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I am submitting herein a thesis written by Peter J. Walczak entitled "Testing Near Airspeed Limits During Safe Separation Flight Test". I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Robert Richards
Major Professor

We have read this thesis and
recommend its acceptance:

Dr. Peter. Solies

Dr. Ted Paludan

Acceptance for the Council:

Anne Mayhew
Vice Provost and Dean of
Graduate Studies

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**TESTING NEAR AIRSPEED LIMITS DURING
SAFE SEPARATION FLIGHT TEST**

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Peter J. Walczak
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DEDICATION

This thesis is dedicated to the countless aviators who have broken artificial limits
imposed by engineers who have never touched an airplane...
...and lived to tell the tale.

ACKNOWLEDGMENTS

The patience and support of the entire F/A-18 Weapons System Integration Team was vital to the completion of many a safe separation test project as well as this thesis. I would like to thank Pete Ordoulidis and Joe Hegedus for struggling with me through both the overspeed ordeal and flight clearance maze. Special thanks go to my former Skipper, Colonel Joe Mortensen, for banging his head against the table, expressing how we all felt and inspiring me to write my thesis on this topic.

ABSTRACT

Although all flight tests possess their own inherent risks, safe store separation tests, especially those targeting release conditions at or near maximum sanctioned clearance limits, add more hazards to an already bloated list of obstacles. Since the success of most modern flight test programs is measured in terms of cost, schedule, and performance, an unsuccessful test flight can add tens of thousands of dollars and months to an already beleaguered program. With ever-increasing flight hour costs and dwindling budgets, reducing or eliminating unnecessary or unsuccessful sorties is essential. The trick, then, is to fly to achieve desired test conditions, yet not exceed aircraft limitations and cause the tester to return to base prematurely or, worse, not return at all.

With the requirement to test near the aircraft airspeed limits, occasional clearance limit violations are expected. However, during the weapons separation Follow on Test and Evaluation (FOT&E) phase of the F/A-18 E and F model Super Hornet, of the 55 attempts at test endpoint conditions targeting 600 knots calibrated airspeed (KCAS), 1.20 indicated Mach number (IMN), and 0.5 g normal acceleration, 11 resulted in airspeed limit exceedances. These failures accounted for 20% of the total number of attempts.

Aircraft clearance limits are imposed by many engineering disciplines. Thorough knowledge of these aircraft limits and their genesis is vital for effective risk assessment, decision making, and avoidance.

This thesis examines modern weapons separation test techniques for the F/A-18 E/F Super Hornet, the obstacles faced with regard to testing near airspeed limits, the

planning and flight techniques required to overcome them, results, and lessons learned for test planners and pilots alike.

PREFACE

Most information contained within this thesis was obtained during actual Naval flight test of Weapon System Integration test projects at the Naval Air Warfare Center-Aircraft Division (NAWC-AD) located in Patuxent River, Maryland. The analysis, opinions, conclusions, and recommendations expressed herein are those of the author and do not represent the official position of the Department of Defense (DOD), Department of the Navy (DON), Naval Air Systems Command (NAVAIR), or Air Test and Evaluation Squadron Twenty Three (AIRTEVRON23). Although information was obtained from actual flight test, dedicated flights to support this thesis were not performed.

The author was the project officer for many of the weapons separation test projects mentioned herein. Although the test methods and techniques discussed in this thesis were developed specifically for the F/A-18 E/F Super Hornet, they may be applied similarly to most any high performance tactical aircraft.

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LIST OF ABBREVIATIONS

6-DoF	Six Degree of Freedom
AGM	Air-to-Ground Missile
AIM	Air Intercept Missile
AOA	Angle Of Attack
AOC	Active Oscillation Control
BFDGW	Basic Flight Design Gross Weight
CFD	Computational Fluid Dynamics
CVER	Canted Vertical Ejector Rack
Deg	Degrees
EMD	Engineering, Manufacturing, and Development
FLIR	Forward Looking Infra-Red
FOT&E	Follow On Test and Evaluation
ft	Feet
HARM	High-speed Anti-Radiation Missile
HSO	Heavy Store Oscillation
HUD	Heads Up Display
IMN	Indicated Mach Number
IN RNG	In Range
KCAS	Knots Calibrated Airspeed
kts	Knots (or nautical miles per hour)
LAR	Launch Acceptability Region
LBA	Limits of Basic Airplane
lbs	Pounds
LCO	Limit Cycle Oscillation
LEX	Leading Edge Extension
LTE	Launch-To-Eject
MAN	Manual
MAX	Maximum afterburning thrust setting
MIL	Military thrust setting
MRI	Minimum Release Interval
ms	milliseconds
MSL	Mean Sea Level
NAVAIR	Naval Air Systems Command
n_z	Normal Acceleration
PB	Pre-Briefed
PSI	Pounds per Square Inch
RTB	Return To Base
s	Seconds
SMS	Stores Management Set
TEF	Trailing Edge Flaps
USN	United States Navy
VER	Vertical Ejector Rack

CHAPTER 1

INTRODUCTION

SAFE SEPARATION FLIGHT TEST

During World War II, most air-to-ground munitions came in the form of free-fall bombs or ballistic rounds launched from some internal aircraft mechanism such as a bomb bay or gun. Although some aircraft did carry weapons externally, due to propeller-driven aircraft performance limitations of the day, release of such ordnance usually occurred at relatively low airspeeds and Mach numbers, limiting the impact of shock wave effects and providing a relatively benign separation environment. During the rise of jet propulsion after the war, however, aircraft performance capability increased significantly. Although large, bomb bay-equipped aircraft still maintained their role as strategic bombers, their smaller, more agile fighter-sized counterparts further evolved. Departing from strictly air-to-air functions, separate new airframe designs sought to fill the billet of tactical strike. These nimble new bomb-dropping specialists became known as “attack” aircraft such as the A-4 Skyhawk, A-7 Corsair II, and A-6 Intruder. Both fighter and attack aircraft refined their single-role doctrines to perfection. Defense budgets are not bottomless, however, and through political and fiscal pressures these distinct airframes ultimately re-merged into the multi-role “strike-fighters” of today such as the F/A-18 Hornet (figure 1).

For over 50 years, wing and fuselage-mounted bombs have been the staple of attack aircraft munitions. The increase in aircraft performance after World War II bred a natural desire for expanded weapon release envelopes. As airspeed and Mach number



Figure 1
F/A-18A HORNET PERFORMING SAFE SEPARATION TESTING
Photo courtesy Vernon Pugh

capabilities grew, however, so did the complexity of predicting weapon separation characteristics. Free-fall weapons that were previously exposed to comparatively benign subsonic flows and dominated by gravitational forces now faced supersonic shockwaves, high dynamic pressures and suction effects to a degree never before experienced. Bombs released in this environment exposed the aircraft to significant dangers as unstable bomb flight caused unpredictable weapon flight paths. Close to the aircraft, even a relatively light, small unstable bomb impacting the airframe could cause severe structural damage or catastrophic failure. Also, bomb-to-bomb collisions, even hundreds of feet away could result in detonation and aircraft destruction. This further emphasized the need for disciplined safe separation testing.

ENDPOINT OVERSPEEDS

Endpoints are defined as the final test points in a test plan matrix and encompass the expected regions of worst case store separation characteristics, but not to exceed aircraft flight limitations. Except in rare cases, for the F/A-18 E/F Super Hornet these conditions occur at 600 knots calibrated airspeed (KCAS), 1.20 indicated Mach number (IMN), and load factor of 0.5 (and thus 60 deg dive). During the weapons separation segment of the Follow on Test and Evaluation (FOT&E) phase for the F/A-18 E/F Super Hornet (as of December 2002), 55 attempts were made at endpoint conditions for the release of various stores. Of these attempts, 11 resulted in exceeding the air-to-ground store speed limit of 635 KCAS, and comprised a full 20% of the total attempts.¹ These overspeeds, like most clearance limit violations, resulted in mandatory discontinuation of

the sortie and immediate return to base for maintenance inspection. An effort to determine causal factors and avoid future excursions was therefore launched.

TESTING CONSIDERATIONS

The total number of required test flights and the allowable amount of leap between test points depend on desired final clearance limits, results from previous separation tests on similar stores, the type and number of different aircraft to be cleared, and type of delivery profiles and minimum release intervals that are desired. Overall, release envelopes should be extended as large as possible to allow for development of new fleet tactics and introduction of new delivery maneuvers. In all cases, the separation characteristics should be tested beyond the limits recommended in a final clearance to allow a safe margin of error for the end user. Additionally, the carriage of stores should at least be cleared to the airspeed, Mach number, and load factor limits of the basic airplane (LBA). For the F/A-18 E/F (a further description of which is located in appendix A), the air-to-ground stores carriage limits are 635 KCAS and 1.3 IMN.

Table 1 further describes the airspeed and Mach number specifications for the F/A-18 E/F.² Although optimally the release regime should also possess the same capabilities, its maximum release load factor (much more commonly known as “g”) should be at least 4.0 and its minimum at most 0.5. Moreover, releases should be demonstrated up to a 60 degree dive and down to their minimum release interval (MRI).^{3,4} According to the F/A-18 E/F specification, all store ejections must be accomplished between a minimum load factor of zero and a maximum from table 2.²

Table 1
F/A-18 E/F STORE DESIGN SPEED SPECIFICATION
Source: *Detailed Specification for Model F/A-18 E/F Aircraft Weapons Systems*

Store			Wing Station Airspeed and Mach Number Limits (KCAS/IMN)			
			Inboard	Midboard		Out-board
Air-to-Air Missiles	Goal		LBA (720)	LBA (720)		LBA (720)
	Required	AIM-7 & 9	635/1.6	610/1.6		575/1.6
		AIM-120	635/1.6	560/1.6		560/1.6
Air-to-Ground Missiles	Required		635/1.3	550/1.3		550/1.3
Tank Inboard, Tank & Weapons	Required		635/1.6	Air-to-Air	AIM 7&9 575/1.6	575/1.6
					AIM120 560/1.6	560/1.6
				Air-to-Gnd	550/1.3	550/1.3
Air-to-Ground Stores*	Goal		635/1.3	635/1.3		635/1.3
	Required		575/1.3	575/1.3		550/1.3

* This requirement applies to both similar and dissimilar stores on adjacent stations.
Note: For configurations involving AGM-88 HARM on the outboard station, the required speed may be 540/1.3

Table 2
F/A-18E/F MAXIMUM RELEASE LOAD FACTOR SPECIFICATION
Source: *Detailed Specification for Model F/A-18 E/F Aircraft Weapons Systems*

Store Type			Load Factor Specification		
			Single Release		Multiple Release
			Centerline or Inboard Stations	Midboard or Outboard Stations	
Air-toAir			6.0	6.0	6.0
Air-to-Ground	Rail Launched				5.0
	Ejector Released	0-620 lbs		5.0	3.0*
		620-1120 lbs			
		1120-2100 lbs		4.0	

*Limits shall be based on flight test results, but not less than a load factor of 3.0 at aircraft delivery weight, which includes 60% internal fuel

CHAPTER 2

BACKGROUND

TEST PLANNING

Safe separation testing for tactical military aircraft generally includes release of a wing or fuselage mounted store (tank, pod, weapon, etc.) and associated data analysis in the form of onboard film or video, photogrammetric data reduction, six-degree of freedom (6-DoF) telemetry, or ground camera footage. Depending on the amount of engineering analysis available, three primary test methodologies exist for the weapon separation engineer: “brute force” flight test build up, endpoint demonstration, and model verification.^{3,4}

The “brute force” build up approach consists only of actual incremental flight test and is considered the most reliable way to definitively prove separation characteristics. It allows direct trend observation of the separating store and results in an ability to provide immediate, although partial, capability to the fleet. Since this method does not rely on analytical predictions or previous separation results, however, it suffers from a high degree of outcome uncertainty and risk. Alleviating these drawbacks requires incremental buildup in small steps which directly leads to an increase in total number of sorties and store assets required. This makes it the most costly in price and man-hours and thus least desirable from a programmatic standpoint.

The method of Endpoint Demonstration is reserved for test stores that can be considered analogous to other stores previously displaying safe separation characteristics. However, despite its name, this method still requires initial separations to be conducted at

benign, preferably repeatable, flight conditions to first verify similarity to the comparison store before proceeding to the critical end point flight conditions. Fortunately, it allows for comparatively quick, inexpensive completion of the test effort since a minimum number of sorties and store assets are required. Testers must proceed cautiously when using this approach, however, since seemingly small inconsequential differences in store or aircraft configuration may, in fact, cause large variations in separation characteristics. This technique, therefore, suffers from a degree of uncertainty since every possible condition in the envelope of a store will not be tested, and unknown performance pitfalls may escape undiscovered.

The Model Verification method is employed by generating an analytical model from wind tunnel data or computational fluid dynamics (CFD) analysis then validating it through actual flight test. Considered low risk from a flight safety standpoint, this approach also reduces program uncertainty by delivering performance expectations up front. A large expenditure of funds is usually necessary early in a program to collect and process the data. However, if the model is deemed accurate, the expense can be compensated in the long run by fewer total sorties. Additionally, requiring analysis completion before actual flight test can occur may result in significant schedule delays if not properly managed. By comparing flight test data with analytical predictions and determining their trends, testers are able to focus flight test efforts on regions of interest within the envelope.

In a perfect world, all three techniques would be fully used in an effort to combine and overlap data. However, the reality of tight budgets and compressed schedules make such a meticulous exploration unrealistic. Fortunately, proper foresight,

planning and safety consciousness usually allow a partial combination of the three techniques to be used. However, despite great leaps in wind tunnel data gathering techniques and computational fluid dynamics (CFD) computer technology, the only sure way to positively determine separation characteristics of a store is to actually release and observe it.

SEPARATION HAZARDS

Barring the unexpected material failure, all separation hazards are historically caused by the same factors, although the results are often quite different. Poor separation performance can be attributed to three major conditions: high airspeed, low normal acceleration, and close release interval.³ Aerodynamic forces can far exceed ejection and gravity forces at high release airspeeds. These problems are exacerbated at supersonic speeds where shock wave effects can cause stores to pitch or yaw back into the aircraft. Additionally, releases in steep dives with their accompanying low normal load factor provide little separation force to move stores away from aircraft. These phenomena cause the most dangerous store separation hazards to both the tester and ground personnel which are store-to-aircraft collisions, store-to-store collisions, and store instability.

