SEMPER VIPER!

JOE BILL DRYDEN
Senior Experimental Test Pilot
In Memoriam

One intense guy. That was my impression of Joe Bill Dryden when I first met him in 1988. His text, after five years of working with him as an editor, never altered this impression. His first drafts always had a look of determination, as if he had chiseled them in stone. Joe Bill was one of the lucky few writers who never had to search for his own voice. He seemed to have had one from the start. And that voice was distinct and strong. His was the only work from a technical writer that I’ve ever had to tone down instead of beef up. Joe Bill never resorted to the passive-voice pussyfooting so common in large corporations. He was always direct.

Over the years, I came to understand that his intensity was not driven by fighter-pilot pride (though he arguably had plenty of that). It was driven by a profound concern for his fellow F-16 operators. When Joe Bill used the word you in his articles, everyone knew what he meant – the F-16 pilot. He based his opinions on an objectivity informed by a lifetime of experience in the cockpit. In other words, he had a real feel for the systems and how they worked for those who would have to work them. He never hid an agenda. When he had one, he’d shove it in your face. He wanted F-16 operators to have the most effective and safest equipment that our technology can provide. And he wanted them to use it effectively and safely. To Joe Bill, “Check Six” meant much more than looking behind your back.

Joe Bill Dryden died on 24 May 1993 when his F-16 crashed during a company acceptance flight over north central Texas. He will be missed by many people.

The photograph above was taken in May specifically for this book. The letter from Joe Bill on page 2 was the last writing that he did for a Code One publication. Joe Bill had wanted to do a second Semper Viper book ever since copies of the first one dried up. I’m sure he believed that there would be more Semper Viper collections to come. As it turned out, the last article in this collection was his final article in Code One and a fitting finale for a man who cared so much about those who fly fighter aircraft.

Eric Hehs
Managing Editor, Code One
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*Former staff members.
Dear F-16 Operator (especially you squadron bubbas):

You are holding the second compilation of articles that I have published in the pages of Code One Magazine through the years. I hear that the first one, Semper Viper I, sold out fast and has become somewhat of a collector's item. For those who missed it, all of the articles in the first edition reappear in this book.

As I pointed out in the original Semper Viper, these articles should not necessarily be considered the definitive answer as to how to fly the F-16. However, they do express my approach to flying the airplane. And this approach goes well beyond the theory stage. I've done everything that I've written about here, either in my career in the Air Force or in my more recent activities at General Dynamics, now Lockheed. In other words, what you see here is not something that was relayed to me by someone who has a brother-in-law who knew someone who once flew in a B-24 in World War II.

As airplanes become more complex and more capable, the amount of misinformation seems to grow as well. The majority of it comes from people who wouldn't recognize an F-16 if I taxied one across their desk. This book should shed a little realistic light on the matter.

I'll admit that the margins pilots have to work within have narrowed considerably as compared with those that existed in the forties and fifties. I violently disagree, however, with people who claim that the F-16 is beyond a pilot's physical or mental capabilities. These articles about how the F-16 flies, using the head-up display, facets of disorientation in the weather or at night, night flying in general, G tolerance, and close air support are my attempt to show fighter pilots just where the limits exist and how to operate well and successfully within them. Enjoy.

Cheek Six!

Joe Bier

Joe Bill Dryden
Senior Experimental Test Pilot
Let's get serious about the Electric Jet (or) SEMPER VIPER!

Flight Controls

by Joe Bill Dryden
Experimental Test Pilot
(but still your basic Fighter Pilot!)
General Dynamics/Fort Worth Division

EDITOR'S NOTE: Those who have been associated with the F-16's development will know that "Viper" was one name being proposed for the world's first nine-g fighter. Although it is now officially called the Fighting Falcon, this high-performance airplane will always ("semper") be affectionately known as the Viper to some. Viper is the call sign for F-16's of the 422nd Test and Evaluation Squadron, 57th Fighter Weapon Wing, at Nellis AFB, Utah.

The F-16 is now in the field in real numbers and it is high time that we set to rest some of the rumors concerning just what the F-16 can and cannot do. To fully understand the F-16, the "Dash One" is the first place to start; but after you've thoroughly digested its contents, reading this document will help fill in some of the blank spaces. It is my intent to try to help clean up some grey areas and point out some things you might not have noticed in the time you've been flying the Fighting Falcon.

If you were to try to sum up the F-16 in a single word, you would find it nearly impossible to do so. I keep coming up with four words, all beginning
with "D," that the F-16 is or is not. The F-16 is not difficult, it is not devious, and it is certainly not dangerous. The F-16 is simply DIFFERENT! If you are a student of aviation history (or perhaps a really crusty old Lt.Col.) you will recall that there was a lot of nervous hand wringing going on in the late 1940s and early 1950s as jet-propelled aircraft began replacing the props. The feeling was that the tremendous differences between jet and reciprocating engines would be difficult for the pilots to overcome. Well, these "differences" proved to be minor. Once you've digested what's gone into the F-16, you'll see that there's a larger delta between it and the aircraft that immediately preceded it (the F-15, F-14, F-4, F-8, MiG-21, Mirage III, etc.) than ever existed between the F-80, F-84, F9F, and the P-51, P-47, F4U. Once you can insert this difference in your brain's core memory you'll begin to see why the F-16 does the things it does so well, and why it does NOT do some of the things you may have been asking it to do. In this article, the F-16 flight control system will be discussed. Future articles will feature aerodynamics, the cockpit, and engine characteristics. When we're through, you should have a better understanding of and appreciation for this "mysterious" electric airplane.

The flight control system is from whence came the moniker "electric jet." The flight control system in the F-16 is different (that word again) from anything you've ever flown in an operational fighter.

That is worth repeating...)

"The flight control system in the F-16 is different from anything you've ever flown in an operational fighter!"

How different? In the past, anytime you moved the stick (or, God forbid, the yoke) you got a corresponding movement of the flight control surface (as long as you didn't exceed the hinge-moment limits of the system). Then, depending on airspeed, cg, and/or configuration, you got a varying response. This is NOT the case with the F-16. You only THINK it's you moving the control surface. In fact, the computer positions the control surface to give you the roll rate or g it knows you want, depending on how hard you leaned on the stick. For example, two pounds of pull or push force might move the stabilator two-tenths of an inch at 600 KCAS. That exact same two pounds of force might move the surface six inches at 180 KCAS. And in some cases, two pounds of force will drive the surface all the way to the stop! At either airspeed, the two pounds of force gave you an incremental .6 g.

The only times you have direct control of the surface are (1) when the weight-on-wheels (WOW) switch is closed (i.e., you are sitting on the ground), (2) when you have the manual pitch override (MPO) switch on and push in the nose-down direction, or (3) when the MPO switch is on, the angle of attack is above 29 degrees, and you pull in the nose-up direction. As a result of the computer determining both magnitude AND direction of surface movement, the F-16 gives you a nearly constant response from a constant input across the entire flight envelope. This is only one of the results you'll see with the electronic rate (g) command system.

Since the "black box" is really flying the F-16, we can instruct it not to exceed a given g, a given angle of attack, or a given roll rate. And it will do this with very few exceptions. These exceptions are why you may have heard some of the horror stories about the F-16. But I'm getting ahead of myself.

I've heard the usual reactions: "I don't want any g limiter on my airplane! If I want to pull 10 or even 12 g I don't want to be limited to ONLY 9 g!"

Now, stop and think a minute. While there may be some instances where this is true, they're very rare.
Tell me one other jet in which you’re even ALLOWED to routinely attempt 9 g. I’ll wait while you think.

And while you’re thinking, consider this scenario: We’re both going straight down at 400 knots TAS. You pull out using 10 g, but I pull only nine. You’ll be recovered to level flight about 160 feet sooner than I will. Since there are few (if any) of us humans who are blessed with senses keen enough to allow them to delay that additional 160 feet before they start to pull out (about .2 of a second) the difference between 9 and 10 g quickly becomes academic.

There’s also energy bleed rate to consider. As you continue to increase the angle of attack in search of more g, the increased drag sometimes results in an increased airspeed bleed rate, such that the average g for any given amount of time turns out to be less than if you started with (and maintained) slightly less g at the beginning. If you get deeply into the engineering involved, you’ll find that the present g limit is as close to optimum as you’re going to get with today’s flight control system technology and F-16 aerodynamics. What this “limiter” ensures, then, is max command in, max performance out.

With the F-16’s g limiter, you can snatch symmetrically on the controls without fear of ever overstressing the aircraft. As a result, some of the initial moves you’ve seen the aircraft perform are astounding. In an amazingly short time, you can have more g than the other guy is allowed. And then you can add another g or two over the next few seconds. If you try to match the resultant pitch rate in any other aircraft, you’ll only succeed in destroying the airplane you’re flying. In addition, the angle-of-attack limiter portion of the electronic flight control system will not allow you to pull the aircraft to an angle of attack where you can get in trouble (more on that later). External stores, however, are no different than you’re used to. You must still pay as much attention to the dash-one and dash-thirty-four as you have in the past.

Since fighters have historically done some funny things at elevated angles of attack and elevated roll rates, we can also instruct the computer to limit the available roll rate in certain portions of the envelope. The result is an F-16 that achieves 324 deg/sec maximum roll-rate command within the first 90 degrees — and this is then cut back as the angle of attack goes up or the configuration changes (e.g., the CAT III switch). There’s a series of flight parameters that the flight control system looks at in determining just what roll rate it’s going to allow, but I don’t have time to mention all of them here. (Take my word for it — trying to go completely through the flight control circuit diagrams in their entirety is enough to give anyone religion.)

Now, before someone comes up with what I’ve heard before (i.e., “My T-38 will roll 720 deg/sec.”) let’s set a few things straight. First of all, that is a bogus number. The T-38’s actual maximum roll rate is barely half that value — and even then it only occurs during the third consecutive, full-deflection roll under optimum conditions, and is entirely too fast to be of any operational use. Instead, consider this: the F-16 is as fast to 90 degrees of bank as just about anything you’ll run across; and although there are areas of the envelope where the computer limits the F-16 to less than 100 deg/sec, you still have nearly twice the roll rate available, under similar conditions, as any adversary you’ll meet. From the obvious amazement of every adversary who views the F-16 across the circle for the first time, it’s obvious that this g and AOA “limit” is not a player in any engagement you’ll come across in the foreseeable future. But before we go on to other considerations, there are some other points about this “different” flight control system I should make.

Recall that it’s a rate command system and not a displacement system, like you’ve been accustomed to flying. With a displacement system, we’ve all become accustomed to the different response rates we get as the airspeed changes. Therefore, we’ve become a nation of “samplers” — constantly reassuring ourselves that we still have control over the aircraft we’re flying. We do this on almost a subliminal level, and are not aware of this habit unless someone points it out. As the airspeed decreases on final, we tend to “sample” to ensure that we’ll have enough control left to complete the landing. As we try to fly really close formation, we
tend to sample to ensure in our minds that we've got enough control not to hit lead. And, because all displacement systems have a small "dead band" that we must go through, we again tend to sample to continuously reacquaint ourselves with just where the dead band ends and control begins. With some airplanes, we tend to keep the stick moving in an attempt to reduce the breakout friction to a manageable level. You may not be aware of this sampling phenomenon, but we all do it to some degree.

Now, enter the F-16—with a rate command system that supplies good, constant pitch and roll response so long as the aircraft is physically capable of flying. Further, there is little or no dead band associated with the F-16. Also, since we are not actually "moving" anything mechanical, there is no friction to consider. So the moral of the story is this: If you don't want the F-16 to move, don't move the stick! This is NOT to say that the F-16 is "too sensitive." Quite the contrary, it is simply a tremendously RESPONSIVE airplane. Resist the temptation to sample or you'll get response in spades. Although this seems like a simple request, old habits die hard, so pay attention to how you're flying the F-16. Become aware of just how you're manipulating the stick and your impression of how hard or easy the F-16 is to fly will improve. Remember—if a correction is necessary don't be afraid to move the stick, but if you don't want the F-16 to move, don't move the controls (i.e., don't sample).

It is also very important to realize that this rate command system works both ways. That is, if you move the stick, you get response. But conversely, if the airplane moves and you haven't asked it to, the flight control system will try to damp that motion without any help from you. This system is not too different from some of the stability augmentation systems you've seen in previous airplanes, with the exception that this one has more authority... much more authority than you've ever seen before. THIS black box is occupied by an 800-pound gorilla, not by some of the squirrels you've had in earlier airplanes. You guys who really look into control systems will be able to see bits and pieces of this "rate" command system in other airplanes. The F-111 (GD's "other" airplane) had some aspects of a rate system creeping into the picture. The F-15 and certainly the F-18 share a lot of this design philosophy. However, none go to the lengths the F-16 does in controlling the basic airplane.

One result is the F-16's very good ride at high airspeed and low altitude. As soon as the F-16 is disturbed by any type of turbulence, the flight control system has a correction in, almost before you can think about it. This self-correcting feature is why you see the horizontal stabilizer moving around so much during taxi. The flight control system is not getting any input from you, but it is feeling the aircraft move as you taxi across all the bumps on the taxi route. So, what you see is the flight control system trying to smooth out the taxiway. This is also why you don't have to put in any check command to stop the roll rate as you try to do any number of precision point rolls.

One minor drawback of this self-checking feature shows up in what has been described as "roll ratcheting." You will recall earlier we talked about how different the flight control system is, compared to what you've been using. The ability to do smooth rolls requires some concentration on your part until you become completely familiar with this different airplane. What's happening is that you're putting in some amount of roll command. Since the roll acceleration of the F-16 is so good, you make the subconscious decision that if you're rolling this fast, this quick, then in a couple of seconds you're going to be going nine million RPM. The natural tendency is to want to slow the roll rate. With a conventional flight control system we simply decrease the amount of stick deflection. In order to accomplish this we relax pressure on the stick and allow the self-centering forces to move the stick closer to center (i.e., less aileron deflection), thus slowing the roll rate to what we want; then apply sufficient pressure to keep the stick at the new position. This relaxing of pressure will normally go to zero momentarily, and with the F-16 this is sufficient for the self-checking feature to stop the roll rate completely. (Remember—you don't have direct control over the amount or direction of control surface deflection.) The roll rate deceleration is ALSO rapid, so your body and hand tend to couple with the aircraft motion and probably make stick inputs that weren't intended.

The end result is some pretty sloppy rolls until we get used to the system. What you need to do is (1) learn to adjust the roll rate with subtle pressure changes on the stick, and (2) get away from the stick position cues you've been used to using. Once you can get yourself "tuned" to using finite pressure changes to control the roll rate, you'll be able to make smooth roll inputs. This is so despite a force-per-roll-rate slope that isn't constant. There are two distinct changes in the slope of the curve. This is to make sure that the airplane isn't too sensitive for small inputs, and that the force required for max inputs is not too high. Those devilish engineers also used two different roll time constants for small and large roll inputs. All this is nice to know, but if you simply pay attention to the amount of force you're using on the stick, you'll be able to do very nice rolls with the F-16.

By now I'm sure all of you are asking why it's necessary to use such a markedly different flight control system. Well, this self-checking feature is really one of the main reasons this flight control system is in the F-16. It allows an aircraft design that uses new and different aerodynamic principles. In the next issue of "Code One" we'll discuss these principles.
Can you now understand why you keep hearing, "I never thought you'd be able to make that corner!"? Heard that in some of your debriefings? Ah haaaa! Then maybe there is some method in their madness.

SEMPER VIPER!

by Joe Bill Dryden
Experimental Test Pilot

EDITOR'S NOTE: This is the second installment in a five-part series that seeks to describe—from a pilot's perspective—what's "different" about the F-16 Fighting Falcon. The first installment described the F-16's flight control system. This installment will begin with aerodynamics before proceeding to an in-depth discussion (to be concluded in the next issue) on departures. General Dynamics Test Pilot Joe Bill Dryden is an experienced fighter pilot whose insightful comments are aimed primarily at other fighter pilots... yet his writing style is characterized by a descriptive ability that everyone will find enjoyable and informative.

When you start looking at the F-16 from the aerodynamic standpoint, one particular fact immediately stands out: This is the first operational aircraft intentionally designed to have a negative static margin. In subsonic flight, the F-16 is negatively stable (read "unstable") in pitch! I doubt if any of you have had the opportunity to fly an aircraft characterized by true negative stability; but if you did, you'd find that with a conventional displacement flight control system you'd spend at least 99 percent of your time just trying to keep the sharp end pointed into the wind. The closest any of you may have come is in the F-4—with three bags and two travel pods, just as you come off the tanker with a full load of gas. In that configuration, if you pull the F-4 to about 14 units, you'd find that it wants to keep right on going, and you have to maintain forward pressure to keep the AOA from increasing right through the departure boundary. Subsonic, the F-16 is constantly trying to do the same thing; but, because the flight control system is constantly monitoring g, AOA, and pitch rate (and comparing it to what you're asking for) you'll never see the same results.

Why design the aircraft in this manner? Because you get several performance benefits from doing so. One reason the F-16 turns as well as it does is because of this negative static margin. What you may recall from AERO 101 no longer applies when you try to evaluate the F-16. I've seen articles in Air Progress that show how the F-15 will turn so much better than the F-16 because the F-15's wing loading is lower. But this is where people get in trouble, because you can no longer apply wing loading to come up with a prediction as to how the airplane will turn. Let me explain this. Since the F-16 is negatively stable, the tail is lifting in order to control the AOA (while you're subsonic). And while the center of pressure shift is such that the F-16 is positively stable when you're supersonic, the amount of down force necessary to keep the aircraft trimmed to a given AOA is less than conventional fighters. As a result, the total lift acting on the airplane is more for a given angle of attack; therefore, the resultant induced and/or trim drag is reduced. Less drag of any kind means better sustained turn and cruise performance. Also, the F-16 has been designed to take advantage of the vortex lift generated by the strakes. This vortex is what you see trailing back on both sides of the F-16 when you turn it hard in moist conditions. They are not there just for more oooohhs and aaaaahs at airshows.

As a result of this vortex lift, there are areas in the flight envelope where as much as 30 percent of total lift is coming off the fuselage. So, if you fall into the same trap that Air Progress did and take the gross weight of the aircraft divided by the projected wing area, you'll come up with a wing loading of about 65 pounds per square foot. BUT (and this is a very BIG but), when you add in all the contributions of both tail and fuselage lift you'll come up with a wing loading of about 40 pounds per square foot. Now you're talking late World War II wing loadings. So can you now understand why you keep hearing, "I never thought you'd be able to make that corner!!!"? Heard that in some of your debriefings? Ah haaaa! Then maybe there is some method in their madness.

So it's really a combination of these two things that gives the F-16 the different characteristics we have to account for when beginning to fly this multirole fighter. The negatively stable aero and the rate command flight control system both go to make up a fighter that'll perform like no other!

CUES/AOA/DEPARTURES

I mentioned, in passing, some less than desirable features that resulted from new approaches to building a
fighter like the F-16. Forewarned is forearmed, so follow me through this discussion of how not to be surprised by the Fighting Falcon.

I’ve heard folks complaining about the lack of cues when flying the F-16. This is true and not true at the same time. The cues are there—it’s just that they’re so suppressed in magnitude (when compared to aircraft you’ve been flying) that they’re often overlooked until you get some experience in the airplane. Without regard to any special order, let’s look at some of the more common ones.

You will have noticed that there’s a decided difference in the amount of time you spend trimming the F-16. This is primarily the result of the flight control system. Since we’re using the flight control system to artificially create a neutrally stable aircraft, trim changes are taken care of automatically as we increase or decrease airspeed. Since the need to retrim the airplane is removed, we can no longer use this cue to tell ourselves on a subconscious level that we’ve changed airspeed.

Also, the lack of a canopy bow has removed one of the larger sources of wind noise in the cockpit, so we can no longer depend on louder background noise to tell us we’re going faster. The increase in wind noise is really still there; it’s just that the initial noise starts at such a low level (compared to aircraft such as the Rhino) that you really have to be paying attention in order to use this signal as a cue—which is hard to do until you get used to the new “feel” of the F-16. Both these characteristics are the reason that you find yourself going 450 KCAS when you wanted 250 KCAS, and vice versa. I regret that I have no real clue for you here other than to use the HUD and really listen to the airplane to show you just how fast you’re really going. Rest assured that I don’t want to go back to a positively stable airplane with a canopy bow to recover these cues.

I do, however, have some very important facts about what the angle of attack is, so pay attention. Most of you transitioning out of the F-4 are familiar with the fact that the F-4 would bludgeon you over the head with buffet levels to tell you, in no uncertain terms, that you were increasing the angle of attack. The buffet cues are still present in the F-16, but the magnitude is probably one-tenth that of the F-4. What happens is this: you’re cruising along at about one or two degrees AOA and you start to turn the aircraft. The first thing you hear or feel is a small increase in the background aerodynamic noise (this usually begins at about six degrees AOA). What you’re most likely hearing is the vortex that’s beginning to be shed by the forebody strakes. This noise increases slowly until you reach 15 to 16 degrees AOA where you begin to get flow separation off the main wing. The resultant turbulent airflow impinging on the rest of the F-16 gives you what has always been described as buffet.

This onset of airflow separation follows the rule we are already familiar with, in that it starts at about 15 degrees at sea level and decreases (as altitude increases) until we see the onset of buffet at about 9 to 10 degrees alpha at 40,000 feet. The reason for this decrease in AOA for the same airframe reaction has not changed since Icarus, and is unimportant here. The main thing to remember is this: IF THE F-16 IS BUFFETING (regardless of the power setting) YOU ARE SLOWING DOWN! If you don’t get slow, the F-16 will NOT depart. If you have enough airspeed, the flight control system will not allow you to do anything that will progress to a departure. It is only when you begin to get below 200 to 250 knots (depending on the configuration) that the F-16 becomes “susceptible” to departure—but even then, you must still FORCE it to depart. So a very important lesson is to be learned here; i.e., pay attention to the buffet level. If you don’t want the F-16 to get slow, don’t fly into buffet. The F-16 will fly well beyond buffet very nicely (remember the unstable aero and fuselage lift) so, if necessary, don’t be afraid to do so. Just remember to use the buffet as an important information cue, and you’ll not become famous (or infamous) with your superiors!

As long as the g is low you can fly the F-16 well at 20 to 25 degrees AOA. Just don’t ever forget that in order to fly at these angles of attack you’re getting slow. What happens is the flight controls don’t have enough authority at these airspeeds to overcome the bad parts of this unstable aero we’ve been using. So, if we make rapid pitch or roll inputs at low airspeed, the flight control system will try to honor our request. But then it quickly realizes that there’s not enough energy in the air flowing around the control surfaces to stop the inertia it just started. So now the unstable aero gets the upper hand, and the F-16 keeps right on going. If you’ve been paying attention and KNOW you’re slow, you’re still not in any trouble. Simply put this knowledge to good use and smoothly approach the limits built into the flight control system. If you can do this in the heat of battle, the flight control system can handle the more benign rates that occur and will still keep you out of trouble. (Never fear. Even these “benign” rates are faster than the guy you’re fighting will be able to generate.)

In addition to using the buffet level as an airspeed clue, there is another area that bears watching—flying the aircraft vertical, or even near vertical. Don’t be led down the primrose path when you read stories about airplanes that supposedly have power-to-weight ratios greater than one-to-one. Writers often don’t have a complete grasp of all the real-world physics involved. For example, despite the stories you may have heard or read, the F-16 will not accelerate straight up for very long . . . and neither will any OTHER aircraft, for that matter. Although the F100 engine is in the 25,000-pound thrust “class” it has never
seen 25,000 pounds of thrust in its life. When you (1) deduct installation losses, (2) realize the engine is probably not in perfect trim, and (3) account for the usual thrust-level deterioration from age, you'll see you don't have a great big area where the F-16 is really greater than one-to-one. Then, when you superimpose a nominal three percent per thousand feet lapse rate on the remaining thrust, you see that when you get to 10,000 feet you only have 70 percent left.

Now remember that in a vertical climb, thrust must overcome weight AND drag. You can see, can't you, that you need a lot more thrust than you have on hand? This is NOT an indictment of the F-16. What you've just read is true of ANY fighter aircraft flying in the world today. In a relative sense, the F-16 is still head and shoulders above anybody you're going to run across in the next few years . . . A-N-Y-B-O-D-Y! Again, the real point is in not getting slow. While the F-16 will go straight up further than anybody you're going to run across in the near future, you're still going to be slowing down when the F-16 is pointed straight up. And whether you get slow through pulling a lot of g or through going vertical, you're now susceptible to a departure if you insist on forcing the issue. Pay attention and you'll know what energy state you're in at all times. If you're in a low energy state (low airspeed), then smoothly approach the limiter and you'll never get in trouble.

The minimum airspeed limits given in the handbook are a very good place to start for maximum maneuver limits. Below these we have to use a little skill and cunning. If you do inadvertently find yourself slower than the limits set forth in the Dash One, all is not lost. Simply keep your wits about you, be sm-o-o-o-o-th with your control inputs, and you're home free!

Now I know it has happened before (and it will happen again) that someone will not be as smooth as they should be in a low airspeed situation, and a departure is going to happen. Let's talk about what happens in a departure so you'll be able to (1) recognize one if it occurs, and (2) recover from a deep stall if the departure progresses to that point.

Just what is a departure? First of all it's quite different (Heard that before?) from the aircraft you've been flying. You're out of luck if you're looking for the cues you used in flying the F-4 or A-7. If you're looking for nose slice to tell you that you're about to depart, it's way too late. Why? Because the F-16 usually does not depart directionally (nose slice) but longitudinally (in pitch). So, by the time you see any left or right nose motion, you're already well into a departure. What has happened is that you've been turning the F-16 hard enough to slow it down, or going straight up in an effort to outzoom the other guy. For whatever reason, you're slow.

Now, suppose you insist on continuing to turn the F-16 hard by snatching on back stick, or couple it in pitch by pulling on the pole with a simultaneous rapid roll. What you've done is to play right into the hands of all the bad parts of the negatively stable aerodynamics I already pointed out. You've rated or coupled the F-16 into an angle of attack range where it wants to keep right on going. And, at the same time, the slow airspeed means the stabilator doesn't have sufficient authority to keep the angle of attack under control. So the F-16 departs. This is never a violent departure. Remember, I told you the F-16 will not depart unless you get slow. If you're going fast enough to give the airplane enough energy to provide a violent departure, then you're also going fast enough to give the control system enough authority to prevent that departure — the one you seem so determined to effect. (So perhaps there is a valid reason for the F-16's flight control system/aero combination.) As a result, departures are very benign. Sometimes you'll not even be aware that you've departed.

Now, about those previously mentioned exceptions. Most configurations will depart only if you let the F-16 get slow, and nose slices usually do not occur in the F-16. However, as happens in other parts of life, there are no absolutes. Nose slice may occur with a 300-gallon centerline tank, Cat I configuration, under certain circumstances above 35,000, or above about 25,000 feet with wing stores or suspension equipment. These nose slices occur only in the high subsonic speed range (i.e., above .88—.9 Mach with a moderate KCAS — something well below 300 KCAS) when making roll inputs on or near the AOA limiter. If you should ever experience one of these nose slices, your first reaction should be to release the stick and let the jet fly itself out. If the aggravating stick commands are maintained, the nose slice may transition into the more traditional upright pitch departure. This pitch departure will be more dynamic than the low speed case. The excess energy will quickly bleed off, however, and the two departures will then be very similar.

Now back to the discussion about pitch departures. What I've described is an AOA excursion to something beyond 25 degrees. The control system is trying to maintain a 25 degree AOA maximum at one g, and as small as 15 degrees at nine g. There is a definite reason for this difference, but it isn't important here. Even though the flight control system is trying all the time, you can force the F-16 beyond this design AOA limit — either through coupling beyond this in roll, by rating it through this limit with an abrupt pull at low airspeed, or by aggravating a nose slice. So what happens now? Usually nothing of which you're aware. Once the control system sees an AOA beyond 25 degrees, it tries to reduce it to below 25, regardless of what you do to the control stick. But if you somehow manage to get the AOA above 29 degrees, then the system, while trying to reduce the angle of attack to within limits, will also negate any yaw rate. So what usually happens is that you're out of the control loop for a few seconds while the "black box" lowers the angle of attack and then gives it back to you. You probably never even knew it.

So why get so excited? Because occasionally the F-16 can trim itself into what has been described as a "deep stall" . . . and if you get yourself into one of these you DO have some problems. Unfortunately, you'll have to wait until the next thrilling episode to find out just what a deep stall really is and how to get the airplane flying again if you manage to get yourself into one.
In the last issue of Code One, I left you hanging (pardon the pun) just as we were getting into a "deep stall." You will recall that to that point I had discussed with you just what the flight control system is doing; how you can use different aerodynamics as a result of using this different approach to flight control systems; how your cues in the cockpit are different when you are flying the F-16; and how you can force the F-16 into a departure if you ignore these slightly different cues. I left you with a description of what a departure is and how it is really no big deal. What might happen next is a "deep stall." And a deep stall just might be a "big deal" if you are not able to recognize one and know how to correct your screw-up! What has happened is that there are certain angles of attack (in the 50-60 degree range) where the F-16 is essentially neutral in so far as pitching moment is concerned (think of moment as a force). If you can somehow arrive in this 50-60 degree AOA range at zero pitch rate, the F-16 is quite content just to sit there forever. The pitching moment chart printed with this article depicts the contribution of all the forces acting on the F-16 to pitch it nose-down or nose-up. Although the computer is actually moving the surface before you engage the MPO, you can think of the three lines showing what forces would result if you were holding the stick full back, full forward, or not holding the stick at all.

The magnitude of the numbers on the left side is unimportant for the purposes of our discussion. Just follow the two lines that show the sum of the pitch forces acting on the F-16 with the stabilator full nose-up or full nose-down. You can see that in the 50-60 degree AOA area, even though the stabilator is already commanding full nose-down, the pitching moment available to decrease the AOA is essentially zero! Remember that I told you that the "black box" has already taken you out of the loop as soon as it saw an AOA greater than 25 degrees. But you, in all your cleverness, did something to the airplane to end up in the 50-60 degree range with little or no pitch rate. The flight control system is doing its best in commanding full nose-down. It just happens to be in the area where it is unable to do what it would like. It is now up to us to rectify our mistake and do our part to recover the airplane.

Look at our pitching moment curve again and notice in the 50-60 degree area that although we cannot command any nose-down moment, we can still command nose-up. How is that going to do us any good when we want to go nose-down? Pay close attention and I'll show you some "black magic" to get around the "black box."

