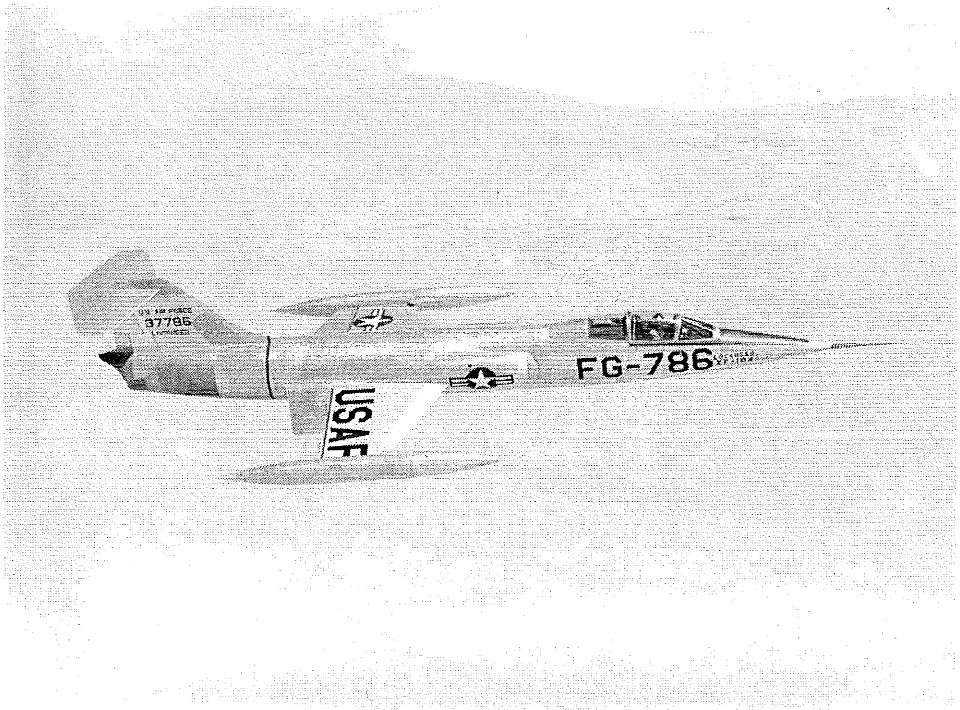
The SURE Project



Lecture – 7/10

STARFIGHTER UTILIZATION RELIABILITY EFFORT

LECTURE 7

LOCKHEED-CALIFORNIA COMPANY

A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

BURBANK, CALIFORNIA 91503

June, 1969

Greetings and Salutations to the Royal Order of Starfighters:

For many years, I have been aware of an increasingly complex problem for Air Defense Units---optimization of the intercept profile. Along about the time that the GCI controllers had perfected their methods with subsonic fighters, a whole new family of interceptors arrived on the scene with large supersonic envelopes. Shortly after this, the supersonic bomber made its debut. The supersonic intercept profile is so difficult a problem that instead of faster intercepts, bigger hunks of the sky are used for supersonic maneuvering and the profiles are greatly extended.

G. L. "Snake" Reaves has also been keenly aware of this problem. At his urging, our computer people developed some minimum time and distance paths utilizing Energy Maneuverability considerations. In order to prove the feasibility of these computer profiles, Snake initially contacted Col. E. P. Deatrick, then Commandant of the ARPS, Aerospace Research Pilot School. A cooperative plan was conceived that proved to be of mutual benefit to the ARPS and Lockheed. The Instructor Pilots of the ARPS were very interested in developing a method of teaching classical envelope expansion and optimum energy conversion techniques. Also, Major Jim Rider, NF-104 Project Pilot was involved in a study of zoom path predictability with the NF-104. Upon analysis of the computer paths, it was decided that proving the accuracy of the minimum time and distance paths would be a major step in achieving the ARPS objectives. Accordingly, Major Rider and some of the ARPS pilots flew computer paths in fully instrumented F-104C's under the monitor of the Edwards Space Positioning Division. These test data were then compared to the computer paths for predictability and accuracy. The closeness of the actual flight path to the predicted was not only reassuring, but definitely established the practicality of the use of optimized profiles by operational interceptor pilots.

In my opinion, the results of Snake's study and the ARPS research flights are a major breakthrough in optimizing the intercept problem.

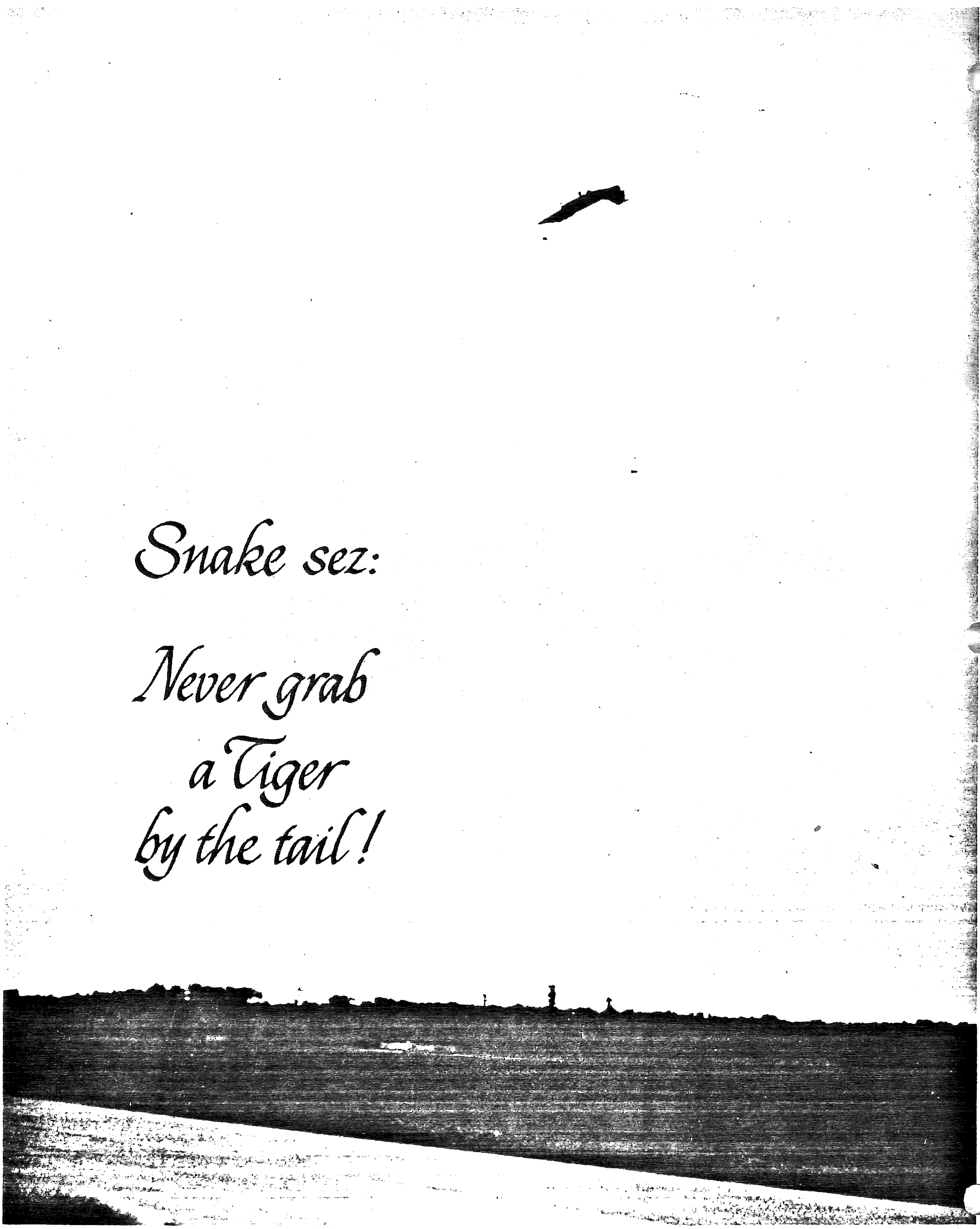
Sincerely yours,

LOCKHEED-CALIFORNIA COMPANY

Tony LeVier

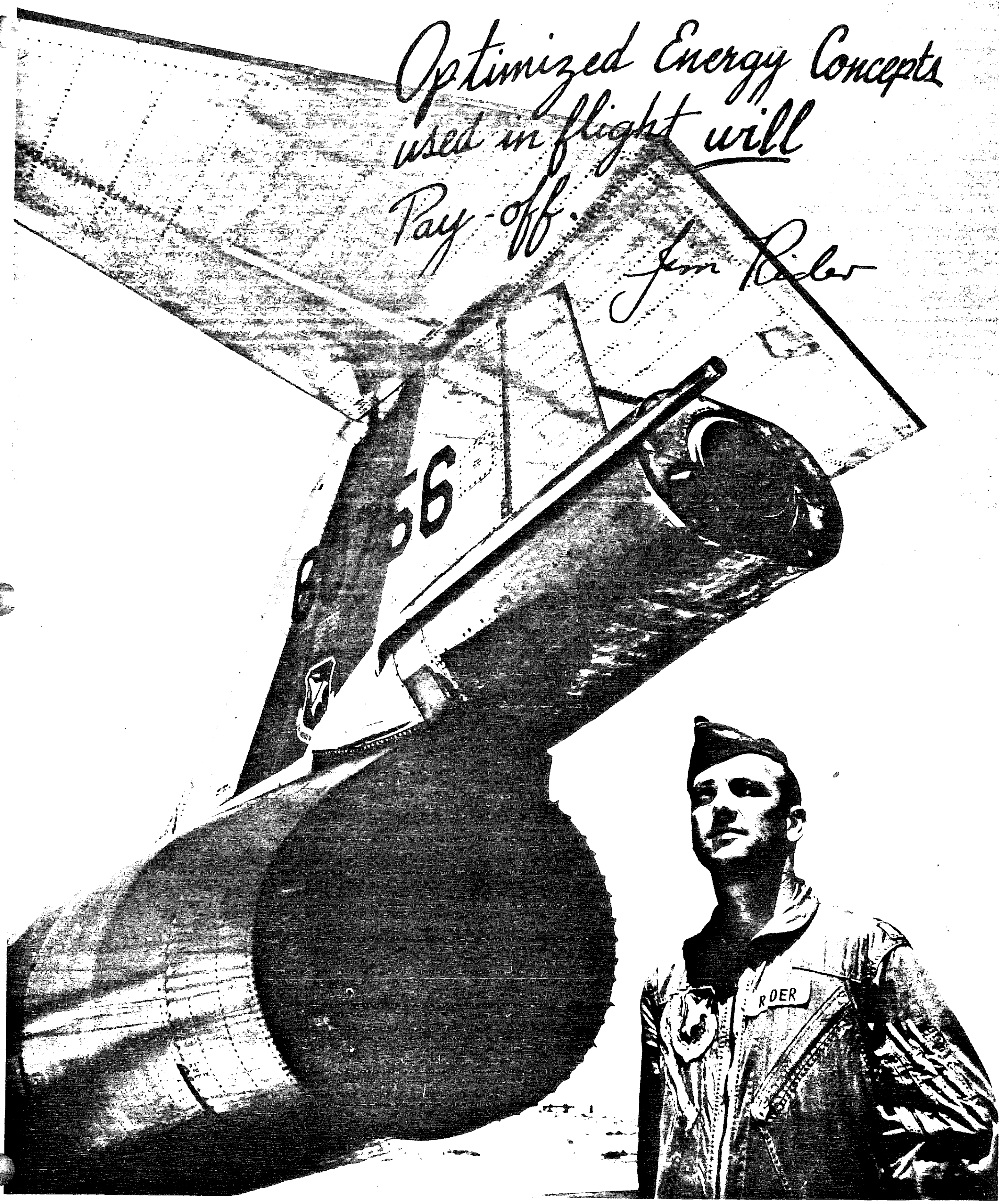
A. W. LeVier
Director of Flying Operations

LOOK TO LOCKHEED FOR LEADERSHIP



Snake sez:

Never grab a Tiger by the tail!


