. For tests on which munition/aircraft separation throughout the trajectory is required, a separate radar should be provided to track the aircraft and record data at 10 sps from prior to release to bomb function/impact.

4. Time of munition separation from the aircraft:

Knowing the moment of separation is essential for good ballistics data. Some means of determining this time are:

a. By means of instrumentation installed on weapon racks, which either transmits the data to the ground to be recorded by ground telemetry systems, with ± 1 millisecond accuracy, or record it by an on-board magnetic tape recorder.

b. By medium speed tracking cameras on 35mm black and white film at 96 frames per second with ± 5 millisecond accuracy.

c. By the tracking phototheodolites ± 0.0167 second accuracy. This accuracy is only acceptable for use in ballistics computations for munitions releases at 300 knots or less.

d. Release initiation by the pilot from the aircraft UHF 1000 Hz tone, to within 0.1 second for standard tones, due to transmitter and receiver triggering delays, and to ± 5 milliseconds for 150 millisecond delay tones. This tone instrumentation is a less desirable alternate than the telemetry and photographic instrumentation described above.

5. Munition function times:

Any special event times such as fins opening, chute deployment, munition functioning, cluster functioning, and impact can be recorded by the instrumentation described above to accuracies as stated. The duration and periods of recording these data must be established; whether it is to be recorded during the complete trajectory or only during specified portions of the trajectory. Thirty-five mm film can be used to record these data. Color film can be used to record events where color contrast is an important factor in facilitating the detection and recording of their occurrence; otherwise black and white film should be used. For events requiring timing accuracies higher than those specified above (i.e. one millisecond or higher), 16mm cameras operating at frame rates of 1000 fps or higher and with color or black and white film as specified above may be required.

6. Impact times velocities and angles:

If submunitions or a munition is too small to be tracked by phototheodolites or the tracking cameras as described above, then CZR-1, fixed Milliken, or similar grid cameras with black and white film will be required.

7. Munition fuze burst heights:

Above fifty feet, normal phototheodolite tracking data is accurate enough. Burst heights from ten to fifty feet should be measured using phototheodolites and high speed cameras (1000 fps rates) with flags of known height at the impact points. Burst heights of four inches to ten feet should be measured using high speed cameras operating at 2000 to 4000 fps on 16mm color film, mounted to cause the cameras to track in azimuth only. Colored Fuze function height reference panels should be within the camera view.

8. Munition or submunitions impact data:

For a large munition (excluding submunitions), scoring by polar coordinates oriented to the target and to the flight line downrange of the target is sufficient. For submunitions released on targeted grids, data gathered should include:

a. Standard grid coordinate scoring for either the submunitions initial or final impact locations.

b. Number of submunitions located.

c. Number of duds.

9. Mass Properties of Munitions:

Weight (mass), center of gravity, and moments of inertia (yaw and pitch axes) of each munition identified by aircraft, mission, pass and aircraft station is necessary to complete data reduction requirements.

10. Meteorological data:

Atmospheric properties (temperature, density, pressure, humidity, etc.) should be obtained from the upper air observations within three hours of the drop time.

Wind direction and velocity from the surface to 3000 feet (5000 feet for guided munitions) at 500 foot increments and from 3000 feet at 1000 foot increments to 1000 feet above the release altitude (to a maximum of 15,000 feet) are required within 30 minutes of the drop time in the vicinity of the drop area. For altitudes of over 15,000 feet, the Rawinsonde upper air data will be used and integrated into the ballistic data printouts. For certain tests, special Rawinsonde missions at times closer to the mission time should be scheduled and their data used for this purpose. These missions may be performed either before or immediate after the mission, whichever is closer to the actual mission time.

8.4.5.3 BALLISTICS TEST PREPARATION

1. Test Article:

Each munition dropped for ballistic test purposes must possess the exact aerodynamic geometric and mass properties of the actual munition. The munitions may be live but are generally inert for testing purposes. Painting the munition to enhance or facilitate optical tracking may be required. If so, the exact paint scheme should be decided upon in consultation with the test range operators.