So, everything is trying to go nose-down but nothing is happening; we are going to be very clever and engage the Manual Pitch Override (MPO) and pull nose-up. From the pitching moment curve you can see that in the 50-60 degree range we have the ability to do just that. But why do we want to increase the AOA when everything is screaming to reduce it? If you pay strict attention to the curve you see that we have the ability to increase the AOA above the 50-60 degree range where we were stuck. Notice also that once we get to still higher AOA we have some ability to move the airplane nose-down - if we now command the tail full nose-down. So, if we do push from here, we can generate a nose-
down pitching rate. As we approach the 50-60 degree area again the moment will once more go to zero, but the difference now is that we have a pitch rate established that will carry us right through the "deep stall" point and recover the airplane. Whew! Just when you thought all was lost. If you'd been paying attention, you would not have gotten there in the first place. But once you did, you can see that recovery is possible from a less than optimum position.

How do we recognize a deep stall? First of all, we should know where the F-16 is susceptible to a deep stall. But in order to deep stall we must first depart. In order to depart, we must be slow (slower than the recommended minimum airspeed maneuvering limits in the dash one). Once we are slow, we must do something foolish - like abruptly pull back stick, or roll rapidly while "snatching" a lot of back stick, or try to "help" the roll rate with a lot of rudder. (The black box will try to fade the amount of rudder we can get under these conditions but we can sometimes fool it here as well.) If you're paying a lot of attention, you'll see a fairly obvious increase in the pitch attitude as the F-16 departs (in other words, the nose goes "up" . . . regardless of the attitude of the airplane at the time). Depending on aircraft configuration, you may then see the nose slice left or right.

Centerline stores make this worse. Centerline stores also tend to make the deep stall more oscillatory in pitch. The F-16 is also not too happy with asymmetry. Something like an ALQ-131 pod at #3 or 7 can make the airplane a potential handfull at the higher angles of attack. There is then a brief period of calm because you've dissipated what airspeed you had going in. From there the F-16 will self-recover or go into a deep stall. If it is going to deep stall, there is a slight but nevertheless characteristic "shudder" as the airplane parks itself in this 50-60 degree AOA region. This shudder is good information, because the F-16 will seldom self-recover after giving you this cue.

Once you're sure the aircraft is in a deep stall (but don't be too quick, because it will usually self-recover) then it's time to get serious about recovering. The deep stall can be extremely smooth or very oscillatory in nature (in pitch and/or roll). The recovery technique is the same in either case. First, find the MPO switch. (A little practice beforehand when things are more calm would be an excellent idea.) Hold the switch in the override position and pull back on the stick. If you can determine where the nose is, the best time to pull is at the lowest point in the oscillation. If the deep stall is extremely stable (and they sometimes are) then just hold the switch and pull. What you're looking for is an increase in the pitch attitude. You're also getting an increase in the AOA, but since the gauge is pegged you'll be unable to see it on the instruments. Depending on the configuration, you may or may not see an obvious increase in pitch attitude. The AOA is increasing, however, while you're holding back pressure - which is what we're really after. If you can detect an increase in pitch attitude, then push when the nose is at its highest point. If, for whatever reason, you're not sure if you can see any increase in pitch attitude, then you can almost do the recovery by the numbers (but the idea is not to be Joe Cool by reaching over, engaging the MPO switch, and then trying to make the stabilator actuator white hot by wildly pumping the stick).

The time required for the aircraft to go through one cycle (nose up to nose down) is very close to three seconds. Now I know it's difficult to establish just how long three seconds is while your body clock is running ten times normal rate, but try real hard. So if all else fails, then (1) find the MPO switch, (2) hold it in the override position (i.e., outboard, left, and/or port), (3) pull back on the stick, (4) count three potatoes, (5) push forward on the stick, and (6) you should be flying again. But you're still at low airspeeds, so all the no-nos that I've already pointed out about snatching on the controls still apply. Be smooth.

If you look at the pitch moment chart again you can see both sides are nearly a mirror image of each other. In other words, the aircraft can do the same thing inverted as it can upright (from an aerodynamic standpoint, not a flight control standpoint). So it is also possible to get the F-16 in an inverted deep stall. If, during your upright deep stall recovery, you continue to hold forward pressure as the nose starts down, it is possible to pitch right over on your back and end up in an inverted deep stall. So, as the nose definitely pitches down, and the AOA is off the peg, quit pushing on the stick. If you're really smooth you can even help your condition by adding a small amount of back pressure to keep the pitch attitude to a manageable level (something like 60 or 70 degrees nose low instead of nearly vertical, or worse).

I told you that you could pitch over on your back if you go too far with an upright recovery. It is also possible to end up in an inverted deep stall from the original departure (depending on what you were doing just before you departed). How do you tell the difference? Easy. If you can see the ground through the top of the canopy, you're inverted. If the cockpit floor is hiding the ground, you're upright. If the AOA gage is pegged at the big number end, you're upright. If it's pegged at the little number end, you're inverted. If you have some small amount of positive g on the airplane, you're upright. If you have some small amount of negative g, you're inverted.

The only difference is this: Remember I told you if you managed to get the F-16 above 29 degrees AOA the black box took you out of the loop, tried to reduce the AOA below 25 degrees, and countered any yaw rate? Well, if you're inverted it does not try to counter the yaw rate. It is possible to develop a yaw rate (read "spin") while you're inverted. It's not difficult to stop, however. Look at the ground near the horizon, or look at the turn needle to determine the direction of rotation. Then step on the opposite rudder to stop the rotation. It's important to do this first, because you can't use the MPO effectively until you've stopped the rotation. Usually, the F-16 will self-recover as the rotation stops. If it doesn't, you'll have to pitch-rock the aircraft in a manner similar to what I told you before. From the pitching moment chart you can see nearly an identical point on the inverted side of the chart. If you get to a negative 50-60 degree AOA the same thing happens. The F-16 will stay
INVERTED DEEP-STALL

- PRESS MPO SWITCH
- PUSH "NOSE DOWN" (At lowest point)
- THEN ...
- PULL "NOSE-UP" (At highest point)
- "NOSE-UP" PITCH-RATE GENERATED
- RECOVER

Horizon
- 50°-60° AOA
- STABILATOR FULL "NOSE-UP"
- NOTHING HAPPENING!

50°-60° AOA

with the help of the TAC fighter pilots stationed there, have designed an excellent training program to show you first hand what I've been telling you here. All it involves is about three hours of briefing and one sortie to show you what you need to know to sort out this "different" airplane when you want to start maneuvering close to (or even beyond) the limits.

NEXT: The F-16's cockpit. Is it just another place for fighter pilots to sit? Or is it also "different" from other fighter aircraft? Joe Bill Dryden will answer these questions in the next issue.

FURTHERMORE

By P.F. (PHIL) OESTRICH
Director, Flight Test

Joe Bill's comments reminded me of my first F-16A deep stall. It was extremely stable and entered via a rudder roll (not likely now, due to the "rudder fader" feature). After wandering around for a turn or so in a very slow, upright spin (also unlikely now), the airplane stabilized in a wings-level, fuselage-level, constant heading, MIL power descent - with no buffet, vibration, or noise. It looked just like a cross-country cruise, except for an indicated airspeed just under 100 knots and an altimeter trying to destroy itself at three seconds per thousand feet. I didn't use the MPO as we hadn't invented it yet, but got the desired results from the flight test spin-recovery chute.

On two occasions I've had such an active deep stall in an F-16B that the dutch roll coupled into a pitching motion and the jet self-recovered... after 30 seconds and 10,000 feet! Bottom line? Joe Bill is "right on" when he says deep stalls can either be extremely smooth or very oscillatory.

One last thought on deep stall recovery: the recovery really ought to be over the first time the nose points near straight down. When it does, get off the MPO switch and do the instinctive thing. Hold the nose there for a few seconds (with whatever pitch command is appropriate) and then start a smooth recovery. Staying on the MPO switch after it's no longer needed generally gets you into the other deep stall.

By STEVE BARTER
Senior Experimental Test Pilot

My experience with MPO cycles in deep stalls has been somewhat different, due to the unusual nature of the testing we were doing. This unusual nature consisted of both symmetrical and asymmetrical AMRAAM/AIM-9 loadings combined with aft CG's - allowing the deep stalls to develop for up to 15 seconds before MPO engagement.

In many cases, of course, we were looking for departures and deep stalls to investigate their characteristics. Specific test maneuvers were accomplished to cause
departures including “rating through the limiter.” Joe Bill said that we must do something “foolish” to depart. Well, my foolishness was that it was my job to fly these configurations.

Two specific test loadings come to mind for multiple MPO cycles. The first had AMRAAMs at stations 1, 2, 8, and 9 with a fuel tank on the centerline. The second had AMRAAMs at the same stations with two 370s and a centerline ECM pod. Both had the center of gravity controlled to the most aft limit. The first configuration took three properly executed MPO cycles to recover from an upright stall, and the second one took four cycles. The problem was that these deep stalls were very oscillatory about all three axes, which caused the yaw rate limiter to work hard to prevent a spin. A part of the yaw rate limiter includes using the horizontal tails for roll, which reduces their authority in pitch. Therefore, it takes more cycles to generate the proper pitch rate or to “catch it” when the yaw rate is low and cause the recovery. All of this is aggravated by centerline stores, especially the 300-gallon tank.

During some of the F-16 departure/deep-stall testing we decided to wait a while instead of immediately beginning pitch rocking with the MPO when definitely in a deep stall. This was to see if the deep stalls became oscillatory. If so, would they self-recover? And if not, were they more difficult for the pilot to rock out of? The answers were yes, no, and definitely yes, respectively. I flew a configuration with a centerline ALQ-119 pod. About 15 seconds after the departure and eight seconds into the upright deep stall, I began pitch rocking. I would describe the deep stall as moderately oscillatory about all axes. This one took five cycles to recover.

Don’t jump to the conclusion that this is a C-model problem. It isn’t. It’s a function of allowing the motions to develop for a long time before using the MPO. The eight seconds was a very long time for me, and none of you should ever wait that long before using the MPO in a deep stall. But … make sure you are really in a deep stall before using the MPO! If you’ve confirmed a deep stall (check all your cues) that won’t self recover, then use the MPO.

I’ll repeat that these were very unusual cases/configurations at grossly aft cg’s, and we intentionally let some deep stalls go well beyond the normal recovery initiation point. Learn from this, observe your cues, and if definitely stuck in a deep stall, use the MPO properly and you will recover.

There’s one other thing you probably ought to be made aware of. Since late 1981 there has been a high- AOA training program at the F-16 Combined Test Force at Edwards AFB. Because several of this magazine’s articles have been about high AOA topics, I thought you might like to hear what this program is about.

The purpose is to provide continuous and on-going advanced maneuvering training to F-16 CTF pilots. Even though the F-16’s high-AOA regime can be described in words, it can’t really be mastered without some hands-on experience. This program gives that hands-on training and, we feel, makes pilots more effective and generally safer. It strives to make them familiar with maneuvers that can be accomplished (1) without departure, (2) with departure and deep stall characteristics, and (3) with recovery techniques. Specific objectives are:

1. To familiarize F-16 pilots with F-16 flight qualities during high-AOA maneuvering - to include normal maneuvering, self-recovering departures (AOA excursions), and deep stalls.
2. To demonstrate and perform maneuvers that can and cannot result in a deep stall.
3. To demonstrate and practice the proper use of Manual Pitch Override.

The actual training has a ground phase and, of course, a flying phase. The trainee pilot flies in the front cockpit with an experienced high-AOA IP in the rear. The ground phase takes about three hours and includes:

1. A basic discussion of the F-16 flight control system emphasizing the high-AOA features (AOA limiting, yaw rate limiting, rudder fadeout, etc.).
2. F-16 departure characteristics.
3. A study of prior flight test departures.
4. A discussion of departure reasons (cg, pilot technique, aerodynamics, etc.).
5. A discussion of recovery techniques for upright and inverted deep stalls.
6. A review of several “flight characteristics” video tapes.

The flying phase consists of one flight in any F-16B (small or big tail) or F-16D, loaded with AIM-9s on stations 1 and 9. Fuel is controlled to arrive at the proper cg for the maneuvers. Initially, various maneuvers are flown which will not result in an AOA excursion (above 29 degrees AOA) or a deep stall. These generally include:

1. A one-g deceleration to max AOA.
2. While at max AOA, a one-g max-command, 360-degree roll.
3. From about 250 KCAS while at max g, a max-command, 360-degree roll.

Next, maneuvers are flown which result in AOA excursions above 29 degrees, but the F-16 self-recovers. These are:

1. From a high pitch attitude and slightly below 200 KCAS, roll 180 degrees and abruptly pull aft and hold.
2. From the same high attitude and well below 200 KCAS, roll 180 degrees and gently apply full aft stick.
3. From a high pitch attitude, hold wings level to zero airspeed.
4. From a high pitch attitude hold wings level inverted to zero airspeed.

As you probably know, many of these maneuvers are not within normal flight manual limits, so don’t go experimenting. Even those maneuvers intended to produce deep stalls usually don’t—they just self-recover. They are presented here in a general form to give you an idea of the extremes we go to for this specific training.

As a high-AOA IP, I have observed highly experienced F-16 pilots who became confused or used incorrect procedures during this training sortie. It happens. Even after a thorough briefing, knowledge of the flight manual, and intentionally departing the airplane. But after observing it first hand and actually having to use the MPO several times in a controlled situation, they were able to “rock out” perfectly. Every pilot I’ve ever flown with on this sortie has said that this training is invaluable.
EDITOR’S NOTE: This is the fourth in a series of articles in which experimental test pilot Joe Bill Dryden describes what’s “different” about the F-16 Fighting Falcon, compared to other fighter aircraft. In part one, Joe Bill described the F-16’s flight control system. Part two involved aerodynamics and “cues” to departures/deep stalls. Part three concluded the discussion on departures and, in this issue, Joe Bill talks about the F-16’s cockpit.

I can remember around 1972, when I first began getting involved with the Lightweight Fighter Program, that it was difficult to visualize just what they had in mind when I was reading about the cockpit layout for the F-16. When I tried to picture what it would feel like on someone’s wing during a night weather approach to about two hundred and a half, I was not too sure I would like what I visualized. However, within my first ten seconds in the cockpit I couldn’t believe we didn’t do this a hundred years ago! It’s great!

I did realize that there would have to be changes in the way I approached some flying aspects that I’d been using in the F-100, F-104, F-4, etc. First of all, the increased seat-back angle made for a far more comfortable cockpit. It was difficult to “gracefully” enter, but once in the seat it felt super. The rudder pedals only moved a half inch, so I could put them where they felt comfortable. In airplanes like the F-4 I was always concerned with being able to get full rudder pedal throw (and a lot of it), so I was forced to fly with the pedals practically under my chin. I was not forced to reach for the stick in the F-16; instead, it felt nicely to hand just over the arm-and-wrist rest. As the YF-16 progressed more and more toward an operational configuration, there were numerous small changes in the stick and armrest/wristrest geometry. The first stick did not move at all, but rather depended strictly on the amount of force you were using to determine the desired pitch or roll rate. It was possible to fly the airplane very well with this fixed stick, but it was decided it would be still better if there was a small amount of motion added. The stick still “moves” only three-sixteenths of an inch aft, three-thirtyseconds left and right, and next to nothing forward. Although this is a very small amount, it is sufficient to give you the tactile cue of making an input. It also lets you know when you’re up against the limiter — something that was difficult to do with the old fixed stick.

Why essentially no movement forward? We found that under negative g you tend to move up and forward in the seat enough to increase the amount of forward stick more than you want to. As a result, it was decided to provide for minimal forward stick movement. The small amount of movement in the other axis seems to be just about the right amount. This stick movement was another area where people not completely familiar with the aircraft made a lot of erroneous inputs about how much movement was really needed. Stop and think about it. If you have much more movement in the pull direction, you quickly reach the point that you’re pushing on the bottom of the stick while pulling on the top. That assumes you have your arm on the rest and are not trying to fly the airplane by moving your whole arm. Instead you should be using only hand and/or wrist movement. So, like the mistakes people make in evaluating the F-16 from an aerodynamic standpoint, people were making bogus decisions because they had not taken the time to completely understand the F-16.

Once I started flying the F-16, I noticed right away that I had a whole new set of muscles in the front of my neck and upper chest. In thinking about this a little further, it should be obvious that the difference in the seat-back angle requires you to exert some physical effort to keep your head from being forced backward under elevated g loads. Even though you’re leaning back in the seat, the natural human tendency is to carry the head still aligned with the local vertical. This is much like watching television at home in your easy chair; unless you’re asleep, your head is not back against the head rest. The airplanes you’ve previously flown wanted to force your head forward under the same g level. This slight discomfort with the newfound muscles quickly passes — just like any other new physical endeavor.

One often-heard item concerning this new seat-back angle is that some people feel they can’t look toward six o’clock as easily as with their previous airplanes. Once again, pay some attention to the fact that this is a different airplane. With a conventional cockpit you’re sitting erect or leaning slightly forward in the seat. The human makeup is such that the head rotates fairly well about the vertical axis. Therefore, it’s fairly easy to rotate the head and eyes far enough left or right to see over your shoulder. You get comfortable with such a motion because you’re familiar with it. These very same people who are complaining seem to forget that they’re usually doing nothing but looking at aircraft structure once they get cranked around. Looking at six o’clock in the F-16 requires a little different technique. Instead of simply turning your head, try this (don’t even think about leaning forward): use the “towel racks” to push or pull

**INCREASED SEAT BACK ANGLE AND RAISED HEEL LINE PROVIDES SUBSTANTIAL IMPROVEMENTS IN:**

- PILOT "G" TOLERANCE LEVEL
- TRACKING ACCURACY
- PILOT FATIGUE

![Diagram showing increased seat back angle and raised heel line](image_url)
yourself left or right as far as you can go (both directions will work, and with a little practice you’ll quickly learn which direction is better at that particular moment). Now, lean your head toward your shoulder in the same direction you’re leaning your body. With a little practice you can get to where you can support your head with your shoulder while you’re pulling g. Now rotate your head about the now-leaning vertical axis and you’ll be able to look nearly right down the back of the airplane. And better yet, those clever devils have not put any aircraft structure in your way. The only possible interference now is from the top of the seat. Amazing!

I’ve not heard many pilot complaints about the lack of a canopy bow in the F-16. I get the impression that everyone is impressed with the markedly improved visibility that results.

ing the physics involved or the tradeoffs required, a lot of attention was suddenly focused on the F-16’s bird-strike “problem.” As a result, the canopy thickness went from three-eighths inch on the prototypes, to one-half inch on the full-scale development airplanes — and finally to three-quarter inch on the production version. Therefore, the possibility of reflections ricocheting around inside the transparency (and then into your eyes) increased markedly. It’s also interesting to note that this additional canopy thickness cost you 22 pounds of additional weight per one-eighth inch increase.

While I have mentioned bird strikes, let me digress for a minute on that subject. It’s important to realize what we’re talking about, when the subject comes up for discussion.

“For a minute I thought I’d forgotten something. I finally realized that I could see like in no other Air Force airplane I’d ever flown.”

That is certainly the most lasting impression I had on the initial takeoff I made in the airplane. For a minute I thought I’d forgotten something. I finally realized that I could see like in no other Air Force airplane I’d ever flown.

However, I have heard some complaints about reflections in the canopy at night. You must remember that the original design of the F-16 revolved around the role of lightweight air-to-air fighter. However, this quickly changed to one of multi-role fighter. The possibility of the aircraft spending much more time in the arena where it might encounter birds was one change. Without fully understand-

First of all, the failure mode with a bird strike in the F-16 is rarely one of penetration (i.e., the bird does not usually come through the canopy). Instead, the impact puts a big depression in the canopy. This depression (dent, if you prefer) then progresses back along the canopy in a traveling wave, giving rise to the possibility that it (the wave) will rap you on top of the head hard enough to incapacitate you. The “sweet” spot required for this to happen is hardly six inches by six inches, roughly centered on the HUD. Anything outside this area does not create enough of a dent to hit you as this traveling wave passes by your head. I feel the odds
against just such a hit are astronomical, but it was not my decision to make. So, what you now have is a canopy that will take a four-pound bird in this area at something in excess of 350 knots. This capability assumes that you are sitting at “design eye.” If it looks like the mission is going to require that you fly at high speeds, in an area where you know there are a lot of birds, you should make note that you can get an increased safety margin simply by lowering your seat below “design eye.” It is also very interesting to note that the F-16 is one of only a few airplanes that has been so thoroughly scrutinized in this area.

There are several other airplanes (I won’t mention any here, but you would recognize them instantly if I did) where the failure mode is one of penetration. And the airspeed that this penetration occurs is not too high (more like around 250 knots). What happens with these airplanes is that the bird hits anywhere on the windshield and travels up the windsreen, making a dent similar to the F-16. The difference is that, once it gets to the canopy bow, this traveling wave is severely snubbed by the canopy frame. The result is an immediate failure of the transparency, and your single-place aircraft has suddenly become occupied by another warm (but rapidly cooling) body. This is not too conducive to a much longer sortie on your part. Of course, there is always the remote possibility of taking a condor right in the chops at 600 knots in any tactical airplane — in which case all bets are off.

Anyway, we were talking about reflections. Because of several reasons beyond the control of both test and operational pilots, we have to live with a canopy whose thickness is very conducive to reflections. Also the canopy geometry, which gives us such excellent visibility in the daytime, is hard to light from the inside without some annoying reflections. We have to recognize they exist and learn to live with them. There are a couple of things you should consider. First of all, learn to fly with the lights as dim as possible. Although not yet designated as the primary flight instrument within TAC (as it is with the Navy F-18 community), perhaps the time has come to consider using the HUD to fly with at night (or in the daytime for that matter). Through some judicious use of the night filter (in conjunction with the day, night, and/or auto bright switch in concert with the brightness knob) you can get the HUD where you can see it perfectly without any annoying reflections. With the panel and console lights very dim (to almost off, which the HUD will allow) you can virtually eliminate any annoying reflections. In fact, that’s exactly what we’ve been doing lately — eliminating reflections. After spending a lot of time and money in apparent dead ends (electroluminescent strip lighting, many different filters, different bezel lights on the various gauges, etc.) we came up with the following solution: we added a master switch for the interior lights in much the same manner as the external lights. We use the present rheostats to set up the various panel lights to where we can see everything comfortably. Then, with a hands-on switch, we turn everything off (the warning lights are rigged to stay dim) and fly using the HUD until we need to check something. Then it’s “click” on, do our check, and “click” off. It works great!

There is still the problem of having to contend with the REO (radar electro-optic) display, but we are working on a filter to help here (and it looks like we’ve come up with one that works well). With some practice on your part, you can come up with the right combination of brightness, symbology, and contrast settings that will allow you to use the REO at night and still not flood the cockpit with green light. There will still be those areas — such as night weather approaches, either single-ship or on the wing — where it could be a bother. In such cases you can turn it down enough (even off) to where it shouldn’t interfere. Experiment a little and you’ll see it’s not too hard to come up with some personal settings that will allow you to see outside through the small amount of reflections that remain.

One final area before we leave the canopy is the refraction and internal reflections of such things as runway lights. I have seen these and do not like them either. I wish I could remove them entirely, but I can’t (with the present thickness). But don’t despair! I have never seen a circumstance in which it was not obvious which lights were the real ones and which were the pretenders. If you realize that the phenomenon exists, there is no reason to “bite” on the wrong picture.

I mentioned using the HUD. It seems like there’s a lot of misunderstanding about what it is that you now have in front of you. What it is, is everything you had “heads down” — except now it’s all in one place. And better yet, you can still look at the real world while you’re looking at instruments. In the next issue of Code One, I’ll discuss — in detail — the capabilities of this marvelous instrument, and hopefully dispel some of the myths surrounding it.
SEMPER VPER!

by JOE BILL DRYDEN
Experimental Test Pilot

The HUD

In the last installment in this series, I mentioned how we should get serious about using the head-up display (HUD) in the most efficient manner. I’m certainly aware of current directives concerning use of the HUD, and it is not my intention to incite a mutiny or even a minor riot. As I write this, however, the F-16 has been flying 12 years, the F-15 is fourteen years old, and the A-7 is on the wrong side of 20! Three very fine aircraft, all equipped with very fine HUDs. Now, it’s simply a fact that there’s a lot of misinformation being passed around out there about just what the HUD is and is not, and how it can or can’t be used. The time has come for someone to stand up and say “the emperor has no clothes.” So let’s us discuss some of the most oft-mentioned HUDisms and dispel the myths, where appropriate.

Rumor #1: The HUD Is Disorienting

False. What is disorienting is being “stuck out in the breeze” with today’s modern bubble canopies — much more so than in earlier airplanes. As a result, the pilot is more exposed to erroneous stimuli than in the past. But the HUD has very little to do with it. This tendency toward increased disorientation is going to occur in the F-16, F-15, OV-10, and the A-10. And you’ll see a small increase in disorientation incidents if and when the F-4 is retrofitted with its new “clear vision windscreens.” The real truth is that you’ve not been properly trained to handle weather. All of us are unique in our response to the stimuli around us. For instance, I know of only two times that I’ve felt disoriented in weather while flying single ship... yet every time I’m flying wing at night I start to wonder, within seconds after entering weather, why lead is using 90 degrees of bank, or why we’re climbing at 70 degrees... inverted! I know it’s always going to happen, so I’m prepared for it. And it’s far easier to keep myself oriented by glancing through the HUD than by having to look down between my toes to find the ADI (like I had to do back in the days of flying the Rhino). Learn your own response to various weather/night situations. Be prepared to cope with them when they occur.

Rumor #2: HUD Symbology Moves Around Too Much

False. Except for severe turbulence, the HUD doesn’t twitch — unless you move the stick. Pay attention to the effect various control inputs have on the HUD. They never vary. Once again, it’s easy when you know what to expect.

Rumor #3: HUD Symbology Moves Off the Side of the Combining Glass

Partially true. If you know what the airplane drift is doing it’s no big deal. (More on that to follow.) At any rate, the drift cutout switch is on the face of every F-16 HUD I know of — so learn what the switch does, and when best to use it.

Rumor #4: HUD Symbology Needs Improvement

True. The Human Factors department (under the guidance of Manuel Tapia) is conducting research to define symbology changes that will improve HUD attitude awareness. After exposure to these candidates, I’m certain you’ll agree that several of them promise a great deal of improvement. But the fact is that even the earliest versions of the F-16A/B HUD gave you a superior instrument that is easier to use than any head-down arrangement.

Rumor #5: The HUD Is Not a Control Instrument

This is the most false of all! Not only is it a Great control instrument, it is a control and performance instrument at the same time! (Much more on that later.)
So what really is this HUD we're talking about? What it is, is everything you had head down — except now it's all in one place. And better yet, you can still look at the real world while you're looking at instruments. The only thing missing is the TACAN information, so why not make the most of it? All TACAN latitudes and longitudes are listed in the IFR supplement. If you take the time to properly plan the flight (you always do, don't you?) then there's no reason not to have all the information you need all the time. If the HSI is too dim to see the DME accurately at night with your dim cockpit light settings, you can always back it up with the distance information off the INS in the lower right corner of the HUD. (With the relative bearing addition to the C/D HUD you can also determine what radial you're on.) The HUD's only real drawback is its field-of-view size. It is necessary to move your head slightly in order to see all the displayed information. But with a little practice it becomes second nature, and you get the information you need at the time. Seldom, if ever, do you need to see the whole field of view at any given time anyway. As long as you can see the velocity vector and any portion of the pitch ladder, you can control the airplane precisely. A larger field of view is nice, however, and you folks who'll be flying the C/D as they get into the field will be better off in this regard. The larger field of view is much nicer, and you can see all you need without any effort (other than moving your eyes). It's obvious that this HUD capability exists.

There are a few "different" pieces of information on the HUD that you're not accustomed to having available. Most obvious is the flight path marker and its interaction with the pitch ladder. First of all, just what the hell IS a flight path marker? It's really very simple — the little symbol that looks like the backside of a fat little airplane with stubby wings and tail. It's there to tell you just where the F-16 is going (in other words, the "vector" of the aircraft's CG). It's calculated in the INS system, but is simply the pitch attitude of the airplane to which we've added AOA (algebraically) and drift left or right from the current wind (there is also some beta — yaw angle if you prefer — but that's usually minimal). With the drift cutout switch, you can remove wind effect, but you cannot remove AOA effect. The drift cutout switch will center the display in the HUD and keep it there . . . but just be careful. Remember which way it moved so you'll know on which side of the airplane the runway will appear if you're flying a "no kidding" approach to (or below) minimums.

A big word of caution here: If you have drift cutout selected and the FCC has failed (one or the other, by itself, has no effect) then the flight path marker will present bogus pitch information if you have any bank established (the greater the bank, the greater the error). So be careful! I've never seen it, but the possibility is definitely there. The C/D will give you a caution/avionics light and "FCC failed" on the PFL. The A/B will not! Both will no longer display the lower data blocks on the HUD, the AOA bracket with the gear, or TGT info with a radar lock-on. These are all good clues, so go back to drift normal or use the head down if the FCC fails!

And speaking of an approach to minimums — here is another area where the HUD really shines. Since you're already looking through the HUD to fly the approach, you're the first to know when you've broken out . . . as opposed to the ridiculous requirement to crosscheck head down, look outside, refocus, look back inside, refocus again, look back outside, etc., etc., ad nauseam. The flight path marker is really useful information. If it's superimposed on the horizon line, then you're flying at a constant altitude, regardless of airspeed. It has always bugged me to be on an approach and constantly having to reset the ADI as the airspeed continuously decreased from initiation until final. With the flight path marker I can put the symbol on the horizon line and know I'm maintaining a constant altitude — whether I'm going 600 knots or 130 knots. I've heard complaints that it's hard to control the airplane with the use of the flight path marker. I disagree. It's really very easy! Follow me through this. (You guys who've been flying an airplane with a LCOS gunsight have a leg up on the dirt beaters or the FAIPs in this category, but everybody should be able to understand the following explanation.)
Let’s assume you’re straight and level (i.e., you’ve managed to get the flight path marker superimposed on the horizon line) and you want to climb or dive a fixed amount. The control input is almost the same as if you were making an aiming change with a LCOS sight. If the piper is behind your intended victim, you’ve learned not to pull the sight directly to the target. Instead, you normally make a correction of about two-thirds the distance and allow the system to settle down. And if you’ve been practicing correctly, you’re rewarded with the sight drifting up to the target. The reason you have to do this is because the increased g necessary to pull the sight to the target is interpreted by the sighting system as an increased target turn rate. As a result, the sight is depressed still further. Then, as you get the sight to the target and partially relax the g to continue tracking, the sight thinks the target has backed off. This means less lead. Thus, when the sight takes out some of the depression, the piper moves out in front. Damn! Hopefully your friendly squadron weapons officer explained what I just did, or you discovered this fact for yourself. The result is, we learn how the airplane reacts to the way we like to fly; then we establish our own set of rules to move the piper fore and aft on the target.

