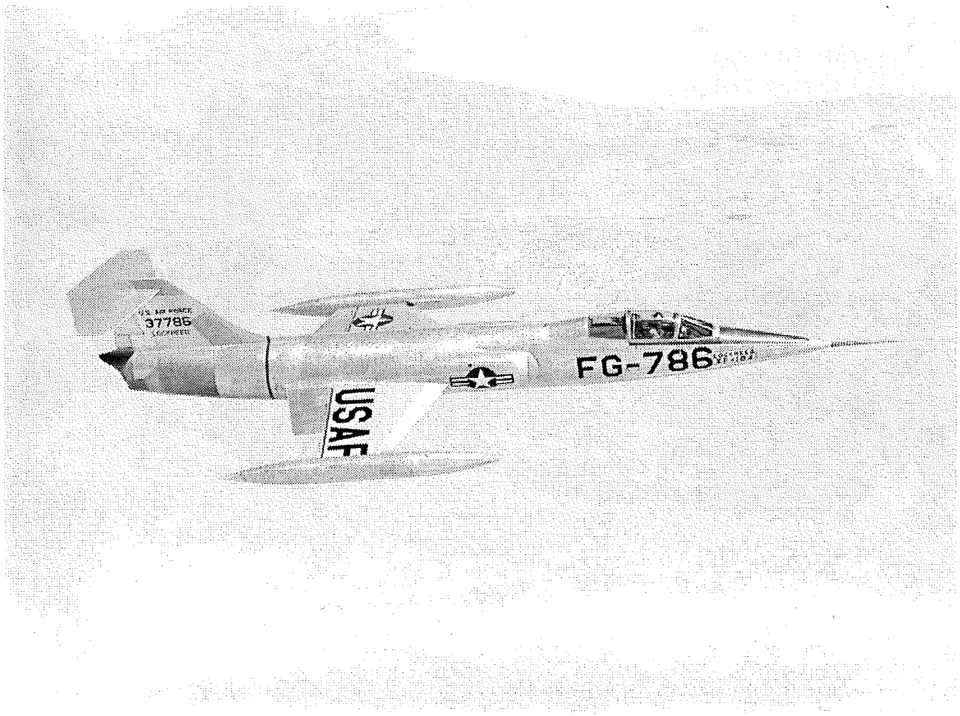
The SURE Project



Lecture – 3/10

STARFIGHTER UTILIZATION RELIABILITY EFFORT

LECTURE 3

A CRITIQUE OF SELECTED F-104 EMERGENCY OPERATING PROCEDURES

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FOREWORD

Sooner or later there comes to every fighter pilot a moment in time that challenges all his mental and physical capabilities. If he employs positive action based upon sound judgment, most assuredly his life will be saved and in many instances, also his machine. If he does not react properly, his life and machine will be at the mercies of the cruel, fickle fates.

As members of the most noble and respected Fraternity of Airmen, it is our responsibility to prepare ourselves, in every way, with knowledge and skill to meet these challenges.

This lecture has one sole aim -- to help you! To help you evade confusion and error in the cockpit -- to help you evade the Accident Board -- and to help you evade that demeaning phrase, "This accident was caused by pilot-error".

REFERENCES

1. T.O. F/RF/TF-104G(MAP)-1, Dated 15 January 1965.

2. NASA Technical Note 2967, "An Analysis of the Power-off Landing Maneuver in Terms of the Capabilities of the Pilot and the Aerodynamic Characteristics of the Airplane".

3. NASA position in space data of simulated X-15 landings in the F-104 aircraft.

4. Theoretical Vector Analysis of C-2 Ejection Seat by G. M. Andre.

5. Lockheed world-wide Field Service Department reports.

6. T.O. 1F-104A-1, "F-104A and F-104G Flight Manual".

7. T.O. 1F-104C-1, "F-104C Flight Manual".

8. LR 14604, Lockheed C-2 Ejection Seat Escape System Tests and Sled Runs in F-104B Sled.

9. LR 14605, Lockheed C-2 Ejection Seat Escape System Tests and Sled Runs in F-104A Sled.

10. AFFTC Report 152286-5832-1958.

AIR START

Regardless of the particular procedure called out for air starting a flamed-out engine, the requirements for a jet engine start are always the same. Whether on the ground or in the air, three functions must be accomplished:

1. Adequate RPM obtained
2. Ignition spark for combustion of fuel-air mixture
3. Proper fuel flow

The requirements of how much RPM and the amount of fuel flow for the initial light-off is dictated by many factors in the design of the engine. As the design of turbo-jet engines has become increasingly more sophisticated, the requirement of "pilot-technique" during the starting cycle has all but disappeared. The critical phase of monitoring and analyzing the starting cycle still remains as a pilot responsibility, however. The air start procedure, therefore, is patterned around these considerations.

Let's take each step of the AIR START procedure and critique it.

AIR START*

Note

> The hydraulic generator will remain operative to energize the primary fixed-frequency bus if windmill RPM is 20 percent or more. This will result in the pilot receiving a fuel flow indication during an air start attempt.

If a flameout has occurred, an air start may be made using the following procedure:

1. START SWITCHES -- START (hold momentarily to ensure switch contact).

Monitor engine instruments for immediate relight if engine RPM is still high.

Critique: This step is to attempt an immediate relight in the case of a flameout that you are quick enough to recognize and catch before the RPM drops too low. However, every flameout I have had in the F-104 unwound

*T. O. 1F-104G-1 Flight Manual F/RF/TF-104G(MAP) so fast that the RPM was below the under-frequency relay before I had time to take any action. All flameouts at altitude unwound so fast that the loss in cockpit pressure was very close to explosive decompression. In any case, if you possibly do see the RPM unwinding from a high setting and know a flameout is imminent, push up on both start switches and hold for good contact at least a couple of seconds. You are meeting all three conditions for starting the engine and if some major malfunction has not occurred, you should get a relight. However, as I stated before, you should monitor the RPM and fuel flow for a normal air-start. The time-delay relay in the start switches will give ignition for approximately 45 seconds. Since many of the air-starts at altitude are a little slow, be sure and give the engine at least 30 seconds for a chance to start.

2. IF RELIGHT IS NOT OBTAINED, OR RPM HANGUP OCCURS, THROTTLE - STOPCOCK AND RETURN TO MILITARY.

Note

> Establish best glide speed and head aircraft toward nearest suitable landing field.

Critique: Be very careful about initiating step 2 before step 1 has been given enough time. If the throttle was at or near idle when the flameout occurred, an air start at altitude will be indicated by a very low EGT indication. In many cases, pilots have stopcocked when they should have advanced the throttle -- they didn't realize that the 80 to 100° EGT was an air-start. However, if after waiting the proper length of time and no relight is obtained, break the process by stopcocking and returning to Military. About this time, you should be turning for the nearest suitable landing field and getting on glide speed. When you establish the recommended glide speed, you will stabilize at very close to 1% windmill RPM for each 1000 feet of altitude. Also, the pressure recovery in the inlets is very near 100% recovery and puts you in the best envelope for air-starting the engine.