2. Test Equipment:

   a. Test aircraft with onboard cameras oriented to view store separation.
   b. Photochase aircraft.
   c. Rawinsonde, pibal or other suitable meteorological measurement equipment.
   d. Tracking radar (optional).

3. Test Instrumentation:

s a. Cinetheodolite cameras.
   b. Medium speed 96 fps time-correlated ground tracking cameras.
   c. CZR-1, fixed Milliken, or similar grid cameras.
   d. Facility for obtaining weight center of gravity and moment of inertia of test munitions.
   e. One thousand Hz UHF tone installed in the drop aircraft is desirable as are beacons or other tracking aids.

4. Test Conditions:

In general, test conditions will be those dictated by the specific munition loading configurations and delivery envelope requirements of the aircraft/munition combination being evaluated. In each instance, the required loading configurations and delivery conditions shall be specified by the certificating agency. The release conditions shall include the extremes of altitude, airspeed and dive or loft angle in the delivery envelope, and several intermediate conditions. In instances where aircraft independent ballistics have not been established for the munition, tests to determine these data shall be included and flown prior to the conditions making up the required envelope. Conditions to obtain aircraft independent ballistic data normally include several airspeeds and altitudes, releasing in level flight.

8.4.5.4 BALLISTICS TEST PROCEDURES

It is necessary for the text aircrew to release the munitions so they will fall on or near the target where test instrumentation can gather required data. But since ballistics do not exist for the munition, aircraft computed weapon delivery devices will be inaccurate. Several methods can be used to put the munition on the target. All the following methods depend on analytical prediction of bomb range from the given test conditions:

1. Onboard Systems:

Aircraft on-board systems can still be used, including fixed-sight depression and computed releases using radar or HUD ranging.

a. Fixed sight depression can be predicted but should be used only to backup other release indications.

b. Radar ranging for release can be used if a radar "show" target is constructed. Usually, an aircraft computer can release the weapon at the proper point after the predicted bomb range is entered into release computers by the aircrew.

c. Similarly, some aircraft permit a predicted bomb range to be entered into it's bomb release computer for release with a visual HUD reference.

2. Ground Systems:

Ground based systems can also help position an aircraft at a given point in space so the munition will impact the target.

a. Radar, usually tracking an aircraft beacon, can help position the aircraft. The radar operator can vector the aircrew to the desired point on the desired heading. This method is particularly useful for high-altitude releases where on-board aircraft systems will be much less accurate. Radar is good for rough alignment regardless of munition release method.

b. Visual guidance can be radioed to the air from a station where a window grid (similar to the fly-by tower) permits left/right or up/down measurement of the aircraft flight path. This method is particularly good for low altitude releases where bomb ranges are short and the release aircraft will pass close to the target and directing tower.

3. Flight Parameters:

Regardless of the method used to get to the release point it is solely up to the aircrew to be at the desired airspeed, Mach, load factor, bank angle, dive angle, etc. Practice passes should be planned for particularly difficult releases where a large number of parameters must be met at once. A 500 foot, 400 knot level release may require little practice, while a 600 knot, 3000 foot, 3G, 30° dive release will require several practice runs. Plan practice missions if required.

4. Established Go/No-Go Criteria:

A minimum of 3 TSPI radars or cinetheodolites may be required to be tracking before good data can be obtained. Establish minimum required equipment during test planning and stick with the plan during execution. The aircrew cannot tell if ground equipment is operating so it is up to the mission director to verify all systems operating just prior to release. Transmit an abort call if systems aren't ready, preferably before high-speed cameras start up for a release.

8.4.6 WEAPON DELIVERY ACCURACY EVALUATIONS

8.4.6.1 PURPOSE

Although not a part of the store certification process, weapon systems accuracy tests are very dependent upon the results of store certification testing. The objective of any delivery accuracy test is to demonstrate that the munition can be delivered on the target within a specified distance or within lethal radius of the weapon. Failing this, one must determine what caused the munition to miss the target and to recommend corrective action.