Optimized Energy Concepts used in flight will Pay-off.
Jim Rider
56
RDER

F-104

FLIGHT PROFILE OPTIMIZATION FOR THE INTERCEPT PROBLEM

Written by G. L. "Snake" Reaves - Lockheed Test Pilot

Cartoons by P. P. "Pete" Trevisan - FIAT Test Pilot

<u>REFERENCES</u>

1. T. O. 1F-104G-1 dated October 1968.

2. Lockheed Report CA/ME 2301 dated July 1966.

3. Lockheed Report CA/ME 2383 dated July 1967.

4. Flight Test Data from research flights flown by the Aerospace Research Pilot School at Edwards AFB.

5. Lockheed IBM 360 Computer Studies and Profiles by Burt McCorkle of Lockheed Computer Services.

6. Optimized Intercept Profile Studies by George Dreiling of Government Market Engineering Branch, Lockheed.

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FOREWORD

I am sure that those of you Tigers who have been in the intercept game over the years have asked yourself many times, "How come the faster I go, the farther away I am from the target at the offset point?" And, "How come the faster I am at the offset point, the longer it takes me to turn and position myself in the attack cone?" This paradox of increasing performance resulting in longer times and greater distances on intercept profiles should not exist. We are absolutely derelict in our tactical application of the weapon system if we do not utilize the weapon in a manner to produce optimized times and distances on intercepts. For too many years, I have been witness to the operational use of the F-104 in a manner that fell far short of capitalizing on the Starfighter's full capability. The reason for this sad state was the lack of scientifically proven profiles wherein our little beast was truly "unleashed" for maximum performance.

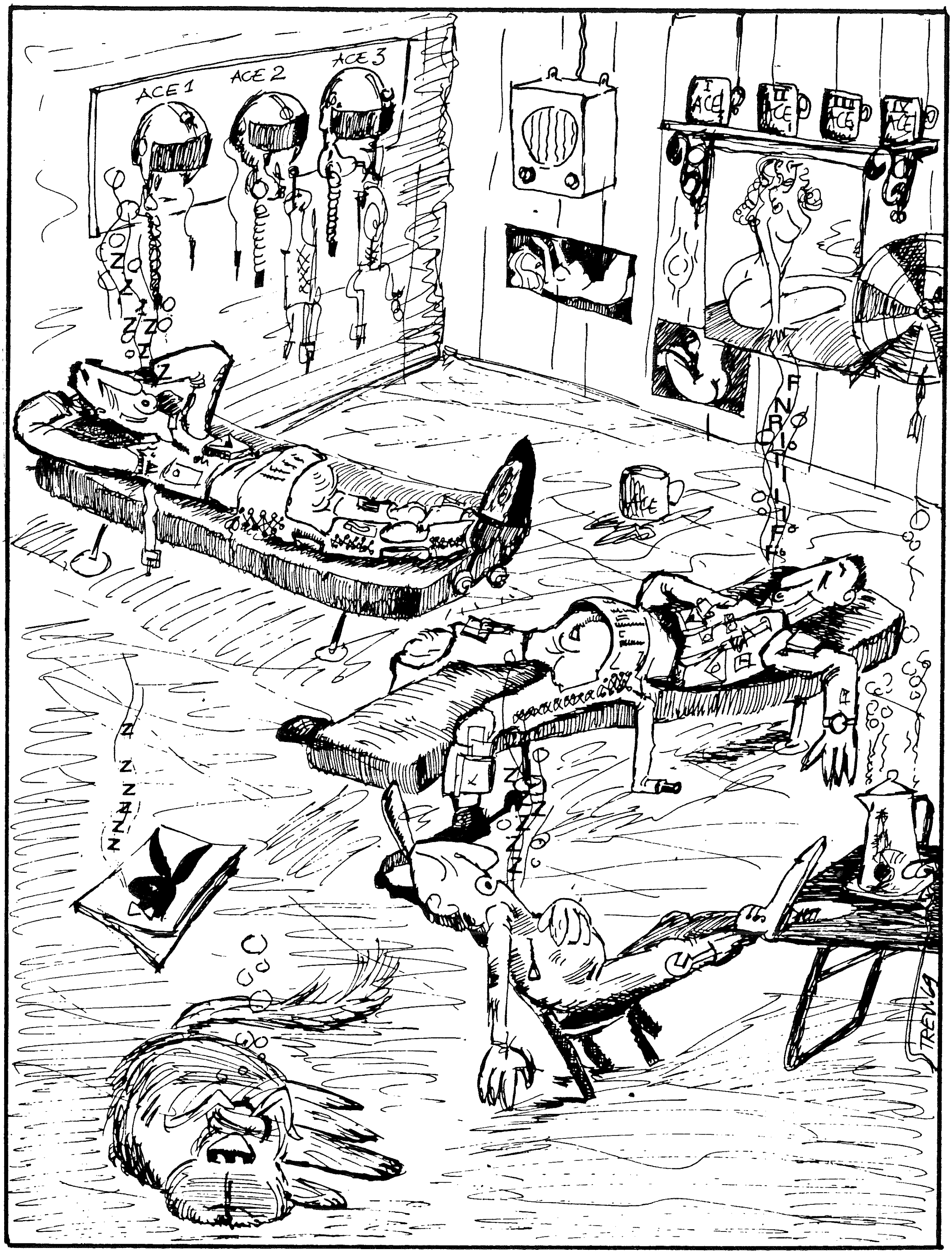
With the development of the Energy Maneuverability concept by Lt. Col. John Boyd, USAF, and the increase in computer know-how at Lockheed, I resolved to attempt a correction of this situation. I would never have succeeded, however, without the understanding cooperation of Col. E. P. Deatrick and Col. H. W. Christian Jr., who were successive Commandants of the Aerospace Research Pilot School (ARPS) at Edwards Air Force Base, California. The flight data for research flights by ARPS pilots on flight paths that were based on Lockheed's computer predicted paths was the critical ingredient needed to complete this scientific analysis.

The first sections of this lecture cover the historical sequence of Lockheed's computer developed flight path study and how the study results were flight proven by ARPS pilots. The last section discloses how intercept missions can be optimally flown by interceptor pilots so as to yield the best possible results.

In keeping with Lockheed's continuous effort to assist you in your operation of the Starfighter, I have written this lecture to answer the two questions:

- How is it possible to reduce the time and distance involved in supersonic intercepts?

- Can computer derived minimum time and distance flight paths based on Energy Maneuverability concepts be effectively flown by Interceptor pilots?



"SNAKE" SEZ: PROPER CREW REST IS NECESSARY . . . . . .IN ORDER THAT YOU

SECTION I

Scramble--Anyone?

When you're sitting number one and the squawk box goes off, a frantic teamwork effort is set in motion to intercept the intruder of the airspace that you're defending. The success of the teamwork effort depends on maximum effort by all involved---as you've been told many times. I have no doubt that all personnel involved do put out a conscientious maximum effort. But what about the machine? Are we utilizing our metallic steeds to get the most out of them? I think not.

In my SURE visits to the interceptor bases worldwide, I have been dismayed at the times and distances programmed on supersonic intercept profiles. A survey of the F-104 fleet reveals that about 50% of the Starfighter inventory have a Fighter Interceptor mission role. While you Strike and Conventional Delivery drivers might only scan this lecture for your academic interest, I think it's the "meat and potatoes" for the intercept problem.

The basic tenets of the intercept mission have not changed over the years. It's still the game of---

Detect
Intercept
Identify
Destroy

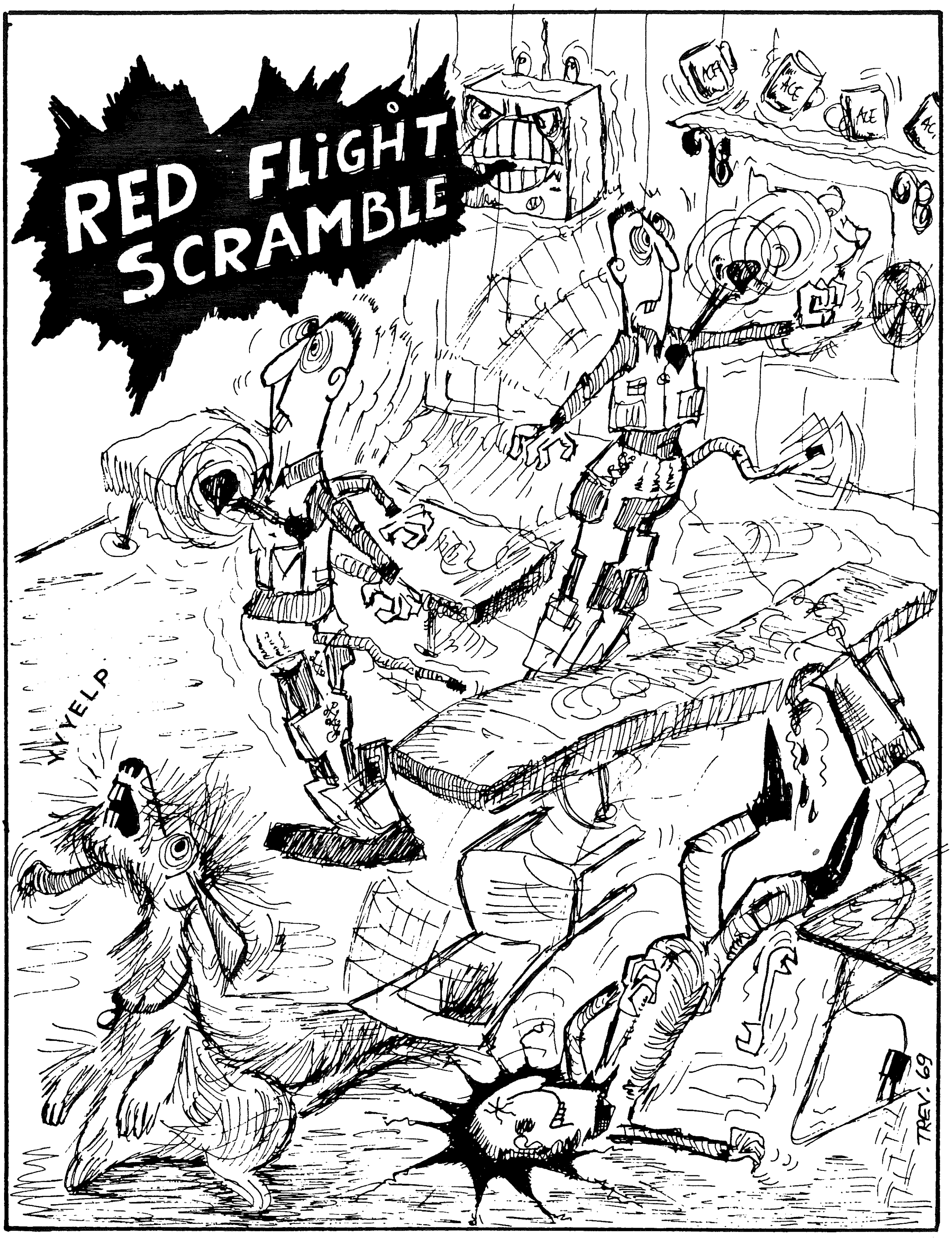
The Detection part of this problem is the responsibility of the GCI boys in the initial phase of the profile. They're the ones who "blow the whistle" to get you going. Once the scramble has been ordered, though, you are faced with these challenges to complete the last three phases.