Controlling the flight path marker requires almost exactly the same technique. If I’m straight and level and I want to pull up to a ten-degree climb, I don’t pull the nose up until the flight path marker is on the ten-degree line. Why? Easy. As I pull, I increase the AOA. Right? As a result, the flight path marker will be depressed from where I just started. When I get to the ten-degree line, I have to decrease the AOA to stop there, so the flight path marker continues to rise slightly. So I overshoot. Damn! Instead, I use my own fudge factor, based on how I fly the airplane. If I’m making a rapid correction, I’ll pull to about six or seven degrees nose high and stop there. If I’m making a slow correction I might pull to eight or nine degrees and stop there. In either case, I end up with the flight path vector on the ten-degree-up line. Viola! This technique works in both directions. All you have to do is establish your own gains, and you can fly the devil out of the F-16 using the HUD. Once you do so, flying any instrument approach is incredibly easy. If you’re using one of the rapidly disappearing GCAs, all you have to know beforehand is what angle glide slope the controller will be using, and when he says “begin descent” you fly the F-16 to that descent angle (regardless of airspeed) and all you should hear is “on glide path.” The same is true of any ILS. Look at the approach plate beforehand and it’ll tell you what the glide slope angle is going to be. Fly the F-16 to that descent angle and the glide slope indicator shouldn’t move. It’s also a further crosscheck that the ILS director bug is working properly. Furthermore, if the flight path marker is 500 feet down the runway, then that is almost exactly where you’re going to touch down (providing you don’t make any gross control inputs, and allowing for a little float during the flare — if that’s how you land the airplane).

With only a little practice you can also use the flight path marker as a bank indicator. The stubby little wings of the flight path marker always remain fixed in the same relationship to the stubby little wings of the F-16. Therefore, the angle between wings and pitch ladder is the bank angle of the airplane. Make sure you know — without thinking about it — whether you’re looking at a positive line (climbing) or a negative line (descending) and the HUD makes for the world’s best attitude indicator.

For you diehards who insist you can’t possibly fly an airplane on instruments without a pitch reference, all is not lost. Simply turn on the standby reticle. You can now increase or decrease the mil setting so that your favorite part of the reticle is superimposed on the horizon line. How about that? Instant electronic attitude indicator! It might even be a good idea for everybody to start this way until you’re comfortable with using the flight path marker.

One other very subtle difference in the HUD exists for those of you who’ve never had occasion to use one. Although a degree is always a degree, it appears that the angles displayed on the HUD are much larger than you’re accustomed to on the normal ADI. If you think about the geometry involved (much longer sight radius with the HUD focused at infinity) it should be clear why this impression exists. The result is that your impression of necessary correction sizes (to fly the F-16 on instruments, using the HUD) are larger than the ones you’re accustomed to using head-down. The first inclination is that you’re making much larger corrections on the HUD. Just install this in core and, once more, the fact that it’s easy to fly instruments on the HUD should be apparent. In other words, what appears to be a small correction on the ADI gives the impression of a much larger correction on the HUD. Just recognize this fact and there should be no reason for confusion.

I told you the HUD is focused at infinity. I lied. At least the engineers lied to me. The HUD is focused close to infinity but not quite. So during the flare make a conscious effort to look at the ground. The HUD symbology will still be clear enough to read but you will be better able to judge just when you are going to arrive on terra firma. Nice landings should result.

I mentioned earlier that the HUD is both a control and a performance instrument. I meant exactly that! All I have to do is place the velocity vector on the horizon line with no bank angle and I know the aircraft is in level flight. I don’t have to look at the vertical velocity because I already know it’s zero. I’m sure it’s zero that I never bother to display it on the HUD. Since the vertical velocity is zero I know the altitude has not changed. If I have not made a power change since the last time I was stable I know the airspeed has not changed. The wings are level so the heading is not changing. Notice, please, that I’ve not yet had to look anywhere but the center of the HUD — hence my comment about field-of-view size having little direct bearing on the A/B HUD. You can never say the same about flying with a head-down pitch reference system — like you still have between your legs in the F-16 or any other airplane. This is not to say that I don’t crosscheck other HUD information. I do exactly that if I want total situational awareness. But the important fact is that aircraft control with the HUD is infinitely easier and more precise than you can get head down. And you can get all this information with only one glance at one part of the HUD.

The main thing about the HUD is that it’s different than what you’ve been using — unless you just came from the A-7 or the F-15. But it makes little difference whether you’ve been using the HUD or not. Sit down, stop what you’re doing, and think about what the HUD will provide. Read the books, engage in some self-study, and the end result is to be better aircraft control. It works. It works well. And it’s time to get rid of all these old wives’ tales that aren’t worth the paper they’re printed on or the booze they’re discussed over at the stag bar. The HUD is an excellent device for aircraft control and weapon delivery. There’s absolutely no reason for guys to kill themselves simply because they haven’t taken the time to get really familiar with a new system and what it can do for them!
I'd like to offer the following opinions for you to consider.

**Not All HUDs Are Created Equal**

We talk of using the HUD to perform certain tasks, provide information, and to make life simpler. Joe Bill and I refer primarily to the F-16 HUD. However, I will comment on HUDs in general because it's important to note that specifications and standards have not been rigorously applied, so what you have are HUD capabilities and characteristics that vary greatly between aircraft types. Originally, the HUD was not envisioned to fulfill a requirement for instrument flight indication. The classic control, performance, and navigation instruments essentially satisfied those needs. The HUD was designed as an air-to-air and/or air-to-ground weapon delivery reference. As such, symbology, layout, fields of view, and information sources varied greatly. It soon became apparent that the flight path marker or velocity vector information, if accurately displayed, provided both control and performance indication without a requirement to interpret and integrate separate indications. As a result, pilots flying airplanes with more capable HUDs (the A-7D or A-7E for instance) soon included the flight path marker in their instrument scan. Many pilots progressed further to making the flight path marker/pitch ladder combination the hub of their display (instead of the ADI) and now included the ADI as just another instrument in the scan. This transition was crucial, since it enforced the pilot's control strategy. No longer did he have to control one or two indications and then interpret five or six others in estimating the airplane's performance state. Now he could use the same indication to control the main performance parameter—the flight path.

Since HUDs have not been integrated into the aircraft to provide an instrument flight reference, each HUD has to be independently assessed to determine whether (or to what extent) it can be used for instrument flying. The F-16, particularly the C/D model, has the necessary HUD capabilities for safe and precise instrument flight. The HUD is reliable, provides failure indications, contains accurate and usable symbology, and (in the C/D) has a good field of view. And the so-called "primary flight instruments," provide both an adequate cross check (should you feel the need) and system redundancy in case a failure occurs in the HUD, in its display generator, or in an information source (i.e., the CADC).

So when anyone addresses the topic of "the HUD" or "using HUDs," they must qualify the specific capability to which they are referring. Some level of standardization is required in HUDs, but in the meantime, individual HUDs can be independently assessed as to their instrument flight reference capability.

**A HUD Can Be Extremely Reliable and Can Indicate Failures**

This appears to be a comment encompassing two separate issues, but in fact they are intertwined. Both capabilities have been criticized as lacking in HUDs. Here you have two of the primary arguments against using existing HUDs or designing future HUDs as the primary instrument flight reference. Well, sure, given the premise that not all HUDs have been designed to perform instrument flying tasks, I'll certainly agree that reliability, redundancy, and adequate failure indications are not always inherent in specific HUD designs. However, a few points need emphasizing.

Let's talk in generalities first. Neither reliability level nor lack of failure indications should ever be used to dismiss designing a HUD as the primary instrument flight reference. Reliability and failure indications, given today's technology, can be specified and designed into the equipment. Furthermore, independent instruments solely for cross-checking HUD accuracy would no longer be required. That level of redundancy belongs in the HUD and in its information sources. Cockpit design is leaning more and more toward multifunction displays (MFDs), capable of providing the same HUD display in an alternate, head-down manner when necessary or desired. As with today's and tomorrow's flight control system requirements, all HUD information required for instrument flight can be provided by redundant sensors and data paths. These integrated inertial sensor assemblies and redundant air data systems would make the HUD as reliable as the flight control system.

How does the capability for failure indication relate to HUD reliability and accuracy? Contemporary airplanes are being designed with continuous system failure monitoring during all phases of ground and flight operations. We simply need to decide what failure indications are necessary, allow system
redundancy to automatically compensate for failures, and reconfigure the system accordingly. Indications to the pilot need not be manifested in the HUD but simply in a fault list or status display. If redundancy is present and the system is capable of a full-up display during failure states, why should the display change? I don’t know about you, but I never cared for partial panel instrument flying. If the failure is in the HUD, rather than in the information source, then an MFD capable of displaying the HUD format provides the pilot with a simple, consistent transition. Now the only time you’re without your HUD display somewhere in the cockpit is if you’ve been degraded to battery only — and that requirement will probably be a separate design issue based on statistical probabilities. So the idea is to make system reliability requirements drive failure indication requirements. Let’s specify and design reliable, accurate HUD information displays based on redundancies in the information sources (which is already available to some extent in electric flight control systems). And let’s provide an ability to alternately display the desired information on a separate MFD.

Those were the generalities. Now, what about the specific airplane we’re flying? Well, we’ve got a different kind of redundancy — the HUD and the head-down instruments. We also have plenty of failure indications through the continuous fault monitoring system and PFL/MFL displays. When the information sources fail, that information is deleted from the HUD. In the case of flight path errors, I have no trouble deciphering the absence of the flight path marker as an adequate failure indication, since it’s the focal point of my scan. And I much prefer this deletion to an erroneous information display. Nothing used to disorient me more than when an instructor would fail my ADI under the bag or in the simulator and the instrument would sit there frozen. It’s extremely difficult to drop it from your scan. If the CADC fails, you simply have no airspeed or altitude. It’s impossible not to notice it — and I realize that impossible is a dangerous word to use. Any subtle degradation in HUD attitude information is also going to affect your ADI — the information comes from the same source. Summing up — the F-16 provides you with sufficient reliability, redundancy, and failure monitoring to use the HUD in any weather with the confidence that you know and understand the state of your airplane and the status of its equipment.

**Meaningful HUD Training Is Necessary To Gain Your Acceptance of the HUD’s Strengths**

In the F-16, when I talk of using the HUD as an instrument flight reference, I don’t mean to say that it’s already optimized for that role. That will come as HMDs further evolve from studies, research, and (most importantly) increased operational use. Is it going to happen? Sure it is, because advanced cockpits and increased pilot awareness of HUD capabilities will demand it. I’m simply trying to convince you — regardless of whether you’re flying your first operational airplane or have logged 5000 hours — that meaningful HUD training in the F-16 (especially the C/D) will make instrument flying easier, will make you a more consistent and precise instrument pilot, and will ease future transitions into different aircraft. But you won’t notice the immediate effects by sampling the HUD on only a few sorties, nor will it impress you if 400/1 in rain is your initiation. *Training is the key! I think Joe Bill and I may differ a little here in that I didn’t immediately get comfortable with the HUD. But the logic was inescapable — it *bad* to be easier.* So, over an 18-month period, I very methodically weaned myself off the ADI, altimeter, airspeed indicator, and VVI in the A-7E. Now I find myself in an interesting situation: in the F-16, I’ve never used any of the head-down instruments (besides the HSI for TACAN) except in a backup situation. Flying F-4s in the Navy Reserve, I have no HUD, so it’s back to head-down attitude instrument flying. From that dual perspective I’m in complete agreement with Joe Bill on the subject of disorientation and weather-induced accidents. I’m convinced that the reason for accidents in IMC conditions . . . is IMC, and the lack of pilot proficiency in IMC. It’s not easy to fly in bad weather. Furthermore, it’s downright difficult to continually scan six to eight different instruments, located who-knows-where in relation to one another, fight the false physical sensations, and still have to *interpret* and *integrate* the information to get an *estimate* of what you *really* want to know . . . which is where you and your airplane are going.

Now let’s take the HUD. Defining it as a “primary flight instrument” can be stated as “sole use of the HUD for any control, performance, or navigation information required for instrument flight.” That may be a handful at first, but in the F-16 there’s no reason to approach it like that. The fundamental transition that must be made is in relocating the focal point of the instrument scan — from the old, head-down ADI to the HUD’s flight path
marker and pitch ladder. Your instrument scan during workup periods can then encompass whatever you need, either on the HUD or head down, until you’re comfortable with the basics of the flight path marker. You must use it every chance you get in IMC conditions, but make it a continual buildup process. Practice self-controlled approaches in actual IMC during medium altitude penetrations. The two-seater can be used for IMC and night unusual attitude recoveries with the rear scater backing you up. Training in controllable situations at every opportunity will soon have you referencing the flight path marker as the focal point for control and performance data. From there, it’s a simple matter of getting comfortable with the HUD as the source for altitude, airspeed, and heading information. Additionally, you’re provided with raw ILS needles and a flight director that makes the whole approach simple. You don’t need a VVI, and I guess bank angle is a debatable topic. I’m perfectly comfortable with the flight path marker for that. I may not be able to nail 45 degrees angle of bank, but I can give you 45 plus or minus five every time — and I don’t have to open up my scan to do it. It also takes some pre-IMC penetration training to remind yourself that even though you’re looking up (and hence out) there’s still no reason to be less than a hundred percent on instruments (i.e., the HUD symbology) except for quick looks for VMC. You really can concentrate fully on HUD symbology in IMC.

In the F-16C we do not have the capability to put the HUD head down on an MFD. That’s regrettable, since it’s sometimes a quick cure for when you’re fighting vertigo and just want to bury your head somewhere. Sure, you can use the attitude instruments, but that flight path marker is too valuable. Additionally, as you get comfortable with the entire HUD display, a head-down replica makes for no difference in control strategy.

Not everything will be intuitive at first, but think back to your initial training with head-down instruments. They’re intuitive now because they’re familiar. I’ll agree that the F-16 HUD could certainly benefit from some symbology optimization. I’ve seen better ideas for certain aspects of HUD symbology in different HUs. But with training and repetition, a rapid interpretation of your airplane’s state will soon become much more complete and meaningful — and that will make you a safer instrument pilot.

The HUD Is Being Successfully Used As the Primary Instrument Reference in Contemporary Fighters

The contention that the HUD is not a suitable instrument flight reference loses credibility when you learn that it is, in fact, being so used. The Navy chose to design its F/A-18 cockpit such that the HUD fulfilled the instrument flight reference requirement. The airplane is still equipped with a very small, pneumatically driven set of performance instruments (altimeter, airspeed, and vertical velocity) and a small, self-contained standby ADI, but these instruments are poorly located for primary use, and are included solely as a backup system. The HUD is it. Additionally, the HUD display can be selected on an MFD if desired. The transitioning pilots are a cross section of the Navy’s entire aviation experience base — from low-hour, first-tour aviators to seasoned flyers with over 5000 hours and 1000 carrier landings. Except for those with prior A-7E experience, all are new to using the HUD for instrument flight. There is no situation more disorienting than over open water on a very black night. Yet, the initial two carrier air wing deployments of the F/A-18 (six squadrons of airplanes) proved that not only could the HUD be successfully used, but that performance could improve as well. Day and night carrier boarding rates (the ratio of successful arrestments to total approaches) actually exceeded overall fleet averages, including those of airplanes (F-4, A-7) that were replaced by the F/A-18. Admittedly, that result is attributable to various aspects of the airplane’s design, but the HUD is certainly a contributor. There is very little difference between the HUD in the F/A-18 and that in the F-16C/D. The F/A-18 includes a bank angle pointer, some TACAN CDI information, a slightly different attitude indication, and proportionally canted pitch bars for unusual attitude determination. I believe that most of those pilots, after training to use the HUD and acquiring the operational experience to go with it, would choose it over traditional attitude instrument flying.

There’s An Analogy With the Sidestick Controller Here Somewhere

It’s not an exact analogy by any means, but acceptance of the HUD for instrument flight can be compared to acceptance of a relatively fixed sidestick for control of the airplane. Both are departures from traditional, warm-feeling systems that worked. Both require some time, thought, and training to use proficiently. Both still have many detractors who are simply unwilling to change. Yet the majority of pilots who have flown both types of instruments and both types of controllers prefer the HUD and the sidestick to the more traditional equipment. Finally, both the HUD and sidestick give cockpit designers the flexibility and freedom required for advanced cockpit and systems integration. Proven, simple designs should not be changed simply because a seductive new technology has appeared. But the HUD and sidestick are technological advances that truly provide more capability for the pilot.

The F-16C/D Is A Great Training Vehicle for HUD Instrument Flying

Now I know this article is not going to make anyone immediately change their philosophy about using the HUD. I saw the same mindsets in the Navy at the beginning of the F/A-18 program that I read about in HUD surveys among Air Force pilots. Primary support for using the HUD came from HUD users — former A-7 drivers. Most others were either misled due to lack of HUD exposure, or were not convinced that there’s any reason to give up using a technique that works. Keep in mind, though, that all of us were initially instrument trained the same way. I’m not advocating that you abandon your present technique. I’m simply expressing an opinion: if you take advantage of the F-16’s very capable HUD and its complete set of traditional instruments, methodically and patiently transition the focal point of your scan to the flight path marker/pitch ladder, and let nature take its course . . . then you won’t be able to stop yourself from converting. Now, I’m not going to be surprised if I get hate mail within a few months stating, "I tried all this HUD stuff and it doesn’t do anything for me.” I can’t help recalling, however, that I started studying the German language in the ninth grade, yet it didn’t make pictures in my mind until the tenth grade. Training is the key. It should start in UPT with a HUD-equipped trainer. If not there, then with your first flight in the F-16.
SEMPER VIPER!

By Joe Bill Dryden
Senior Experimental Test Pilot
The F100 Engine

EDITOR'S NOTE: This is the final installment in a six-part series on the F-16 Fighting Falcon in which Senior Experimental Test Pilot Joe Bill Dryden has examined the "electric jet" and told us how this remarkable airplane differs from other fighter aircraft. This interesting and informative series has alternately focused on the flight control system, aerodynamics, departure/deep stall characteristics, the cockpit, the HUD, and (in this segment) the engine. It has been the intent of this series to involve operational F-16 pilots in an in-depth discussion of the airplane's capabilities in the hope that broader knowledge will result in better, safer pilots. We hope that you have enjoyed this series, and we invite your comments.

You may have noticed that some of the newer F-16s entering the field are equipped with the F110-GE-100 engine, and a few have the F100-PW-220. Both of these new engines are a tremendous improvement over the present F100-PW-200 (which itself is no slouch). This last installment in the Semper Viper series is about the F-16's powerplant, but since there are presently over 1500 F-16s out there with the older Pratt & Whitney, we'll limit our discussion to that engine.

During the time that the prototypes and Full Scale Development F-16's were being designed, the F100-PW-200 engine was the best one available that provided the required performance. The F100 is different from any engine you've experienced in previous fighters, so a little discussion would be worthwhile here. A few courses of action worked out ahead of time (you do this for all situations you might run across in flight, don't you?) would keep you on the good side of everyone involved. Let's see ... where do we start?

How about the BUC? I've really gotten upset with all the misinformation that's going around about the BUC. First of all, it's a simple backup system for the main fuel control, really not much more complicated than a kitchen faucet. Because it is simple, you (the pilot) must make allowances for its simplicity. It's important to remember this. If you treat the BUC the way it's supposed to be treated it's nearly foolproof! But if you insist on being "Joe Cool" and not paying attention to just how the engine control system works (EEC, UFC, or BUC), it'll jump up and bite you so fast your head'll swim. Read the books, ask questions, and when it becomes obvious that the main fuel control is going south, don't be afraid to switch to BUC! It's up to you to know — and know cold — the BUC operating envelope, the rate you can move the throttle, and exactly where the BUC start and BUC idle positions are on the throttle quadrant. If you know this, and can make allowances for the fact that it is such a simple system, then it works well.

Another major place for getting into trouble is in the area of stagnations — one of the unfortunate side effects of pushing the state of the art with afterburning turbofans.

Excuse me. That should read "augmented" turbofan. Every new design engineer wants to become famous, so he/she changes the name of everything, just because it happens to be slightly modified. (Pilots aren't exempt from this disease, either.) As a result, you see "power lever" instead of throttle, "augmentor" instead of A/B, "intermediate" instead of MIL, "crew station" instead of cockpit, etc. Sometimes it's really necessary to read between the lines.

Where was I? Oh yeah! Afterburning turbofans. Since the fan duct now allows almost direct access from the A/B to the compressor, these new engines are much more likely to stall when selecting A/B than are the turbojets you're used to operating. Also, it's possible for these stalls to progress to an even less desirable event called a stagnation. (Don't get the impression that you can expect one of these on every flight, but — once again — forewarned is forearmed.) What happens is that the stall can continue, driving the basic engine down to an RPM from which it will not self-recover (all the while putting out no useful thrust.). This is bad with the F100 because if you don't recognize the condition and do something about it, you'll be left with a melted ingot in the engine bay!

So how do you recognize one of these hummers? It's real easy, but more on that in a minute. First, the engine must stall in order to stagnate. Did I mention cues? With the exception of an off-idle stall, there's nearly always some duct rumble that precedes a stall. With an off-idle stall, the energy available to make noise is not there and you might not hear any rumble. It's also possible you might not even hear the
stall. This is certainly not the case with the engine in any other condition. There's almost always a lot of duct rumble, and then a very definite "bang" or "pop" when the engine stalls. The engine control design incorporates an automatic throttle retard if the engine stalls, but I've yet to see the fighter pilot who couldn't beat the automatic system, hands down. If the engine stalls, you're not getting much thrust, so it makes little sense to leave the throttle in the A/B range. Retard the throttle to MIL, allow time for the system to reset, and try it again — cautiously — if you're sure you're not in region three. But don't get carried away. If you know you were at 400 KCAS, one g, and 20,000 feet you are obviously well into region one . . . and an engine stall here indicates a sick engine. Bring it home without further attempts!

Now about those stagnations. If you allow the engine to continue stalling, it's very likely you'll get a stagnation. How do you recognize one? Very simple. The book says that if RPM is low, FTIT is high, and the engine does not respond to the throttle, then the engine is stagnated. Actually, however, recognizing a stagnation is far simpler than that. Even with the wildest temperature fluctuations (weather-wise), you'll never see ground idle RPM lower than 61-62 percent, and this idle RPM increases with altitude. So it's incredibly simple: if the throttle is in the operating range and the RPM is below 60 percent (especially if you have heard and/or felt the engine stall) chances are extremely good that you have a stagnation on your hands. There is never an excuse to let the FTIT get anywhere near the peg! You should have enough situational awareness to know the stagnation exists almost as soon as it starts. Don't be spring-loaded to the stagnation position — there's always the possibility that you could have a problem with the EEC or even the UFC. But the chances are very good that if you've felt or heard the engine stall and the RPM is below 60 percent (especially if the throttle is above idle) you've very likely inherited a stagnation. Check the FTIT. If it's increasing, you can be sure you have a stagnation. Don't wait! It's not going to get any better. Shut the engine down and prepare for an air start. If you've caught the stagnation early enough, the FTIT will be below 700 degrees almost immediately, and all you're doing now is waiting for the RPM to get within the 25-40 percent range specified in the dash one. Bring the throttle around the horn and you should be well on your way to an air start. Remember that the F100 can take what seems like an eternity to complete a start (sometimes over a minute), so don't abandon a successful start because of impatience. If you didn't catch the stagnation early and the FTIT is on the peg, you're in for a long wait until it falls below 700 degrees. Not catching the stagnation early also means the RPM is lower once you decide to shut the engine down. Lower RPM and higher FTIT will make it much more difficult to arrive at the below-700-degrees FTIT and 25- to 40-percent RPM that you need. You might even have to move the throttle out of cut-off early in order to keep the engine RPM from going below 25 percent. (You should be aware that the RPM will decay very rapidly, especially at the lower altitudes — and you don't get any
As you may have noticed, the word "different" has occurred several times in the course of this article series. I've attempted to discuss these differences in such a way that you arrived at the conclusion and meanings I was trying to convey. The F-16 is truly a different approach to building and flying fighter airplanes than you've ever seen before. But if you want to see still higher and higher performance, eventually you're going to have to abandon the steam-powered aircraft of the past and move on to bigger and better principles. The F-16 is a legend in its own time. History will rank it on the same level as the Spad, Sopwith Camel, Fokker Triplane, Spitfire, FW-190D, Mustang, Zero, and Sabre. Consider yourself lucky that you're a part of aviation history. Learn the differences in the airplane and profit from them. If you do so, I can guarantee that you'll become a tremendously effective fighter pilot while loving every minute you fly the F-16. I've been flying this airplane going on thirteen years now and I still love every second I can get my hands on it.

Years ago, a poet named W.B. Yeats penned words that surely must apply to the F-16 (edited just a little):

I know that I shall meet my fate
Somewhere among the clouds above;
Those that I fight I do not hate,
Those that I guard I do not love...
No law nor duty bade me fight,
Nor public men nor cheering crowds;
A lonely impulse of delight
Drove to this tumult in the clouds.

I can think of no more lonely or lovely impulse of delight than the F-16! Treat it right and it will reply with more raw performance than you would ever have thought possible. It really is the best fighter in the world today! Enjoy.

Check six . . .
EDITOR'S NOTE: OK, OK! So we told you in the last issue that the "Semper Viper" series was concluded. But Joe Bill decided you needed a little something extra, so here it is — just when you thought it was safe to go back in the magazine — "Semper Viper II." Absolutely, positively, without question the last installment in the "Semper Viper" series . . .

. . . or is it?

Landings In the F-16

By JOE BILL DRYDEN
Senior Experimental Test Pilot

Probably the most frequently asked question during any of my discussions about how to fly the F-16 involves how to land one of these sleek little beauties. For some reason, people are intimidated trying to land the F-16. Let me make the following statement concerning the F-16 and the ability to land same: the F-16 is not hard to land (i.e., get it on the ground in a safe, professional manner). However, the F-16 is probably one of the hardest airplanes I have ever flown to repeatedly, consistently, predictably get a "grease job." Although I've been at it a few years, I'm still not happy with my ability to do it. There are several reasons for this phenomenon (from a purely technical standpoint — before anybody makes any smart remarks).

Let's go through a typical approach. I hope to cast a little light on what is going on here and what you can do to try to improve your "grease job percentages." Reread what I said earlier in this series about the flight control system (how it is different from anything you have ever flown before), as this system has a very definite bearing on your ability to land. Also recall the little subtleties about not staring at the HUD during the flare. Instead, make sure that you are making a conscious effort to look at the runway and the surrounding terrain so as to be able to judge your height above the ground accurately. (It's easy to get sucked into this trap.)

Let's start at the break. First of all, I like to fly — or watch — a crisp (read rapid) break. But be aware! If you pull the airplane as tight as it will fly, you're building in a lot of problems for your turn to final. Nobody wins a-pattern-tightness contest, just as nobody wins a low-flying contest. But that's no excuse to fly a cross-country around the pattern, either. So use your head during the turn to downwind. As always, the usual requirements to lower the gear still apply sometimes about now. It seems like there are still those among us who cannot remember to lower the landing gear. And raising the gear-warning tone airspeed to just under Mach one is not going to help, either. If you can't remember to massage the gear handle on an even number of times on every
sortie, then you should be looking for another line of work. Also, I recommend using the speedbrake — especially with
the F100-PW-200 engine — as it allows you to carry a little higher power setting for a little better engine response on
short final. Both the F100-PW-220 and the F110-GE-100 engine are better in this respect.

You have read in the dash-one and heard about the
recommended 11- or 13-degree approach for the F-16. You
can use either one with the same success. It does not really
say at exactly what point you have to have the angle of attack
established. If the test point requires, I can fly a constant 11-
or 13-degree approach throughout the whole pattern. Left
to my own devices, however, I usually fly an approach that
results in a slowly increasing AOA from the time I roll off the
downwind (or “180” — I mustn’t overlook our new Navy
pilots) until touchdown.

I usually have about six or eight degrees as I start to turn
final. About halfway through the turn (the “90” for our Navy
friends) I pass through about nine to 10, 11, or 12 on short
final, and 13 degrees or just prior to touchdown. You will
usually be making a slow power reduction throughout the
approach — but there are exceptions, depending on the
configuration — and slowly increasing backpressure until
you set 15-degrees AOA.

At this point, stop making pitch changes (unless gusts,
jet wash, etc., require a correction) and use power to
touchdown point or sink rate. As with up-and-away flying in the airplane, I recommend that you do not
trim. I do feel like I want to trim off the pressure during the
final turn, but I have found that I always have to run the trim
the other direction on final — right back to the neutral
position. As a result, I still believe that the statement about
not having to trim the F-16 unless the airplane is asymmetrical
is always valid.

Anyway, I am now on short final (usually over the
overrun) with 13-degrees AOA, slowly dragging the power
to idle, looking for the ground effect (seldom a pitch
change) to cushion the touchdown, and rolling the aircraft
on the ground.

Well... not always. Why? One of the main
reasons why you seldom feel you made a smooth
touchdown is in the landing gear. It is a very stiff
landing gear, without very much travel. Several
other airplanes I have flown have oleos in the gear
that give the impression they are about 18 inches in
diameter and have a stroke of at least four feet. Such
a cushion will cover up a lot of sins and is probably
why you thought you could do such a good job of
landing your previous aircraft. Unless you do a
nearly perfect job, you're going to come away with
the impression that you had a firm (sometimes
Firm, or even FIRM) touchdown in the F-16. Worse
yet, the airplane bounced. Most of the time it hasn't
really bounced. The aircraft is moving up slightly on
the gear, but not enough to actually pull the wheels
off the ground. Have some of your squadron mates
look at your landings and then collate their observa-
tions with what you remembered or recorded on
the HUD film. You will find that, quite often, what
felt like a less-than-perfect landing really did not
look too bad from the outside.