3. IF NO START OCCURS, RAT HANDLE - PULL.

Note

> Do not extend the ram air turbine above 35,000 feet as chances of obtaining normal engine operation are remote and the increased drag will reduce glide distance.

Critique: This step will insure that the number 3 boost pump is energized by the A. C. Emergency Bus and more positive ignition is assured by power output through the 20 amp. transformer rectifier through both batteries and buses for the dual ignition.

4. START SWITCHES - START

Do not stopcock throttle before this second actuation of the start switches.

Critique: You should now definitely monitor the three requirements to ascertain air-start capability:

1. Check RPM: If the normal windmill RPM of 1% per 1000 ft. altitude is not available - you may be encountering an engine seizure.

2. Ignition: With the RAT extended, you have every likelihood of electrical power for ignition spark. Just make sure you recycle the start switches every 40 seconds.

3. Fuel Flow: Definitely look at the fuel flow gauge and check that you have 500 lb. /hr. minimum starting fuel flow. If you do not - then you probably have had a main fuel control failure or engine-driven fuel pump failure. In any case, with no fuel flow indication on the gauge, you will not get an air-start.

To establish the excellent air-starting capability of the F-104, I am including the J79-GE-11A air-start envelope for your study. Before analyzing this envelope, you should be made aware of the Military Specification that General Electric had to prove in order to establish the envelope. The Mil. Spec. stated two specific guide lines:

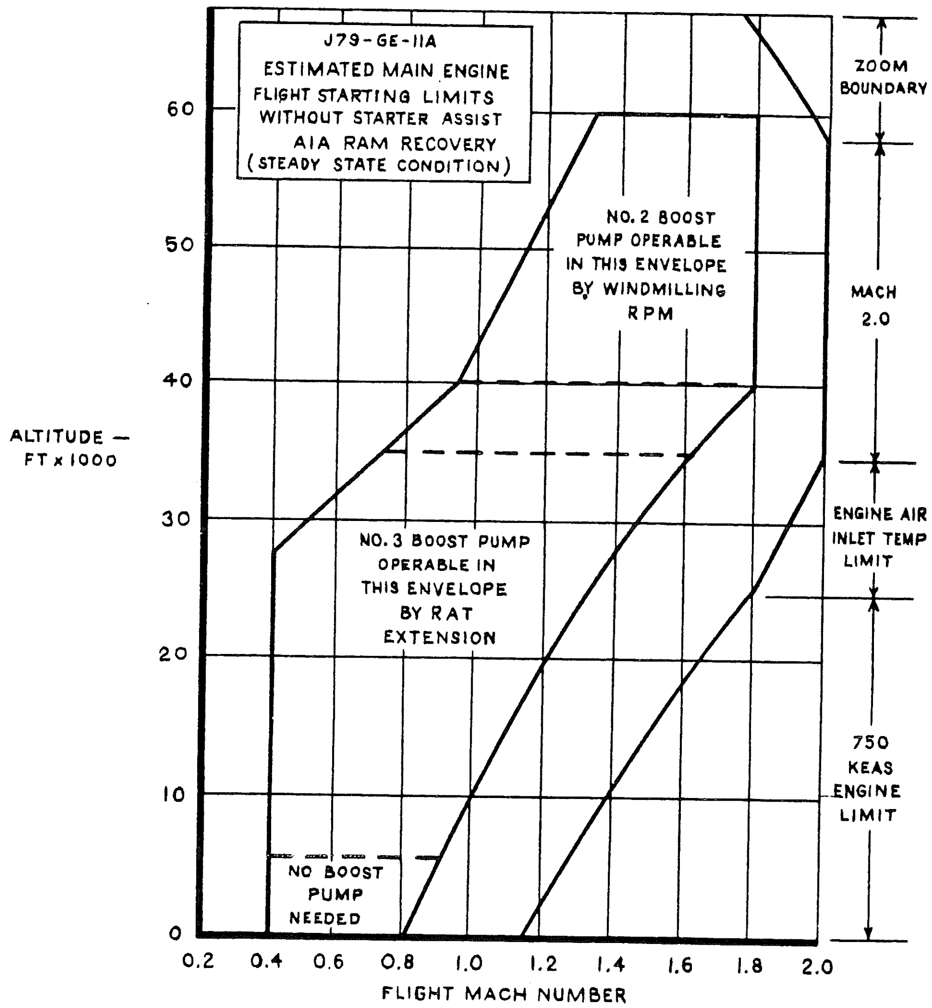
1. At proper glide speed and normal engine windmill RPM, the engine must demonstrate air-start capability up to 6000 feet without the assistance of boost pump pressure.

2. Above 6000 feet, the engine air-start capability must be demonstrated within the flight envelope at those points that the fuel pressure to the engine driven fuel pump is 5 psi above the fuel vapor pressure. (This Spec. requirement then involves the factors of fuel tank pressure and boost pump pressure.)

Now, let's examine the air-start envelope. First of all, note that the title block states that the data is estimated. This is a mere technicality due to the fact that G. E. never flew an air-start program with the -11A engine. The -11A cycle is, however, basically the same as the J-79-7 and G. E. flew this engine and established the envelope. General Electric is very confident that this envelope represents a realistic -11A capability. Looking at the envelope in detail, you will note that it covers an extremely large segment of the overall performance envelope. If you happen to encounter a flameout at the extreme speeds of the performance envelope, there is an "automatic" recovery in that the deceleration will immediately put you back in the air-start envelope. The high altitude air-starts are assisted by No. 2 boost pump operation as shown and medium to low altitude starts are assisted by No. 3 boost pump operation - if the RAT is extended. In between these two large segments is a grey area of operation where you are between losing the No. 2 boost pump operation and you are still higher than the recommended altitude for RAT extension. In this area, pilot judgment must prevail.

John Fritz of General Electric also wants you to know that if the RPM has not been allowed to drop to stabilized windmill, results can be better than shown. For instance, he has started a J-79-7 between .95 and 1.0 indicated Mach number at 60,000 feet, using immediate ignition with RPM above 90%. He has also started at 1.8 indicated Mach number at 35,000 feet.

I hope this will give you better understanding and confidence in the air-start capability of the F-104.



FORCED LANDING

In critiquing the forced landing procedure I would like to quote from the handbook*: "The most important elements of a successful forced landing are simulated flameout landing practice, close control of glide speed, and a carefully executed flare".

I think this is the key statement to describe the problem and I want to cover each phase of this statement.

1. Simulated forced landing practice: The value of practicing the flameout pattern is evident in many ways. You become accustomed to all the perspective points at hi-key, lo-key and flare - if you're honest with yourself! You will learn how to hoard your airspeed, utilize minimum bank angle and smoothly transition from the steep final approach to a "ball park" touchdown. Also you will be able to ascertain a go, no-go point to safely bail out if you can't make it. But the most valuable return you will obtain from the practice will be the proficiency and skill to handle other emergencies that require a precautionary pattern for minimum time and safety considerations.