Anything striking an airframe has the obvious potential to damage it. Even small, relatively light weapons can impart a great deal of energy especially when released at the aforementioned high speeds. Despite being heavy, a large and massive store does not necessarily fall away from the separation aircraft any more cleanly nor exhibit any less motion than a lighter counterpart. In fact, they can be surprisingly agile. Given the fact that most ordnance is carried under an aircraft's wing, the weapon's proximity to vital control surfaces further increases the risk of catastrophic damage. An unexpected bomb-

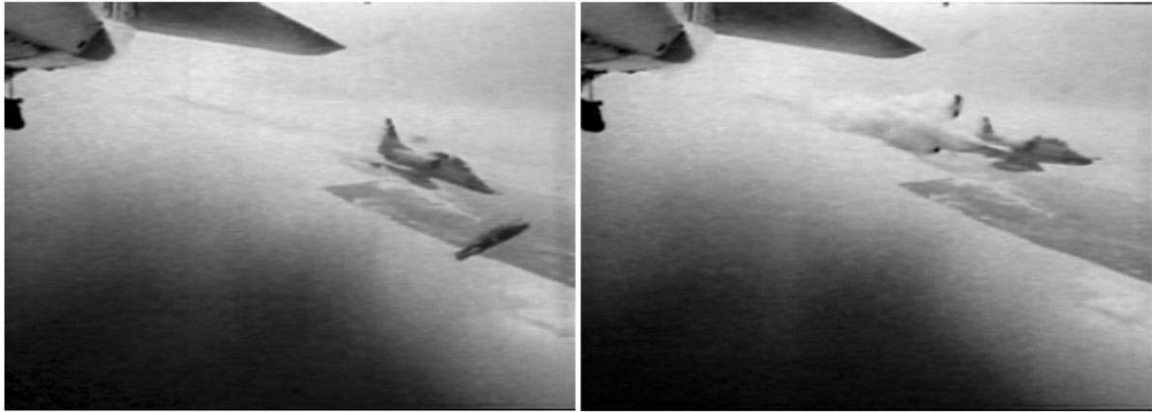


Figure 2
RACK AND BOMB STRIKING A-4 CHASE AIRCRAFT
Source: F/A-18 Project Office

to-aircraft collision with an ordinarily benign 1000 lb general purpose bomb and rack can be deadly to the tester or chase as shown in figure 2. Fortunately the aircrew safely ejected in this case.

Store-to-store collisions below a releasing aircraft may not seem as dangerous as striking an aircraft outright. However, they not only possess the potential to pitch up towards the releasing aircraft and hit it, but, if live weapons, an impact can cause premature detonation as well. The results of an exploding live bomb mere feet below are almost guaranteed to be catastrophic. Additionally, collisions can cause bombs to bounce apart, reducing overall accuracy when attacking a target or falling completely outside expected bomb dispersion patterns.

Store instability can cause the weapon to tumble and most likely fall short of an intended target. It has the distinct possibility of falling outside a test hazard pattern or, if employed operationally, destroying an unintended target. Weapons with simply weak stability are little better and may cause a “coning” effect where the bomb spins, circumscribing a spiraling cone, greatly reducing accuracy.

Table 3
TYPICAL WEAPONS SEPARATION FLIGHT COST
Source: F/A-18 Project Office

Item	Cost (U.S. Dollars)
F/A-18E Flight Cost (1.5 hours)	\$16,200
Test Item Preparation (6 bombs)	\$5,400
Range/Airspace (1 hour)	\$9,400
Telemetry (1.5 hours)	\$7,500
Onboard Camera Support	\$6,800
Photogrammetric Processing	\$8,000
Data Reduction	\$2,300
Total:	\$55,600

FLIGHT TEST COST

Possession of a test asset is not enough to execute a successful test. Rather, the project teams must share the responsibilities of feeding and maintaining them as well. Table 3 shows the approximate cost breakdown for a typical 1½ hour weapon separation test flight on an F/A-18E. These costs account for only the test itself, preparation, and post flight data reduction, and do not include the man hours involved with test planning or report writing.

TEST BUILDUP

For initial separation flights on untested stores, the first release conditions should be as benign as possible. This leads to a single store released from a parent rack in straight and level flight at a normal load factor of 1.0. Airspeed should be low to minimize dynamic pressure and allow examination of the store's basic dynamic behavior during release. If possible, it should be at the airspeed corresponding to the aircraft's maximum range to minimize induced drag on the wing and reduce any local flow angularities. These airspeeds provide another benefit since most aircraft store suspension

equipment is oriented to provide zero store angle of attack (AOA) at maximum range airspeeds, thus further eliminating another source of perturbation.³

Level releases should then be performed at incrementally higher and lower airspeeds until the maximum and minimum desired limits are reached. Overall separation characteristics as determined by their variation in the aircraft's flow field at different speeds can now be determined. Once a straight and level investigation has been completed, parameters such as mach, dive angle, normal acceleration, and release interval may be incrementally expanded.

As dive angle is increased, the component of gravity perpendicular to the aircraft datum line decreases and thus reduces the net separation force. Thus, aerodynamic forces and stores dynamics begin to have a greater effect on separation characteristics (figure 3). Optimally, the airspeed with the least aerodynamic influence, as determined from the level release investigation, should be used for the first separation at each dive angle.

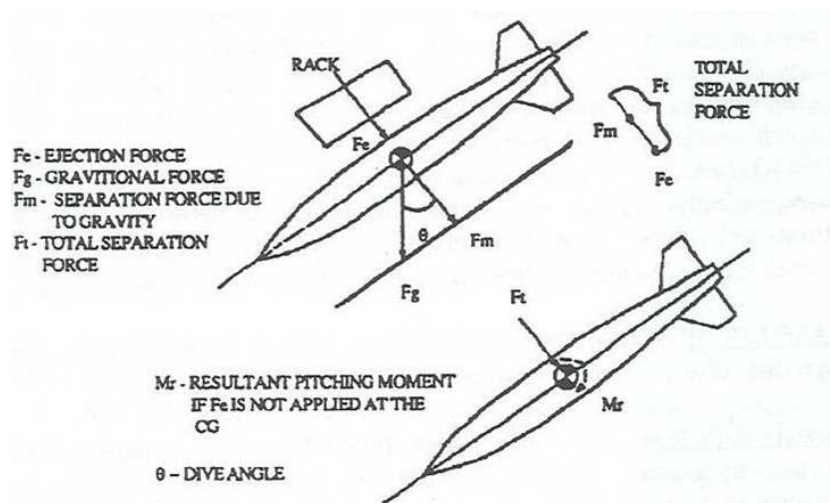


Figure 3
FORCES DURING SEPARATION FROM STRAIGHT PATH DIVES
Source: USNTPS FTM-109, Systems Testing

Then, releases at gradually increasing airspeed and Mach number should be performed until maximum airspeed is reached. With satisfactory releases from level and shallow dive high-speed situations, separations from steeper dives may be tested in increments of up to 15 to 20 degrees.⁴ If results have been favorable thus far, usually only a few high speed points need be completed in the dives before testing the maximum speed endpoint.

In cases where flight test separations are being used to verify an existing analytical model, only certain key test points may be desired for comparison. In this case, although the overall flight test is less rigorous due to a reduced number of sorties, it is nevertheless still critical to approach each point in a build up manner until the model is proven. Even then, unexpected singularities may still exist that were not uncovered by the model. A sample test matrix is provided in appendix B.

RELEASE PARAMETERS

Certain aircraft parameters are critical for satisfactory post flight data analysis and are listed in table 4. The most vital information is airspeed, Mach number, and normal acceleration (n_z), all normally obtained from either on-board instrumentation or pilot's flight instruments. Normally, free fall weapons are tested between a normal load factor of 0.5 and 1.0, whereas forward-firing ordnance such as missiles may be tested from 0.5 g up to 6.0 and above.⁴ Due to the near-impossible nature of achieving exact parameters simultaneously, nominal tolerances are provided in table 4 as well.

Interestingly, during separation testing, the altitude, although critical for data analysis, is considered non-critical to the test pilot (other than for terrain avoidance) and allowed to "fall out" of his test conditions scan. Since on a standard day 600 KCAS and

Table 4
CRITICAL AIRCRAFT PARAMETERS

Parameter	Units	Typical Test Tolerances
Altitude	Feet	±1000
Calibrated Airspeed	KCAS	±10
Indicated Mach Number	IMN	±0.02
Normal Acceleration (n_z)	g	+0.1 / -0.2
Dive Angle	Degrees	±5

1.20 IMN roughly intersect at 18,000 ft MSL, which provides adequate altitude for a safe dive recovery maneuver, the test team will usually accept whatever release altitude is achieved based on environmental conditions.

RELEASE MANEUVERS

A maneuver, of some type, must be used to achieve target parameters. The most common procedure used in safe separation testing today is the straight path dive. Usually achieved from a roll-in maneuver where the test aircraft is rolled to inverted, pulled down to desired dive angle, then rolled upright again, this type of dive makes attainment of release parameters both rapid and repeatable.

STRAIGHT PATH DIVES

Proper planning of test conditions is critical since dive maneuvers are not just used to help accelerate the aircraft to test airspeeds. Test points demanding steady load factors of one and below (normally experienced when employing freefall weapons operationally) require a straight path dive angle. To determine what dive angle is appropriate for desired conditions, one must calculate the arccosine of the target load factor. For example, a test load factor of 1.0 is best attained from straight and level flight

(zero degree dive angle) while 0.7 is achieved from approximately a 45 deg dive and 0.5 from a 60 degree dive. To ensure repeatability and comparability with an analytical model, the tester must minimize variations in gravity vector position. Thus dive angles are normally restricted to within a tolerance of ± 5 degrees.

At straight and level conditions where poor aircraft performance capabilities prevent attainment of target parameters, especially low altitude, high transonic Mach number points, shallow dives angles (normally up to 30 degrees) may be used to accelerate into the test point. Although a steady shallow dive as much as 35 degrees would still result in a load factor within normal test point tolerances of +0.1 and -0.2 for a 1.0 load factor test point, (i.e. load factor is 0.8 in a 35 degree dive) it would exceed normal dive angle tolerances of ± 5 degrees and would shift the direction of the weight vector and is therefore unacceptable. Once conditions are attained, therefore, the aircraft must be recovered to near-level flight for release. This greatly increases pilot workload, however, and often results in failure to achieve test conditions since most excess Mach number and airspeed built up in the shallow dive is counteracted by the bleed rate necessary to recover to near straight and level flight.

CURVILINEAR DIVES

Although desired load factors can theoretically be attained from most any attitude by applying a sustained forward push on the control stick and commanding the aircraft to fly a constant target load factor, it is not authorized for free-fall ordnance testing. This technique, known as a curvilinear dive, reduces the gravity component of the separation force to below that which is experienced in a straight path dive delivery of comparable

dive angle. Essentially “flying into the bomb”, this method decreases the resultant separation force and thus the safety margin of separation. In fact, the F/A-18 E/F Tactical Manual states “avoid pushovers during weapon release to prevent aircraft to bomb or bomb-to-bomb collisions”.⁵ If a constant pushover is applied, a pitch rate, however minor, ensues. Depending on where test conditions are approached in the dive and when the pushover is initiated, the actual store release may occur at an unpredictable dive angle, not only altering gravity vector placement, but making it difficult to repeat the test point for later comparison. Additionally, this technique increases the pilot’s workload as there are fewer steady state parameters; he must not only monitor and anticipate target test conditions, but must also more closely monitor normal acceleration and constantly modulate stick inputs to maintain it. Although still higher workload, this method usually has less safety impact on separation tests involving forward-firing rail-launched missiles, since they eject forward and away from the aircraft and do not linger beneath.

PILOT RELEASE TECHNIQUE

Since aircraft conditions are usually changing very rapidly, especially when performing endpoint separation testing from a 60 degree dive, the first priority is to stabilize as many parameters as possible and eliminate them from the test pilot’s visual scan. The first likely candidates are heading and dive angle (and its accompanying load factor), which can be attained as soon as the aircraft has finished its roll-in maneuver. Maintenance of the target dive angle (and thus load factor) is facilitated by applying slight nose down longitudinal trim so that little to no control stick input is required. Next, by modulating throttle setting, Mach number should be captured so that attention may

then be diverted to monitoring airspeed buildup and anticipating desired release conditions. Given the transient nature of airspeed as the aircraft is accelerating, descending, and maintaining constant mach, release conditions will be realized for only a fleeting moment. Once attained (within a nominal tolerance), the test pilot must then command release of the test store. The method of ensuring complete and unperturbed separation is often referred to as a “pickle, pause, pull” technique whereby the test pilot depresses the weapon release button, holds it down for the duration of store release (usually fractions of a second), then begins a dive recovery.

DIVE RECOVERY

After weapons release (or simulated release in case of a practice profile), the test aircraft must arrest its rate of descent and return to level or climbing flight. This is accomplished by the dive recovery maneuver which consists simply of a wings level pullup to the horizon or above.

SOURCES OF FLIGHT CLEARANCE LIMITS

Various aircraft clearance limits are imposed by many engineering disciplines such as flutter, loads, structures, flying qualities, and propulsion. Understanding the genesis of these limits helps both the test planner and test pilot make informed decisions when assessing a project’s physical risk. For the F/A-18 E/F, like many aircraft, aeroelastic concerns, specifically flutter, dominate the overspeed hazard assessment. Loads and structural considerations, usually confined to very specific aircraft store configurations, take a distant second place.

AEROELASTIC EFFECTS

Flutter prediction is often considered a “black art” and is still in its infancy. Many techniques exist for flutter flight testing, data gathering, and information interpretation, but none is an exact science. During an aircraft’s design, flutter is never truly totally eliminated, but rather its effects are moved to a part of the aircraft’s envelope that should not be attainable in normal flight. Expertise on the flutter phenomenon and its effects rests with only a few engineers. This lack of universal comprehension sometimes leads to frustration and recklessness in the rest of the aviation and engineering communities. Normally based upon structural and aerodynamic models, each segment of flutter analysis utilizes several simplifying assumptions. These approximations naturally affect the validity of any predictions, especially in transonic flight regimes where transonic models are poor. Since these analyses are, by themselves, insufficient to clear an area of flight envelope, they are usually supported by wind-tunnel comparisons and ground vibration tests. Nevertheless, flutter predictions should always be verified through dedicated flight test using the same caution and build up as any other flight-test evolution.⁶

Flutter

Although only one of many aeroelastic effects, the “flutter mechanism” is made up of a complex combination of forces and moments, structural dampings, and structural stiffnesses. Basically, this interaction causes an oscillation in the form of rapid wing twisting, or control surface or panel vibration. If two or more of these natural vibration

modes coalesce, flutter may ensue. Overall system damping is comprised of both structural damping, provided by such things as shape and construction material, and aerodynamic damping generated by the air mass and “centering tendency” of the high velocity air stream. Most structural modes will show an increase in frequency as airspeed is increased due to aerodynamic “stiffening”. If left unchecked, these oscillations can grow divergent and can progress until some structural failure occurs.

