EAGLE TALK

McDonnell Aircraft Company

MCDONNELL DOUGLAS

P.S. 1257
15 JUNE 1990
VOLUME IV

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Discussions about McDonnell Aircraft Company's

F-15 EAGLE

Volume IV

(REPRINTS FROM MCAIR PRODUCT SUPPORT DIGEST)

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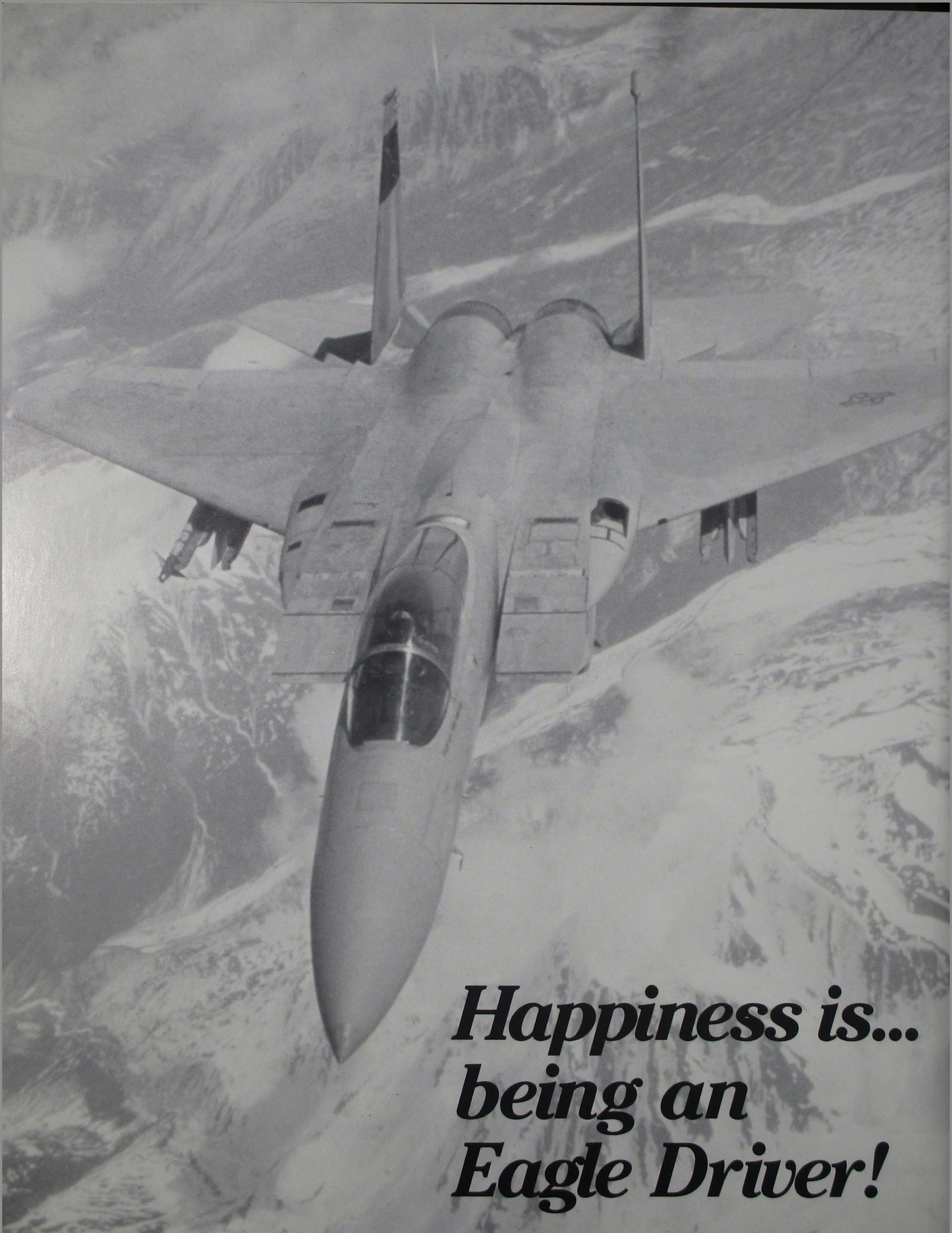
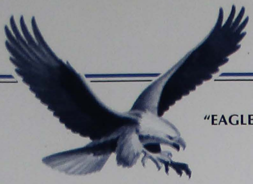

Happiness is...
being an
Eagle Driver!



"EAGLE TALK" . . . discussions about McDonnell Aircraft Company's F-15 Eagle

(reprints from the MCAIR PRODUCT SUPPORT DIGEST)

The F-15 Eagle became operational on 14 November 1974, at Luke Air Force Base, Arizona. There have been more than 1,000 F-15A, B, C, D, and E model aircraft produced for the air forces of the United States, Japan, Israel, and Saudi Arabia. Only speculation is possible regarding the Eagle's ultimate position in the history of aviation and the world, but its position thus far is both secure and spectacular. The MCAIR customer support publication – PRODUCT SUPPORT DIGEST – has documented this "progress of the Eagle" from the very beginning in articles and reports by flight test and engineering personnel. Prepared exclusively for our military customers, these articles offer both an informal history and in-depth technical discussions about the F-15. There is a tremendous amount of information packed into these slender volumes of talk about Eagles, but there are two points to bear in mind when reading: one concerning the "currency" of the material; one its "applicability."

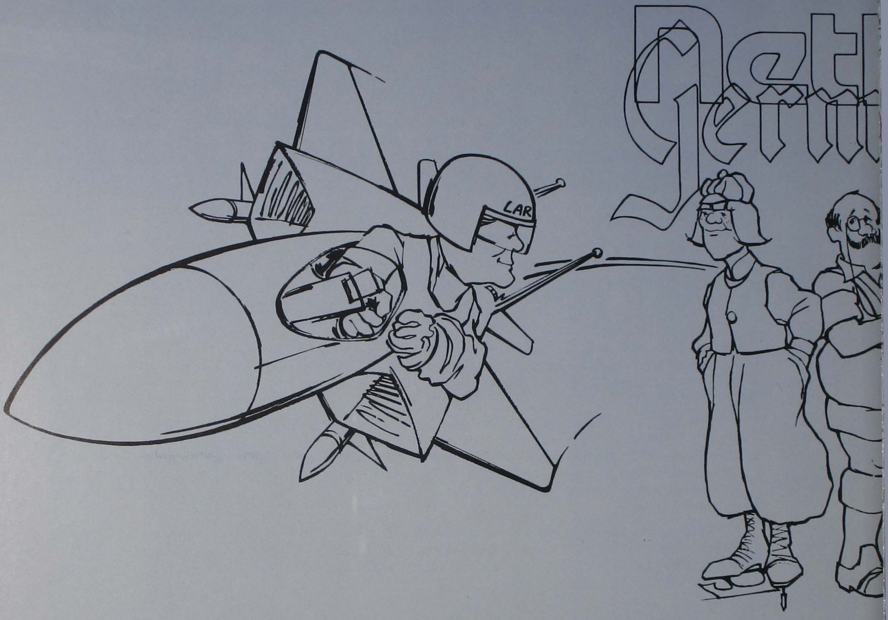
- Articles published herein were up-to-date and valid technically as of the time of original publication (indicated in the table of contents). However, the F-15 Eagle as it is coming off the assembly line today contains many differences from the earlier configurations. Ship No. 1 and Ship No. XXX (latest to fly) may look alike on the outside but, from both system and operational standpoints, they are not alike. If you read something in these articles that does not resemble the cockpit or system as you know it today, please "check six" to see where the information is coming from – its date of publication. It would have been too difficult and time consuming on the part of our authors to review every past article for current validity. Therefore, we suggest you use these volumes for background and general information on aircraft systems, techniques, and procedures. EAGLE TALK contains a wealth of wise words, but only your technical order is guaranteed to have the latest, and the official, ones. Which leads directly into the second point.

- Please be sure you understand the "type" of information provided in these volumes (and in the PRODUCT SUPPORT DIGEST from which they were reprinted) so you won't be looking for advice that isn't there and thus be disappointed. Our publications do not discuss F-15 "tactics." How to utilize the aircraft in combat is the subject of official military documentation; our only objective to inform you about F-15 "capabilities." The theory behind this is that the more information you learn in our publications, the better you should be able to apply the information in yours.

- A lot of the following information applies to all models of the F-15. For example, the discussion on Angle of Attack and Turn Performance clearly applies to the F-15E as well as the F-15A. If you are fortunate to fly our latest and greatest Eagle, you will find that most of what is included in Eagle Talk IV applies to your aircraft as well as the "A" through "D" Model.

(GLEN LARSON, EAGLE DRIVER)

TABLE OF CONTENTS



ON THE ROAD (AGAIN)

By PAT HENRY/*Director of Flight Operations, MCAIR*

(reprinted from USAF FLYING SAFETY magazine, December, 1982)

McDonnell Aircraft Company is "taking the show on the road!" Well, not exactly the whole company, just a few of the F-15 pilots.

A few years ago, company pilots routinely traveled to military organizations that flew the F-4 for the purpose of providing insight and information from the perspective of a company test pilot. Now we have begun a new series of visits, this time for the F-15.

Our purpose in conducting these briefings is twofold: To provide squadron pilots with in-depth information on the airplane and its systems, and to gain feedback from the wing level on the strong or weak points of the aircraft.

The briefings currently cover eight general subject areas that cover 16 specific topics plus a condensed briefing that lasts about 45 minutes and touches very briefly on all the topics. Before making a presentation at a wing, we will be in touch with the Safety and Ops officers. The staff safety officers may be interested in accompanying us during the individual briefings in order to see the material first hand, judge reception, and hear the feedback. We plan on at least a two- or three-day visit at each F-15 wing, if required, and will be presenting information at two (or more) sessions a day. We will be happy to cover all the information we have formally prepared; if another topic is of concern, just let us know, and we'll gather as much information as we can. We want to be flexible and responsive to the needs of the entire F-15 community.

Introduction/Safety

The introduction reviews some basic design goals of combat survivability and takes a brief look at safety records.

(Continued on Page 4, Column 2)

OFF THE ROAD (AWHILE)

By GLEN LARSON/*Senior Experimental Test Pilot*

True to Mr. Henry's word, as indicated across the page, MCAIR has been "on the road" for the past year, with a series of F-15 briefings directed specifically at Eagle pilots. In this case, "MCAIR" means me in that I presented all the briefings. I have appreciated the opportunity to become the "voice of the Eagle," so to speak; and am proud to have been assigned to carry on a long tradition at McDonnell Aircraft Company. Nobody has been around here long enough to remember whether a "contractor pilot briefing team" went out in 1945 with the company's first fighter, the FH-1 (I wasn't even born then!), but for many years it has been standard policy for our flight test organization to share what we know about our airplanes with the customer. Somebody from St. Louis is almost always "on the road (again);" and now that I am "off the road (for a while)," I'd like to tell you a little about my year-long adventure with the F-15 road show . . .

This program differed somewhat from previous ones in that my intent was not so much to focus on specific issues, as to provide insight into some of the engineering and development that has gone into the F-15 since its inception in 1965. I structured my briefings in "segments" (the eight subjects and 16 topics noted by Pat in his article) to allow each individual unit to request specific presentations according to their particular needs and interests. As it turned out, each unit requested all eight subject areas, which indicated that the contractor and the customer look at the Eagle pretty much the same way.

The best part of the trips was renewing old acquaintances and making new friends in the vast F-15 community (if I could have flown on the same airline, I'd have enough mileage credit to go around the world twice — free!). And

(Continued on Page 4, Column 1)
▶

OFF THE ROAD (AWHILE) (CONT'D)

without exception, the hospitality I experienced at each base was superb — interest in my material was high; questions asked were relevant and penetrating; and the pride we here at MCAIR have in building the F-15 was just as evident out there with you who are flying it. Here's how things went, command by command, with some examples of the types of questions I encountered at each location.

My tour of TAC actually started *outside* TAC, at the USAF Safety Center at Norton AFB, California. Since one of my primary goals was to help improve an already exceptional safety record, it seemed appropriate to visit first with the USAF safety experts and discuss the overall program.

The next stop was at HQ/TAC Safety and DO offices to explain our goals; and the inaugural show was then presented at Langley AFB in November 1982 to the 1st TFW and 48th FIS. This was followed by trips to Eglin, Nellis, Luke, and Holloman for discussions with the people at the 33rd, 57th, 405th, and 49th Wings.

One of the most interesting parts of each trip was the exchange of information, and I learned a great deal about problem areas in the field. Some of the subjects brought up were: muting of the UHF by the voice warning system; secondary power system; canopy; and OWS anomalies. These problems and others you brought up have been passed on to our engineering staff and where possible, solutions will be forthcoming.

Also, I have been able to work directly with several individual pilots. Major Dave Perron from Langley has given us some great information on INS and OWS problems, as well as some weapons problems. Major Dave Greschke of HQ/TAC, Captains Paco Geisler from Nellis and Neil Kacena from Luke, and I spent many hours discussing stall and spin characteristics of the airplane. Hopefully, some revisions to Section 6 of the DASH ONE will result.

ON THE ROAD (AGAIN) (CONT'D)

Engines/Performance/JFS

Engines have always been a high interest item, and this presentation explains how the top speed of the airplane is affected by engine trim levels, ambient temperature, and aircraft configuration. Included in this presentation is a brief look at engine trim in terms of past, present, and future trim levels. The JFS is presented in a brief review of airstart envelopes. Fuel leaks are discussed in terms of where they happen, the causes, and pilot actions.

High AOA

High angle of attack is a subject of continuing interest. Here we cover the biggest contributor to loss of control and how to recognize the signs of impending control loss. We also explain the autoroll; and as an extension of autorolls, the roll coupling phenomena, which is especially relevant to "jink out" maneuvers.

G-Loads/OWS

G-loads, especially over-gs, have plagued fighter aircraft for years, and the F-15 is no different. In this presentation, we take a look at how g loads affect the aircraft and how we integrated the OWS (overload warning system) to open the g limits to 9.0 gs symmetrical.

Flight Controls

The flight control system isn't really a deep, dark mystery; and in this briefing, we go back and explain

Alaska in March was outstanding! Most of the snow was gone, except for some huge mounds left over from snow clearing operations. The 43rd TFS at Elmendorf ("Top Cover for America") play for real since they frequently look the "opposition" in the eye during Air Defense scrambles, not to mention the excitement of short runways made icy slick by the long Alaskan winters. Fulfilling night flying requirements when sunset is at 2200 must be agonizing!

Incidentally, it was here in AAC that I was first struck by the incredible variety of climatic, geographic, and situational challenges faced by the Eagle and its pilots. Most USAF assignments are at one location for one to three years, so "global" operational complexities only come across when one makes a rapid around-the-world tour as I did — in Alaska the harsh climate; typhoons and immense flight distances in PACAF; rains, fog, and exceptionally congested airspaces in USAFE; the mixture of all of these conditions and more resulting from F-15 basing at TAC sites all around CONUS. All of this must create mind-boggling "management" problems.

Many of the questions and comments at Elmendorf were similar to those in TAC, but one was unusual — Captain Phil Skains had noted an apparent discrepancy in the flight manual takeoff performance chart with regard to max abort speeds. It appears that the chart is "backwards," i.e., abort speeds for heavyweight airplanes are higher than for lightweight airplanes! Guess what? The chart is right. (The last issue of the DIGEST contains an excellent discussion of this pecular phenomenon and explains why the chart is correct.)

My Pacific tour started with a visit to HQ/PACAF in Hawaii, where I talked with the PACAF staff and then spent half a day on the beach. What a great way to start a briefing tour, even though the beach bit may not have been what my boss had in mind when he sent me out there! The next stop was HQ/5th AF at Yokota for a staff briefing some basic design goals and how they were implemented, along with a discussion of malfunctions. Also included is a section on c.g. position and how it affects turn performance.

Maneuvering Performance

One question we are asked constantly is: "What is the AOA for an optimum turn?" This briefing answers that question in terms of maximum and optimum turn performance and also explains the best acceleration profile.

Landing Gear

Landing gear problems have been with the F-15 for some time, and a final change has been implemented that eliminates all single point failures and adds some extra features to warn of any gear not being extended. The pulser brake system is currently entering service, and this new system is explained from a pilot's viewpoint. Late rotating airplanes are still a problem, so a review of the causes, solutions, and pilot techniques for slow or late rotating aircraft is provided.

New Programs

Several new programs are coming down the pike, and this final presentation covers the latest information on the MSIP (Multi-Stage Improvement Program) effort, the Dual Role Fighter (F-15E), and yet to be approved design studies such as new engines, electronic flight controls, integrated flight and fire control, drag chute, and several other items.

and a mandatory tour of the local electronic emporium. My final stop in the Far East was with the 18th TFW at Kadena, where Colonel "Mac" MacFarlane of "Streak Eagle" fame is Vice Commander. The term "cross-country" takes on entirely new meaning at Kadena since they routinely travel vast distances on deployments to such places as Australia. They also logged a non-stop marathon to Eglin in Florida for their very successful William Tell competition last year. (Conformal tanks anyone?)

Questions and comments here were again similar to TAC and AAC, but they have had some special problems with the vertical tail structure. This one has our full attention and will be resolved in the near future. Captain Rick Carrier had some good questions on the "dual gradient" stick force design. On paper, it would appear that a design which requires 3 3/4 pounds/g up to 3 g's and a change to 2 pounds/g above 3 g's would cause problems. In fact, the reverse is true. Early testing indicated that stick forces at higher g levels were unacceptably high, and a design change was needed to get the forces down to a reasonable level. In daily operations, the pilot won't even notice the difference in stick force levels. (Got to go a long way back to get this one, but an article in Issue 4/1973 of the DIGEST has an excellent analysis of the engineering and simulation work which went into resolution of stick force per g and other flight control system complications.)

Europe in June. Fantastic! First stop was Ramstein/Sembach to visit with the HQ/USAFE and 17th AF staffs, then back to Frankfurt for a flight to Amsterdam and a short drive to Soesterburg. Four days with the "Wolfhounds" of the 32nd TFS were delightful. Again, similar problems were brought up here, and Leiutenant Colonel Mike Francisco asked some good questions about the OWS. (The latest in a series of DIGEST discussions on the overload warning system is presented on page 14 of this issue. The article addresses several points relating to OWS parameters and interfaces that were the subject of questions during my briefings, and is worthwhile reading.)

The next leg of the trip took me back to Frankfurt for a drive down the Mosel River to Bitburg for sessions with the 36th TFW. Comments again were similar to other bases, but Captain Stub Henderson had some good questions about INS align times — can they be reduced? The answer is yes and no. No, the current system can't really get much better than the rapid align feature; and yes, a new INS can be made to align somewhat faster. (The last issue of the DIGEST had the first of a two-part series of good articles on INS characteristics and CND problems; the next issue will offer some cockpit INS alignment tips and a preview of some new ideas in inertial navigation systems.)

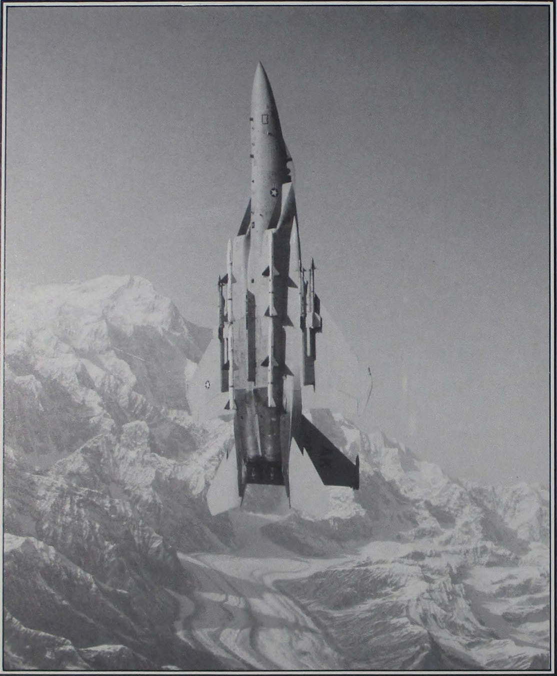
Now that our first F-15 world tour is completed and this article published, I can sit back and relax — but just for a while. Because of the success of the program, we are planning on continuing this type of presentation, with changes and updates as appropriate. And as a follow-up to this program, a special pilot-oriented Product Support document will be coming out soon.

Our company aircrews and technical specialists have been writing articles about the F-15 for publication in the DIGEST for more than ten years, but many of the past issues of the magazine are no longer available. If you are fairly new to the Eagle, you probably aren't aware of just how extensive a storehouse of ops-type knowledge has been accumulated through these articles, so we're putting together reprint collections of them all. Several volumes of "EAGLE TALK" (P.S. 1257) are to be published. Volume I is in work now and will be composed of general interest articles arranged in chronological order — sort of a pilot's history of the F-15 from first flight up to the present. Volume II (and subsequent volumes) will contain the more technically-oriented article reprints, arranged in subject order, such as flight controls, engines, systems, avionics, etc.

As for myself, I plan to follow up this summary DIGEST article with several detailed ones, based upon those areas in my briefings that seemed to be of the most interest to you — turn and acceleration performance, out of control and spins, landing gear, etc. Also, with the assistance of our engineering people, I plan to include answers to many of the questions you all threw at me, so make sure to reserve your copy of the next few DIGESTS.

If your unit would like one of our pilots to visit and present a briefing on a specific subject, please let us know. In the meantime, remember that we also encourage individual pilots to call, write, or stop by St. Louis to discuss problems or offer suggestions for the F-15 program. You can call us at (314) 232-3456, write us at Department 290, or stop by our office in Building 42 on the MCAIR flight ramp. Our door is always open, and I'd personally welcome the opportunity to return your super hospitality of the past year! ■

ANGLE OF ATTACK a



Of the many questions about the F-15, a few seem to be asked repeatedly, and one of the most frequent is -

"What are the angle of attack guidelines for turn performance, acceleration, cruise, and endurance?"

This article, in addition to developing AOA guidelines, provides a pilot's perspective on turn performance. It is the result of several months' effort and was a part of the briefings recently given to F-15 pilots worldwide. Like the F-15 itself, this discussion is the result of a team effort and my special thanks and appreciation are offered to several individuals. Dave Thompson, Chief Technology Engineer, was a special source of technical advice and guidance; and without the help and engineering expertise of Clarence Mongold, F-15 Aerodynamics Branch Chief, Carl Miller, Lead Technology Engineer, and Drew Niemeyer, Technology Engineer, this article could never have been written.

Ever since aircraft were first used in air-to-air combat, pilots have been concerned with how to get maximum turn performance out of their machines. Aerodynamicists have developed equations that explain the turning performance of any aircraft; but until recently, few guidelines existed to aid the pilot. Early fighters had control systems and aerodynamic characteristics that provided a wide variety of clues for turning performance. Lumped together, they provided what was often called the "feel" of the aircraft; and with that, the pilot could maneuver his fighter very effectively. With the advent of hydraulic (irreversible) controls and artificial feel systems, these guidelines became unusable; and other guidelines such as airspeed or angle of attack were used. Before moving on to specific guidelines for the F-15, we need to review some basic theory.

AN ENGINEERING PERSPECTIVE

Angle of attack is used by the Navy as a landing aid because unlike airspeed, the AOA value for final approach remains constant, regardless of gross weight or altitude. AOA is also used as a reference for turn performance. Angle of attack is simply the angle between the chord line of the wing and the free stream airflow, which is usually presented to the pilot in actual degrees, as in the F-18, or in non-dimensional units, as in the F-15 or F-4. For the F-15, an approximation of the actual angle of attack in degrees can be obtained by subtracting ten from the indicator reading. (For example, at 40 cockpit units, the wing is at approximately 30° AOA.) "Corner" velocity, which is the minimum speed at which the aircraft can reach (but not sustain) the maximum allowable g load, and "on speed" turns are also common references.

Let's review F-4 "on speed" turns for a moment. The "on speed" reference, or 19.2 units for the original F-4, developed as a landing aid for the Navy, happened to work out as a reasonable reference for maximum performance turns in ACM. It is often assumed by F-4 pilots that the 19.2 unit reference is at maximum coefficient of lift (C_L) - not true, it actually occurs just below the peak in the C_L curve, as shown in Figure 1. This is a good reference for ACM because above 19.2 units, induced drag is so high that the rate of energy loss is unacceptable; and more importantly, the handling

By GLEN LARSON/*Senior Experimental Test Pilot*

d TURN PERFORMANCE

qualities degrade markedly. Unpleasant characteristics such as nose rise, nose slice, and departure/spins can develop rather quickly at higher angles of attack.

What about the slatted F-4's? How come 23-24 units are used instead of 19.2 units? The basic reason is that the slats keep the airflow attached to the wing at higher AOA's, improving the high AOA handling qualities of the airplane. The addition of slats to the wing extends the lift curve, as shown in Figure 1, allowing the aircraft to fly to higher AOA's.

What are the limiting factors for turn performance? The turn equations shown below have only two variables: g's and true airspeed.

$$\text{Turn Radius} = \frac{V^{2}}{11.3\sqrt{n^{2}-1}}\ \text{feet}$$

$$\text{Turn Rate} = \frac{1092\sqrt{n^{2}-1}}{V}\ {}^{\circ}/\text{sec}$$

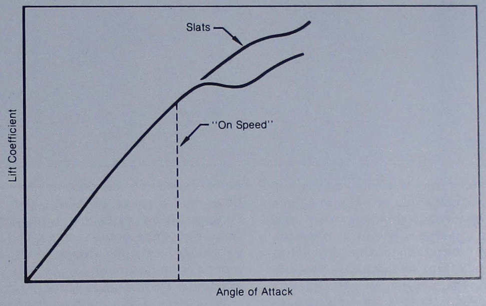
Where V = True Airspeed in Knots
n = Load Factor or G's

The physical limits that apply to these equations are: structural limits, aerodynamic limits, and thrust (power) limits. Let's examine these three limits and how they apply to the equations.

- Structural Limits – In order to get the radius as small as possible and the rate as high as possible, it's necessary to operate at the highest possible g level at the lowest possible true airspeed. The g limit is determined by the aircraft structure, and the g capability of the aircraft is determined by the aerodynamics of the aircraft. At high speeds, loads on the aircraft structure are the limiting factors; while at low speeds, aerodynamics limit the g level attainable.

- Aerodynamic Limits – This can be thought of as a lift limit, control surface deflection limit, or a handling qualities limit, depending on the type of aircraft. In the F-15, the effective aerodynamic limit occurs at full aft stick. Large lateral asymmetries (one wing heavy) in any aircraft can cause some unpleasant handling qualities at high AOA's which will force the pilot to operate the aircraft at a lower AOA, thus limiting the g capability. Whatever the effective aerodynamic limit is caused by (handling qualities, maximum lift, or weight asymmetry), it has the effect of limiting the g's the aircraft can pull, which lowers turn performance.

FIGURE 1 - F-4 LIFT COEFFICIENT VARIATION WITH ANGLE OF ATTACK



Up to this point, we've been discussing instantaneous turn performance. For sustained or optimum turn performance, the third limit (thrust) becomes a major consideration.

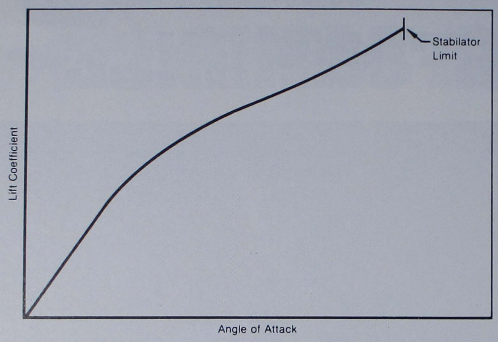
- Thrust Limits – This one isn't quite as straightforward since energy-maneuverability (E-M) must now be considered. E-M considerations become important since maneuvering flight is a dynamic situation. E-M can be broadly defined as the "total energy" of the aircraft at a given point in time, and is made up of a combination of kinetic energy (speed) and potential energy (altitude). The excess thrust available (thrust minus drag) can be thought of as the ability to change total energy, resulting in a gain in speed or altitude if thrust exceeds drag. E-M concepts are usually presented in the form of a graph known as a V (velocity) and H (altitude) diagram, with contours of constant P_s, or specific excess power. P_s is a number that quantifies aircraft capability to change energy at a given flight condition and is usually expressed in terms of feet per second. When the V-H diagrams for different aircraft are calculated for the same g level, a pilot can tell quantitatively how much advantage (or disadvantage) he has relative to an adversary. Referring back to the turn equations, it becomes apparent that the more g's the aircraft can sustain at a given speed, the better the turn performance. In E-M terms, this means that the higher g levels attainable at $P_s = 0$, the better the turn performance.

As a review, here's a specific example: A B-52 at 520 knots true airspeed and 5 g's would have exactly the same turn rate and radius as an F-15 at the same conditions. Obviously, the B-52 couldn't get to 5 g's (structural limits), would quickly reach $C_{L\max}$ and stall (aerodynamic limits), and couldn't sustain 5 g's (thrust limits). The F-15, however, will easily sustain 5 g's without exceeding structural or aerodynamic limits. These concepts are excellent for understanding relative turn performance, but don't provide any readily available guidelines.

A PILOT'S PERSPECTIVE

Now that theory is out of the way, let's explore some practical applica- ▶

FIGURE 2 - F-15 LIFT COEFFICIENT VARIATION WITH ANGLE OF ATTACK



tions. For purposes of this discussion, there are really only two kinds of turns to be concerned with: *maximum* and what is sometimes known as *optimum* turns. A "maximum" turn is defined as the best rate and radius possible without regard to energy loss. Defining an "optimum" turn is not quite as easy because pilots have used that term to describe a turn that was actually a sustained turn. A "sustained" turn is one that is performed at a single set of conditions that results in a specific *sustained* g level. The exact combination of AOA and speed will vary, depending upon gross weight and altitude. Rather than develop exact AOA's for each combination of conditions, we will determine a range of AOA's that encompass most sustained turn conditions but since some energy will be gained or lost, this range does not represent an optimum.