   At this point I would like to inject my opinion on the argument of practicing SFO patterns or completely forbidding them.

   Every fighter pilot who comes to grips with an emergency will strive to do his best - often he will give his life to prevent his disabled plane from crashing in a populated area. Other times he winds up in an emergency condition where he has been placed at a disadvantage. This disadvantage is not through lack of courage, but from lack of knowledge and experience due to the fact that he hasn't been allowed to practice and thereby develop the skill and technique to cope with the emergency. In all likelihood, if the pilot observes that he has a reasonable chance to save the aircraft - he will take the chance. I maintain that it is better to train for these emergencies. Then the pilot will be qualified to determine:

   A. Is it possible to recover by a precautionary pattern?
   B. If something goes wrong in the precautionary pattern, can the aircraft still be landed?
   C. What is the best procedure to land and stop the aircraft out of the pattern?

   Only by conscientious practice can the pilot be expected to cope with the various landing emergencies.

*T. O. 1F-104G-1 Flight Manual F/RF/TF-104G(MAP)

2. Close control of glide speed: Maintaining the proper glide speed is the most critical aspect of flight during the pattern. This function will assure maintaining the proper energy level with a minimum trade in loss of altitude. Variations of speed during the pattern will only increase the difficulty of pilot judgment in all aspects. Too low an airspeed on final will result in not having enough energy for flare. Too high a speed on final can result in too great a sink rate for accurate judgment during flare and result in a hard touchdown. Peg the speed and hold it.

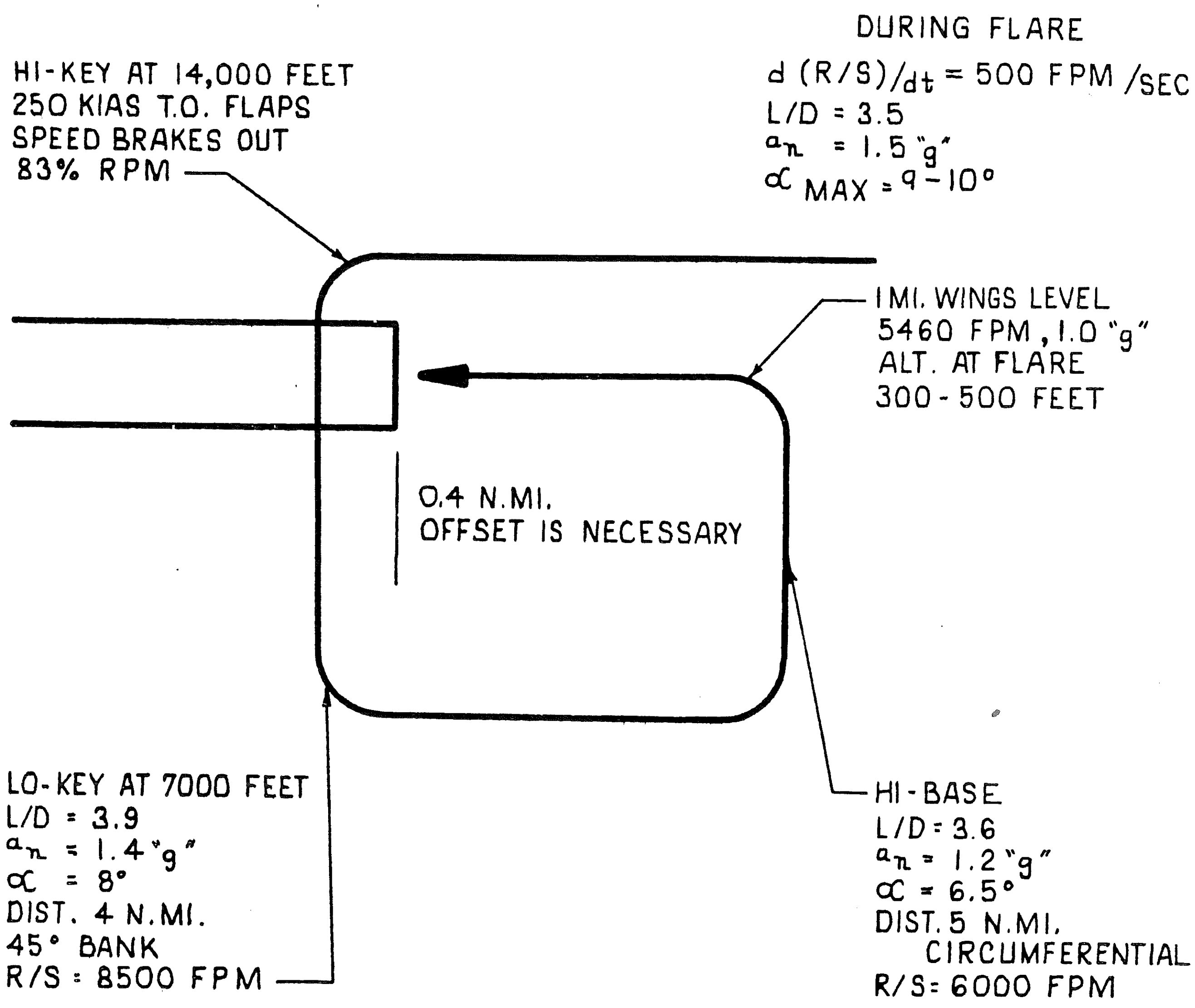
3. Carefully executed flare: All of the best piloting skill during the pattern will be for nothing if you do not make a very smooth flare to touchdown. In the entire pattern, this phase requires the greatest skill. All of the maneuvering has been done solely to place the aircraft in the proper flare position. At the right glide speed, you have just enough energy to flare - with little room for error. Smoothness is not only recommended, it's a must!

In order to present a wider perspective to you of the SFO pattern, I have researched the data from NASA on their simulated X-15 patterns using the F-104. By analyzing their position in space data, we can obtain a good comparison of the difficulties you will face with any configuration other than what we recommend.

First let's examine the aerodynamic factors present in our recommended SFO pattern. This is shown in the following presentation, but let's define the symbols:

R/S	=	Rate of Sink.
L/D	=	Lift to drag ratio which is an indication of the aircraft efficiency.
a_n	=	Amount of g load.
α	=	Angle of attack.
$d(R/S)/_{dt}$	=	Rate of change of rate of sink - a good indication of the minimum rate at which you must decrease the sink rate to keep from crashing.