1. Get safely airborne in minimum time.
2. Begin on-course climb immediately.
3. Accelerate to the required speed and altitude (for the offset point) in minimum time and distance.
4. Make a 180° turn from the offset point to arrive on the proper altitude and track behind the target.* This should be flown in minimum time and distance.

*Excluding head-on attack capability.

5. On the proper track and altitude, you should detect the target on your airborne radar in minimum time.
6. Tracking and steering to weapons launch in minimum time and distance.
7. If the target is friendly, report the identification.
8. If the target is hostile, pursue the attack until the target is destroyed.

Steps 1 through 6 comprise the INTERCEPT phase of the game. Of these, steps 1, 2, 5 and 6 have been well established for optimum efficiency. But how about steps 3 and 4? Actually, they are the heart of an "optimized" intercept profile. How are steps 3 and 4 being flown today? Let's take a look.



....WILL BE MENTALLY ALERT
AND PREPARED FOR IMMEDIATE ACTION AND ....

SECTION II

To Catch a Fly in the Sky

I still remember my first visit to a GCI site and how the controller explained their positioning of the interceptor at the offset point and turned him in on the bogie for the attack pass. That basic theory of the closure rate relationship and the set turn rate of the interceptor has not changed to this day. A certain amount of refinement has entered the picture, to be sure. And the big talk nowadays is all about automatic guidance information, which will take the place of the human controller whispering his directions in your ear. Even so, all my contacts with the F-104 Interceptor Drivers around the world have revealed a dismal picture---YOU AIN'T USING THE MACHINE LIKE YOU SHOULD! Also, the automatic guidance profiles do not, I repeat, do not utilize the maximum performance capability of the F-104.

I can remember when the Human Factors people decided that 1.2 times the target speed was an optimized overtake speed as you approached the maximum launch point for your missile. There was some pretty good reasoning behind this, since it was based on time requirements for human manipulation of weapons systems. But then, this magic number somehow became a limiting speed during the entire intercept phase! In some strange manner, it became the maximum speed allowable on the outbound heading to the offset point. If you're in the unheard of, unimaginable position of having plenty of time and distance to complete the intercept before the intruder is over your home drome---be my guest. But if you're anxious to nail the bogie as fast as you can---you shouldn't limit yourself to 1.2 times the target speed. Not only is this an unrealistic limitation of performance but in many cases, downright silly. We both know, Ace, that if you're after a "snooper" at 55 to 60 grand and it's one of those big winged, slow jobbies that putts along at .7 to .8 Mach, you are in dire trouble if you attempt to catch him at only .96 Mach number. Figure 6-6 of your Pilot's Handbook* shows that you are above the lg power limited ceiling at this Mach number and Figure 6-3 shows that even if you got there, at Mach .96, you'd be in Shaker and Kicker even under lg conditions. Forget it.

Considering another type of intercept problem, we find again that we're being unnecessarily held back because of standard turn limitations at high supersonic speeds. This is the case of a fast, high altitude intruder. In this case, for step 3 of the profile, you'd make a level acceleration out to the required supersonic speed. Let's say you even have to go to Mach 2.0. Depending on

*Reference 1

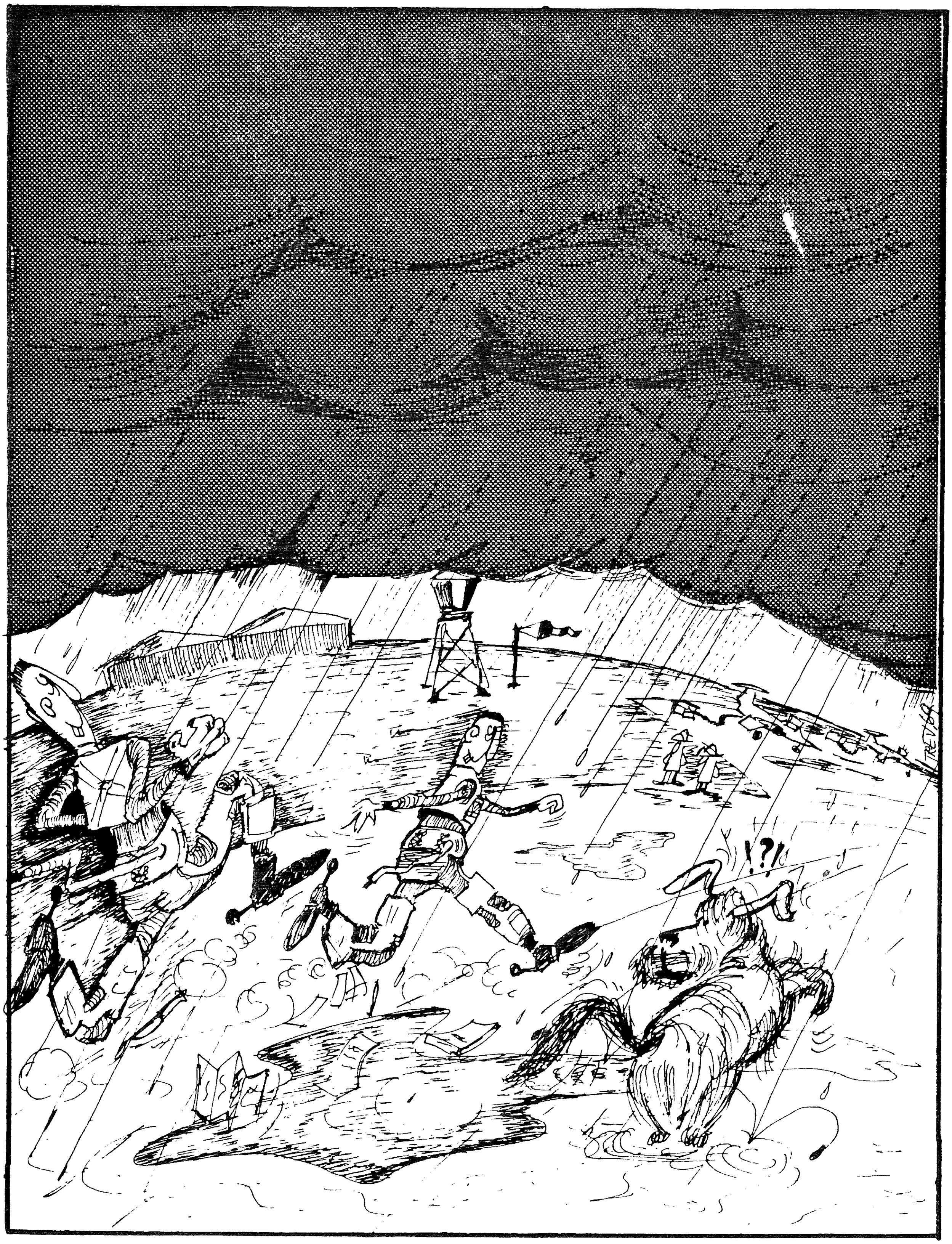
atmospheric conditions, you'd probably fly your acceleration at 36,000 feet. With a configuration of Tip Sidewinders, the Pilot's Handbook* in Figure A9-4 tells you that you'll eat up about 4 minutes of time and 55 nautical miles in distance. By following standard procedure, your GCI station would have guided you on a heading to put you at an offset point, so that you could perform step 4 in the standard manner. In order to perform the standard turn of 60^{o} bank and 2g's, you will have been guided to an offset point that is displaced about 22 nautical miles** away from the intruder's track. Flying the 180^{o} turn will take about 1.8 minutes.** Now, if the target just happened to be at your co-altitude, you could then begin step 5. But what if he's still above you? Like 15,000 or 20,000 feet above you? What now? You must expend more time and more distance (need I say it?---on the <u>inbound</u> track) before you will be in position to initiate step 5.

Without going into more examples, of which you're well aware, I'm sure you're receiving me loud and clear. And as some of you Intercept Drivers have said to me before---"There's gotta be a better way!" Also, in view of the problems you already face, i.e., closeness to borders, very short warning times and all the other obstacles thrown in your way, it behooves us to once again put on that old thinking helmet and see if we can help ourselves to do a better job.

If we look in Webster's New Collegiate Dictionary, we find the following definition of optimize, "To make as perfect, effective, or functional as possible." Since steps 1, 2, 5 and 6 of the profile are already optimized, let's concentrate on those critical steps---3 and 4. If we can find a way to optimize these steps, we will have achieved what we're after. Maximum output of human personnel <u>and</u> the flying machine.