Flutter speed is considered the airspeed where damping is zero and an oscillation barely possesses constant amplitude. Any minute energy addition in the form of an airspeed increase or small load factor perturbation can cause the oscillation amplitude to increase with time. Known as “divergent flutter”, this will eventually result in the component exceeding its structural limits. Since this damage can be wreaked quickly, almost instantaneously, within two or three cycles, flutter is extremely dangerous and potentially deadly. Flutter susceptibility generally increases with airspeed and is further irritated by thin flexible structures. Increases in torsional rigidity increase the flutter speed, whereas modifications in bending rigidity provide little change.

Normal design practice requires an aircraft to be flutter-free beyond a speed 15% above design limit flight speed (or $1.15 V_L$)⁷, thus providing a margin of safety in the event of exceeding an aircraft speed limit. Some loading configurations, especially those developed after initial flutter analysis, will require a repeat of the flutter determination procedure. If they do not meet the initial design criteria, they will usually require reduced envelopes to ensure safe flight outside flutter-prone areas, rather than redesign of the aircraft.

Limit Cycle Oscillation (LCO)

Another phenomenon driven by aeroelastic effects is limit cycle oscillation (LCO). Although by strict definition it is not considered flutter and is certainly not nearly as destructive, LCO is formed by similar components. It is a case where aerodynamic damping exactly counteracts structural damping. This sustained sinusoidal structural oscillation maintains constant amplitude with time, will generally only increase with airspeed, and will continue indefinitely until a change in airspeed, altitude, or some other disturbance triggers a change in aerodynamic damping. LCO has proven unpredictable through analysis, although leading edge devices and increasing load factor or AOA have all been linked with it. Although by itself a neutrally stable oscillation, it has shown both resistance and susceptibility to occasional divergence. However, LCO usually only promotes material fatigue, aircrew discomfort, or system degradation.⁶

LCO is most often seen during carriage of heavy underwing stores and is sometimes known as heavy store oscillation (HSO). The F/A-18 A/B/C/D Hornet has been known to experience LCO quite severely when carrying wingtip missiles and high pitch inertia stores (such as 2000 lb bombs) on outboard wing stations, which is why it utilizes a function known as active oscillation control (AOC) for certain store loadings at low altitudes. This logic, which is incorporated directly into the flight control computer system, uses the lateral accelerometers to sense and ailerons to damp an annoying 5 to 6 Hz wing oscillation.¹¹

External Store Effects

Overall aeroelastic stability of an aircraft is greatly influenced by the carriage of external stores^{6,10}. Each symmetric loading combination uniquely changes the mass distribution and airflow around the wing, thus changing the tendency for the overall structure to experience flutter, usually to a lower airspeed. Conversely, asymmetrical loading of either stores or internal wing fuel tends to be stabilizing and increase flutter speeds. The two most critical loadings for the F/A-18 E/F Super Hornet occur with wing tip missiles on and either a “clean” wing devoid of stores or one with outboard wing station pylon-mounted AGM-88 High Speed Anti-Radiation Missiles (HARM). Although analyses show that the aircraft indeed has its required 15% airspeed cushion, the vertical stabilizers and rudder have demonstrated the minimum analytical margin.^{8,9}

LOADS LIMITS

During the design phase of an aircraft, the largest load that an aircraft component is expected to encounter throughout all phases of flight is known as the “limit load”. To provide an additional margin of safety, these limit loads are multiplied by safety factors (usually 1.5) to determine the required “ultimate load” or the force that a component must be capable of withstanding without actually breaking. Component limits are not restricted merely to wing airloads from high load factor maneuvering, although lifting surfaces are usually critical under those conditions.¹² Rather, every component must withstand all forces induced from every phase of flight. Components, which are manufactured to ultimate load specifications, must later be tested to determine actual restrictions to be imposed on aircraft and operator. After all, if a critical aircraft component breaks at high

speed, the consequences could be just as deadly as a store-to-aircraft collision. Although usually less likely to be approached or exceeded during safe separation testing, the F/A-18 E/F Super Hornet's loads limits are established based on either actual static ground testing or through purely analytical strength calculations.

Static ground testing involves testing an actual component representative of a production aircraft part and incrementally loading it until actual failure occurs, hopefully occurring at least at the ultimate load value (again, which is usually 1.5 times the anticipated limit load). Subsequently, the test aircraft would then be operationally restricted to conditions which would generate two-thirds of the tested and proven failure load. Analytical calculations, on the other hand, are performed when static failure load data do not exist and mathematically determine under what load a component will likely fail. The test aircraft is then operationally restricted to flight conditions which would create 50% of that calculated load. Since it provides more fidelity, the static ground test is always the more highly desired source for load limit determination. However, the cost of manufacturing and testing parts to failure often prohibits this method. It is everyone's hope that these two test methods will result in established restrictions that are as good as the original limit load assumptions, although realistically the analytical method is not likely to do so. In the end, to provide yet more safety margin, the fleet operator is further restricted to conditions that would generate 80% of the established test restrictions. Interestingly, recent static ground tests on the wing of an F/A-18E/F showed that it did not fail until 204% of the wing bending limit load.^{13, 14}

Dedicated in-flight loads testing has been performed on the Super Hornet using load measuring strain gauges and accelerometers located strategically throughout the

aircraft. These tests have revealed that, when carried, the components most susceptible to a loads-induced failure during weapons separation testing is the 480 gallon external fuel tank aft pivot and the wing store pylon aft attach points. These problems are exacerbated especially when the fuel tanks are carried on the wing stations due to the often intense underwing span-wise airflow. To further aggravate this condition, the primary separation test aircraft (aircraft number E-10, side number 400) is only capable of carrying what are known as “Rev A” pylons. These pre-production variants consist of weaker aft attach points than their newer, stronger “Rev B” brethren. So, when carrying empty fuel tanks on these pylons on the inboard stations, the maximum limit airspeed is reduced to 570 KCAS when adjacent to fuselage-mounted forward-looking infrared (FLIR) targeting pods or 600 KCAS without. Fueling the tanks further restricts the maximum airspeed below 550 KCAS.¹⁵

CHAPTER 3

FACTORS AFFECTING SPEED CONTROL

While focusing on the 11 overspeed incidents, the 55 attempts at 600 KCAS, 1.20 IMN, and 0.5 load factor endpoints were analyzed to determine what common threads, if any, could be established as contributing factors to airspeed control. A data summary is presented in table C-1. The various components were broken down into two categories: factors that directly and immediately affected maximum airspeed, and those factors that were indirect contributors.

DIRECT CONTRIBUTORS

By plotting maximum airspeed against various dive and recovery parameters, several contributors became apparent.

DIVE RECOVERY AIRSPEED

The airspeed at which recovery was initiated was perhaps the single biggest contributor to overspeeds and was defined as the airspeed at which load factor began to increase above the steady state dive load factor tolerance. The airspeed at which dive recovery is initiated intuitively leads to peak airspeed control: the “earlier” that a dive recovery is initiated, or, more precisely, the lower the airspeed that dive recovery is commenced from, the more airspeed buffer that will be available before limit speed is attained. Conversely, the “later” it is initiated, or the faster the aircraft is when recovery is commenced, the closer the accelerating aircraft will be to the limit airspeed. As shown

in figure C-1, in all overspeed cases the beginning of the dive recovery was not initiated until 610 KCAS or later. Interestingly, the same figure also shows that several runs were conducted quite successfully despite beginning dive recovery faster than 610 KCAS. Therefore, other contributors must clearly exist. Regardless, overspeeds during endpoint testing can be significantly reduced by prompt dive recovery immediately after weapon release.

RECOVERY LOAD FACTOR

Peak load factor was defined as the highest commanded normal acceleration experienced throughout the dive recovery. Short duration spikes in load factor or responses due to transonic pitchup effects were not included. Generally speaking, the higher the load factor, the higher the airspeed energy bleed rate. As shown in figure C-2, over 70% of all overspeed cases occurred during dive recoveries of less than 4.5 peak load factor. As a result, although once again not fully conclusive, higher load factors from harder pullouts, targeting at least 4.5 during recovery will significantly lower the probability of overspeed occurrence. This observation also necessitates a suitable minimum available load factor capability for the aircraft so that after avoiding the overspeed, these elevated load factors do not drive the aircraft into an overstress situation. Aircraft gross weight and any flight clearance load factor limits imposed (which are often artificially low) will ultimately determine the final load factor available (or “g-available”). For the F/A-18 E/F, this is known as “ $n_z W$ ” and is determined by calculating the ratio of 42,097 lbs (the “basic flight design gross weight” or BFDGW)

and actual gross weight then multiplying it by the flight clearance load factor, which is ordinarily 7.5, barring any non-standard and weaker aircraft components.

RECOVERY LOAD FACTOR ONSET RATE

Load factor onset rate (better known as “g-onset”) was defined as the rate of load factor build up from the time of dive recovery initiation to the time of reaching peak steady load factor. The data from figure C-3 shows that almost two-thirds of overspeeds (64%) occurred from dive recoveries using load factor onset rates of less than 2/s.

Therefore not only is a high peak load factor pullout helpful, but it must be accomplished in a timely manner so that it is hopefully reached before the peak airspeed is realized.

Nevertheless, a high load factor onset parameter is also unfortunately not a cure-all and must be used in conjunction with other mitigation techniques.

THROTTLE SETTING

Engine thrust is really the only instantaneous control the pilot has on acceleration in the aircraft’s x-axis. Many high drag store configurations targeting 60 degree dive endpoints require maximum afterburner (MAX) to just barely achieve test conditions. Unfortunately it is impossible to sufficiently quantify thrust output, for although the throttle’s angular position is measured, telemetered, and recorded throughout a typical weapon separation flight, the total thrust is not. Throttle position, however, can be a valuable tool to compare relative power settings. Figures C-4 and C-5 each compare the throttle settings from two weapon separation runs on one sortie, each coincidentally containing a successful non-overspeed and an unsuccessful overspeed case. Maximum afterburner on the plot is about 45 deg throttle angle, while full military power (MIL) is

reached about 35 deg and flight idle around 7 deg. Recovery was initiated at time zero. From the figures, the non-overspeed cases show a significant throttle reduction compared to their overspeed counterparts. Figure C-4 illustrates the importance of power reduction at recovery. On the live run of flight #455, power was reduced to mid-range almost $\frac{3}{4}$ of a second after recovery was initiated and did not result in an overspeed. Table C-1, on the other hand, shows that the practice run on flight #455 initiated recovery a full 6 knots (kts) sooner than the live run yet resulted in a peak airspeed 9 kts faster. In fact, of all overspeed runs, the practice run of flight #455 started recovery at the lowest airspeed (610 KCAS) and used the highest peak load factor (5.9), yet still oversped. The sustained excessive power setting of the suspect practice run in Figure C-4 explains why.

Figure C-5 tells a similar story. Specifically, it shows that both runs of flight #457 approached the recovery point near maximum afterburner, but that in the practice run, the throttles were retarded about 0.5 sec sooner and almost to idle. In the live run, on the other hand, throttle reduction was delayed and only reduced to mid-range power. Moreover, table C-1 shows that the live run of flight #457 initiated recovery 2 kts sooner, and pulled out with a 0.8/s greater onset rate to 0.5 higher peak load factor, yet still oversped. This punctuates the impact that power setting has on speed control.

Thus, timely reduction in power setting, especially to idle power, assists greatly in overspeed avoidance, especially when coupled with the recovery timing and techniques above.

INDIRECT CONTRIBUTORS

CONFIGURATION

Aircraft load out and subsequent drag has a major impact on overall aircraft performance. Unfortunately there is little that can be done to quantify the “dragginess” of an aircraft. Although the “drag index” calculation available in the aircraft operator’s manual¹⁵ is useful for determining specific performance characteristics such as range, fuel consumption, and optimum airspeeds, this only applies to cruise phases of flight. It cannot be used to accurately predict performance under the conditions of a typical separation flight such as steep dives from 40,000 ft at maximum afterburner. It can, however, be invaluable in providing a relative drag value for qualitative purposes so that a pilot may make comparisons to other previously flown loading configurations. Basically, the more ordnance on the aircraft, the more drag and the longer it will take to attain test conditions, but the faster the aircraft will decelerate during recovery. However, the flights listed in table C-1 had widely varying drag indices from over 250 down to 50 and showed no correlation with overspeed tendency.

DIVE ANGLE

The method chosen to achieve target release conditions depends on the performance capabilities of the aircraft and the conditions themselves. Of all the indirect overspeed components, dive angle plays the biggest part. For tests requiring steady state load factors below 1.0, dives are required- and the lower the target load factor, the steeper the dive. Naturally, the steeper the dive, the more likely the aircraft is to accelerate since the weight vector will be more in line with that of the desired thrust vector. Beware,

however, because steep dive angles are a double-edged sword since not only do they promote acceleration to achieve test points quickly, but they also hinder deceleration after release. Endpoint release tests using dive angles shallower than approximately 45 deg are manageable, for although test conditions are often challenging to achieve from an aircraft performance standpoint, the aircraft can easily be recovered after release without breaking airspeed limits. In fact, during the same FOT&E period, no reports of weapon separation related overspeeds were reported from 45 degree dives.¹

Unfortunately, test points are not only defined merely by airspeed and mach, but by normal acceleration as well. When attempting steady 0.5 load factor points, a 60 degree dive is required. A devoted airspeed scan is more critical at these higher dive angles. When pursuing a 600 KCAS, 1.20 IMN, 0.5 load factor test point from a typical 60 degree dive, airspeed build up rate when nearing release conditions is typically over 15 kts per second. Given a normal F/A-18 air-to-ground store carriage limit of 635 KCAS, any hesitation or fixation in pilot attention can lead to aircraft overspeed in around two seconds.

Shallower dives would naturally be desired to produce a manageable acceleration. However, as established earlier, alternate techniques of setting shallow steady dive angles, then pushing over to achieve target load factor are not acceptable for free fall ordnance, despite establishing desired normal accelerations. Fortunately, for most forward-firing, rail-launched ordnance this restriction does not necessarily apply. The shallower dive and slower acceleration can be partially offset by using a pushover technique to establish dive angle and is explained later. One major disadvantage of the shallower dive method is that it often does not produce desired steady state load factors.

This must be compensated for by using the previously forbidden pushover-to-release method, thereby increasing the pilot's workload and risk of out-of-tolerance missile separations.

DIVE TECHNIQUES

The method used to get to the final dive angle is as important as the dive angle itself. Roll-in maneuvers consist of performing an unloaded aileron roll to inverted, pulling down to the desired dive angle, then performing an unloaded roll back to upright. Since the aircraft must bear a positive load factor during most of the maneuver, especially the pull down, it suffers from increased induced drag which tends to cause the aircraft to bleed precious airspeed.