But once you get the impression that you
bounced, you open Pandora's box for a plethora of
possible mistakes that make the landing seem like it
is hard to accomplish.

Let's take a second to go off on a slight tangent and talk
about some aerodynamics. Just bear with me and we'll get
back to the bounce. The F-16 will fly as slow as about 105
knots at 25 to 26 alpha. (It used to be even slower, before the
airplane started getting its "middle-age spread." We never
seem to learn anything from history.) But we're forced to
land the airplane at only 13 alpha because of the geometry as
to where the landing gear is located and where such things
as engine nozzle, speed brakes, ventral, etc. are placed. The
point is that the F-16 is nowhere near ready to stop flying
when it touches down. Remember this. You'll see it again.

Now, back to the bounce. Whether you did bounce or not,
if you now get in and stir the controls (i.e., pull back on
the stick) the airplane will come off the ground for sure. Also
— as I discussed in the first part of "Semper Viper" — you do
not have to increase back pressure after touchdown to main-
tain your attitude, as you've had to do in the past with other
aircraft. If you insist on doing so, you'll pull the aircraft off
the ground even if you made a perfect touchdown.

So, any combination of slight bounce to moderate
bounce — plus not paying attention to the amount of back-
pressure you're using — can complicate an otherwise
normal landing. Because of the stiff gear, you can expect a slight
bounce (or at least an impression of one) on nearly every
landing. Just hold the attitude and the aircraft will touch
down again shortly thereafter in the same attitude. Of
course, if the touchdown has been complicated with an
asymmetrical main gear touchdown (i.e., one wheel before
the other), a gusty crosswind, or jet wash, etc., then you're
going to have to make a series of control inputs as well as a
power change. But if the approach has been otherwise
normal, you should have to do nothing but watch the aircraft
touch down again shortly thereafter.

There is also the matter of crosswinds to consider. The
airplane is no problem in crosswinds. It has a large margin
built into the dash-one limits. All you have to do is crab into
the wind and fly a wings-level approach as you do in normal
winds. Again, if the winds are gusty, you're going to be

Make a conscious effort to look at the
runway and the surrounding terrain
to judge your height above the ground
accurately.

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making more control corrections than normal. Go ahead and touch down in the crab, using the power and flight controls as usual. The only real difference is that, as the nose comes down, be ready for the upwind wing to want to come up. Add whatever roll command is necessary. The airplane will usually align itself with the runway as you lower the nose. If not, then use whatever rudder is appropriate.

As always, the usual requirements to lower the gear still apply sometime about now.

But once you get the impression that you bounced, you open Pandora's box for a plethora of possible mistakes that make the landing seem like it is hard to accomplish... The point is that the F-16 is nowhere near ready to stop flying when it touches down.

For you guys flying those airplanes with the drag chute, the same holds true. Make a normal landing using whatever crab is necessary, then deploy the chute. The airplane doesn't care if you're in a two- or three-point attitude. It actually doesn't care if you're on the ground yet. Notice that it takes about two full seconds for the chute to deploy fully after you move the switch. If stopping distance is really critical — due to glare ice, combat damage shortening the runway, or whatever — then hit the switch about two seconds short of touchdown. Use a little caution, however, the first few times you try this, because the airplane stops when the chute comes fully open.

With a full chute just at the touchdown point, and the proper braking procedures, it's easy to produce landing rolls of less than 1000 feet on dry runways with a light airplane. If the crosswind is near the limits, you can expect some directional control problems, but the technique is still to use the chute. Just keep your hand on the switch. You can realize the nice feeling of deceleration as the chute opens, then release it immediately if it looks like directional control is becoming a problem — regardless of the RCR.

Let's digress again and talk about alpha at touchdown. How much is too much? If the aircraft is sitting on the ground in a static condition, parts of it will start hitting the ground not too much past 13 degrees. But if the airplane has anything near flying airspeed, you can sometimes get away with almost 15 degrees without problems. A big GOTCHA, however, is sink rate: if you touch down with too much of it, the clearance angle starts to come back toward 13 degrees again. A lateral/roll input at the same time (to compensate for a gusty crosswind) is also a big pitfall. The moral is that it's not a good idea to be touching down above 13 degrees — unless you want to become famous with your supervisor. But once you're firmly on the ground, you can go to 13, or even slightly beyond, without hitting anything. This is important if getting stopped on a slippery runway is the item at hand (i.e., any braking).

While we're talking about AOA at landing, you guys who are just checking out in the airplane will want to note that the F-16 is one of the few aerospace vehicles where you can see the touchdown point while you're in a landing attitude. In many other airplanes you've flown, you sometimes can't
Regardless of the RCR, the nose will eventually come down, even if you're using full back stick. This will happen real quick on a dry runway, but sometimes involves a long delay if the buffs and polishers have had much time to work on the runway. But don't insist on holding the nose up much below 80 knots, as a gust can rapidly increase the deck angle without your being able to do much about it — in much the same way as you depart if you're slow while airborne and insist on forcing the issue.

As soon as the nose gear approaches the runway (you don't have to wait for it to get completely on the runway, but don't get too eager), hold the override to get the speed-brakes full out, keep the stick full back (every little bit helps — even if it's only two feet), and bury the pedals if you haven't already done so (if stopping distance is a problem).

Notice that I bring the nose gear to the runway with the brakes and not the stick. It can be done, but you are asking for problems if you try to pin the nose gear on the ground using forward stick. Doing so can induce a lot of other problems, not the least of which is that the hook will very likely miss the wire if a barrier engagement is in the cards. But if you still have eight thousand feet to go on a dry, 12-thousand-foot runway, use your head and disregard the last instruction about burying the pedals — just go for a reasonable taxi speed. This technique is the best way to stop the airplane. And it works the same, regardless of the runway conditions. You don't have to use several different techniques as the conditions change.

See the runway — much less the touchdown point — once you establish the landing AOA. The lesson here is that there's a different (that word again!) sight picture associated with landing the F-16. Resist the temptation to keep pulling the nose up as the ground approaches. This is a sure-fire way to get the kind of attention none of us need.

Like the book says, the maximum braking occurs in a three-point attitude with maximum anti-skid braking. This is true on a dry runway but is not necessarily the case if the runway is slick for whatever reason. The unfortunate part is that, once you let the nose down, you cannot get it back up without adding power (not recommended). So it helps to practice the same technique on every landing. I've found the following works best: Touch down in the manner we've already discussed, and hold 13 degrees — or, if you feel real confident, a little more than 13 (the point is that aero braking is much less than 13 degrees doesn't buy you very much). Then start down on the brakes at a controlled rate. If the braking action is good, the nose will immediately start down; but if the runway is slick, you'll find you can hold the nose up and the resulting aero braking is more than you would obtain in a three-point attitude. The “moment” of the brakes will try to bring the nose down, but you can control it by adding backpressure. It's important to realize that I am not adding any backpressure until after I start wheel braking. If you get too eager, you'll sure as hell pull the aircraft off the ground, just like we discussed a few lines ago.

**THE F-16 IS NOT HARD TO LAND!**
I have had several questions lately concerning aspects of the F-16 that I have covered in earlier Code One issues. This short article will be a potpourri of answers in an attempt to amplify some of the points I made in previous articles.

With an eye to no particular order let's begin.

I have had several inquiries that stemmed from the information I put out in the article about landing the F-16 (Vol. 2, No. 3). Many of them concern the point I made about using the brakes. Several of you still want to tie an airspeed to the time you start using the brakes. This idea is not at all necessary. As soon as you are sure that the airplane is on the ground to stay, you can start what I described.

If you recall it goes something like this. After I am sure I am down for good I make certain that I am holding
thirteen alpha or maybe just a little bit more (but be caaarreeeeeful — the added drag of scraping the speedbrakes, tailpipe, or horizontal tail doesn’t help stopping much, but it can add a lot of notoriety that none of us needs.) Landing at normal weights you are going to be around 100-120 knots at this point. But it makes no difference if I have landed heavy and still have 150-160 knots. I recheck that I am holding the attitude that I want and start down with brake pedals. The nose usually will try to start down within a few hundred feet. But, this reaction will vary over a large range depending on the RCR at the time. As the nose starts down, I smoothly start adding back pressure to hold the attitude I want. (Remember my comments about starting too soon and pulling the aircraft off the ground. This will only result in delaying the point you can effectively start this whole braking process!) Depending on the conditions, I sometimes find myself with what feels like nearly full aft stick and nearly full pedal travel just before the nose comes down to the runway.

(Again — look for a wide range of reactions depending upon the present runway conditions. If you are on a nice dry runway, the nose will come down very quickly. But...if it is nice and icy...)

As the nose approaches the runway I make sure the speedbrakes are fully extended (careful — not too fast — make sure that the nose is definitely started down, certainly something less than eight to nine alpha, before you lean on the switch to override the 43 degree limit) while continuing to hold full back stick. At this point interject a little of that jet-age wisdom we have been giving you credit for having. If the end of the runway is still rapidly approaching, continue with full speedbrakes, full back stick, and the pedals welded to the floor. But if I observe what appears to be a large portion of the interstate highway system extending all the way to the horizon, I come off all the inputs I am making and let the airplane coast to the end of the runway at a reasonable taxi speed. Some of the techniques I have heard about making every stop a three-point, max antiskid braking effort are not really valid in every instance. One reason I have heard is that less heat goes into the brakes as a result. This is only true if the aircraft is pulling one way or the other because of an improperly adjusted nosewheel/nosewheel steering. If this is the case, you are going to put more BTUs thru one side or the other if you make a slow leisurely stop, as opposed to a max effort. Otherwise, you are better off using a combination of aero and wheel braking to get the aircraft down to a reasonable taxi speed. As I said before, this method works regardless of the present conditions and doesn’t require you to change your technique every time the weather changes. This technique also works for the F-16s that are equipped with the drag chute. The only difference is that the drag chute compresses everything into a very short space and time.

Another item that has to do with landing the airplane is my comment about pitch and/or roll inputs in the flare (Vol. 2, No. 3). As I said in the first article, you are better off in the beginning to set thirteen alpha on short final and then control the rate of descent and the touchdown point with power. This will very nearly always result in the most consistent touchdowns. After you are sure that you do this repeatedly, then you can start making control inputs during the flare. The most important item to remember at
this point is to make sure that the control inputs are small. And when I say small, I mean SMALL. As I have said on more than one occasion, the F-16 is a very responsive airplane that does not take kindly to gross control inputs. Make your inputs when they are necessary, but keep thinking, tiny!

Now, having said all that, I must point out that I have found myself in heavy jet wash that required immediate and large inputs. So don’t sit there and feel that because I said small inputs that that is all there is to landing the F-16. The baseline I gave you is for consistent winds (including calm) and the absence of jet wash. Gusting winds, especially gusting crosswinds and the presence of somebody’s wake will require you to increase the frequency and magnitude of your control inputs right now! Another item that sometimes gets overlooked is the size of the required power corrections. On several occasions I have seen people trying to row the aircraft around the pattern with the throttle. This is not the best technique either. Just as the airplane is very responsive to stick inputs, it is almost as responsive to power changes. Like the stick inputs, the power changes must be made as soon as they become necessary, but the size of them is much smaller than most other aircraft you may have been flying.

Using the flight path marker, especially after you are established on final, will give you an immediate clue when the changes are necessary. And, if you pay close attention you will see you are making power changes on the order of one-half percent. So, remember, on both counts, timely but usually very small corrections result in the best approaches and landings.

The next item I have several questions about concerns the “bite block” I advocated using when you think you are going to be pulling a lot of G (Vol. 1, No. 2). This appliance is just one more thing to add to everything else that I described. It is nothing magic but adds to whatever else you are already doing. Make sure you describe the device correctly to the orthodontist when you ask for one. The device is not just a mouthpiece you may have been fitted for when you were playing football. I have heard it described two different ways. Some call it a TMJ appliance. TMJ is an abbreviation for temporomandibular joint. Others term it a MORA, which is short for mandibular orthopedic repositioning appliance. As I said before, I saw an article describing the device in the 2 June 1980 issue of Sports Illustrated. The idea was the brainchild of Dr. Richard Kaufman of Long Island, New York, for some of our Olympic luge team members. But I felt that it had
some application to our business. I had one made and am now convinced that it works. Get the device made, snap it in your mouth, and go fly. Don’t just think about this new item to the exclusion of everything else you are doing. When added to the other things, I feel certain you will agree that it does increase your overall G tolerance. Remember — attention to details (all of them).

With the best of intentions on my part in describing the F-16 in Code One (Vol. 1, Nos. 1, 2, and 3), I still hear that some of you in the field are departing the airplane from time to time. STOP IT! I made the point several times that if you know just what the limiters do for the airplane you should be able to take advantage of the flight control architecture to fly the airplane to the limits of the envelope, without any fear of losing control of the airplane. If you smoothly approach the limiter, you will stay out of trouble. Take note that when I say smoothly, I don’t automatically mean slowly. The two do not necessarily have to happen together. When you are driving home in the evening, you don’t come abreast of your driveway and then rip the steering wheel a half turn or more left or right to turn into your drive. You wouldn’t expect A. J. Foyt to come roaring down the front straight at Indy and enter turn one by yanking the wheel hard left.

Why do you think you can get away with it in an airplane? You can bet your buns that AJ is doing his damnedest to go faster than everybody else, AND he is doing it by being smooth. I frequently use maximum roll rate commands and I sometimes find myself against the AOA limiter. But I—don’t ever—try to get to these limiters instantaneously! And most certainly I do not try to get against both limiters at the same time. A big part of your SA in the middle of any kind of flying should include what you are doing with the stick. It should also be ingrained by now that the airplane behaves differently as you increase the altitude. A maneuver you can get away with impunity at 10,000 feet will sometimes result in an immediate departure at 40,000 feet. But, once again, earn the flying pay you are taking home. SA should be able to tell you your altitude plus or minus a couple of thousand feet without any conscious effort! Use your head for something other than a model for the PE guys to pour your formfit helmet over.

If you guys have any other questions please let me know. I am always happy to try to clear up any concerns you may have about the Electric Jet. Keep the cards and letters coming.

Check Six!
Those of you familiar with automobile racing will immediately recognize the names of Roger Penske and Mark Donohue, an owner/designer and engineer/driver team that dominated automobile racing for a long time. Each time they would enter some new class of racing they would immediately begin to be a threat to the “old heads,” and would soon be winning everything in sight. On one occasion, Mark was being questioned by reporters as to the secret of his success. He replied that he had an unfair advantage . . . and let the question drop. For weeks this answer drove the reporters nuts as they tried to figure out just what this “unfair advantage” really entailed. When finally pressed further, Mark said this unfair advantage was, simply, attention to detail. Please keep that remark in mind as you read the remainder of this article.

Several F-16 accidents give all the indications that the pilot hit the ground in a perfectly good airplane. One reason advanced for some of these accidents was that the pilot was unconscious at the time.

Why was he unconscious? (A rhetorical question.) It appears that he had pulled more g than his body was capable of withstanding. How could this happen? Are you not a dyed-in-the-wool fighter pilot, ever capable of sustaining at least 12 g?

Can you really? Any time you want? Let’s look a little deeper into the mechanics of functioning effectively (the operative words here) under the g loads the F-16 is capable of delivering.

How about your own pink body? What kind of physical condition are you in? Are you really? Do you take proper care of the carcass the genetic pool provided for you? Do you get the proper diet? Do you get the right amount of rest? Do you sometimes fly despite a partially debilitating illness? Worse yet, do you sometimes indulge in a little self medication for the aforementioned illness? Do you take good care of the equipment issued you? Do you use all the equipment that is available? Do you drink a little too much? Hummmmm?

If you’re serious about flying high-performance fighter aircraft, then you’d better get serious about just how you condition your own body. Consider the following:

- How much exercise do you get? The idea here is not to become a marathon runner or a triathlon competitor. In order to be really in shape for these events your blood pressure would become too low to fly fighters effectively. But neither can you emulate a sloth, swilling beer in front of your TV set every evening and weekend. It’s up to you to establish a routine that will provide a lot of walking, a moderate amount of running (especially up stairs), a reasonable amount of sit-ups, and a general routine of weight work in order to be in the physical condition necessary to really use the airplane to its maximum.

- How much rest do you get? Do you really get a good night’s sleep before you go fly? If your body is not rested and ready, then neither are you. I think it was Casey Stengel who, when asked by a sports reporter about his rules concerning sex before the “big game,” replied, “Hell, it’s not the sex that gets you, it’s the staying up all night looking for it!” The moral of the story is this: if you’re accustomed to getting six, seven, or eight hours sleep a night, then don’t stay up to one or two in the morning and expect to be a hundred percent four hours later when you strap yourself into your F-16.

- Do you eat right? Just like your jet, you need the right kind of fuel in order to fly. I’m not going to go into a nutrition course here. You all know what is contained in a “balanced diet.” Make sure you eat the right kinds of food before thrusting yourself into the high-g environment.

- Do you smoke? There’s been a controversy lately about “blood doping” by some of our Olympic athletes. What they’ve been doing is extracting and saving some quantity of their own blood. Then, just before the big event, they infuse the additional blood into their system. The idea is to “supercharge” their blood system with an additional amount of oxygen-carrying red blood cells. This is certainly nothing that we could or even should try to do ourselves, but why go to the opposite extreme and tie up a large proportion of what red blood cells you have with useless CO? DON’T!

- Then there’s the touchy subject of drinking. Fighter pilots are somewhat the victims of a macho, hard-living, hard-drinking image that has existed since WWI. I’m not a teetotaler. I drink something besides diet soft drinks. But I don’t
drink more than one beer if I'm going to be flying the next day (especially if I'm going to be flying EARLY the next day). We're nowhere near the limit of a human's ability to fly airplanes, but you're sure cutting into your margin if you insist on staying up late and trying to drink everybody under the table. You are NOT sober the next morning if you try to go fly. For that matter, you can sometimes find traces of alcohol in your system more than 48 hours later. A very insidious side effect is that alcohol in your system can confuse and partially replace the fluid normally contained in the inner ear, which can screw up your inner ear calibration and give you erroneous inputs under g just when you can ill afford them.

OK. Enough about your body. It's all yours, but it's up to you to take the proper care of it. Just don't forget that the high-g environment you're trying to exist in is more than the average citizen can tolerate. You must have the self discipline not to fall prey to the wrong fighter pilot image. That should have changed about the time we quit flying P-51s and P-47s.

Now let's talk about your equipment. In what kind of shape is your g suit? I know of two individuals who thought it wasn't macho to wear a g suit. (One of them is a mort. In an airplane. While pulling a lot of g.) Make sure your suit is in good condition and is properly fitted; i.e., snug if not downright tight. Do you always make sure you zip up the thigh zippers? I'll bet you sometimes forget. Do you always plug the sucker into the connection — properly or otherwise? (The new connectors will go a long way to insure that the connection stays put once you've pressed them firmly together.) Make sure you have the g suit refitted after it stretches (they all do). The new quick-fill valve now being installed in the airplane will help a lot.

I definitely get the impression that we're not all doing the right kind of M-1/L-1 (select one). Make SURE you know just what it is that you're trying to accomplish with the maneuver. In its simplest terms, you're trying to artificially raise your blood pressure while pulling g. Over any period of time, it's up to you to provide about 80 percent of your g tolerance by this straining maneuver. EVERY muscle in your body should be tense. You should feel like you're hyper-constipated. Your thighs and calves should be tensed. You should be trying to curl your toes out the bottom of your boots. You should be straining with every muscle in your upper body. You should also be aware of your breathing. The worst thing you can do is hold your breath while pulling g. I've seen people who try to do exactly that (not recommended)! The medical community tells you should be taking a breath about every three seconds. I'm not sure this is true for each and every one of us, but it seems fairly close. I breathe at about that rate. Check yourself. It's easy. Just go hot mike during your next engagement and then listen to the tape. What you should hear is a sharp (i.e., rapid) intake of breath, about three to five seconds of relative silence while you really bear down with the M-1/L-1, and then a sharp exhalation followed instantly by the next inhalation to start the next cycle.

Now here's a g-tolerance tip I'll bet you haven't heard about. I saw an article in the 2 June 1980 issue of Sports Illustrated that really started me thinking. The article was about our Olympic Luge team and how they had been helped by a dentist. It seems that he'd made them a mouthpiece to wear during their runs on the luge to improve their ability to pull g during the turns. I figured that if it could help these folks pull three to four g for less than ten seconds, then it should certainly be able to help us pull nine g for a longer period of time. I had the dentist at Edwards AFB make one for me and I'm convinced it improves my g tolerance by at least one g. This is just my subjective judgement, but I'm sure that the improvement is at least that much. The kind of mouthpiece I'm describing is a TMJ bite block. It is very important that you make this distinction. It is NOT the kind of mouthpiece you wear playing football or any other contact sport. It's not there to keep you from chipping your teeth. TMJ is short for temporomandibular joint ("jawbone" for you ag majors). The principle involved is that all of us have some degree of misalignment as to how our teeth match up. We subconsciously hold our jaw in the proper position so our teeth mesh. This TMJ bite block helps align the jaw properly so we can now relax and not have to use unnecessary muscular strength. It also gives us something to bite on to help strain. The more muscles we can use effectively, the higher we can raise our blood pressure to combat g effects. I know some of you think this is a bunch of BS, but give it a try before you write it off. Go to your dentist on base and tell him you want to be fitted with a TMJ appliance. I'll be surprised if you don't think it makes an improvement in your ability to sustain g. It is not magic. (The bite block is just one more item to add to what you already should be doing.)

Before I end, I want to discuss one more aspect of pulling g. There's some concern that the ability of newer airplanes to pull g in a hurry, or "onset rate" (specifically the F-16, but with its new g limiter the F-18 is probably as quick) decreases your ability to pull g. I don't see where this is a player. If you're flying the airplane, it should never be a surprise that there's suddenly a rapid increase in g. If the message goes from your brain to your right hand ("Mongo, PULL now!") it should also be able to send a message in parallel to the REST of Mongo—"Here comes a lot of g!" Although these new airplanes are capable of high onset rates, you're the one controlling the onset of the onset. Understand? It should come as no surprise, then, that there'll be a lot of g to contend with shortly after you yank on the stick. You're the one in control. Get ready early! Just because you know that the g limiter will prevent you from an over-g on the airplane does not remove your obligation to prevent an over-g on YOU!

Attention to detail. You can make it work for you. I'm no superman, but I'll be happy to demonstrate a constant nine g for more than 45 seconds. Any time you'd like. Because I'm looking for any detail that will help me win . . . I'm looking for that "unfair advantage."

Check six.
I was tickled that the HUD article (head-up display, not Paul Newman) Joe Sweeney and I wrote for the Winter 1986-87 issue of CODE ONE created more than a moderate level of interest. However, on several occasions, in several places, I have been stung by “expert” opinions about how the HUD in the F-16 is fraught with “insidious” failures. Holders of these opinions appear to have more than their fair share of metaphysical insight, extrasensory perception, clairvoyance, intuition, crystal vision, metapsychosis, or a priori knowledge. I suspect what they don’t have is a general knowledge of just what the HUD is all about. Or, worse yet, they don’t have the objectivity and independence of thought not to parrot some staff officer’s attempt to lend credibility to the edict from on high: HUDs WILL NOT BE USED AS A PRIMARY INSTRUMENT REFERENCE!

To be fair, though, not all of the article’s readers were so confused. Many are honestly trying, as I am, to contribute ways to improve the fighter pilot’s knowledge of the HUD. They will not be put on my list of dilettantes. (That’s dillytaunts for you Ag Majors.)

Because this is important, I have done some exhaustive research on the subject and have put together a list of insidious failures with the HUD in the F-16. Here they are:

1. 
2. 
3. 
4. 
5. 

Well . . . ? Do you notice a pattern starting to emerge? See? It’s not that hard to break the code. There are NONE! Passionate declarations about all these failures just lend another data point to the Drydenian theorem of conservatism of intelligence, to wit: For every PhD, there is always an equal and opposite PhD. Furthermore, since the head-down ADI (attitude direction indicator) gets its attitude information from the same source as the HUD, i.e., the inertial navigation system (INS), why wouldn’t these same “insidious” failures be just as insidious with the ADI? My “experts” don’t want to answer that one.

So I’ve made my point. Let’s take a few minutes now to expand the discussion on the use of the HUD that Joe Sweeney and I started a few issues back. Please recall the original article we offered as Part 5 of the “Semper Viper” series in Code One. Everything still applies. Joe made the very valid point that the HUD is no better or worse than the sources from which it derives its information. For example, the form, fit, and function INS that is provided on the F-16 is GFE (government-furnished equipment), and is the source of information for the pitch ladder and velocity vector. Even more important, Joe mentioned the built-in self-test in both the source “black boxes” and the HUD itself. The HUD is designed with very stringent requirements that result in the fact that, if anything is the least bit suspicious, the HUD no longer displays that part of the information. In addition, the systems will report the detected failure on the pilot’s fault list (PFL) so there is no doubt that the failure took place. Thus, the pilot can make allowances for the problem.

How will some of these failures look to you in the cockpit? For instance, what if you have an INS dump completely? What kind of clues can you expect? The approach that Joe and I mentioned still applies. If the HUD doesn’t like the information it is getting, it doesn’t display it. Period. Therefore, the velocity vector will disappear and the pitch ladder will probably freeze or disappear completely. It is apparent even to the most casual observer that you have a problem. Your corrective action? If you are on visual flight rules, no sweat. If you are in the soup, go immediately to the standby ADI, as the normal head-down ADI gets its information from the same source as the HUD (and also will most likely be wrong). Only after you are sure that the ADI head-down is working, should you stop using the standby as the center of your crosscheck. After you are sure you are upright, you can check the PFL and I’ll bet it says the INS failed. Nothing insidious here.

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Holders of “expert” opinions about how the HUD in the F-16 is fraught with “insidious” failures... appear to have more than their fair share of metaphysical insight, clairvoyance, crystal vision, or a priori knowledge.

But what if you have a problem with the central air data computer (CADC) or the air data converter (ADC)? An ADC 003 that indicates a problem with the bus traffic from the ADC to the HUD will result in a PFL to that effect. However, you should know well ahead of the point that you consult the PFL as the airspeed and the altitude scale numbers disappeared when the malfunction occurred. The tic marks on the scales still remain as an indication that you have the scales selected, but all the numbers have vanished. Nothing insidious here, either.

In my earlier observations about the HUD, I mentioned the only possible “insidious” failure — and even that one required an obvious failure PLUS a switch change on your part. That one involved the erroneous pitch information: OK straight and level, but, as you roll in some bank, the pitch indication is wrong and gets worse as the bank angle increases. This can happen only if there is an FCC (fire control computer) failure after you have selected drift cutout. (You must have both present; neither by itself can produce the same result.)
Should this occur, you will know immediately. In the C/D aircraft, you will get a PFL displayed on the data entry display (DED), but in the A/B, it will be displayed only on the face of the FCNP (fire control navigation panel). In both cases, nearly all the data on the bottom of the HUD will disappear. If you are looking at the radar, you will notice that nearly all the target info has disappeared. If the gear is down (in either model), the AOA bracket on the HUD will disappear. I don’t think this can be classified as insidious, either. We learned that this was the result of an equation screw-up in the HUD, and it is not present in Block 40 aircraft and is being corrected in the Block 25/30 airplanes. The corrected equations have been supplied to Ogden for the Block 155 birds. In the meantime, if you detect an FCC failure, make sure you’re not in drift cutout. So, let’s face it. Possibly one, and ONLY one, insidious failure, and that is being rectified.

Now, having said all that, my years of experience still tell me that there are no absolutes. The engineers assure me that the system is designed to work a particular way, and I feel that is the case. I am not saying that some off-the-wall, totally insidious failure is not possible. (My innate suspicious nature warns me against that.) I’m a pilot first and an engineer second. So, keep your wits about you. It just might happen that the groundspeed calculation in the INS runs away and gives you some screwy indications without tripping the MFL flags. So, use your head. If the display changes some weird way or if it is not responding to a control input you are attempting, be wary. You are the pilot. The government does not pay you a bonus over the ground-pounders just because it thinks you are a good guy or you are particularly good-looking. EARN the flight pay you take home!

In the -34, you will notice several PFLs that state that the HUD is degraded. Most of these have to do with deflection voltages that mean some of the information will not be presented in exactly the right place on the HUD display. For example, the pitch ladder will not necessarily be exactly to the correct scale. But the velocity vector will still be displayed with the correct relationship to the pitch ladder so the aircraft control is not in question. Before I get any I-told-you-so’s from the nitpickers, may I point out that is what you have all the time with the ADI. The thirty- to forty-plus degrees in both directions you can see on the face of the instrument is not real-world, either! Nevertheless, the PFLs are important if you are participating in Gunsmoke, Long Rifle, etc., as it does have an effect on the aiming references on the HUD. These PFLs and MFLs (maintenance fault lists) are certainly part of ensuring that the F-16 is completely operational for the competition. Or for combat. Write them up when they happen!

My conclusion, as you may have guessed by now, is that trying to find reasons why the HUD cannot be used is futile. All of those you can find are bogus. Let’s get on with the program!

Aside from the dilly taunts from the uninformed about alleged nastardly, sneaky failures of the HUD, I have been asked some really good questions that I want to address. I just had to get this other stuff out of the way. (Thanks for hanging in with me so far!)

The first involves using the HUD for an instrument takeoff. It can be done very nicely. This point, and those that follow, have to do with just what information you are looking at as you face the HUD. I talked about the velocity vector in the previous article and how this is the different piece of information that is missing from any ADI you have used in the past. But the HUD still has all the information that any ADI had before, i.e., all the pitch and roll information, plus all the performance instruments conveniently grouped close by. (OK, OK . . . No tack. Not that important.) The velocity vector provides the information as to just what the flight path of the airplane is doing and you can determine what this is by viewing it directly! This is what you had to do indirectly in the past by observing and interpreting the ADI and the several performance instruments that go along with it. Since all the information is still present on the HUD that was included on the entire instrument panels of the past, you can use the HUD in the same way you did in your previous airplane. I mentioned using the standby reticle before, but the same holds true with any fixed part of the HUD. So, if you cannot see the velocity vector for any reason, you can still fly the aircraft head-up using the HUD. During an instrument takeoff while the aircraft is still on the ground, for instance, the velocity vector is useless, since the aircraft is not yet flying. If the INS has failed, and you have done an in-flight alignment, the velocity vector will not be available. If you are at an angle of attack greater than about 15 degrees, you will not be able to see the velocity vector off the bottom of the HUD. If you are very slow with a lot of crosswind, the velocity vector will be off one side of the combing glass. In every case, the HUD is still perfectly useful. Take the time to determine the approximate size (in degrees) of all (or at least most) of the fixed displays on the HUD. Once you have a feel for their size, you can then make pitch corrections against the pitch ladder in exactly the same manner you do with the ADI approach in any other situation. In other words, any fixed part of the HUD is exactly the same as the small aircraft symbol you have been using on the ADI in the past.