Maximum Performance Turns

Intuitively, a maximum performance turn would be at the point where the wing is producing maximum lift or C_{Lmax}. The F-15 is somewhat unusual in that it won't reach C_{Lmax} in a sustained turn because it is prevented from reaching that point by available stabilator authority, which limits lift, as shown in the lift curve in Figure 2. This is an intentional design feature of the F-15 which keeps the loads on the tail structure at a manageable level, and which also has the added benefit of preventing the aircraft from reaching very high AOA's where unpleasant handling qualities can develop. This implies that the F-15 wing cannot be stalled; and in a gradual 1 g deceleration, it really doesn't stall. The aircraft ends up in a full aft stick, high sink rate condition that resembles a stall (wing rock, buffet, etc.), but it isn't truly stalled (i.e., above C_{Lmax}). In an abrupt turn, the AOA will overshoot the value for a steady C_L, but will return to a steady value of C_{Lmax}.

Guidelines for maximum performance turns can be determined from Figure 3, which is a plot of turn rate and radius without regard for energy loss. Two general conclusions can be drawn:

- These turn rates generally cannot be sustained; therefore, it's better to operate above 300 KCAS in order to be able to use the maximum available turn rate. As the speed decreases, turn rate increases until reaching a maximum at 300 KCAS; thereafter, the turn rate decreases as speed decreases.
- Since the wing C_{Lmax} can't be reached, the best guideline is to simply pull to the stick stop (full aft stick) or the g limit, whichever occurs first. For a 9 g airplane (symmetrical), the crossover speed is 305 KCAS. Above 305, stop pulling when you hear the OWS tones; below 305, pull to the aft stick stop. (For a non-OWS equipped aircraft, the crossover speed for 7.33 g's is 275 KCAS.) This speed, 305 KCAS, is the corner velocity of the F-15.

Incidentally, there is a modification to the control augmentation system that significantly increases the instantaneous pitch rate at low speeds. This change (which has been tested by the USAF at Edwards AFB) is in the proposal stage for retrofit, and is included in the Dual Role Fighter proposal.

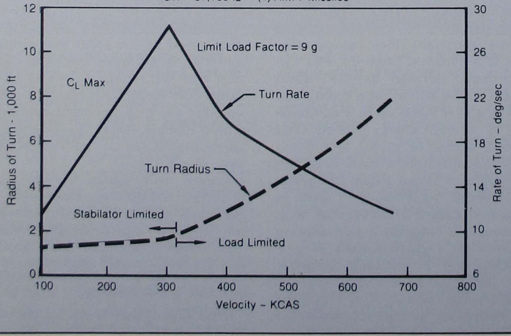
A word of caution for non-OWS equipped aircraft: The classic academic definition of corner velocity is the lowest speed at which the aircraft can reach its structural limits. This implies that you can snatch the stick full aft and not exceed the structural limits; however, any time you are rolling the aircraft or are at high gross weights, the g limits are lower, so be careful. In any event, the OWS is smart enough to allow for these factors. Also, observe the asymmetric load limits and stay below 30 units AOA if the imbalance exceeds allowable limits.

Sustained Turn Performance

The most significant limit on sustained level turn performance is thrust minus drag, or Specific Excess Power. Energy-Maneuverability considera-

FIGURE 3 - F-15C TURN PERFORMANCE

Alt = 10,000 ft Maximum Thrust
GW = 37,100 lb (4) AIM-7 Missiles



tions, discussed earlier, become important since we are dealing with dynamic maneuvering flight.

The chart in Figure 4 is similar to Figure 3, but with one significant difference: it is for sustained performance or $P_S = 0$. This chart defines turn performance for a specific set of conditions (altitude, weight, and thrust). Generally speaking, a pilot wants the best rate possible without losing energy. Therefore, the area around 500 KCAS is best for this type of turn since the rate is maximized. The radius isn't a significant consideration since you are trying to turn as quickly as possible and still sustain energy. Unfortunately, this chart doesn't provide enough information to develop AOA guidelines.

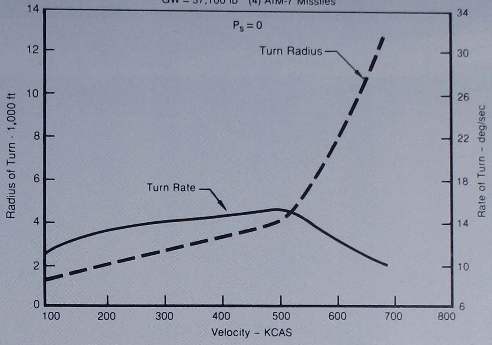
Figure 5 is a pilot-oriented chart designed to more clearly explain optimum turn performance; it may appear slightly confusing initially, but with some explanation, should become quite clear. The chart is designed to be pilot-usable. The vertical axis is the g level read in cockpit, and the horizontal axis is angle of attack in units. The lines fanning out from the origin are airspeeds read on the A/S indicator and plotted across the airspeed lines are lines of $P_S = 0$ for mil and max power.

From Figure 4, we determined that 500 KCAS is the speed for max sustained turn rate for the given conditions. If that's true, then the $P_S = 0$ line for max power should reach almost 9 g's just above 500 KCAS on Figure 5, which it does. The effect of thrust on turn performance is clearly illustrated by the difference in sustained g between mil power and max power; in this case, a 3 g advantage in max power. The speed at which a given g level can be sustained can be thought of as an "ultimate" or "sustained" corner velocity. This is in contrast to classic corner velocity mentioned earlier where the aircraft can reach the maximum structural limits, but cannot sustain that g level. In fact, the "classic" corner velocity of the aircraft can be determined from this chart. The upper right hand corner represents the lowest speed (305 KCAS) that the aircraft can reach, but not sustain 9 g's.

By referring to the AOA scale, the exact AOA for a given speed and power combination can be determined for sustained turns. For example, at 405 KCAS, you can sustain 6 1/2 g's at 19 units in max power or 5 g's at 16 units in mil power. The best sustained turn points for a 37,100 pound aircraft are at 500 KCAS, 13 units at mil power for 5.8 g's and 507 KCAS, 16 units at max power for 8 g's. It is possible to draw lines of $P_S = 0$ for an adversary aircraft on this chart and get an instant comparison to your own.

FIGURE 4 - F-15C TURN PERFORMANCE

Alt = 10,000 ft Maximum Thrust
GW = 37,100 lb (4) AIM-7 Missiles



It's difficult for a pilot to remember precise values of AOA for all the combinations of speed and power settings. To make things easier, a range of AOA's that encompass most sustained turns can be determined by defining a range of airspeeds generally flown in air combat. You can, of course, pick your own speed ranges; but for the general case, 300 to 600 KCAS is reasonable. The range of AOA's that correspond to this speed range is 12-22 units. This is a fairly wide range and, with experience, you may want to shade it one way or the other, depending on the tactical situation. This range of AOA's will not give true sustained turn performance, but is a good "rule of thumb" guideline that will result in some energy gain or loss. For example, mil power at 22 units and 350 KCAS results in a loss of energy; and max power at 12 units and 450 KCAS will result in a gain.

Another guideline for sustained turns is the beginning of aerodynamic buffet. Since there are no lights, tones, bells, or whistles to tell the pilot when he is in the range of 12-22 units, the beginning of light buffet can be used as an approximate guideline to determine when you're in the 12-22 unit range. Table 1 is a summary of the AOA's at which various aerodynamic buffet levels begin. The distinction between light and moderate buffet is somewhat subjective, but the point at which light buffet begins is usually apparent.

Figures 4 and 5 are for 10,000 ft MSL; but since energy maneuverability is

FIGURE 5 - F-15C TURN PERFORMANCE

Alt = 10,000 ft 97 1/2% Thrust
GW = 37,100 lb (4) AIM-7 Missiles

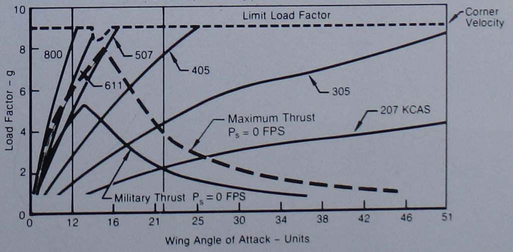


TABLE 1 - BUFFET ONSET POINTS

Mach Number	AOA for Light Buffet	AOA for Moderate Buffet
.4	18 Units	22 Units
.5	18 Units	22 Units
.6	18 Units	22 Units
.7	18 Units	22 Units
.8	17 Units	20 Units
.9	14 Units	16 Units

FIGURE 6 - F-15C TURN PERFORMANCE

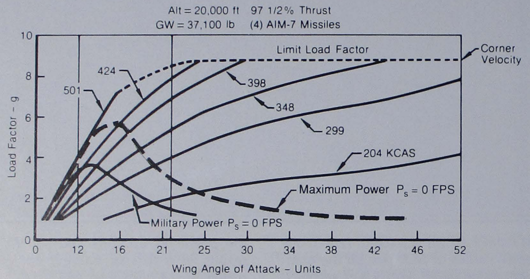
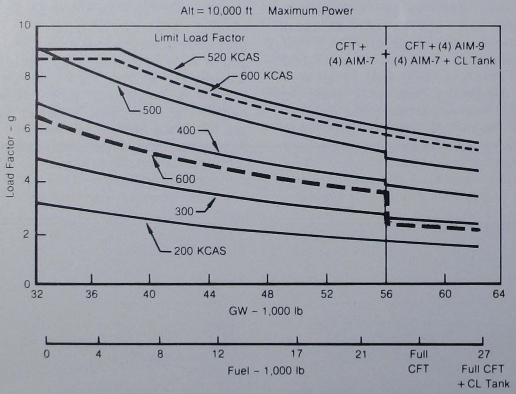


FIGURE 7 - F-15C SUSTAINED G CAPABILITY



dependent on altitude, what happens to this 12-22 unit reference at higher altitudes? Figure 6 is identical to Figure 5 but is at 20,000 ft. As expected, for a given power setting, the g capability is reduced. You can't sustain 8 g's, but can sustain 6 g's in max power. The range of 12-22 units, as shown on Figure 6, remains valid as a guideline at 20,000 feet, or for that matter, any altitude. The g's that the aircraft will sustain will be different. The point at which the aircraft will sustain the most g's at 20,000 ft in max power is at 424 KCAS, 16 units AOA, resulting in **5.6** g's; and for mil power, 12 units AOA, resulting in **3.5** g's at 424 KCAS.

The effects of weight are similar to the effects of altitude. The guideline of 12-22 units AOA still applies, but the g level that the aircraft can sustain will change. Figure 7 for max power and Figure 8 for mil power, show how sustained g will drop as weight increases. The vertical axis is the load factor or g level the aircraft will sustain, and the horizontal axis is gross weight; and for clarity, an additional scale shows fuel on board. To use the charts, enter with the gross weight (or fuel on board) and go up to the speed you are interested in and then across to read the sustained g level. If a diagram similar to Figure 5 were developed for a high gross weight, the AOA would still fall in the 12 to 22 unit range.

Since you may enter combat at speeds other than corner or sustained corner velocities, other lines on the charts illustrate the sustained g level possible for a given speed and weight combination. For example, a CFT-equipped aircraft weighing 52,000 pounds (**19,000** fuel), in max power at 400 KCAS, can sustain 4½ g's, and at 40,000 pounds (7,900 fuel), 5½ g's. In any case, the guideline of 12-22 units still applies. The configuration of the aircraft has little effect on sustained turn performance; however, weight has a dramatic effect. The charts are for a CFT equipped aircraft, but apply to other configurations as well. Simply calculate the gross weight for your configuration and use that value rather than fuel on board to determine the sustained g.

Acceleration

What's the best technique for accelerating the F-15? The answer depends on what you are trying to accomplish, because the F-15 is somewhat unique with respect to acceleration characteristics. Aircraft accelerate best when the total drag on the aircraft is at a minimum. This usually occurs for most fighters at the point where the wing isn't generating lift, which happens when the flight path is near ballistic and the g load is approaching zero. However, with the F-15, minimum drag does not occur at zero lift. The reason for this is its sophisticated wing camber design, in which the F-15 wing can be thought of as having a leading edge flap that is permanently extended to meet a design requirement to sustain high g's at high altitudes.

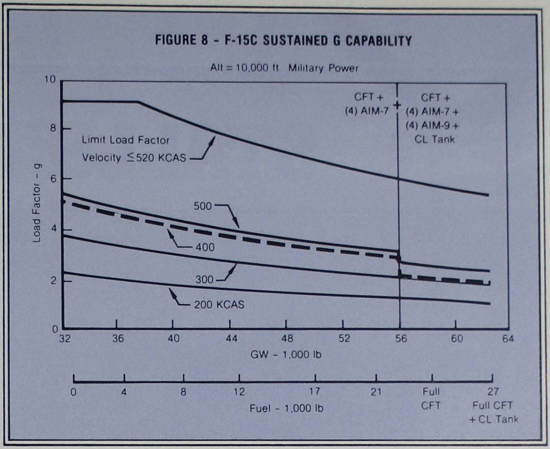
Precise values of AOA can be determined for use as a guideline to accelerate at minimum drag: below 1.2 Mach, 8 units, and above 1.2 Mach, 9 units, results in minimum drag. In the range of .4 to 1.0 Mach, 8 units AOA will be at 1 g or slightly less; but at higher Mach numbers and lower altitudes, 9 units AOA results in a 2 to 3 g turn. Rather than attempt to fly precise values of AOA, a more reasonable method is to pick a range of AOA which will result in a slightly longer time to reach a given speed or energy level, but allows the pilot to initially set the AOA in a range and then pay attention to the target. The range of 5-10 units represents a reasonable compromise.

One final point: the F-15, like other aircraft, will accelerate downhill using the added acceleration from gravity. However, because of the wing design, the F-15 gains less from pushing over during an acceleration than do most fighters, so don't spend a lot of time going downhill. Depending on the tactical situation, level off or climb back to Eagle country!

Cruise and Holding

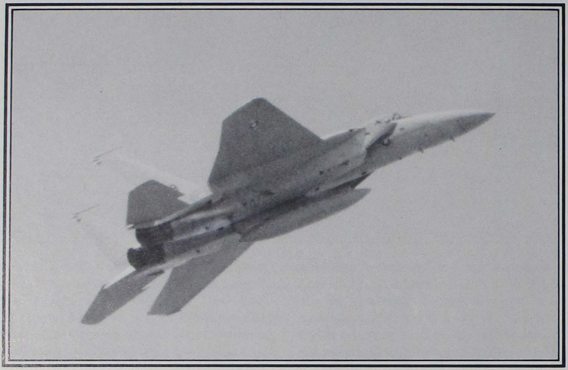
To wrap all this up, guidelines can be developed for best cruise and best loiter. Since the AOA reference for best cruise or loiter is nearly constant for all altitudes and weights, it can be used in place of airspeed. For max range cruise, the numbers work out such that 12 units gives the best range; and for holding, 14 units gives the minimum fuel flow for max endurance.

FIGURE 8 - F-15C SUSTAINED G CAPABILITY



In summary, you might want to tape the following information to your kneeboard for quick reference during those moments of doubt . . . Sustained turn performance is generally in the range of 12-22 units AOA; and maximum performance turn guidelines are the stick stop or g limits (whichever occurs first). For acceleration at minimum drag, use 8 units below 1.2 Mach, 9 units above. Best cruise is at 12 units and best endurance is at 14. While these guidelines are unique to the F-15, similar charts can be developed for any aircraft and associated guidelines determined.

STALLS, SPINS, and



An article of the length and detail of this one and which addresses such a complex subject requires a great deal of assistance from the engineering community. Special thanks are due to several individuals who were key contributors to what you are about to read. Jack Krings, currently Director of Marketing for Navy and Marine programs in Washington, D.C., flew the original F-15 spin tests and deserves special credit for his pioneering effort in the program. Dave Thompson, Director of Program Engineering for the F-15E; and Clarence Mongold, Branch Chief, F-15 Aerodynamics, were of invaluable assistance. Extra recognition goes to Pat Wider, Lead Engineer, F-15 Aerodynamics, who patiently reviewed multiple rough drafts for engineering accuracy. These gentlemen made this article possible; and they, along with the rest of the MCAIR team, have produced the finest flying fighter in the world.

Aircraft loss of control and spins have been with us since shortly after the Wright brothers' flight at Kitty Hawk and by 1916, spins had become fairly common events. For a while, they were used as defensive maneuvers in air combat, but as such were of limited value; an attacker simply waited for his target to recover and then resumed the attack. Aircraft design theory evolved to more modern designs and for the first time, pilots encountered the flat spin which proved difficult to stop. Aircraft with weight concentrated in the fuselage (such as the century-series fighter) will flat spin, and also exhibit some exciting gyrations during spin entries.

Spins should not be feared – understood and respected, yes, but not feared. Our purpose here is to impart some general understanding of loss-of-control and spins and, specifically, how the F-15 behaves during high-angle-of-attack flight. The F-15 has successfully demonstrated numerous spins and spin recoveries. The spin characteristics are well known; and with sufficient altitude, the recovery procedures are reliable – there aren't any deep dark secrets or hidden surprises.

Spins in any aircraft share some common characteristics. For example, spin entries at high speeds will be more violent and spins entered at high gross weights tend to be higher-energy spins from which it takes longer to recover. Also, the character of a spin entered at 40,000 feet doesn't differ significantly from one entered at 20,000 feet. Current generation aircraft such as the F-15 have design features that make it difficult to spin. If you do manage to enter a spin, other design features make recovery easier.

The F-15 flight control system is designed to provide comfortable, predictable response throughout the flight envelope; and the aerodynamics provide honest, straightforward handling characteristics. Directional stability remains positive at any angle of attack normally attainable in flight, which makes entering spins difficult. In addition, the control system has features that prevent inadvertent prospin inputs at high angles of attack. As a result, it isn't necessary (as it was with other systems) to "fly with your feet" when at high AOA. The F-15 system lets the pilot do what comes naturally – fly with the stick. Nothing magic about it. The mechanical flight controls simply blend rudder and aileron together to provide coordinated flight using very little rudder at low angles of attack, but rudder almost exclusively at high AOAs.

Rudder rolls are really uncoordinated maneuvers. Some aileron is needed during a rudder roll; but in the heat of battle, it's tricky to use just the right amount of aileron. Using too much aileron can result in adverse yaw which can lead to a departure. Your flight control system blends the proper amount of aileron and rudder for relatively coordinated flight during all flight conditions. The system doesn't eliminate aerodynamic phenomena such as adverse yaw or the dihedral effect (roll due to yaw); it uses the dihedral effect to your advantage and keeps adverse yaw under control.

To help understand the complex world of high-AOA flight, we need to establish some definitions for a common frame of reference; review the causes of departures/spins and autorolls; as well as briefly explore aerodynamic, kinematic, and inertial coupling.

DEFINITIONS

Exactly where a stall occurs in a modern high-performance aircraft is difficult to determine. In some older

By GLEN LARSON/*Senior Experimental Test Pilot*

AUTOROLLS

fighters, a stall is an exciting event. The AOA gets high enough that as the wing quits producing lift, directional stability breaks down and yaw rates can develop rather quickly. As a result AOA limits are often imposed in an attempt to prevent departures or spins. These are artificial limits, since high AOA isn't the source of the problem. The real cause is the breakdown in directional stability, which makes the aircraft susceptible to developing a yaw rate. However, a stall in an F-15 is a "non-event." It's not possible to exceed the point of maximum lift (i.e., the "classic" stall) even with full aft stick. A stall is characterized by moderate wing-rock and buffet and a high sink-rate. Accelerated stalls behave much the same way, assuming a symmetrically-loaded airplane. The most important thing is that total directional stability remains positive.

Departure and out-of-control aren't as easily defined. As an aircraft progresses from controlled flight to a spin, several events occur. For the purposes of this discussion, we will use operationally-related definitions of out-of-control and departure. Simply put, out-of-control is the point at which the aircraft no longer responds in pitch, roll, or yaw to pilot inputs. With this definition, it's possible to be out of control for some time before actually departing since we define departure as the point where the aircraft flight path changes drastically from the expected. In case there is any doubt; if the yaw-rate tone is steadily beeping, the aircraft has departed.

Causes of out-of-control or departure can be the result of a combination of circumstances. Traditionally, a spin is encountered after increasing AOA to the point that directional stability is weak enough that a yaw rate develops. As AOA increases, the aircraft will stop responding since the controls will lose effectiveness. If directional stability is weak, a yaw rate will develop and the aircraft will seem to have a mind of its own. At this point, you are not necessarily in a spin. You *have* departed controlled flight since the aircraft is doing something you didn't command, but it hasn't necessarily entered a spin. Generally speaking, neutralizing the controls at this point will allow the aircraft to fly itself out. This phase of flight between a departure and a spin can be very brief, depending on the dynamics of the maneuver. The gyrations the aircraft goes through in this phase can be mild or eye-watering, depending on speed or energy level at departure.

The first of two spin modes encountered by the F-15 is the oscillatory mode which, as the name implies, exhibits large variations in pitch, roll, and yaw. You can expect to see ±30° pitch oscillations, some bank oscillations, and yaw-rate hesitation with intermittent spikes as high as 100°/second. The good news is that this mode is generally recoverable with neutral controls, but may take some time and altitude to recover.

The second spin mode is the flat spin, also referred to as a "smooth" spin. A flat spin has very little oscillation in any axis and the yaw rates will be fairly steady (generally higher than in the oscillatory mode – somewhere in the neighborhood of 66° to 130° per second). These high yaw rates can result in "eyeballs out" g-loads of 1 to 4 g's, which is uncomfortable to say the least. During the spin test program, at least three-dozen flat spins were performed, all of which recovered with full anti-spin aileron and stabilator. It's not necessary to first be in an oscillatory spin to develop a flat spin; under certain circumstances, the aircraft will go directly into a flat spin. Inverted spins were also tested and found to recover with neutral controls.

DEPARTURES AND SPINS

The contributors to spins and out-of-control conditions can be divided into major and minor categories. A significant contributor can be flight control inputs, even though the flight control system is designed to control adverse yaw or other inputs that can induce yaw rates at high AOAs. During the spin test program, it was necessary to "trick" the control system in order to enter a spin. It's also possible to trick the system during ACM and apply pro-spin controls inadvertently. If, for example, in a hard or "break" turn, the aircraft rolls out on its own (perhaps due to weight asymmetry or something else), the natural reaction is to unload and counter the roll with opposite stick. If the stick is near neutral when applying aileron opposite the roll, the result will be yaw away from the stick input and is in the same direction as the yaw that was present with the initial uncommanded roll. This combination is pro-spin. Don't misunderstand this discussion as meaning that you're going to instantly spin out of a hard turn. That's not true, but pay attention to what the airplane is telling you. Any uncommanded motion is cause for neutralizing the controls and taking a few seconds to see what's going on.

During the spin test program, the "trick" used to enter a spin was to pull into high AOA, develop some sideslip and yaw rate with rudder, then suddenly move the stick to neutral and apply full opposite lateral stick while AOA was still high. This action, in effect, bypassed the aileron washout feature and the technique was successful in getting into a spin about 50% of the time. Power settings and longitudinal c.g. position have relatively minor effects on departures and spin recoveries. The flight conditions, altitude, and Mach number were also players, but of relatively small consequence.

AOA, on the other hand, does have some importance. Generally, as AOA increases, directional stability decreases; but as long as the dihedral effect remains strong, there's no problem. In the range of 30-35 units, the static directional stability has gone to zero or less, but the dihedral effect is very strong. Static directional stability and dihedral effect make up the total directional stability of the aircraft. In the 40-45 unit area, the dihedral effect contribution to stability is reduced but still positive; and since the static directional stability has gone negative, total directional stability is weakest. It's difficult to quantify this reduction in stability in pilot terms, but the important thing is that the total directional stability is still positive; whereas in earlier century-series fighters, total directional stability went to zero or negative at high AOA. Any time directional stability is reduced, the airplane

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is more subject to developing sideslip and yaw rate. The source of this yaw rate can be pilot input, inertial coupling, or anything that causes the nose to move sideways.

Aircraft configuration also has some effect on departure resistance. When the aircraft is flown with centerline tank only, the total directional stability is slightly reduced, resulting in lower departure resistance. When loaded with wing tanks, the directional stability is essentially the same as a clean airplane, but the longitudinal (pitch) stability is slightly reduced. The biggest contribution that the airplane makes to loss of control at high AOA is in lateral c.g. or lateral weight imbalance.

LATERAL ASYMMETRY

The airplane will probably always be out-of-balance laterally to some degree; therefore, limits need to be established because the flight characteristics can change dramatically as a function of asymmetry. The aerodynamic characteristics of asymmetric external loads have little effect on the departure resistance of the F-15; weight is the big factor. Incidentally, this lateral c.g. shift affects *all* aircraft. Since fighters carry wing tanks and bombs/missiles on the wing, they are subject to the effects of a lateral c.g. shift caused by weight asymmetry. I suspect that many F-4 stall/spin accidents may have been due to a large weight imbalance, either fuel or wing stores. (Experience in Southeast Asia with the F-4 bears this out. Large weight differences between left and right bomb loads were not uncommon.)

The Category II test program determined that operational loadings of up to 10,000 foot-pounds were acceptable, although the handling qualities at high AOA were somewhat degraded. The limit of 5,000 foot-pounds was recommended for training in order to avoid degraded handling qualities. Testing has shown that with an asymmetric load of 5,000 foot-pounds, the aircraft is still very departure resistant. Above 10,000 foot-pounds, departure susceptibility increases to the point that fully-developed spins can be generated in as little as 3 to 4 seconds with only full-aft stick.

Since 5,000 foot-pounds may not mean much to you, let's put it in terms of equivalent loadings. The rolling moment in foot-pounds is calculated by multiplying the distance from the centerline to where the weight is located times the weight. If the external load is balanced, 650 pounds of internal wing-fuel imbalance equals 5,000 foot-pounds (650 pounds times the 7.7 foot distance from centerline equals 5,000 foot-pounds). With two AIM-7s on one side, only 200 pounds of internal wing-fuel imbalance is needed to add up to 5,000 foot-pounds. In any case, below 30 units AOA, the aircraft will generally not depart at any level of asymmetry. That's where the 30-unit Dash One limit comes from when the internal wing fuel imbalance exceeds 600 pounds (200 pounds for imbalanced missile loads).

FIGURE 1 - LATERAL ASYMMETRY DUE TO WING FUEL AND MISSILES

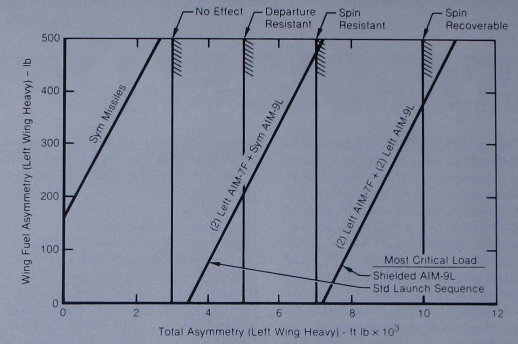


Figure 1 is a graphic representation of the preceding discussion. The horizontal axis is total asymmetry in thousands of foot-pounds; the vertical axis is internal wing fuel imbalance, left wing heavy. The divisions defining the points of departure, resistance, spin resistance, etc., are based partly on test data and partly on analytical data. Configurations up to one full external wing tank were evaluated up to 30 units for stalls and departure susceptibility.

The departure characteristics of a symmetrically loaded airplane are relatively straightforward. There's adequate warning in terms of buffet and wing-rock; but for an asymmetric load, these warnings may be reduced, and the first indication of departure may be the departure warning tone. If you don't back off (reduce AOA) at the first warning tone, the next event could be a fully developed spin – especially with a large asymmetry.

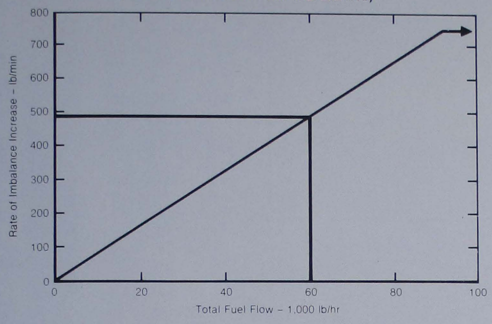
Just because you begin an ACM engagement with balanced internal wing fuel doesn't mean you can't get into trouble. Figure 2 shows how quickly an imbalance can develop if one of the wing fuel transfer pumps fails. Total fuel flow in thousands-of-pounds per hour is on the horizontal axis, and rate of wing fuel imbalance in pounds per minute is shown on the vertical axis. For example at a fuel flow of 30,000 pounds per hour per engine, the imbalance will increase at a rate of 480 pounds per minute, which means that after a two-minute engagement in burner, the imbalance will be 960 pounds (equating to nearly 7,400 foot-pounds of asymmetry). Asymmetry can ruin your whole day by quickly putting you in a high-rate flat spin, which will require a great deal of altitude to recover.

RECOVERY PROCEDURES

The recovery procedures in the Dash One were developed to cover all out-of-control/spin events in a logical and rational manner. At the first sign of an out-of-control condition (the airplane quits responding correctly to your inputs), neutralize the controls and let the basic stability of the airplane straighten things out. If the aircraft fails to recover, it may be in an autoroll or a spin; the next step is rudder opposite the roll direction which is the best recovery from an autoroll (more on autorolls later). It really doesn't matter if you misidentify a rolling departure as an autoroll since the rudder is the appropriate control to reduce sideslip and yaw rate (assuming you use the correct rudder). Rudders alone have little effect on getting in or out of spins. A word of caution here: *don't use aileron opposite the roll in an autoroll or rudder roll.* That's one of the quickest ways to enter a spin!

During any out-of-control event, listen for the departure warning tone as it's designed to give you specific warnings. It first comes on at 30°/second yaw rate. Except for autorolls, it was

FIGURE 2 - RATE OF WING FUEL IMBALANCE
(ONE WING TRANSFER PUMP INOPERATIVE)



found during testing that the airplane would always self-recover if the pilot neutralized the controls at yaw rates of 30°/second. Above 60°/second, the "beep" rate of the tone reaches a maximum and positive pilot action (anti-spin controls) will probably be required to recover. The control augmentation system (CAS) is shut down at 42°/second yaw rate to prevent pro-spin CAS inputs and the spin-recovery mode is engaged at 60°/second, allowing full aileron/stabilator deflection regardless of fore and aft stick position. If the beep rate has reached a maximum, you're probably approaching (or are in) a fully-developed spin. The last step in the procedure – lateral stick full in direction of yaw – requires a bit of thought. Spend a few seconds determining which way you are spinning before putting in any aileron. (In fact, any time the departure warning tone is on, be very careful with aileron – especially with the stick near neutral longitudinally.)