Another method to establish the aircraft in a dive is to push over, rather than pull down. By eliminating the roll to inverted and instead applying forward stick and unloading the aircraft to somewhere between a load factor of 0.2 and 0.5 (the F/A-18 E/F is limited to a 2-second transient duration between -0.2 and 0.2 load factor)¹⁵, a gentle pitch rate ensues while the aircraft accelerates. By unloading the aircraft, the angle of attack and weight that the wings must counteract are diminished. This creates a reduction in induced drag and thus lower total drag, allowing the aircraft to accelerate faster than if it had been loaded at 1.0 n_z or above.

Figure C-6 compares both these techniques performed in maximum afterburner while targeting the same release conditions of 600 KCAS, 1.20 IMN, and 0.5 n_z . In the roll-in method, by the time the aircraft reaches its target dive angle (60 degrees in this case), it has gained barely 10 kts. In fact, it does not really begin appreciably accelerating

until the jet is unloaded and rolled upright again. In the pushover-to-dive technique, however, the aircraft is accelerating throughout the entire maneuver- by the time it has reached its maximum dive angle (which in this case is 30 degrees- half that of the roll-in example), it has gained over 100 kts.

There are many other factors to weigh, however. The roll-in maneuver attains its maximum dive angle in almost half the time (figure C-7) than its pushover counterpart and is useful for dealing with constrained airspace and focusing supersonic shockwaves for noise abatement. Conversely, the entire pushover technique profile takes about 1 ½ times longer to fully complete (even when targeting half the dive angle)- valuable seconds when burning upwards of over 400 lbs of fuel every minute in maximum afterburner. Also, in this method, the aircraft translates forward the entire time as it slowly increases dive angle and thus requires more distance to perform. Also, the pushover-to-dive is usually reserved for shallower final dive angles which also tend to extend the dive profile and produce higher steady state normal accelerations.

As established earlier, pushover-to-release techniques to attain release conditions for free-fall ordnance are not authorized, however as suggested, they may sometimes be used for forward-firing, rail-launched missiles.

FAN SPEED LOCKUP

The F/A-18 Hornet incorporates an engine “fan speed lockup” system that prevents engine inlet shockwave instability (also known as “buzz”) at high Mach numbers. Basically, when above 1.23 IMN and the throttles are retarded below MIL power, the system holds engine speed and airflow at MIL power levels. Fan speed lockup

is deactivated when the aircraft decelerates below 1.18 IMN. Thus, if attempting dive recovery above 1.23 IMN the engines will be stuck at MIL power until decelerated below 1.18 IMN. While even in MIL power this deceleration would occur rapidly during a pull out, it may not be possible while stuck at MIL in a steep dive. Nevertheless, a few seconds of unintended excess power during dive recovery can contribute to an overspeed situation.^{15, 17}

SPEEDBRAKE

The speedbrake is a pilot-controlled drag-increasing device usually consisting of dedicated extendable aerodynamic surfaces. On most tactical aircraft, such as the F/A-18 A through D Hornet, the speedbrake is mounted on the empennage area, operated by hydraulic power, and controlled from the cockpit. The F/A-18 E/F Super Hornet, however, is not fitted with independent speedbrake surfaces. Rather, a speedbrake “function” is provided to increase drag by partial deflection of several of the aircraft’s primary flight control surfaces including ailerons, rudders, trailing edge flaps, and spoilers.

At subsonic speeds with gear up and flaps in AUTO mode (essentially UP), the speedbrake function flares the rudders and symmetrically raises the ailerons trailing edge up approximately 95% of their travel capability at the given flight conditions. This ensures that about 5% of surface authority is available for yaw and roll control. If needed, yaw and roll commands supercede speedbrake use of the ailerons and rudders. Trailing edge flaps (TEFs) are also symmetrically lowered to further increase drag and to counter the loss of lift caused by the deflecting ailerons. Spoilers which account for only about

10% of the total speedbrake function capability, are later raised to their full 60 deg up position only when the speedbrake command reaches 75% of extension. The stabilators are commanded to counter pitch changes due to the deflection of all speedbrake surfaces other than the spoilers. Delaying spoiler deflection until 75% of aileron, rudder, and TEF function allows the pilot to use partial speedbrakes to assist in airspeed modulation, while avoiding minor spoiler-induced pitch transients.

At supersonic speeds, speedbrake surface deflections are changed. The rudders are not deflected above 1.05 IMN, due to vertical tail loads. Moreover, the ailerons and TEFs are not deflected above 1.10 IMN due to a lack of effectiveness. The spoilers are therefore deflected immediately upon speedbrake actuation, since they are the only effective surface at these conditions. At supersonic speeds, the stabilator is programmed to counter spoiler deployment transients. The speedbrake function is completely disabled above 1.50 IMN.¹⁵

This capability is useful for making gross changes in airspeed throughout the dive when power corrections are applied too late. Unfortunately, due to the changes in underwing airflow, the speedbrake function must be fully deselected by the time release is commanded. So, during typical 1.20 IMN endpoint test dive recoveries, the F/A-18 E/F speedbrake function only applies spoilers and is virtually useless for preventing overspeeds. After initiating dive recovery and power reduction, however, the aircraft will eventually slow and allow full deployment of speed brake surfaces once below 1.05 IMN, assisting dive recovery deceleration then.

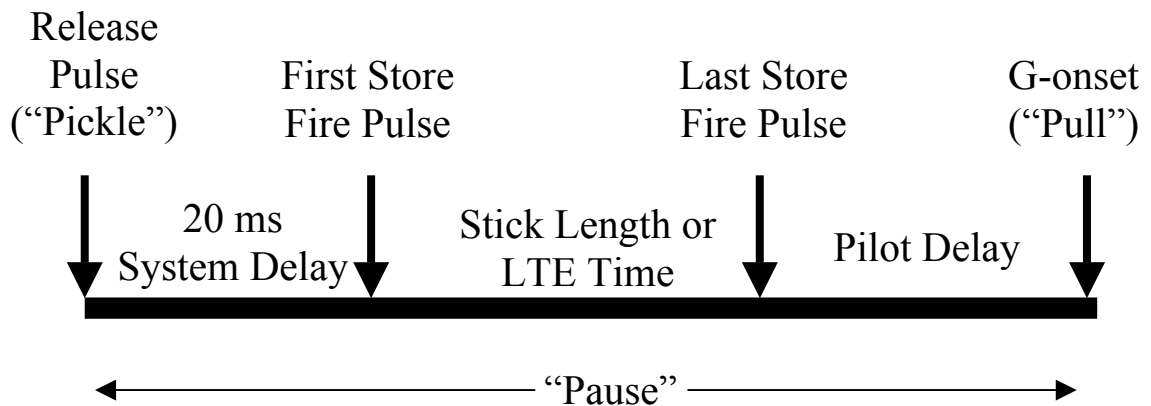


Figure 4
SEPARATION DELAYS

Source: *Endpoint Overspeed during Weapon Separation Testing Brief*

RELEASE DELAY

The method used for commanding store separation plays a major role in ensuring a timely dive recovery, depending on the weapon. While the normal technique is the "pickle-pause-pull" method, the duration of pause must account for all expected release delays. These contributors to the release timeline duration are intrinsic system delay, stick length (in the case of free-fall ordnance) or launch-to-eject (LTE) time (for missiles), and pilot delay (figure 4).

System Delay

System delay consists of the time required for the release command from actuation of the weapon release switch (known as the "pickle" switch) to be sent to the mission computers, processed, transmitted to the stores management set (SMS), sent to the station encoder/decoder, then sent to the impulse cartridges in the rack for detonation,

release hook opening, and ejection foot extension. The system delay for the F/A-18 E/F is approximately 20ms (or 0.02 seconds) and is considered negligible.

Stick Length

Although during separation testing most weapons are released in the “manual” mode (MAN) and ejected immediately upon transmission of the weapon release command, this often does not hold true for long strings of multiple bombs or missiles that require an energizing period before launch. Cases where several bombs are released singly in sequence introduce a discrete time interval between each separation, thus extending the duration that the test aircraft must remain on conditions. Basically, the more bombs and the larger the interval, the longer the aircraft must dwell in its dive and the longer the weapon release button must be held. The duration of this “stick length” is determined by adding the intervals of each successive bomb to drop after the first. For example, a stick of four bombs released singly at 40ms intervals will add up to a 120ms total stick length. So, assuming an instantaneous pilot reaction immediately after the last bomb falls off the aircraft, test conditions must be maintained for merely 140ms. However, due to poor separation characteristics or insufficient data, some weapons must be released at much longer intervals to avoid bomb-to-bomb collisions. Although not likely to be employed by the end user in the fleet in quantities more than one, some weapons may require intervals as high as 300ms. In an effort to gather maximum data, the test community must often drop several of these weapons in sequence at endpoint conditions. This would drive a four-bomb stick length alone to over 600ms or 0.6 sec. When accelerating at over 15 kts/s in a 60 degree dive, a test aircraft can gain over 9 kts

in 0.6 sec. These rough calculations do not include system or pilot delay which can add more seconds to the timeline and tens of knots to airspeed.

Launch-To-Eject (LTE) Time

Missiles possess inherent launch delays of their own and stem from requirements to power up and download tracking data prior to launch. Known as “launch-to-eject” (LTE) times, they can often be as much as 1.5 seconds. Again, when accelerating at 15 kts/s a timely missile launch is critical to a successful dive recovery. When attempting endpoint conditions, it is important to understand the nature of these delays and options. For example, safe separation testing is considered partial-task and usually does not consider weapon performance post-release. Fortunately, many missiles have jettison modes where the missile is commanded to power up and skip data transfer phase before launch. This results in LTE times below 1.0 second and often instantaneous.

Pilot Delay

In addition to weapon LTE times, many “smart” weapons, when released in their typical automatic modes, require the launch aircraft to satisfy certain launch envelope parameters. The aircraft mission computers usually calculate weapon performance capability based on current aircraft conditions. Often in the case of many guided weapons, desired target coordinates must be specified in the mission computers as well. Even if the weapon is physically disabled and incapable of steering to a designated target, it must be delineated and within calculated range to satisfy automatic mode launch criteria. This presents a unique problem for the test pilot since he must not only monitor aircraft parameters for valid separation test purposes, but must also watch weapon

envelope indications to ensure that they satisfy launch requirements. This distraction can lead to fixation on parameters that, although vital for successful weapon launch, are extraneous with regard to aircraft test conditions and safety.

The pure pilot delay time is difficult to quantify since it varies from person to person. The average is assumed to be about one second; however, any pilot distraction can extend this value. If, for example, the pilot waits for visual confirmation of missile fly-out on a launch, he must visually scan and mentally process his outside environment. This simple task can add seconds of delay during an already critical phase of flight, thus leading to late dive recoveries at prohibitively high airspeeds.

AGM-88 HARM SEPARATION TEST OVERSPEED EXAMPLE

In November, 2002, an endpoint test flight was conducted on an F/A-18 E aircraft (number E-10, side number 400) for the AGM-88 HARM. The target conditions were typical 600 KCAS, 1.20 IMN, and 0.5 n_z to be attained from a steady 60 degree dive. The missile was to be launched in its “pre-briefed” (PB) mode whereby the aircraft mission computer uses target coordinates set by the pilot to calculate range and determine, based on aircraft conditions and weapon capability data, whether the aircraft is in position to satisfy missile launch range criteria.

It was noticed throughout the first live run attempt that the aircraft was displaying “in range” (IN RNG) indications but not “in zone” (IN ZONE), thus not meeting suitable launch logic. However, fixation by the pilot on this information caused vital aircraft parameters to drop out of his scan which resulted in a late dive recovery and subsequent overspeed. However, since both the pilot and test engineers in the range control room

were distracted by the unsuitable launch indications, neither noticed the airspeed limit exceedance. After deliberating with the test engineers over the radio, the suspected solution was to adjust target coordinates and move them closer to accommodate the actual aircraft test location.

Believing that the launch problem was resolved, a second live run was conducted. This time, indications at roll-in were favorable, switching from IN RNG to the desired IN ZONE. But as the pilot's scan switched from launch criteria to aircraft conditions, the range indications switched back to IN RNG, unnoticed. Thus as release parameters were attained, the pilot depressed the weapon release button and paused, anticipating LTE time and expecting missile flyout momentarily. However, the launch never came. After pausing just a few more seconds in case the missile were to launch late for some reason, dive recovery was finally initiated. Once again, due to fixation of the pilot and ground personnel, the overspeed was not noticed until post flight review was performed. Analysis showed that the rapidly shrinking missile envelope or "launch acceptability region" (LAR) experienced in a steep 60 degree dive constricted too far, so as to place the computed target point outside the maximum acceptable launch range.

Figures 5 through 9 show the progression of events from the pilot's heads up display (HUD) perspective. The time from launch command at 591 KCAS to dive recovery initiation was around two seconds, with overspeed of the 635 KCAS limit occurring merely one second later. The maximum airspeed attained was 653 KCAS with peak load factor of 4.1 being achieved well after top airspeed.