After completing ballistics testing, data for a weapon on a given aircraft are reduced for inclusion into the aircraft technical order ballistics tables and into the actual aircraft weapon release computers. Operational Flight Program (OFP) updates to weapons computers are issued continually as new weapons, rack, and configurations are tested and fielded. Some more modern OFPs even take into account the individual stations on a rack a bomb is released from. As each OFP is issued, it must be proven to drop bombs accurately with a test program employing a variety of munitions at various release conditions.

8.4.6.2 AIR-TO-GROUND BOMBS

The simplest and most easily understood accuracy tests are those involving air-to-ground, unguided bombs. Gun and missile accuracy testing will not be addressed here, but some of the analysis techniques in the following discussion also apply to gun and missile accuracy testing. Bomb delivery should be accomplished with as much realism as possible; that is, the conditions should be those anticipated for operational employment. These conditions (or tactics) are determined by the using command. If the user doesn't request it, recommend to them a variation in release conditions to simulate a wide range of employment techniques. For example, new cluster bomb units may be employed close-in at 200 feet level at 600 knots, or using a long range toss from miles away. Similarly, a radar-fuzed weapon may be employed with burst altitudes from thousands of feet height to nearly the surface. Verifying the OFP or ballistics tables at a great variety of conditions will cost time and money, so plan carefully to conserve resources. You should be able to verify the OFP with fewer sorties than in the ballistics determination phase.

8.4.6.3 MANUAL BOMBING ERROR ANALYSIS

The basic objective in analysis of air-to-ground weapon accuracy is the identification of the individual delivery error sources and determination of the magnitude of the resultant target miss-distances. These error contributors may be categorized as aircraft position/velocity errors and bomb ejection/trajectory errors. The identification of each of these errors allows complete analysis of the delivery and correction of the errors where possible.

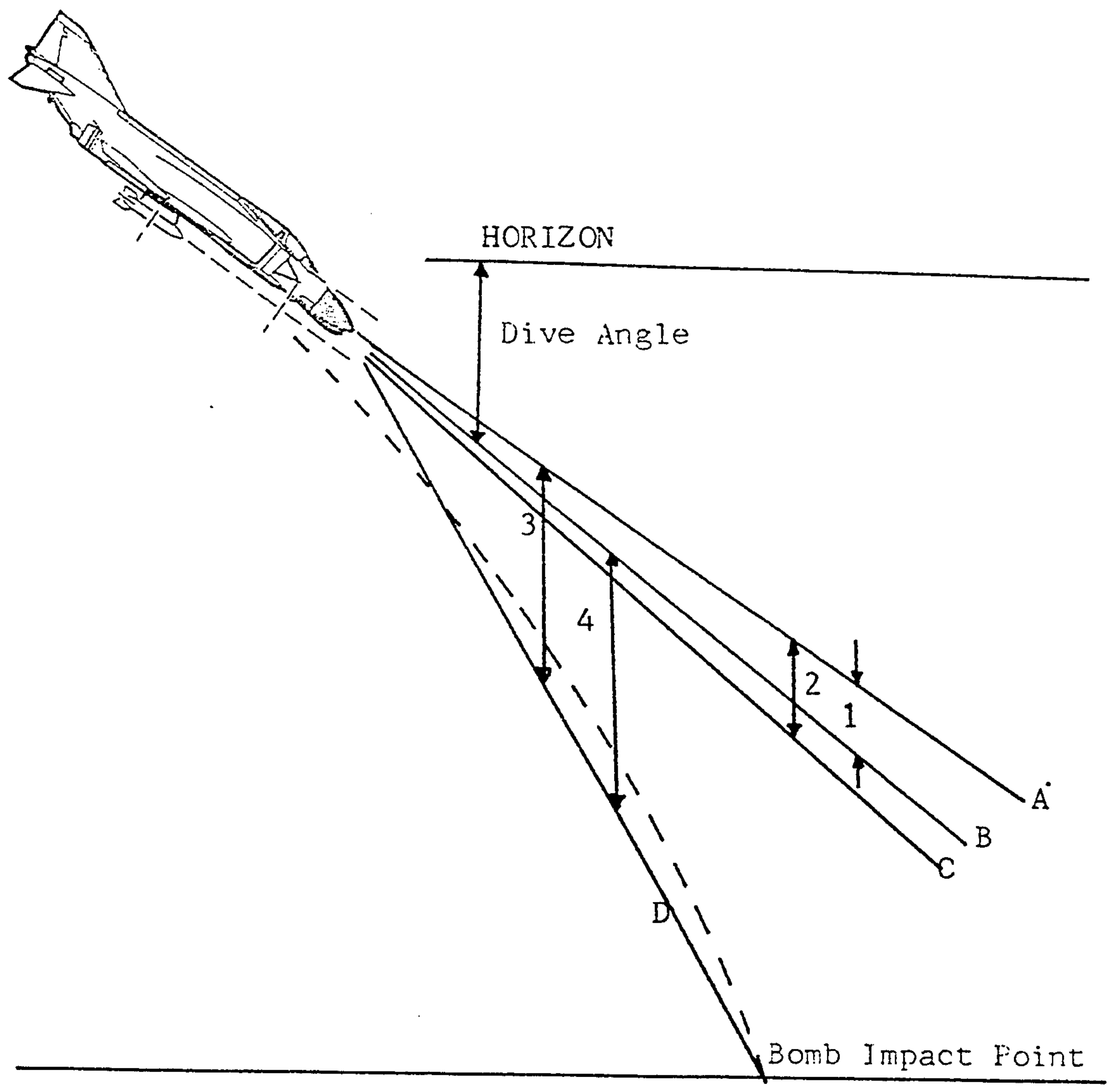
The initial step in the conducting analysis is to identify all impact errors caused by deviation from the programmed release conditions. The remaining errors must then be attributed to ejection, trajectory, or uncorrected wind error. Manual and computer systems require varied approaches in the determination of aircraft position/velocity analysis and are addressed.