The best way to recover from a spin is to decide which way you're spinning, put the aileron in the correct direction (the wrong way accelerates the yaw rate), and *wait*. It can take up to 10 seconds (and two turns) before any change in yaw rate is noticeable. Be patient, you may not be able to detect any change in yaw rate until just before recovery. The exact time-to-recover depends on several variables. If the yaw rate hasn't exceeded 60°/second, you need to have the stick centered fore and aft or you won't get full aileron deflection and recovery will take longer. Large weight asymmetry will lengthen the recovery time, as will cycling the recovery controls in and out. Finally, if you're still spinning at 10,000-feet AGL, get ready to eject because there probably isn't enough altitude left to recover.

During the recovery phase of a flat spin, the aircraft will remain in a fairly flat attitude until the yaw rate stops. The nose will then drop, sometimes past 90°, to a slightly inverted position. At this point, it's much like the recovery from a tail slide. The airplane will do a couple of rolls while regaining flying speed. These are rolls due to sideslip, *not* autorolls.

AUTOROLLS

The autoroll is a special case and is one of the most misunderstood phenomena in the F-15. The autoroll is not unique to the F-15; other aircraft, such as the F-111, autoroll very easily. An autoroll can be stopped with very little energy or altitude loss; but before discussing recovery, let's review the causes of autorolls. The technical reasons are a little deep, but an autoroll can consistently be entered from a specific set of flight conditions and control inputs:

- Airspeed in the 200-300 KCAS range
- 20-30 units AOA
- Roll and yaw initiated with a rudder input
- Relaxing of aft stick to induce coupling

The aerodynamics of all this are complex. The first principle is the dihedral effect which causes the initial roll due to yaw; then easing of aft stick inertially couples pitch and roll to produce a yaw acceleration. During an autoroll, the airspeed is well above the stall speed and the AOA is held in the 20-30 unit range through inertial pitch coupling. The roll rate will be pretty fast, approximately 150°/second, and the flight path will be ballistic.

During the entry to the autoroll, inertial coupling will appear to the pilot as an increase in the roll rate as the stick is eased forward. Although the primary motion apparent to the pilot is roll, there is a yaw rate present (around 30°/second). The yaw rate warning tone may be on or off during the autoroll. The CAS aileron rudder interconnect gets in the act during the entry phase because it works as a function of AOA and roll rate and applies rudder to coordinate the roll. This rudder deflection is in the direction to get into an autoroll, but fades in a few seconds and *will not* keep the aircraft in an autoroll. If friction in the rudder cables is high, the rudders will tend to stay slightly deflected in the direction of the roll and that *will* tend to keep the autoroll going. An aircraft with little or no rudder friction or rudder displacement from whatever cause will not stay in an autoroll. In any event, it's easy to recover.

The best way to recover from an autoroll is to apply *rudder* opposite the roll. Technically speaking, the rudder is being applied to eliminate the sideslip; however, it's easier for the pilot to determine roll direction, so referencing recovery procedures to roll direction makes more sense. As soon as the roll stops, neutralize the rudder and be ready to come in with a little aft stick to counter the "nose tuck" that follows. This nose tuck is very mild and is caused by inertial coupling.

Other recovery techniques do exist, but are of academic interest only. For example, doing nothing at all will work. An autoroll will eventually stop, depending on rudder cable friction. Time and altitude loss may be excessive, therefore this technique is not recommended. Moving the stick fore or aft may possibly work through coupling, but isn't recommended since it doesn't directly affect the yaw rate and can lead to extreme AOAs. Aileron applied *with* the roll (an unnatural tendency) will break the autoroll phenomenon, but the transition from an autoroll to an aileron roll is impossible to detect. Aileron against the roll (normal reaction) is *definitely not recommended* since it is a pro-spin control and it is possible to get into a spin in as little as three or four seconds. There is plenty of warning from the departure tone and aircraft motion that things are going from bad to worse.

Aircraft configuration has no effect on getting in or out of autorolls. Weight asymmetry doesn't affect autoroll entry or recovery, but does make it easier

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to spin out of an autoroll if the wrong recovery technique is used. Warnings are somewhat reduced so your best indication that things are getting worse is the departure warning tone.

COUPLING

Several times I've referred to aerodynamic and inertial coupling, both of which are complex phenomena. The good news is that coupling can be reduced to some fairly simple concepts. The term "coupling" simply refers to the response of the aircraft about one axis due to a disturbance about another. An example of uncoupled aircraft motion is the response of the stabilator. Pulling aft on the stick in straight and level flight causes a collective motion of the stabilator, resulting in a nose-up motion. The pilot has commanded a pitch motion, and only a pitch motion has resulted. An example of a coupled aircraft motion is the combination of roll and yaw that results from rudder deflection. The pilot has commanded a yaw with rudder and the aircraft also rolls. This particular type of aerodynamic coupling is the dihedral effect.

"Kinematic" coupling occurs if an aircraft is rolled rapidly about the longitudinal axis, as shown in Figure 3. What was AOA (α) becomes sideslip (β), triggering roll due to yaw. Aircraft don't roll purely about their longitudinal axis, so the results are mixed with inertial coupling. To understand inertial coupling, imagine an aircraft represented by a system of weights, as shown in Figure 4. The fuselage is represented by large masses near the nose and tail, the wing by smaller masses near the wing tips. If the aircraft is rolled rapidly about the flight path (velocity vector), the masses in the fuselage will overpower the smaller wing masses and will pull the nose and tail away from the flight path. This is an example of roll coupling into pitch and is dominant at high speeds, and is the reason many fighters are prohibited from continuous 360° rolls. (A more in-depth explanation of this whole subject is presented in an article titled "Whifferdills, Divergences, and Other Roll Coupling Phenomena" by MCAIR project test pilot Larry Walker in DIGEST Issue 6/1979.)

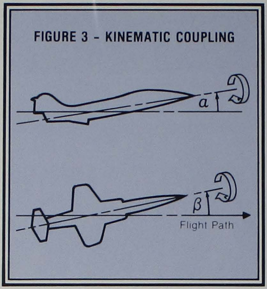


FIGURE 3 - KINEMATIC COUPLING

There are some important things to understand about coupling:

- Aerodynamic, kinematic, and inertial coupling never operate independently.
- It's very difficult for a pilot to judge what degree or type of coupling is present.
- It's possible to get away with a coupling-prone maneuver several times; but on the next one, you could break the airplane.

Every airplane in the world is subject to coupling to some degree, and several examples of coupling were encountered during the F-15 spin test program. Other than entering from an autoroll, they were successful in generating a spin with a clean configuration aircraft only 50% of the time. Occasionally, instead of spinning, the aircraft was inadvertently inertially coupled into a maneuver that saw g-excursions of up to +9 g's.

Another maneuver subject to coupling is a negative g "guns jink-out" (rapidly moving the stick forward and to the right or left corner). You're walking on the ragged edge with this maneuver and if the aircraft couples up, it'll water your eyes. At high speeds, structural damage is a very real possibility and at lower speeds, out-of-control may result. These things won't happen every time, so be careful and remember that the stick doesn't have to be against the forward stop to trigger coupling.

A third and probably the most significant example of coupling is the spin itself. Without inertial coupling, the F-15 couldn't spin. As in the autoroll, simultaneous yaw and roll rates inertially couple with the pitch axis, preventing a reduction in AOA. Reducing the yaw rate with recovery controls lessens the magnitude of the coupling, allowing the nose to drop.

The world of departures, spins, autorolls, and coupling is a complex one. However, total understanding of the dynamics of it all isn't necessary; an awareness of the causes (conditions/configuration) is desirable, but the most important point of this discussion is to pay attention to your airplane. It will "talk" to you and by its response (or lack of response), tell you how it feels about what's going on. The Eagle is the most stable and forgiving fighter ever built; but it can change character rapidly and become downright unpleasant if you don't pay attention to what it is telling you! ■

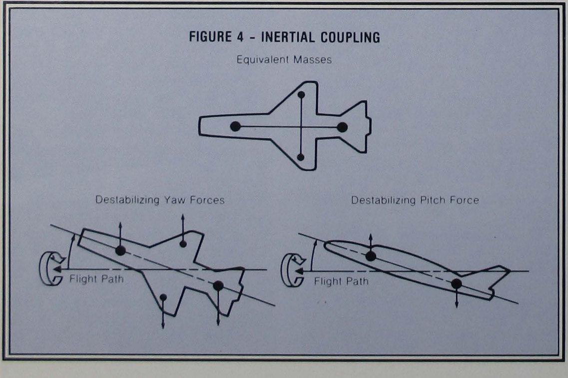
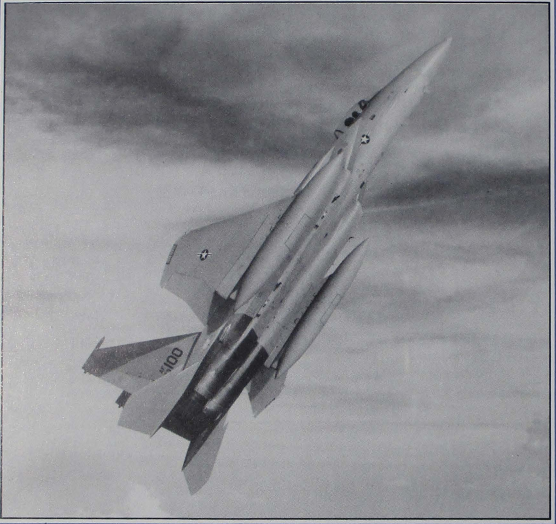


FIGURE 4 - INERTIAL COUPLING

The F-15 Eagle has proven it can meet the challenge.

CENTER OF GRAVITY

By GLEN LARSON/*Senior Experimental Test Pilot*



Aircraft center of gravity concepts, handling qualities, and ballast considerations would appear to be relatively simple subjects to discuss. In reality, and as I found after deciding to look into these aspects of F-15 operations, they are not simple and writing this article was possible only with the contributions of several members of the MCAIR engineering team. My appreciation is expressed to Dan Knewitz, Section Chief, and Bob Hahn, Lead Engineer Weights for cg data. Clarence Mongold, Branch Chief, and Bill Nelson, Section Chief Technology, provided aerodynamic data. Bill Hollingsworth, Lead Engineer Technology, did the performance comparisons. Special thanks go to Bill Crawford, Technical Specialist F-15 Guidance and Control, and Bill Bath, Lead Engineer Systems Safety, for their careful review of multiple drafts of this article for accuracy.

The position of the center of gravity (cg) has a dramatic effect on the way an aircraft behaves in flight. Aft movement, for example, usually produces the most challenging flight characteristics and to retain reasonable handling qualities, ballast is needed to keep the cg within predetermined limits. Ideally, no ballast would be required, but with the wide variety of bombs, missiles, and fuel tanks carried on fighters today, ballast is inevitable. Usually, the combination of external stores and internal fuel that produces the most aft cg determines ballast requirements. During testing, an aircraft is flown with different center of gravity positions and aft limit is established in terms of handling qualities.

The following article is an introduction to the technical aspects of center of gravity management. It includes a discussion of the changes in aircraft response as cg changes and a review of cg travel in the F-15 with some performance comparisons.

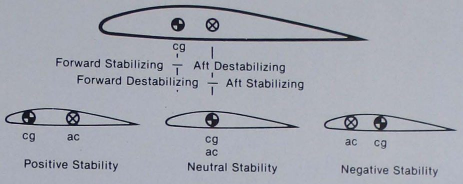
ENGINEERING PERSPECTIVE

The general relationship between the cg and aerodynamic center (ac) is shown in Figure 1. The closer together the two points are located, the less stable the aircraft will be in the pitch axis; however, these points are not constant, fixed reference points. The aerodynamic center will move as a function of AOA and Mach number. For example, high Mach numbers tend to move the ac aft and high AOAs can move it either way. Burning and dumping of fuel or weapons release will move cg fore or aft, depending on the specific aircraft design. (For instance, cg in the F-4 normally moves forward with fuel consumption; however, if fuel is dumped immediately after takeoff, cg will move aft and if not managed properly, can change aircraft stability from positive to negative.)

The cg position influences the static stability of an aircraft, as well as dynamic response. There can also be a lateral shift of cg, but we will limit this discussion to fore and aft cg changes. (For a discussion of large lateral weight imbalances, see my article in DIGEST issue 3/1984 "Stalls, Spins, and Autorolls.") Longitudinal stability of an aircraft is expressed in terms of four reference points: stick-free neutral point, stick-fixed neutral point, stick-free maneuver point, and stick-fixed maneuver point.

Stick-fixed stability is indicated by stick movement, whereas stick-free stability is indicated by the force the pilot applies to the stick. For example, the stick-fixed neutral point is the cg position where changes in stabilator deflection approach zero for an incremental speed change; and the stick-free neutral point is the cg position where stick forces do not change when speed changes. Stick-fixed and stick-free maneuver points are defined similarly except that the variable is normal acceleration (g's) instead of speed. In any case, unaugmented, irreversible hydraulic control systems with a simple spring-feel system have the same stick-fixed and stick-free neutral points. For

FIGURE 1 - AIRCRAFT STABILITY RELATIONSHIPS



the purposes of this general discussion, we can consider the neutral point and aerodynamic center as essentially the same point.

PILOT PERSPECTIVE

Precise definition of these points is not of much concern to the operational pilot. What is relevant is that the aircraft does not immediately become uncontrollable if cg is aft of the neutral point. However, the aircraft will be hard to control and tasks such as gun tracking will be very difficult to perform.

As cg moves aft, static stability decreases. When cg reaches the neutral point, control forces (without some type of flight control augmentation such as the F-15 CAS or the F-4 stability augmentation system) essentially go to zero. Strictly speaking, the difference between cg position and neutral point is the static margin. For example, imagine an aircraft stabilized and trimmed for one-g flight at 300 knots. If cg is at neutral point and the aircraft is slowed to 250 knots, there will be no change in stick position or force. Without augmentation, a neutrally stable aircraft will be difficult to trim. A longitudinal stick pulse will result in the aircraft not returning to the trimmed condition, and close attention is necessary to control the aircraft.

When cg is aft of the neutral point, the aircraft becomes unstable; and if changed from a given trim condition in flight, will require forward stick pressure when slowed and aft pressure when accelerated, just the opposite of what is normally experienced. Further aft movement results in the cg and maneuver point becoming coincident. The difference between the maneuver point and the cg position is the maneuver margin. If these points are coincident, an aircraft can theoretically be stabilized at a constant g and speed with no change in stick force or position. The aircraft will be very difficult to trim, control forces will be very light, and there will be a tendency to over-control. Also, there will be little need to change trim as speed changes, which is actually a desirable characteristic for tasks such as ground attack. However, without flight control augmentation, an excessively high workload is created, especially for instrument flight.

Although the discussion has centered on aft movement of the cg, there is a forward limit as well, which is usually the result of structural loads or nose wheel liftoff requirements rather than handling quality problems. Moving the cg well forward will make the aircraft very easy to trim. Stick forces will be relatively high and the aircraft will have a "heavy" feel. Moving the cg aft to a mid-range location reduces control forces and does not make trimming more difficult.

A positive static margin allows a pilot to fly aircraft without artificial control augmentation. For example, the F-15 can be safely flown and landed using the mechanical system alone, and although the F-18 has a four-channel digital flight control system, it can be flown through a mechanical backup system in the event of complete electrical failure since both aircraft have positive static margins. All current operational aircraft have a positive static margin except the F-16, which has essentially neutral stability. An aircraft with neutral stability requires high levels of concentration and flight control augmentation is necessary to reduce workload.

(Future aircraft may have large negative static margins, such as those being tested in the X-29, since there are significant improvements possible in performance. Spectacular gains in turn performance, as well as reductions in aerodynamic drag, result from a large negative static margin.)

F-15 CENTER OF GRAVITY

The discussion so far has been directed toward aircraft with unaugmented control systems. The F-15 basic mechanical flight control system contains devices such as the pitch trim compensator (PTC) and pitch/roll changer assembly (PRCA) that are designed to provide neutral speed stability (no trim change with speed changes) and change the gearing between the stick and stabilator to keep stick forces nearly constant throughout the flight envelope. The control augmentation system (CAS) contains

FIGURE 2 - BALLAST LOCATIONS (F-15C)

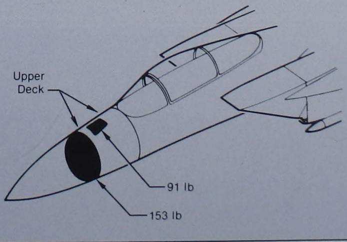


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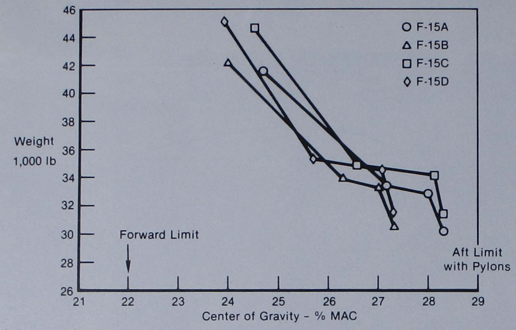
FIGURE 3 - CENTER OF GRAVITY TRAVEL



the devices necessary to damp undesirable motion in the various axes, as well as authority to move flight control surfaces in response to pilot inputs. These systems work together to fine-tune the aircraft to provide constant, predictable aircraft response by compensating for cg or ac movements as much as possible.

The majority of the ballast in the F-15 is carried on the bulkhead just aft of the radar antenna bulkhead. Figure 2 shows location and approximate amount of ballast in certain C models. The A model carries 270 to 290 pounds, the B model 0 to 38 pounds, and the D model carries zero ballast. MSIP aircraft will carry 0 to 39 pounds in C models. These ballast amounts are pre-TCTO 818 (Modification of ICS Ballast Adjustments) and vary according to individual aircraft differences.

With some minor exceptions, cg in the F-15 moves aft as the aircraft gets lighter. Figure 3 is a greatly simplified cg movement chart, which does not include external tanks or weapons release. *It is intended to generally illustrate the cg movement due to fuel consumption in various models of the F-15 and should not be used to determine the cg of a specific aircraft.* The vertical axis is the gross weight of the aircraft, and the horizontal axis is a percent of mean aerodynamic chord (MAC). The MAC is an imaginary line drawn between the leading and trailing edges of the wing, near midspan.

Distances along this line are expressed as a percentage, with leading edge as zero and trailing edge as 100%. Each line on the chart illustrates cg movement for each model of the F-15. At first glance, it appears that the C model enjoys a cg that is farther aft than other models. That is true only when all aircraft are compared at the same gross weight. However, if two models such as a C model and an A model were to take off together and begin an ACM engagement soon after entering the area, the C would actually have a cg up to ½% ahead of the cg in the A. (For example, an A model at 39,000 pounds has a cg at 25.5%, but a C at the same point in the mission would weigh about 42,000 pounds and have a cg position of 25%.)

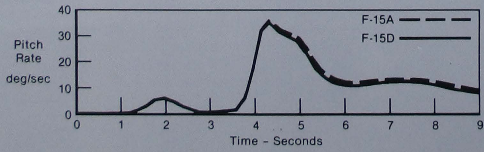
The forward cg limit for the F-15 is established by various structural loads and nose wheel liftoff speeds. However, the aft limit is not as easily defined. The neutral point for an F-15 moves as a function of external stores. For example, neutral point for a clean F-15 is at 32.5% MAC, but addition of conformal fuel tanks moves it to 31.0% MAC. The aircraft has been safely flown and landed in a three-tank and eight-missile configuration with cg at 30% MAC or a .5% static margin. Testing has shown that the CAS can handle a negative margin as large as 1%; however, the current aft limit of 29% MAC for most store loadings was established during USAF testing to determine handling qualities for close formation and air refueling. During flight tests, the cg was varied from 24.5% to 30% MAC. In several instances with the CAS off, a low frequency pitch oscillation developed caused by the pitch trim compensator (PTC). The g on the aircraft typically changed by plus or minus .5 over a period of 7 to 10 seconds because the PTC response to pilot inputs was out of phase, which resulted in a mild pitch oscillation. Although easily compensated for by the pilot, it was deemed unacceptable for high gain tasks such as air refueling and close formation. Consensus of pilot opinion was that a cg aft of 29% would result in marginal flying qualities for air refueling with pitch CAS off.

HANDLING QUALITIES

Handling qualities are determined during the development phase of an aircraft. A subjective pilot evaluation determines if the aircraft has level I, II, or III handling qualities as spelled out in MIL-F-8785(ASG). Level I is defined as being completely acceptable for all mission elements with a reasonable pilot workload. At level II, the mission can still be accomplished but pilot workload is higher; and at level III, the aircraft can be controlled but pilot workload is excessive and mission effectiveness is impaired. The F-15 in the air-to-air configuration has level I handling qualities throughout its flight envelope with CAS on and, in small parts of the envelope, handling qualities degrade to level II with CAS off. (Handling qualities of the F-4, by comparison, do not remain at level II throughout its flight envelope – most notably at low altitude and high speed.)

For the F-15, the loading requiring maximum ballast was: 1100 pounds internal fuel, two empty external wing tanks, centerline pylon, four AIM-7F missiles, 20mm ammunition fired (cases retained), and a 50-percentile physical profile pilot. The amount of ballast for this loading was based on results obtained during handling quality tests.

FIGURE 4 - PITCH RATE RESPONSE



Loading four AIM-9 missiles, an empty centerline tank, downloading the four AIM-7 missiles, or adding internal fuel moved cg forward, which resulted in a more stable static margin. For example, increasing internal fuel to 3700 pounds moved the cg forward 1.5% of the location with 1100 pounds of fuel in C/D models and approximately 1.0% in A and B models.

PERFORMANCE EFFECTS

To illustrate the effect of cg position on turn performance, let's compare an A model with a D model at the same point in a mission: 50% internal fuel, four AIM-7s, and full 20mm ammo for each aircraft. In this configuration, cg position of the A will be at 26.1% and at 25.0% for the D. (The configuration for both aircraft must be the same; the fact that tanks or AIM-9s are not included doesn't make much difference.) In order to allow simulation of rapid full-aft stick without exceeding aircraft load limits, 220 KCAS at 10,000 feet MSL was used as a starting point.

These conditions were used in a six-degree-of-freedom simulation, the results of which are shown in Figures 4 and 5. The aircraft were assumed to be straight and level at time zero. A roll to approximately 90° of bank was completed in two seconds and full aft stick was applied. Pitch rates peaked at approximately 35° per second for both aircraft in about four seconds. Six seconds into the run, two seconds after full aft stick, pitch rates were 12° per second for the A and 11° per second for the D, as shown in Figure 4. Plots of actual degrees of turn against time are shown in Figure 5. After eight seconds of running time, the A will complete 4° more turn than the D, which is essentially the same as a 4° nose position advantage in six seconds. The same comparison with both aircraft at the same weight results in smaller performance differences.

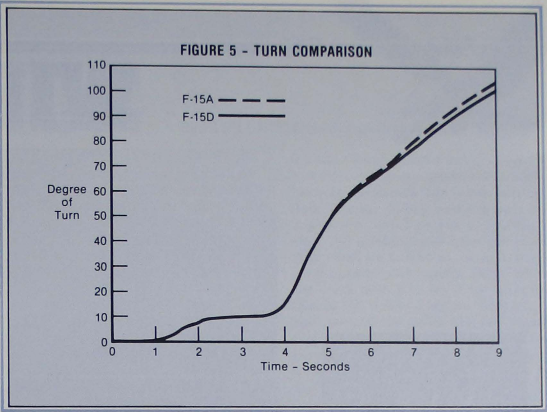


FIGURE 5 - TURN COMPARISON

BALLAST MANAGEMENT

Prior to TCTO 818, no ballast was removed from the aircraft when the internal countermeasures set (ICS) was installed in the equipment bay aft of the cockpit. This TCTO is intended to eliminate the performance penalty caused by carrying approximately 200 pounds of unneeded ballast with ICS installed. When ICS is installed, ballast must be removed, which keeps the cg in the range it would be in without ICS.

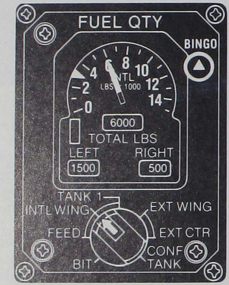
A word of caution about nose strut servicing is in order at this point. Moving weight around in the aircraft changes the load on the nose gear and it is *very important* that the strut always be correctly serviced. An F-15 unit experienced loss of nose gear steering during taxi after TCTO 818 was incorporated. Initially, it was thought that removing ballast for the ICS installation caused the nose to be "light," resulting in loss of steering during taxi. The problem was eventually traced to over-serviced nose struts which extended the strut far enough to engage nose wheel centering cams during taxi. The result; no steering. To properly service the strut, the full T.O. procedure must be followed since correct strut dimensions with full fuel does not indicate correct servicing.

TCTO 818 is an excellent form of ballast management since it allows maintenance to manage ballast for the configuration of the aircraft. However, to operate at cg's near the neutral point, major and perhaps unreasonable changes would be needed. For example, an electronic fly-by-wire system would allow the F-15 to operate at or near the neutral point. That sounds good, but the gains may not offset the cost. The CAS-off refueling problem, discussed earlier, can be minimized by installing a pitch damper not associated with the CAS or by simply installing a device to allow the pilot to disable the PTC. Either or both of these options would minimize the pitch oscillation encountered during CAS-off refueling, but these options have not been fully evaluated to determine their effectiveness. An "active" cg control system would keep the cg as far aft as possible by controlling internal fuel transfer; however, a system of this type would add weight and complexity and be of limited value.

Ballast in one form or another will be carried in fighter aircraft for a long time. A great deal of time and energy is expended during the design and development process to keep the need for ballast at a minimum. However, the final decision on handling qualities, and therefore aft cg limits, rests with the pilots who evaluate aircraft during the development phase.

As you can see, cg position and its effect on the aircraft is a complex subject. There are no clear-cut answers, but TCTO 818 is a major step in the direction of tailoring ballast to configuration and ensuring that performance losses are minimized. ■

WING-FUEL



A large wing-fuel imbalance can ruin your whole day by making it easier to get into a high yaw rate flat spin due to degraded high-AOA handling characteristics. The causes of these imbalances can be traced to sources such as the fuel/oil heat exchanger, a failed transfer pump, indicator malfunctions, and others.

The malfunction that will cause an imbalance to develop the fastest is a failed wing transfer pump. The rate at which an imbalance will develop is dependent on total fuel flow. (A rough guideline is one-half your total fuel flow.) For example, on a cross-country, total fuel flow is in the 5500 pounds per hour range, and an imbalance caused by a failed transfer pump will develop at the rate of 2750 pounds per hour or 46 pounds per minute. In ACM, where 60,000 pounds per hour isn't unusual, the rate is 500 pounds per minute. The rate will also be affected by a failure of one of the three electrical phases that power each pump. The failure of one phase is, in effect, a partial pump failure and may result in asymmetrics of 400 to 500 pounds.

A transfer pump failure can be insidious. If you have external tanks, they will transfer to any internal tank that will accept fuel; therefore, it's impossible to detect a failed wing transfer pump by reference to the fuel gauge until the externals are dry. An imbalance that becomes apparent during ground operations may be normal and the result of something other than a transfer pump failure. For example, if the aircraft isn't reasonably wings-level during refueling, one internal wing tank may not fill completely. An internal wing-fuel imbalance on the ground is not necessarily a valid indication of a transfer system problem.

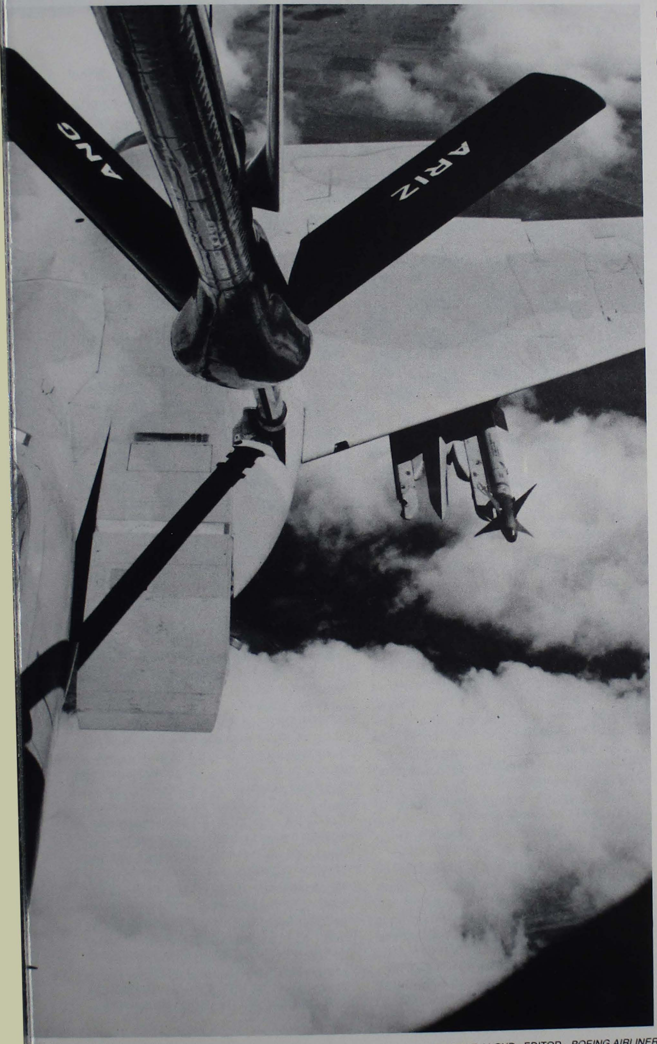
The heat exchanger can cause a wing-fuel imbalance due to a failed thermal bypass valve. This valve is designed to control the fuel recirculation to the wings as a function of temperature. It's designed to begin opening at a fuel temperature of 185°F and is fully open at 200°F. These valves do not require any power source, and the predominant failure mode is loss of calibration resulting in incorrect temperature scheduling. The result is that the valve on one side isn't opening and closing at the correct time, which will cause an imbalance. If one valve was fully open and the other closed, the imbalance would develop at a rate of 30 pounds per minute; however, the actual rates are somewhat less since it's unusual for one valve to be failed fully open while the other remains closed. Since the functioning of these valves is dependent on fuel temperature, imbalances will tend to develop at low total fuel flows since that is where fuel temperatures will tend to be higher. Presently, the only way to fix a failed thermal valve is to remove the heat exchanger.

If you find yourself in an airplane with a large fuel asymmetry, stay below 30-units AOA and you won't have any problems. Testing has shown that the aircraft is departure resistant at any level of asymmetry as long as you stay below 30 units.