This event clearly demonstrated the criticality of a timely and aggressive dive recovery. The automatically computed launch mode, although tactically representative,

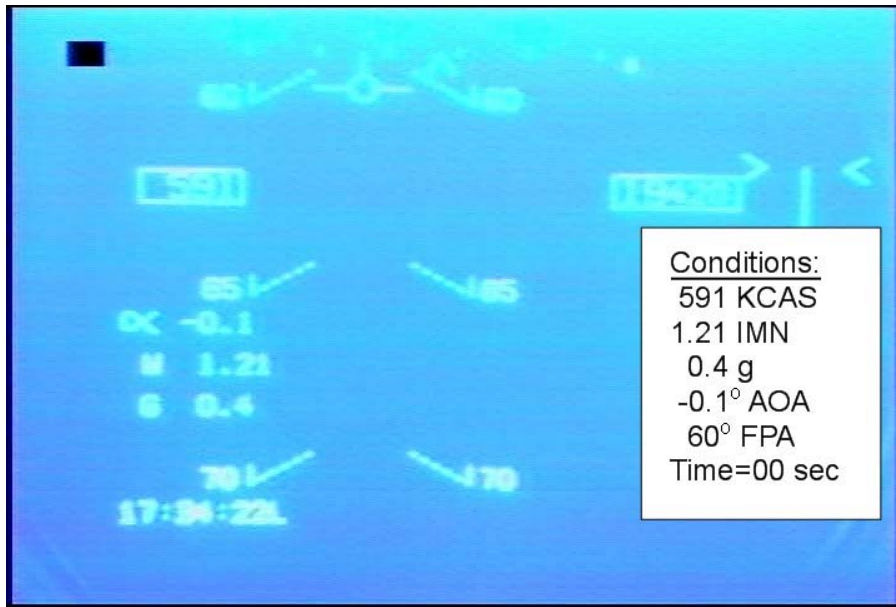


Figure 5
HUD AT ATTEMPTED WEAPONS RELEASE
Source: Author

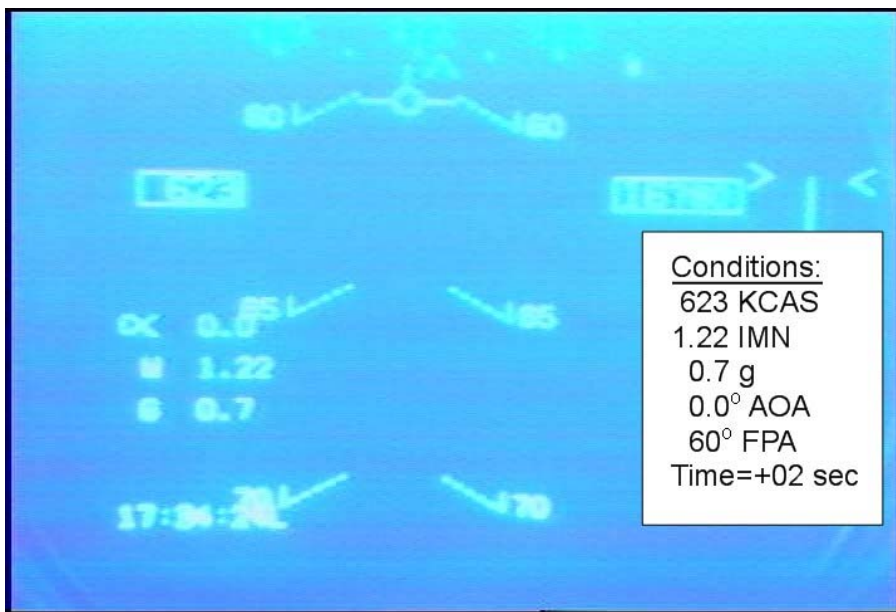


Figure 6
HUD AT DIVE RECOVERY INITIATION
Source: Author

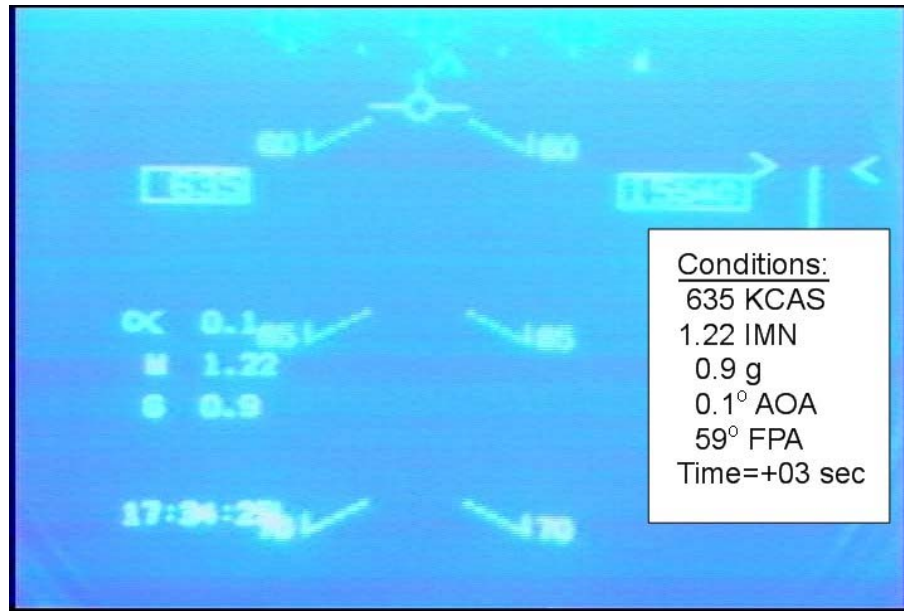


Figure 7
HUD AT LIMIT AIRSPEED
Source: Author

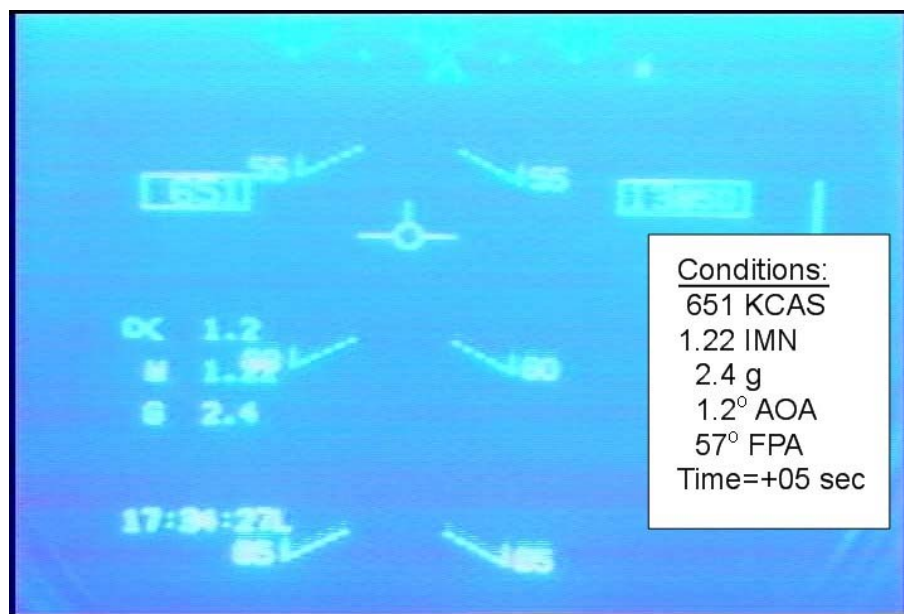


Figure 8
HUD NEAR PEAK AIRSPEED
Source: Author

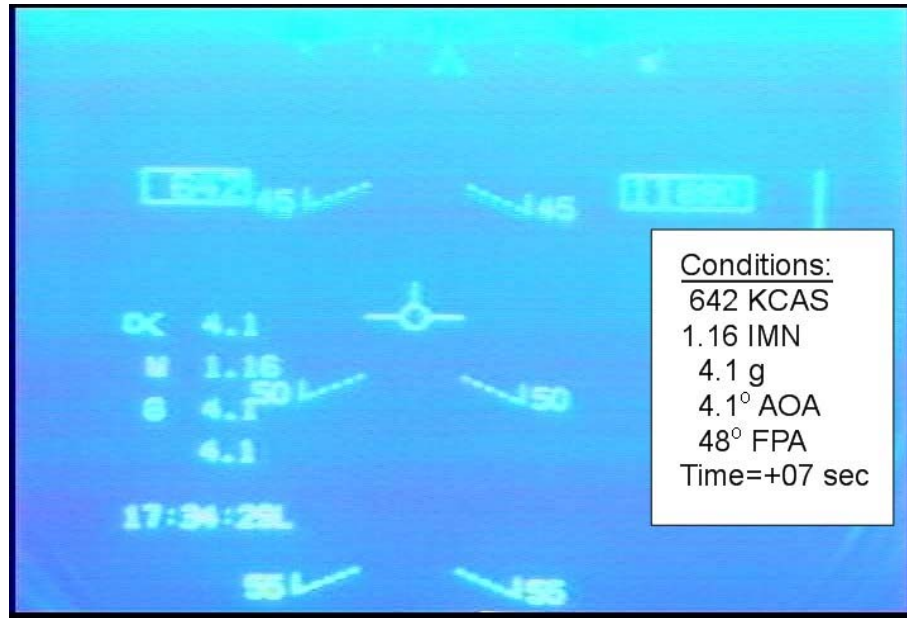


Figure 9
 HUD AT PEAK LOAD FACTOR
 Source: Author

hindered the success of the test. Pilot distraction, whether warranted or not, directly contributed to the late recovery attempt.

CONTRIBUTING FACTORS SUMMARY

Several components control the probability of overspeed, but none operate independently. Timeliness of recovery is indeed the most critical aspect, with indirect factors determining how much acceleration the recovery must combat and how long it may be delayed.

Perhaps the most unique overspeed instance was during aircraft number E-4's flight #455 where dive recovery was initiated at 610 KCAS yet still oversped. This is a prime example of how all the aforementioned factors interact and must be all taken into

account together. In that particular overspeed situation, recovery was not only attempted “earliest” from the lowest airspeed, but also used the highest peak load factor of all overspeed cases. However, load factor onset was only a paltry 1.31/s and power setting was set near full MIL power. This proves that the techniques must work in concert, for failure to respond to any single aspect of recovery airspeed, peak load factor, load factor onset, or thrust reduction can still result in an airspeed limit exceedance.

CHAPTER 4

CONCLUSIONS

QUESTIONS FOR THE TEST PLANNER

Before any safe flight test can be planned, the test engineer and pilot must ask three questions: 1) Do we really have to go to these conditions? 2) What different ways can we get there? and 3) What are all the limits, their sources, and their hazards if exceeded?

The first question appears obvious; test planners would never begin the process unless appropriately tasked. However, requirements can often be unclear in a design process. While a written specification may declare an ultimate requirement, there may be different methods to achieve the goal other than pure flight test to those exact conditions. Everyone may have their own idea on how to clear to that goal. For example, where flight test engineers and test pilots might accept nothing less than actual weapon release at actual parameters, weapons clearance personnel (the engineers who actually draft final flight clearances) may accept lower airspeeds and Mach numbers and be satisfied with extrapolation to desired conditions or merely comparison to existing models. Although sometimes risky, this method is useful in areas of the envelope where little adverse response is expected from the store. Nothing can be more damaging to a test project than the customer asking “Why have you been trying to test to these conditions, failing, and wasting my money? You never really had to test to that airspeed!” It has happened.

Next, all methods of achieving test conditions should be explored in “brain-storm” fashion. Just because certain techniques and profiles have been a staple for many

years does not mean alternate methods do not have merit. In fact, it behooves the project team to review every possible technique each time a new plan is developed. Although “cut and paste” from one test to another is easier and faster for the test planner, the plan must not revolve around the ease of planning but rather success of the test. Many techniques that seem taboo by some may be intuitive to others and must be examined and rationalized thoroughly. A perfect example is the requirement to perform a 60 degree dive to attain a load factor of 0.5 for a missile separation test. In that case, many test engineers believed the pushover-to-dive then pushover-to-release technique to be completely forbidden, however, after several overspeeds from a 60 degree dive, further investigation showed that those concerns were mostly predicated on free-fall weapons.

Lastly, thorough knowledge of the limits and an understanding of what drives them are essential in making proper risk assessments. When confronted with a restriction that could potentially be exceeded during a test flight, the test planner should review the technique used to achieve conditions and the criticality of the limit. If both the probability and severity of breaking a limit is high, then it should not be approached. On the other hand, if the severity of breaking a limit is low, then risking occasional exceedances may be warranted. Only through thorough investigation and discussion with the experts can one accurately assess the hazards. Using seat-of-the-pants feelings or common sense is no substitute for thorough research in this area

OPTIONS FOR THE TEST PLANNER

When confronted with a test-hampering restriction, the test team has only four options: officially change the limit, alter the conditions, adjust the technique used to

achieve conditions, or selectively accept the exceedance. The decision must be made only after comprehensive review of all options and their risks.

The natural first response when faced with any obstacle is usually to try to remove the obstacle. Of all the options to a test planner, this one should be considered the most “right”, yet is usually the most difficult and frustrating to achieve. It can be performed through careful research of the restriction and analysis of its consequences. Usually, submission of a flight clearance change request is required since the test teams normally do not “own” the clearances. This route, although optimum in that it may relieve an artificial hurdle, usually takes a long time to pursue, so proper foresight and planning is essential. Also, since it is the flight clearance personnel who must perform their own analysis to determine the merit of their restriction, it will take their time and money to fix, often neither of which is available. Since many restrictions are artificial and based on a lack of data, not proof of jeopardy, most clearance experts are unlikely to budge on their limit stance.

Changing the target test conditions is often the path of least resistance but requires the most concessions from the test team. Unfortunately test teams are sometimes quick to concede to programmatic pressures and sacrifice good engineering. While parameters may sometimes be flexible and adjusted through negotiation with weapon flight clearance authorities, they are often rigid and critical for collecting required data. Before altering test conditions, therefore, one must first determine if suitable data can be collected elsewhere in the envelope. If the answer is no, then the conditions should not be changed. This, of course, must be weighed against gathering no data at all.

If the conditions are critical and the hazard of exceeding a limit is high, then the technique performed to achieve conditions must be altered to avoid the danger region in question. Most previously established techniques are familiar to the test pilot, so although this approach may seem easy from a planning standpoint, it may elevate the data risk by presenting an unfamiliar technique to the test pilot. In any case, the test team must investigate all options and solicit alternate ideas. Research of historical methods often surprisingly reveals a plethora of suitable alternate techniques.

If conditions are essential, no other techniques exist, and the hazard of limit exceedance is low, then the test team may elect to selectively ignore the limit. This course of action does not suggest wonton disregard of regulations, but rather a disciplined study of the risks and benefits of exceeding a discreet limit. Any test that is expected to break a limit every time on every flight should instead be further reviewed for a better technique. This approach specifically lends itself to projects that have implemented all other reasonable mitigation processes yet still face an occasional exceedance of a low-hazard limit. Although often quite reasonable, this is a potentially risky method to attempt. It is also extremely difficult to accomplish and requires the most research from the test planner since it needs the concurrence of the project team's chain of command who is unlikely to oppose a limit imposed by the flight clearance authority. Nevertheless, since flight test costs a lot of money and consumes many resources, it sometimes behooves a test team to put forth the effort to build a case for its chain of command, so that they may make an informed decision. The case for selectively accepting the exceedance must also include the team's plan to deal with the exceedance and how to ensure that the aircraft is unimpaired afterwards, be it airborne chase aircraft inspection

or ground inspection with engines running. Decisions “on the fly” and deviations from a well thought out plan can be dangerous, so documented procedures approved by test entity leadership are essential.

The test team will face a multitude of hurdles throughout all stages of the test. There exist a multitude of limits, both real and artificial, that could hamper an otherwise successful test. A thorough understanding of the risks and benefits of different methods to avoid the limits is vital in choosing which course of action to take. In any case, if a limit exceedance is so hazardous that it could result in damage to the test aircraft or loss of critical data (which is why one is performing the test in the first place) then the test point should naturally not be conducted.