* Reference 1

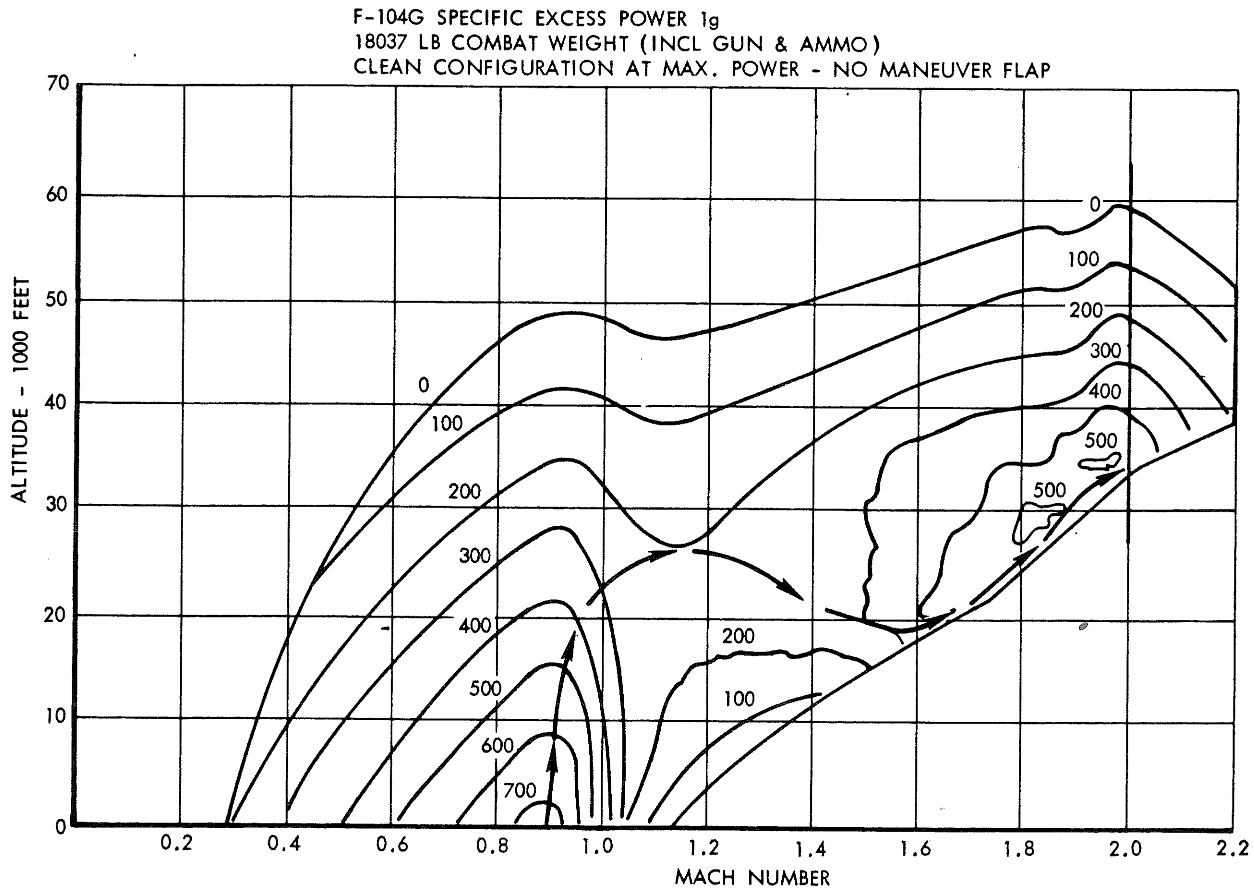
**Reference 1, Figure A9-88



. . . . .WILL BE IN PROPER PHYSICAL CONDITION FOR STRENUOUS DUTIES THAT . . . .

How Can We Get There Fustest With The Mostest?

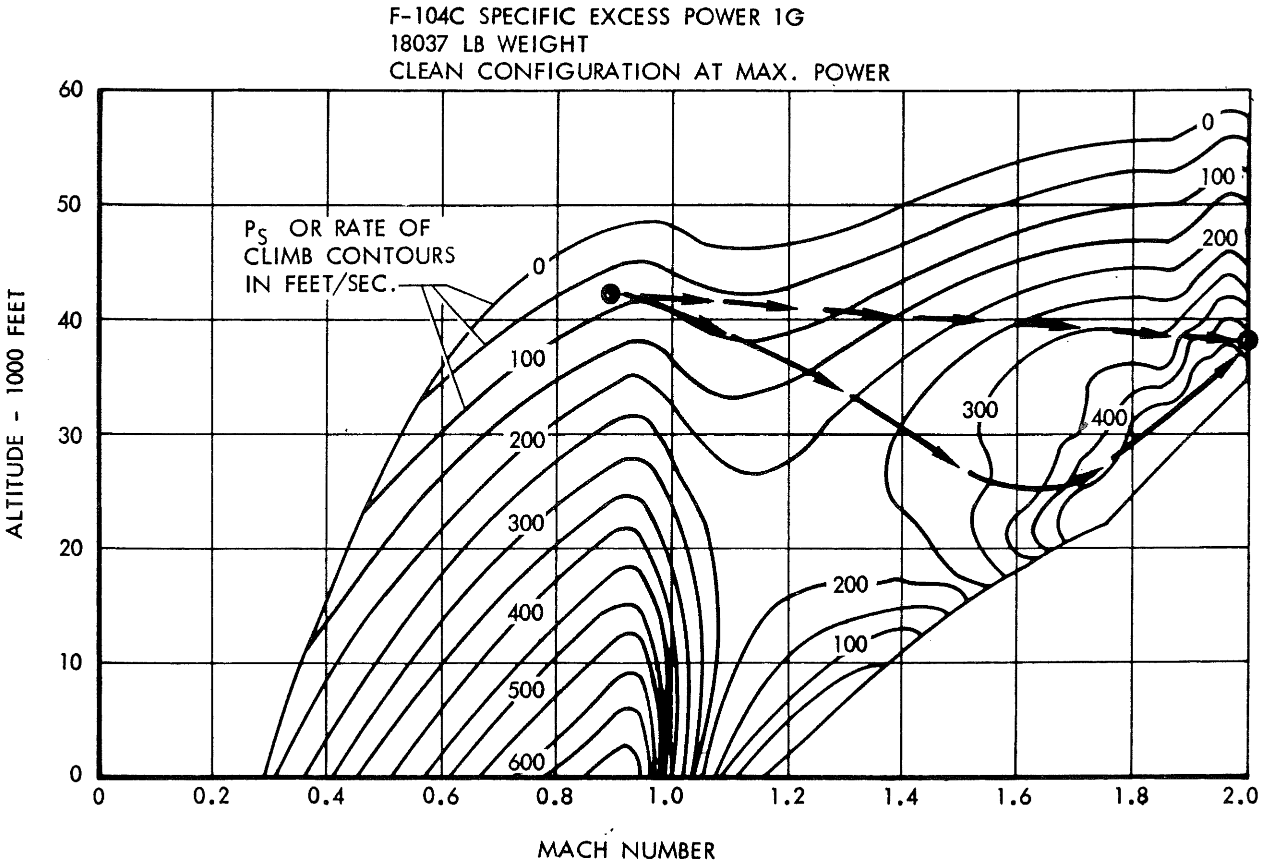
On pages 5 through 14 of SURE Lecture 6, I derived the Energy Maneuverability theory for you and explained how we let the IBM 360 computer give us values of climb rate available (P_s) at various Mach numbers and altitudes. On pages 15 through 21, I then discussed an optimized path to fly during acceleration that would cut down time and distance to Mach 2.0 versus a level path at 35,000 feet. Also, I alerted you about the factors affecting the minimum time path and that the path was theoretical and not proven by flight tests at that time. That path (I'm sure you remember) looked like this:



In December 1967, I contacted Col. E. P. Deatrick, Commandant of the Aerospace Research Pilot School, (ARPS) and discussed Lockheed's computer study with him. It so happened that a number of students in the school were then being assigned various class projects in an effort to research and enlarge upon the basic school curriculum. Capt. Mike Loh, USAF, and Herr Wolfgang Diegmann, German Test Pilot for BWB, became very interested in making the computer path profile flights their class thesis. Their objectives were twofold:

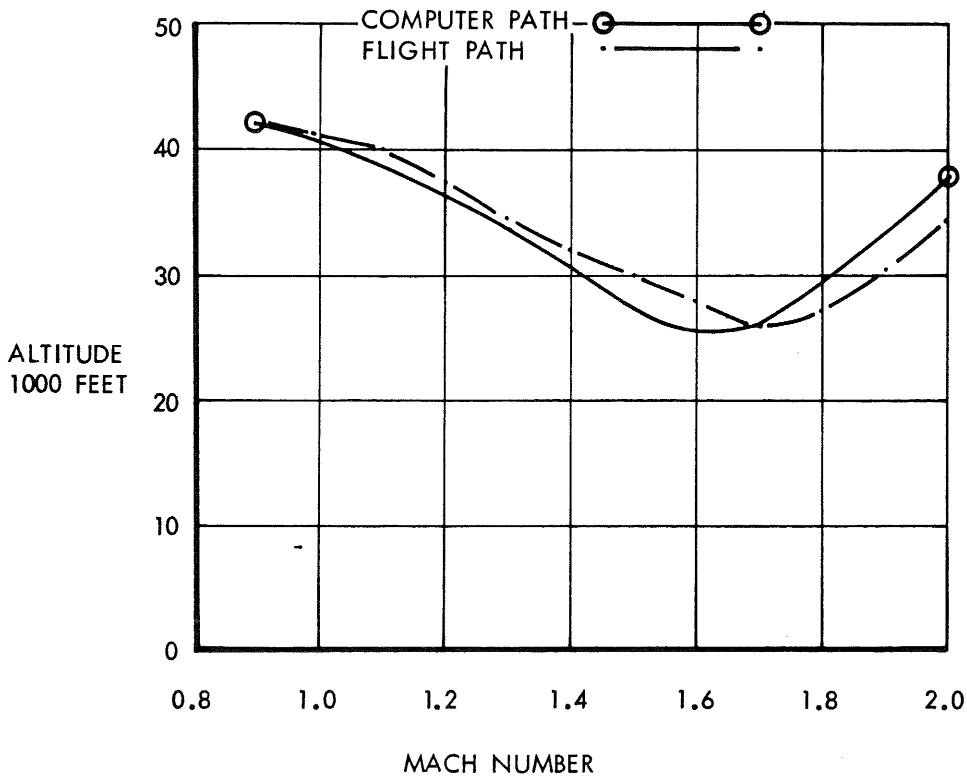
1. Investigate and study a minimum time and distance path that would enlarge the available classroom material about Energy Management.
2. Provide the ARPS with a more efficient path to accelerate for their zoom climb profiles.