The only difference is that the small aircraft happens to be in the center of the instrument.

Consider an instrument takeoff. As the F-16 sits slightly nose-down on the ground, you will notice that the horizon line is just above the top of the airspeed and altitude scales. Notice also that the ten-degree down-line is just below the info at the bottom of the HUD display. So it stands to reason that the display is close to ten degrees wide, n’est-ce pas? So, during a takeoff where the visibility is truly poor, just add backpressure until the horizon line has moved down to just below the info at the bottom of the HUD display. In doing so, you will have raised the nose of the aircraft very close to ten degrees: right in the middle of the 8 to 12 degrees the Dash One calls for! Wonderful!

You will see the velocity vector start to move up, indicating the aircraft is now off the ground and climbing. See how easy that is? From that point, continue using the velocity vector as you normally would. The same holds true any time the velocity vector is not displayed on the HUD, but you still have a valid pitch ladder, i.e., you have not received information to the contrary through the warning and caution system. Even if you can see only the very end of the pitch ladder lines, you can still make one, two, or nearly any number of degree inputs by referencing the pitch lines to any fixed part of the HUD display and pushing or pulling on the stick. I am not saying that this is any kind of ideal presentation. But I am saying that there is absolutely no reason to become disoriented or, worse yet, lose control of the airplane just because you have a less-than-perfect display for that short a period of time. So, even if I were faced with a partial INS problem that did not allow use of the velocity vector, I would try to obtain an in-flight alignment, turn on the standby reticle, turn on the vertical velocity scale (I don’t use it if the velocity vector
is working), and proceed to fly, using the HUD the same way I used the ADI etc. in previous airplanes. What I just described doesn't really exist. But... with a subtle software change, the HUD could look to the CADC for the vertical velocity instead of just turning it off when it detects bad INS poop. This certainly should be a change candidate. Think about it. This technique is much easier, since all the information is in the same place — hence an easier crosscheck. Only if I couldn't obtain a valid pitch ladder on the HUD would I resort to using the head-down displays. In other words, there is a lot of information on the HUD that is there for the taking if you choose to make use of it. A good example of that is the

![Warning... trouble?](image)

point I made in the previous article about the ability to use the C/D HUD to determine the radial I am presently flying on or through.

Simply perform the following mental gymnastics. Look at the heading of your jet, take the relative bearing of the bearing pointer that you have selected with the latitude/longitude of the TACAN station, and add to or subtract from your heading. (For example, if the relative bearing is to the left of the nose, subtract. If the needle is to the right, add the relative bearing to your heading.) Then take the reciprocal and that is the TACAN radial you are on. Sounds a bit difficult, but, with a little practice, it will become a snap. To give a practical for-instance, I have the coordinates of the TACAN station at Nellis under a convenient way point. I am heading 180 degrees (south) and the relative bearing to the way point is 90 degrees left (pointing to the left wing tip). I have to be within a degree of the 270-degree radial out of the TACAN station. A big boost to my SA (situation awareness) if I am in the weather. It appears that it will be possible to

install the C/D wide-angle conventional (WAC) HUD in the A/B airplanes during or after the OCU (operational capabilities upgrade). The WAC HUD is going in the A/B airplanes we will be delivering to the latest A/B customers. The present HUD in the A/B is perfectly adequate and better than any existing head-down ADI system, but the WAC HUD is still nice.

You C/D drivers will like the subtle changes that the 30B software will provide in the HUD. The horizon line has been extended to provide a better clue (a further extension would be better still) and a roll index has been added at the bottom of the display. Although some of you guys will prob-

ably like this a lot, I have mixed emotions on this one. I would like to see the roll index as a de-clutter option, since I still get all the roll info I need from the position of the velocity vector in relation to the pitch ladder. I would be interested in hearing your impression when you get a chance to see it.

Therefore, to make short work of it, the insidious failures that the Chicken Littles keep talking about do not exist. First, the HUD is designed to make it plain, in no uncertain terms, that it has a failure, and failures truly are few and far between. I personally have had only four problems with the HUD in thirteen years of flying the F-16. They were very apparent when they happened.

Second, the HUD provides a wealth of information that contributes greatly to the pilots' SA as to the attitude, energy state, and positional info that is there for the asking. Why not use it? Better, easier, and more precise control of the aircraft will be the only result. ■
Viper Charmers Learn New Tricks

by Joe Bill Dryden
O.K. OK. One more time. The head-up display does not cause spatial disorientation. The HUD is a better way to fly instruments.

Of course, this presupposes that you know how to fly basic instruments in the first place. In previous articles for Code One I have tippy-toed all around this subject. I have said, with quiet understatement, that you have not been trained to fly in the weather. I did not elaborate. The time has come, however, to stand up and speak the unspeakable: emperor est nekidusJaybirkud. For you ag majors, that would read the emperor has no clothes. (I hope there are no classic Latin instructors on the magazine distribution list.) Even if your Latin is as shaky as mine, you can probably deduce that we’re on to something that nowadays is seldom, if ever, haulied out in the open for serious discussion. So...take a deep breath. Here it is.

Until you put real people, in real airplanes, and fly them in real weather, — with the luxury of an IP growling, “Not so fast, dummy” — you are not going to train people who have a real capability to fly in weather.

Until new pilots have been shown how to budget and/or ration their time, depending on the task at hand, SDO incidents probably will continue to plague us. This assertion is entirely consistent with Captain Milt Miller’s reasoning in his great dissertation on low-level flying. The logic of an awareness of time to ground impact for a particular altitude and task should be processed in the same manner in regard to SDO (and perhaps ground impact as well) when you are flying without benefit of a visible horizon. From the insights of a conscientious and caring instructor (plus a lot of self-inspection on your own) you should be able to develop a feel for just how much time you can devote to any other task except watching your attitude (preferably on the HUD). And it is imperative that you guys recognize this fact. Countless man-hours and millions of dollars have been expended in an attempt to correct “supposed” HUD deficiencies that are, in reality, directly attributable to two things. They are simply that the pilot’s internal time clock has never been correctly regulated and that the pilot has not been completely conversant with what the HUD is saying.

Regardless of the type of display that you use (HUD, head-down, MFD, steam gages, etc.), you are going to look up suddenly and see an attitude you don’t instantly recognize if you allow yourself to be distracted by some other task. However, you can handle it if, from pilot training and your own reservoir of experience, you know that the task at hand, when combined with the present weather conditions, requires 10, 20, 50, or even 90 percent of your attention to stay oriented. The voice of experience might tell you, for example, that you had to devote 100 percent (that’s nearly all of it for you BA majors) just to stay right side up. Ergo, you would ignore any other request on your time until the situation eased, verdamit? Just like the book says in nearly every case: maintain aircraft control. You cannot develop this feeling for available time by getting the majority (read waaayy too much) of your training in a simulator. The myriad destabilizing stimuli are not available in simulators, for one thing. For another, you cannot remove the feeling that the floor of the Sim Building is comfortably and solidly beneath you, or, put another way, that you’re not fixin’ to die!

For these reasons, then, you may not have a clue about what your personal reaction would be while on final at Hahn with the low-level-fuel lights starting to flicker, a partially obscured ceiling, a vis-88th mile in blowing snow, and a reported RCR less than six! (The same thing applies in the middle of the IO — that’s Indian Ocean for you landlubbers. The only difference is that RCR isn’t as important on the ship.) That’s why it is vital to take the time to evaluate how you fly instruments. If you cannot mentally visualize what your personal response would be to various types of weather, if you don’t have a feel for how much attention you must pay to the attitude of the aircraft, if you don’t have a feeling for just how much time you can spend looking for the proper approach plate prior to the IAF; and if you’re not clear and certain about the proper response when the controller changes the runway while you’re on the downwind at 2000 feet AGL, then now is a very good time to think about what your personal responses will be in these situations. And while you’re thinking about that, remember to factor in how your responses would change as the weather changes, better or worse.

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**Flying aircraft of any kind in weather is an unnatural act.**

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When was the last time you reviewed AFM 51-37? There’s some good poop in there. And I recommend that you talk instruments in general and disorientation events in particular in flying safety meetings. Plus, get away from covering only the canned items during annual instrument refresher training. And just a word to you stan eval flight examiners. Are you tailoring your instrument flight evals to include true learning situations? Really? If you are not, you are cheating yourselves and your fellow Air Force and Navy aviators. Flying aircraft of any kind in weather is an unnatural act. It requires a conscious, deliberate operation that does not take kindly to inattention on your part. If you do not know the basics, you had better take the time to learn them. And if you think you already have a handle on them, better not forget that they never change or go away. If you don’t think of them every time, you can get just as disoriented with 10,000 hours of experience as you can with 200. As easy as the handsome ski instructor makes it look, if he doesn’t think constantly about keeping his knees together, he looks like hell.

Now that we’re all d’accord, all psyched up with the mental self-discipline necessary to fly instruments, gather around. Joe Sweeney and I are going to show you how to make it all a little easier, how you can find a little extra time to do other tasks, and how you can still keep yourself right side up.

We showed you before that, with the HUD, you now have the ability to view directly the flight path of the airplane. You really do. But lest you dismiss this as a commonplace statement unworthy of our usual revela-
tory pronouncements, think again. It's profound, n'est-ce pas? Why? Since you now have the ability to view directly the flight path of the airplane, mental gymnastics to interpret the control and performance instruments are superfluous! You can reallocate that time to perform other tasks. Moreover, what we have been calling the "cross check" could probably be better described as the "point check." The philosophy of flying aircraft on instruments, using the HUD, has changed. We know more, so we can do more. Knowledge is power.

You can get all the information you need for determining the performance and for controlling that performance by looking at one and only one point on the face of the HUD. When your internal clock whispers to your brain "time's up" on the task at hand and you redirect your attention to airplane control, all you have to do is look at the flight path marker on the HUD. You then immediately have all the info you need to control the aircraft. You can tell the bank angle immediately and know instantly if you are maintaining level flight, or climbing, or diving. You can do this directly, with no interpretation required, without moving even your eyes, much less your head.

All right, now, before I begin to hear screams of anguish: I do look at the complete HUD display, and I would advise you to do the same to fill in all the gaps in the great SA picture in the sky. It is important to keep track of the altitude, airspeed, heading, DME, etc. The main point is simply that, in order to control all these parameters, you can use the flight path marker to control the performance and determine the magnitude of the performance all in one — and only one — place. It's important to grasp this for more than one reason. The most important reason, however, is the ability to control the aircraft directly and much more precisely using HUD techniques. The next thing to realize is that to further improve HUD displays, it is not necessary to try to make HUDs look like the head-down displays you have used in the past. If you insist on using this approach, all you are going to do is screw up an excellent control device.

Come to think of it, though, wouldn't it be a good idea to borrow from the F-18's bag of tricks and be able to put the HUD presentation head-down on one of the MFDs?

Well, back to this tendency to try to improve HUDs by making them clones of the head-down displays we all know and love. An example of this counterproductive tendency is a bank-angle display. You simply do not need a bank-angle display in order to fly the airplane precisely. Granted, there are a few weapon system operations that may need a precise bank angle, but it is altogether unnecessary on basic instruments. Joe and I disagree a little as to the actual magnitude, but we are in complete accord that you can control the bank angle very closely using the flight path marker. I can look back on every basic instrument maneuver, or complete approach, I have flown in the past, and look forward to every one I'm going to fly in the future, and know I never have needed and never will need to use exactly thirty degrees of bank. If you look at the angle formed between the stubby little wings on the flight path marker and the pitch ladder, that is the bank angle of the airplane. Even the most junior rudder among us can tell if he or she has a small amount of bank, a moderate amount of bank, a steep bank, or — "sweet Hey-Zeus" — I'm upside down! In short, your performance is not going to suffer the least bit by not using exactly thirty degrees of bank. Ipso facto, your overall performance will improve, because, as you establish "about" thirty degrees of bank, you know the turn is perfectly level (without having to look elsewhere). You cannot do this with an ADI. And the fact that I have twenty-eight or thirty-two degrees of bank established only serves to make a very slight change in the rate I approach the new heading I want. I am still going to roll out on the desired heading, regardless of how fast or slow I approach it.

As an example, the question of tailoring the HUD display scale to be able to detect small rates in changing airspeed is no longer that important, because the actual magnitude of the airspeed does not have the direct effect it has had in the past with the attitude, head-down type of flying associated with ADIs. In the past, a change in the airspeed meant (through the resultant changed AOA loop) that the picture I was holding on the ADI was no longer correct (i.e., the flight path angle, or vector, if you prefer, had changed, but I had no indication of that). As a result, I had to change the picture to make sure I was still doing what I wanted. Further, in the interim, as I was correcting the airspeed, I had to check the other instruments to determine what effect this subtle change in the flight path angle had wrought on the other flight parameters. (I was also compelled to check to see if the new attitude picture was having the desired effect etc. ad nauseam. Whew!) This is simply not the case with the flight path marker on the HUD. If I am holding the flight path marker on the horizon, I know I am in level flight whether the airspeed has changed or not. Whoo, now, I am certainly not saying that I ignore the airspeed; it is simply not as important a parameter as it used to be. Why, then, spend a lot of time and money "improving" that part of the display?

A case in point. I have flown precision approaches where, as the controller said, "Start your descent." I went to full AB. At decision height, I had in excess of 650 knots (just below the mach). But, by holding a "picture" of two-and-a-half degrees down, all the controller said was "on the glide path," although he didn't say it very many times. Incidentally, this was at a USAF installation. It would be different at other locations. It might even be other than two-and-one-half degrees at a USAF base, so you'd want to check the approach plate ahead of time.

This is not the way to fly GCAs. (It also drives the controllers our of their trees!) Just remember that airspeed is no longer as important as it once was. Why? Because direct knowledge of just what the flight path angle truly is offers a whole new approach to instrument flying. Please do not construe this as a license to steal. You must not ignore totally any of the parameters you checked in the past. However, since the velocity vector combines, in one location, much of the information you once secured only after a series of mental interpolations and extrapolations, the manner, frequency, and order that you secure information from the HUD is different from the pitch attitude approach you have been using head-down in the past.

To see what I mean, look over my shoulder as I fly an ILS precision approach. After assuring myself that I have the localizer nailed with a little back-and-forth check between the tachpole, the "raw" localizer line on the HUD, and the heading, I check the airspeed enough to establish that the required airspeed I had mentally calcu-
lated in relation to thirteen alpha was correct. At that point, I stop paying a great deal of attention to the airspeed and fly using the AOA bracket. I am looking at the tadpole and the velocity vector to establish the proper vector to stay aligned on the localizer and the glide slope. The tadpole should be very close to the glide-slope angle published for this particular approach (if I have smoothly started the descent at the proper time.) If not, SA should be on top of the fact that the required correction will briefly call for a different descent angle. If I am holding thirteen alpha, or even eleven, if you choose, I can now easily and precisely control the airplane in all six degrees of freedom by looking in a very narrow window toward the bottom of the HUD combining glass. (Being in the bottom is another very good reason not to have any kind of bank angle display to clutter up the picture.) With an occasional glance toward the altitude to check the progress toward minimums, I am in complete control of the situation, with a high degree of SA, using a "point check," not a "cross check." Understand that, drawing on my own experience, there is still a small amount of time checking the entire display to keep SA as high as possible and to be alert for any possible malfunctions. Malfunctions of any kind are indeed rare, but I want to be alert to handle anything. Are you still with me?

And you run another risk of degrading the HUD if you try to install flight director bars. Remember them from the T38? The actual tadpole might be changed slightly to improve its readability in every situation, but trying to make the HUD look like the head-down approach from another airplane would reduce your ability to utilize the HUD to its fullest potential. Instead, take the time to realize that the tadpole position represents the intersection of the pitch and bank steering bars in a much more efficient and space-saving display. Otherwise, you will have to expand your point check to find the now-displaced raw ILS data.

Your good manners, gentle reader, have overcome my enthusiasm for this subject. I can see you suppressing a yawn. I will therefore end this modern fable with a few scraps of clothing for the heretofore nekkid emperor, to wit:

1. Spatial disorientation is not a new phenomenon, nor is it going to go away with some magic change in display technology or format. Deprived of a visible horizon, you can’t even function in two dimensions. I can put any one of you in an automobile in the middle of a large parking lot, blindfolded, and you can’t drive in a straight line for any length of time. Why should you be able to in a three-dimensional world? If you didn’t leave UPT with a warm fuzzy feeling as to your own reaction to various weather situations, you had better begin a self-study program to bring yourself up to speed. You IPs in the fighter lead-in or RTU bases should be alert for the lack of this capability in your students (and yourselves, for that matter). Know, cold, your personal reaction to various combinations of day, night, weather, rain, snow, formation, or single-ship. That way you can anticipate what’s coming next. Think in terms of how much time you can afford to allow for other than maintaining aircraft control. Do nothing but that, if the situation demands.

2. Flying the HUD in the F-16 or flying in any other HUD-equipped airplane requires a game plan different from any you have ever used before. It is more precise and allows a slightly reduced level of effort to maintain air-
craft control if you now play ball in the new diamond. LEARN the new rules. I will give you my personal guarantee that you will be a better, more precise instrument pilot if you do.

3. Make sure you know what it is that you are being asked to evaluate before you start making suggestions to “improve” HUD presentations. If you insist on trying to make the HUD look like the instrument panels on the F-4, the F-14, or the T-38, all you are going to accomplish is to plunge the weather-flying business back into the dark ages. HUDs can be improved, but there are only a few areas that really need improving. Therefore, make sure that you are a complete HUD flyer before you go off “open-loop” with all your requirements to “qualify” the HUD as an instrument-flying device.

4. Please call our hand. Joe and I are prepared any time to demonstrate what we are saying. We are not talking “concepts.” Concepts are always free! We actually practice what we have been putting forward.

5. Finally, let us know about your techniques when it comes to flying the HUD. Joe and I are more than open to suggestions as to how to maybe make it better. I am not at all reluctant to plagiarize somebody’s better technique if it improves my own. We’ll make every effort to get the word out to the field. Our main purpose is wanting you all to be better instrument pilots, especially in the F-16, but in other airplanes, too. Give us a holler.

Check six . . . when your internal clock tells you that you can spare the time.
The NIGHT HAS A THOUSAND EYES

By JOE BILL DRYDEN

As I have wandered through the hallowed halls of the world of aviation, I have run across many of my fellow pilots who have had a real aversion to flying at night. I must admit that I, given a choice, would rather fly in the light of day. But I can now say truthfully, with the work we have been doing with the F-16 over the past few years, that flying at night is not so bad. It can even be a lot of fun!

With the exception of the usual night proficiency requirements and the occasional high flight, I didn’t do anordinate amount of night flying until I showed up in Southeast Asia (SEA) in 1967-1968. As a member of “D” flight in the 555th TFS “Triple Nickel” I was having a hell of a good time going north until LBJ, for reasons that he did not share with us, decided to keep us out of Route Package 5 and 6.
Flying at night with the standard HUD.

It even gets worse...
Would you like to go home?

The pilot's night vision is improved with LANTIRN Head-Up Display.

Better... Let's stay awhile.

Night flying is no longer a problem with NAV FLIR/LANTIRN and Night Vision Goggles.

Now... We can be somebody!
As a result, 7th AF, now with an extra squadron on their hands, decided that we should join our fellow squadron, the 497th, in its efforts at night work. Although I personally never did mind flying at night, trying to use an F-4D as an instrument of war, in the dark, was not my idea of the most efficient use of the available equipment. In the daytime, I had the distinct impression that the cockpit had been laid out by a drunk hobo, on a blind burro, in a snow storm. At night, the cockpit was even worse! With systems no more sophisticated than the human eyeball and the intelligent use of the occasional flare, we were supposed to deny the bad guys access to South Vietnam.

I was amused at all the advice the “old heads” were putting forth about the techniques to use at night:

1. Don’t use the AB at night because that gives away your position. (How is that any different from the daytime, when they can see you all the time?)

2. You must not strafe at night because the muzzle flash will give away your position. (Same reasoning as No. 1.)

3. Don’t use more than 60 degrees of bank at night. (Are the laws of aerodynamics different in the dark?)

This advice, as well as the cockpit layout and the night lighting in the F-4 was, shall we say, less than optimum. I did take a cue from the guys in the 497th as to the use of tape. I know I must have shifted the CG forward at least one percent after I had finished taping up the nuisance light sources in the cockpit. I finally arrived at the following solution. Heavy use of tape, then turning the cockpit light rheostats almost (in some cases completely) off, I would then take the red filtered map light, stretch out the cord to full length, route it under the manual canopy release handle on the right side of the cockpit and clip it on the glareshield and point it to shine on the ADI. With a three-axis gyro on the F-4 ADI and the use of the aural tone for angle of attack, I created a poor-man’s HUD (although I didn’t realize it at the time . . . more on that later.) I would then depend on my long-suffering GIB (guy in back) to provide me the rest of the information unless it was only available in the front cockpit. If that was the case, I would either fly straight and level or give him the airplane and turn up the lights to get what I wanted, turn them back down, and proceed with the mission. Despite all this aggravation, we did some very good work from time to time, although I hardly think we really affected more than ten percent of the night traffic inbound to South Vietnam (or Vietnam . . . as Robert Strange used to say).

Why so dark? (Another of my rhetorical questions.) If you want to see out of your cockpit at night, then you must make sure the inside is dark as well. The same is true with the panel lights in your car. If you are serious about seeing anything while you are driving in the dark, you should ensure that they are turned way down. I am always tickled passing people on the freeway (they were only going 54 mph) and seeing the level at which they have their panel lights. (Especially those with the latest “fad” digital panels. They are usually so bright the headliner, and the driver’s eyebrows, are starting to smolder . . . I doubt they can see past the hood ornament, but they want the rest of the bourgeoisie to know that their new car is on the leading edge of technology.)

The same holds true with today’s F-16. If you want to see outside at night, then it must be dark inside. But, with today’s technology there are a lot of other systems you can use besides the aforementioned mark-one, mod-zero eyeball and the SUU25 flare dispenser.

The one you are probably most familiar with is Martin Marietta’s LANTIRN. A very good system to help you fly in the dark. However, we have been looking at some ways to be even more effective at night than with LANTIRN alone. Now I am not going to insult your intelligence by saying I am going to turn night into day! Only God can do that . . . and he has proprietary rights! But, I will say that, with very few exceptions, you can fly the F-16 at night in exactly the same manner you can in the daytime: the same maneuvers, the same delivery systems . . . everything.

LANTIRN gives you a FLIR (forward-looking infrared) picture that is then presented on the HUD and a TFR (ter-

Atlantic

Pathfinder

Both good NAV pods. With TERPROM and NVG’s they are quite capable.
ing laser designation for guided weapons. I certainly could have used this system many times in many parts of SEA. As such, LANTIRN provides a major step (but not necessarily the final increment) toward giving me and the rest of the F-16 pilots (and the rest of the TAF as well) a real capability to fly and fight at night!

A few systems can be added to the existing LANTIRN, or used independently to improve still further the ability to detect, identify, and destroy the bad guys. Having firsthand knowledge of how well some of them work, I would love to reify some of my more memorable missions from the yester-years in SEA. How sweet it would be!

Let me take the time to talk to you about what we have been doing (while staying in the unclassified category). What about navigation? In SEA we had to depend on dead reckoning (DR) and the slim possibility of map reading in the dark, aided by the inertial system (INS). What if I told you that you could use a system that would navigate you nearly 100% of the time to within 50 meters of where you wanted to go? It’s even better than that a large part of the time. For in-

stance, tell me which end of the bridge or what corner of the building you are interested in, because it will usually take you precisely there! (We enter coordinates down to six feet of accuracy.)

If you have to fly over long stretches of water or extremely flat land, the system will degrade gracefully, meanwhile making automatic allowances for this degradation with no action required of the pilot. If the NAV symbol was in the center of the HUD, the worst you would see would be the target in the HUD field of view. This system falls in the category of digital terrain systems (DTS) and, more specifically, TERPROM. TERPROM stands for terrain profile matching and is a product of British Aerospace. There are several other DTS systems in development, but this is the one we have been working with and it works in spades! It has to be seen to be believed. The accuracy, without the requirement to make any updates, regardless of the length of the mission, is astounding! If you would allow me to put my retired USAF fighter pilot hat back on, I would say that it should be an urgent-action TCTO on every TAF aircraft that is presently equipped with INS.

By always knowing exactly where you are, and how long (to the second) it is going to take you to get exactly where you want to go, the reduction in cockpit work load is staggering. The Global Positioning System (GPS) can also be very accurate, but, because of the way it works, it can only do accurate navigation. The GPS is referenced to the center of the earth, or at best sea level, and does not have the first clue as to the big rock rapidly approaching the end of your pitot boom. However, because of the way that TERPROM works, you also get two other very important capabilities for the same price, size, and weight. Since TERPROM uses the terrain profile for its navigation, it can also use the same data concurrently to provide a predictive, all-attitude ground-proximity warning system. The operative word here is predictive. Every other system in being, or under development, is an historic ground-prox warning. In other words, the system says, “By the way, Maverick, you just screwed up!” as the nose of the aircraft starts deforming at ground impact. The TERPROM will tell you well in advance, regardless of the pitch or roll attitude of the airplane, that if you insist in continuing with what you are doing, for the next ten to twenty seconds you are going to pass closer to some terrain feature than you
told me to warn you about. This feature can work the same, whether the upcoming clearance problem is due to the ground or is a man-made object.

Finally, while TERPROM is doing the two tasks above, it can also provide indications on the HUD to allow you to fly a very covert, yet very accurate, terrain-following profile. These are the three main items that all go a long way to improve operability, increase safety exponentially, and make a drastic reduction in the cockpit work load. Not at the top of the list with the other three but still very useful is that TERPROM can provide a passive ranging to use with the present F-16 delivery modes. This passive ranging can actually improve CCIP operation at shallow dive angles.

If you have seen the LANTIRN HUD, you will have noticed that it is not quite like the HUD used in the other C Models. The symbology is nice and clear and the field of view is about two and one-half degrees bigger on either side. This is nice to have if you are flying at night, depending only on the LANTIRN system, but we have seen a companion system that, as I said before, would improve the operation of LANTIRN or could be used independently. This falls under the heading of night-vision goggles (NVG). While the LANTIRN HUD is nice at night, it is less than optimum in the daytime. And rather than try to improve the fixed field of view by making the HUD larger, why not work on the field of regard? This field of regard can be increased tremendously with the intelligent use of the right kind of NVG. The ones we have been using are called “Cats Eyes” (a product of GEC Avionics) and work very well. It is important to make this distinction as there are other types of night-vision devices that, while they provide some measure of night vision, are not very compatible with the F-16 cockpit (or any other fighter cockpit). I have heard all the arguments about how the NVG are heavy, awkward, have a narrow field of view, etc. All these criticisms are true in varying degree, but I have to ask, What capability do you have without them? A big zero. There are better systems being developed and we will be flying them soon. For example, we are looking at helmets that integrate, into the body of the helmet, all the fixtures that is hung out in front at present. But in the meantime the NVGs provide several capabilities that are missing at present:

1. Although there is a technique to using the NVGs that must be learned, the NVGs provide almost the same size field of regard that you have naturally in the daytime.

2. Almost as important is that the goggles are simply light-amplification devices that use whatever available light is present to provide a usable picture to the wearer. Even on nights when there is only very faint starlight, the NVG can provide useful details to the pilot. Of equal importance is that the goggles operate in a different part of the spectrum than the FLIR systems utilize. As a result, the “Force” has much more likelihood of having some capability on any given night.

Although FLIR systems look good in the desert, they may not play so well in SEA (or any other high-humidity area) during the wrong time of the year. The FLIR performance depends on the total amount of water vapor in the air. In other words, the absolute humidity and not the relative humidity. This characteristic is measured in terms of so many grams of water vapor per cubic meter, e.g., seven grams of water per cubic meter. It is important that you understand this characteristic as it makes a big difference in your mission planning. If you go on the more widespread relative-humidity measurements, you can often come up with the wrong answer. For example, I have flown in the area around Fort Worth when the weatherman was reporting a 65% relative humidity. Under these conditions, I had a FLIR image that showed me usable details less than two miles in front of the airplane. Conversely, I remember flights in northern Europe when the weather-guesser was calling the humidity at 94% and I could see nearly six miles! In the first example, the dew point was 76 degrees F. In the second, 28 degrees F. As a result, the first flight was looking at an air mass containing more than twenty grams per cubic meter, and the second contained less than three. I can remember flying in rain that was falling through a dry-enough air mass that I could still see about three miles. So when someone (your author excepted, of course) shows you a tape of some system’s FLIR performance, be very skeptical unless they specify under exactly what absolute-humidity conditions the flight was conducted.

The point is that you need both a FLIR system and some sort of low-light-level NVG to be sure of having a usable weapon system on any given night in any given area. In the same location I have flown one night with a very wet air mass but with a quarter moon that resulted in great NVG performance and only marginal FLIR operation. At a slightly different time the following night (after a front passed), I was flying in a nice dry air mass before moonrise, with an overcast that extended to above 35,000 feet where I could see next to nothing with the NVG. Nevertheless, the FLIR was beautiful.

I have already touched on how I feel that the cockpit should be dark in order to see outside. This is vitally important if you are depending on seeing outside using just your eyeballs. It is even more important if you are trying to use NVGs. The underlying reason comes from opposite ends of the problem, however. Without the NVG, it is important that you dark-adapt. Any light will reduce your capability to adapt and use what innate night-vision capability that humans possess. With NVG systems, you never dark-adapt. But, if the cockpit is not dark, the NVGs pick up reflections in the cockpit that you would not be aware of otherwise and reduce the capability of the goggles. A very insidious, and potentially very dangerous side effect exists for those of you who still want to fly around with your cockpit lights turned up.
On more than one occasion I have visually tracked F-16s and F-15s outside of ten miles, at night, using nothing more than NVGs and the light cast by the glow in the canopy from their cockpit lights. Not a very good deal if you want to survive for the next sortie.