THE NEW APPROACH

After painstaking review of the F/A-18 E/F weapons separation overspeed history and specifically the obstacles faced during the AGM-88 HARM safe separation project, several technique modifications can be established to mitigate the probability of overspeed. In some cases, the approaches are not optimal but nevertheless still necessary compromises to decrease the probability of exceedance. While many of these methods are not new, they can be reinforced again. Despite being optimized for endpoint testing, they can be applied to most any weapons separation work.

CHANGING THE LIMIT

In the case of the air-to-ground store airspeed limit on the F/A-18E/F, which is approached using normal straight path dive delivery methods, the various options were

explored. In most configurations, the most likely airspeed limit is imposed by aeroelastic concerns. Since the aircraft was designed with a 15% airspeed margin above cleared flutter limits, any excursion up to 650 KCAS, for example, would only consume 2½ % of that margin, still leaving a full 12½ %, or almost 80 kts. This would provide plenty of safety buffer for the test pilot, yet still allow him to proceed with his mission after an accidental overspeed. However, attempts to obtain formal dispensation from the flight clearance authority proved fruitless. Wording such as the following was incorporated, but to no avail.

“Request authorization for inadvertent airspeed exceedance during aircraft dive recovery. Exceedance will be no greater than 15 KCAS, less than 5 seconds in duration, and above 10,000 ft. Aircraft which experience inadvertent exceedances within these parameters may continue with flight test if the aircrew does not experience any airframe vibrations, there are no degradations in flying characteristics, and the aircraft can be visually inspected by chase or maintenance personnel.”¹⁶

The author, having flown the AGM-88 HARM overspeed flight, maintains that the risk of the aircraft explosively fluttering at 650 KCAS in any configuration is extremely low, having flown there, and that a happy medium exists somewhere. The key lies in bringing the clearance authorities together with the testers and negotiating a safe and suitable solution.

ALTERING THE CONDITIONS

Data Point Reduction and Extrapolation

Although considered bad engineering by some, targeting a slightly lower airspeed data point and extrapolating results out to desired conditions can be applied. This is

usually reserved for stores that have shown no adverse trends and have demonstrated improvements in response as airspeed and Mach number increase.

Airspeed Tolerance Band

As a smaller corollary to the data point reduction method, adjusting the target airspeed, but maintaining the same tolerance band can be used. Ordinarily, endpoints targeted 600 KCAS with a tolerance of ± 10 kts. By adjusting the target to 590 KCAS and shifting the tolerance to $+20/-0$ kts, the same allowable airspeed envelope is allowed, but now the test pilot can get into the mindset of targeting a lower planned airspeed. This provides an additional 10 kts buffer before limit exceedance, if properly executed. Since releases may consistently occur 10 kts slower than actual desired conditions, however, this technique should also only be reserved for tests where exact airspeeds are not critical.

ADJUSTING THE TECHNIQUE

Dive Recovery Method

Revealed as the number one contributor to successful overspeed avoidance, the dive recovery must be expeditious and aggressive. Since timeliness is essential, test runs will now be immediately aborted if attaining 610 KCAS or greater. The recovery will be to at least a load factor of 4.0 and use a 2.0/s load factor onset rate. Throttles will be immediately retarded to idle power and speedbrakes deployed.

Minimum Available Load Factor

Since peak load factor was established as a contributing factor in whether an aircraft oversped or not, it must be anticipated. Because it was established that dive recoveries should target a load factor of 4.0, the aircraft should also have an available n_z of at least 5.0 to allow 1.0 of buffer before overstressing the airframe.

Pushover to Shallow Dive and Pushover to Desired Load Factor

Although these are three separate phases of the delivery profile, consisting of the pushover-to-dive, shallow dive, and pushover-to-target load factor, they must normally be performed together in succession to be effective. The low, manageable forward acceleration supplied by the shallow dive usually drives the necessity for the other two elements. Since this technique contains the push-to-load factor method, it is reserved for forward firing, rail-launched ordnance only.

Dealing With Fan Speed Lockup

When attempting 1.20 IMN endpoints from 60 degree dives, it is quite possible to accidentally attain 1.23 IMN and invoke the fan-speed lockup logic. With engine thrust fixed at full MIL power, dive recovery can be hindered and overspeed facilitated. If encountered during live runs, the run will be immediately aborted and dive recovery will immediately be initiated. During practice runs, however, where the value of merely pointing the aircraft's nose in a 60 degree dive cannot be overstated, if 1.23 IMN is achieved the run will continue and the test pilot may use throttle and speedbrake to reestablish the proper profile and simply recover prior to reaching 610 KCAS.

Pickle vs. Jettison

Since it was recognized that excessive LTE times can prevent a prompt dive recovery, cases where depression of the weapon pickle switch do not result in immediate ejection of ordnance, should be modified to use selective jettison modes, if available. If releasing ordnance in sticks or strings (where jettison modes will not be helpful), total stick length must be calculated and applied to the target release airspeed so that the middle bomb will be released on desired conditions.

ACCEPTING THE EXCEEDANCE

Since the test community has a responsibility to “over-test” its aircraft for the fleet operator, someone somewhere must assume the risk of doing so. The professional weapons separation engineers must work in concert with their air vehicles counterparts to meticulously examine and assess the hazards of overspeeding. This knowledge must be presented to the leaders of the flight clearance process to change the limits, or at least provide partial, if limited, capability beyond that of the fleet operator. If the experts in the flight clearance process refuse to even consider a review of any sort, then the responsibility falls upon the leaders of the test squadrons. These warehouses of expertise have experienced engineers capable of performing their own analyses required to appropriately assess these risks.

With limited aircraft assets, sortie costs over \$55,000, and the consumption of hundreds of man-hours, one failed test sortie can set a project back for months. In test situations where there is no probability of damage or injury, yet which are bound by artificial restrictions established by professional analysts, the test team’s chain of

command owes it to both the warfighter and taxpayer to allow testing to continue when a limit is breached, within a reasonable boundary, if no damage is done.

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APPENDICES

APPENDIX A

THE F/A-18 HORNET FAMILY

The F/A-18 A/B/C/D model Hornet (figure A-1), also known as the “Heritage” Hornet, is the Navy and Marine Corps’ first tactical aircraft to provide capability for supersonic carriage & release of conventional air-to-ground weapons. It is a twin-engine, carrier-based strike-fighter, designed from the ground up as both a fighter and attack aircraft. Boasting a mid-wing design, it has provisions to carry one fuselage centerline and four wing mounted weapon pylons in addition to two fuselage and two wingtip air-to-air missile launchers, for a total of nine weapon stations. Since air-to-ground weapons may only be carried on the centerline or wing pylons, expanded carriage capability is provided through the use of vertical ejector racks (VERs) and their canted siblings (CVERs). Hung from aircraft pylons, these racks have the capacity to carry two air-to-ground free fall bombs each.¹⁷

The F/A-18 E and F model Super Hornet (figure A-2), although visually similar to its predecessor, has 25 % larger wing, 34% larger leading edge extension (LEX), 36% larger horizontal stabilizer and 15% larger vertical tail. Material changes include incorporation of high-strength steels and advanced composites that, along with modern manufacturing techniques, have resulted in a significant reduction in the total number of airframe structural parts. The aircraft is powered by two General Electric F414 afterburning turbofan engines, each designed to provide approximately 22,000 lb of thrust at MAX power (static thrust ratings based on sea-level standard atmosphere). Internal fuel capacity of the F/A-18E model is approximately 14,600 lbs. The avionics

suite maintains 90% commonality with the existing avionics in the F/A-18C/D models. The Flight Control System (FCS) is an enhanced version of the existing F/A-18 fly-by-wire system, designed to increase reliability and maintainability and is actuated by a 3000 and 5000 psi dual-pressure hydraulic system. It also sports the capability to carry two additional under wing weapon pylons for a total of eleven weapon stations. When carried, the Super Hornet wing pylons are rotated, or “toed”, outboard 4 degrees. Additionally, the outboard-most pylons are canted 3.5 degrees outward. Also, the engine inlets are of a faceted squared design, thus altering the airflow between the fuselage and inboard wing stations.¹⁵

All F/A-18 versions have mid-empennage mounted horizontal stabilizers that extend outboard to a point in line with the wing weapon pylons. This placement has prevented the clearance of aft ejecting stores (such as flare dispensers) due to stabilizer strikes. Additionally, the F/A-18 E/F Super Hornet has suffered from horizontal stabilizer airflow disturbance during release of some high drag free fall bombs, causing undesirable pitch transients.

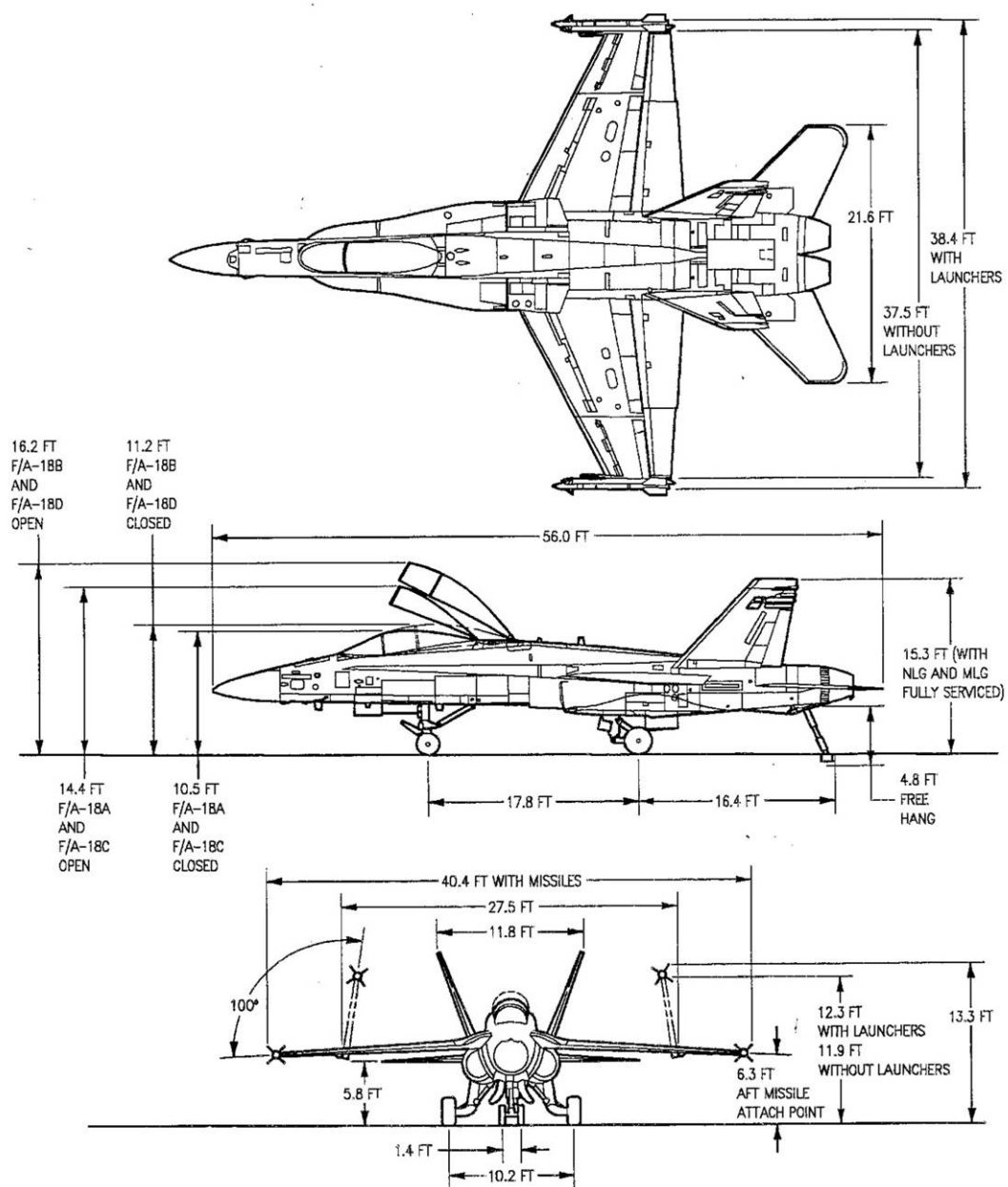


Figure A-1
F/A-18 A/B/C/D HORNET BASIC AIRCRAFT
Source: *General Aircraft Information Maintenance Manual*

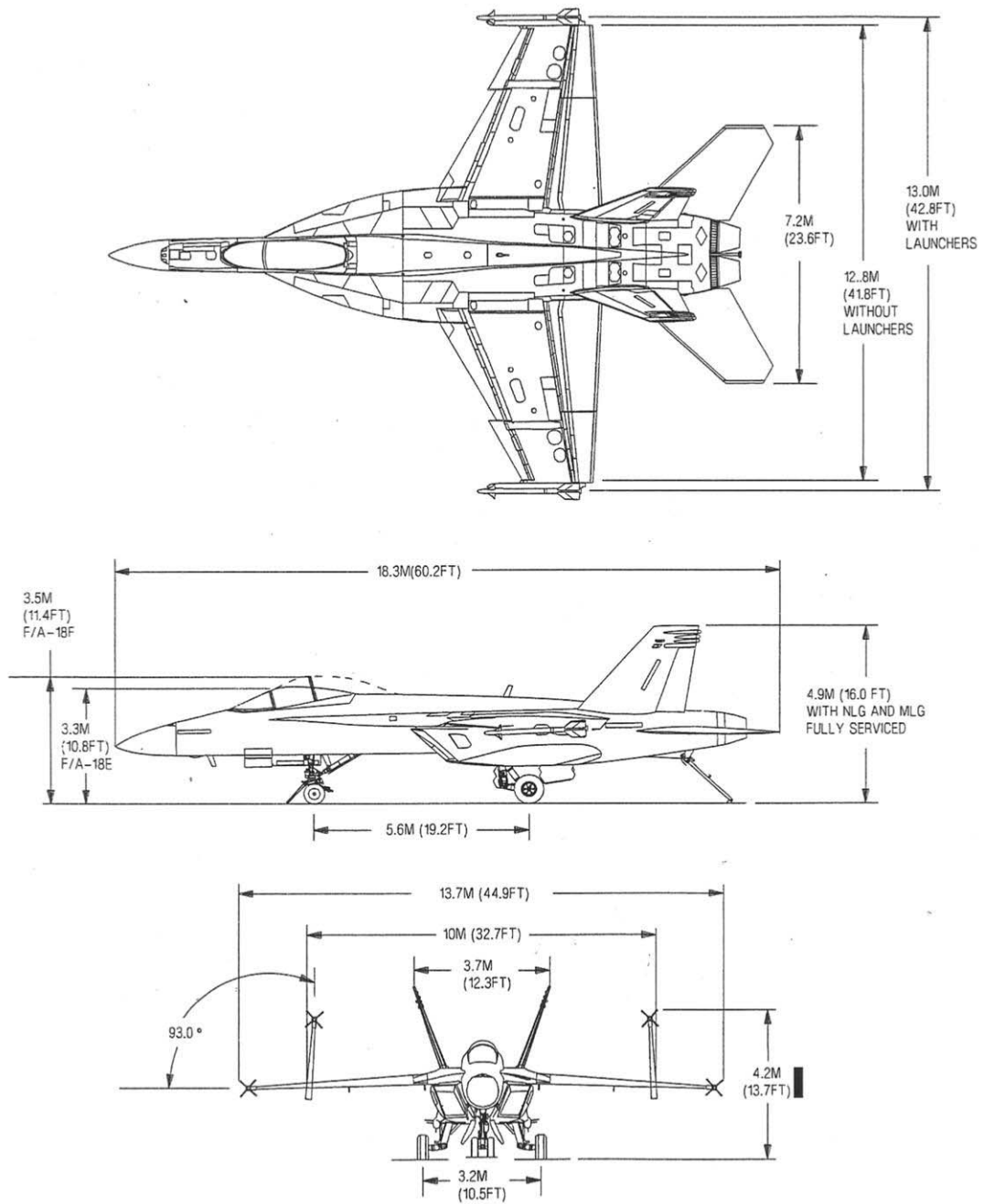


Figure A-2
F/A-18 E/F SUPER HORNET BASIC AIRCRAFT
Source: *General Aircraft Information Maintenance Manual*