SFO APPROACH PERFORMANCE
RECOMMENDED PATTERN



The pertinent points to derive from this depicted pattern are:

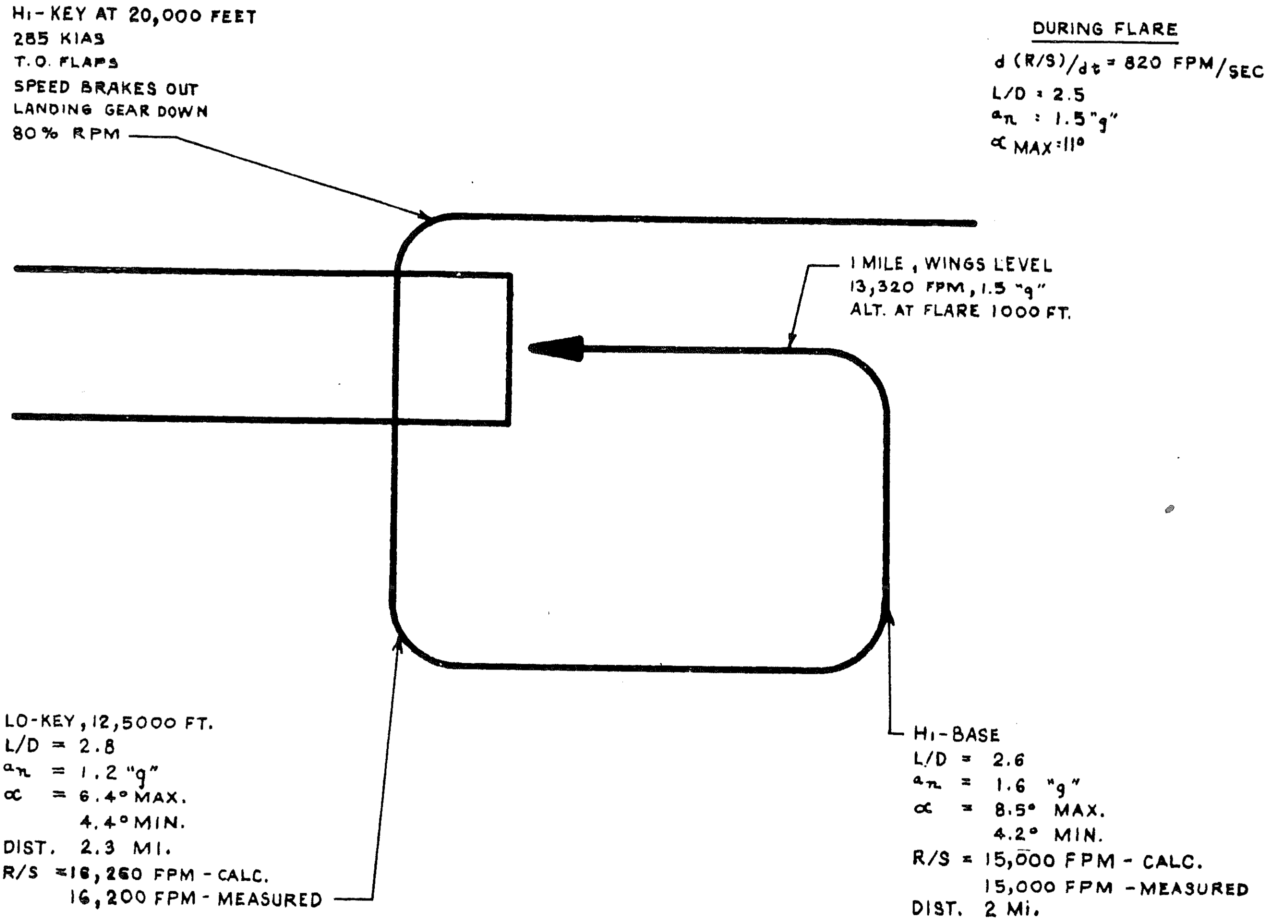
1. Duration: Approximately 120 sec. or 2 min.

2. Average R/S = 7000 FPM

3. Radius of pattern from end of runway = approximately 1.5 miles.

Now let's look at a pattern where you drop the landing gear at hi-key rather than during flare. This pattern is shown in the following presentation:

SIMULATED X-15 LANDING PATTERN WITH F-104



The extremely important points to derive from this pattern are:

1. Duration: 95 sec. measured

2. Average R/S: 14,840 FPM

3. Radius of pattern from end of runway = approximately 1 mile.

And now let's analyze the flight characteristics of this pattern vs. the recommended pattern.

1. Duration: The duration is at least 25 seconds shorter even though the hi-key is started 6,000 feet higher!

2. Rate of Sink: The average descent rate is more than twice as much as the pattern with landing gear up.

3. Radius of pattern: Due to the high sink rate, the pattern must tighten up to arrive at the flare point in proper position.

4. L/D: The efficiency of the aircraft is greatly degraded due to the increased drag of the landing gear.

5. a_n: Very little "g" load is on the aircraft due to the fact that the pattern is a spiraling, steep descent.

6. α: The angle of attack is high and at the maximum for lift throughout the pattern.

7. Altitude at flare: The height at which the flare must be started is over three times that of the recommended pattern and almost at normal traffic pattern altitude.

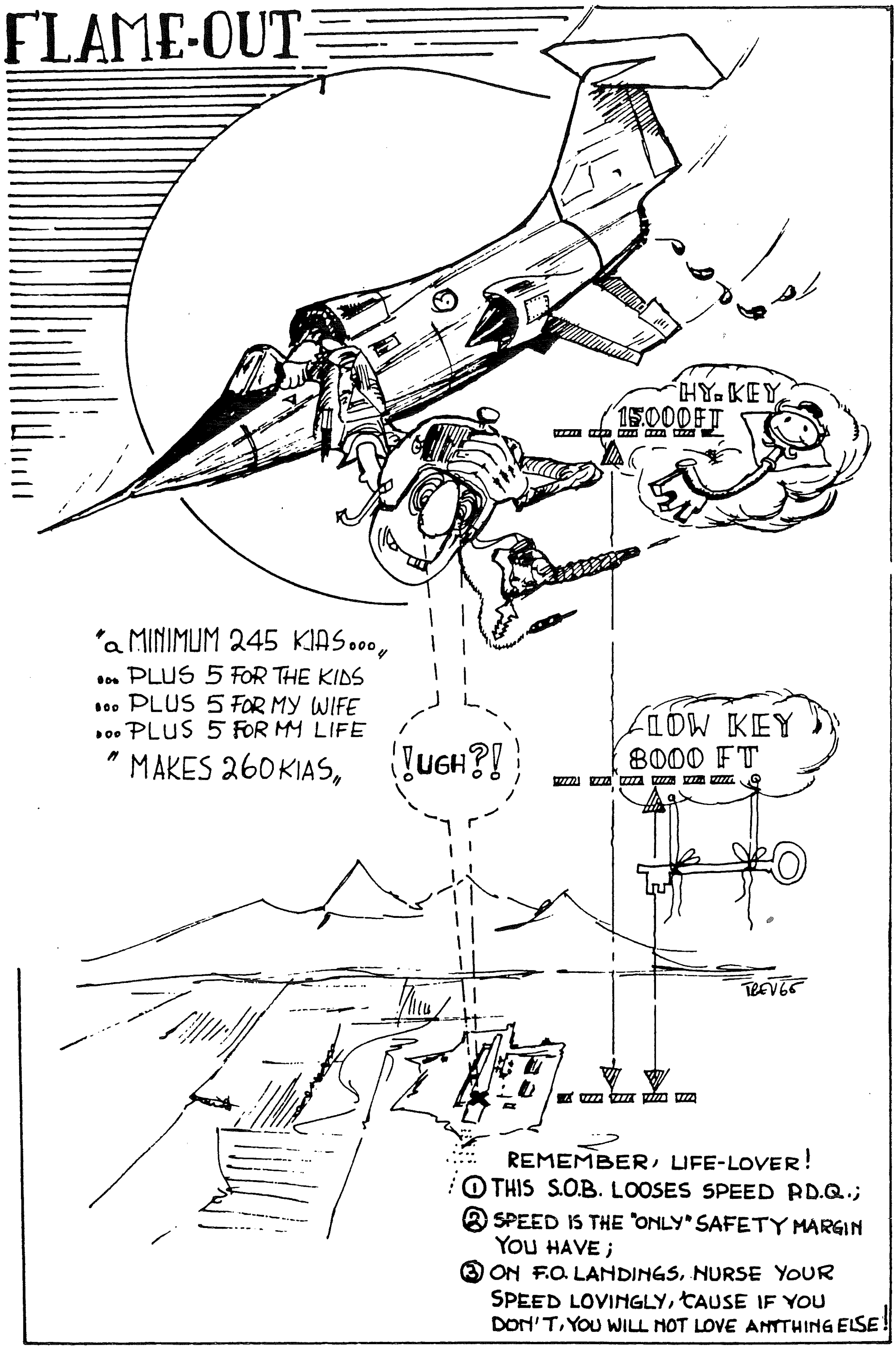
By now, you should be receiving my message loud and clear. Anytime you lower the gear before flare - you are attempting an X-15 landing! The X-15 landings are made on a dry, lakebed with natural runways 15 miles long, under carefully controlled conditions. Anyone who attempts the same maneuver under emergency conditions and expects to be successful on a 9,000 foot runway is strictly from "Wildsville".