1. Bomb Sight:

The positioning of the aircraft for weapon release is predetermined by establishing the geometric/velocity relationships necessary to deliver the bomb on target. The bomb range is a function of altitude, airspeed, flight path angle, and bomb drag. Therefore, given the above conditions, the resulting bomb range is known. But how does the pilot achieve all these conditions and know where the bomb is going to impact? He knows this through the use of a sight system on the aircraft that can either be a fixed sight indicating where the bomb will land if all the preplanned conditions are achieved, or a computing sight that may be mechanized in various ways but generally is predicting the weapon impact point based upon the actual aircraft conditions. In order to understand a simple fixed sight, several terms must be understood. The Fuselage Reference Line (FRL) is the aircraft longitudinal axis or a line parallel to it. A mil is a unit of angle measurement equal to 1/64000 of the circumference of a circle and is the unit of measurement used in sight settings. One degree equals approximately 17.78 mils and a mil is approximately one milliradian. The Zero Sight Line (ZSL) is the reference line of the sight at zero mils depression. Normally the ZSL is referenced to the FRL in determining the sight alignment. This is one source of error in weapon systems accuracy testing, and proper sight alignment must be established prior to any testing, and may have to be reverified during testing or at the end of the test program. Sight alignment procedures are prescribed in the appropriate aircraft maintenance technical orders.

2. Typical Problems:

A typical bombing problem is illustrated in Figure 10. The angle between the horizon and the flight path is the dive angle used in determining bomb range. The sight depression from flight path (SDFP) is the result of the difference between the flight path/ground interception point and the bomb range and is the depression that is computed and presented in the technical order ballistics tables. Since the ZSL is not generally along the flight path and its position is directly related to angle-of-attack (AOA), the ZSL difference from flight can be calculated based upon the aircraft's gross weight and calibrated airspeed. This depression is added to the SDFP to get the total depression that the sight must be set at.



ANGLES	
1.	Angles of attack.
2.	Two degrees (35 mils) below FRL.
3.	Sight depression from zero sight line (or from FRL).
4.	Sight depression from flight path.