Another source of imbalances can be

IMBALANCE

By GLEN LARSON/*Senior Experimental Test Pilot*



malfunctioning level control valves. A problem with these valves will usually become apparent at low power settings (low transfer rates), and the rate of asymmetry development is relatively slow. All aircraft have been modified with what are known as "snap action" level control pilot valves. These allow the feed tank fuel level to decrease (about 150 pounds) before "snapping" open to refill the tanks. This has the effect of ensuring that both wing transfer pumps will transfer fuel to the feed tanks by creating adequate volume in the feed tanks to accept fuel.

One of the often overlooked sources of asymmetry is the fuel gauging system. At times, due to intermittent grounding and loose wires or grounding between the inner and outer probes in the tank, a sudden asymmetry may appear to develop. Normally, this would appear during acceleration, deceleration, or heavy maneuvering. In any case, troubleshooting for any asymmetry problem should begin with the fuel gauging system.

The fuel system should maintain an imbalance of no more than 200 pounds, if operating correctly. The wing transfer pumps have "trimmer" valves installed to match output pressures at transfer flow rates. Current "Dash One" procedures allow an asymmetry of up to 600 pounds with a balanced external load; however, if the asymmetry consistently exceeds 200 pounds inflight, write it up since there is a problem somewhere in the system.

If you find yourself in an airplane with a large fuel asymmetry, stay below 30-units AOA and you won't have any problems. Testing has shown that the aircraft is departure resistant at any level of asymmetry as long as you stay below 30 units.

Clear, concise write-ups are essential to getting a fuel imbalance problem solved. Maintenance needs to know exactly when the imbalance appeared and how quickly it developed. If time and workload permit, a chronological record of the fuel readings will help trace the problem, and a short discussion of your flight conditions prior to noting the imbalance will also be helpful. All of this information will help maintenance get your Eagle fully mission capable as soon as possible. ■

LANDING and R

By GLEN LARSON/*Senior Experimental Test Pilot*

In the tactical aviation world, the majority of a pilot's time and attention is concentrated on fighter tactics, which is only appropriate. However, the phase of flight from touchdown to clearing the runway is also important, often overlooked, and not clearly understood. Knowledge of the most effective braking techniques for any situation which might be encountered should be an integral part of your Eagle "bag of tricks." Mr. Ray Ehle, Senior Design Engineer and our recognized expert on F-15 braking systems, deserves credit for making this article possible through contribution of his technical expertise. Mr. Bill Bath, Systems Safety Unit Chief, is due special appreciation for his patient and careful review of multiple drafts for accuracy. Thanks to the efforts of these gentlemen and other members of the MCAIR team, all of your landings and rollouts should be routine events.

Your F-15 mission has been a long one – multiple ACT engagements interspersed with several refuelings, and to top it off the weather at the home drome isn't all that great. A weather approach, perfect landing, and now it's time to relax. Hold it – you still gotta get that 33,000 pound jet, rolling at 120 knots, stopped!

The laws of physics that describe how airplanes stop aren't really deep, dark, or mysterious. In fact, they are fairly exact and straightforward – it's the application of these laws that's sometimes tricky. Before developing pilot procedures for landing and rollout, we need to review some basic concepts of braking and how the anti-skid system fits into the picture. The objective is to (safely) maximize the drag on the aircraft during landing and maintain directional control at the same time. There are only two sources of drag during the landing roll: that produced by the rules of aerodynamics and what you get from the wheel brakes.

AERODYNAMIC BRAKING

Aerodynamic braking is quite straightforward – the amount of drag force varies directly as a function of airspeed and wing angle of attack. The higher the speed and the higher the angle of attack, the more drag produced. Most Eagle drivers use aerodynamic drag to one degree or another by holding the nose up during rollout. This means of slowing is relatively effective during the high speed portion, and there's nothing to wear out.

The amount of drag produced by holding the nose up can vary, depending on pilot technique; if the nose-high attitude is less than about 10° some drag is lost, and at 15° the tails will contact the runway. Holding the nose up at about 12 to 13° is a comfortable attitude that produces reasonable aerobraking, without scraping the tails. This angle is not AOA, it is the angle between the -w- symbol and the horizon line on the HUD.

Aerodynamic braking (as well as aerodynamic directional control), decreases as speed decreases; and before losing stabilator authority at around 70 KCAS, it's a good idea to lower the nose to the runway. Flaps position or speed brake position doesn't seem to add much drag, but because every little bit helps, speed brake out and flaps down is what we recommend. (A word of caution: when the flaps are up, stabilator effectiveness is increased and you can easily drag the tails.) There is a point around 70 knots where aerodynamic braking with the flaps up is no longer effective; and although the nose is between 12 and 13° pitch attitude, the aircraft will not slow down. The aircraft is in equilibrium, therefore, it's possible to go off the end of the runway with the nose still in the air! Eventually, you *have* to get on the brakes.

WHEEL BRAKING

As usual in the world of physics as applied to fighter aircraft, nothing operates independently and everything is related to some degree. Drag produced by the wheel brakes is really made up of three components – weight on the wheels; available friction coefficient; and slip rato. The drag available from these components varies as a function of several major variables – aircraft weight, speed, aerodynamic lift, runway condition (wet or dry), runway surface, and tire wear.

Friction coefficient is used to express how much of the weight on a wheel can be converted into drag. For example, if the friction coefficient is .8, then 80 pounds of drag can be produced for every 100 pounds of weight on the wheel. A value of 1.0 is theoretically perfect, and 0 describes a frictionless environment. On a dry runway, the friction coefficient stays fairly constant regardless of speed; but in reality, braking effectiveness is less at high speed because weight on the main gear is less due to the aerodynamic lift being generated by the wing at high speeds. Runway surface also impacts how much brake drag can be produced. A grooved and brushed concrete surface will allow

LLOUT

the tire to get a good "grip" during braking and keeps water from interfering. A smooth, oily surface will have a much lower drag capability. Add a little water, and it's like glare ice! Tire tread also has some effect on producing drag. Smooth tires actually produce more drag on dry runways; but on wet runways, they "hydroplane" easier and don't produce as much drag. Be sure to follow T.O. guidance for tread wear limits, especially on a wet runway.

On wet runways, friction coefficient decreases a great deal with increasing speed. One reason is *hydroplaning,* a phenomenon which is always present to some degree on any wet surface. Hydroplaning is best described as the tire "floating" on a thin film of water. Under extreme conditions of standing water and high speeds, the tire is lifted completely off the runway surface. Since friction coefficient, by definition, implies that the tire must be in contact with the runway, little or no drag force can be generated through friction. As a guideline, you can expect to experience total hydroplaning in the F-15 at a ground speed roughly equal to the expression $9 \times \sqrt{T.P.}$ (where T.P. is tire pressure), or 149 knots for the F-15.

Don't interpret this as meaning that you can't have problems at speeds below 149 knots. There are other kinds of hydroplaning such as viscous (sometimes referred to as reverted rubber) hydroplaning, which can reduce friction coefficient at much lower speeds. The concept is similar to classic hydroplaning, except that the lifting mechanism is steam generated by heat from a skidding tire. The speed at which you can expect to encounter this is very hard to precisely define. Generally speaking, it will be at a speed equal to around $7 \times \sqrt{T.P.}$, or approximately 116 knots. Be careful, however. Once viscous hydroplaning starts, you may stay in it for awhile. Incidentally, viscous hydroplaning leaves distinctive skid marks. Instead of long black streaks, there will be long streaks of spotless runway surface, a phenomenon explained by the "steam cleaning" action between the tire and the runway.

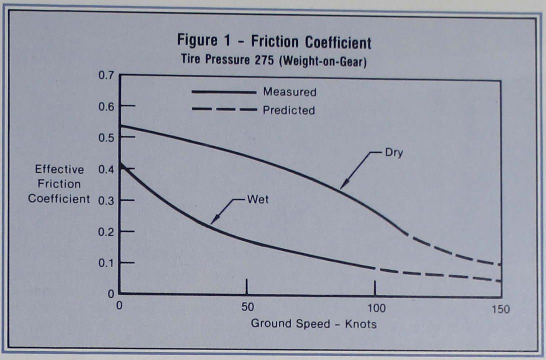


Figure 1 - Friction Coefficient

Tire Pressure 275 (Weight-on-Gear)

Figure 1 ties all of the above discussions together. This chart is based on actual test data up to approximately 100 knots; beyond that point, it is predicted data. The curve for a dry runway clearly shows the reduction in effective friction coefficient at high speeds. Even more impressive is the reduction in effective friction coefficient on wet runways at high speeds. From this chart, it's obvious that there isn't much friction coefficient to convert weight to drag at high speed, especially on a wet runway. The anti-skid system does a pretty good job of maximizing whatever friction is available, but remember that under some conditions there isn't much available.

ANTI-SKID

Earlier generation anti-skid systems used a variety of concepts to prevent skids. Some simply controlled wheel speed, while others controlled optimum deceleration rates. The Mark III anti-skid system used in the F-15 (also in the F-4, F-18, and space shuttle) is designed to maximize braking effectiveness by maintaining an optimum "slip ratio." A wheel must rotate at some speed less than the free-rolling speed in order to produce any kind of drag. The tire is actually skidding to some degree, and the amount of skid is called the slip ratio. Analysis shows that the F-15 gets its best braking effectiveness at a slip ratio of approximately .2 to .3.

Figure 2 shows how braking effectiveness changes as a function of slip ratio. It's important to note that the vertical axis represents maximizing whatever friction coefficient is available, which, in some cases, may be very low. The upper curve, showing how drag force goes down as a skid is approached, explains why the aircraft seems to accelerate as it enters a skid. There really isn't any acceleration causing a speed increase. Instead, the *rate of deceleration decreases,* giving an illusion of acceleration. At high speeds on a wet runway, there isn't much friction coefficient available; so even though the anti-skid is working, little deceleration will be apparent.

The Mark III system contains several interesting features in addition to preventing skids. Touchdown protection prevents hydraulic pressure from reaching the brakes for five seconds after the proximity switches tell the system that the aircraft has touched down. This ensures that the brakes will not be locked at touchdown. In order to provide braking immediately after landing, a wheel spin-up override feature allows normal braking as soon as the wheel speeds up to 50 knots or greater and the ARI is defeated at the same time to enhance lateral control for crosswind landings. Crossover protection compares the speeds of both wheels and reduces pressure to both brakes if one wheel speed is 50% less than the other wheel. In order to ensure that braking is available at taxi speeds, the anti-skid is cut out below 15 knots.

DIRECTIONAL CONTROL

A related and equally important concept is cornering force. Cornering force is what keeps the airplane traveling in the desired direction (main gear contribution) and steers it (nose gear contribution). The lower curve in Figure 2 shows how the force changes with the

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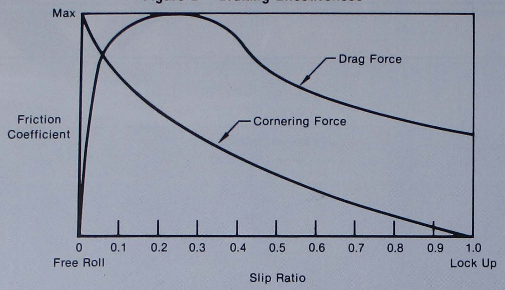


Figure 2 - Braking Effectiveness

slip ratio. In full skid, there is no cornering force available on the main gear. Directional control is poor; braking effectiveness is at a minimum; and to make matters worse, it's hard on tires. Once the aerodynamic power of the rudders is no longer effective, you're in trouble – no directional control and little braking effectiveness.

NORMAL PROCEDURES

With all of the innovative technology just discussed, the pilot still has the most important role to play when it comes to "stopping the Eagle." To quote from an article written in 1965 by McDonnell Test Pilot, Don Stuck: *"Above all, remember that the most important facet of your landing occurs before the aircraft is even on the ground – the final approach."* Those words, written for early F-4B operations, are every bit as true today. It is very important to fly a proper, on-speed approach. The energy that must be dissipated after landing is simple kinetic energy given by the equation:

$$K.E. = 1/2\, mv^2 \quad \text{where} \quad m = \text{mass}, \; v = \text{velocity}$$

Every extra knot of speed on final approach increases kinetic energy as the *square* of velocity. Every extra pound adds energy in a 1 to 1 ratio, but also requires extra speed, hence a double whammy. That's where the guidance "don't land heavy or fast" came from. This isn't meant to imply that you should fly or land slower than the flight manual dictates. It simply means that you will have a lot of excess energy to deal with if you land faster or heavier than necessary.The amount of runway used during landing roll depends not only on runway condition, but how much energy you land with and how far down the runway you touch down.

Once on the runway, kinetic energy must be dissipated through aerobraking or wheel braking. Aerobraking is generally the best choice initially since it minimizes brake wear and tear. After lowering the nose, get on the brakes with smooth, steady pedal pressure. The system is designed to operate with a full 3,000 psi of hydraulic pressure at the control valve. Full pedal deflection, carefully applied, provides the best wheel braking. Remember, at high speed little deceleration from the brakes will be appparent, especially on a wet runway. It's not a good idea to use differential braking for directional control since this results in longer landing rolls. Besides, the full-time nose gear steering does a better job of steering.

Once your speed is under control, go ahead and clear the runway at a taxiway before the end of the runway (local procedures permitting). It's pretty scary to discover little or no braking at 100 knots with 2,000 feet remaining. Get slowed down early and keep as many options available as possible!

MINIMUM RUN LANDINGS

The technique for minimum run landings depends entirely on the runway condition. For dry runways, fly an on-speed approach, lower the nose immediately after touchdown, and apply full anti-skid braking. On a wet runway, you *must* use aerobraking initially. Attempting to use wheel brakes immediately after touchdown on a wet runway will result in landing distance more than double that possible if you aerobrake first. In both cases, be sure to plan your approach to land at the proper distance down the runway.

COMPLICATIONS

Aerobraking always works, but wheel brakes do occasionally fail. Remember, you have five mechanical ways to stop an F-15: normal anti-skid braking; pulser brakes; non anti-skid brakes; emergency brakes; and the hook. (And further remember that the pulser brakes work either automatically as a backup to normal anti-skid or upon pilot activation of the PULSER switch on the miscellaneous control panel.) If you are absolutely convinced that the brakes have failed, I recommend putting the hook down before doing anything else. It's retractable and a reasonably reliable device. If you're still convinced that the brakes aren't working, try the pulser switch.

The pulser system is specifically designed to prevent blown tires; it "pulses" whatever pressure you apply to the brakes at a frequency that allows the tire to spin up and roll roughly two-thirds of the time instead of skidding full time. This ratio allows some braking action and retains directional control at the same time. If you don't have the pulser, or it doesn't work, non anti-skid braking is next. Be careful! It is nearly impossible to detect a skid, and it only takes a few seconds to blow a tire. If you're still not getting any braking, go to the emergency brakes.

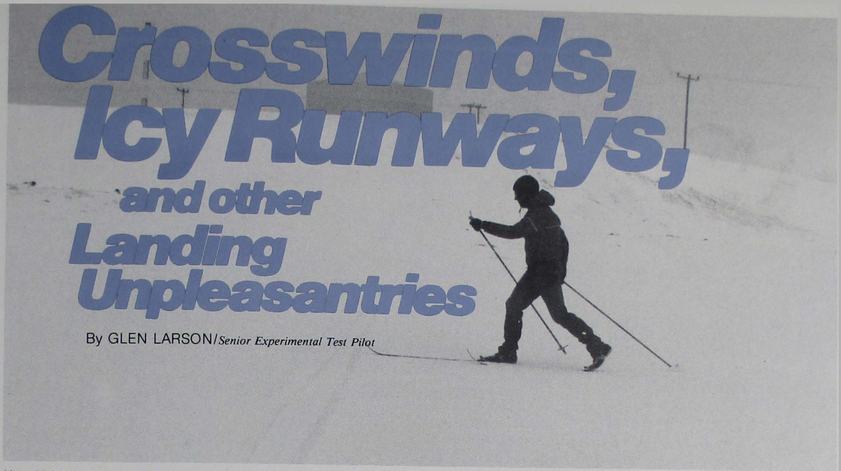
In my opinion, the emergency system is misnamed; it should actually be called an "alternate" brake/steering system. The emergency system has gotten a bad reputation; and to become more comfortable with it, I recommend exercising the system frequently. During taxi, pull the handle and get used to the feel of the system. If the brakes "grab" when you pull the handle, there's excessive friction in the cables and the system needs maintenance. Loss of steering when you pull the handle means that the hydraulic shuttle valve is sticking. Hitting the paddle switch will cut out the normal system and allow the emergency steering system to do its job.

If all of your braking efforts have been to no avail and you are still sailing merrily (more or less) down a rapidly diminishing runway, prepare to take the cable. The hook is already down, and your attention should now be devoted to getting your direction of travel pointed straight down the runway. If you've begun to drift off the runway, don't try to get back on the centerline. Trying for the centerline is actually aiming for the other side and will compound your problem. Accept an off-center cable engagement; the system can handle it.

As noted in the beginning of this article, stopping the Eagle is usually a routine event. During landing and rollout, the name of the game is to stay ahead of your airplane and keep as many options available as possible. Fly the approach correctly . . . touch down at the proper point . . . use aerobraking/wheel brakes as appropriate . . . be ready to go to back-up systems. For those rare occasions when "routine" suddenly turns into "spectacular," I hope this discussion will have given you some ideas with which to handle the situation. ■

Crosswinds, Icy Runways, and other Landing Unpleasantries

By GLEN LARSON/*Senior Experimental Test Pilot*



Navy JOC John Peterson does some cross-country skiing, not on a far off slope in the mountains of Iceland, but right on the NATO Base at Keflavik, home of the 57th Fighter Interceptor Squadron and their F-15 Eagles. Peterson, base assistant public affairs officer, helps make the point established in the article below. Ice, snow, and wind may be just part of the sport for a skier, but these harsher elements of nature add severe complications for fighter pilots attempting to land fighter airplanes at places like Keflavik. (Photograph by J01 Howard W. Watters, Editor of THE WHITE FALCON, base newspaper.)

Combinations of icy runways, crosswinds, low ceilings, snow, and darkness can generate pucker factors that are right off the scale! However, it's an unfortunate fact that the pilot has little control over these adversities, and the best he can do is minimize their effects upon his approach and landing. Since instrument and night flying advice is not the purpose here, let's limit our discussion to crosswinds and low RCR's (runway condition readings).

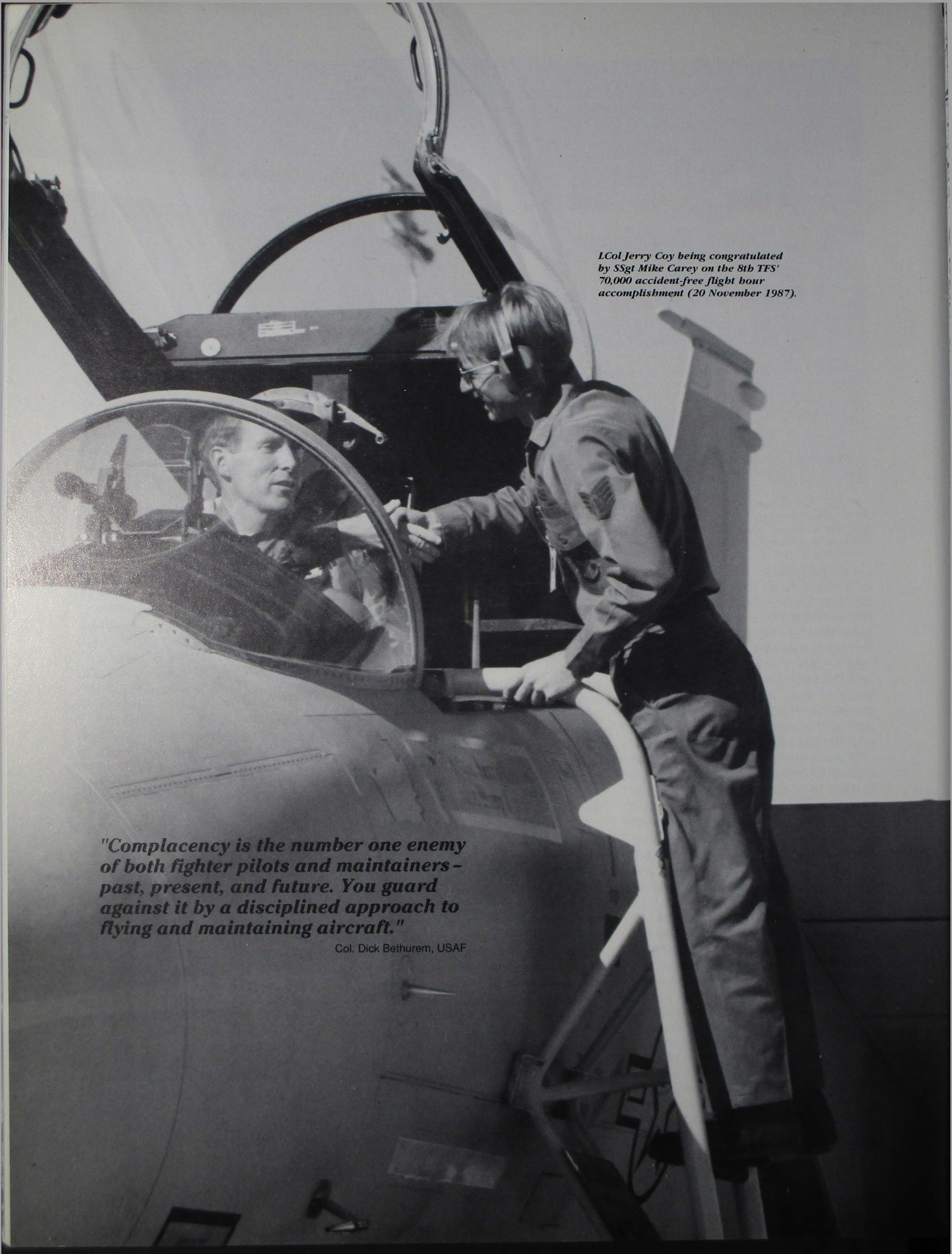
Crosswinds, up to the recommended limit of 30 knots, aren't a major problem in the F-15. There is plenty of directional control available from the rudders and nose gear steering, and the flight control system is designed to minimize directional control problems. The ARI, which normally coordinates the rudders and ailerons in flight, is cut out when the wheels spin up to 50 knots on touchdown. Without this lockout feature, applying aileron to keep the upwind wing from rising in a crosswind situation would also deflect the rudders upwind. This would add to any weathercock tendency and the net result would be exciting (*?*@!) to say the least. Incidentally, the ARI will cut back in when the wheel speed drops below 50 knots during the landing rollout. The 50-knot signal is supplied by the anti-skid system. If this system is off, ARI will be cut out any time the gear is down.

The key to an uneventful crosswind landing is to establish a wings-level crab with your flight path straight down the runway. The velocity vector may be unusable since it could be at the limits of the HUD field of view. Hold the crab through touchdown and gently raise the nose for aerobraking. If the crosswind is more than 25 knots, an aerobraking attitude of more than 10° may be uncomfortable since the upwind wing will produce a great deal more lift than the downwind wing; and nearly full stick may be needed to keep the wings level. In any case, if it gets too uncomfortable, or you begin to drift toward the side, lower the nose to the runway, and use the nosewheel steering as necessary.

Extremely low RCR's present their own problems. The aerodynamic controls such as rudders, etc., will do a fine job of keeping you going straight . . . up to a point. Once below about 100 knots, they lose their effectiveness; and you have to depend on the tires to keep you straight. Unfortunately, the maximum available tire cornering force is quite low, which means that steering effectiveness from the nosewheel and the stabilizing effect from the main gear are greatly reduced. The possible extreme result – little or no directional control, ground loops, etc. Add in high idle thrust due to low temperatures, poor braking effectiveness, and things can get exciting real quick! By now, the best choices should be obvious – divert or take an approach end cable! If no cable is available, and the entire runway is a sheet of ice – *divert!* If diverting isn't a viable alternative, be prepared to shut down an engine after touchdown and lower the hook for the departure-end cable. If you miss the cable, be prepared to roll off the end since the landing roll can exceed seven to ten thousand feet in extreme cases. It's better to roll into the overrun at 20 knots under control then go off the side at 80 knots out of control.

Combine crosswinds with very low RCR's and the *only* choice is to take a cable – approach end is your best option or a mid-field at least. Hold the crab through touchdown and use aerodynamic controls to keep your direction of travel straight down the runway. Accept a crab angle during rollout and cable engagement. If you drift to one side, don't worry about getting back to the center. Get things under control and stabilize the aircraft direction of travel straight down the runway before trying to correct your runway position. An off-center, crabbed engagement won't hurt anything. Finally, don't be any heavier than absolutely necessary, and don't fly a fast final.

Flying jet fighters is great fun – most of the time. However, crosswinds and icy runways can be a tough combination in any aircraft anywhere in the world. The key to safe operations under difficult conditions is to fly smart! Avoid heavy weights and fast landings, use cables, and think well ahead of your aircraft! ■



LCol Jerry Coy being congratulated by SSgt Mike Carey on the 8th TFS' 70,000 accident-free flight hour accomplishment (20 November 1987).

> ***"Complacency is the number one enemy of both fighter pilots and maintainers – past, present, and future. You guard against it by a disciplined approach to flying and maintaining aircraft."***
>
> Col. Dick Bethurem, USAF

HOT BRAKES

By GLEN LARSON/*Senior Experimental Test Pilot*

Overheated brakes and tires are not part of normal training operations – they usually result from aborted takeoffs or heavy-weight landings, neither of which are daily events. "Hot brake" definitions could easily be established in terms of measured temperature of the aircraft brake discs after landing, but since the Eagle does not have a temperature indicator installed, some more general guidelines need to be developed. With the able assistance of Glen Kirkland, Section Chief, Design; Ray Ehle, Senior Design Engineer; and Steve Meyer, Systems Safety Engineer, this article has a go at the task. Incidentally, what you are about to read is a follow-on to my article in the last DIGEST on F-15 landing and rollout characteristics (i.e., overheated brakes can result from less than desirable landing/rollout situations).

First of all, it is important to understand that "all" brakes – in the family station wagon, a Greyhound bus, an F-15 air superiority fighter – heat up to some degree. That's how they work – by converting *kinetic* energy into *thermal* energy. The point at which brakes become overheated is a function of their heat-absorbing capacity. That simple statement takes us into the not-so-simple area of materials technology.

The brakes in your Eagle are made of advanced carbon material. This material has several advantages over steel, one of which is its ability to absorb large amounts of energy without overheating. Carbon brakes can tolerate operating temperatures of nearly 4000ºF, while conventional steel brakes can't go much above 1200ºF. This tremendous increase in temperature capability has led to some misunderstanding about when F-15 brakes are really overheated. The "overheat" limits for the F-15 are established by the limits of the wheel and axle materials, and to better understand the situation let's look back at the baseline design criteria for this airplane.

The original stopping performance specifications for the Eagle were based upon steel brakes and required the following performance –

- 45 "normal" stops – equivalent to braking at 133 knots (1.1 times the stall speed) and 35,000 pounds gross weight for the A/B model; or 138 knots and 38,600 pounds for the C/D;

or

- 5 "overload energy" stops – equivalent to braking at 137 knots (1.0 times stall speed) and 45,000 pounds for the A/B; or 143 knots and 47,000 pounds for the C/D;

or

- 1 "rejected takeoff" (high speed abort) at 151 knots (stall speed) and 53,000 pounds for the A/B; or 165 knots and 68,000 pounds for the C/D. ▶

The carbon brakes currently installed on the aircraft exceed these requirements, including the high speed abort. However, the energy level of a high speed abort is so high that even carbon brakes are good for only one stop and the brakes will be dangerously hot. The brakes can be considered to be overheated at the point at which the fuse plugs melt, releasing pressure in the tire, which will have built up to 600 psi. The fuse plugs are designed to release the pressure in the tire before temperatures in the tire or wheel flange reach the point where the materials are weakened enough that they may fail explosively. There is, however, a large safety margin built in since the tires and rims are capable of withstanding 1190 psi pressure.

While overheated brakes are easy to define, the question remains – when do F-15 brakes begin to get hot? The answer to that question lies in determining how much energy has been put into the brakes during landing. That energy is "kinetic" energy, which is equal to one-half the mass times velocity (ground speed, in this case) squared, or

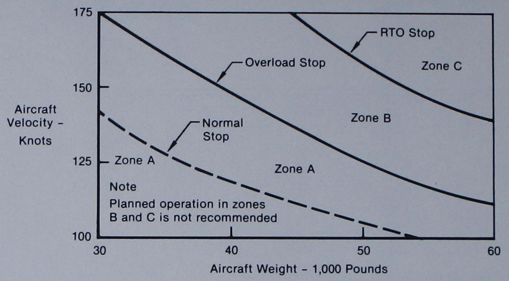
$$K.E. = 1/2\, mv^2$$

The pilot has two primary ways to get rid of that energy – aerodynamic braking and wheel brakes. (Since braking techniques were discussed in detail in my last article, we'll concentrate now on just the energy absorbed by the brakes.) Because the temperature the brakes eventually reach depends entirely upon the energy they must absorb, the two primary variables involved are the aircraft speed and gross weight when the brakes are applied. For example, good aerobraking before applying the wheel brakes will reduce the energy put into the brakes significantly. The pilot is the only one who really knows how fast he was going and how much the aircraft weighed when he applied the brakes.

Traditional indications of hot brakes – smoking or glowing brake discs – are not reliable indicators for the F-15. It is a characteristic of carbon brakes that they can "glow" visibly and not present any danger! Smoking brakes are usually caused by contamination of the brakes by oil or hydraulic fluid, and in fact, hot brakes will smoke very little because any contaminant will have been vaporized by the intensely hot brake discs.

Since you as the pilot are the key to determining if the brakes are hot, figures 1 and 2 are designed to help you in that determination for the A/B or the C/D model F-15's.