Returning to my statement of being honest with yourself, I want to earnestly emphasize the following points in your SFO practice:

1. Do not fool yourself on recognizing the go, no-go point. As your pitot boom circumscribes the arc while turning from high base onto final, peel that eyeball and keep a close look at whether it will point to the first third of the runway after you roll out on

final. If it points short - this is no-go. If it points far enough up the end of the runway - this is go.

2. Flaring the aircraft: The configuration and airspeeds in the manual are the closest balance to attitude, rate of sink, and other factors that can be used to duplicate the flamed-out condition - <u>up to the flare!</u> From that point on, you should retard the throttle to be honest with yourself as to rate of airspeed bleed-off and flare capability.


FLAME-OUT
HY. KEY
15.000 FT
"a MINIMUM 245 KIAS..."
... PLUS 5 FOR THE KIDS
... PLUS 5 FOR MY WIFE
... PLUS 5 FOR MY LIFE
" MAKES 260 KIAS"
!UGH?!
LOW KEY
8000 FT
TREV 65
REMEMBER, LIFE-LOVER!
① THIS S.O.B. LOOSES SPEED P.D.Q.;
② SPEED IS THE "ONLY" SAFETY MARGIN YOU HAVE;
③ ON F.O. LANDINGS, NURSE YOUR SPEED LOVINGLY, 'CAUSE IF YOU DON'T, YOU WILL NOT LOVE ANYTHING ELSE!

ENGINE FIRE

Due to the by-pass airflow design, any fire in the engine bay area is damped and restricted with little chance of spreading outward. The fire warnings in the flight history of the F-104 have been mainly due to:

1. Leakage of BLC air on detectors.

2. Malfunctions of detector pick-ups.

3. Electrical system malfunctions.

4. Misalignment of fuel spray nozzles in the combustion chambers.

In all of the flight history of the F-104, none have ever reported to have unexplainedly "blown-up". Therefore, the emergency procedures are patterned to have you perform the quick, necessary steps (in case there is a fire) and then you have time to do a more thorough investigation before a sudden move is required. My personal experiences and those of pilots I have known, indicate that a cautious, restrained approach is better, when those red lights come on, rather than a quick, hurried procedure before you are sure what has gone wrong.

In my flying career, I have always known positively when there was a fire. And when there was only a light flashing but no engine indications, I hesitated about cutting off the throttle and grabbing the D-ring. In cases of real fire, very seldom do the engine instruments lie. More often than not -- they're telling the truth. And in those cases -- there's only one step.

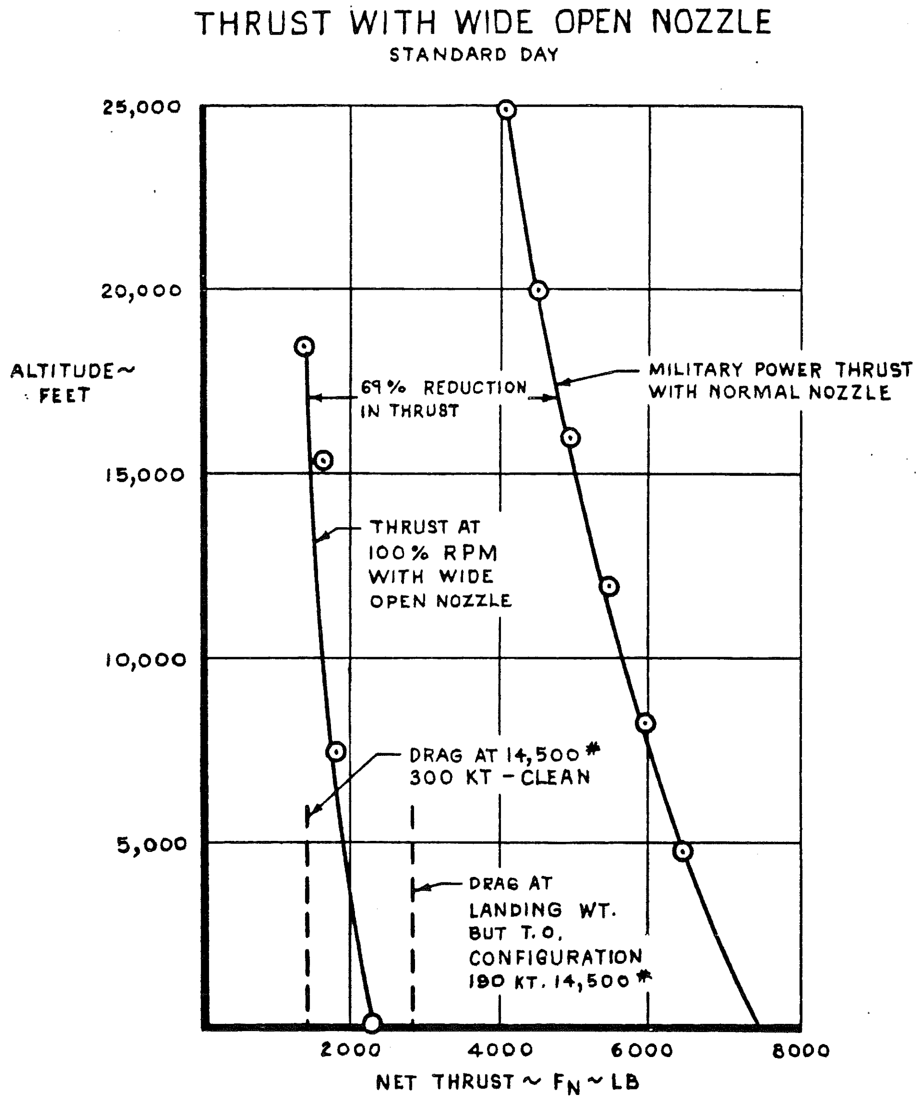
Fire really means only one thing to a pilot - bail out. But make sure it's a fire and don't leave a well bird (with false warnings) and be rather embarrassed later.