A cooperative study effort between Capt. Loh, Herr Diegmann and myself resulted in our (Lockheed) supplying them with an optimized computer path for acceleration on their zoom profiles. Due to the fact that they must climb to over 40,000 feet at .9 Mach for a pressure suit check prior to accelerating and zooming, they were committed to begin their accelerations from this point rather than on the climb-up of the optimized path for intercept. Their desired end-point conditions after acceleration were Mach 2.0 at 38,000 feet and a flight path angle (γ) that would lend itself to the start of a straight ahead zoom climb. We gave them a computer derived flight path based upon the E-M considerations of a clean F-104C with 4,000 lbs. of fuel remaining. This path can be seen on the EM plot below. We also compared this path to a standard straight line descent from 42,000 feet to 38,000 feet. Here's how they look:



Utilizing the photopanel and camera that were located in the nose of the F-104C, Capt. Loh and Herr Diegmann flew some exploratory profiles and recorded time, altitude, Mach number and load factor. From this data, they reached some preliminary conclusions that "optimized computer paths can be flown with moderate precision and the standard cockpit instrumentation." Their primary pilot technique was to unload the aircraft through the transonic region, i.e., as they smoothly pushed over to start down, they "unloaded" the lift on the wing. This pushover continued until they established a constant descending flight path angle (γ) to 1.3 Mach which they held and then they began smooth beep-trimming to level flight at 1.6 Mach. The beep-trimming, which was continuous clicks of the trim tab button on the control stick, was necessary to keep from inducing too many g's in the level-off. From this point, a gradual climb with beep-trim to keep IAS between 700-720 knots was used until the terminal conditions were met. A comparison of the "average" path to the computer path can be shown thusly:

ARPS
F-104C ACCELERATION PATHS



This plot illustrates one of the difficulties of this path. And that is the fairly abrupt rotation of aircraft that is necessary because of the dive angle that you have as you approach the lower altitudes. Both Capt. Loh and Herr Diegmann overshot the rotation and therefore pulled more g's on the level-off than programmed. You can see too, that this resulted in a climb lag and they were only at 34,000 feet instead of the programmed 37,200 feet when they reached Mach 2.0.

For a further analysis of these paths, let's look at a tabular comparison.

Flight Path	Time	Fuel	Distance	Initial Alt.	Minimum Alt.	Final Alt.
Standard (smooth, constant γ descent)	4.38 min.	1260 lb.	56 n. mi.	42,000 ft.		38,000 ft.
Computer Path	2.17 min.	1019 lb.	32 n. mi.	42,000 ft.	25,375 ft.	37,200 ft.
Flight test paths (mean averages)	2.3 min.	1300 lb.	34 n. mi.	42,000 ft.	26,000 ft.	34,000 ft.

Since the fuel figures were read from the cockpit gauge, I'm sure you can see that there's not a great deal to be upset about with a difference of 281 lbs. between the predicted and the tabulated figure. The indicator needle width covers 100 lbs. on the gauge and when you couple this with a mental subtraction of figures while flying the profile, the 1300 lb. figure should not be taken too literally. The times, distances and altitudes can be closely compared, however. In this comparison, we were extremely pleased that the times and distances were so close. The closeness of these parameters verifies the preliminary conclusion about the feasibility of flying the computer paths with good accuracy. Now what about the comparison of the Flight Test paths to the standard? That saving of 2 minutes and 22 nautical miles to reach the end conditions graphically demonstrates the worthiness of our computer path study. And, I would venture that the 47% saving in time required and 39% in distance is highly impressive in consideration of intercept profile optimization.

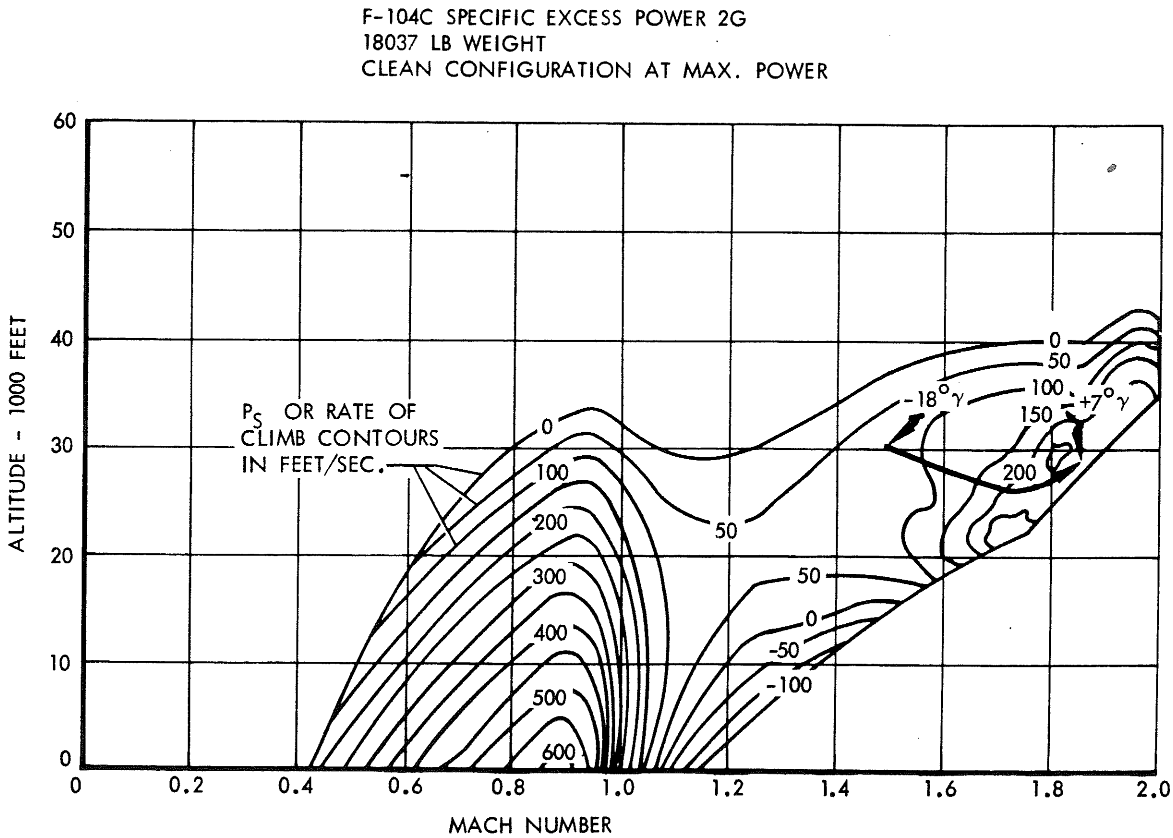
But even though the class thesis of Capt. Loh and Herr Diegmann established the feasibility of flying our computer paths, I was not satisfied with the stringent requirements of the path that they flew. An examination of some of the parameters along this path will show you what I mean.

I have listed below three flight parameters along the computer path at three particular points in time, considering time, t, was zero at the beginning of the path.

Time	Altitude	Flight Path (γ)	Mach number
27 sec.	34,800 ft.	-18°	1.25
68 sec.	25,375 ft.	0°	1.6
94 sec.	28,685 ft.	$+7^{\circ}$	1.77

This shows that to follow the computer path exactly, they had to rotate from a flight path of 18° below the horizon to 7° above the horizon in 67 seconds. And, the key factor is that they were programmed to pull a maximum of only 1.5g's during this rotation. It wasn't exactly a square corner but it's too tight for operational flying. That's the main reason that they overshot and pulled up to 2g's.

Now, if your thinking helmet is working, you'll remember that in SURE Lecture 6 on pages 21 through 23, I explained to you how we developed various P_s envelopes for constant g values. And with the sustained g loads, I pointed out how the P_s contours shrink down. So, let's look at the path that Loh and Diegmann flew under the 2g condition during their rotation from nose down to nose up and we'll see how tight that corner is. For this purpose, I had our computer run out the 2g P_s contours and I have plotted the rotation phase so that we can make a good analysis.

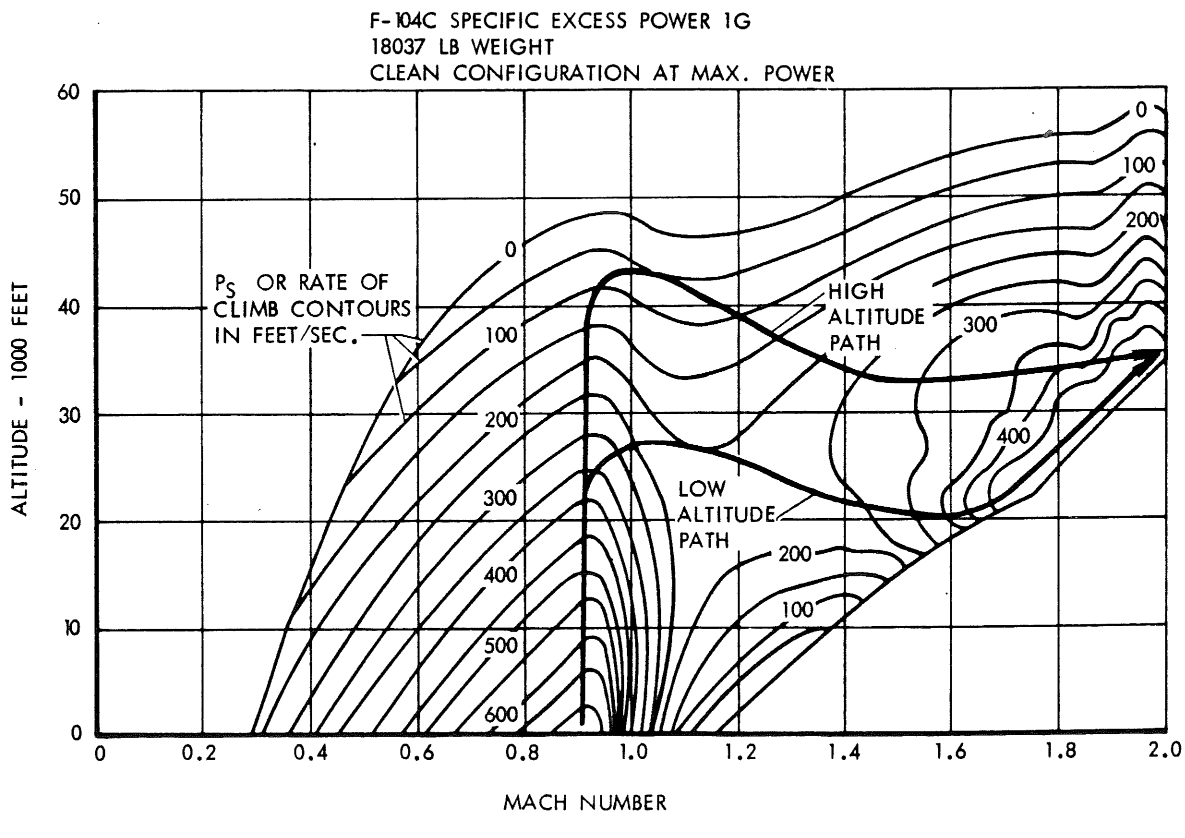


As we thought, the P_s values are lower whenever you approach 2 g's during a rotation phase. Looking back at the 1 g Specific Excess Power plot, you can see that at Mach 1.6 and 26,000 feet, you have 325 feet/sec. P_s value. But if the dive is so steep that you pull 2g, you can see that you've decreased your P_s to 125 feet/sec. at this point. It means a loss of 200 feet/sec. or 12,000 feet/min. of P_s. Any tight corner that can cause you to deviate away from 1g (in the positive direction) should be avoided for an acceleration path. The reason that the computer can fly this path is because it utilizes an intricate, searching process to find and use the precise g level to assure proper rotation. But you and I, Ace, fly in real time and we lack any self-correcting feedback to help us like the computer has.