FIGURE 1 - F-15A/B BRAKE OPERATION

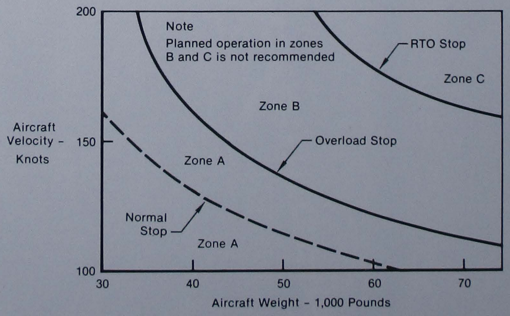


"Velocity" on the vertical axes is ground speed at which the brakes are applied, and the curved lines represent the specifications discussed earlier and assume full stop landings. The dotted line labeled "Normal Stop" is where the aircraft is operated routinely. "Zone A" is defined as the general area where routine operations are carried out, and no danger to equipment or personnel should exist. To keep the energy levels in the brakes reasonable, a one and one-half hour cool-down period is suggested between events. The line labeled "Overload Stop" represents the dividing line between normal and overload stops (defined earlier). "Zone B" can be defined as the area where the brakes will get hot and where repeated operation is not recommended. As the conditions approach "Zone C," the brakes will become hot, fuse plugs may blow, and fires could result. Caution should be exercised, and a minimum two-hour cool-down period is required between events.

The "RTO Stop" (rejected takeoff stop), or high speed abort line represents the point at which you will have extremely hot brakes. Routine operation in Zone C is definitely not recommended, and you can expect to damage wheel, brake, and tire assemblies. The possibility of personnel injury also exists. You should encounter Zone C only during high-speed, heavy-weight aborted takeoffs.

The differences in gross weights and braking capabilities between the A/B and C/D Eagles are obvious in the two

FIGURE 2 - F-15C/D BRAKE OPERATION



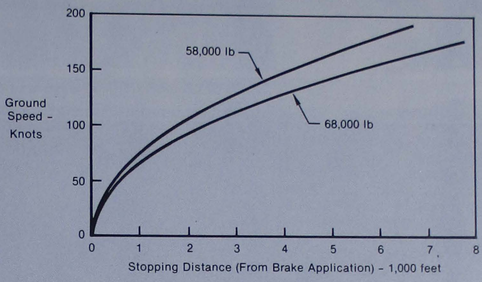
figures. It's nearly impossible to heat up the C/D brakes during normal training operations. With a two-pylon and centerline tank configuration, there isn't enough energy available to get hot brakes during normal landings. However, add CFT's, three tanks, and an extensive taxi, and it's another story – an abort at 170 knots and 68,000 pounds puts you in Zone C. Not only are you going to heat things up, but getting stopped in the remaining runway may be difficult.

Few Eagle drivers routinely operate their airplanes at high gross weights, but the advent of conformal fuel tanks will change that. Not only will hot brakes be a potential problem, but stopping distances will become critical. Figure 3 shows how much runway it will take to stop at max gross weights on a dry runway from the point of brake application. Using the previous example of 170 knots and 68,000 pounds gross weight, it will take about 7,500 feet to stop. Pilot reaction time will eat up another 1,000 feet, and pretty soon the runway isn't long enough, and to complicate things, the brakes will be extremely hot. A high speed abort at high gross weights is a potentially dangerous situation. Since experience with CFT's and three tanks is limited, get into the books and know the numbers before you start to roll!

Other variables can also heat up the tire and wheel assembly, creating additional problems. Malfunctions such as dragging brakes will add heat, as will long taxi distances because of added braking requirements and higher tire temperatures due to tire sidewall flexure. In fact, rolling to the end of the runway and a long taxi distance adds more heat to the system than an early turn-off and a direct taxi route. Don't interpret this as meaning that maximum anti-skid braking for an early turn-off is better than controlled aero braking. In general, hard braking or easy braking at speeds under 90 knots will create about the same brake temperature. Below 90 knots, zero drag is replaced with engine idle thrust. The point here is to avoid taxiing long distances where possible, and don't taxi around trying to cool the brakes. Remember, the brake discs reach their maximum temperature immediately when the wheel stops rolling, and the structure and wheel and tire assembly reach maximum temperature about 15 to 30 minutes after the wheel stops since it takes a while to conduct the heat from the brake discs.

In summary, F-15 brakes based on carbon technology present significant advances in energy absorption capabilities, and we can no longer depend on visual clues to evaluate hot brake situations. You as the pilot are the key element in the process, and need to be aware of airplane speed and weight when the brakes are applied. Routine operations in Zone A will not produce hot brakes. When speed and weight are high enough to get into Zone B, the brakes can be considered hot, but not necessarily dangerous. In Zone C, things are extremely hot, and extra caution is definitely in order.

FIGURE 3 - F-15C/D STOPPING DISTANCE
(Dry Runway, Maximum Anti-Skid)



FLYING CONFORM

By GLEN LARSON/*Senior Experimental Test Pilot*

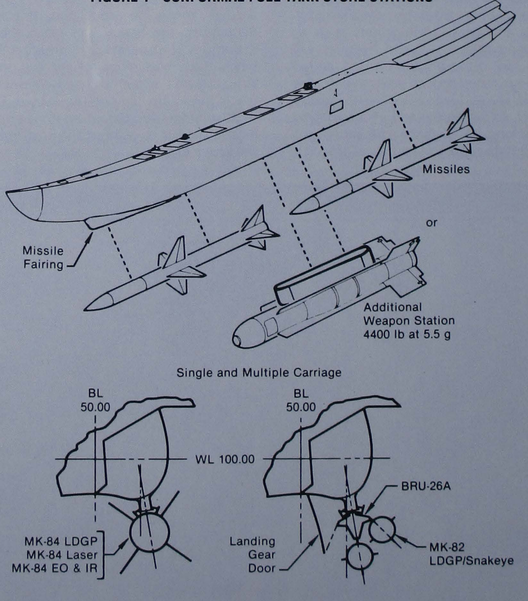
Flight characteristics of any fighter aircraft always generate a lot of discussion among aircrews, and the F-15 is no exception. Today, several squadrons worldwide are flying F-15C/D aircraft configured with ''conformal fuel tanks'' (CFTs). Any time there is a major change to an aircraft configuration (and the addition of a 32-foot, 1200-pound conformal fuel tank under each wing root is unquestionably a major change), pilots are going to have a lot of questions. The intent of this article is to provide some answers through flight performance comparison data and figures for aircraft equipped with a centerline tank or with CFTs. (Incidentally, even if you are not flying C or D aircraft with conformal tanks right now, you probably know that the F-15E ''dual role fighter'' on our production line today also has them, so there is quite likely a ''CFT Eagle'' in your future and your close attention to this article is encouraged!)

After getting into some of the finer aspects of this subject, I realized the facts were not as simple as they first appeared, and writing this article was made possible only with contributions of several members of the MCAIR engineering team. My appreciation is expressed to Jim Agnew and Bill Nelson, Section Chiefs Technology; Drew Niemeyer, Senior Engineer Technology; and Bob Anderson, Chief Technology Engineer, for providing the aerodynamic data and performance analyses presented herein.

One of my earliest presentations in this lengthy series on flight characteristics of the F-15 discussed angle of attack and turn performance. While the data presented in that article back in 1984 touched upon the effects expected from the addition of conformal fuel tanks to the airplane, my emphasis then was on the basic Eagles most of you were flying at the time. Today there is a ''new kid on the block'' – CFTs are one of the most recent additions to production F-15s – and it's time for a detailed look at what's in store for the Eagle driver whose next assignment may be to a CFT-equipped F-15 squadron.

You may also have heard these fuel tanks referred to as ''fastpacks'' or pallets, but by any name, they mean significant expansion of capabilities for

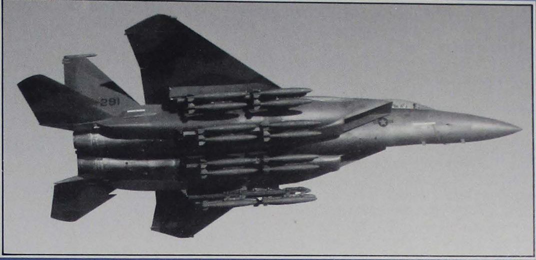
FIGURE 1 - CONFORMAL FUEL TANK STORE STATIONS



AL FUEL TANKS

the airplane. The addition of nearly 10,000 pounds of fuel in CFTs increases combat radius dramatically, and provides unit commanders with unprecedented flexibility in combat tactics and strategy.

As you might expect, all these good things aren't free without charge; some compromises are necessary. Speed and turn performance are affected, and since these are two topics of great interest to all Eagle drivers, we will examine exactly what effect CFTs have on F-15 top speed and on both instantaneous and sustained turn performance. But first, a little background about these strange looking objects that are appearing on more and more of our Eagles these days.



HISTORY

Conformal fuel tanks originated as a MCAIR advanced design concept shortly after the original F-15 contract was awarded and well before first flight of the airplane in 1972.

The CFT prototype program was initiated and funded by the company as one of the ways to take advantage of the Eagle's inherent versatility and growth potential. The tanks are "wet" (no bladders) and are made of conventional aluminum skin, frame, and stringer construction. Each tank is divided into three compartments, with electric transfer pumps in the aft and center compartments. The CFT fuel system is connected to the aircraft manifold through a single quick-disconnect probe. The aircraft fuel system permits transfer, refuel, normal defuel, and dumping of CFT fuel. (At a rate of 145 gpm, it takes a little over ten minutes to dump a full CFT fuel load.)

F-15B S/N 71-291 (a pre-production two-seater) was modified to carry the CFTs; and the first prototype tank set was flown on 27 July 1974. This prototype set was used on a transatlantic flight in August 1974 – a nonstop, unrefueled, 2,650 nautical mile trip from Loring AFB, Maine, to RAF Bentwaters, England.* Seven more transatlantic flights and one transpacific flight were subsequently flown. In mid-1978, the Government of Israel placed an order for CFTs. The first set, delivered in June of 1980, was used for heavyweight testing and certification for 68,000 pounds gross weight operations.

Go-ahead was received in June 1982 from the US Air Force for initial production of the -2 CFTs. The F-15 multi-stage improvement program (MSIP) provided several major updates and changes to the aircraft, particularly a programmable armament control system (PACS). This weapon system update also required

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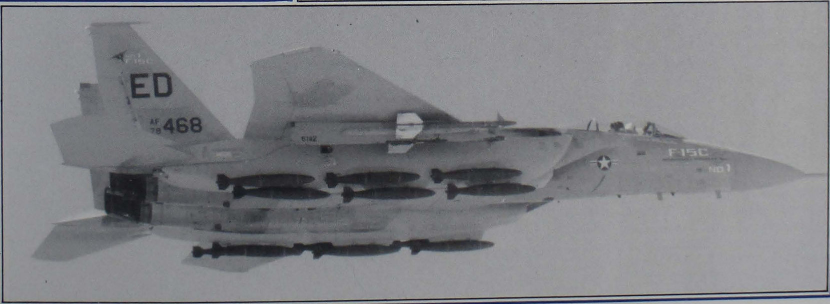
If you have a copy of "EAGLE TALK" (Volume I), there are two interesting articles therein, reprinted from the 1974 DIGEST and titled "Fast Pack to Farnborough," on the early engineering and flight test history of conformal fuel tank design and development. . .



changes to the CFT air-to-surface weapons configuration interface, and the original contract was amended to immediately begin production of the -3 CFTs. This configuration included air-to-surface weapon interfaces for both MSIP and non-MSIP aircraft.

Today, F-15C/Ds currently assigned to the 57th FIS at Keflavik, Iceland; 1st TFW at Langley AFB, Virginia; 18th TFW at Kadena AB, Japan; and the flight test centers at Eglin AFB, Florida and Edwards AFB, California are presently flying -2 or -3 CFTs. All F-15Es will be equipped with the latest version, the -4 with tangential weapons carriage, slated to go into production in the near future.

WEAPON CARRIAGE CAPABILITIES

CFTs are designed with both air-to-air and air-to-surface stations, as shown in figure 1. This gives the aircraft equipped with PACS five air-to-surface stations, all capable of various single and multiple store loadings. During the AFC (advanced fighter capability) demonstration program in 1982, a test aircraft equipped with CFTs was loaded with five BRU-26A bomb racks and twenty-two MK-82 bombs. Although (refer to the top photograph on previous page) this was certainly an impressive load, the aircraft suffered from the effects of a 198 drag index (127 after bombs dropped), contributed primarily by the BRU-26A bomb racks.

Therefore, the best load for an air-to-surface mission with current production CFTs has been determined as the MK-84 family of bombs utilizing direct pylon carriage. With a maximum load of five bombs, the drag index is greatly decreased to 63 (42 after bombs dropped). These drag indexes include four AIM-9s. In comparison, the drag index of a four AIM-7/four AIM-9 configuration is 33, and adding a centerline tank increases the total to 58.

TANGENTIAL CARRIAGE

The name of the game during the comparative evaluation for the F-15E Dual Role Fighter (DRF) was range and payload. The operational analysis people favored twelve MK-82s; but as you can guess, this weapon load was far from optimum (drag index of 116). In order to reduce the drag (thus increasing range), MCAIR funded the "tangential" bomb carriage test on the CFTs. This method of carrying various bomb configurations greatly reduces the amount of drag associated with current CFT multiple and single carriage.

In a program that took only six weeks from go-ahead to first flight with bombs, the tangential carriage concept was evaluated. Arrangement of the bombs and the dramatic decrease in frontal area (refer to the bottom photographs on previous page), plus additional external fuel which can be carried provides a 28% range improvement for a MK-82 bomb load. Remember, the name of the game is combat radius and/or time on station. CFTs aren't suited for ACM missions 20 miles from the field but are ideal for deep interdiction or long range CAP/escort missions.

Now that I have provided you a peek into the improved capabilities of the next generation of CFTs, let's get back to what is at hand – a discussion concerning the basic, non-tangential carriage CFTs, commonly referred to as -2 and -3 versions.

AIRCRAFT PERFORMANCE

How do conventional CFTs affect the capabilities of the F-15? The best way to answer that question is in terms of speed and turn performance.

Speed

In level flight, the total subsonic drag of a CFT-equipped airplane is significantly less than one carrying a centerline external tank. Above 1.0 Mach, the drag of the CFTs is somewhat more than that from the centerline tank. In any case, drag from two CFTs is much less than that produced by two or three external tanks.

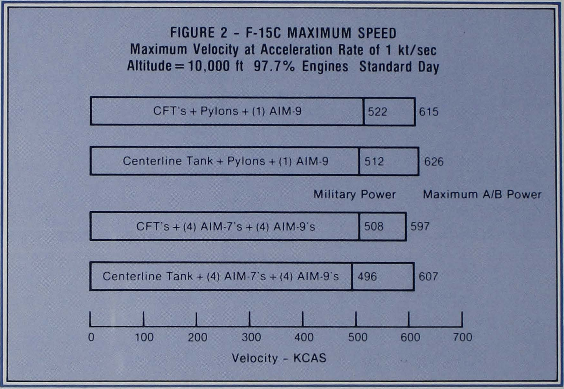


FIGURE 2 - F-15C MAXIMUM SPEED
Maximum Velocity at Acceleration Rate of 1 kt/sec
Altitude = 10,000 ft 97.7% Engines Standard Day

Figure 2 shows the top speed attainable in level flight at 10,000 feet MSL with 97.7% thrust engines. The first configuration (pylons and one AIM-9) is one typically employed in training; the second is a full up air-to-air load. For comparison, top speeds were calculated for these configurations with a centerline tank and with CFTs. As you can see, in a training configuration an aircraft with CFTs will reach 615 KCAS, and with only the centerline, 626 KCAS in full afterburner. (Incidentally, these speeds should be representative of the real world since they were determined by calculating what the speed would be at an acceleration rate of one knot/second. That level

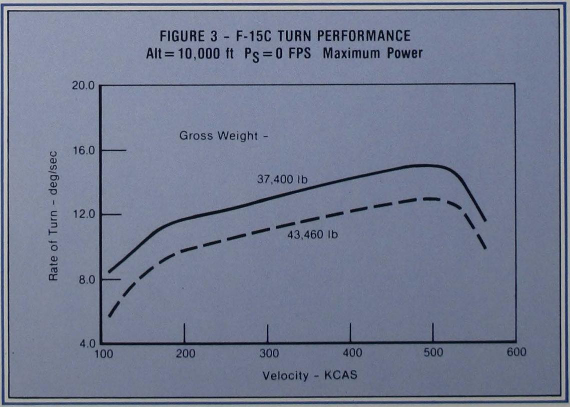


FIGURE 3 - F-15C TURN PERFORMANCE
Alt = 10,000 ft $P_S = 0$ FPS Maximum Power

of acceleration was chosen since it will seem to most pilots that the aircraft is no longer accelerating at that point.) In mil power, you can expect to see 522 knots with CFTs onboard, and because of slightly more drag, 512 knots with the centerline tank alone.

Speed by itself doesn't tell the whole story; the time required to reach these speeds is also critical. In max power at 10,000 ft, it takes 19 seconds to go from 300 to 500 knots when configured with CFTs, pylons, and one AIM-9 at 50% fuel weight. Dropping the CFTs and adding the centerline tank results in 17 seconds at 50% fuel weight. If however, we look at the CFT configuration at the same weight as the centerline tank loading, we would see a time of 16 seconds. Since aircraft acceleration is highly dependent on weight, the basic difference is due to the additional weight in fuel and structure for the CFTs. In mil power, the time is about 56 seconds for both the CFT and centerline tank configurations.

Altitude also has some effect. For example, in max power at 20,000 feet you can expect to see 553 knots with CFTs, two pylons, and an AIM-9, or 569 knots if you drop the CFTs and put on a centerline tank. In mil power, both are about 445 knots. Times to accelerate in max power from 300 to 500 knots at 20,000 ft with 50% fuel weight are 26 seconds for a centerline tank, 30 seconds for the CFTs.

All these numbers demonstrate that conformal fuel tanks will not materially change speed and acceleration characteristics when compared with a centerline tank equipped F-15. And remember, the centerline only carries 3,965 pounds of fuel, whereas the two CFTs carry a total of 9,630 pounds.

Turn Performance

Configuration differences have essentially no effect on instantaneous turn rates. It is only the change in gross weight or load limits (stores remaining on board) that actually affect instantaneous turn rates. However, sustained turn performance will be affected by both gross weight and configuration differences.

Figure 3 is a comparison of sustained turn rates for low and high airplane gross weights at various airspeeds. The solid line shows a 37,400 pound aircraft (a fairly low gross weight) with four AIM-7 missiles onboard. Its maximum sustained turn rate is about 15 degrees per second at 500 knots. The dashed line is for a gross weight of 43,460 pounds also with four AIM-7s onboard (loading really doesn't matter a great deal at this speed; the weight is more significant). The best sustained turn rate drops to approximately 13 degrees per second, but it still occurs at 500 knots.

Since sustained turn rate is a function of how many g's the aircraft can withstand, we need a chart that shows how

FIGURE 4 - F-15C W/O CFTs SUSTAINED G CAPABILITY
Alt=10,000 ft Maximum Power

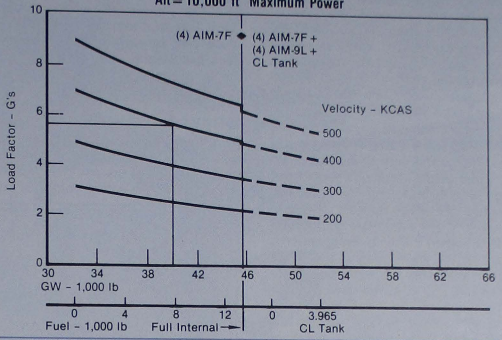


FIGURE 5 - F-15C+CFT SUSTAINED G CAPABILITY
Alt=10,000 ft Maximum Power

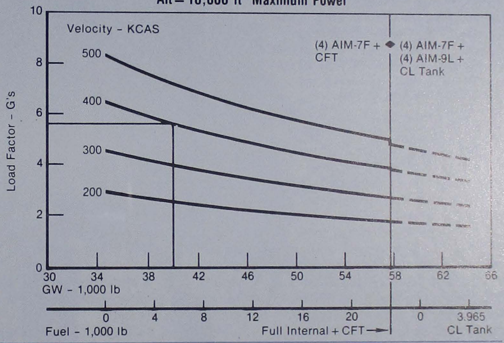
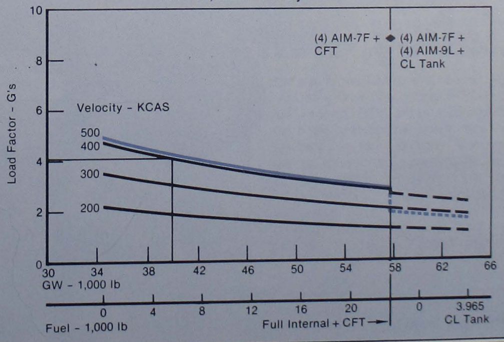


FIGURE 6 - F-15C+CFT SUSTAINED G CAPABILITY
Alt=10,000 ft Military Power



sustained g changes with weight and speed. Figure 4 relates load factors (or g levels) to aircraft gross weights and amount of fuel on board. The constant airspeed curves, from 200 to 500 KCAS, represent sustained g levels at various gross weights. A specific example is shown on the chart: an F-15 at 40,000 pounds gross weight and 400 KCAS will sustain 5.5 g's at 10,000 ft.

The most important point concerning figure 4 is the significant decrease in sustained g capability with an increase in aircraft gross weight. Additional weight and drag reduce sustained g capability, especially at higher speeds. The step change in the g sustainable on the 500 KCAS line when changing configuration is caused by the added drag of the AIM-9 missiles and centerline tank. Below approximately 300 KCAS, the drag of these configuration changes has little effect on sustained turn performance; above 300 KCAS, the effects become more and more significant. This is why it helps to jettison the external tanks – lower weight means higher sustained g's and less drag means higher speeds with better acceleration.

Figure 5 is identical to figure 4 except that the configuration includes CFTs. At 40,000 pounds gross weight, the aircraft still sustains 5.5 g's at 400 KCAS but the fuel onboard is 5400 pounds, compared to the fuel onboard in figure 4 of 7800 pounds.

Figure 6 is included for comparison with figure 5. The two charts are identical except that the values in figure 6 are calculated at mil power. As expected, the sustained g level at 40,000 pounds gross weight and 400 KCAS drops to 4 g's from the 5.5 g's sustained with max power. Higher altitudes have a similar effect. At 20,000 feet, the sustained g at 40,000 pounds will be 4 g's at 400 KCAS in max power and 3 g's in mil power.

Another interesting point on this chart is that the 500 KCAS sustained g capability is about the same level as the 400 KCAS. This is explained by the fact that at 500 KCAS, most of the available thrust is required for level flight, leaving very little for sustained turns. Sustained turn performance is highly dependent on weight; therefore, at the high fuel weights possible with CFTs, sustained g capability will be significantly lower than for a basic F-15.

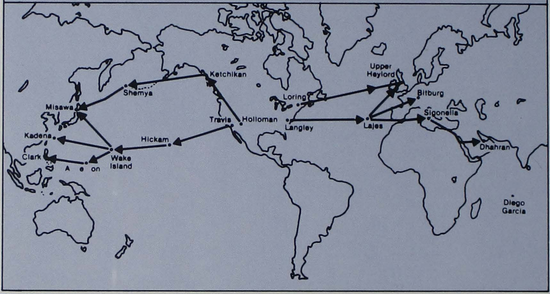
HANDLING QUALITIES

Handling qualities of a CFT-equipped airplane are not noticeably different from those of a clean airplane. The major effect is, again, the added weight. Because of the higher weights and inertia, the airplane may be perceived as being slightly less responsive. At high angles of attack, the only noticeable difference is a slightly higher angle at full aft stick. This results from a reduction in the basic nose-down pitching moment of the aircraft due to the CFTs.

Additional ballast isn't required when CFTs are added, and fuel asymmetry shouldn't be a problem. The CFTs are designed to never exceed 500 pounds imbalance during normal system operation, and they will feed before the internal wing tanks to minimize any imbalance possibility.

In summary, the price which must be paid for conformal fuel tanks in terms of performance is relatively small when compared with the tremendous increase in range they provide. Figure 7 shows the deployment capability of the CFT-equipped F-15 aircraft, which is unequaled in the world today. CFTs full of fuel are not appropriate for daily training flights to a restricted area or MOA 50 or 60 miles off the end of the runway. They're definitely a hindrance if you're trying to shoot the dart or fight DACT right after takeoff. But if you've got to go to war tomorrow – without tankers – then they're indispensable. You need CFTs to provide prolonged air cover for ground forces, AWACS protection, or airfield defense. ■

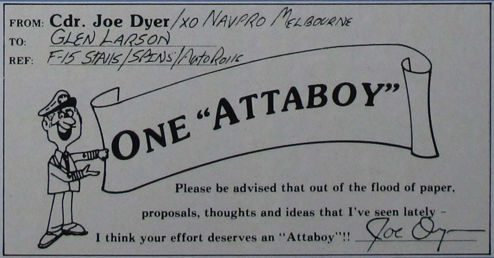
FIGURE 7 – F-15C WORLD DEPLOYMENT WITHOUT TANKERS



Attaboy, Glen

Glen Larson came to McDonnell as a test pilot in 1979, and began writing cockpit-oriented articles for the DIGEST on the USAF F-15 Eagle almost immediately. He is an aeronautical engineer, has a graduate degree in business, and belongs to the American Institute of Aeronautics & Astronautics and to the Society of Experimental Test Pilots. Despite his obvious qualifications for doing so, Glen allows no room in his aircrew discussions for unhelpful "technologicalities" – as a recent delightful message from downunder proves.

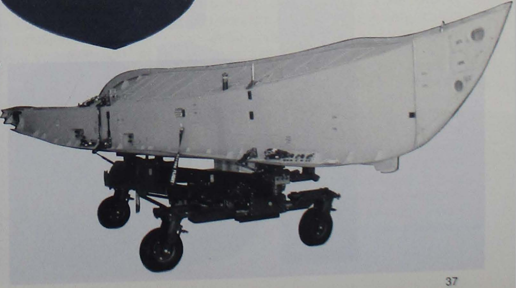
Commander Joe Dyer, executive officer of the USN NAVPRO group at Melbourne, Australia, saw a reprint recently of one of Glen's Eagle articles in FLYING magazine, published by USAF Safety Center. In a note accompanying the neat little certificate reproduced here, the commander complimented our pilot/author Larson for a ". . . super job of transferring technical knowledge to operational folks, without using $C_{\eta\beta}$ even once!" How about one more "attaboy," this time to Cdr Dyer for seeing what this magazine and its contributors are all about!


FROM: **Cdr. Joe Dyer**/XO NAVPRO MELBOURNE
TO: GLEN LARSON
REF: F-15 STALLS/SPINS/AutoRolls

ONE "ATTABOY"

Please be advised that out of the flood of paper, proposals, thoughts and ideas that I've seen lately – I think your effort deserves an "Attaboy"!! Joe Dyer

The article you have just finished reading presented some advice and guidance by a MCAIR/St. Louis test pilot on flying the F-15 Eagle equipped with conformal fuel tanks (CFTs). The article beginning on the next page takes you to Keflavik AB, Iceland for some comments and opinions by aircrews and maintenance personnel of the 57th Fighter Interceptor Squadron – the first all-CFT Eagle squadron. However, many of you probably have yet to see one of these new creatures head-on, so this page presents views of the F-15 with and without conformal fuel tanks, how conformal tanks are ground transported and attached to the aircraft, and the tanks themselves.



"If We Didn't Get Them, They Didn't Come Our Way."

The 57th Fighter Interceptor Squadron has been stationed at Keflavik International Airport in Iceland since 1954. They began to fly the McDonnell F-4 Phantom in 1973, and in November of 1985 converted to the MCAIR F-15C/D Eagle equipped with conformal fuel tanks (CFTs). "Bear Hunting" is exceptionally good in this part of the world, and CFTs are making it even better. Here is a first-hand report by the people who are accomplishing . . .

Conformal Fuel Tank

F-15 Operation
in
Icelan

COLONEL ROBERT G. JENKINS
Commander
Air Forces Iceland

Last year, we more than doubled our previous year's level of activity. . .or more correctly I should say that the Russians more than doubled their previous year's level of activity, since what we do up here is in direct response to what they do out there!

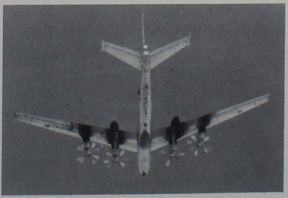
When I use the word "activity," I'm referring primarily to the entrance into Icelandic air space of the Soviet TU-95 bomber series of aircraft with the NATO code name of "Bear;" our identification and surveillance of them; and our subsequent escort of them out of our zone of responsibility. We get activity almost every day of the week out of the Russians, and the trend each year has been for more rather than less.

They are flying several versions of this airplane – anti-submarine, air-to-ground stand-off missile carrier, and reconnaissance/electronic intelligence gathering types. We've had them all come through here, on their way into the North Atlantic, or completing a training run against the Norwegian coast or the U.K., or heading on over to the North American coast for practice with their long range missile carriers.

A quick-reaction alert is maintained at Keflavik at all times with two F-15s. The AWACS is also on the same alert, as is the tanker. Most of our intercepts are accomplished after coming off the ground, but sometimes during CAP. It's a combination of these capabilities – ground and airborne – that has produced the results. The motto up here is – "If we didn't get them, they didn't come our way," and there are releasable intelligence figures to prove it. In 1985, there were 170 intercepts and last year was about the same.

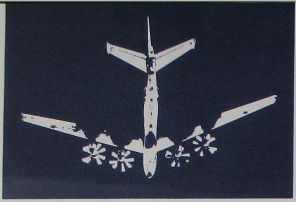
The feeling here at Keflavik is that we are really on the leading edge of air defense operations around the world. First, because we are closest to the Russians, and second, because we intercept more Russian aircraft than the rest of the Air Force put together. With just 20 fighters. Sometimes we have two intercepts running simultaneously; it's not at all unusual to have a couple sets of Bears airborne in our area. And in my opinion, we couldn't do what needs to be done here without the F-15 Eagle jet.

As you know, the F-4 series (first the C and then the E) was used here for more than 12 years, until late 1985. I flew the Phantom myself for years, loved every minute of it, but what we are doing with the Eagle in Iceland just could not be done by the F-4, or any other airplane. You have to think about Iceland – where it is, what it is – in order to understand ▸



The "Iceland Defense Force" (IDF) was created in 1951 when the United States and Iceland signed a defense agreement. However, U.S. forces first arrived on this island nation strategically located in the North Atlantic halfway between New York and Moscow in July of 1941. In addition to their direct defense role, American military personnel constructed the Keflavik airport as a refueling point for aircraft deliveries and cargo flights to our European allies.