NOZZLE FAILURE

The five times that I have been forced to land the 104 with open nozzles and no afterburner, struck me every time like trying to land the Starfighter with a T-bird engine. Every bit of airspeed had to be carefully nursed and the entire pattern flown very smoothly to get the bird over the threshold.

Failures of the exhaust nozzle control system have prompted many improvements and design changes. Starfighters will soon be equipped with positive nozzle locks in addition to the emergency nozzle closure system. This will greatly reduce the incidents and accidents attributed to nozzle failures.

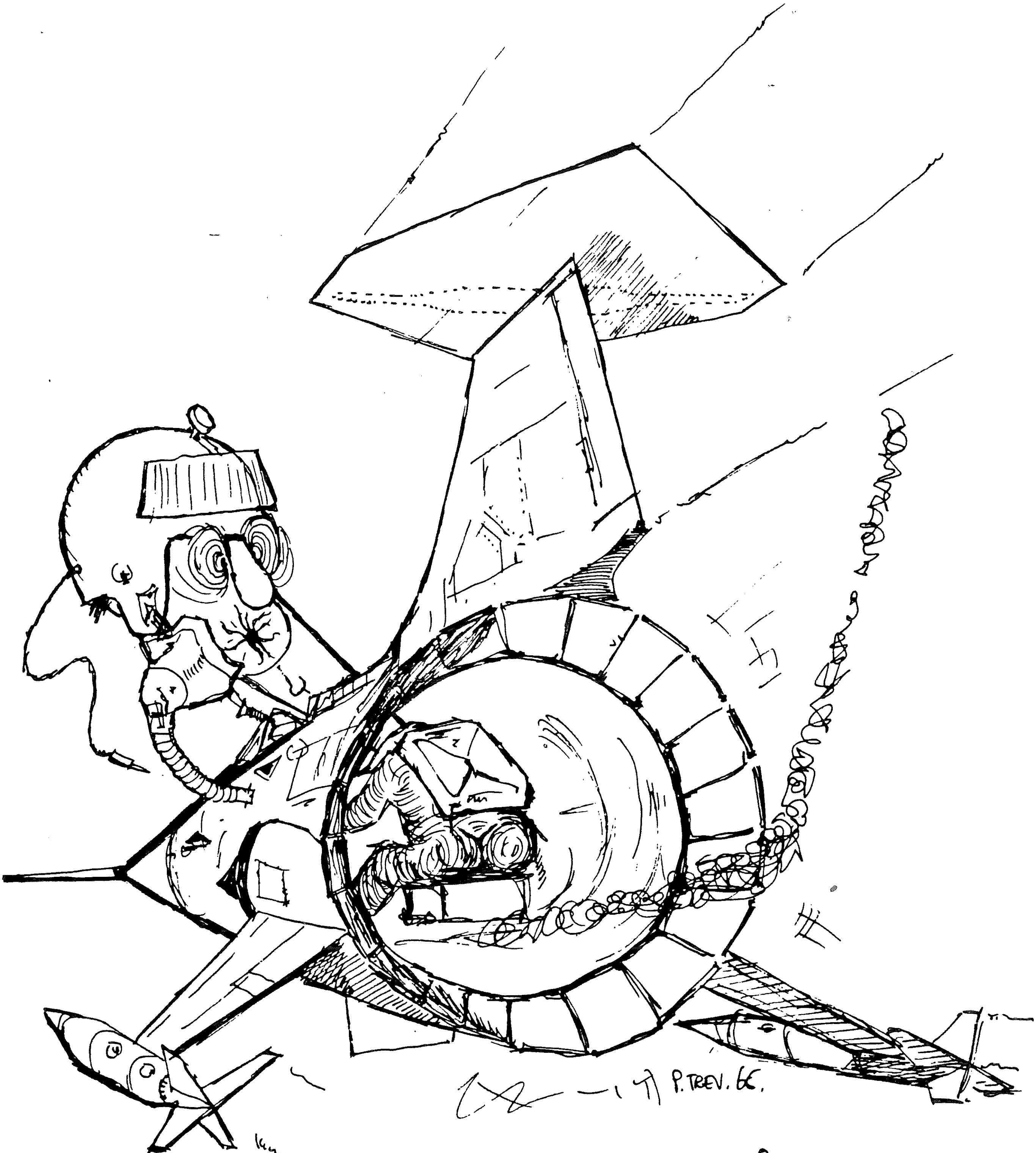
We at Lockheed have only conducted tests on the J79-3A engine as to thrust and drag relation with wide open nozzles. I am including the results in this lecture in the form of a plot to enlighten you on the important aspects.



From these tests you can see that there is not enough thrust to maintain altitude with any configuration and takeoff gross weight. Even if you work the gross weight down to normal landing weight, the realistic flight envelope is quite restricted. There's no room for error and you must make good your first approach -- unless you can relight the afterburner. Also, many pilots in the field have actually accomplished approaches down to the touch-down point by using the afterburner and judicious use of the speed brakes, landing gear, and flaps.

The main point to be stressed from the flight test data and my experiences can be seen on this plot. You will notice that even at landing weight, the drag line for the landing configuration is greater than the available thrust. Therefore, you cannot maintain level flight any time you are in a landing configuration. So fly her smoothly to a nice high base leg and don't go into the landing configuration until the runway is made.

The engineers and pilots at Lockheed have worked many years for the improvements in the Nozzle Area Control and for the emergency systems. Anytime you have a nozzle problem -- use the emergency systems as recommended in the handbook. With proper operation of the emergency systems, you can land from any pattern - precautionary, normal or GCA.



NOZZLE FAILURE
TO WIDE, WIDE OPEN AREA

EJECTION

A survey of actual ejections at low altitude raises some serious questions on why some are successful and others are not. In those cases where all the mechanisms worked on schedule but the ejection was unsuccessful, there is only one answer - the ejection was attempted outside of the envelope of the seat. Since the handbook cannot cover all the critical aspects of ejection parameters, I want to inform you of some life-or-death points in ejecting from the F-104.