The realization of the undesirability of diving down with a steep flight path angle and having to make too tight a rotation, caused me to consider another path for the ARPS Drivers to use for acceleration. But, before I was able to have Mike and Wolfgang fly any more paths, they graduated. At this stage of the game, I contacted Col. H. W. Christian Jr., the new Commandant of the ARPS. He agreed to the continuation of the optimum path study and the research flights. Therefore, I began coordination with Major Jim Rider, NF-104 Project Pilot for the ARPS. Surprisingly, he had also analyzed the disadvantages of the dive to the lower altitudes and in our discussions, we deduced that essentially there are two optimum paths for acceleration to Mach 2.0.

"Two optimum paths---?"

Correct. It turns out that it all depends upon your initial starting point. Here's an E-M plot of the two paths to show what I mean.



If you are committed to fly up to the initial point that the ARPS Drivers do, then you should fly a modified descent followed by a shallow climb to Mach 2.0. Following this path, you fly along the top side of the supersonic P_s island contours. If, however, you are climbing from takeoff and want to fly the nearest optimum path for acceleration, you fly along the lower side of the supersonic P_s island contours.

You will notice that the lower altitude path has also been modified in comparison to my earlier recommendation. This is because Jim and the ARPS Drivers discovered a distinct disadvantage in flying right along the limit line. They found that anytime you are on the 750 knot EAS limit line, you are close to encountering the backside of the supersonic P_s island contours if you happen to overshoot the speed. If you will look closely at the P_s contours in our plot, you will see that we have not plotted any curves out beyond the aircraft placard line. But by visualizing or mentally extrapolating the shape of the contours, you can see that they are curving back around in their circular shape. Therefore, any path out beyond the placard line may be in the area where P_s is diminishing. You definitely cannot accelerate properly under these circumstances and it will kill your whole profile. Another thing you might have noticed from a close examination of the P_s contours along the limit line is that any path along the limit line does not cut through the middle of the peaks of energy. It's as though you are too far to the right side of a valley, when you should be following a path in the middle of the valley and going downhill while cutting the P_s contours through their middle.

"What are you trying to tell me, Snake?"

Just this, Ace---analysis and flight tests now show that you should not strive to fly exactly along the 750 knot EAS line in full T_2 reset when you want to accelerate to Mach 2.0 and 35,000 feet. The correct path is to cut the P_s contours as near to the 90° right angle aspect as possible. This will result in the quickest passage to the higher Energy Additive rates. This path lies back inside the limit line and under 750 knots EAS.

"But in SURE Lecture 6 on pages 18, 19 and 20, you talked about riding the T_2 line!"

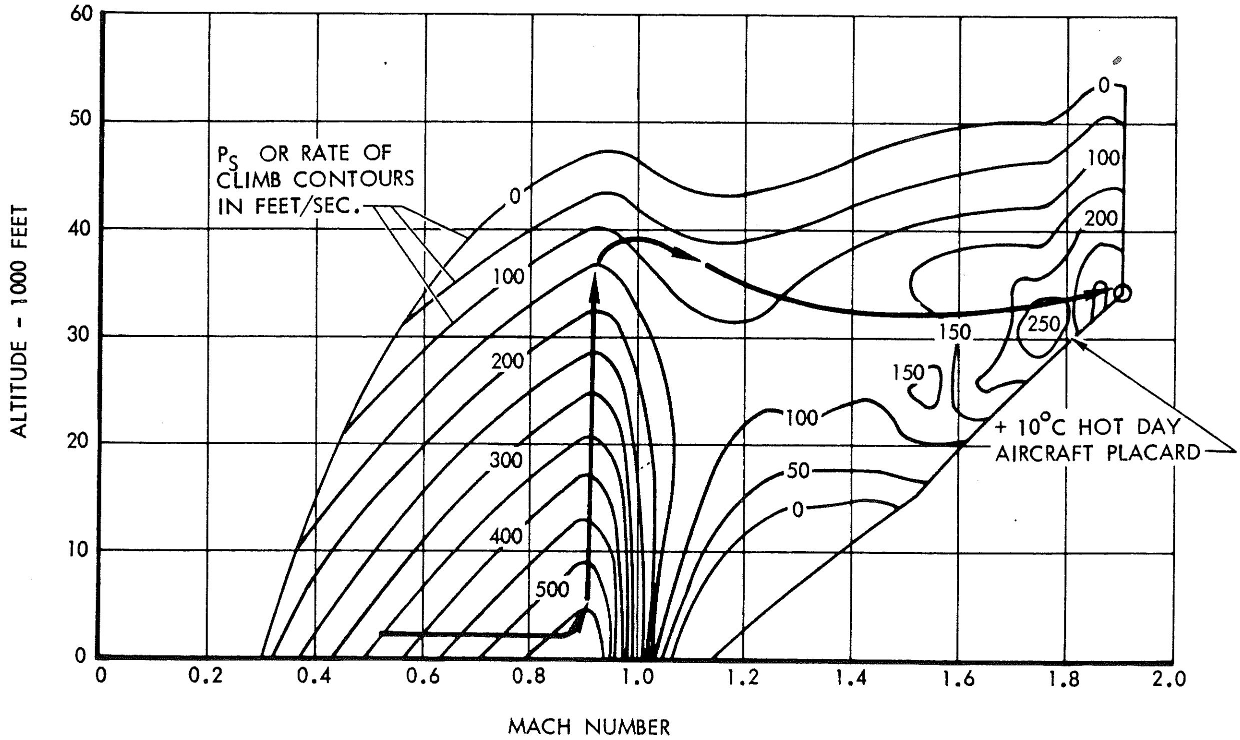
OK, hardnose---OK. It's another beer at the bar on me---but at least I'm now showing you the proven path. Shall we continue?

Both the low and high altitude paths employ a pushover to assist the transonic acceleration. This maneuver takes advantage of reduced drag due to lift by unloading the lift from the aircraft wing and simultaneously utilizes the pull of gravitation for still greater acceleration. A quick look at the high altitude path shows that the ARPS Drivers climb on up along the normal A/B climb schedule until they reach the tropopause level. They then begin a gentle, straight ahead pushover so that they peak out around 0.5g and 5,000 feet above the tropopause. Then they continue over to a steady, shallow dive angle and hold it until they intercept Mach 1.4 at about 33,000 feet. I say about because you'll see later how you can balance out a number of factors to your benefit. From this point, Jim developed a shallow climbing technique to Mach 2.0 that he will explain in detail. Yes, Ace?

> "What if the atmospheric temperature is hotter than Standard day temperatures?"

That's a good point and in this case, you'll have to make a decision about when it is better to fly the high altitude path, that the ARPS pilots do, rather than the low altitude E-M path. So that you can get a feel for the effect of temperature on our P_s values, I had an E-M plot run off for a 10^{o} C hotter than Standard day. And for a practical look the plot is for a configuration of Tip-Sidewinders on an F-104G. On this plot, I have drawn the computer derived path for the high altitude route.

F-104G SPECIFIC EXCESS POWER 1G + 10 DEGREES C
19184 LB WEIGHT
TIP SIDEWINDERS AT MAX POWER



It definitely appears that the best path for acceleration with this hot temperature condition is along the ARPS high altitude path. Especially so in consideration of those low P_s values around the 1.2 to 1.4 Mach range and around the 20,000 ft. level. Notice that we even have a O P_s contour in that lower altitude region and you should certainly avoid that condition. The effect of higher temperatures is to gradually eliminate the optimization advantage of the low altitude path. OK, what's got you upset, now?

"Well, I see how temperature can effect the low altitude path and I can dig that part of climbing up and unloading over the top and how gravity can help me to accelerate, but I think we're still in a ball of snakes."

Why?

"Because no matter how we get to Mach 2.0 and 35,000 feet, we'll still have to do the standard type of turn from an offset distance of over 20 nautical miles. Right?"

Wrong, Ace. Because Lockheed has a flying machine that never gets off the turf but it can fly the 104 through a multitude of different paths and tell you the best way to turn around at any Mach number and any altitude.

"What are you talking about?"

Lockheed's IBM computer, of course.

"Man---I got you again. On page 38 of SURE Lecture 6, you talked about the computer having a strict limitation of 2-dimensions and that ain't gonna help us get around this turn from the offset point."

I'm crushed, Ace. Haven't you ever heard the expression---Look to Lockheed for Leadership?

"What are you getting at?"

Fall in trail and follow me.

DEMAND CALM, CLEARHEADED EFFICIENCY SO THAT YOU ....

SECTION IV

"Is it a Bird? Is it a Plane? No, it's the IBM 360!"

Before we talk about our new system of 3-dimensional flight paths, let's spend a little time discussing the computer process to search for and find an optimized path between two points in our flight envelope. The first thing we'll do in order to try to understand the unique language of computer programmers will be to find a good, useful analogy that will help put the big picture clearly before us. So how about playing the game of optimization with me, Ace?

"How do I do that?"

Let's suppose you were standing at the foot of a mountain and a blindfold was tied over your eyes and you were given a cane. Then you were told that the object of the game is for you to find your way to the top of the mountain. And to give you the proper incentive, you're told that if you find the shortest route up to the cabin at the top of the mountain, you'll find a welcome reward.

"Like what?"

How about one of Hugh Hefner's Playmates waiting for you with a cold, dry Martini and a vacant Bearskin rug in front of the fireplace?

"Rog---let me go, let me go!"

Now, wait a minute. Remember I said you're blindfolded, with a cane in your hand and I said you have to find the shortest route to the top. So what are you going to do?

"Is this a normal type mountain with valleys and ridges?"

Yep---normal, normal old mountain.

"Well, since a blindman always taps the cane out in front of him---I'd do the same. That would tell me whether the ground goes up or down."

Right, but why not tap all around in a 360° circle and find out where the ground goes up the steepest?

"Oh yeah, that would tell me the quickest way to go up."

Right---after all, the shortest route is going to be when you follow the steepest existing gradient---right?

"Uh huh, but wouldn't I then eventually find myself on the nearest ridge of the mountain which might wind around a little but would be the shortest way to the Bunny?"

Absolutely, and all you'd have to do would be to keep tapping around and follow the steepest existing gradient which would be the path along the top of the ridge. By following the ridge to the top of the mountain, this would be the shortest route from your initial point---got it?

"Well, that's a pretty simple method to just keep following the steepest existing gradient."

Right, Ace and in computer language, this is known as the steepest ascent or steepest descent method. Now maybe you're beginning to understand the basic fundamentals of optimizing flight paths since I'm sure you've recognized the similarity between our E-M plots and a surveyor's terrain contour map. By flying the steepest ascent or descent between points, we will be flying an optimized route. But there's obvious constraints you have to abide by.

"Constraints........?"