After the conclusion of WW II, all troops were withdrawn from Iceland but in 1946 a special agreement permitted continued use of Keflavik airport for flights in support of occupation forces in Europe. In 1949, Iceland became a charter member of NATO (North Atlantic Treaty Organization), and in 1951 the IDF was established. As a NATO member, Iceland has provided an effective base for anti-submarine warfare patrol aircraft and communication facilities, for search and rescue operations, and for stationing air defense forces which include AWACS, ground-based radars, and a fighter-interceptor squadron.



the capability the F-15 provides for the mission up here.

This island sits out in the middle of the North Atlantic, smack dab in the middle of some of the harshest weather in the world. It's not always harsh, but it can turn that way almost instantaneously. The closest alternate place to land is Scotland – over 700 miles away. That simple statement has some quite profound implications if you're a fighter pilot; it dictates a lot of things, and is a necessary part of everybody's thinking. The extra on-station time possible with the F-15 and its capability for going to a distant alternate as circumstances may require, make a tremendous difference in operational planning – not only in the active mission but in the training mission as well.

With the F-4 for example, with three bags of fuel, you could take off from here on an intercept mission, go out about 200 miles to the edge of the MADIZ (military air defense identification zone), and have about 15 minutes of playing time before coming home or calling up a tanker. If an alternate was needed, you had to refuel almost by the time you got airborne. With the F-15, with conformal tanks, there is an hour forty-five of orbit or CAP available to wait out there for whatever may be coming in. And for training missions, weather does not down the Eagle very often. We have been able to lower weather minimums way below what had to be maintained for the Phantom because we always know exactly how much fuel is aboard – there is plenty of time/fuel for good training sorties, come back to Keflavik for a low approach, and divert to Scotland if the weather has suddenly closed Iceland.

What with everything I'm saying about the Eagle versus the Phantom, don't underestimate the F-4. It can carry the same basic ordnance as the F-15, and particularly with the slatted wing, it's still a top air-to-air machine. And tough as hell – I remember Phantoms being practically shot to pieces in Vietnam and still bringing people home safely. So what I'm talking about now is pure technology and state-of-the-art capability. In my opinion, there are two basic areas in which the Eagle shows to great advantage in this tactical environment. We've already talked about one of them – its on-station time capability – and the other is avionics. Especially the pulse-doppler radar.

Up here we have two ways to detect and track incoming unidentified aircraft. Ground radar sites are at both ends of the island, and we use the E-3A for airborne surveillance. Every once in a while, something will happen to our AWACS. Not often, but occasionally, and we'll have to put the F-15s out there on combat air patrol by themselves to find the Bear. They don't have a problem. That's not to say the Eagle is a mini-AWACS, but its radar is very good and a great advantage to us.

You mix the technology of the F-15 with the skills of our aircrews and the result is an unbeatable combination. Without a doubt, the most experienced pilot group in any one squadron in the Air Force today is assigned here. The average pilot in our squadron is a senior captain with 1200 – 1500 hours of fighter time – most if not all in Eagles. Every one of these guys falls under the Air Force definition of "experienced" with respect to previous tours. The environment here and the risk factors are such that we need highly qualified aircrews. Certainly, we do training missions, but we do not fly in a quote training unquote atmosphere. In Iceland, things are about as real as they can get. ———

The 57th Fighter Interceptor Squadron activated as a fighter training unit in January 1941 at Hamilton Field, California. Their first aircraft were P-39 Airacobras and P-40 Warhawks. After a short tour to Alaska, the unit returned to Hamilton, transitioned to the P-51 Mustang, and continued training new fighter pilots until deactivation in April 1944.

Reactivated in 1953 in Maine with F-89 Scorpions, the squadron moved to Iceland in November 1954 (as the only fighter unit assigned to the Military Air Transport Command), converted to the F-102 Delta Dagger in 1962, and in the ensuing 11 years made more than one thousand intercepts of Soviet military aircraft. By now a part of ADC (Air Defense Command), the Black Knights picked up the F-4C Phantom II in 1973 and greatly increased their mission capabilities. Four years later, they upgraded to the F-4E, and in July 1985 began conversion to the McDonnell F-15 Eagle. In their time with the Phantoms, the 57th FIS flew 151 consecutive months without a Class A mishap, intercepted more than 1200 Soviet intruders, and received numerous awards (including the Hughes and Baker trophies) for excellence in operations and maintenance.

The mission of the squadron is to be prepared at all times to intercept, identify, escort, and if required, destroy unauthorized intruders that penetrate sovereign airspace surrounding Iceland. This requires tactical planning and training for fighter operations required by the Commander of Iceland Defense Forces in fulfillment of USCINCLANT (United States Commander in Chief Atlantic) directives. The 57th FIS is assigned directly to Air Forces Iceland (AFI), the joint air component command of IDF and is a subordinate unit of First Air Force and Tactical Air Command at Langley Air Force Base, Virginia.

F-15 pilots and maintenance personnel are on alert 24 hours a day to provide immediate response. Aircraft can be airborne within minutes of a "scramble" order to intercept and identify unknown aircraft. The squadron has a secondary mission during peacetime to photograph intercepted Soviet bloc aircraft in support of continuing intelligence requirements. The Black Knights are in constant training to keep personnel and equipment at peak efficiency – demonstrated by an average of more than 100 Soviet intercepts each year.

At the present time, the 57th FIS is the only USAF squadron flying all F-15s equipped with conformal fuel tanks as the standard operating configuration. Tanks are not downloaded for any mission, but a CFT fueling "lockout" procedure is used when a complete fuel load may not be desired – during sortie surges and special exercises for example, and only when local weather conditions indicate full fuel reserves will not be required.

LIEUTENANT COLONEL LEIF R. DUNN

Commander

57th Fighter Interceptor Squadron

I took command of the squadron here in February of 1986, and the job has proven to be a lot more interesting than with a standard state-side FIS. While we are getting fairly well into Eagle flying now, there is still something new every day that reminds all of us that this is a pretty special situation. We are operating as an Air Force tenant at a Navy base located on a remote island nation subject to some of the wildest weather imaginable. And those are just a few of the differences!

Our supply is basically by military air and sea lifts with lateral support lines five to six thousand miles long. If we run out of parts – F-15 parts, typewriter ribbons, cans of paint – we can't run down to the air logistics center, the K-Mart, or Ace Hardware. If it isn't on the island, we either do without or sit at the end of a mighty long supply chain. There is no Federal Express to Keflavik – Icelandair or standard military airlift gets our MICAPS in and out – and such a logistic stream is always more demanding on the planning process, and often frustrating. But when something works right, it really feels good; and most things are working pretty well today – especially for an organization still undergoing the effects of conversion from one aircraft to another.

We have been producing steady increases in our maintenance capability. Our program is maturing slowly. Deferred discrepancies have been going down; cannibalization rates are coming down slightly – though it's important to note that our "cann" rates are still higher then we'd like, which really reflects the long logistic tail up here. Our scheduling effectiveness has been going up; MC rates are climbing slowly but surely; NMCM and NMCS rates are coming down.

Something else to consider when looking at the numbers hung up so far by the Eagle in the 57th FIS is "sortie duration." Our average sortie is about 80% longer than one in a standard TFS. An average mission up here lasts about 1.9 hours – state-side is about 1.26 for a TFS, 1.5 for a FIS. So we fly fewer sorties but many more hours than most comparable units. And time in the air is what burns up turbines, what burns up avionics.

Our average active air mission is almost five hours – at night, in weather, daytime, you name it. During a recent combat sortie surge exercise, we had a guy log a 3.3 unrefueled. That's worth saying twice – 3.3 hours unrefueled! Those are things that do not normally happen and are out of the ordinary for your standard fighter unit to do. Our longest active air mission to date is over six hours. That's a long time in the air, considering an average tactical deployment mission – CONUS to Europe – is about 9½ hours. Several times a week, we make four, five, six hour trips to work in the MADIZ – military air defense identification zone – defined for Icelandic military aircraft operations. Those missions will take the Eagle out to an operating radius of 500 miles or so. That's exceptionally demanding on both aircrews and airplanes, and is unique to activities in this small branch of the Air Force.

The "Black Knights" are the only unit that routinely flies the air-to-air mission with CFTs (conformal fuel tanks). These tanks make a significant difference in both the capability and performance of the F-15. The capability improvement is why we've got tanks. They provide lots more low-drag onboard gas – aerodynamically speaking, it's basically internal fuel.

All of our Eagles are equipped with CFTs, and we always fly that way because our nearest alternate is over 700 miles away. We need that gas on board in order to get any kind of productive training missions accomplished. We take off with all this fuel, accomplish the mission, and recover with almost as much gas as I would take off with at Eglin! We'll get back to the fix with around 10,000 pounds of fuel on board and that allows us to shoot the approach, take a look at the weather, decide to come directly on in with all that gas or stay in the pattern, burn down a bit more, and then land. We don't like to land with over about 8,500 pounds on board, especially when the weather is poor and the runway is less than optimum, which it often times is.

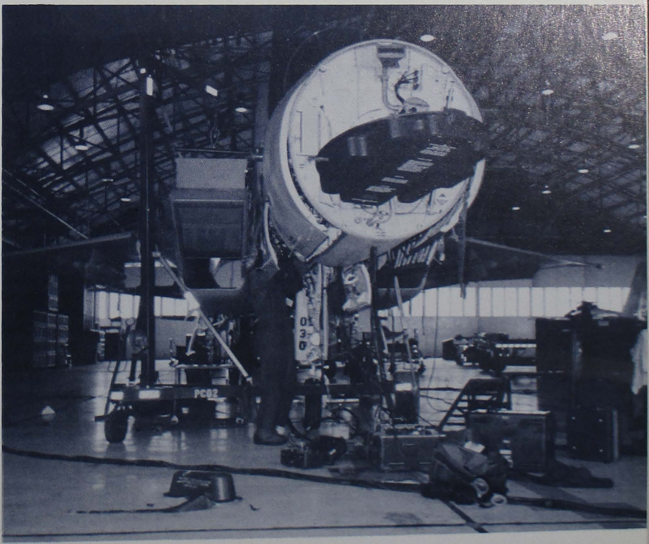
The weather here is probably no worse than at Bitburg or Soesterberg or any of the continental bases in terms of ceiling and visibility, but what we get here are the combined effects – wind, rain, snow, ice, reduced ceiling and viz – and all those things are synergistic. You wind up very often in flying conditions that any one of which wouldn't be uncomfortable, but the combination makes it tough. Up here, flying is done in a region where you want everything going for you that's possible.

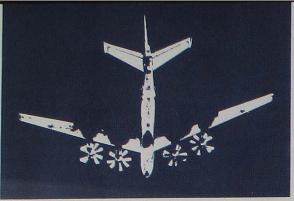
You want lots of gas to get someplace if you need to go there; you want the hook to work; you want the cables up; you want the runway swept; you want the urea down; you want the GCA up; and you want the ILS working. Percentages are not that high to begin with, and every additional decimal point helps. If there is to be a failure in any system, you want the whole thing up front – and that's one of the pluses for the Eagle; it's such a good systems airplane and most everything on board works all of the time.

We have very few hard avionics failures. Something goes out on occasion, but it usually doesn't happen all at once. It degrades gradually, and when it does start to die on you, there is the redundancy of the flight control systems, the hydraulics and everything else to take up the slack. All of these good things let us operate with no alternate, with 800 miles of water on all four sides, and still feel as though we are in a fairly safe environment. Remember, there is no place to land except right here. When you come back with less than 8,000 pounds of gas, you've got two options – you can either land here or hit a tanker. Other than that, there is no place to go.

The threat up here for the 57th FIS is presently a bomber and air-launched cruise missile threat. That may change and we may be relocated, but for the time being we have a defense mission and a basic air sovereignty mission, and both are very amenable to the F-15 configuration currently assigned to us. We are happy with the performance of the CFT-equipped jet in those respects, and it is well suited to the missions here.

Any time you add to the basic weight of an airplane, you are going to suffer a corresponding loss in performance somewhere. CFTs add about 2,500 pounds of structural weight to the Eagle, shift the CG around a bit, and increase starting fuel weight by close to five tons. Naturally the cost shows in initial maneuvering performance. The benefit comes in a tremendous increase in capability in terms of range/payload – how far we can go and what we can do when we get there. That's why CFTs were originally bought, that's how we're ▸





using them, and we are getting magnificient utility out of them in that respect.

Pilots who come to this configuration of the F-15 find the initial difference in terms of maneuvering performance to be striking. I know I have. It is not the plain "A" model by any stretch of the imagination. It is not a clean A; in fact, it's not a clean anything – it's a much more rough handling airplane, much more sensitive than the clean A model. The biggest difference right off the bat is when you have 22, 23,000 pounds internal and an operational overload warning system – the transonic allowable G is very low. We keep very good tabs on our Level I OWS activations, to make sure the guys are aware that when you get into a transonic thumbprint with a heavy jet, it can be over-G'd in a heartbeat. We are very careful of that.

The payoff comes very quickly – as soon as the gas burns down, gross weight is reduced and you've got performance similar to a non-tanked C or D model. It's just a matter of how much the airplane weighs at any given time; initially, the difference is striking, but CFT Eagles overall perform about like any other F-15. Low speed handling characteristics, available G, thrust-to-weight, are all far superior to the F-4. And of course, the weapons systems are way above anything else flying. If nothing else, we could just go 350 miles away, wait for the other guy to run out of gas, and then shoot him in the tail. My only point is that with a jet that can get as heavy as this one, unless a pilot sits down and thinks about it, tries to anticipate it, he can get surprised. And up here, the fewer surprises the better!

MAJOR RONALD R. DUFRESNE
(former) Chief of Training
57th Fighter Interceptor Squadron

What makes flying the F-15 in the 57th so unique is that the squadron has a wartime and a peacetime mission. While most fighter squadrons spend their time in controlled training for their wartime mission, this unit must manage its wartime training around its relentless peacetime air sovereignty mission over Iceland. Couple this with Iceland's dynamic operating environment and the myriad of other defense activities here at the Naval Air Station, and you've got a real challenging and interesting assignment.

Being part of the cadre to convert the unit from F-4s to F-15s was a real privilege. Strategically speaking, equipping the 57th FIS with the F-15C with conformal fuel tanks has made a quantum improvement in the overall US/NATO defense commitment to Iceland and the Greenland/Iceland/United Kingdom (GIUK) gap. I think the CFT/F-15 is the perfect weapons system for this unit's peacetime and wartime missions.

A lot of Eagle drivers may scoff at hanging CFTs on the F-15, but I don't know of a pilot in this unit who hasn't come around to recognizing how much they add to the jet's capabilities – especially here in Iceland. Sure, every guy wishes all he did was fly clean A-models, day, VFR, two v two, VID required – but that's not reality. And true, the CFTs reduce Eagle performance by a few degrees per second or by a few Gs, but a good pilot doesn't employ the airplane such that he depends on those few extra degrees or Gs – if he does he needs to sit down with his squadron Weapons Officer for a little chat about tactics.

Up here, the weather can change in a heartbeat and your nearest alternate is over 700 miles away. I don't know of any other fighter squadron in the Air Force that must gear all of its operations to such a simple fact. The CFTs allow us to get reasonable day-to-day training, yet provide sufficient fuel reserves to deal with Iceland's weather – a major limiting factor. What the CFTs add to the Eagle's capabilities are what's important – especially to us in the 57th FIS.

First, as I've already alluded, is the added endurance. Because we can carry more gas, we get to fly longer and more often than would otherwise be possible up here in Iceland. And as a Training Officer I can say that there is no substitute for flying training – not a simulator, not ground school. The fact is that 57th F-15 pilots are getting twice the flying training that its F-4 pilots were getting – and that's because of the CFTs. 57th FIS pilots are better trained today than they've ever been – and that's a fact, Ivan!

Second, CFTs have added significantly to our ability to conduct our peacetime air sovereignty mission. It used to be that Soviet TU-95 Bears would come meandering around the Icelandic MADIZ, to be greeted by three-tanked Phantoms who could stay with them so long as there was a tanker near by. Now, CFT Eagles meet them, with the gas to keep an eye (and weapons) on the situation as long as Ivan wants (feels safe) to hang around. Personally, during the many intercepts I've been on, I detect a wise sense of respect from the Bear drivers towards the presence of the 57th's F-15s.

Finally, CFTs have added immeasurably towards the execution of our wartime mission. The added endurance they provide equates to added station time in maintaining air superiority CAPs over Iceland – a real force multiplier! I believe the Soviet Icelandic planners have their work cut out for them.

In my opinion, equipping the 57th FIS with the F-15 configured with conformal fuel tanks was a super decision. I'm proud to serve in this outstanding and vital unit. If anyone ever had any doubts about how vital the 57th's mission is, they should read Tom Clancy's books! The Black Knights of the 57th FIS are ready and able – in peace or in war – to provide air superiority in the GIUK gap.

The Story of the Four Bears

"We're sleeping in the barn after having gone out in the afternoon and hacked a couple Bears. The horn goes off in the middle of the night, so the two of us take off into the weather, and after awhile we're night air-refueling out over the Norwegian Sea in the middle of nowhere. A little later we pass the AWACS on its way home because it's been working all night. There goes our 'big picture,' but we know from intelligence that there is traffic out there somewhere, so with plenty of gas onboard we set up our CAP.

"We know where to look generally, but that's all the guidance there is. So we try to locate our own Bears in autonomous long range search. After a little while, sure enough . . . hit! Let's see what we've got here. Looks good. Hold it and go see what it is. Drive up and check it out. He's all blacked out, but it's a hack – another Bear that won't get an unaccompanied tour of Iceland!

"There is still fuel to spare, so after he leaves our zone, we pick up the CAP again. About three hours later, there comes another hit on the radar. What have we here? Go check it out – another Bear! Turns out it was the same one; he had gone way out of the Icelandic MADIZ, and came back in from another direction. So our four-Bear day turns out to be two, plus one twice. Eagles on Bears – not a bad way to make a peacetime living in a peacetime Air Force!

(Major Dufresne)

The 57th FIS...
Bear Hunting

MAJOR RALPH G. AGUIRRE
(former) Assistant Director of Operations
57th Fighter Interceptor Squadron

(Everybody knows me as "Slick" so please don't put my real first name in the article!) I've been flying the F-15 since 1976 and have around 1700 hours in it now. This is the first place I've been where they've used conformal fuel tanks as the standard configuration, but I've gotten so used to the feel of the airplane with CFTs that I never think about them anymore. Except to be glad they're there! But yes, an Eagle with those bulbous appendages not only looks different, it flies different – in part of the regime.

It is necessary to maintain a "heavyweight" fuel awareness not necessary at other places because we are taking off with 24,000 pounds gross fuel weight, every time and all the time. Abort speed with airplanes weighing as much as ours do is pretty low, so when the runways are wet and icy that possibility has to be firmly in your mind. Another aspect is that if you have a problem after getting airborne, you're not going to be able to land right away unless you accept landing very heavy and take the cable.

One night, I took off single ship into an 800 foot ceiling to chase down an element that had left fifteen minutes before, so I was by myself when I got a bleed air light shortly after takeoff. This is the kind of emergency that says get back on the ground ASAP because you have no idea what that bleed air may be doing inside your airplane. However, it was close to 20 minutes before enough fuel had dumped to get me down to a weight comfortable for landing on a wet, slushy runway. So on CFT takeoffs, you always need to be cognizant of weight, and on landings, you would like to have 8,000 pounds of fuel or less.

Then, when you hit the work area – and ours are fairly close, like 50 miles or so – with any other Eagle jet you are good to go for ACT, you're ready to fight even with fuel in the centerline. Not so with CFTs. When we hit the area, there is probably still 3,000 pounds of fuel in each CFT, and we don't fight until it gets below 1,500 in each. We need to do something else for awhile to reduce the weight, so we practice intercepts on the first few passes – typically supersonic intercepts, and we get good training out of it.

There are some other things to watch for that are CFT related. For instance, you've got to check the balance in them because the F-15 doesn't like an imbalance there any more than it does out on the wings. Another example is the heavyweight flying characteristics. One of my first flights here was to try doing some roll slides on a guy, and as I was just rolling up with about 3 Gs on the departure to put my nose on him I was getting the low rate beeper on the OWS. So sure, it's a heavy jet at first and it doesn't fight the same at first. Once the CFTs are empty, it's almost like a vanilla F-15. And without all that fuel, we wouldn't be able to do our job here in Iceland as well. We'd be on the way back to base, or hitting a tanker, or not even out there in the first place. With empty tanks, the airplane doesn't want to accelerate supersonic as well as other Eagles, but as far as turning performance and nose rate go, they seem to be fairly full up for the C model once the tanks are empty. I've certainly got no complaints.

If we didn't have CFTs, we'd be flying around in a three-bag configuration which would limit us in many ways. We couldn't do ACT at all or BFM with those things on our airplanes. So much of what we do is driven by our alert commitment and the tactical situation here. When Soviet activity increases, we may not be flying just the two alert birds; we might have to take four of the training lines and turn them into alert birds and put them out on Bears too. You have to have your fleet configured the way it's going to be employed, which is to chase down Soviet airplanes.

To me, an Eagle is an Eagle is an Eagle. All the models you've manufactured have been great! It's the only jet I want to fly. I've had some catastrophic things happen and it's still brought me home. Once an engine compressor section blew up about 100 miles out over the Atlantic – knocked holes in the top and bottom of the airplane and took out a lot of the hydraulics. It was doing uncommanded aileron rolls and stuff, but that Eagle got me back. I guess I've had three-fourths of the emergencies in Chapter 3, but have landed them all with no sweat.

Out All Night Long

"It's a moonless night and we're in the murk. We drive right up next to him, and can barely see his outline. During the intercept, he's all blacked out, but he knows we're there – he's got a radar warning receiver just like we do. Once we start getting up close of course, he turns the anti-collision beacons on 'cause he's afraid we'll hit him! This close, we feel the vibration of his counter-rotating props.

"During the day, it's really neat too. We fly right next to the Bear because part of our job is taking pictures of them. An F-4 is better as a camera platform because the WSO can take the snapshots while the other guy just flies the airplane. But anyway, sometimes the Russians are not too cooperative with our intelligence-gathering efforts. They'll abruptly start a turn, and you have to drop the camera and grab the stick to get back in position, pick up the camera again – and all the time they're doing the same thing to you. Guys in the blisters on the back of the Bear are waving and taking pictures right back! They are just as interested in us as we are in them, and they must have a really great collection of Eagle photos.

"I haven't done things like this since Vietnam. Like the other day, I was scrambled at 2330, got on four Bears, landed at 0445, had some coffee while the jet was turned, and flew again until 0800. I mean I was out all night long. Great fun, and I really dread the day they make me quit flying Eagles!"

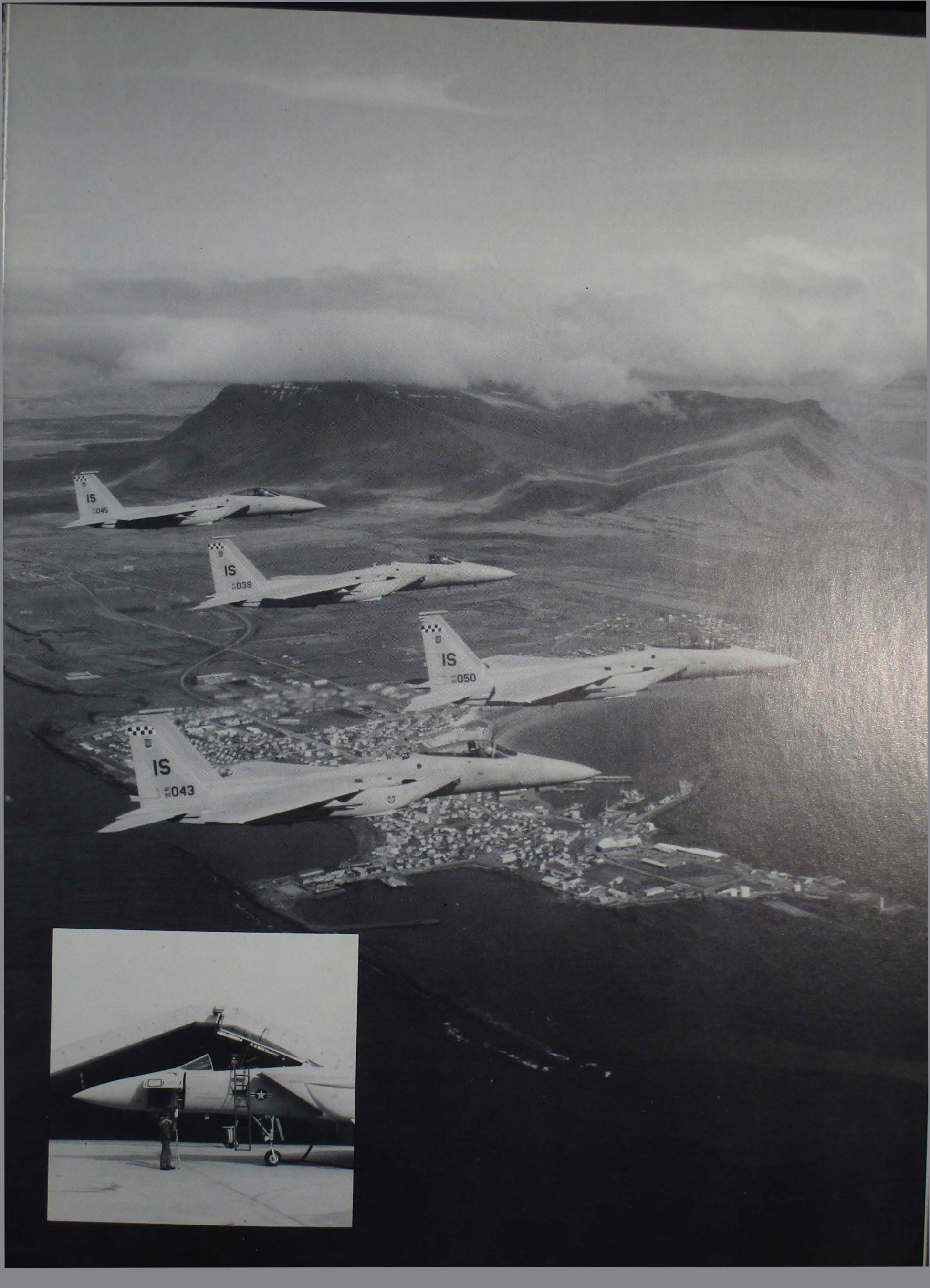
(Major Aguirre)

CAPTAIN ROBERT R. RUDOLPH
(former) 'B' Flight Commander
57th Fighter Interceptor Squadron

Our primary mission up here of course, is intercepting Soviet Bear bombers up by the Arctic Circle. For that mission, the Eagles have been just superb. The configuration we fly is two CFTs with two AIM-7 missiles. No external tanks. That gives us plenty of gas to scramble out of here, afterburner takeoffs, climb to a medium flight level, cruise out to our stop point which may be 300 – 400 miles away, set up a CAP and stay on station for quite some time in the maximum endurance mode, and then recover. You get a lot of cockpit time during scrambles up here. The F-15 has a lot of endurance advantages over the F-4s that were here before.

We always fly in pairs, so add the endurance factor and the two APG-63s, and things just can't get much better than that! Two Eagle radars both looking at the same piece of sky, include GCI and an AWACS, and it's a very capable team, both day and night and in the weather. Not much gets by us.

There certainly could be times when I'd rather have a different Eagle fuel tank ▶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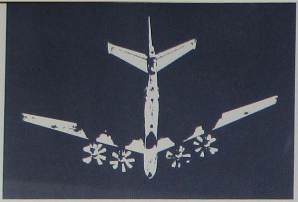


configuration, but not up here and not as the opposition here exists today. We have a rather benign threat as far as maneuvering capability is concerned, and all that extra gas and on-station time is very important.

I also flew the F-15 at Langley, but in an entirely different mission situation – there it was against similar-performing airplanes and in a counterair type mission. Lots of gas was not as important as maneuvering potential, so it was better to have the extra fuel available in jettisonable tanks.

MAJOR ALLEN B. DECKER
Chief of Maintenance
57th Fighter Interceptor Squadron

This is my third F-15 unit and my ninth year of association with the Eagle jet. This mission, this F-15 configuration, and this place present by far the greatest challenges I've experienced thus far in my Air Force career. The mission is absolutely fantastic. Nowhere else in the Air Force can the "alert hype" be felt as often as here. There is often plenty of alert traffic on weekends or in the "wee hours" of the morning. And that means as much to us in maintenance as it does to the ops people.

The adrenaline really flows when our alert lines launch, and especially if additional alert lines must be generated from within our resources or off the daily flying schedule. When the "hype" is over, however, the maintenance phase curve and scheduled maintenance plan are often fractured and we have to pick up the pieces and get back on track. It's often a tough price to pay in terms of work hours, non-mission capable time, and nerves, but the "mission" sets the pace and everything and everybody follows in step.

Our F-15s with conformal fuel tanks also present a tremendous challenge. The 57th FIS has more CFT experience than any other Air Force unit, and that's a source of pride even though we spend a lot of time working with them. The original idea was to just put them up and leave them up, but there are many times we have to remove them to facilitate other maintenance or for repair action on the tanks themselves. There have been a few problems with fuel leaks, fire ducts, and skin cracks, and we've been asked to test some CFT parts to solve some of these problems. We enjoy the opportunity to identify areas for improvement; and as our experience with the system grows we find that the main thing CFTs require is to understand them. Maintenance needs to adjust and adapt to the challenge they present, because there's no doubt that they are a valuable asset to us and worth the effort. Iceland has the perfect mission for an aircraft configured this way, and the F-15 is the perfect aircraft for the mission.

There's no single way to describe working on the F-15 in Iceland. I've been stationed at Bitburg and have been to Bodo, Norway and Aalborg, Denmark with the Eagle, but this is like nowhere else! The combination of wind, wind, and more wind, blowing snow, snow pellets (a big difference when they hit you upside the head), cold, long days, short days, lots of light and no light at all, make this a difficult place to work on aircraft – any aircraft.

With the arrival of the F-15, NATO has provided for hardened shelters, which give some relief from the elements. However, just the simple tasks of towing aircraft, AGE, or CFTs, or just plain walking from one place to another are often burdensome and can sometimes present equipment-damaging or life-threatening situations. Within twenty-four hours of arrival at Keflavik, everybody learns to be weather-wise and cautious. Happily, there is a big surge in facility improvements that will alleviate aircraft maintenance problems up here.