REFERENCE LINES	
A.	Fuselage reference line (FRL); pipper sight line at zero mils depression.
B.	Aircraft flight path.
C.	Radar antenna boresight (BST) line.
D.	Depressed pipper sight line.

FIGURE 10. THE BOMBING PROBLEM

3. Pipper Position:

Assuming a no wind release, the aiming index on the sight should overlay the target at the moment of release. Aiming index misplacement at release will result in an impact of one foot per mil per 1000 feet of slant range IN THE MIL PLANE (the mil plane is the plane perpendicular to the sight line and a straightforward trigonometric conversion allows conversion from the mil plane to the ground plane). Aiming index position error at released is recorded from gunsight video.

4. Position/Velocity Errors:

Airspeed, dive angle, and altitude errors can usually be accounted for by computing the bomb range from ballistic equations using the actual conditions at release and comparing that bomb range to the precomputed bomb range to correct for being off conditions.

5. Winds:

The technical order ballistics tables provide wind correction factors in feet/knot for crosswind and mil/knot for head/tail wind. These corrections are based strictly on the bomb time-of-flight and are equal in magnitude to the wind speed times the bomb time-of-flight and can be fairly accurately approximated in feet by taking the wind speed in knots x 1.69 x bomb time-of-flight. The direction is simply downwind of no-wind impact point. Again, a ground-to-mil plane conversion can be accomplished to obtain the desired units. this impact error may be easily corrected in the analysis process. The wind data for this analysis is obtained from a Rawinsonde balloon. This balloon should be released as close to range time as possible since winds can vary considerably in a short time. Error analysis missions should be scheduled in periods of calm whenever possible.

6. Release Dynamics:

The foregoing discussion has assumed stable flight conditions at the time of release; this may not always be true. For example, the aircraft may be approaching the target on a ground track 200 feet to the right of the target and momentary left rudder may be applied to center the aiming index on the target and the bomb released. This has little effect on the trajectory and the bomb will impact (all other things being equal) 200 feet to the right of the target. A momentary change in pitch, roll, or yaw attitude at delivery has little effect on weapon impact. If the conditions are known, the effects may be corrected and the error analysis accomplished. If the condition is known to exist but the magnitude cannot be determined, the data point (release) must be discarded for purpose of error analysis. An aircraft undergoing G variation at release will effect AOA, ejection velocity, and trajectory. Precise data and computer programming is required to analyze this condition; it is best to throw out the data if unprogrammed accelerations are present at release. The presence of release dynamics may be determined from onboard recording of pitch, yaw, roll rates and G measured at the center of gravity. Phototheodolite data can be used for ground track information.

7. Miscellaneous Errors:

The only remaining errors should be caused by measurement/instrumentation errors and ballistic dispersion (i.e., bomb-to-bomb variations in weight, cg, moment of inertia, ejection velocity, carriage location, fin misalignment, etc).

The end result of this error analysis is to standardize a group of releases to identical conditions resulting in a group of theoretical impacts. If the theoretical impacts show significant variation from actual impacts, the cause(s) of the variation must be determined. Aircraft positioning differences between theoretical and actual impacts must lie in the separation/ballistic characteristics. These variations are usually consistent and will result in a detectable bias (i.e., all bombs long of predicted impact). Actual ejection velocities determined from separation testing must be compared to those used in computing ballistics. Delays between bomb button actuation and ejection cartridge firing must be determined and compared to design values. If variances are discovered, they must be eliminated or the ballistic tables must be corrected accordingly and reevaluated.

If the aircraft position is consistently in error, the cause(s) must be determined. Aircraft position, velocity, and attitude indications should be checked against actual conditions. Gunsight harmonizations should be verified. The technical order ballistics figures for mil depression should be investigated and verified.