Sure, what if you had been tapping along, following the ridge and suddenly came to a cliff face that practically went straight up? You wouldn't be able to go that route even though it would be the shortest. You'd have to search around for the next steepest gradient and, if possible, follow that one. So that our computer paths are not unrealistic, we have incorporated into the computer the constraints of g limitations and the maximum C_L capability of the F-104. These constraints, like the cliff face, can limit us in trying to fly between two points in our flight envelope while staying on the ridges of the E-M contours. Sometimes, we bump up against the fact that the required g load to fly along a path exceeds the aircraft limitations, therefore we have to take another path. There are two other constraints upon the flight path that can preclude or limit the duration of time, or distance that we fly along the steepest ascent path. They are the initial conditions and the end conditions that we impose on the flight path such as flight path angle or a minimum or maximum speed. As far as the payoff functions to be optimized, we can require the path to be flown within a minimum time, or within a minimum distance or fuel expenditure.

We can further expand our comprehension of optimization with another consideration. In SURE Lecture 6, you became familiar with the E-M Specific Excess Power plots. And you saw how they resembled terrain contours with their valleys, peaks and ridges. I explained how those contours represented the computer calculations of P_s. However, we can also make other parameter calculations in the optimization search. Say, an investigation of P_s divided by the associated fuel flow at each h-M point. This would allow us to find a minimum fuel path and we would again find that to fly between two points on the contour map there would be valleys, peaks and ridges in the envelopes. So what would we do to optimize?

"Fly the ridges!"

That's right. Whatever the parameter that you've optimized within the flight envelope, you want to stay <u>on the ridges</u> as much as possible. Now that you understand about the steepest ascent method and the payoff functions, let's probe further into the computer aspect of optimization.

Since the computer has already made all the P_s contours for various g loadings, a first approximation or first "nominal" path can be outlined for flight between two points in the envelope. The computer works on velocity (V), altitude (h) and the flight path angle (γ) as I explained in SURE Lecture 6. The computer recognizes these aerodynamic parameters as "state variables." If you consider only a 2-dimensional look at the flight path, anytime you push or pull the control stick, you'll induce g's along the flight path. To the computer, load factor, a_n, is called a "control variable." Obviously, anytime you change the control variable you are changing the derivatives of the state variables, i.e. $\frac{dV}{dt}$, $\frac{dH}{dt}$ and $\frac{d\gamma}{dt}$. Or, you are changing the rate at which they are varying with respect to time along the flight path. Anyway, the computer first flies along a selected "nominal" path, which is based upon a control schedule picked by the programmer to try to satisfy the end conditions. At preselected intervals along the path, the computer stops and looks around at the changes taking place in the state variables.

"Cane tapping, eh?"

Righto, and it also carefully stores everything it finds from its cane tapping into its memory banks for future investigation for better paths. When the computer reaches the end point, it records the elapsed time and looks at its actual final conditions versus what the desired conditions are. In all likelihood, the desired end conditions will not be met by the first nominal path. So, the computer now goes back along the first nominal path and searches for a better path while observing the local constraints and utilizing all of its stored information. Eventually a better path is derived and this new path now becomes the nominal path. The computer then flies the new nominal path and at the endpoint again examines the end conditions. This "iterative" process is continued by the computer until the "nominal" path becomes an "optimized" path. That is, it optimizes the payoff function while staying within all local constraints along the path and meeting the required end conditions.

"That's not so hard to understand." .

Of course not, but in order to see how we got to 3-dimensional capability, I want you to read this explanation.

FLIGHT PATH OPTIMIZATION METHOD

Burt McCorkle

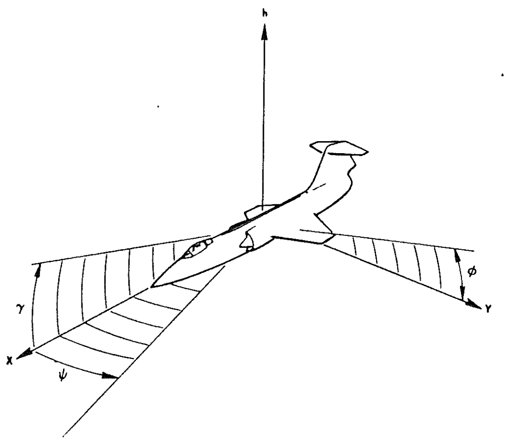
Lockheed Computer Services

"The numerical flight path optimization method for a high performance vehicle consists of an iterative scheme designed to converge upon a time history of the vehicles control so as to maximize or minimize some terminal quantity (payoff function) while satisfying specified initial and terminal constraints on the state variables of the problem simulation. The method of steepest descent has proved to be the most practical numerical method for obtaining good approximations to optimum solutions. This method requires a first guess control time history which generates a nominal trajectory. The sensitivities of the nominal trajectory due to changes in the control and state variables are mathematically investigated and the results systematically recorded in the computer. The steepest descent algorithm employs these sensitivities in a gradient technique to determine changes in the nominal control which generates a new trajectory with improved performance with respect to the payoff and constraint functions. This new control schedule then becomes the nominal control for the next iteration of the procedure.

The sensitivities mentioned earlier are used to mathematically investigate the neighboring surface in control space by use of a series expansion about the nominal trajectory. These sensitivities are determined by a set of differential equations which are adjoint to the linearized equations of motion. The boundary conditions for these adjoint equations are not available at the initial point of the nominal trajectory but they are available at the final point of the trajectory as they are functions of the partial derivatives of the payoff and constraint functions with respect to the state variables of the problem. Thus, the adjoint equations are solved by integrating them backwards (from final time to time zero) along the same nominal trajectory just completed. The method of steepest descent consequently requires the dynamic solution of two sets of equations for each iteration--- the forward integration of the nonlinear equations of motion, and the backward integration of the linearized adjoint sensitivity equations. The steepest descent method requires a separate set of adjoint equations for each final constraint of the problem in addition to a set corresponding to the payoff function. Until last year, the derivation of these adjoint equations was based on the restriction of the problem to a single control variable stored in the computer as a function of time. That control variable was load factor, a_n. In 1968, the problem was re-formulated in that vehicle control was introduced as a matrix variable which makes possible the optimization of problems containing multiple control variables. This new formulation complicates the problem considerably in that the number of sets of sensitivity functions increases geometrically with the number of control variables. This new formulation makes possible the optimization of vehicles in three dimensions by the introduction of bank angle as a new control variable and a new coordinate axis, Y, to measure distance from the vertical plane.

We now have a new three dimensional fixed coordinate system, which generates new equations of motion for the three dimensional paths."

Three-dimensional Coordinate System



For 3-dimensional flight paths the equations of motion are:

(Eq. 1.) $\frac{dV}{dt} = \frac{g}{W} \left(T - D - W \sin \gamma\right)$

(Eq. 2.) $\frac{dh}{dt} = V \sin \gamma$

(Eq. 3.) $\frac{dW}{dt} = -ff$

(Eq. 4.) $\frac{d\gamma}{dt} = \frac{g}{V} \left(a_n(t) \cos \phi - \cos \gamma\right)$

(Eq. 5.) $\frac{d\psi}{dt} = \frac{g\, a_n(t) \sin \phi}{V \cos \gamma}$

(Eq. 6.) $\frac{dX}{dt} = V \cos \gamma \cos \psi$

(Eq. 7.) $\frac{dY}{dt} = V \cos \gamma \sin \psi$

Nomenclature:

D	-	drag
g	-	gravitational acceleration
ff	-	fuel flow
h	-	altitude
T	-	thrust
V	-	velocity
W	-	weight
X	-	range along X-axis
Y	-	range along Y-axis
γ	-	flight path angle
ψ	-	heading angle
$a_n(t)$	-	load factor schedule as a function of time.
$\phi(t)$	-	bank angle schedule as a function of time

For 2-dimensional paths contained in the x-h plane, bank angle, ϕ, Y-distance, and heading angle, ψ, remain zero. Thus, equations 4 through 7 simplify to:

(Eq. 4.) $\frac{d\gamma}{dt} = \frac{g}{V} \left(a_n(t) - \cos \gamma\right)$

(Eq. 5.) $\frac{d\psi}{dt} = 0$

(Eq. 6.) $\frac{dX}{dt} = V \cos \gamma$

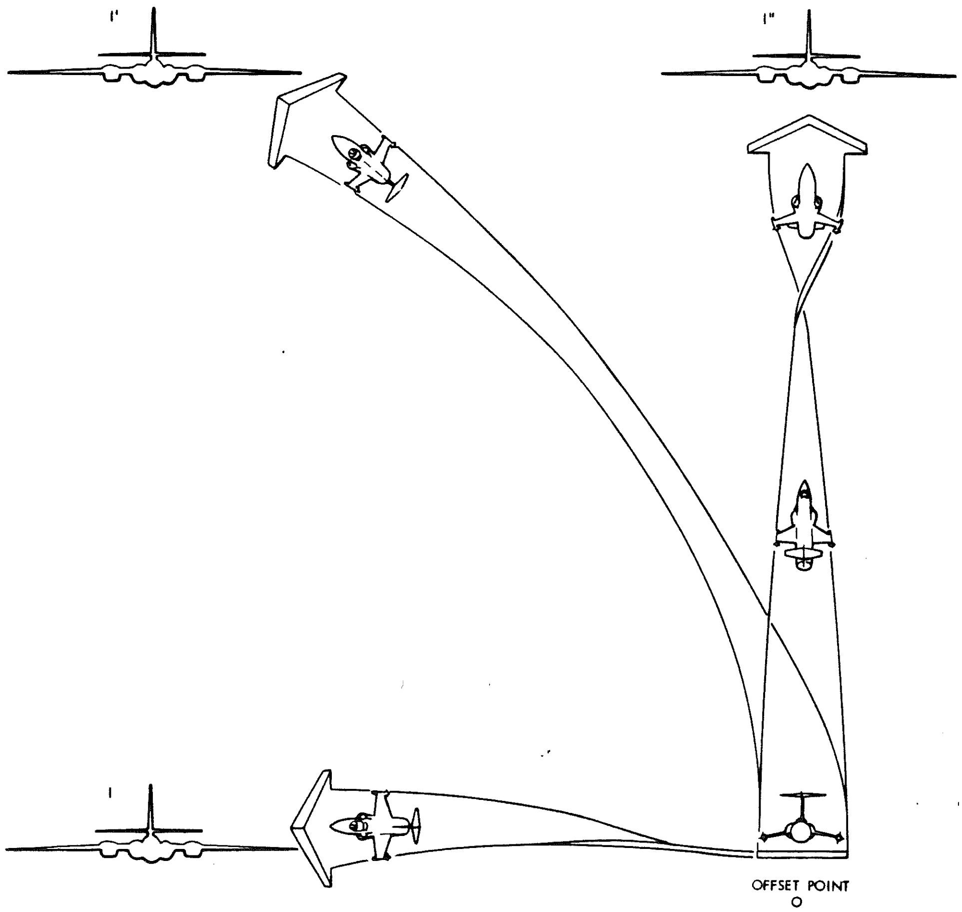
(Eq. 7.) $\frac{dY}{dt} = 0$

So you see, Ace, we now have ourselves a three-dimensional flying computer for our F-104 profiles.