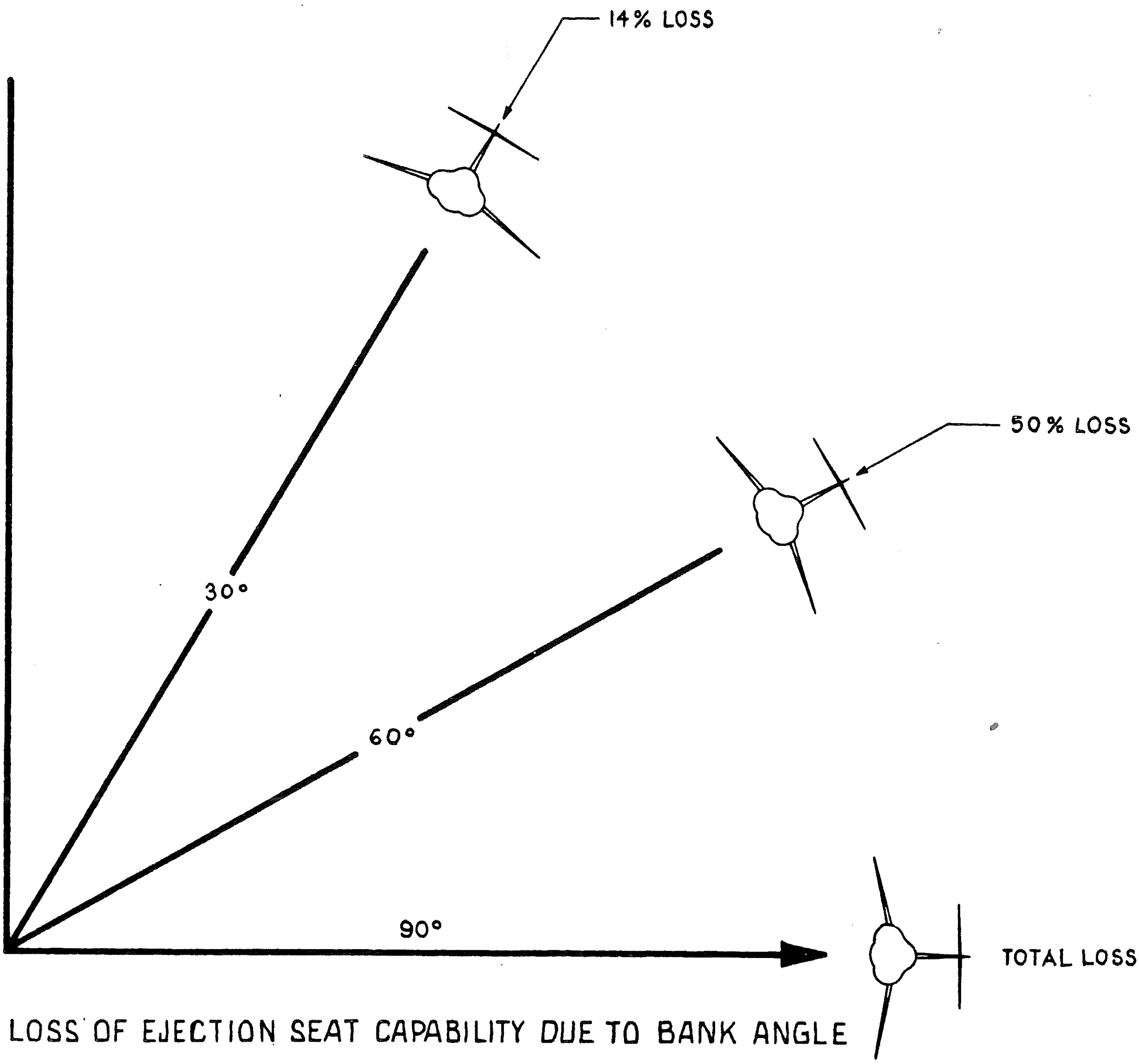
The F-104 pilot's handbook states: "During any low-altitude ejection, the chances for successful ejection can be greatly increased by zooming the aircraft (if airspeed permits) to exchange airspeed for altitude. Ejection should be accomplished while the aircraft is in a positive climb and airspeed is above 120 knots IAS. This will result in a more nearly vertical trajectory for the seat and crew member, thus providing more altitude and time for seat separation and parachute deployment."

While not stated directly, I want to point out that the most important by-product of the trade of airspeed for altitude is the positive rate of climb condition that we are putting the Starfighter into which will do more to increase our flight time than mere altitude alone.

When we eject from an aircraft, we have two vertical velocities or forces working on us. We have the rocket boost from the ejection seat and we have the vertical speed of the aircraft - the same rate of climb that you read in the cockpit. Eject in a climb, and these two vertical forces add together and give you a real high ride and a nice long time for your chute to open. Eject in a dive and the rate of descent of the aircraft will subtract from the velocity of the seat giving you a low ride and maybe your final "hard-landing".

As an example, let's go back to the SFO pattern where we find on the base turn to final, or the go, no-go point, that our rate of sink is around 6,000 feet per minute. If at this point, you believe you misjudged the pattern and will not make the runway, you should grab the D-ring and go! Don't hesitate for one second, because you are already approaching the limit of the seat envelope. Why? Well look at it this way. The ejection seat gives an average velocity of 5,000 feet per minute, while the rocket is burning. Since you are descending at 6,000 feet per minute, all the ejection seat will do for you is slow your rate of descent down to 1,000 feet per minute. With perfect functioning of the seat mechanism and the zero lanyard, you will still make the nylon letdown but you'll be surprised how close it will be.

In addition to the dive angle, any bank will also reduce the vertical component of the ejection vector. The following chart shows the loss in vertical velocity and height achieved of the seat when ejecting out of a bank.

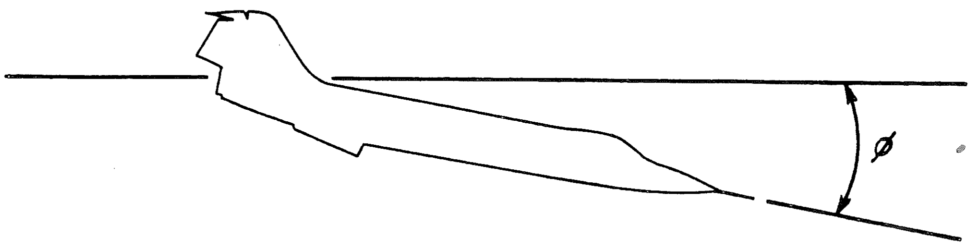


LOSS OF EJECTION SEAT CAPABILITY DUE TO BANK ANGLE

Now for your information and study I want to present the results of a mathematical study of dive angle vs. airspeed and the computed true altitudes for chute deployment. The calculations are derived from the trigonometric and geometric conditions imposed. The work is done in terms of relative vertical velocities and relative times, thus giving relative distances, the summation of which equals the minimum ejection altitude.

Before explaining the methods used in the mathematical computations, definitions of symbols and abbreviations must be explained.