By now I can hear all the gears turning. How do you fly with a dark cockpit? Simple. With all the lights off, you will be using the HUD. Before you say anything, I know what the official policy is in that regard and I encourage you to reread the several previous articles on that subject in Code One® (Vol. 2, Nos. 1 and 4; Vol. 3, No. 1). But what better way could there be? You have the FLIR image being displayed on the HUD and with the HUD symbology superimposed, you have nearly all the information you need to fly the airplane at very low altitudes and high airspeed. (Before this is all over, I will list what I think is the ideal equipment suite in order to safely and effectively fly at 100 to 200 feet, in excess of 540 knots, in the dark! So please stay tuned.) As I mentioned above, with the F-4 it is difficult to fly with the lights off all the time because I can’t see the fuel gage, the engine gages, etc. So, from time to time I was forced to find the light rheostats (which meant changing hands and flying left-handed for a while...ughhh) and turn the lights back up, check everything, and then turn them back down. This would be the case in the F-16 as well, except we made a very useful change in the interior lighting panel. We added what is, in essence, a master switch in much the same manner as the external lighting panel. The only difference is that the interior master switch is in series with a hands-on switch that will go on the stick or throttle. Now, I use the rheostats to set the lights in the same manner I did in the past, except I set them up even brighter than before so I can see everything clearly, with no fear of misinterpretation. Arm the system with the master switch, labeled NVG (smart—n’est pas?) and turn the lights off with the hands-on switch until I need to check something. Then it’s—click—check what I want—click—off. The lights that I am talking about now are all the incandescent lights in the cockpit; you still set the HUD, SMS, REO, or MFDs independently as you did before.

As you recall, you do not have to worry about dark-adaptation. Remember, you never dark-adapt with the NVG, anyway. Sounds kind of scary, but it works superbly. Everyone to whom I have demonstrated this technique, although maybe skeptical at first, has come away saying this is a very useful capability. The Israelis are putting it into their next block of aircraft. It really does work and allows you to keep the cockpit dark to keep the reflections down, see outside, yet check the systems quickly when you wish. We also have finally come up with some effective filters for the REO in the A/Bs and the MFDs in the C/Ds that completely eliminate the reflections that would be left from them.

How about the goggles? I mentioned before that you would use the goggles to look outside of the HUD field of view using low-light-level techniques and the HUD for control of the airplane and to view the world as the FLIR system thinks it looks. How can I see the FLIR image while I’m looking through the goggles? Easy. We put a little sending unit at the base of the HUD field of view and a receiver on the goggle so that, as I look at the HUD, they shut off automatically and then turn on instantaneously when I look off the HUD field of view. I can also select the goggles to stay on while I’m looking at the HUD for those nights when the humidity has the FLIR working at a disadvantage. This allows me to look everywhere I could in the daytime as well as at night. With any background light at all it is almost as good as the daytime, with the exception of the field of view (small—but the field of regard is still large) and the fact that everything is green. It works great.

The use of this HUD/NVG (with the cutoff) combination allows for another interesting technique. As I roll into a turn I simply turn my head in a natural manner (avoiding the possibility of dis-
orientation by using any kind of "snap look" techniques) and check what I can expect to encounter during the course of the turn. I then return my head toward the center and stop just short of the point that I would turn the NVG off. Now, with only eye movement (a technique with which you were born), I can look across both the NVG and HUD field of view.

This provides a 40- to 50-degree field of view which does wonders for your SA. Depending on the number of degrees to be turned, I glance well into the turn, as necessary, until I roll out, each time returning to the point just short of turning the NVG off. Smooth!

So . . . lots of background, but how does this all play together? Follow me.

1. It goes without saying that TERPROM should come first on everybody’s list! With such a system you can do everything better, day or night, rain or shine, regardless of what your mission is.

2. Make the cockpit lighting mod. This capability is useful for all your night sorties, even if you can’t afford the rest of the equipment or your mission does not require you to fly at low altitude in the dark. With it, you are now ready to go to . . .

3. NVGs. With the cockpit good and dark you can now use the goggles like gang-busters on the nights where the ambient lighting conditions allow. By the way, the Cats Eyes are completely compatible with the HUD symbology, so there is no problem looking forward and seeing the HUD symbology at the same time. Don’t worry about not having the LANTIRN HUD. The goggles negate the requirement for the larger field of view anyway. Next . . .

4. FLIR pod to be carried on Station 5A. If the equipment is not available or you can’t afford the LANTIRN system, there are several contractors who have supplied us usable pods that are very effective, e.g., Pathfinder (which is a derivative of the all-up LANTIRN NAV pod, also made by Martin Marietta), Atlantic (another product of GEC Avionics) etc . . .

5. Some sort of targeting pod at 5B. If you are lucky enough to have access to the LANTIRN system, use it. If not, there are other systems standing in the wings that may suffice.

You are now ready to go to work in the dark and gloom of night. As I said before, we have not turned night into day. But I will say in the strongest possible terms that, with the only exception of flying out a little longer and turning back in a little easier, if multiple attacks are required, I fly the F-16 with this equipment in exactly the same manner I do in the daytime. Exactly!

I have the navigation equipment to navigate and find the target. I have a system that I can use to fly covert terrain-following precisely. If I already have the full-up LANTIRN system available, I have the choice of which sensor I want to use as the tactical situation dictates. Or, with very little extra integration, I can run both through a Kalman filter arrangement to use both in the most effective manner. I can also use any bank angle that I can personally handle without fear of overloading the sensor. I have a FLIR system to use to actually see the countryside and goggles to fill in the field of regard, as well as back up the FLIR system on the nights when the weather does not cooperate. My precise navigation system is accurate enough that I can find the target in my precision strike pod (LANTIRN or otherwise) to ensure a first pass attack on the target, all the while reducing the cockpit work load and allowing me to scan for threats that I did not have the time to do before. The goggles allow me to use the total field of regard to employ offset pop tactics in exactly the same manner as I would in the daytime. I can now be somebody at night. Although there will be doubting Thomases reading this, I can assure them that they can use this equipment to fly as low as 100 feet, as fast as their configuration allows, pop for low-angle low drag, or pop to the moon for really steep deliveries, release the weapon, and immediately dive steeply into a black hole to get back down to very low altitude—all on the first pass. I have had too many people doing it on their first sortie in the airplane to feel otherwise.

We are also working on a concept that shows a lot of potential as well. We have labeled it “Falcon Eye.” It involves a head-steered FLIR so you can use an IR system over the whole field of regard just as you would look around in the daytime. This offers the additional flexibility to display symbology in front of my eyes all the time instead of being restricted to the HUD (another boost to your SA.) In order to provide the flexibility in the frequency spectrum that the FLIR pod-NVG combination does, we are melting-up a low-light-level camera that will display on the HUD where the IR image used to be displayed. Slick. I’ll keep you advised.

It would sure be great if I could go back in time to the 1967-68 era in SEA and take this equipment with me. I know a couple of nine-level gunners and truck drivers just north of Mu Gia pass and just off “Thud Ridge” I sure would like to cross paths with again.

I saw a good cartoon from the A-10 guys showing the guy saying that “It doesn’t matter who won the air war if the Russian tank commander is eating his lunch in your snack bar.” Well, it doesn’t matter how you are doing in the daytime if, as you walk out to your jet for the “Dawn Patrol,” you find your steed crushed into aluminum splinters by the tread of a T72 tank while you were in bed.

Check Six! Even in the dark.
Falcon Eye
CHECK THREE AND EIGHT AND ELEVEN AND...
After Dark

54 CODE ONE
Building the System

By Larry N. Lydick,
Engineering Project Manager

The security guard said good night and the hangar door clanged shut in front of the AFTI/F-16. The remaining dim ceiling lights set the mood for some serious thoughts about night attack. I slid into the cockpit and closed the canopy as my thoughts came together. There just has to be some way to let the pilot see the world around the airplane in a fashion more natural than FLIR imagery in a static display.

I moved a small piece of Plexiglas through various positions around the cockpit as if it were a mobile combiner while I tried to imagine how a gimbaled projector might always present to the combiner just the right FLIR image and regard needed by the pilot. In a flash I had it! The projector could be a miniature CRT buried in the pilot’s helmet with a small, attached combining glass just in front of the pilot’s eye. The FLIR would need to be head-steered. I could hardly wait to disclose my idea to the world at large.

The year was 1982, and can you imagine the chuckles coming from my friends, Johnnie Stegemoller of GD’s Pilot/Vehicle Interface Group and Dr. Tom Furness at the Armstrong Aerospace Medical Research Laboratory, as I described my invention. They had been working with the idea for fifteen years! Tom grinned mischievously as he described the history of visually coupled systems, and revealed that the concept was entering flight test in the Army AH-64.

Well, the fact remained that a system that would allow a fighter pilot to look wherever he wants and examine targets with an easily controlled narrow field of view (NFOV) was a great idea, so we all began advocating a head-steered FLIR program for the F-16. In late 1984, senior management at General Dynamics requested that I start a technology transition program as a ‘next step’ beyond night vision goggles (NVG). Thus, the Falcon Eye Program was born. In just two-and-a-half years, John Fortune, John Curtis, and Mitch Snyder guided the program to first flight using F-16B No. 2.

“Falcon Eye,” a title applied to the avionics suite of head-steered FLIR, helmet-mounted sight and display (HMS/D), and low-light-level TV (L3TV), has evolved through a complete cycle of design and fabrication, ground and flight tests, and flight demonstration. First flight, a day shakedown flight, took place in August 1987 with Jon Beesley at the controls, and the first night sortie occurred only days later.

The Falcon Eye concept is unique among fighter night nav and attack systems. It provides the pilot with 1:1 registered FLIR imagery in a 30-degree-field-of-view helmet display. The pilot head-steers the FLIR and display through virtually the same unobstructed regard as normally available for daytime contact flying. The FLIR is equipped for 5.6X NFOV operation, and the visual coupling with the HMS/D assures that the FLIR’s line of sight is the same as the pilot’s. This arrangement appears to be a uniquely satisfying answer to the old bugaboo of “how to steer the soda straw.” To date, after 25 development flights, there have been no complaints of vertigo or disorientation from the pilots. The pilot can smoothly head-track targets in the NFOV after two or three flights. Thus, the Falcon Eye concept may meet critical requirements for orientation and safety during low-level night operation.
Also unique to the HMS/D concept is the availability of off-axis symbology. The HMD is, in reality, a miniature HUD with full stroke and raster capability. With much of the developmental testing behind us, the pilots fly the entire sortie with the fixed HUD turned off. F-16 bombing accuracy is degraded when the HMD reticle is used to attack the HMD image of the target. During the attack phase of a mission, the system instrumentation shows the pilot to be looking from wing tip to wing tip, and high up into the canopy during tight turns.

The head-steered FLIR was built by Texas Instruments. It is easily removed from the nose of the F-16 by first removing the streamline fairing, removing an extra line of bolts from the equipment access door and frame, and sliding the FLIR out sideways in the usual fashion. The turret LRU weighs only 70 pounds, so special handling equipment is not required.

Two helmet displays have been tested. One system built by GEC Avionics is biocular (one CRT servicing two eyes) and helmet-mounted. The other is monocular and mounted on the oxygen mask. The mask and display are supported by a thin nylon string connected between the mask nosepiece and a velcro patch on the helmet brim. Both systems introduce much less head-supported pitching moment than do night vision goggles, and both have been ejection-wind-blast certified, including proof of nil effects on ACES II pitot pressures. The entire Falcon Eye system has been integrated with the other system in F-16B No. 2. Special techniques were used to reduce digital signal transport lags in the head-steering signals from the HMS.

Let's see what the pilots have to say about the visual experience, the development flight testing and the philosophy of designing a system directly to the PVI requirements.

Developmental Flight Tests

By Jon S. Beesley, Test Pilot

Recently, I flew a series of close air support attack runs against tanks operating at Fort Wolters, west of Fort Worth. The digital database and automatic target handoff systems (ATHS) made navigation to the targets easy. The target location, elevation, and type were passed to the FCC without the need for voice communication. No pause was required on the way to my simulated war. I flew straight toward the tanks in the CCRP mode at 500 KCAS at low altitude. Four nautical miles from the target I "actioned" left to set up for a pop-up and right roll-in (yes, the airplane rolls right). At three-and-a-half miles and prior to beginning the pull-up, I was able to acquire the targets near the TD box approximately 45 degrees right of the nose (obviously not a standard F-16). During the pull-up, I once again checked the target formation and pulled the nose toward them for a CCIP pass. On final, I selected the center
tank for my simulated "wrath" and made a 10-degree CCIP pass. Weapons release was followed by a hard turn off, and then back to low altitude for egress. Sound standard? Hardly. It all occurred on a moonless night.

I've had the good fortune to be involved with the Falcon Eye Program from the first flight through the majority of its developmental flights and all of the demonstrations so far. I'll recount flight segments to provide a brief history of the 12-month developmental flight test effort.

Nose-Mounted FLIR First flight, first problem. I had hardly cleared the traffic pattern when it started: a low-frequency rumble when I turned my helmet left or upward. Obviously, the aerodynamics of the FLIR fairing needed some work. As it turned out, a small pocket, between the FLIR and the fairing, resonated like Low C on an organ. Some judicious carving on the fairing left side after the flight cured the problem throughout a 550k envelope. Subsequent flights cleared the system for operation to 7 Gs (design point is 9 Gs) and we were ready for night operations.

In the early night flights, when I had manual FLIR control available, I attempted to tune the FLIR better than the automatic schedules. No way! I obviously brought a lot with them from their LANA programs.

A more difficult problem concerned the tremendous number of scenes that the FLIR must adjust to (i.e., wherever you want to point your head). Optimizing this situation took about 10 flights, because the system has to adjust rapidly for varying proportions of hot F-16 nose and cold sky.

Helmet Mounted Sight and Display The head-mounted displays were relatively trouble-free from the beginning. Both displays were easily adjusted to give four Gs without losing the raster image. Less satisfying was a bad habit of the helmet position tracker, which occasionally created a glitch in its line-of-sight commands. The most famous glitch caught Joe Bill while he was upside down in a high pop. The FLIR tumbled and Joe Bill reverted to the HUD to recover. In those earlier flights, obviously, we were flying at conservative altitudes, between 500 and 1000 feet. The head tracker software is now glitch-free and we are comfortable at low altitude.

Low-Light-Level Television (L³TV) The Falcon Eye mechanism allows the pilot to select his forward scene between FLIR/HMD and L³TV/HUD, thus providing extra capability on poor FLIR nights. However, an on-going effort to develop a L³TV to complement the Falcon Eye sensor has met with frustration. Thus far, we have not been able to obtain a camera and display with the sensitivity of the NVGs. An alternative would be an INVS helmet that incorporates both NVG and CRT functions.

System Operation I can detect tank signature targets at the "action" point using the NFOV, and begin to maneuver accordingly. Narrow field of view takes some training, since we normally fine-track with our eyes rather than our heads, but most pilots have been pleased with their abilities after two or three flights. Maneuvering for the attack is almost like in the day. Narrow field of view is used like a cross-check item. Wide field of view (1:1 registered) is used for orientation and final piper placement.

Having the stroke HUD symbols in the HMD helps retain orientation, particularly after rainstorms when the world goes to one temperature. The IR scene may not be the best under such conditions, but the targets still shine because their IR level remains high.

Now, when I fly other airplanes in the daytime I reflexively look off-axis in the direction of the turn points or targets expecting to see their marking symbols. No such luck! I have found myself "spoiled" by Falcon Eye.
Design Philosophy Comparisons

By Joe Bill Dryden, Senior Test Pilot

Gear up ... turnout of traffic ... fence check. I fly at 100 to 200 feet at 480 ... then 540 ... and finally Vmil. I scan left and right as far as I like, to survey the approaching and receding terrain. As I do so, I get symbology information in front of my eyes all the time. I zoom (the picture that is ... you have been watching too many "Top Gun" movies) to inspect closer, various things that attract my attention.
I was a little skeptical the first time I flew the Falcon Eye system, but I am now convinced that this approach will surpass the use of the night attack systems I elaborated on in the last issue. As I pointed out, the best approach to flying in the dark is to have several systems on board to ensure that you have some capability to fly on any given night. You will recall that I tried to point out most emphatically that you need an accurate navigation system. This appears to fall in the general category of digital terrain system (DTS), but more specifically a system called “TERPROM.” You need to modify the cockpit lighting system (not a major mod but rather a very simple one), and then you need something to see outside the cockpit. There are two technologies that enable you to do this, FLIR and NVGs. Since they operate in different parts of the frequency spectrum, you will have some capability to operate on any given night. In the past, we have displayed the FLIR information (from a fixed FLIR pod) on the HUD field of view and used low-light-level goggles to fill in the total field of regard.

Now with Falcon Eye, we have mechanized a head-steered FLIR system that is displayed on the helmet in much the same manner as the combining glass with the “Cats Eyes” NVGs. I think you’ll see how this will be better when I point out that, because of the way this FLIR information is passed to the helmet, we can now superimpose symbology over the FLIR imagery. (In essence, you carry the HUD along with you everywhere you look. I love it!) The FLIR system is still susceptible to the present humidity and haze conditions, but, with the addition of this symbology, the vastly increased SA really goes a long way to improve the level of comfort in flying the airplane at high airspeed and low altitude.

The increased SA, resulting from the ability to look around while keeping the information from the HUD visible at all times, is really great. Of course, as you look off the bore line of the airplane, the symbology changes slightly as you are no longer looking along the flight path of the airplane. Therefore, you will not see the pitch ladder as soon as you turn your head enough to be out of the normal HUD field of view. You will still be able to see the horizon line regardless of where you look, which is nice! In addition, you still have the altitude and airspeed scales, and a heading scale to show you where your head is pointed. (As you look where the airplane is going, the symbology changes just slightly to show you that where you are looking is now also the heading of the airplane.) You can see fairly comfortably looking left to the aft fins of a tip missile (Station 1) to the seeker head of the right tip missile (Station 9), down to the top of the radome (just like in the daytime) and up just about as far as you can comfortably raise your head.

Of course, all the nav and weapons-delivery symbology is on the helmet display. With this step the fun really begins. (All the caution, warning, fuel, etc. displays are also incorporated in the helmet, so you safety guys can relax.)

You have seen how I feel about the importance of a system like TERPROM. (Check the last issue.) The system is seldom more than 50 meters off. I said that if the nav or target symbol is in the center of the HUD field of view, the worst that the system gets would have the target or turn point in the field of view of the HUD. Well, with Falcon Eye, this incredible accuracy can now be used to an even greater advantage because the symbology set includes these same symbols when I am looking off the HUD field of view. As a result, I can now keep track of their location even when I don’t have the airplane pointed at them. Further, if neither the airplane nor my head is pointed in the right direction, I still get an arrow in the field of view to show me which direction to look so I can see the point of interest. (Hang on...it gets even better.)

Now that I am looking at the point of interest, I can zoom the field of view to inspect it while I am still some distance away. This allows much more freedom of action, as I have advance knowledge of what I am looking at (which I didn’t have with NVGs), nor do I have to overfly the turn point to know just exactly where I am. You still can’t say the same in the daytime — Ha!

If you fly close air support (CAS) or battlefield interdiction (BAI) missions for that matter, you can get updated target location information through the datalink system ATHS that Jon mentioned and know the symbology will be overlaying the target even though you do not have the airplane pointed at it at the time. You can see the target better, much earlier than you would with a navigation FLIR, because you can take advantage of the zoom capability to see things at a greater range. You can do off-axis pops and still keep track of the target the whole time. If the moon is right, you can do this with the previously mentioned NVG/FLIR combination, but it is much easier with the Falcon Eye and its accompanying symbology, and, as you get really proficient, you can zoom in the picture even during the pop.

It is a slick system. I like it!

So...building on the last CODE ONE® article, I’ve offered you a different and potentially much better approach to flying and fighting in the DARK!

Check three and eight and eleven ... meanwhile keeping track of the HUD symbology and potentially doing some serious killing in the dark. ■
Much has been said lately about a "new" airplane to replace the A-10 in the Close Air Support (CAS) role. Depending on your political (or technical) persuasion, you may or may not be a proponent of the F-16, A-10, F-18, AV-8B, or "Mud Fighter" to perform the CAS mission for the United States Army.

I am prepared to go out on a limb and say that I think the F-16 Fighting Falcon can easily perform the CAS role, as well as Battlefield Air Interdiction (BAI), and provide for its own self-protection against airborne threats. Experience in various parts of the world has shown that the F-16 can, while hauling the iron, achieve a better air-to-air exchange ratio than the dedicated air-to-air guys. I am not sure that I would feel good trying to extrapolate the other CAS contenders into the same real-world situations.

The F-16 has already shown that you can physically hit any target that you can see. This has been proven many times over in every competition that the F-16 has entered (14 major competitions to date). The question is never whether the plane is going to win, but rather which F-16 outfit or pilot is going to win the competition or Top Gun. The F-16 was designed to deliver its bombs within six mils of accuracy. It has repeatedly demonstrated that it can deliver ordnance consistently with much better results than this six-mil design specification. In order to assure a win, some competitors have been compelled to deliver ordnance to less than one mil. (Not an altogether easy task!) The winner of the level bomb part of Gunsmoke '87 (I believe my memory serves me correctly) had a CEA of 0.25 meter. That's less than 10 inches! Not bad when you consider that you're moving at over 800 feet per second. Given such impressive performance, we knew that the F-16 could easily handle the CAS mission. But would the pilot be able to 

use the capability of the airplane? You can hit any target that you can see, but can you always see the target in question (or at least see the target locations)?

So my partner in crime, Mr. Jon Beesley, and I came up with seven questions that need answering before the accuracy of the F-16 can be fully utilized.

1. Do you really know where you are in your F-16?
2. Does the ground observer or any other agency that you are working with really know where he is?
3. Does the ground observer really know where the bad guys are?
4. Can the ground observer tell you where the bad guys are in real time and in a hostile comm environment?
5. Provided that all the above can come true, can you enter all the information in the airplane without making errors?
6. If we are still keeping up with all the requirements, is there some display in the airplane that can show us where the bad guys really are so that you can pick them up visually?
7. Will this also work at night? How about bad weather?

None of these is any small task. Let's address them one at a time.

We quickly came to the conclusion that although the INS in
the airplane is much better than we were used to in the past—think F-4, for example—it was not good enough to point us to within six miles of the target. You could not even depend on the INS to ensure that you were pointed where you would be able to find the target area, much less see the target.

One system that we were asked to help develop falls under the general category of digital terrain systems (DTS). British Aerospace joined with us to help demonstrate a system that they called TERPROM, short for TERrain PROfile Matching. As I have pointed out in previous articles, this system has to be seen to be believed! Its accuracy is a fundamental change in the way that you can use fighter, strike, or recce airplanes. It has a favorable impact on the trash haulers as well. Anytime that you need to say exactly where you are, a system like DTS is the only way to go. It is in the same category as jet engines, powered flight controls, and airborne radar in the impact that it will have on aviation!

TERPROM will also significantly reduce the pilot’s work load. Jon and I have had a hard time quantifying the exact reduction, but suffice it to say that the time you have to spend on the navigation problem is effectively reduced to zero. All you have to do is keep the symbology on the HUD in the correct order, and you are going to get where you want to go and arrive at larger than an M16 rifle (although it’s still shaped like a rifle). Incorporated in this “rifle” is a GPS receiver (so the observer knows where he is) and the necessary equipment to allow the ground observer to determine the target’s exact location. A patent is pending. The rifle can also encode the location and type of target and then send all this information in a data burst to the F-16. And all this can happen in less than a second! You can actually be receiving updates on a moving target during your pop.

So: with one piece of equipment for the ground observer and a black box labeled ATHS (for automatic target handoff system), we have solved Number 2, 3, and 4 concerns. ATHS is nothing more than a smart modem that allows us to use whatever radio net that is common to us and the ground observer. And if we can keep all the software gurus working in the right direction, all this equipment will be compatible with the Army’s present comm and info nets. By that I mean we can all be part of the same net in real time. The ground observer can send target type and location information to the artillery, to helicopters, or to us (the fast movers) at the same time. He can coordinate all of our efforts to ensure the most efficient use of what munitions we have at that time. He can coordinate strike times so that the bad guys never have any respite. And while he is doing this, he can see that there is no conflict between our arrival and departure times.
to minimize any possible fratricide. Wonderful.

ATHS also solves problem number 5. As it receives this data burst from the ground observer, it is talking on the multiplex bus in the aircraft. It inserts the data that the ground observer has "burst" to us under one of the way points that we have told it ahead of time. This is exactly how the system works now with a DTC—or as if we keyed it in manually (without any errors).

For the latest demonstrations, we have been using a B model F-16. We have wickered the software so that as the ground observer transmits to us in data burst, the system can insert the location of turnpoints and IPs the observer wants us to use directly into Waypoints D and E. Waypoint F is reserved for the target location. In addition to the location of the target, the ground observer can use any one of 22 target identifiers (e.g., bunker, armor, AAA, and intersection) to better describe the type of target. With a C or D model, we could devote an entire page on the MFDs so that the ground observer could transmit a whole encyclopedia of info to us about the target.

Now we know where we are and how we are going to get to the assigned area. The ground observer can determine exactly where he is and precisely where the target is located. He can get this information to us in real time (and not very much real time at that), and we can ensure that the information is inserted into the system just as fast and without the chance of our making an error. So now on to point number 7.

Since I can position my aircraft precisely and the ground observer can give me the precise location of the target, I can make book that the target that the observer wants me to hit—once it is in the HUD field of view—is located within a very few meters of the symbology on the HUD combining glass. Slick!

There will no doubt be those in the audience with the idea that in order to see the target, I must slow down. I disagree. If the bad guys are doing their dead-level best to make sure I don't see them, it makes little difference whether I'm going 200 or 600 knots. We have done extensive simulation that shows that there is no difference, this side of three decimal places, between going slow or fast as to whether I will acquire the target visually. Plus I am more survivable going fast.

Another item that helps is the laser used by the ground observer to determine target location. If the observer resumes lasing as I start down the chute (and if I have brought a Pave Penny pod along), I will see the Pave Penny symbology overlaid on the target symbol on the HUD. Bomb the symbology! It works, and it works well. With what I have seen I would not hesitate to drop (depending on the weapon I was carrying) within 100 meters of the friendslies. And I don't take that decision lightly.

I know that a lot of you old infantry types will not feel too good about my explanation concerning this new equipment. But don't be too quick to make a judgment. Once you have seen this system in action, I feel certain that you would not hesitate to call in an airstrike on the bad guys 100 meters in front of your posi-

We should all remember that nobody controls anything until there's a 19-year-old private with a rifle standing on it!
I have done numerous inflight engine restarts in the course of testing several different engines. However, each one of them was done with a full-up (i.e., completely functional) engine and fuel system. The usual drill is to establish the conditions that you need for the test point. If it is going to be required, manually turn on the jet fuel starter and/or the emergency power unit. With that all set, shut the engine down by selecting cutoff with the throttle, wait for the engine to unwind to the desired rpm, and then position the throttle to idle or above for the start. As a result, the fact that I was going to do an airstart was never a surprise. I always knew ahead of time that the engine was about to quit.

Recently I saw how the engine would quit in other than the normal airstart-test type of atmosphere. Although these tests were accomplished on the ground, I saw several things that I hadn’t seen before, things I’d like to pass along. You can never know too much about the airplane.

I am sure that you are aware that there have been some as yet unexplained flameouts with the F110 engine. What we attempted to do was to try to induce as many potential malfunctions in the airplane as possible in order to shed some light on some of the past accidents/incidents. The

BY JOE BILL DRYDEN
Senior Experimental Test Pilot

CODE ONE 65
airplane was tied down in the normal manner and then fully instrumented to record all the parameters of interest.

One large impression that I had was how tenaciously the engine will cling to life if it has fuel. On one test we had artificially closed the master fuel shutoff valve to only 5% of capacity, that is, 95% closed. (There is no way that you can do this in your airplane without some really weird failure, or a plumbing change like we had for the purposes of this test.) The boost pumps were off and the refueling door was open so the system was depressurized. The engine was in idle and running just fine. The test point called for me to snap-accel the engine to 95%. The engine only briefly touched 95%, immediately rolled back to 92%, and hesitated there for a few seconds. It then rolled back to about 87% for a few seconds. Subsequently it flamed out, but had an automatic restart accomplished in time to catch the rpm at 80%. It stayed there for another few seconds, and then flamed out again. The engine then auto-transferred to SEC and got another auto restart at 72-73%. It maintained this condition for a little while and then flamed out again, with an auto re-

start in SEC at about 65% where it stayed for awhile and then slowly continued to decay toward zero rpm. From this, and other similar runs, I feel that if the engine is operating properly, you have little fear of its quitting as long as the aircraft is providing fuel.

I have taken the time to go through our metal mockup here at the factory in no little detail. The fuel system is simple and straightforward, designed to fail toward an operate condition, should a malfunction occur. Hey, I agree with you that the fuel system diagram in the Dash One is really not too clear as to what fuel gets directed to which tank. The one that I have included in this article is a little easier to interpret, because it was drawn with no lines crossing another line. It is a little strange though, since it ends up that the left side is on the right and the right side ends up on the left. If you take the time to look at the fuel routing from the farthest point in the system all the way to the engine, you will see that it is a very simple route. There are actually two separate routes in parallel with one being the siphon route and the other the powered, boost pumped/scavanged route. The

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**Diagram Description:**

- **Ground Refuel Receptacle:**
  - F-1
  - F-2
  - FWD RES
  - PUMP NO. 1
  - TO VENT BOX
  - RIGHT WING
  - EXT TK XFER SOV
  - WING FUEL PUMP
  - TO F2 SCAVENGE SYSTEM

- **Aerial Refuel Receptacle:**
  - AFT RES
  - PUMP NO. 3 & 4
  - XFEED VALVE
  - PUMP NO. 2
  - TO VENT BOX
  - LEFT WING
  - EXT TK XFER SOV
  - WING FUEL PUMP
  - TO F2 SCAVENGE SYSTEM

- **Fuel System Components:**
  - GRD FUEL RECEPT
  - HYD B
  - IDG ADG
  - JFS CONTROL VALVE
  - TO JFS
  - HYD A
  - FUEL/OIL HEAT EXCHANGER
  - MFOSV
  - FUEL FLOW XMITTER
  - FUEL STRAINER
  - TO ENGINE

- **Additional Components:**
  - CENTERLINE EXTERNAL FUEL TANK
  - PUMP NO. 5
pickup in each tank is carefully thought through and there is little if any fuel that is not usable in the system — if you have all the boost pumps on. I really don't think the aircraft fuel system is at fault.