Iceland is a "remote" tour for maintenance personnel, so we come under MPC (military personnel center) at Randolph rather then being directly under TAC. Therefore, selections for assignment are based upon eligibility for overseas tours and the result is that we don't necessarily get a large number of F-15 experienced people. Incoming maintenance personnel are often highly experienced on other aircraft, but their actual time on Eagles is usually low or non-existent. They are also frequently unfamiliar with TAC maintenance or supply concepts. Couple all this with the fact that Iceland is a one-year (soon to be 18 month) unaccompanied tour means that there is a continuously ongoing maintenance training program. People up here have to learn F-15 maintenance by doing it for the first time in the weather, in the dark. That's not easy, and people who complete a tour in Iceland are ready for anything their future may have to offer.

We certainly get productive work from all of our maintenance personnel, but in a fuel systems troubleshooting situation for example, someone with two to four years as an F-15 specialist would have a head start because they've already seen a certain problem many times. They would know pretty quickly whether it's an old, repetitive problem or something brand new. In our case, maintenance specialists often have to go to the troubleshooting tree and work the T.O. word-for-word from the beginning. Nothing wrong with that, of course, but it does take time, and skews into the "maintenance indicators." In light of emphasis upon those indicators, our relative experience level is high on the list of recurring problems we need to solve.

All in all, I'd have to sum up my exposure to maintaining the F-15 in Iceland with "it's been a real experience!" I've learned more about the Eagle, cold-weather maintenance procedures, maintenance people, and myself than at any other time or place in my career. ■

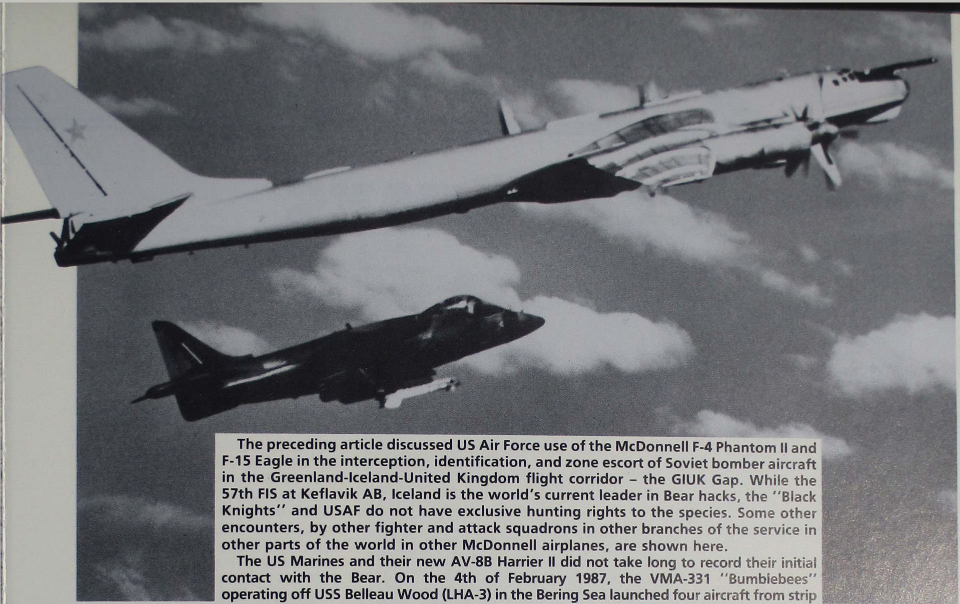
Divert to the Nearest Alternate

It isn't just the 57th Fighter Interceptor Squadron pilots and their Eagles who are affected by the weather in Iceland. Civilian flights also face the possibility of heading for an alternate landing field. For example, last December, MCAIR field service engineer Tom Cline was being transferred from Elmendorf AFB in Alaska to Keflavik, in what might have been termed a "frying pan to the fire" move except that the analogy is totally inappropriate to the climates at both places. While his commercial flight had departed late from the States, it was now back on schedule, and the weapon systems specialist was ready for his official introduction to Iceland. In more ways than one.

As the aircraft arrived over Keflavik International Airport that morning, so did a sudden snowstorm. After circling the area for two hours, the flight was diverted to Scotland, and Tom didn't make it back to Iceland until late that evening. That's the same potential situation faced by every "Black Knight" pilot when taking off in an F-15 for a sortie from Keflavik. Scotland 752 miles away may suddenly and necessarily become the nearest alternate landing field.

Once back in Iceland, Tom said he didn't really mind the diversion – he'd never visited Scotland before. And, in the words of his new boss at Keflavik, field service engineer-in-charge Lonny Duchien, it had been "a truly fantastic day."

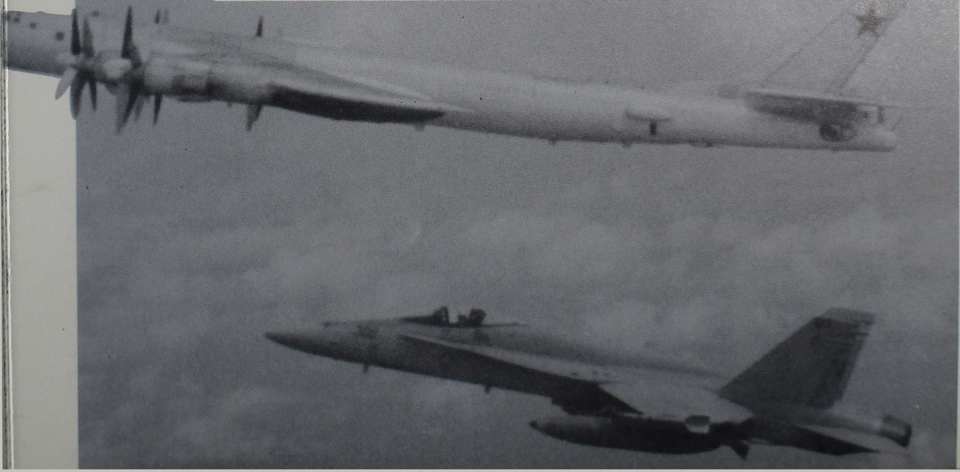
MCAIRPLANES and the BEARS



The preceding article discussed US Air Force use of the McDonnell F-4 Phantom II and F-15 Eagle in the interception, identification, and zone escort of Soviet bomber aircraft in the Greenland-Iceland-United Kingdom flight corridor – the GIUK Gap. While the 57th FIS at Keflavik AB, Iceland is the world's current leader in Bear hacks, the ''Black Knights'' and USAF do not have exclusive hunting rights to the species. Some other encounters, by other fighter and attack squadrons in other branches of the service in other parts of the world in other McDonnell airplanes, are shown here.

The US Marines and their new AV-8B Harrier II did not take long to record their initial contact with the Bear. On the 4th of February 1987, the VMA-331 ''Bumblebees'' operating off USS Belleau Wood (LHA-3) in the Bering Sea launched four aircraft from strip alert status to intercept a TU-95. While the Soviet bomber routinely makes intelligence gathering flights in this part of the world, it was the first such encounter for the AV-8B, and the Harriers quickly joined on the intruder to escort it away from the ship.

The US Navy introduced the F/A-18 to the hunt on 18 March 1985, when two Hornets launched from alert status aboard USS Constellation (CV-64) and intercepted a flight of two TU-95 Bears searching for the battle group in the western Pacific. The ''Stingers'' of VFA-113 and ''Fists'' of VFA-25 joined on the Soviet bombers and escorted them in their unsuccessful attempt to overfly the carrier. This encounter marked the first time a Bear had felt the sting of the Hornet, and occurred during the maiden deployment of the F/A-18.



FUEL LEAKS

By GLEN LARSON/*Senior Experimental Test Pilot*

Fuel leaks in the F-15 are infrequent, but the potential for losing your entire fuel load in just a few minutes does exist. (In fact, not long ago an F-15 flamed out approximately 20 minutes after takeoff because of a massive fuel leak.) While the magnitude of a leak can range from very minor to severe, it usually can be controlled by following checklist procedures. Before getting into causes and corrective actions however, we need to review the basic layout of the fuel system.

Figure 1 is a simplified sketch of the F-15 fuel system. The left side represents the feed tanks and the components on the right side of the diagram lead to the engines, which are just downstream of the fuel flow transmitters. The various components located in the feed tanks aren't of much interest since a leak in that area isn't a threat to your fuel supply. The plumbing, external to the tanks and located in the heat exchanger and engine bays, is the main area of concern. Figure 2 is a photograph of the plumbing from the heat exchanger and airframe mounted shut-off valve to just before the fuel flow transmitter. (Because these components are located in an area that is difficult to photograph, we assembled the various parts on the hangar floor so you could clearly see what the components actually look like.)

The fittings highlighted on Figures 1 and 2 are Wiggins couplings that connect the fuel/oil heat exchanger and the airframe mounted fuel shut-off valves to the plumbing. These couplings are very reliable, but if incorrectly reassembled during maintenance, leaks can result. Your primary indication of a leak is a rapid, unexplained decrease in fuel quantity. Although a better indicator would be fuel streaming from the fuselage, it won't always be visible from the cockpit, and your wingman (if you have one) may not be able to see the fuel vapor at night or in heavy weather. As usual, there's a "gotcha" --failures within the indicator or quantity measuring system may indicate a fuel quantity decrease without actual fuel loss. In most cases, your wingman will be able to confirm the actual presence of a leak; but, single ship, at night, in the weather, you can't tell if it's real or not. Your best bet is to head for the nearest suitable base.

The flight manual contains two emergency procedures to control fuel loss. Which one you use depends on where the fuel is being lost. If it's coming from the wing dump masts, then the procedure for UNCOMMANDED FUEL VENTING (pages 3-22 and 23 in TO 1F-15A-1) is the one to use. This procedure will stop the loss of fuel through the plumbing to the wing masts, which are actually vent (both sides) as well as dump masts (right side only). Fuel loss from both sides indicates a fuel system pressurization or transfer malfunction, and the loss rate will be less than the maximum fuel dump rate of about 900 pounds per minute. This procedure will usually stop fuel loss through the vent/dump masts, whatever the cause, including failure of the dump system to stop when you turn the switch off. Remember that your feed tank fuel (about 2700 pounds) will never be lost through the wing vent/dump masts, even if the dump system can't be shut down for some reason, since fuel in the feed tanks can't be dumped. Fuel loss through the vent/dump masts is at a low enough rate that you should have enough time to sort things out and get to the nearest base or tanker.

Potential for massive fuel loss exists in the plumbing to the engine bays. The fuel lines from the feed tanks to the engines are capable of sustaining flow rates of over 100,000 pounds per hour, which can deplete your entire internal fuel load, including feed tanks, in about eight minutes. Fortunately, loss rates of that magnitude are rare and, while exact rates are difficult to predict, will generally not exceed 20,000 pounds per hour except for a catastrophic failure.

The most likely source of a massive leak in the plumbing is the Wiggins fittings and the loss rate depends on how loose the fitting becomes. Little maintenance is required in these areas except for the fuel/oil heat exchangers, which are often changed as a result of internal wing-fuel imbalances. Some other causes of an imbalance could be a failed wing transfer pump or other components within the fuel system, which are discussed briefly in my accompanying article. Removing and reinstalling the heat exchanger is difficult; if one of the Wiggins fittings is incorrectly reassembled, a massive, uncontrollable leak can result.

The flight manual procedures for IN-FLIGHT FUEL LEAK (page 3-23 in TO 1F-15A-1) recommends *increasing* airspeed to maximize your range. Don't confuse this situation with the traditional concept of slowing down to maximum endurance speed to conserve fuel. The idea here is not fuel conservation – the fuel is running out the bottom of the airplane anyway so you might as well use it to get to the nearest airfield. *And remember the warning which tells you not to use afterburner to get home.* Lighting the afterburner will almost certainly ignite any fuel leaking from the fuselage.

The most difficult part of the procedure is deciding exactly which side of the aircraft is the source of the fuel loss. Referring to Figure 1, if fuel is being lost downstream in the engine plumbing, for example, then the associated fuel flow indicator would show a higher than normal fuel flow. Since the fuel flow transmitters are located downstream of the heat exchangers and because of the relatively high pressure in the lines, the fuel flow indicators won't be much help if the leak is upstream of the transmitters – the readings will be normal.

Engine operation will probably be normal as well. A leak will fill the various cavities in the engine and airframe mounted accessory drive (AMAD) bays, and fuel will vent from panel areas all over the bottom of the airplane. Your wingman may be able to make an educated guess as to which side seems to be leaking so you can shut that engine down with the FIRE button. Keep an eye on the fuel gauge. If the fuel loss rate decreases, great – you picked the correct engine. If not, reset the FIRE button and restart the engine and shut down the other engine with its FIRE button. Remember, even if you get the leak stopped, fuel will continue to run out the bottom of the airplane until all the cavities in the engine and AMAD bays have run dry.

If the fuel loss cannot be stopped by shutting the engine down with the FIRE buttons, it wasn't your day because the most likely source is the fitting upstream of the fuel/oil heat exchanger and airframe mounted shut-off valve. A leak from this fitting will deplete your entire fuel supply since it won't stop when the associated feed tank runs dry. The fuel crossfeed valve in the feed tanks will open and allow the other feed tank to supply its fuel to the open coupling. Testing has determined that the maximum loss rate from the Wiggins coupling upstream of the airframe mounted shut-off valve is approximately 350 pounds per minute. You can't stop this leak, but the remaining steps of the INFLIGHT FUEL LEAK procedure will help reduce the loss rate. Selecting STOP TRANS(FER) may save some fuel from being lost overboard, and resetting the FIRE button and starting the engine will allow you to head to the nearest suitable field as fast as possible without using afterburner.

Finally, get the emergency generator on-line, confirm emergency boost pump pressure, and place both main generator switches OFF, like in the last portion of the UNCOMMANDED FUEL VENTING procedure. This stops the transfer pumps and turns off the main boost pumps. The emergency boost pump can't pump as much fuel as both main boost pumps, which should reduce the loss rate to about 250 pounds per minute if the leak is in the fitting upstream of the heat exchanger.

It is very important to closely monitor the feed tanks. With the generators off, fuel will gravity-transfer into the feed tanks, but not fast enough to keep up with engine demand plus loss rate. To refill the feed tanks, simply turn the generators on and select NORMAL TRANSFER; and it's a good idea to turn the main generators back on for landing.

Maintenance procedures have been revised to help ensure the heat exchanger Wiggins coupling is properly installed each time the heat exchanger is replaced; and starting with F-15C production number 335 and F-15D number 55, the wing fuel recirculation system will utilize the electrically controlled solenoid valves instead of the current failure-prone passive valve. Fleetwide retrofit is awaiting approval.

In the meantime, keep an eye on the fuel gauge; if it begins to decrease rapidly, follow checklist procedures and head for the nearest airfield. ■

FIGURE 1 – LEAK AREAS

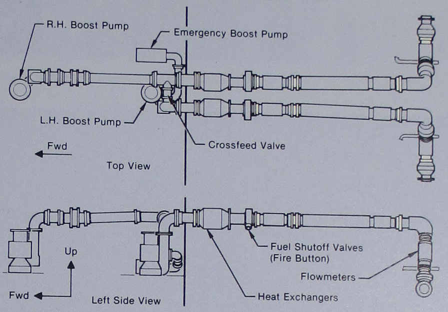
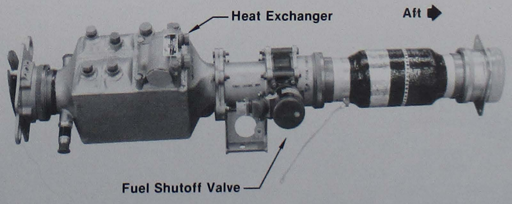


FIGURE 2 – FUEL FLOW PLUMBING



THE EAGLE'S

By **GLEN G. LARSON**/*Manager, Program Development*

BOB WILLIAMS

ENGINES PART I

This is the last of a series of articles based on a "Road Show" Program that was presented to F-15 units worldwide. Each unit was visited at least once, with the objective of briefing every F-15 driver in the world. For the small percentage we missed, articles based on the presentations were published in the Product Support DIGEST starting with Vol. 30, No. 3, 1983, "On the Road (Again)." The presentations and articles were intended to "tell it like it is" in pilot terms. Subjects that were not common knowledge in the Eagle community or controversial issues were picked on purpose. The following article addresses one of those controversial areas – engines. It is divided into two parts: the first is historical in nature based on the "old" engines, and the second part (by Gary Jennings, MCAIR Project Pilot, in an upcoming issue) is based on the latest and greatest engines.

In the early 1980s, pilots began suspecting a thrust loss in their F-15s. This loss, most noticeable at low altitudes and on hot days, was real and had been developing gradually over the years. Top speed was noticeably less than in the past!

But before getting into details, we need some definitions.

- *Thrust level* – Expressed as a percent of thrust. By definition, thrust is expressed as a percent of test information sheet (TIS) thrust and full "spec" thrust is defined as 102% TIS thrust. *All* engines have demonstrated 102% average Mil power thrust during static sea level acceptance testing, which equates to 14,380 lb of thrust. All references to percent thrust in this article will be in percent TIS thrust. Remember: 100% spec thrust is defined as 102% TIS thrust.
- *Engine pressure ratio (EPR)* – This is a key parameter used to define engine thrust. It is the ratio of the pressure in the back of the engine to the pressure at the front. (Airlines use this to set takeoff power.) In the F-15, the actual thrust of the engine during trim runs is determined by measuring the EPR and airflow (approximated by fan speed). There is no reliable cockpit indicator of thrust levels.

Downtrim

From 1974 through 1986, all F-15s were delivered with the F100-PW-100 (or simply -100) afterburning turbofan engines. The F100 engine was at the forefront of technology in its day, combining hydromechanical and electronic controls to produce 23,800 lb of static thrust in afterburner (AB). However, operational experience quickly pinpointed a problem which has plagued the engine throughout its service life: hardware durability which directly affects thrust level.

Engine-hot section components, primarily the high pressure turbine and its stators, showed significant erosion after only 600 engine cycles. (An engine cycle is defined as one trip from cutoff to Mil to cutoff, or three round trips from idle to Mil to idle.) An average F-15 flight puts 2-3 cycles on each engine, and 600 cycles equals about 1.4 years of operation.

As the turbines deteriorated, the engine's efficiency and thrust declined. Meanwhile, depot costs associated with repairing the engines began to soar! USAF program administrators recognized the need to reduce costs and directed that the engines be downtrimmed (lower fan turbine inlet temperature – FTIT – and hence, reduced turbine deterioration).

The initial downtrim plan was to reset all engines to three "clicks" of fan turbine inlet temperature trim. In some cases, this caused up to 10% loss in thrust! (FTIT is adjusted on the electronic engine control – EEC – through an allen head screw that clicks as it turns. Each "click" is worth about 6° C of engine limited FTIT which equates to roughly 1% Mil power thrust.) The final downtrim plan, implemented in the late seventies, was to set all engines to no less than five clicks of FTIT trim.

Every F100 engine since day one has demonstrated at least 100% (102% average) Mil power thrust during acceptance testing, however, new engines were adjusted to a five click trim setting before delivery, which resulted in thrust levels of 99-104% TIS thrust. During acceptance testing, thrust is measured with the engine in a test stand that is instrumented with strain gauges to provide a direct measure of thrust. The next best way to measure thrust is by using airflow and EPR. It is important to remember that FTIT is *not* a good measure of thrust.

Unfortunately, there are no instruments available to the pilot in the F-15 that provide an indication of thrust level. A new engine running at 900° in Mil power can produce more power than an engine due for overhaul running at 940°. A logical question is why not set the engines at 102% TIS thrust (100% of spec thrust) all the time? The answer is simple: The need to prolong engine life, increase engine availability, and reduce costs.

Thrust Levels

Thrust level is determined by the trim setting, which is set by maintenance during ground runs. (The newer digital electronic engine controls don't have a trim requirement. These devices are discussed in the second part of this article.) During trim runs, maintenance calculates the engine thrust level and adjusts the EEC by setting "clicks" of trim to adjust the thrust level. Unfortunately, there are no mandatory periodic thrust checks once the airplane leaves the factory. The engines are retrimmed (thrust checked) only after a major component, such as EEC or unified fuel control (UFC), is replaced or if the pilot writes up the plane for low thrust, an AB problem, etc. Using the current technical order "tune up" procedure, the engines are guaranteed to produce only 95% TIS thrust. The estimated field average trim is currently about 97% TIS, however, in the early '80s there were cases where engines produced as low as 90% TIS thrust.

Trim procedures have been changed several times over the years. Old heads may remember trim procedures that utilized mysterious things called "false EPRs" or "the saw-tooth EPR problem." Those problems have been addressed in the current technical order trim procedure, which fully provides a reasonably true measure of thrust.

Operational Effects

Thrust levels directly impact sustained turn performance, time to accelerate, and top speed. All of these are important in various ►

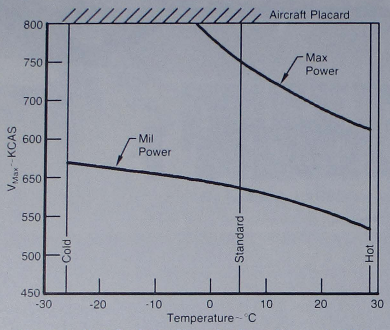


Figure 1. New Engines (Clean Configuration) – 5,000 ft

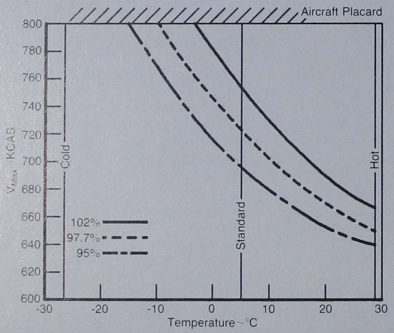


Figure 2. Maximum Power (Clean Configuration) – 5,000 ft

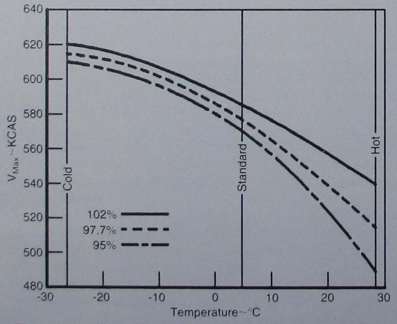


Figure 3. Military Power (Clean Configuration) – 5,000 ft

phases of air combat, but the impact on sustained G levels is relatively small when compared to factors such as weight and configuration. Therefore, the following discussion addresses only top speed and time to accelerate at three thrust levels in various configurations and at different ambient temperatures.

Figure 1 shows the top speed attainable in the clean configuration at 5,000 ft mean sea level (MSL). The vertical axis on this and all other charts represents V_{Max}, which is defined as the speed at which the aircraft is accelerating at 1 kt/sec. This acceleration level was chosen somewhat arbitrarily and is intended to realistically represent the point where the pilot perceives that the aircraft is no longer accelerating. (For flight test programs, airplanes are usually instrumented with a flight path accelerometer which very accurately measures when a true V_{Max} or the point of zero acceleration is reached.) The horizontal axis is the ambient temperature *at altitude*, and the curves are for Max AB and Mil power with new (102% TIS thrust) engines.

Figure 2 is at Max power, but with different trim levels. From the two charts, it is apparent that the top speed attainable can be as low as 640 kt or as high as 800 kt. These two charts illustrate quite clearly the effect of temperature and trim levels. As is the case with all jet engines, ambient temperature will impact performance. Turbofan engines, such as the F100 engine, are more susceptible to high ambient temperatures than pure turbojets such as the J79 in the F-4 Phantom.

Figure 3 is similar to Figure 2, but it is for Mil power and shows that the speed will range from 620 kt on a cold day with new engines to 490 kt on a hot day with 95% TIS thrust engines. It is interesting to note that ambient temperature seems to have less impact in Mil than in Max. The reason isn't really engine related. As an aircraft accelerates toward Mach 1.0, it encounters a phenomenon known as the transonic drag rise in the .85-1.2 Mach area. The speeds in Mil power are at the leading edge of this phenomenon and there isn't enough thrust to get past the drag increase.

Recognizing that few, if any, training flights are ever flown in a truly clean configuration (no pylons), Figures 4 and 5 illustrate the effect of a normal training configuration consisting of centerline tank, two wing pylons with two adaptors, and one AIM-9 training missile. In Max power, the aircraft will reach the tank limit on a standard day, but as the temperature increases, the top speed drops to about 615 kt in Max power and as low as 450 kt in Mil power on a hot day, as shown in Figure 5.

The story isn't complete without the same diagrams at higher altitudes. Figure 6 shows what to expect at 30,000 ft in Max power. In this case, a Mach scale has been added for a "standard" day. (The Mach will change slightly as temperatures change, but for the purposes of this discussion, it's close enough.) For comparison purposes, both configurations are shown in Figure 6 and the speeds can vary from a maximum of the airframe limit on a cold day to as slow as 500 kt on a hot day with a lot of drag and 95% TIS thrust engines.

Top speeds don't tell the complete story. The time required to accelerate to V_{Max} is important but is not easily measured by the pilot. To keep things "real world," Figure 7 shows the times needed to accelerate from 300 to 600 KCAS at Max power. This speed range was chosen for no other reason than it is representative of the speed ranges encountered in day-to-day training. Straight and level was chosen as the flight condition to reduce the number of variables. However, straight and level isn't always the best way to do a minumin time acceleration with the F-15. (For a discussion of this, see the DIGEST, Vol. 31, No. 2, 1984, for an article, "Angle-of-Attack and Turn Perfomance.") It's easy to check these times yourself.

Stabilize at 300 kt straight and level. Light the burners rapidly and as soon as stage five lights, start your clock. Stop the clock when you reach 600 kt (watch for Mach 1.0!). The results will give you a *rough* estimate of your engine thrust levels.

Performance in the air combat arena is always an emotional

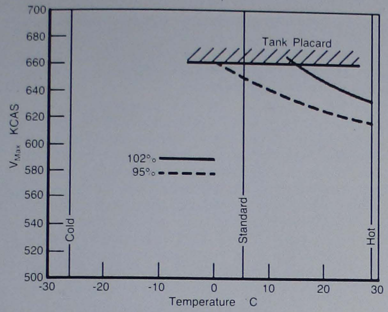


Figure 4. Maximum Power (Training Configuration) – 5,000 ft

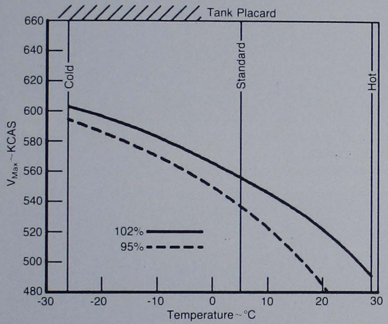


Figure 5. Military Power (Training Configuration) – 5,000 ft

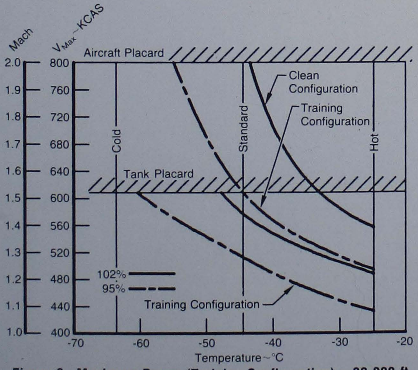


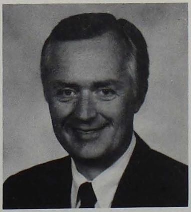
Figure 6. Maximum Power (Training Configuration) – 30,000 ft

Acceleration Times – 300-600 KCAS

	Clean Configuration		Training Configuration	
Engine Trim	Std Day	Hot Day	Std Day	Hot Day
102%	17 sec	25 sec	19 sec	29 sec
97.7%	19 sec	28 sec	21 sec	34 sec
95%	20 sec	31 sec	24 sec	39 sec

Figure 7. Max Power – 5,000 ft

issue; in this article we have addressed a small but important part of the big picture. Although the discussion was mainly historical, all the concepts apply today. The difference lies in the fact that the engines have evolved to the point where thrust loss problems are minimized. In addition, maintainability and reliability have improved and operational problems with engine stalls have become the exception rather than the norm. The next article (Part II) will discuss in detail the performance gains of the newer version of the engine and will explain some of the changes designed to increase its reliability. ■



Glen Larson has been with McDonnell Aircraft Company as a test pilot and marketing manager since 1979. His academic background includes a BS in Aeronautical Engineering from the University of Wyoming and a Master's degree in Business from the University of Utah. During his flying career, he logged over 4,000 hours in military and contractor flight operations. While assigned to the 8th Tactical Fighter Wing, he flew 220 combat missions in the F-4 Phantom. He is a member of the American Institute of Aeronautics and Astronautics and the Society of Experimental Test Pilots.

Author's Note: *Each article in this series has been the result of the efforts of several members of the MCAIR team. This article is no exception. The subject of engines required more intensive effort than most. Special thanks is due to John Housley, Unit Chief, Technology, for his patient review of multiple drafts; Tom Patten, formerly Section Chief, Technology, and currently A-12 MCAIR/General Dynamics-FW Representative at General Electric, West Lynn, Massachusetts, who was the major contributor to the original briefing; Maynard Jones, Lead Engineer, Technology, who did the performance comparisons; and to Mel Goode of Pratt & Whitney who reviewed multiple drafts of the original briefing and subsequent articles. My thanks also to the F-15 team at MCAIR whose efforts have made articles such as this possible and, in a greater sense, made the Eagle what it is today – the finest fighter in the world!*

OWS Overloads *vs* Wing Buffet

By GARY L. GRABER/*Section Chief, Technology*
F-15 Structural Dynamics & Loads
and
RONALD A. MELLIERE/*Branch Chief, Technology*
F-15 Structural Development

Many Eagles are spending time in the shop for repair of outer wing upper surface cracks. There have been questions concerning the cause of these cracks and subsequent suggestions on what should be done to prevent cracking. There are two theories as to the cause: more frequent static overloads – overload warning system Severity Code 1 – and wing buffet.

First, a word about the overload warning system (OWS) overloads. This system was developed to minimize the occurrence of structural overloads that resulted in structural damage to the aircraft. Every Eagle driver knows that he has a 7.33 G machine symmetrically at basic flight design weight (37,400 pounds). But not every driver remembers during "the heat of battle" that he may have only a 5.5 G machine symmetrically or 4.3 G asymmetrically for an established heavier gross weight. The results have been and are continuing to be wrinkled upper inboard wing skins, bent structure and cracks in spars and panels!