V_A:	Velocity of aircraft
V_{VA}:	Vertical velocity of aircraft
V_{VSR}:	Vertical velocity of seat with rocket burning
V_{VS}:	Vertical velocity of seat without rocket burning
V_{VM}:	Vertical velocity of man before chute opens
V_{VMD}:	Average vertical velocity of man during chute deploymer
V_{VMP}:	Vertical velocity of man at instant chute inflates
ϕ :	Aircraft dive angle below horizon



t_0:	Time D-ring is pulled = 0
t_1:	Time till seat leaves aircraft = .47 seconds
t_2:	Rocket burning time = .28 seconds
t_3:	Time from rocket burn out till separation $\doteq$ .64 seconds
t_4:	Time from separation until chute pins pulled = 1.0 seconds
t_5:	Time for chute to deploy = 2.4 seconds
a_m:	Man deceleration during chute deployment = 162 ft/sec^2

V_{VA}: $V_A \sin \phi$

Seat initial velocity at exit = 45 ft/sec

Seat final velocity at burn out = 120 ft/sec

$V_{VSR} = \frac{45 + 120}{2} = 82$ ft/sec (Relative to the aircraft only)

A_M (man deceleration) is given in the direction the pilot is falling.

This must be resolved into a vertical component.

decell = 162 Sin ϕ

And velocity v at instant of chute deployment will be $V = V_o + at$, $V = V_v$ seat/man + $(-162 \sin \phi)(2.4)$ where 2.4 seconds is the time for chute deploymcnt. Average velocity during this period is:

$$\frac{V + V_v \text{ seat/man}}{2}$$

Therfore: $\frac{V + V_v \text{ seat}}{2}(2.4)$ = distance d5

$d_1 = V_{VA}(.47), \quad V_{VA} = V_A \sin \phi$

$d_2 = V_{VSR}(.28), \quad V_{VSR} = V_A - 82 \sin (79 - \phi)$

$d_3 = V_{VS}(.64), \quad V_{VS} = V_{VSR}$

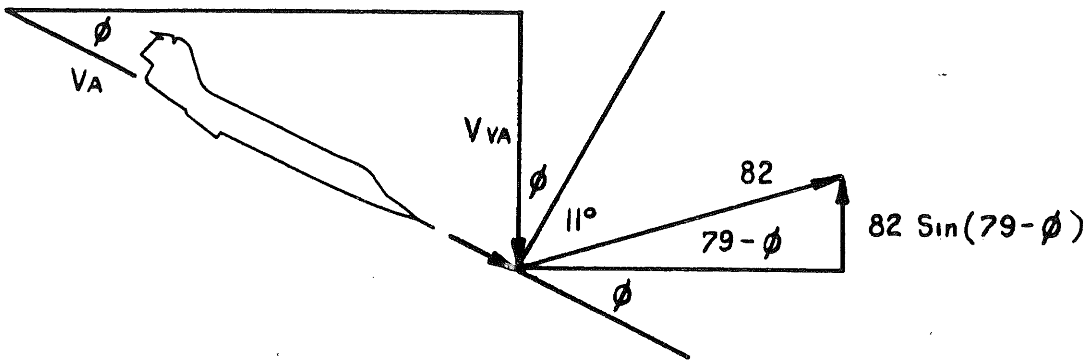
$d_4 = V_{VM}(1.0), \quad V_{VM} = V_{VS} = V_{VSR}$

$d_5 = V_{VMD}(2.4), \quad V_{VMD} = \frac{V_{VMP} + V_{VM}}{2}$

NOTE: The assumption is made that after rocket burnout and until parachute begins to deploy, the vertical velocities will not change appreciably. This is due to the fact that such short times are involved.

Therefore: $V_{VSR} = V_{VS} = V_{VM}$

NOTE: The further assumption is made that during parachute deployment deceleration the direction of the retarding vector shall be opposite the direction of the aircraft flight path. This is a conservative assumption since, in reality, it will be more vertical. It is impossible to accurately define the actual angle at which deployment occurs.



Method:

Formulas

$V_{VA} = V_A \operatorname{Sin} \phi$

$d_1 = V_{VA}\, t_1$

$V_{VSR} = V_{VA} - 82 \,(\operatorname{Sin} 79 - \phi)$

$d_2 + d_3 + d_4 = V_{VSR}\,(1.92)$

$V_{VMP} = V_{VM} + (-162 \operatorname{Sin} \phi)\, t_5$

$V_{VMD} = \dfrac{V_{VMP} + V_{VSR}}{2}$

$d_5 = V_{VMD}\,(t_5)$

$d_1 + d_2 + d_3 + d_4 + d_5 =$

Minimum Ejection Altitude

Sample Case
(400 Knots / 45° dive)
(400 Knots = 675 ft/sec.)
(t_5 = 2.4 secs.)

$V_{VA} = 675\,(\operatorname{Sin} 45^{\circ}) - 484$ ft/sec.

$d_1 = 484\,(.47) = 228$ ft.

$V_{VA} - 82\,(\operatorname{Sin} 79 - 45) = 438$ ft/sec.

$d_2 + d_3 + d_4 = 438\,(1.92) = 841$ ft.

$V_{VMP} = 438 - 114.5\,(2.4) = 163$

$V_{VMD} = \dfrac{163 + 438}{2} = 300$

$d_5 = 732$

$d_1 + d_2 + d_3 + d_4 + d_5 = 1{,}801$ ft.

Minimum Ejection Altitude

Results:

DIVE ANGLE (DEGREES)	AIRSPEED 175	200	250	300	400	500	600
Altitude above ground D-ring must be pulled to achieve parachute deployment.							
10	43	73	143	214	372	495	674
20	179	210	348	486	777	1039	1315
30	206	306	508	712	1115	1399	1918
45	480	612	895	1181	1801	2176	2894
60	699	877	1179	1577	2274	2973	3670
90	1013	1214	1617	2024	2835	3618	4437

NOTE:

(1) The above figures are true altitudes above the ground and reflect the total distance the man would travel until deployment. If parachute stabilization is desired 100 feet above the ground, then 100 feet should be added to the above figures.

(2) Since it is possible for the altimeter to have an error or lag due to high rate of descent, nonstandard conditions, etc., the reading on the altimeter must not be construed as the true altitude above sea level. Of course, local ground elevation must be accounted for.

(3) Also, you will find upon close examination of sled test data that the figures in the above chart are conservative (i.e. larger). And, of course, the figures do not represent the effect of hooking up the zero delay lanyard.

I hope this study will promote some hard thinking toward weapons delivery dive angle and minimum altitudes for ejection. Also, remember to get that nose up and hold those wings level. If you are in some control problem at low altitude, don't turn loose of that stick and pull the D-ring with both hands, as the aircraft rolls, into a 90° bank. Hold the bird level and pull the D-ring with one hand. Remember - it's even been done with one finger.*

*See SURE lecture "A Test Pilot's Review of F-104 Accidents"