APPENDIX B

SAMPLE F/A-18 E/F SEPARATION MATRIX

STORE	Load	Test Point	F/A-18E/F Aircraft Stations											±10 kts	±1000 ft	±5 deg	+0.1/-0.2 g	±0.02			● SEPARATING STORE	
														AIR SPEED	ALT	DIVE	ACCEL	IMN	MRI	QUAN/ MULT	Alt Loss / Min Alt	NOTES/REMARKS
			WT 1	OB 2	MB 3	IB 4	MW 5	CL 6	MW 7	IB 8	MB 9	OB 10	WT 11	KCAS	Feet MSL	Deg	G	msec		ft		
MK-82/ BSU-33		1												535	12.1k	60 +2/-5 deg	0.5	0.98	40	7/1	7559/ 3541	Matches MK-82/ BSU-86 point E4448
		2												550	8.5K	45	0.7	0.95	50	10/1	5496/ 2004	Matches MK-82/ BSU-86 point E5188
		3												530	12K	60	0.5	0.97	40	4/1	7893/ 3107	Matches MK-82/ BSU-86 point E4447
		4												600	18K	60	0.5	1.20	40	7/1	11829/ 5171	
		5												600	18K	60	0.5	1.20	40	4/1	11662/ 5338	
		6												600	18K	60	0.5	1.20	50	10/1	12120/ 4880	

- Notes:
- (1) The following configurations are authorized for station 6: Clean, or 480 EFT, or store identified for release.
 - (2) In addition to the authorized loads on station 5, the following are authorized for carriage on station 5: TFLIR, ATFLIR, or corresponding camera pod.
 - (3) Out-of-sequence release authorized by stepping to station 10 (first bomb off in release) for Quantity<7, Multiple=1.
 - (4) 480 FTCP (Fuel Tank Camera Pod) authorized for use on Stations 4 & 8 in place of 480 EFT

Figure B-1
MK-82/BSU-33 SEPARATION TEST MATRIX
Source: F/A-18 E/F MK-82/BSU-33 Safe Separation Test Plan

APPENDIX C FLIGHT TEST DATA

Table C-1
SUMMARY OF WEAPONS SEPARATION ENDPOINT ATTEMPTS

Peak Airspeed (KCAS)	Recovery Initiation Altitude (1000 feet)	Recovery Initiation Airspeed (KCAS)	Peak Load Factor (g)	Load Factor onset rate (g/sec)	Duration Above 635 KCAS (sec)	Aircraft #, Flight #, and Run Type
653	15.6	637	3.7	1.45	4.30	E10-203 Live
653	16.5	619	4.1	1.13	4.08	E10-197 Practice
646	15.4	626	5.3	2.13	2.17	E10-189 Live
643	16	632	4.0	2.42	2.41	E10-117 Live
643	15.7	621	3.2	1.11	1.99	E10-197 Live
642	16.2	626	4.1	1.31	1.70	E10-188 Live
642	15.8	626	3.7	2.20	3.45	E10-181 Live
642	16	626	3.2	1.22	2.73	E10-203 Practice
640	16.4	622	4.3	1.76	1.41	E10-125 Live
638	18.2	610	5.9	1.31	2.11	E4-455 Practice
637	15.1	629	5.5	3.10	0.80	E4-457 Live
635	15.8	621	4.7	2.32		E10-125 Practice
635	16.6	619	3.4	1.30		E10-181 Practice
634	16.4	619	4.3	1.46		E10-184 Live
633	13.9	631	5.0	2.28		E4-457 Practice
633	17	612	3.8	0.82		E10-214 Live
633	16.1	608	3.7	0.84		E10-213 Practice
632	15.1	617	4.5	1.52		E10-189 Practice
630	17.4	618	5.0	2.66		E10-129 Live
630	18.2	600	4.4	1.17		E10-197 Practice
629	16.9	619	3.5	1.65		E10-203 Practice
629	15.6	618	5.9	1.75		E10-232 Live
629	18	616	7.1	3.87		E4-455 Live
629	16.4	614	3.9	1.52		E10-188 Practice
627	15.7	622	4.6	2.66		E10-110 Live
626	17.4	603	5.0	1.34		E10-184 Practice
625	14.8	618	5.4	2.71		E4-529 Live
625	17.7	608	4.8	1.80		E4-500 Live
624	16.9	617	4.0	1.88		E10-186 Live
624	16.3	609	4.2	1.17		E10-213 Practice
624	18.4	597	3.8	0.99		E10-197 Practice
622	15.8	617	4.8	1.96		E10-128 Practice
622	17.5	615	4.4	2.37		E10-186 Practice
622	16.8	613	3.8	1.63		E10-184 Practice
622	18.5	604	3.6	1.00		E10-177 Live
622	16	602	3.9	1.14		E10-213 Practice
621	17.8	606	5.5	1.87		E4-501 Practice
620	17.8	610	3.9	2.22		E4-503 Live
620	17.8	598	4.2	1.20		E10-214 Practice
619	16.4	609	3.7	1.64		E10-108 Practice
619	17.7	607	3.2	1.44		E10-116 Practice
618	17.1	608	5.6	1.94		E10-232 Practice
618	18.5	602	4.6	1.37		E4-500 Practice
617	16	600	3.3	0.98		E10-177 Practice
616	17	610	3.3	0.89		E10-115 Practice
616	17.8	604	4.3	1.90		E4-493 Live
612	17.9	604	3.9	0.94		E4-503 Practice
612	16.9	601	3.8	1.57		E4-487 Live
610	16.3	609	3.5	1.79		E10-109 Practice
609	17.5	601	5.6	2.93		E4-501 Live
608	18.7	596	4.9	1.58		E4-492 Practice
606	17.3	591	3.1	0.75		E4-486 Practice
606	16.4	590	4.9	1.66		E4-528 Practice
605	16.4	590	6.4	1.99		E10-231 Practice
601	17	584	4.4	1.35		E4-528 Practice

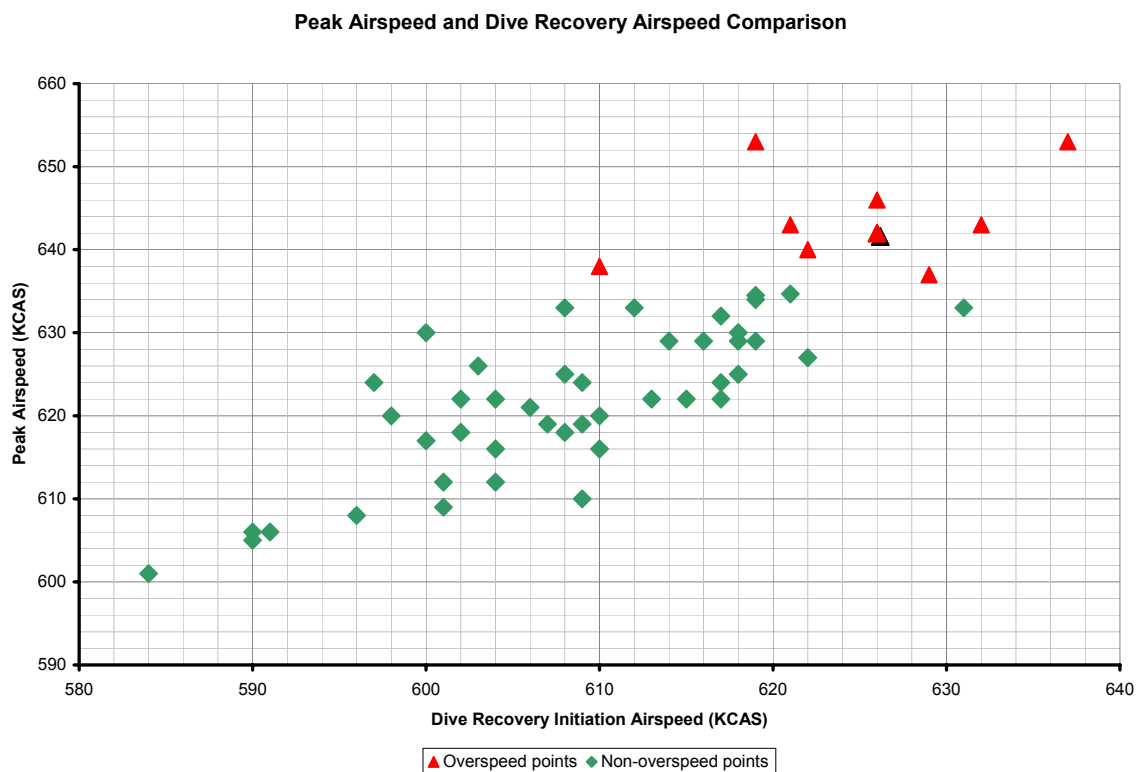


Figure C-1
EFFECT OF DIVE RECOVERY AIRSPEED ON PEAK AIRSPEED
Source: *Endpoint Overspeed during Weapon Separation Testing Brief*

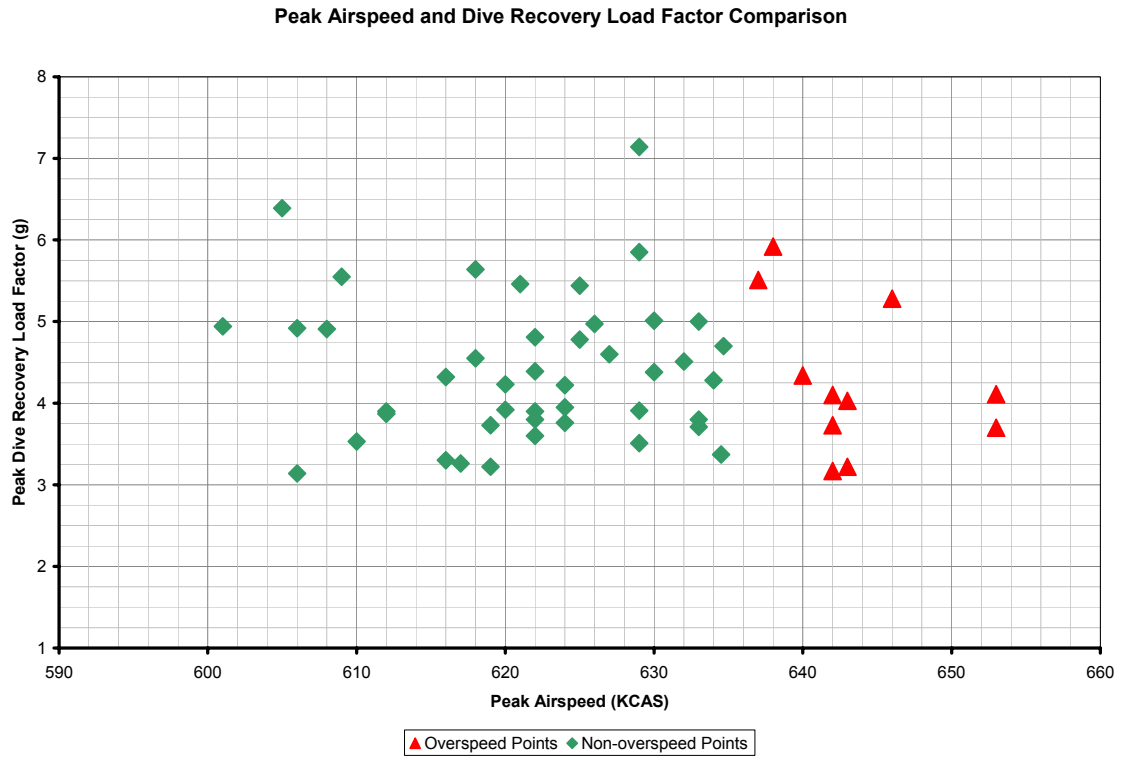


Figure C-2
EFFECT OF PEAK LOAD FACTOR ON PEAK AIRSPEED
Source: *Endpoint Overspeed during Weapon Separation Testing Brief*

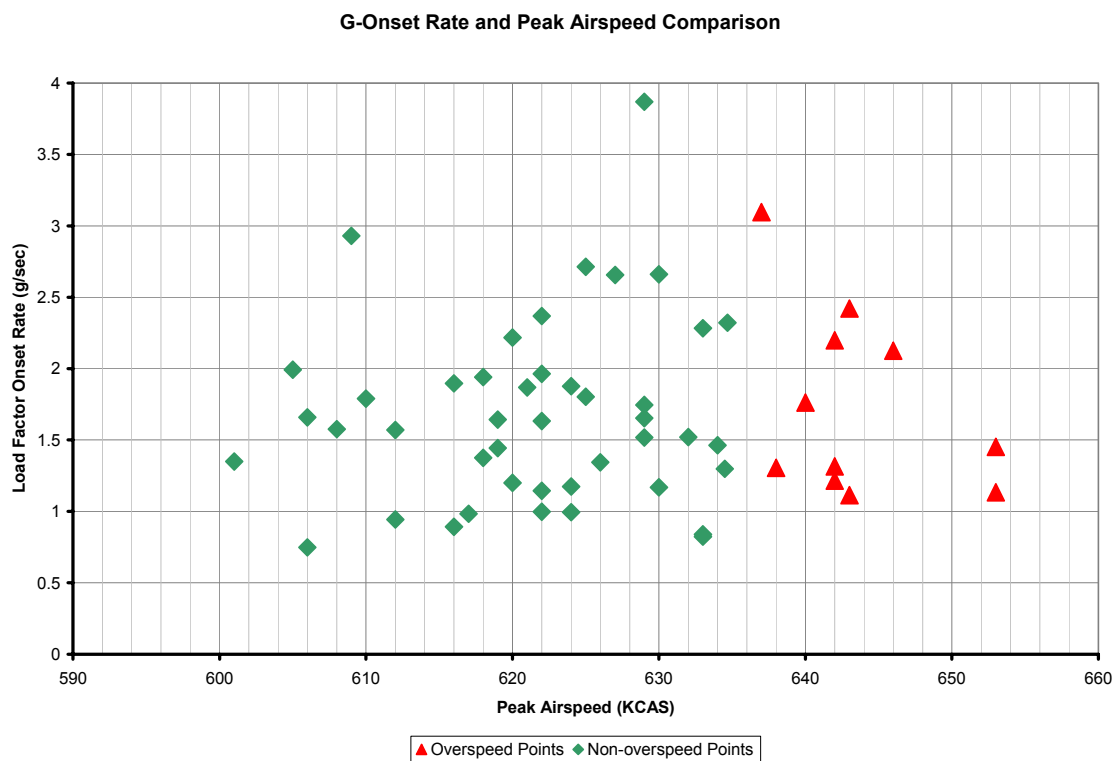


Figure C-3
EFFECT OF LOAD FACTOR ONSET RATE ON PEAK AIRSPEED
Source: *Endpoint Overspeed during Weapon Separation Testing Brief*