When used properly, OWS allows the pilot to aggressively fly the aircraft "to the limits" at all flight conditions, gross weights, and configurations. Displayed Nz allowable (normal load factor) and "Betty" will tell him if he has a 7.33 G or a 4.3 G machine, and stored data in the central computer will tell the maintenance technician if the aircraft experienced an overload. Comments in recent field service reports have indicated that some pilots may be ignoring the OWS:

"The pilot stated that he heard the OWS tones but continued to follow through with his maneuver;" and

"The pilot did not really think he was pulling that many Gs."

These kinds of OWS overloads can and must be eliminated. The OWS must be used properly to be effective.

Let's look at the F-15 wing design fatigue load spectrum. Presented in Figure 1 is the design curve for exceedance per 1,000 flight hours vs percent design limit load (DLL) on the wing; in other words, the number of times the structure was designed to experience loads at or above that particular level in 1,000 flight hours. This curve represents what the structure was originally designed to do and it was based on predicted aircraft usage criteria established during the initial design phase. It is important to note that we are talking about repeated occurrences of static maneuver loads on the primary load carrying structure. Note the logarithmic increase in the number of exceedances as the percent of DLL decreases.

"The pilot heard the OWS tones but *continued* to follow through with his maneuver."

A comparision between the design fatigue load spectrum and how the Eagles are actually being flown is reflected in Figure 1. The actual curve represents what the structure on the average fleet aircraft is experiencing. This data was derived from information collected by the signal data recorder system onboard the aircraft. As shown in Figure 1, the actual usage is much more severe than the design had predicted.

The F-15 Eagle was designed for one exceedance of 100% DLL (OWS Severity Code 1 overload) per 1,000 flight hours as compared to the 60 exceedances they are experiencing. Because of the logarithmic increase previously mentioned, this becomes even more pronounced at the lower load levels – Eagles are presently experiencing approximately 1,400 more exceedances of 80% DLL than the design called for. Decreasing or eliminating OWS Severity Code 1 will have a significant impact on the overall fatigue life of the structure provided there is a corresponding decrease in the number of occurrences at the lower load levels. It will also reduce the over-G inspection burden and maintenance associated with inner wing damage – wrinkled skins.

By analysis it has been estimated that the actual fleet usage is accumulating fatigue damage at approximately four times what was called for in the design of the tension critical lower surface structure of the wing. However, the upper surface of the outer wing (where the cracks are occurring) is primarily loaded in compression for the high-G maneuvers discussed above. In general, compression loads will not cause fatigue cracking in the locations experienced by the fleet. The Eagles are simply being flown more aggressively than was predicted in the design phase. Although the more severe loading spectrum does reduce the fatigue life of the aircraft, it is not directly causing the current outer wing cracks.

Now that we know everything we care to about static overloads and predicted vs actual usage, let's look at wing buffet, which is caused by flow separation over the upper surface of the wing. The flow separation typically starts at the wing tip (sometimes referred to as tip stall) and moves inboard. This phenomenon is dependent on Mach number, dynamic pressure, and angle-of-attack (AOA). The separated flow creates turbulence which excites the wing structure.

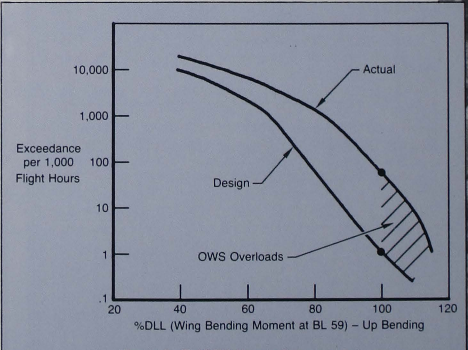
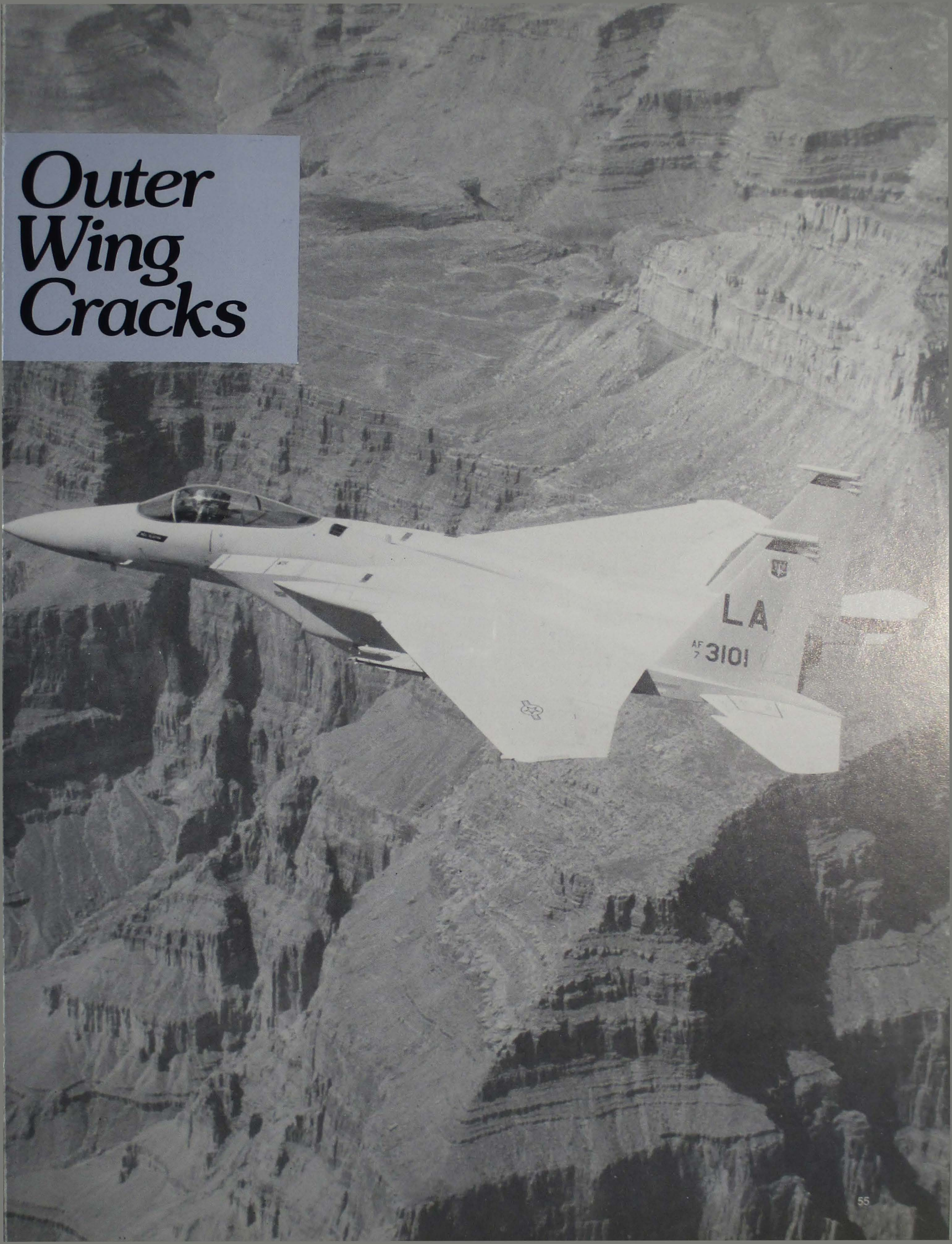


Figure 1. F-15A/B Usage Comparison

Overall wing vibratory modes as well as local panel modes are excited at their natural frequencies. Moderate to heavy wing buffet occurs between Mach .75-.95 at 8-15° AOA, with the highest buffet levels occurring at Mach .9 at 12° AOA. Buffet intensity is proportional to the dynamic pressure at a given AOA and Mach number. Figure 2 shows a time history of flight-measured wing tip acceleration, AOA, and normal load factor ▸

BOB WILLIAMS

Outer Wing Cracks



during a 9 G pull-up at Mach .8 at 20,000 ft.

Wing bending moment at two locations, along with AOA for the same maneuver, are shown in Figure 3. Wing tip acceleration can be related to local panel response, whereas the wing bending moment can be related to the response of the major load carrying structure. The relationship between wing bending moment and wing tip acceleration indicates that the local panel modes are being excited more than the overall wing modes. Wing midspan acceleration, not shown here, has similar response characteristics as tip acceleration, but with lower levels. Similarly, outboard wing bending moment shows larger relative oscillations than inboard wing bending moment. As one would predict, this indicates that the largest displacements and strains occur locally toward the wing tip and not on the major load carrying structure. This is further evidenced by the locations of the actual outer wing cracks.

> "The pilot did not really think he was pulling *that* many Gs."

As shown in Figures 2 and 3, buffet onset occurs around 8° AOA. It's important to note that wing bending moment starts to level off or actually decrease with an increasing load factor and AOA. This is partially due to Mach bleed (and corresponding loss of dynamic pressure) at the higher load factors, but it is also due to the separated flow at the tip (tip stall). This latter effect is shown in Figure 4 by the more pronounced effect at the outboard wing bending moment than inboard. One should also note that even though this is a 9 G maneuver, the wing bending moments are below 100% DLL. This is typical of the majority of the flight envelope where wing buffet can occur. There is a narrow band of the flight envelope where wing buffet can occur at 100% DLL as shown in Figure 4. However, the vast majority of wing buffet occurs at wing loads below 100% DLL.

One area of concern that is going to need further study is the interaction between "buffet" induced damage and the reduction in allowable static wing load. This is called residual strength analysis and describes the reduction in load capability of a structure when known damage exists, such as outer wing skin and/or rib cracks. It is because of this that the F-15 is placed in a periodic inspection program for outer wing damage with intervals of 25-100 hours based on the extent of the damage found. This provides a "safety net" to ensure that the damage does not grow beyond allowable limits. Engineering analyses are underway to better understand this problem.

Now that we have discussed one potential problem (more severe usage) and one existing problem (wing buffet), a word about what we are doing to solve them. The effect of the increased severity of actual usage on the safety-of-flight critical tension structure, including the increased frequency of OWS Severity Code 1, is currently being evaluated in a full-scale fatigue test of an F-15A and F-15C wing at Wright Patterson Air Force Base (AFWAL – Air Force Wright Aeronautical Labs). This test will determine where the fatigue-critical areas are and when they will be showing up in service. Test results will be correlated with service failures for test spectrum validation. After the tests are complete, the force-wide inspection program will be adjusted to monitor those areas. This is designed to locate the primary safety-of-flight structure which will first develop cracks due to repeated maneuver loads.

To solve the existing problem of outer wing upper surface cracks, we will conduct a flight test program in early 1990 to measure local wing panel strains and accelerations during buffet. This data will be used to validate a detailed finite element model of the wing. This validated model, along with all the ground/flight test results and the new usage data, will be used to define design changes required to eliminate the problem. ■

Editor's Note: ***The DIGEST has printed several articles on the various aspects of OWS. For additional information on OWS, see the Product Support DIGEST reprint PS 1321. If you don't have a copy available, contact your MCAIR field service engineer or the DIGEST (see address on inside front cover).***

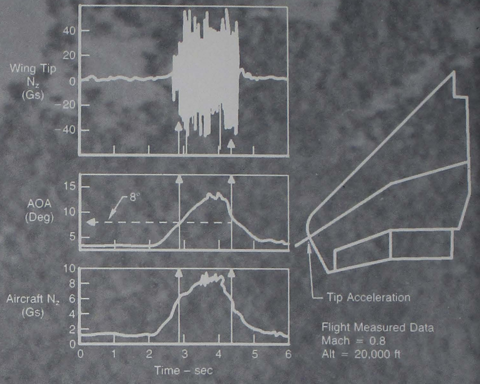
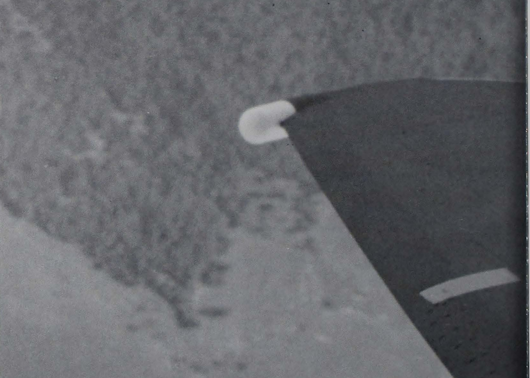
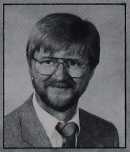
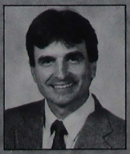


Figure 2. Outer Wing Buffet Response





Gary Graber joined McDonnell Douglas Corporation in the Loads Department at MCAIR in 1969 after receiving his BS degree in aerospace engineering from the University of Kansas. He has worked in loads on the F-4, Space Shuttle, F-15, and S/MTD projects and is currently on the F-15 project in charge of structural dynamics and loads. Gary's duties include the development of the OWS algorithms, and he is the engineering coordinator for F-15A/B/C/D/E placards/operating restrictions.



Ron Melliere joined McDonnell Douglas Corporation in 1969. He received his PhD in mechanical engineering from the University of Missouri at Rolla in 1970. After four years at McDonnell Douglas Missile Systems Company in Advanced Structural Technology and Harpoon Strength. Ron has spent the last 15 years in the F-15 Strength Group where he is currently in charge of structural development. His duties include responsibility for all fatigue and fracture mechanics activities on the Eagle.

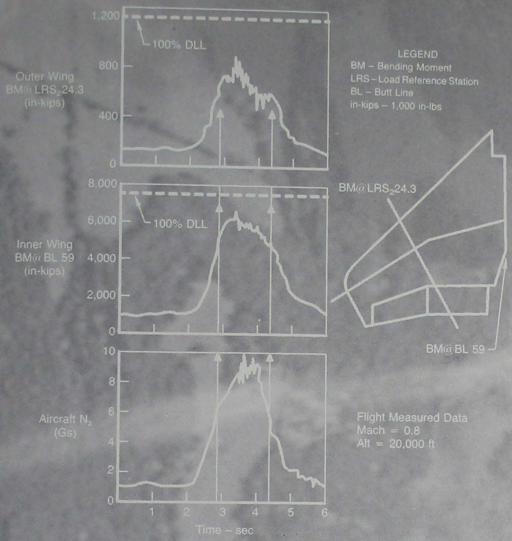
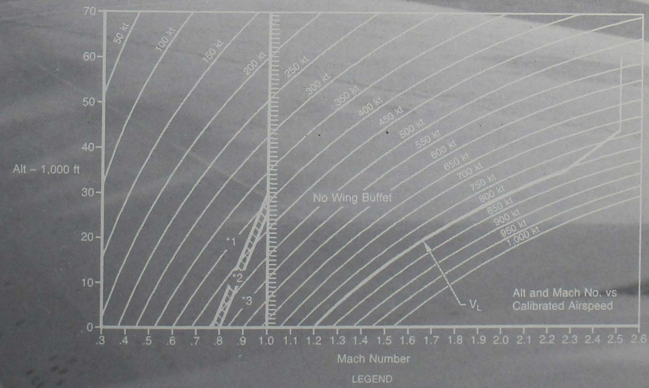


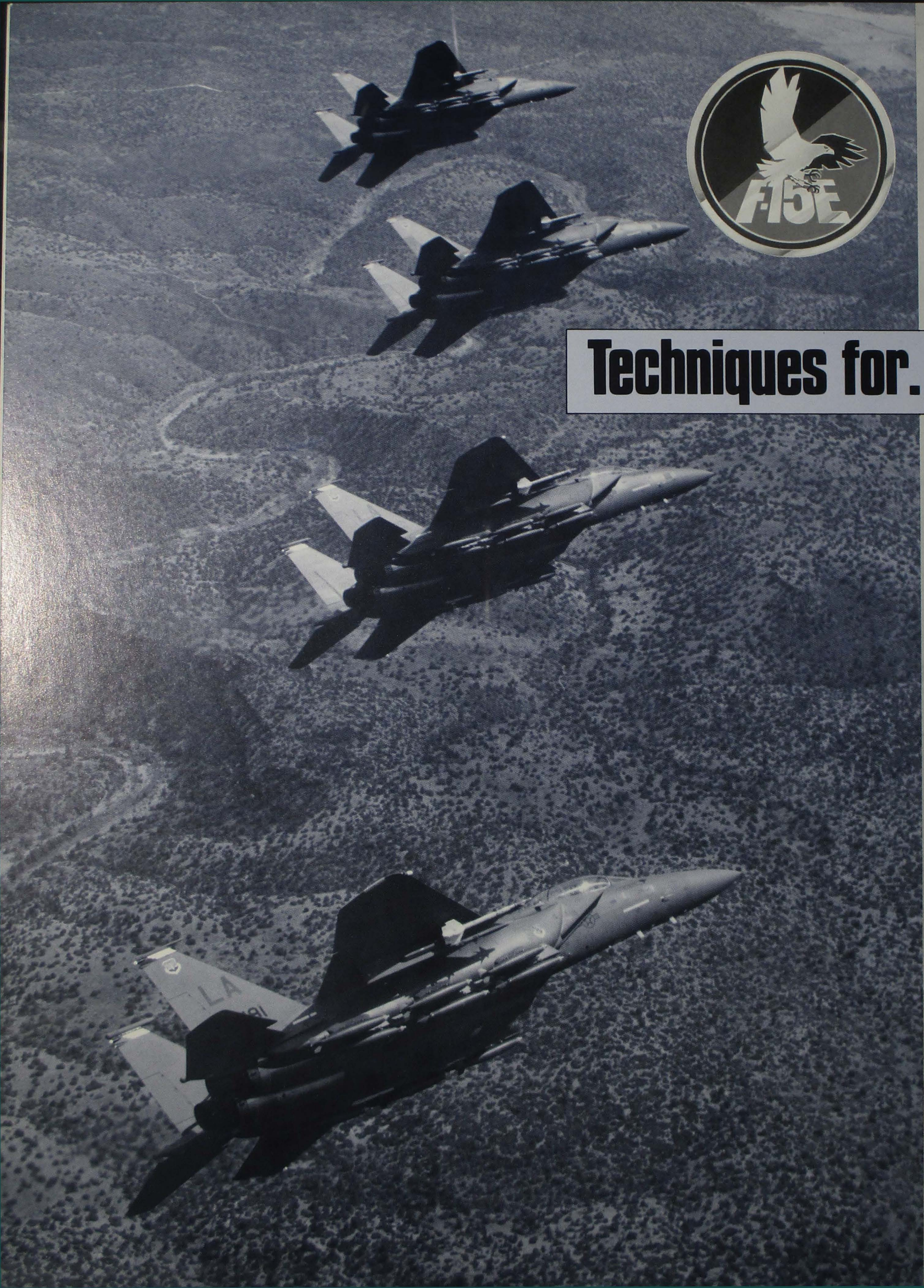
Figure 3. Outer vs Inner Wing Buffet Response



LEGEND

*1 – Buffet occurs below 100% Wing DLL (100% DLL occurs above 15° AOA)
*2 – Buffet occurs at 100% Wing DLL (100% DLL occurs between 8-15° AOA)
*3 – Buffet occurs above 100% Wing DLL (100% DLL occurs below 8° AOA)

Figure 4. Wing Buffet Characteristics – Relationship of Wing Buffet & 100% Wing DLL



Techniques for...

Radar Bombing

F-15E STYLE

By **JOHN YORK**/*Senior Systems Operator*
and
DAVE PLITT/*Unit Chief, Electronics*

The F-15E Eagle, with its state-of-the-art AN/APG-70 High Resolution Map (HRM) radar, presents a major improvement in radar bombing. The new technology used in the HRM radar requires the operator to change several of his techniques to accomplish the best radar bomb scores. In earlier generation aircraft, the weapon system operator (WSO) in an F-111 or a bombardier/navigator (B/N) in an A-6 would get his best results by concentrating on careful radar scope tuning and precise cursor placement all the way up to weapon release. In the F-15E that has changed because scope tuning is mostly automatic. The best results are achieved by using the radar to refine the inertial navigation system (INS) velocities before the bomb run starts, and by making the HRM map where the radar is most accurate and the target is identifiable.

Understanding the radar designation process is necessary to be able to obtain the best bomb results. We have broken the task down into two requirements: achieving accurate high resolution maps that minimize bombing error, and constructing good quality maps that aid in target recognition.

Improving HRM Accuracy

The HRM mode provides impressive mapping capabilities, an example of which is shown in Figure 1. But, it is important to note that improper techniques can result in maps that, while looking impressive, can induce errors into a weapon delivery. The accuracy of the HRM mode is highly dependent on the quality of the velocity information that is provided to the radar.

Bad velocities will affect the bomb scores in two ways: map designation error, and navigation error. Map designation error will cause the entire HRM patch map to be shifted left or right in azimuth from where it should be (relative to the map line-of-sight at the time of map construction). This, in turn, causes the target designation to be off to the left or right, as shown in Figure 3. Navigation error will cause the designation to drift off the target ▶

> **Improper techniques can result in maps that, while looking impressive, can induce errors into a weapon delivery.**

Figure 1. High Resolution Map Video

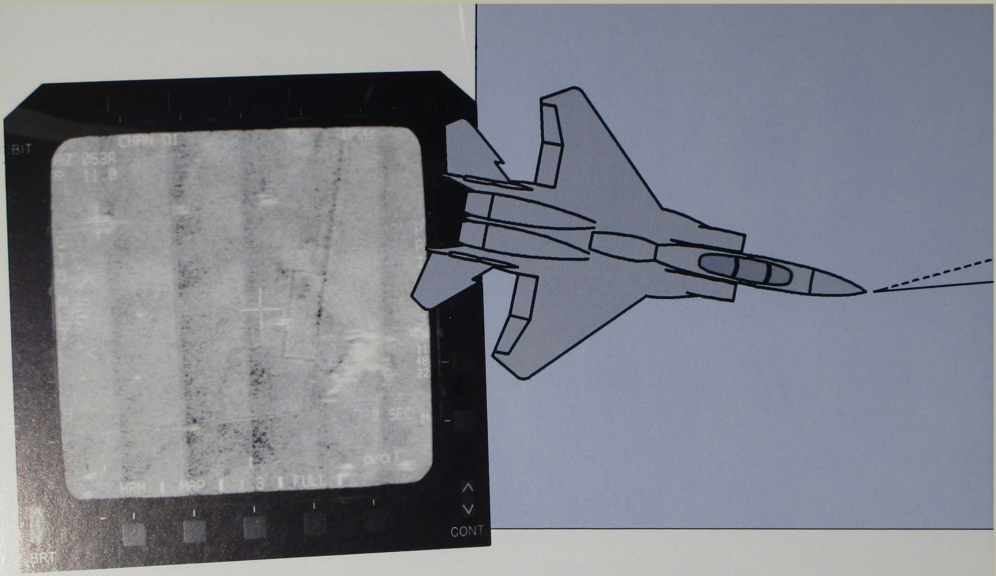


Figure 2. HRM with Array Shading

as the aircraft flies to the weapon release point. The longer the navigation time, the greater the drift that occurs. Both of these errors are reduced by using the radar's precision velocity update (PVU) mode to achieve accurate velocities before making the HRM patch map.

The PVU mode is used to improve the accuracy of HRM designations. But the PVU mode itself can be made more accurate. Any misalignments between the INS unit and the radar antenna will cause the PVU mode to incorrectly calculate velocity. While mechanical boresight techniques identify large misalignments, small errors still exist. Were these errors not compensated for, velocity errors would be induced whenever the PVU mode was used to update the mission navigator (MN). The technique that compensates for these pointing errors is the INS PVU procedure. While updating the INS velocity, estimates of any pointing errors are formed. Once this procedure has been performed, it need not be rerun unless the aircraft configuration is changed (antenna or INS removed or the central computer reloaded).

Updating the INS velocities with the PVU mode is different from updating the MN velocities, or from updating the INS or MN position. In those cases (MN PVU or position update), the update occurs *all at once.* Whereas the INS PVU velocity update is an ongoing process initiated by the operator, it will continue until manually stopped. In theory, the longer the update process continues, the more accurate the update. In practice, 3-6 minute updates will suffice.

In order for all the pointing errors to be identified, the heading, attitude, and velocity of the aircraft should be changed during the update. An update performed during continuous straight and level flight at a constant speed would have no chance to identify the system pointing errors and should therefore be avoided. While there is no *perfect* update profile, one that contains 90-180° heading changes, some combination of climbs, dives, accels, and decels, as well as periods of straight and level flight, will work best. Keep in mind that the PVU mode performs best during maneuvers under three Gs.

Now that the pointing errors have been minimized, we are ready to use the PVU mode to improve our HRM accuracy by updating the MN velocity. Since an MN PVU is a *snapshot* correction, it gets stale with age due to INS velocity drift. For the best results, the MN PVU should be performed just prior to building the map used for target designation.

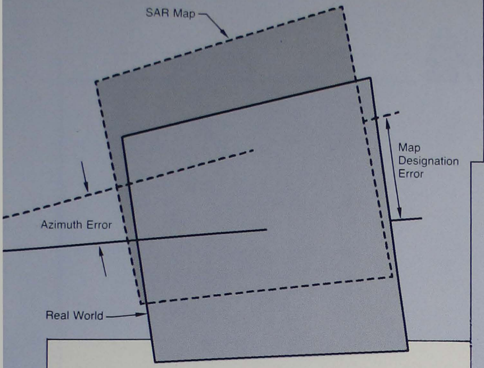
One visible mapping effect that is often seen is termed *array shading.* This is where the individual vertical strips (arrays) that make up the map become dark on one side, giving the map a striped appearance, as shown in Figure 2. This is a direct indication of how much velocity error the radar is seeing. Designating on a map with array shading usually means a poor bomb score. If you see array shading and haven't done an MN PVU recently, do one before constructing any map that requires accurate designation. If you see array shading after doing MN PVU updates, it probably means those pointing errors are not being removed – time to do that INS PVU.

The WSO can further improve his bomb scores by using the HRM radar where it works best. Although the PVU will reduce the velocity errors, it isn't perfect. The effect of any residual velocity error can be minimized by following some simple rules:

- Use the smallest display window possible;
- Map at high ground speed;
- Map at short range; and
- Avoid small squint angles.

Whenever you cut the map construction range in half, you also cut radar designation and navigation errors in half. The bomb score from a map made at 5 mi should be about twice as good as one at 10 mi (ignoring altitude and ballistic error effects). Aircraft speed also works the same: the bomb score from a map made at 500 kt should be about twice as good as one at 250 kt. Of course, most crews usually don't fly at 250 kt in the target area.

The squint angle (the angle off the aircraft's nose) is the most important factor for radar bombing accuracy that the operator can control. Radar map designation error is much worse near the blind zone/velocity vector. Turning the aircraft to perform mapping at 30-45° off the nose will decrease the designation



error by 70-80% over maps made at 10°, as shown in Figure 4. As a bonus, the map will take less time to construct at larger squint angles. If you can do nothing else, make your HRM patch map at as large a squint angle as possible.

High Resolution Map Quality

The quality of the HRM video can vary with changes in grazing angle (the elevation angle below the horizon) or the level of aircraft maneuvers. While HRM accuracy is not affected by reduced map quality, the ability to find the target can be destroyed. The operator can control the environment in which the HRM construction occurs so as to achieve usable map video.

The first step in getting a useful HRM map to work from is to reliably map the desired area the first time. Start by having the appropriate sequence point (SP) displayed beneath PB 17 on the A/G radar display format, and having an accurate terrain altitude for the SP. The radar determines its elevation coverage by using the stored terrain altitude of whichever SP is below PB 17. Without the correct SP number displayed, the radar could cause maps where either the top or bottom fades into black.

Consistently mapping the target area on the first map also requires keeping the MN position updated. By keeping the MN position accurate, you will be able to begin mapping with smaller patch map sizes without fear that the target won't be on the map. This also aids target recognition, since the target will more often be near the center of the map. Remember that if you use HRM patch maps to update the MN position, all the techniques discussed in this article should be followed to keep the update accurate.

The optimum grazing angle for the best quality HRM video is between 2-10°. As the grazing angle is reduced below 1°, terrain masking will increase and vertical targets will dominate the map scene. The result is impaired target recognition. Unfortunately, low grazing angle maps are common in the low altitude environment of the F-15E. The operator can maximize the grazing angle by a combination of increased altitude and decreased map range. In addition, flight planning becomes essential when low grazing angle mapping is expected so as to identify intervening terrain problems and to pick appropriate target or offset points.

As G-loading and aircraft vibration increases, map defocusing and smearing can occur, hampering target recognition. The best maps will be made when aircraft maneuvers and buffeting are at a minimum.

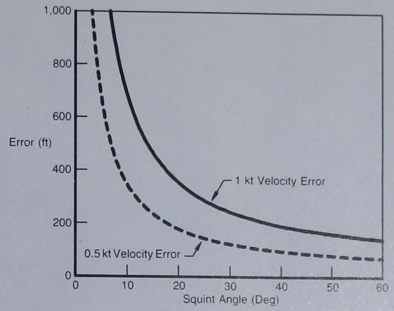


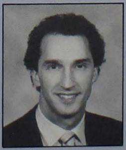
Figure 4. HRM Designation Error – 500 kt, 10 MN

Now let's summarize by walking through a sample HRM weapon delivery:

- Make sure INS PVU has been run for the current aircraft configuration;
- Keep MN position updated (every 5-10 min);
- Select MN PVU just prior to constructing patch map for designation;
- Perform MN PVU with minimal maneuvers;
- Select the proper SP (with proper stored altitude);
- Map at high speed;
- Map at short range;
- Use smallest display window possible;
- Avoid small squint angles;
- Avoid extremely small grazing angles;
- Minimize aircraft maneuvers during map construction;
- Designate the target accurately (use EXPAND if desired); and
- Minimize the time between map construction and weapon release.

Until our continuing discussions in an upcoming issue of the Product Support DIGEST, we would like to leave you with this final thought: HRM radar bombing is a whole new ball game, and when done effectively, the results are *better bomb scores with less workload in the target area.* Following the guidelines listed above, along with a little old-fashioned experience, will reward you with excellent bombing scores. ■

John York graduated with a BS and MS in electrical engineering from the University of Illinois in Champaign. Since joining MCAIR in 1985, John has been involved in several flight test programs on the F-15E, and the F/A-18D Night Attack. He has logged over 2,700 hours in several different fighter aircraft. During his 8 year tour with the USMC, he accumulated 1500 flight hours in the A-6E Intruder as B/N. John is a member of the Society of Electrical and Electronics Engineers (IEEE).



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