8.4.6.4 COMPUTER BOMBING ERROR ANALYSIS

1. General:

Error analysis of computing positioning systems is more complex than that required for manual systems, in that determination of delivery conditions is internal to the system. There are many variations of computer bombing systems and various modes of operation; however, the following general description may apply. Weapon type, loading station(s), rack type, fuzing, burst altitude, and arming delay for the weapon may be programmed into the bombing computer prior to flight. Ballistics data and separation effects computations are contained in the OFP update being tested. The weapons computer is fed information on airspeed, altitude, G, attitude, present position, and heading from various aircraft systems (i.e., inertial platform, radar, Air Data Computer, etc). Ballistic data is continually compared with aircraft and target parameters. Steering information is displayed to the pilot to place the aircraft on a course to release conditions. When ballistic data and aircraft/target parameters concur, the weapon is automatically released (or enabled for release on pilot action). An alternative mode combines ballistic data with aircraft position/velocity parameters to continuously compute an impact point and displays this information to the pilot in the HUD.

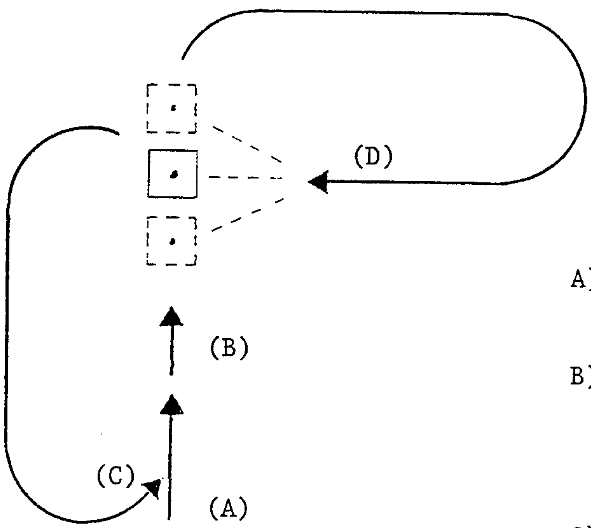
The problem then, is to determine the appropriate aircraft generated parameters at release and compare them with actual data (determined by space positioning) to discover why the bomb did not hit the target. One might assume that no analysis is required if the bomb hits, or comes reasonably close to the target. This is not so. Errors may be self-compensating. These errors must be identified and the sources corrected to assure uniform bombing results.

2. Flight Test Procedures:

To execute the test, the pilot should make sure aircraft systems are as accurate as possible. INS alignment should be as good as can be attained. The HUD, radar and any other sub-systems in the delivery system should be boresighted or aligned before the start of testing. These actions are designed to minimize errors and simplify data reduction.

In the air, the accuracy of the aircraft systems should be verified. One method of verification is a "cloverleaf check," (Figure 11). INS drift will appear on the HUD if a ground stabilized pipper is placed on the target and one or more dive passes are made to observe the pipper move over time. Radar or other ranging system errors can be observed by making a dive pass from 90 degrees to the original heading. Ranging errors will appear as left or right mis-alignment of the pipper when viewed from the side. The system check should be videotaped through the HUD. Drift or ranging errors can be accounted for in data reduction, but excessive errors might be grounds for terminating the mission.

The pilot should then make delivery passes from operationally significant parameters in accordance with the test plan. He should try to put the pipper on the target each



A) Ground-stabilize the HUD pipper on the target.

B) Pulse the stick to 5 g's. If the box jumps off the target, the vertical accelerometer is in error.

C) Circle back to the same run-in heading and observe INS drift effect on the pipper location.

D) Observe aircraft ranging errors by viewing the pipper position from the side (take INS drift into account).

FIGURE 11. TYPICAL CLOVERLEAF CHECK

pass, but not do abrupt maneuvers in the last seconds to accomplish that. Abrupt maneuvers may complicate data reduction. Correlate pipper position and bomb impact point in the debrief. Photo chase and on-board photography are not normally required.

All bomb passes should be videotaped through the HUD. The pilot can review the HUD video to confirm release parameters in debriefing. INS data should be retrieved after landing. Inertial radial error rates, indicated ground speed at a stop, and elevation errors should be recorded for data reduction.

3. Analysis:

The first step in the analysis is to take the actual release conditions (i.e., airspeed, altitude, dive angle, winds, etc.) from space positioning data and compute the ballistics of the weapon from release point to impact.