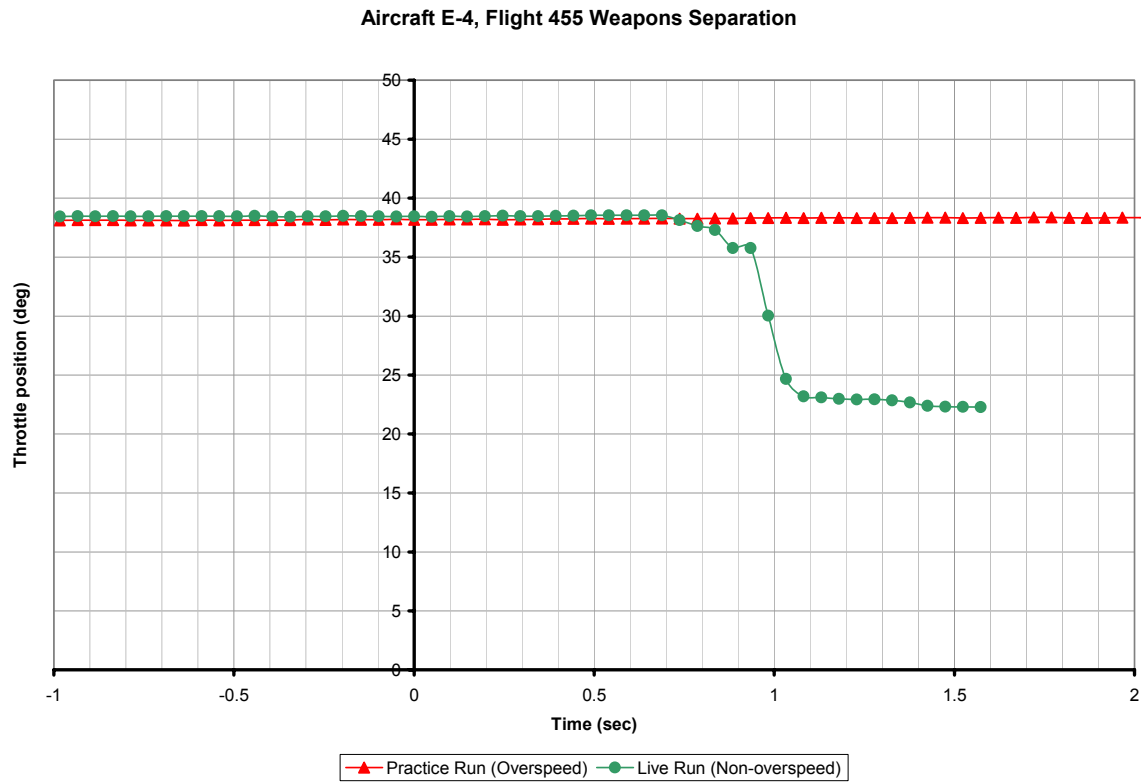


Figure C-4
FLIGHT 455 THROTTLE POSITION COMPARISON
Source: Author

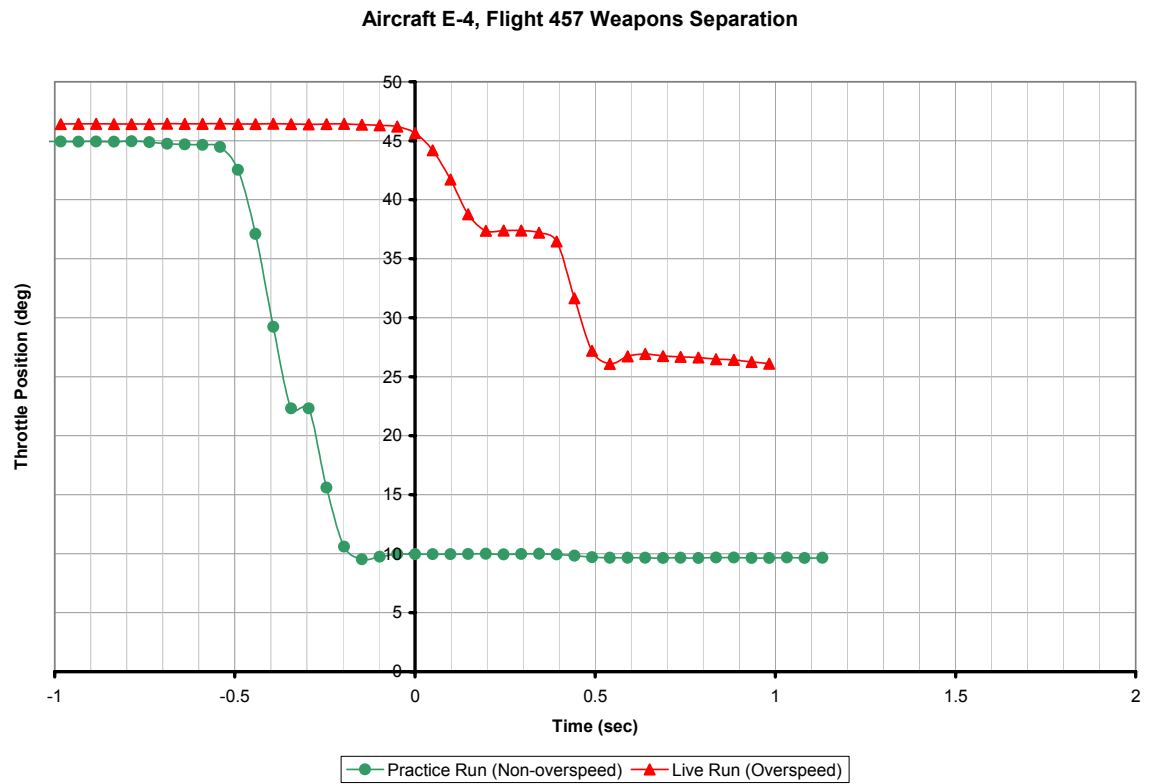


Figure C-5
FLIGHT 457 THROTTLE POSITION COMPARISON
Source: Author

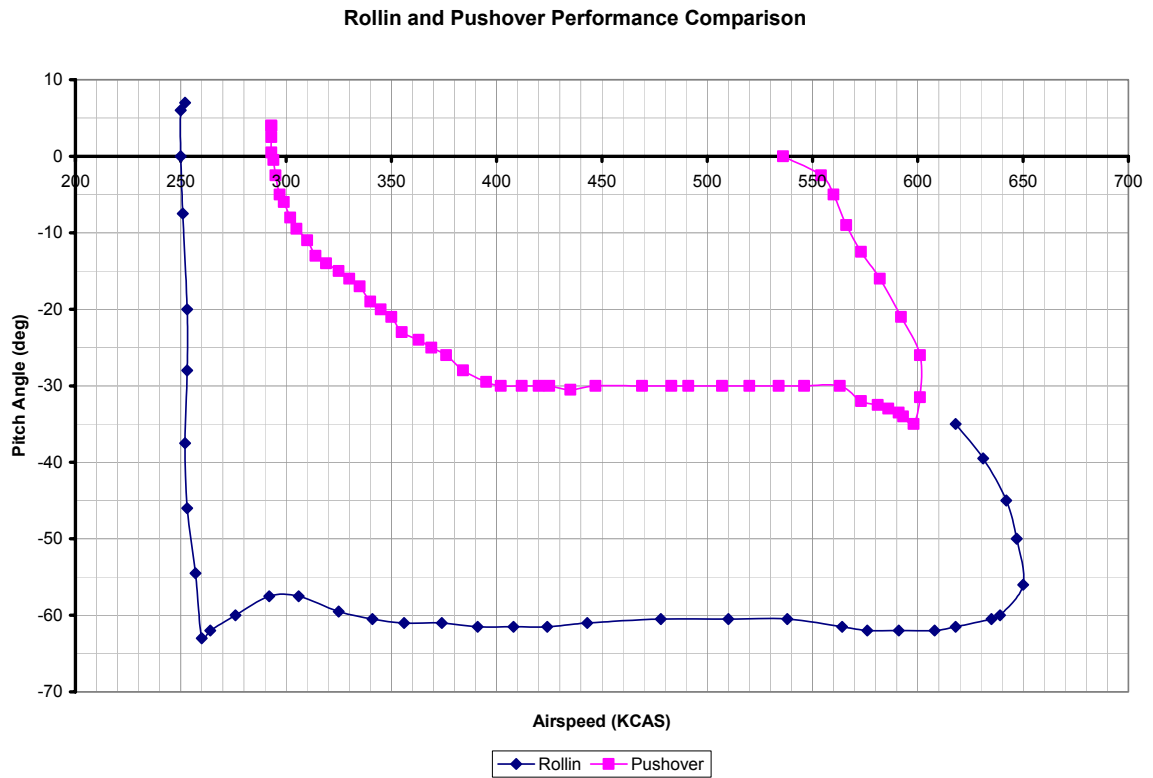


Figure C-6
ROLLIN AND PUSHOVER ACCELERATION COMPARISON
Source: Author

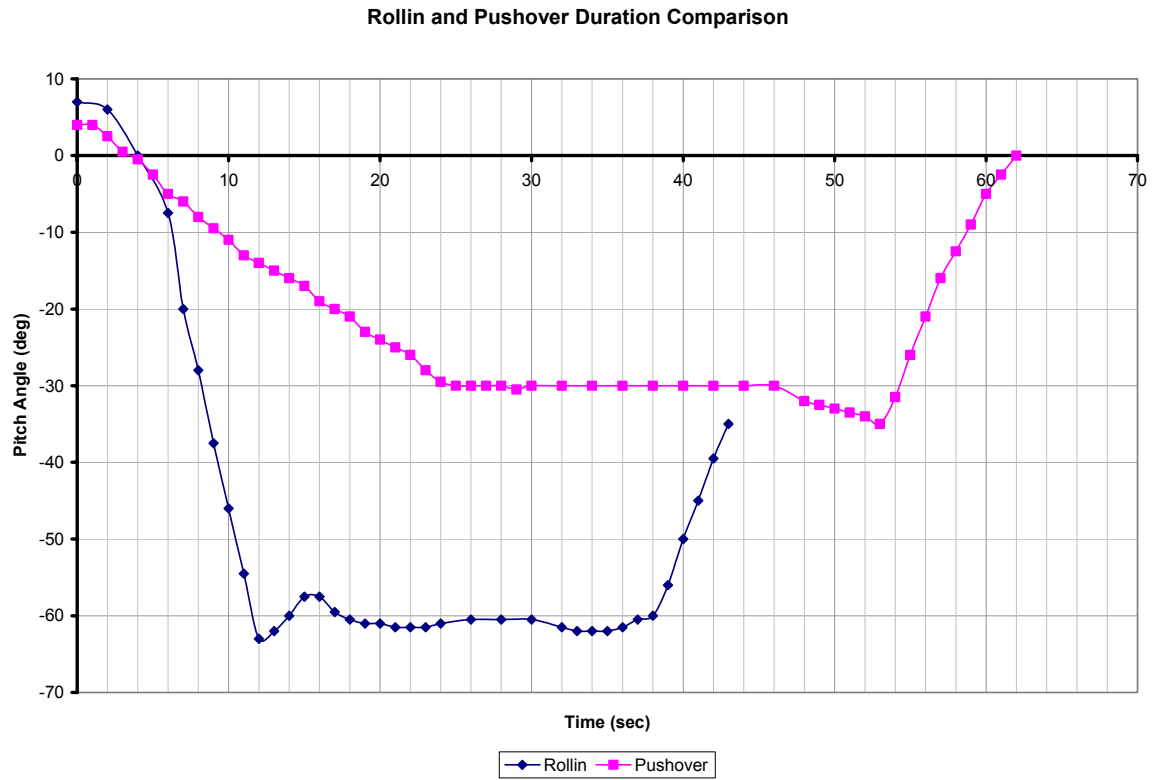


Figure C-7
ROLLIN AND PUSHOVER DURATION COMPARISON
Source: Author

VITA

Born on June 10, 1971, Lieutenant Commander Peter J. Walczak grew up in Durham, Connecticut where he graduated from Coginchaug Regional High School in 1989. Attending the State University of New York Maritime College in the Bronx, New York, he graduated in 1993 with a Bachelor of Engineering in Electrical Engineering and a United States Coast Guard Merchant Marine Third Assistant Engineer's License. Immediately following graduation, he was commissioned as an Ensign in the United States Navy. He began flight training in 1994 and received his Naval Aviator "wings of gold" flying tactical jet aircraft in 1996. After completing F/A-18 Hornet training in Lemoore, California in 1997, he was assigned to the "Fighting Redcocks" of Strike Fighter Squadron Twenty Two, flying the F/A-18C where he performed various additional squadron support roles including maintenance department Quality Assurance Officer. After an overseas deployment to the Arabian Sea and several combat missions defending the Iraqi No Fly Zone in support of Operation Southern Watch, he was selected for U.S. Naval Test Pilot School. As a test pilot in Air Test and Evaluation Squadron Twenty Three in Patuxent River, Maryland, he is currently serving as maintenance department Line Division Officer and F/A-18 E/F Weapon System Integration Project Officer where he is involved with several integration projects, mostly safe separation, for the Super Hornet. He has accumulated over 1400 flight hours in 20 different aircraft and will return to a fleet F/A-18 squadron in January 2004.