How about the engine? Once again, I really don't think that the engine is at fault. I can't say unequivocally that there is not some gremlin lurking somewhere in the engine just waiting to catch you unaware, but I don't think so.

What does that leave? Your fuel management — or the lack thereof. As I just said, the system is simple and nearly foolproof and is intended to be essentially automatic. However, if you leave the air refueling (AR) door open, the external tanks will not transfer and you have in essence trapped all the fuel in the external tanks. You also partially degrade the siphon action from one internal tank to the next internal tank. It should be obvious: DON'T leave the door open! Flight Leads, what are you doing? Tell Blue Four to close the door. Wingmen, you don't do the Force any good by being hashful in pointing out to Lead that his refueling door is still open!

But there is no "trapped fuel" light in the aircraft to remind you and you must see this by monitoring the fuel indications (ALL the fuel indications! Not JUST the totalizer). Although the Dash One can be read to mean that you should leave the fuel quantity select knob in the normal position in order to be afforded the fuel trimmer and bingo fuel warnings, I suggest you reread the book and leave the knob on the external tank group that should be feeding at the time. And you might want to take another look at Maj. Steve Kniffen's excellent "Trapped External Fuel" article in the 4 July 1968 Code One.

Until the external tanks empty and you start burning internal fuel, there is no place for the system to pump fuel to keep things trimmed anyway. Plus, I hope you aren't flying a profile that has your bingo fuel occurring before the external tanks go empty.

OK, I'll get off my boxe du detergent. Pay attention to the fuel in the airplane and where it is all located and you should not be faced with any sudden silences as the engine quits with fuel still left on the totalizer.

If you do screw up, there are a couple clues that might save you (at the last possible moment). As the fuel gets so low in the reservoir that you are in danger of flaming out, the first indication is a wildly fluctuating fuel-flow meter. For example, if you are cruising along with a fuel flow in the vicinity of 4000 lb/hr, it will suddenly jump up to 8000 to 10,000 lb/hr — drop back to 4000 — jump to 7500, etc. This will continue for a short time, depending on the rate that you are using fuel, and then you will start to hear strange noises as the combustion becomes unstable in the engine. You will hear a low rumble as parts of the ejector nozzles become too lean to burn. As this continues for awhile, the engine will start to roll back, sub-idle, and then inexorably fade toward zero, regardless of the throttle position you might have at the time. You should have long since noticed that the tanks were not feeding, the needles did not match what the totalizer was saying, and noticed the forward and aft low-level lights, the master caution light — to mention a few. But maybe you will notice these clues.

The Dash One is fairly clear as to what to do once the fact that you have trapped fuel finally sinks into your consciousness. But a couple things are worth pointing out. Get the AR door closed! The system will not pressurize until you do. Make sure that you have the air source knob in norm or dump for the same reason. I would probably then accomplish Steps 5 and 6 together. Step 5 gets around one of the possible failures in the fuel system where the airplane thinks that the centerline tank (phantom or otherwise) is still feeding and had not allowed the external wing tanks to start. Step 6 changes the pressurization schedule in the internal system and allows the external wings to fill the internal wings perceptibly faster. You are still faced with what now appears a maddeningly slow transfer rate from the internal wing to the fuselage and thence to the reservoirs. The turbine pumps provide about 6000 lb/hr, plus some help from the siphoning system, counting both sides (3000 per side). So, if at all possible, try to ensure that you are burning something less than 6000 lb/hr. If you catch it in time, you will probably survive to tell the story. And tell it! Maybe your candor will save an F-16.

But if you don't catch all the clues in time (over ten of them as I look around the cockpit from left to right) and get the fuel low enough that one or both of the reservoirs are empty, you are in real trouble. The engine has flamed out. Without the engine providing bleed air, you cannot get the fuel that remains out of the external tanks. If enough air has been going through the system it might have been picked up in the separate line to the JFS and it might not stay running. You are in a world of hurt.

So. Am I making sense? If I am proven wrong, you will see it here in print, but I don't think the engine is at fault. Time will tell. There are only three failures within the fuel system that will preclude fuel from transferring from the external tanks and one of them is failed to the operate position. You must have power on the airplane in order for the solenoid valves on the open AR door to depressurize the system. Even with the door open, if you lose power, the system is fail-safe. The solenoid valve will close, the door remains open, but the system will repressurize. So, unless something does turn up in the engine, I encourage you in the meantime to pay attention to where the fuel is in the airplane and make sure it is getting to the reservoirs. The engine will keep running.

Check Six. And the fuel gage . . . and the fuel sel knob . . . and the needles . . . and the AR switch . . . and the AR light . . . and the ECS knob . . . and the forward res light . . . and the aft res light . . . and the master caution light . . . and bitching Betty. Isn't there some clue in there somewhere? Unless something does break in the engine, a flameout should never be a surprise!
WHAT'S UP, DOC?

BY JOE BILL DRYDEN
SENIOR TEST PILOT

This issue begins the sixth year of publication of this magazine. The regular turnover of pilots in the operational wings (plus our very modest start) means that some of you, maybe a lot of you, may not have seen some of the earlier issues. That fact, coupled with two recent articles from some well-meaning but perhaps uninformed flight surgeons, suggests that there are at least a dozen people who have not read every word I have laboriously put down on the fascinating and tres important subject of disorientation, specifically disorientation and how it interfaces with the cockpit and HUD of the F-16. I want to bring all of you up to speed, so what I'm going to tell you now falls into that general category, but does apply to any airplane, however.
The author made the point that the HUD is directly in the pilot’s line of sight. If somebody can point out to me a better location, I’m listening.

First, when I talk about weather (IMC), I mean that we are in a condition where we have been deprived of a suitable means to keep ourselves oriented as to the local horizontal and vertical. This does not necessarily have to occur inside a cloud (although this is where it usually happens).

Just as we all differ somewhat as to our reaction to various situations that we would encounter in flight, we are all alike in that we cannot continue to function correctly for any given length of time if we do not have a horizon or at least some plane of reference to keep ourselves upright. When I say "plane of reference" I usually mean the ground...if you are in a low visibility situation where the horizon is not visible...and you have some a priori knowledge of what the ground is doing under you. Lead's aircraft will also work well (if he knows what he is doing). If at least one of these references is not available, some sort of disorientation is inevitable.

Q. How can we get around this human failing? A. Provide some sort of artificial horizon.

But providing some sort of artificial horizon by itself will not correct the problem! Furthermore, providing the FOURTH artificial horizon in the cockpit of the F-16 (as suggested by one flight surgeon friend of mine) will not reduce the problem by one-quarter! You already have three in your cockpit: the HUD (the best one you have), the normal head-down ADI, and the standby ADI.

Before any of you jump to point out that the HUD is not the primary reference, let me remind you that the USAF Instrument Flight Center (IFC) is very close to perfecting a "USA Standard" HUD symbology set that will allow just that. Despite the incredible inertia created by some rather myopic individuals who attempted to discredit the HUD with the stroke of a pen, the HUD lives and will soon be given the credit it has deserved all along! Ignorantia juris neminem excusat! In its initial form in the A/B models, it works far better than the head-down ADI. The slightly larger size in the C/D is better, and the improved symbology coming out of the IFC will make it better still.

Regardless of how good it gets, however, it is still an ARTIFICIAL horizon! What I said above is true, regardless of what type of aircraft we are talking about.

Well, then. Just what is the key ingredient to prevent disorientation? It is amazingly simple. The key ingredient we must be aware of in combating disorientation is time (tiempo...tempus...zeit...chronos), eons to nanoseconds, tick-tock. Think of that meter on your wrist whose size is supposed to separate you from the other, shall we say, more ordinary pilots. T-I-M-E. If you do not have some sort of innate sense of time, you are lost.

How much time has it taken you to read this far? Where did you get this sense of time? Hopefully the genetic pool provided you with a good sense to begin with, and then you had a great instructor in pilot training that led you down the proper path. The path I refer to is the one that allowed you to catalogue this inbred sense of time against various situations you might confront in flight. I mentioned above that almost of us will eventually succumb to disorientation when deprived of the proper external references. But each of us has a little different reaction to different external stimuli. Some things that would turn me upside down immediately (vestibularly speaking) would not make an impression on you for quite a goodly number of seconds. On the other hand, I might do well for a while in a situation that blows you away instantly. Each of us must recognize these varied situations and know just how much time we can devote to any task other than flying the airplane in IMC. At this stage of the game I have a pretty good idea of what misinformation I am going to have to filter out when I am presented with a given situation. I hope you have done the same. Although some of them may overlap with those of mine and other pilots, you will still have a set that is unique to you and you alone.

Don't tell anyone about this, but I spent some time in Air Training Command as an instructor in T-37s. I used to go through a "little exercise" with the majority of my students to demonstrate how this sense of TIME applied to flying any airplane on instruments when the conditions dictated. (Although I never indicated to the students just what the exercise was and most of them hated me for it, I don't know of any of them who have bought the farm in IMC.) For those of you who have forgotten or might have never been exposed, there is a series of maneuvers designed to teach pilots basic instrument techniques. They are referred to as vertical "SSs" and are further broken down into vertical S A, vertical S B, etc. When you get to a vertical S D you are expected (in a T-37) to climb and descend through a 1000-foot altitude band, maintaining 160 KCAS and 1000-feet-per-minute rate of climb and/or descent. Further, you do this in a 30-degree bank and each time you reverse the vertical direction, you are expected to reverse the direction of bank.

It is not as difficult as it sounds, and is designed to teach the pilot a good instrument crosscheck and the ability to use the instruments to determine just what his aircraft is doing and is it doing as he wishes, i.e., Is he the pilot or the passenger? As soon as it became apparent that the student pilot was in the ballpark as to flying the vertical S D, I would simply
ask him what the minimum descent altitude (MDA) was for the ADF/ILS approach into Norton AFB, California.

The usual first response out of my student was an incredulous look as if I was crazy! (Watch your airspeed...well, what is the MDA?...you overshot your altitude...I'm waiting...you don't know...you're fast...watch the bank angle...if you don't know where can you find it?...Aha, yes it is in the approach plates for southwest US...you missed your altitude again...your rate of descent is too high...where are the approach plates?...you don't know...you're fast again...how about the map case?...your vertical velocity is too high...you're overbanking.)

You get the idea.

The whole point was to show students that it is possible to do more than one thing at a time if they can budget their time. If they got real good at this exercise, I would add little items like starting to pull circuit breakers so that they didn't have all of their instruments, all the while insisting that they fly a perfect vertical S D. Some of you might feel like this is the Marquis de Sade approach to instruction, but I had a definite reason.

By insisting that the students do what I asked, I felt that in the future they could fly the airplane on instruments, with distractions, and with a degraded aircraft – all because they had a good idea where the priorities properly lie. That is, the most important thing is to fly the airplane, knowing what time you can spend doing other tasks, even if the airplane is not completely sound. I know some of the students hated me for being such a hard-ass, but I was after making them good pilots even when they did not have all of their normal senses available to them at the time. (They might not thank me, but their mothers will!)

I have observed that many training efforts have simply identified the reasons we cannot function in IMC, without enough effort to equip pilots with the skills necessary to overcome this deficiency.

I saw a fairly recently produced film that showed the pilots the danger of disorientation. In it the pilot crashes on a night range mission and then we get to listen in as to the explanation of just what happened. Maybe you've seen it, the one where the pilot wakes up in the aircraft graveyard and has the situation explained by the old trickster and his comely assistant. The scenario has our late hero pulling off the pass in a left, 45-degree climbing turn and not realizing that he is having problems and ends up buying the farm in a right, 135-degree bank, descending turn.

The trickster explains all the things that you have heard before about how our vestibular senses can be fooled in flight to show why our hero was fooled. He goes into such things as cockpit lighting, reflections, workload, and many other minor and/or major items that contribute to spatial disorientation.

Some of the recent articles from the flight surgeon community go even further afield. One article I remember was published in the middle of 1990 and was intended to inform F-16 pilots of the dangers inherent with flying the F-16. The author points up such facts as the missing canopy bow in the F-16. If you are flying VMC, the canopy bow has nothing to do with it, as almost all pilots are quite capable of determining that their head and not their seat is the closest part of their anatomy to the canopy, i.e., the head is always up in relation to the airplane and if the head is pointed at the sky, the airplane is rightside-up. Voila! If you truly are IMC, there is nothing against which you can compare the canopy bow anyway! The author made the point that the HUD is directly in the pilot's line of sight. If somebody can point out to me a better location, I'm listening. He points out the T-38 is a better aircraft because it is "designed to vibrate in a turn or at higher airspeeds, effectively saying to the pilot that he is performing the maneuver properly." For Pedro's sake, do
The reason that the HUD is so very much better is that in the same TIME you spend determining your attitude looking at an ADI, you can determine both your attitude and a large measure of the aircraft performance looking at the far-better HUD.

you really think that Northrop intentionally designed buffet into the T-38? If they could have accomplished the same thing, buffet-free, they would have done so in a heartbeat!

And listen to this: he says that the small size of the cockpit contributes to disorientation in the F-16! Have any of you seen an A-4 or any of the Mirage series of airplanes? Talk about your small cockpits! I don'trecall seeing any of these airplanes littering the countryside after the pilots became disoriented. Good grief.

All these points, along with several others the aeromedical mentions, have much to do directly with the pilot's becoming disoriented. The fact remains that we can all fly airplanes as long as we have access to the proper external cues. Without that access, we need some artificial device.

While all of the above might be considered to be outside contributory causes, none of the facets covered in the movie nor any that the medical folks mentioned address the basic reason that the pilot screwed up and the airplane crashed: the pilot was not paying enough attention to TIME! All of the items mentioned in the film and the articles from the medical community are only a list of items that you should already know about if you have catalogued your responses in the airplane when you are deprived of the correct outside references. We all know what will happen in the weather or any other period of reduced visibility, such as low-level flying at night. We all should be aware that in a very short period of time we can no longer continue to fly correctly without some help. If I take any of you and ask you to drive your car across a large parking lot, blindfolded, you will not be able to continue in a straight line for very long. It is even worse when we try to do it in an airplane in three dimensions. But if I let you peek occasionally, the task is simple. The task is also simple in an airplane if I let you look at the velocity vector/pitch ladder relationship on the HUD or one of the ADIs in the cockpit from TIME to TIME!

And here is the key definition to the whole problem. Once we have become comfortable with how much time we can spend away from whatever artificial horizon we enjoy the most (and you probably already know I strongly favor the HUD), it is very important that you understand what I mean when the time has elapsed and it is now time to LOOK! As soon as it becomes necessary to fly the airplane on any sort of artificial horizon, it means that we throw away completely half of how we keep ourselves oriented. (It is really much more than half.) As soon as we have to use an artificial horizon, we no longer have the luxury of using any sort of peripheral cue that we do without any conscious effort when we are VMC.

So, when I say LOOK at the artificial horizon, I'm referring to a conscious act...a cognitive, foveal (fovealcentralis for you pre-med majors) stare at the artificial horizon. You must spend some finite period of time LOOKING (refer immediately to the first part of the preceding sentence) at the artificial horizon of your choice. You cannot depend on your peripheral vision to keep track of the artificial horizon. You must make a continuing series of LOOKS at the HUD and/or ADI in order to keep yourself rightside-up!

The reason that the HUD is so very much better is that in the same TIME you spend determining your attitude looking at an ADI, you can determine both your attitude and a large measure of the aircraft performance looking at the far-better HUD. In addition, the extended horizon line of the new IFC standard symbology also gives you a quicker mental picture of what the real horizon is doing in comparison with your airplane. I'm sure that you'll love it. So, regardless of how many ADIs you festoon around the cockpit, none of them do any good because none of them will interreact correctly with your now-lost peripheral vision. You must LOOK at the instrument to do yourself any good.

Let me give you a couple of what-ifs. Flying at night very close to the ground is a situation with which I am not unfamiliar. Using some combination of night-vision goggles, fixed or head-steered FLIR, I frequently find myself somewhere in the twilight zone (pardon the pun) between day, VMC and night, IMC.

Although the night-vision systems go a long way to help me see what is going on, I sometimes find conditions where the going gets very difficult, if not impossible. In such a situation, I cannot depend on my daytime, peripheral vision to keep myself oriented. The situation is further complicated by the fact that at 100 to 200 feet, in excess of 500 knots, I have only a couple of seconds where the wrong attitude will result in hitting the ground. Forget just being disoriented. As a result, I am forced to spend a considerable period of time LOOKING at the HUD. The ADI will simply not tell me all the information quickly, as the HUD does. Be aware that the duration of each look may be very short, but nevertheless it is a cognitive operation as I described above.

It really gets interesting if I am required to perform something, head-down in the cockpit. At that moment, it quickly gets to: think what it is I need-LOOK-move my hand to where I think the switch/info is contained in the cockpit (in an A/B it is usually on the FCNP, in a C/D it is usually on the ICP)-LOOK-glance to see if my hand is where I think it is-LOOK-move the switch-LOOK-observe the results-LOOK-ad nauseam. In this situation, if I have not looked at
the HUD for more than about one second, the bells and whistles are going off in my head, big time. In other words, I find myself in a rhythm of LOOKING and then doing some other task, the frequency of which is determined by conditions I find myself in. It is just that easy.

In the film I mentioned, our now-dead hero goes into a left, 45-degree-bank climbing turn, gets engrossed with looking for lead and supposedly allows the airplane to roll into a right 135-degree-bank descending turn and hits the ground. Now think about that for a minute. I'll wait.

Even if we assign a roll rate of 20 degrees per second (we are all capable of detecting roll rates with much lower thresholds) it will take nine (9) seconds to roll this 180 degrees and then some measure of time until ground impact. What was our hero doing all this time? Why didn't he catch the aircraft roll attitude in some intermediate position? If we assign more realistic roll rates to the problem (those slow enough that we would be guaranteed we would not detect that we were rolling) el piloto had a huge amount of time to realize the situation and make the proper corrections. What should he have done? Look for lead...his internal clock has gone off because his preprogrammed time assigned to this situation has run out...LOOK at the artificial horizon of his choice...look for lead...again to the artificial horizon...ask lead for his position...LOOK...decide if lead's position is within the gimbal limits of the radar...LOOK...position the radar to scan for lead...LOOK... The pattern continues as necessary. Get the picture? In the Dash One, the first part of any emergency is MAINTAIN AIRCRAFT CONTROL. It does no good to accomplish all the CAPS if you hit the ground immediately thereafter. It sometimes becomes necessary to LOOK at the artificial horizon at the expense of every other task.

Learn to recognize these situations and there will never be an excuse to become disoriented. This is all true regardless of what type of aircraft you are flying...not just the F-16!

Remember: T-I-M-E. It will keep you out of trouble! Check Six...if the situation at hand will allow.
By Joe Bill Dryden
Senior Experimental Test Pilot

All right, you F-16 drivers. No excuses for losing control of an F-16. This fact, though well punctuated on these pages in the past, hasn’t kept my compadres in our safety department from passing me reports of some of you losing control. In some cases, this has led to the loss of an aircraft (three in the last two years). My immediate response is to dust off some old copies of Code One and do a little clench-fisted highlighting. For those of you who’ve misplaced your back issues, here’s a refresher on maintaining control and what to do when you’ve lost it.
While it is not too smart, tactically, to fly slow, you can continue to point the lift vector even when the airspeed is off-scale low.

In the first five issues of Code One, I offered a series of articles for your enlightenment and, of course, your reading pleasure. In that series, called “Semper Viper,” I went into some detail about the radical design of the F-16 – its use of negative stability in particular. The airplane is designed to be negatively stable in pitch. Its computer-controlled flight control system uses all the good parts of negative stability and keeps all the bad parts in check. This was a radical departure (punintentional) in aerodynamics and flight controls, and it gives the F-16 some unique characteristics. That gets me back to the topic at hand.

The most important thing to remember about the F-16 is that it will not depart if you don’t get too slow. But being slow does not guarantee a departure! You must still inject a large degree of ham-handedness before you will depart. The last thing I want to see is a knee-jerk reaction of establishing some minimum airspeed on F-16 maneuvering. While it is not too smart, tactically, to fly slow, you can continue to point the lift vector even when the airspeed is off-scale low. (It is not a very big lift vector under these conditions, but you can still point it to make the aircraft go where you want it to go. You just won’t go very fast in that direction until you get some smash.)

In “Semper Viper,” I also went to some lengths about the limiters in the F-16 flight control system. The limiters keep an unstable aircraft under control. If you’re slow (both airspeed and mentally) and you make some sort of gross or rough input, the flight control computer will try to honor your request. However, it immediately senses that the airplane will depart control as a result. Even though you keep pulling or rolling, the flight control computer has reversed the control input (sometimes all the way to the opposite stop). Because you are slow (airspeed only in this case), the control surface doesn’t have enough authority to maintain the control it desires. So the aircraft departs. This situation is your fault, not the airplane’s.

What are some of the cues you should be looking for? If the airplane is buffeting, you’re slowing down. (The altitude or power setting doesn’t matter. If you are in buffet, you are slowing down.) The airplane will fly very well deep into buffet, so don’t be afraid to pull if the situation dictates. Just remember, to turn in this situation, you must give away energy (airspeed). Before any of you point out that you can maintain this or that altitude/G combination, go back and take another look at that same combination and you will find that the angle of attack is too small to produce buffet. A little more alpha and buffet appears, and you start to give away airspeed. The same holds true if you are flying vertical, or near vertical. In my previous articles, I went into greater detail as to why. For now, accept the fact that you will slow down if you try to go vertical for very long. (You can’t escape the laws of physics, even in an F-16. But you can come closer than in any other jet.)

So, you’ve been paying attention and know that you’re slow (airspeed for sure, maybe mentally). It may help to sneak a peek at the HUD. Still, if you’re aware of the cues peculiar to the F-16 (and I’ve discussed these a time or two in the past), you should never be surprised that you’re slow. If you are slow and the aircraft is not going where you want it to go, it’s no big deal. Simply allow the flight control limiters to do their thing, and you will get where you want to go without any undue dramatics. How? Be ssssmooooth.

Smoooooth (that’s five o’s) doesn’t necessarily mean slow. There’s a subtle difference between the two words. If you know that you’re slow, and you want to pull or roll the aircraft, then do exactly that. The input should be simply “and pull” or “and roll.” More about defining “and” in a second. It shouldn’t be pull or roll. It shouldn’t be “and pull/roll” or “and roll/pull.” In other words, don’t assault the two limiters at the same time.

Speaking of time, you might ask, “How long is an ‘and’?” The answer depends on your airspeed. At 600 knots, it might be 0.001 second. At less than 100 knots, it might require almost a full second of input. You want to let the flight control system know the input is coming, allowing it to make complete use of its limiters.

Figure 1 gives you a better idea of what I’m talking about. The upper line represents any of the limiters in the flight control system. It could be the AOA limiter or the roll rate limiter. If you make a brutal input, the aircraft immediately tries to honor the request. If you have sufficient airspeed (energy) in the airflow around the control surface, you might see a slight overshoot. But the flight control system can quickly return to the desired limit. If you are slow, you’ll have a gross overshoot. In this case, the negative stability takes over. All bets are temporarily off as far as controlled flight is concerned.

Take a look at the smooth input line that I describe as “and pull.” If your initial input is smooth (and technically slow) for the first few nanoseconds, you can continue to accelerate your input in the desired channel. Notice that the aircraft response is different since we have given the control system a “heads-up” that a large input is coming. The flight control system knows the limit is there and starts backing off.
Figure 1

AIRCRAFT RESPONSE
(LOW AIRSPEED)
ABRUPT

LIMIT AOA OR ROLL RATE

AIRCRAFT RESPONSE
(HIGH AIRSPEED)
ABRUPT

AIRCRAFT RESPONSE
(HIGH AIRSPEED)
SMART INPUT

AIRCRAFT RESPONSE
(LOW AIRSPEED)
SMART INPUT

ABRUPT STICK INPUT

SMART STICK INPUT
“AND PULL”

0.001 SEC @ 600 KCAS
1.0 SEC @ 100 KCAS

TIME ➔
Don’t wait for a deep stall to familiarize yourself with the MPO switch.

to avoid overshooting it. If you fly the airplane in this manner, it is nearly impossible to depart. The only exception: you are nearly vertical and the airspeed truly goes to zero. When the aircraft falls backward for a short time, it is possible to depart.

In addition to the occasional screw-up with the airplane nearly vertical, you heavy handers may experience some departures due to rough control inputs at low airspeeds. Despite my words of wisdom, some of you are still going to make less-than-ideal inputs to the flight control system. Once the airplane departs, it will behave in one of four ways:

1. The airplane will recover on its own. It desperately wants to recover. The flight control engineers did a good job in this respect. Even though you have just departed a negatively stable airplane, it will recover without your help more than eighty percent of the time.

2. The airplane will go into an erect deep stall. Figure 2 shows that in the fifty- to sixty-degree AOA range, the total moments (read forces) on the airplane are essentially zero. Therefore, if you do something foolish to force the F-16 past the AOA limiter of twenty-nine degrees and arrive in the fifty- to sixty-degree range with little or no pitch rate, the F-16 is happy to stay there.

3. The airplane will go into an inverted stall with no rotation. The other side of Figure 2 shows a location similar to Case 2 above. The aircraft will behave inverted as it does erect.

4. The airplane will go into an inverted deep stall with some amount of rotation. (In “Semper Viper,” I went into some detail as to why.)

So, now, how do you recover?

In Case 1, do nothing. Consider yourself lucky. Go home. Take some time to explain to yourself how you screwed up and don’t do it again. Share your experience with your pilot babbas.

In Case 2, you must do something to recover the airplane. Watch what it’s doing in the pitch channel – the channel that makes your eyes go straight up and down in your head. Ignore any inputs that make your eyes go left or right and ones that make them go clockwise or counterclockwise. (Usually all three motions are present in various amounts.) To recover, you must reinforce the pitch oscillations. Depending on the configuration and the conditions that produced the deep stall, the magnitude of the pitch oscillations will vary from deep stall to deep stall. But the frequency of the oscillations will be fairly constant at about three seconds from one extreme (nose high) to the other (nose low).

Find the MPO switch. As I’ve mentioned in the past, you should practice locating this switch when it’s less hectic in the cockpit. In other words, don’t wait for a deep stall to familiarize yourself with the MPO switch location. Hold the switch outboard. When the nose is at its lowest point, pull back and hold. At the same time, the other side of your brain should start counting the seconds – one thousand, two thousand... When you think the nose has reached its highest point and has reversed its direction, push and hold the stick. (The MPO is still outboard.) Check back with the other side of your brain. If it is just completing three thousand, you’re doing it right.

A common mistake is to try to do the pitch rocking too fast. (Your body clock is usually running about ten times its normal rate about now.) Another common mistake is to confuse a yaw or roll oscillation with a pitch increase. Remember what I said about your eyeballs. You should only be concerned with movements straight up and down in relation with your head. (Of course, I’m assuming you’re sitting straight up. You are, aren’t you?) Don’t bite on yaw oscillations and pull when it’s not called for.

As you push, the nose should pitch down, hesitate slightly, and then pitch farther down. You’ll see the AOA gage break off the peg (32.5 +/- a little), and you’ll be flying. If the nose reverses in pitch, pull the normal three seconds and repeat the process. As the nose pushes down and you’ve recovered, quit pushing so you don’t pitch over on your back and enter a situation described in Case 3.

Case 3 is a mirror image of Case 2. Once you’re sure that the airplane is indeed in an inverted deep stall (remember, it wants to recover on its own), follow the sequence described above. To review: (1) MPO outboard; (2) When the nose is at its lowest point, pull and hold the MPO and begin counting; (3) When the nose is at its highest point, (inverted) and total time is three seconds, pull and hold. The nose will pitch down, and you should be flying again. Don’t continue pulling and force the airplane into an erect deep stall. Just like before, don’t confuse a yaw or a roll for pitch.

Some people would call Case 4 – an inverted deep stall with some rotation – a spin, but the marketing guys get upset with me when I do. Whatever you want to call it, your eyeballs will be travelling in a fairly constant direction left or right, rather than oscillating left and right. To recover, stop on the opposite rudder to stop the rotation. (Pitch rocking is usually ineffective if the airplane is rotating.) The airplane will usually recover on its own when you stop the rotation. If
it doesn’t, you have just entered Case 3. Recover the aircraft as described above, go home, and make sure you don’t do it again.

For those interested in some nontextual training, the test pilot cadre here at the fighter factory has had an offer on the table since 1978 to provide a short briefing and a one-sortie program to show you all you need to know about keeping the shiny side up all the time. The sortie was designed by the test and operational pilots of the F-16 Combined Test Force at Edwards AFB. I’ve already trained pilots in two foreign air forces and am scheduled to fly with a third soon. Alone, I have done more than 250 intentional deep stalls with these pilots and recovered all of them. Call me stallworthy.

The training sortie includes five maneuvers that, if you understand correctly, will ensure that you never depart the F-16. To make certain that all the bases are covered, I force the F-16 into a deep stall in four additional maneuvers so that you can recover the airplane. These maneuvers get your own references to match up with what I have been saying here about timing, sounds, sights, etc. One sortie will ensure that you’ll never lose control of your jet. Give us a call and we’ll take you for a spin, or rather, an inverted deep stall with some rotation.

**Check six...** and remember – a departure won’t improve your tactical situation. ■
The tremendous changes in the balance of military alliances worldwide in the last year or so will have a tremendous effect on military planning. Options range from no change from previous plans to complete abolition of the Department of Defense. Somewhere between these extremes falls various options for upgrading, instead of replacing, our present fleet of tactical airplanes. For such options to work, the people writing the upgrade specifications need to know what they are writing about. From some of the specifications I’ve seen for the F-16, this is not always the case.
Every model of the F-16 has many systems that can be upgraded. For the sake of brevity (and editorial restraint), I'll limit today's sermon to two areas: night vision goggles and head-steered or fixed forward-looking infrared systems. I'll sing praises and blast faults of other systems in future issues.

To be effective, an NVG system must have three ingredients. The first has to do with the placement of its light intensification tube.