If ballistic analysis verifies the actual weapon impact (within dispersion limits), this demonstrates that weapon ballistics and bomb computer programming are correct. If the theoretical and actual impacts do not agree, the equations are modified until agreement with the actual ballistics (from theodolite data) is accomplished. The bomb computer equations may then be verified against the correct (i.e., test verified) ballistics and modified and retested as necessary. If programming the weapons delivery computer with the modified ballistics does not result in correlation between actual and theoretical impacts, the fault must lie in computer mechanization. This must be investigated by the contractor and corrected as necessary.

Once the ballistics have been verified or corrected as required, the effect of aircraft release conditions on target miss-distance must be determined. The weapon ballistics and the bomb computer may "agree" on where the bomb will impact but this may not occur on (or near) the target. This can only be caused (assuming no operator error) by the aircraft position/velocity sensors providing incorrect inputs to the weapon computer.

A typical example of this type of error is as follows: Assume the bomb impacted 200 feet long in range and weapon ballistics and computer operation were verified correct as previously discussed. Investigation of computer input data (recorded on magnetic tape) might show a ground speed of 300 knots (perhaps an output of Doppler radar). Review of space positioning data might show that the actual aircraft ground speed at weapon release was 350 knots. This 50 knot release airspeed error would be translated in to an equivalent impact miss-distance, and be shown to account for the 200 foot long impact. In practice, all pertinent aircraft sensor outputs should be compared with space positioning data to determine any deviations and subsequent effects on weapon impact.

GLOSSARY OF ABBREVIATIONS

4T	AEDC Four-foot transonic wind tunnel
AC	Alternating current
AEDC	Arnold Engineering Development Center
AFDTC	Air Force Development Test Center
AFFTC	Air Force Flight Test Center
AFLC	Air Force Logistics Command
AFSC	Air Force Systems Command
AOA	Angle-of-Attack
ARA	Aircraft Research Association, Ltd.
ASEP	Advanced Safe Escape Program
ASIM	Aircraft Stores Interface Manual
CDP	Certification Data Package
CEP	Circular Error Probable
CFD	Computational Fluid Dynamics
CFP	Capture
CG	Center-of-gravity
cm	centimeters
CSDP	Compatibility Source Data Package
CTS	Captive Trajectory System
C_{ℓ_β}	Dihedral Effect Coefficient
C_{n_β}	Static Directional Stability Coefficient
DC	Direct Current
DT&E	Developmental Test and Evaluation
DTNSRDC	David Taylor Naval Ship Research & Development Center
ECM	Electronic Countermeasures
EED	Electroexplosive Devices
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interface
FM	Frequency Modulation
Fps	Frames per second
FRL	Fuselage Reference Line
F_s	Stick Force
G	load factor
HERO	Hazards of Electromagnetic Radiation to Ordnance
HUD	Heads Up Display

Hz	Hertz
IAW	In Accordance With
ICT	Integrated Combat Turn
IOT&E	Initial Operational Test & Evaluation
JMEM	Joint Munitions Effectiveness Manual
KCAS	Knots Calibrated Airspeed
LEL	Lower Explosive Limit
m	meter
MER	Multiple Ejector Rack
mils	Milliradians
mm	millimeter
NWC	Naval Weapons Center
OFP	Operational Flight Program
ONERA	Office National d'Etudes et de Recherches Aerospatiales
OT&E	Operational Test & Evaluation
PCM	Pulse Code Modulation
PMD	Program Management Directive
PO	Program Office
q	Dynamic pressure
SDFP	Sight Depression from Flight Path
SPM	System Program Manager
SPO	System Program Office
SPS	Samples per second
SSDP	Standard Source Data Package
TAC	Tactical Air Command
TER	Triple Ejector Rack
TO	Technical Order
TSPI	Time-Space-Position Information
UEL	Upper Explosive Limit
UHF	Ultra-high frequency
UK	United Kingdom
USAF	US Air Force
VKF	Von Karmen Facility
WSDP	Weapon Source Data Package
ZSL	Zero Sight Line