Light intensification tubes are wonderous. They can amplify ambient light between 8,000 and 12,000 times. From the latitude here at Fort Worth (thirty-two to thirty-three degrees north), you can see the Northern Lights (Aurora Borealis) with them as soon as you get to any altitude and away from the city's lights. If you know where to look, you can see various gas nebulae without optical magnification. Those billions and billions of stars that Carl Sagan keeps mumbling about pierce the black. The Milky Way looks milky.

Closer to Earth, you can see airplanes at night (if their lights are on) from distances that would blow away ol' Chuck's most outrageous - and patently bogus - claims of daylight vision. The first time you look through a pair, you'll be scared when you realize that all those airplanes have been there in the past.

Depending on where these tubes are placed, NVGs can be divided into two broad types. For the sake of this discussion, I'll refer to the them as ANVIS and Cat's Eyes. With the ANVIS type, you look directly through the light intensification tube. With the Cat's Eyes, you look at an image that has been piped to your eyes from a remote intensification tube. Although you will see or hear about many different NVGs from many different contractors, they all fall into these two categories.

The distinction is important because the ANVIS type does not work well in a fighter cockpit. ANVIS NVGs make it extremely difficult to see cockpit displays. If you are trying to view a FLIR image on the HUD (an image from a LANTIRN pod for example), you must now view the real world through two levels of less-than-optimal resolution. Not good. Since all Cat's Eyes NVGs use a combining glass arrangement, you can see what you need through what is essentially a thick pair of glasses. These goggles work especially well if some sort of automatic cutoff is provided for them when you want to look inside the cockpit.

If you haven't already guessed, an automatic cutoff is numero dos on my three-part ingredient list. Depending on the cockpit configuration, NVGs must have an automatic cutoff for one or more parts of the cockpit. I won't take time to explain how this is done, but take it on faith that an automatic cutoff system is not too complex.

ANVIS goggles can be shut off automatically as well. But you'll find yourself staring down two black, and I mean really black, holes. The relatively clear combining glass of the Cat's Eyes NVGs provide a much more direct view of the cockpit.

The third ingredient has to do with the cockpit lights. NVGs don't discriminate between a panel light in your cockpit and a bright star in the sky. They amplify every light between 8,000 and 12,000 times. Even though you turn down your panel lights to a level that you think is essentially off, the cockpit will be filled with bright constellations of green, glowing orbs. Those very dim lights will cast 8,000 to 12,000 times brighter reflections in the canopy as well.

An automatic gain control in the tubes modulates the light amplification to protect you and the system from sudden bright lights. The gain control responds to cockpit illumination as well (and will lower the light amplification accordingly). This will, in turn, lower the system's effectiveness to outside lights.

This conflict can be resolved by adding NVG-compatible lighting - the third ingredient. Since the goggles are sensitive to light in the lower part of the visible spectrum and just below (near infrared for you Scientific American readers), blue-green lighting (which is just above the lower part of the visible spectrum) will go undetected. Voila! Eight thousand to 12,000 times zero is still zero. The exact frequency of this "invisible" color for the NVGs varies from application to application, but it is essentially what you and I would call blue-green.

While the goggles can't pick up this blue-green lighting, the human eye actually sees best in light from this part of the spectrum. Our increased sensitivity to this part of the spectrum is an indirect benefit of the NVG-compatible lighting; you can read the gauges better with the blue-green lighting than you can with the red, orange, or blue-white lighting currently in vogue. But this benefit has its drawback as well. Your eyes will be more sensitive to the canopy reflections of the cockpit lights. Although some people would try to pass this off as a minor irritation, it can be very distracting.

Furthermore, light intensification tubes can be tuned so that they intrude into this blue-green part of the spectrum.

With ANVIS-type NVGs, you view an image directly through the light intensification tubes.
With Cat’s Eyes NVGs, you view an image projected onto a combining glass.

They can then be used to detect NVG-compatible cockpit lighting of other planes. You thought you were being sneaky by extinguishing your exterior lights, eh? It is possible to see LANTIRN guys, who typically fly with their blue-white cockpit lights turned up bright, as much as ten miles away! This fact could make life very unpleasant for our intrepid night fliers.

To solve this problem, you must determine what lights are mission essential and then provide a switch to turn all the others off and on as necessary. Mission-essential lights in the F-16 would probably include the HUD, the REO/SMS (radar and stores management system) in the F-16A/B, the multifunction display in the C/D, the fire control navigation panel in the A/B, the integrated control panel/data entry display in the C/D, and probably the radar warning receiver and the chaff/flare panel in all models. A few other lights might qualify, but this is fodder for an operational test and evaluation program.

NVGs improve situational awareness tremendously. I’m certain that if the LANTIRN guys had them, the last two pilots who bought the farm in LANTIRN-related accidents would still be here to discuss the pros and cons of NVGs.

As I’m writing this piece, I am waiting to go out tonight and fly with one contractor’s new integrated NVG helmet. It appears to work very well. With a few minor changes, it would go a long way to properly integrate an NVG device into the cockpit. It is not operational as yet, but I don’t think it is necessary to wait for the perfect solution to a problem when you have an effective solution with the clip-on Cat’s Eyes at present. If you consider and include all the items I listed above, NVGs work very well. (If you don’t, they work poorly or not at all.)

NVGs amplify light in the visible spectrum, with only a small intrusion into the infrared. As we continue into the invisible IR region, we get into FLIR territory and into the second part of my sermon.

Videos from FLIR systems look magical; they appear to turn night into day. This initial impression, however, can be misleading. The marketing video you’re seeing was probably recorded on a flight in the Edwards or Nellis area, where the 140-degree daytime temperatures and the incredibly low absolute humidity provide nearly perfect thermal contrast and transmissivity conditions. The same system, under poor conditions of thermal contrast and transmissivity, does not perform nearly as well.

Flying a FLIR-only system for a night-attack mission, you run the risk of encountering many nights when you can’t see at all! As a result, you are forced to fly MEAs, won’t find any of the bad guys, and risk getting your a--- shot off (or hitting the ground) in the process.

What I said is true of NVGs as well. On some nights, NVGs are just so much excess baggage! You really need both parts of the spectrum available at the same time if you want to be a true around-the-clock attack jet. In other words, you need a fixed FLIR on the HUD and some sort of NVG. Similarly, head-steered FLIRs, which can be superb in their own right, need as a minimum some sort of low-light-level device on the HUD. The two-turret, head-steered systems are better yet. One turret has a two-field-of-view FLIR. The other incorporates some sort of low-light-level TV sensor.

Some really forward-looking and forward-thinking pilots are working on systems that fuse information from the two types of devices. Put simply, an algorithm makes a pixel-by-pixel analysis of pictures from both devices and produces a single image that contains the best information from both parts of the spectrum. I am not talking concepts here (they’re cheap). Although the system is not operational by any means, I have seen the basic principle in operation. One contractor’s efforts with a fused infrared/electro-optical or infrared/low-light-level-TV images are quite remarkable. The fused image was superior to an independent picture from either of the two sensors. This approach makes both parts of the spectrum available all the time. It also greatly simplifies the HMD since it displays a single image on the helmet.

Make no mistake! Even with this device, there will be nights when I should stay at home. The reason has to do with the physics behind the sensors. Those making the decisions for this equipment should try better to understand these fundamental characteristics.

What I’ve said here is vital if we are going to add new capabilities and to improve existing ones. Everyone likes to play in the technological sandbox. But this predilection should not overshadow what’s in the best interest of those who will eventually use the products of our technology—the operators. We must provide them with the best possible weapon system that we can.

End of sermon! ■

Check Six.

ILLUSTRATIONS BEN JUAREZ

CODE ONE 83
Flying through

BY JOE BILL DRYDEN
Senior Experimental Test Pilot
Last issue, I pointed out that looming budget cutbacks may force us to take a serious look at modifying existing aircraft rather than buying new ones. My purpose was to make sure that the people writing the specifications for these mods would come up with more realistic requirements for night-vision goggles and forward-looking infrared systems. This time, in the same vein, I want to address head-up displays.

Before I get started on HUDs, however, one final word on night-vision goggle systems. The switch I mentioned for turning the NVG-compatible cockpit lighting on and off should be a hands-on switch. The folks in our cockpit lighting lab have developed several options – the leading candidate being a switch on the underside of the throttle. It works smoothly and makes switching the appropriate lights on and off a completely subconscious act by the pilot. Now, on to HUDs.
We should quit trying to make HUDs more complicated than they have to be. We should figure out what is truly needed, provide that - and nothing more.

If you have been following my journalistic endeavors here in Code One, you know how I feel about HUDs. (HMDs fall into the same category.) They are superior instruments for flying under instrument conditions. With this said, their acceptance has been unnecessarily delayed by the myopic attitudes of a few individuals who have not taken the time to understand the slightly different technique necessary to take advantage of their clear superiority. Strangely enough, although the edict remains on the books, to wit, “the HUD shall not be considered the primary flight reference,” both the F-15E and the new C-17 have completely glass cockpits with none of the “classic” head-down flight instruments. Hummm.

I can’t say that we haven’t tried to change the situation. Working with the Instrument Flight Center at Randolph AFB, our human factors section has invented a superior means of displaying information to the pilot necessary for using the HUD as the primary flight reference. But when it came time to implement the changes, self-proclaimed experts stepped in and undid our efforts. So, once again, the powerfully uninformed are attempting to carry us head-long back into the dark ages.

These experts have failed to grasp the following: As soon as science can provide pilots with the sensor/computer combination to display a velocity vector (whether on a HUD, HMD, or a head-down display), you can radically improve your ability to control an aircraft on instruments. Until this fact sinks in, those ignoring it will continue to delay the acceptance of an excellent approach to flying when pilots are deprived of a visible horizon. I can’t say it any plainer than that.

Perhaps a flashback will make things even clearer. Until the first true HUD became available, cockpit instruments were simply a continuation of efforts started by Gen. Jimmy Doolittle several decades ago, when he guided his plane with needle, ball, and airspeed instruments.

Before HUDs became available, pilots had to control their planes, under instrument conditions, with what was described as control instruments (the attitude director indicator or ADI and the tachometer) and performance instruments (essentially, the rest of the cockpit). The plane was controlled by making the “picture” on the ADI agree with what was necessary to maintain that desired flight condition. But that was only the first step. Pilots had to check all of the performance instruments visually and then mentally integrate all this information to make sure that the airplane was truly doing what they wanted it to do.

A velocity vector display – whether it’s on a HUD, an HMD, or a head-down, monochromatic or multicolor multifunction display – drastically simplifies this operation because it provides in one place both the control instrument aspect and the performance information. You control the airplane with the velocity vector and its relationship to the pitch ladder. At the same time, you receive nearly instantaneous feedback on most of the airplane’s performance. As a result, the amount of information required from what used to be called performance instruments is drastically reduced.

With one quick look in a very narrow area around the velocity vector, you know immediately if you are maintaining level flight, climbing, diving, or turning. Again, all this information appears in one place. No need to look elsewhere. As a result, the velocity vector diminishes the importance of the airspeed, altitude, and heading. It eliminates the significance of vertical velocity entirely. You have no need to know the rate you are climbing or diving. All these rates have been converted into the angles they have been all along and then displayed directly. As a result, you can fly more precisely, more safely, and more easily – all at the same time.

Here’s a specific example. In the F-4, as I entered the glide slope in a GCA (that’s short for ground-controlled approach: the ground controller is using a radar to help me land), I normally lowered the nose about one-eighth of a bar width on the ADI. At the same time, I made about a two percent reduction in power, tried to hold that picture on the ADI and waited for the vertical velocity to settle down. With some luck, the vertical velocity ended up where I intended when I started the process – about 750 feet per minute rate of descent.

Even if I was successful the first time, if one – and only one – variable changed, I had to detect it first by integrating all the info from the performance instruments and then by trying to correct the situation by changing the picture on the ADI (usually with a power change as well) and hope, once again, that this was now what I needed. It seldom was.

A velocity vector greatly simplifies the procedure. Let’s assume I have done my homework and know the glide slope angle. (They are all published in the approach books.) When it comes time to enter the glide slope, I simply push the velocity vector down to that value. This is nominally a minus two-and-one-half degrees. From this point on, all I should ever hear from the controller is “on glide path.” The same is true of instrument landing systems, microwave landing systems, or even a self-contained radar, GPS, or DTS approach. (For those of you who have not been keeping up with your
flying magazines, GPS stands for global positioning system and DTS for digital terrain system.) Notice that I didn’t mention power, or airspeed, or vertical velocity.

In the F-4, I had to go through the mental gymnastics of combining ground speed and vertical velocity to maintain that two-and-one-half-degree glide slope. With a HUD, I can see the results of those calculations directly without straining my brain. Within reasonable limits, all the other variables can change without having to change the position of the velocity vector at all. Consequently, my approach has to be easier and safer.

While I cannot completely ignore airspeed, it is no longer a key factor. In fact, if I already have the drift angle killed (that is, no further heading changes) before entering the glide slope, the HUD is the only place I have to look – to ensure that the velocity vector is superimposed on the two-and-one-half-degree down mark and to consider the angle of attack bracket (close to the velocity vector), which I’ve already checked against the airspeed.

Now, with an occasional glance at the altitude to see how I’m progressing toward decision height, I don’t have to look anywhere else during the approach. Furthermore, because I’m using the HUD, I’m already looking through the canopy where the runway will appear. Hence, I’m the first to know when I break out of the clouds. This is not the case if I fly with my head down in the instruments.

I am not suggesting a cavalier approach to flying instruments. I do look at other information on the HUD. The point I’m trying to make is that I could accomplish the approach in exactly the manner described. Further, a velocity vector obviates the need to cram all the information into the HUD or a head-down display that was spread over the entire panel in the past. The information is no longer required in the same format as it was before we had velocity vectors. Nor is all the information considered on the same level.

We should quit trying to make HUDs more complicated than they have to be. We should figure out what is truly needed, provide that – and nothing more.

As I said last time, if we are going to add new capabilities to the airplane or improve existing capabilities, we need to make sure that we give the operators the benefit of the doubt and understand what it is that we are trying to improve.

End of sermon. Again.

Check Six!
DON'T STRETCH THE LIMITS

BY JOE BILL DRYDEN
Senior Experimental Test Pilot
I've spent part of the last few weeks looking over the shoulders of some of the engineering disciplines here at Fort Worth as they deciphered data from the many recorders scattered about the F-16 to try to quantify the attempt of one pilot who did his damndest to see just how high the F-16 will fly. (The pilot and his unit will remain nameless.) This data reduction was not in the interest of documenting a record, other than one for a pilot not thinking through the consequences of his actions.
The high-altitude attempt, which I'll discuss in detail later, reminded me once more of how the fighter community may have little or no knowledge as to how various limits are established for their airplanes. Back in the good ol' days when I was still a young pup in the F-104 and F-4, even I had a hard time understanding the reasoning behind certain limits. On more than one occasion, I suspected that my airplane was physically capable of doing whatever I wanted it to do, regardless of what the dash one or wing regulations mandated. But two stints at Edwards AFB and one at the Tactical Air Command Systems Office at Wright-Patterson AFB (looking over shoulders at the F-16 System Program Office) gave me an appreciation as to how and why most of the limits are established for this or that airplane.

From the start, everyone should be clear on the following: This is a discussion of various limits that apply to the F-16 in particular and to all aircraft in general. It is neither an encouragement nor a license to exceed any operating limit. Once you read everything I'm going to say about some of the limits (especially the physical ones) on the F-16, you should better understand why they exist and, I hope, be much more inclined to abide by them.

Limits fall generally into three broad categories: economic, physical, and political (yes, political).

Situations in which the customer or the SPO feels that it is unnecessary to fund tests beyond a given point produce economic limits. You will frequently encounter these limits with munitions (weapons, *las armas*, *les armes*, *Waffe*, etc.). Have you ever considered it odd that nearly all the air-to-ground weapons have a Mach 0.95 carriage limit? You won't find some little-known Newton's Fourth Law that states that the upper limit for air-to-ground weapons is Mach 0.95. This limit usually exists because the money necessary to fly the sorties and reduce the data to extend the limit was not available.

Be advised that a Mach 0.95 limit does not necessarily imply an economic limit. For example, this limit is realistic in a physical sense when it comes to some types of fuses, though internal electric fuses go a long way to improve this situation. Also, some weapon configurations may have a flutter problem or at least a limit cycle oscillation problem beyond Mach 0.95.

You may have noticed that the limits on some weapon configurations have been extended to allow supersonic carriage. Most of these are parent carriage on the MAU-12. However, the majority of configurations still restrict you to Mach 0.95 employment because the load was not tested (because of money) for release at higher airspeeds.

I'd like to know just how well the airplane will fly in this configuration.

Though economic in nature, these limits often have as much of an impact operationally as do the physical limits. For example, some have complained that the week-driving accuracy that the F-16 is known for was not replicated in the Iraqi fracas. Videos revealed, however, that the tactics used produced a large number of releases in the vicinity of Mach 1.05 to 1.1. The fact that none of the weapons hit the airplane is good testimony that such releases work. But why no good hits? At the risk of sounding like a broken record, economic reasons.

Since the tests did not call for supersonic releases, supersonic tests were never performed. Further, the near-flow-field effects change drastically when the airplane is transonic. The information in the fire control computer is in error at these speeds because its information cuts off at Mach 0.95. If the separation effects were quantified in the Mach 0.95 to 1.2 range, the accuracy would return to the level normally expected of the F-16. Though this may sound a little simple, quantifying these effects would require one thing - money. Still no free lunch.

Let's look at political limits before getting physical. I can recall two good illustrations. One involves the flight control system of the F-16. Like most of you, the first time I was exposed to the F-16 flight control description, I was not sure that I liked what I read. In particular, the system had no physical connection between the stick and the flight controls, only electrical signals. Having flown with the system all these years, I now have the utmost confidence in it. Having said that, however, I would still like it to be investigated a little further.

One of the possible failure modes with the F-16 flight control system involves one or more of the flight control surfaces being voted out of the flight control computer loop, in which case the surface would be instructed to lock in the faired position. I'd like to know just how well the airplane will fly in this configuration. I suspect that it will fly fairly well as long as the pilot doesn't ask for some maximum input in the affected channel. But we don't know for sure.

I can, however, point to a previous experience with the F-16XL. During a test point looking at the roll response of the airplane at very high Q (a fancy scientific term for high calibrated airspeed), one of the test pilots (nice guy by the name of Jim McKinney) had the misfortune of making a maximum roll input to the left at very high airspeed coincident with hitting a pretty good patch of turbulence. The sharp additional load from the turbulence physically broke the horn on the bell crank connecting the right elevon to the hydraulic actuator. Jim said that it sounded like a cannon going off in the cockpit. (The elevon, the inboard control surface on the XL wing, is primarily for pitch control. But the control surfaces help each other depending on the rate requested and whether one is being tasked in its primary channel.) The air loads caused the right elevon to snap back over center, which violently checked the roll. So violently that it snapped off the vertical fin.
cap, the right dummy AIM-9, and the front and rear third of the right missile launcher.

The elevon was now free floating and damped to the still free-floating, but generally streamlined, position. Jim prudently elected to discontinue the flight and returned to land. Obviously he did not make any gross control inputs, but he had no indication that he had lost the use of one of the major flight control surfaces until after the landing. Based on this episode, I feel the little airplane will also fly okay with a locked flight control surface. But I don't know for sure and won't until someone goes up on a briefed flight with an instrumented, cine-tracked, debriefed, and data-reduced F-16.

When such a test was requested, one of the past center commanders refused to allow it. He said, "Let the operators find out about it." So for political reasons, the flight control system of the F-16 was not tested completely. As I said, I have great faith in the F-16 flight control system. But, given enough time, it is surely going to happen at about two o'clock in the morning during a deployment that Blue 4 announces, "Hey, lead, my right stabilator just locked."

"Now what do you do? Do you let him refuel? Do you send him to Keflavik that's reporting 200 and one-half. It would be nice to know how the airplane will respond ahead of time.

Another good political limit with the F-16 is the crosswind landing limit. During the test program, I landed the F-16 with a direct crosswind of thirty-eight knots. I must admit that the airplane was very unhappy and my gains were a little higher than normal. As a result, we recommended a direct crosswind landing limit of thirty-five knots. The four-star test pilot, however, said "twenty-five knots."

"But, General, we've landed in excess of thirty-five knots." "Twenty-five knots!"

"Okay, twenty-five knots."

That's one limit not tested because of politics and one established because of politics.

Now for the promised physical limits. Two examples are worthy of discussion. The first involves the calibrated airspeed limit on the F-16. The dash one sets the KCAS limit at 800 knots. Interestingly, the airspeed limit is actually based on the engine operation. With the original -200 version of the F100 engine, you almost had to dive into the point to exceed 800 knots. But just such a dive could surpass the physical limits of the engine because the -200 engine control system essentially runs open loop. That is, the control system would allow the compressor discharge pressure to increase beyond the physical limits of the engine. Therefore, the limit was established at 800 knots to ensure that the -200 engine remained within its envelope.

A tragic accident exemplifies the frivolity (read stupidity) of exceeding this limit. One of the pilots in the test squadron at Eglin (someone who certainly should have known better) took it upon himself to see just how fast the F-16 would go. On the way back from a rather mundane test mission, he climbed to 16,000 feet, turned the stick full up, and nosed over into a dive. In reconstructing the flight, we feel that he got well on the high side of 850 knots. Since the compressor discharge pressure was uncontrolled, the pressure became high enough to distort the engine case. The turbine rubbed the engine case at a ferocious rate, went through the turbine tip seals, and began eating into the engine case with equal fury.

The engine casing in this area is constructed mostly of titanium. Those of you familiar with the periodic table of elements may remember that titanium is in the same family of elements as sodium, lithium, and magnesium. The temperature to get titanium burning is very high (that's one reason it is used in the engine). Once any of these metallic elements start burning, though, you have one hell of a fire. With a fire of this intensity in this part of the airplane, you have effectively wrapped prima cord between the trailing edge of the wing and the leading edge of the horizontal tail and lit that sucker off.

The intense fire quickly burns around the entire fuselage and through both hydraulic control systems in spite of the best efforts of design engineers to isolate the two systems from collateral damage resulting from multiple combat hits. Under such conditions, all bets concerning the control of any aircraft are off. Even the most thoughtful attempt to design redundant safety systems can be sidestepped by stupid actions of a pilot. With no hydraulic pressure, you are nothing more than a passenger in an aircraft going down at almost 1,000 miles per hour. The airplane continues to descend and you don't even have a vote. That's not a feeling I want to experience.

Somehow our intrepid (but not too forward-thinking) aviator got out of the ruined airplane. But he broke both arms in the process. He ended up drowning in the Gulf of Mexico. A very bad scene from any perspective.

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So if the engine is not the limiting factor, what is?

Those of you who may have been getting in the books or listening to the engine awareness briefings of both Pratt & Whitney and General Electric will probably now want to point out that the later -220 and -229 versions of the F100 and all models of the GE F110 engine have positive, closed-loop control systems. I'm glad you've been paying attention. The -220 engine has more thrust than the -200, once you get it moving. But it is seldom more than ten percent better. So you'll still usually have to dive the airplane to exceed 800 knots.

But the -229 and all versions of the F110 have enough power to go right through 800 knots like it isn't even there, straight and level, sometimes as high as 15,000 feet. So why not exceed the limit?

Pay attention. The newer engines control the compressor discharge pressure for the most part by rolling back fan rpm, which cascades through the engine and, thus, effectively limits the N2 (the high-pressure compressor) discharge pres-
The airplane has some fantastic flying characteristics. Learn to use them to the fullest and surely you can have fun and still remain within the airplane’s physical limits.

number, n’est-ce pas? Under test conditions, I’ve been as fast as 845 knots with the early GE engine. Further, it was readily apparent that the airplane was nowhere near ready to quit. It is really a ride to feel those levels of acceleration for that length of time and still know in your heart that there is a lot left. We could have easily taken that airplane (one of the old beat-up, full-scale development airplanes, F-16A No. 1) and set a low-altitude speed record with no preparation other than getting the Federation Internationale de Aeronautique to Edwards to certify the timing. But once again the political climate was not right to grant the F-16 any favorable notoriety. Plus, we were told in no uncertain terms that we were not even to talk about such an attempt. Too Bad! It would have been fun to see just how fast we could have gone. It most certainly would have been a big number.

I almost choke, however, when I hear that some pilots have had the airplane as fast as 870 knots. Even considering that the speed may inflate a little every time the story is told, I really don’t like to hear about anyone exceeding 800 knots for no apparent reason.

Why?
Anybody have a clue?

The answer concerns the canopy. It has never been qualified at the kind of airloads and temperatures involved with flight in excess of 800 knots. If you don’t think the airspeed effects on the canopy are real, the next time you have the opportunity to fly for any period of time with the clock reading more than 500 knots, take your glove off and feel the inside of the canopy. It gets damned warm. Further, the effects are exponential. And going from 500 to 800 knots is a hell of a lot more than the sixty-percent increase that simple, linear arithmetic would lead you to believe.

Don’t get me wrong. In combat (the operative word), knowing what I know about the F-16 engine combinations available, if I had a MIG-29 just out of range at twelve o’clock (or worse yet, just in range at six o’clock), I wouldn’t hesitate to go over 800 knots. But doing it as a matter of routine in peacetime because it’s fun is plain dangerous. No one really knows just how many pressure and temperature cycles involved with these airspeeds the canopy can take before it starts to get tired. And I can guarantee that you will not want to be the name behind the data point associated with a face full of canopy somewhere in excess of 700 knots just because your squadron bubbas have ignored the airspeed limit one time too many. This is a very real physical limit. I strongly encourage you to respect it.

This brings me back to the high-altitude attempt mentioned in the beginning. From what we can determine, our stalwart aviator decided to see just how high he could fly. He started out right in that he climbed to a fairly high altitude, pushed over into a very good Ratowski path, and adroitly accelerated to maximum Mach at the tropopause. He was now out at the Es lines you have seen only on some of the classified charts in Intel. No problem, so far.

But from this point, he became dumber than dirt. He pulled the airplane into almost a vertical attitude and peaked out at a very high altitude. There is no reason to give any credibility or acclaim as to the exact height reached, but trust me — it was way up there. If he had flown the profile correctly, he probably could have gone even higher. But this is not the first thing he did wrong.

We had pressure suits in the prototypes and flew the F-16 at sustained altitudes considerably higher than 50,000 feet. The zoom potential is even higher. But the production F-16s do not incorporate a pressure suit, and it is senseless to go above 50,000 feet without one. You have probably seen the demonstrations in the altitude chamber in which someone wearing a pressure suit and holding a beaker of water is explosively decompressed to some altitude well above 50,000 feet.

Your ninth-grade general-science teacher spoke with straight tongue when he or she taught you that as the pressure is decreased, so does the boiling temperature. Sure enough, the water at room temperature violently (almost explosively) boils off in a cloud of vapor. While this demonstration supposedly shows you what will happen to your blood in the same situation, it is a little over dramatic in that it doesn’t consider the pressure retention of your skin and clothing.

Ergo, you are not going to “boil off” at a similar rate. However, it is correct in that your time of useful consciousness is effectively nil under the same conditions. If you don’t get down tout de suite, you are history without a pressure suit. Our pilot was above 50,000 feet without a pressure suit. Strike One.

Our high-flying pilot also failed to consider that the engine does not enjoy these altitudes any better than humans do. That is why you can’t get them restarted at any ol’ place in the envelope. You can tune a jet engine to run at these
altitudes, but it is difficult. (This is why we have rockets.) So during the climb, the engine quits. Strike Two.

At extremely high altitudes, the control surfaces have little or no effect. In case you haven’t been paying attention, ask Ensign Wesley Crusher just what the calibrated airspeed is at Warp Eight. It is zero. And unlike the warp-drive-equipped Enterprise, the F-16 and all other airplanes respond to calibrated airspeed to control where they go. (We don’t even have impulse engines.) So our pilot rapidly approached very low calibrated airspeeds in his climb even though he may still have been supersonic. He was more appropriately classified as ballistic. Strike Three.

The pilot tried to roll left, but the inertia effect of the engine took the aircraft to the right. (He will later complain about the flight control system for rolling the wrong way.) Fortunately, the bleed down rate of the cabin pressure when the engine quits is slow enough to allow him to subsist until the airplane fell to a lower altitude, where he has some hope of surviving and getting the engine restarted.

Back at the base, he has to explain why the emergency power unit fired. But this will be the least of his worries. He is lucky to be alive. All in all, a poorly thought-through stunt that very nearly cost us a valuable airplane and an expensive pilot.

In case you think you are smart enough to get away with such a stunt, read carefully. In the old days with the F-100 and F-104, you could just “happen” to drop the film canister on the ramp if you had the camera running during some event you didn’t want the world to know about. In the F-4, you had to be sure that the radar camera wasn’t running and that your GIB [guy in back] wasn’t suffering from a guilty conscience.

But the F-16 has any number of hidden places where interested parties can retrieve data and reconstruct an entire flight if necessary. For example, the altitude in the crash-survivable memory is limited to 50,000 feet mean sea level, or MSL. When the data in the crash-survivable flight data recorder from the flight I described above was downloaded, the readout indicated a long (very long) string of special events data had been recorded at altitudes in excess of 50,000 feet.

The engine monitoring system computer revealed that the engine problem occurred at an altitude greater than the engine recorder limit of 70,000 feet MSL. If you look still further, the altitude data stored in the electronic control assembly will record altitudes as high as 100,000 feet MSL, which is nearly 20,000 feet higher than the altitude limits of the central air data computer stored in the flight loads recorder and, if selected, on the video tape.

All of these sources include airspeed and altitude information and many other interesting flight profile and aircraft systems parameters as well. There are also other locations where data lurks that I didn’t mention. Good luck dropping all of these on the ramp! The moral: 1984 has indeed long since come and gone in the F-16. All it takes is for someone to suspect that something is awry. The airplane can tell us very nearly exactly what you did from the time you started until the time you shut down.

If you don’t like the economic limits, try to convince the chain of command to spend the money to get them changed. If the political limits bother you, use the proper channels and attempt to get them changed. But for Pete’s sake, realize just what the physical limits truly are and don’t exceed them. If you do, at best, you’re going to get caught. And you could very easily lose your life. The airplane has some fantastic flying characteristics. Learn to use them to the fullest and surely you can have fun and still remain within the airplane’s physical limits. Step outside them, even briefly, and either way, you’re toast.

**Check Six!**