"Now we can make an optimized turn from the offset point---right?"

That's right. But we first have to make an extensive investigation as to the most optimum way in which we can turn. In the Handbook*, from Figures A9-77 to A9-93, you are given some parameters about turning in Full A/B with various configurations and gross weights. But these curves, while telling you g load and turn radius, are tied to the constraints of a turn with constant speed and altitude. Assuming your target was at your co-altitude when you were at the offset point, these curves will tell you the optimum load factor and bank angle to turn so that you will hold the same speed throughout the level turn. Obviously these curves do not tell you what the turn results would be, for example, if you pulled into the edge of shaker during the turn. You would bleed some Mach, to be sure, but you'd turn tighter and quicker. Maybe this gives you a little insight into the limitations of those curves.

Now let's take a look at a simplified sketch of possible types of turns that we could make from the offset point.



*Reference 1.

From this figure, let's assume that 0 is our offset point. If I, I' and I'' represents possible locations of intruders inbound, then case 0-I involves only a level 180° turn to arrive in the 5 to 7 o'clock position in order to be in the attack cone. If the intruder is inbound at some point along the line I-I', then the 180° turn becomes more and more of a chandelle until 0-I' is the maximum gain in height and distance covered during the 180° turn. 0-I' represents the classical chandelle case. Between 0-I' and 0-I'', the turn comprises a combination of chandelle and Immelman until 0-I'' is the pure Immelman.

In our search for an optimized path for minimum elapsed time and shortest radius of turn while given the task of climbing from 35,000 to 50,000 feet, we even had the computer try to fly an Immelman from Mach 2.0 at 35,000 feet to see if it would be possible. True to our expectations, the computer optimized a pull up to a flight path angle over 50°, but then it told us that even continuing to pull maximum lift coefficient---it could not complete the Immelman since the energy loss rate at this point was increasing drastically. A beneficial fall-out of this particular study was that Major Rider was able to teach the NF-104 pilots, from this optimized path, exactly how to most efficiently pull into zoom climbs with the minimum loss of energy. This greatly assisted him in his zoom path predictability objective for the ARPS.

> "That Immelman was like tapping the cane and bumping into the cliff face, wasn't it?"

You better believe it. But by working away from the impossible and "iterating" through the realm of flight paths that were possible, we ran out an optimized path for Jim and the Tigers at ARPS to play with. It had the classical shape of a supersonic chandelle and a minimum time and distance that delighted us. The only trouble was that it was "too optimized."

> "Too optimized?"

Yeah---the IBM, bless its little metallic Cardiac, faithfully followed the maximum lift coefficient and whipped the 104 around while bleeding from Mach 2.0 down to 0.9. At that time, my thinking helmet flamed out and I gave the computer path to Jim without giving it a thorough checkout. The ARPS pilots quickly found out that to fly this path, it required them to honk the little beast around <u>right on the edge of the kicker boundary!</u> In fact, a couple of the ARPS Drivers encountered APC kickers while trying this chandelle and discovered that it immediately "blew" the whole profile. Also, you can tell by looking at the plot on page 16 of SURE Lecture 1 that they were treading that fine line of minimum directional stability during this high g maneuver. Belatedly, I realized that the maximum lift coefficient constraint that the computer had flown was in reality our APC kicker boundary. Calling a frantic halt to the proceedings, I had Burt reprogram a shaker constraint into the IBM and this became the maximum g boundary for the supersonic chandelle. With my thinking helmet fired up, I was now satisfied that this would be the best optimum path to test for predictability and accuracy. I was convinced that if the ARPS pilots could fly this highly optimized test path, by following the data we gave them frôm the computer, then operational pilots could definitely fly the looser, operationally optimized paths. The data from the computer is quite extensive and tabulates the following values as a function of time:

Control Variables	State Variables	Aircraft Data
Load factor	Altitude	Weight
Bank angle	Velocity	Thrust
	Mach No.	Lift
	Flight path angle	Drag
	X-distance	Lift coefficient
	Y-distance	Drag coefficient
	Dynamic pressure	Shaker boundary

Major Rider and the ARPS pilots now had a supersonic chandelle from the computer that was practical. Therefore, I took them the revised computer data and they launched on the second phase of this computer path study.

CAN SAFELY LEAP INTO THE MURK AND ....

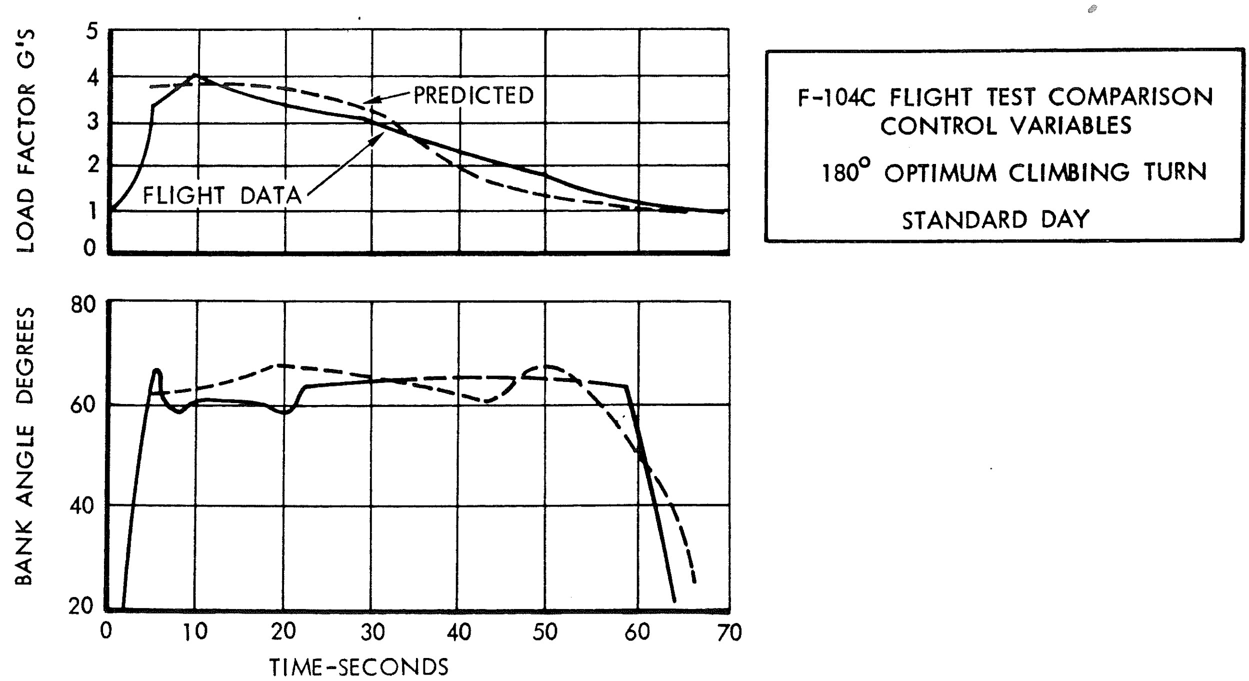
SECTION V

"A Mach 2.0 Bank, Yank and a 4g Pull? ! ?"

After receiving the optimized test profile from Lockheed, Major Rider and the ARPS pilots first analyzed the computer data for the control variables and state variables during the 180° turn. The turn was designed to complete a course reversal while climbing from 37,000 to 50,000 feet and bleeding down from Mach 2.0 to Mach 0.9. For data comparison, the F-104C instrumentation had airborne oscillograph data traces which contained many of the same data factors as the computer path. The remaining data factors were recorded by the photo-panel. From the Edwards Space Positioning Division, digital readouts from the radar tracking system gave precise positioning of the F-104's during their flight profiles. The ARPS pilots were briefed by Major Rider as to the technique to fly and then carefully debriefed after each flight. Each pilot's data was analyzed and his recommendations noted. This knowledge was then cranked into the next pilot's briefing. Quickly the profiles became better and better. In a surprisingly short time, all pilots were able to fly the profile with reassuring consistency.

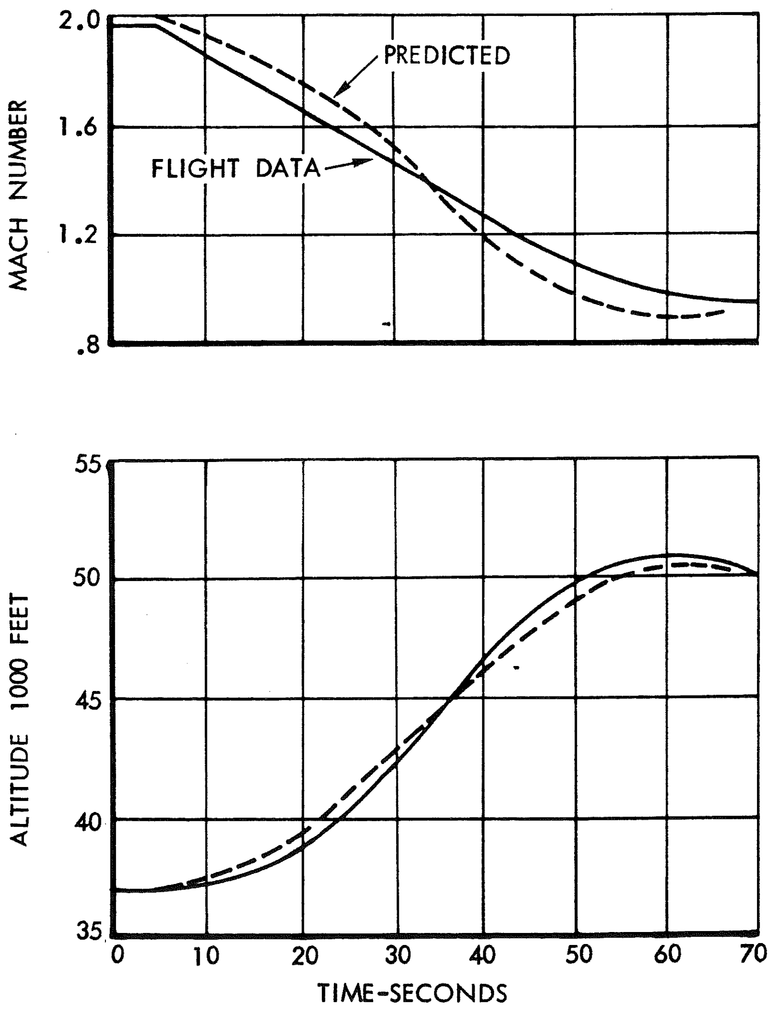
"Well how tight could they make the turn from the offset point?"

Patience, Friend---first let's examine a "representative" profile and compare it to the predicted profile. The "representative" profile represents what each ARPS pilot was able to do after 4 to 6 attempts at the optimized turn. Before we look at the X-Y distance and altitude comparison, though, why don't we see what the computer gave for the control variables schedules. That way we'll have an appreciation for how the ARPS Drivers flew their chandelles. Here's the plots of load factor and bank angle:



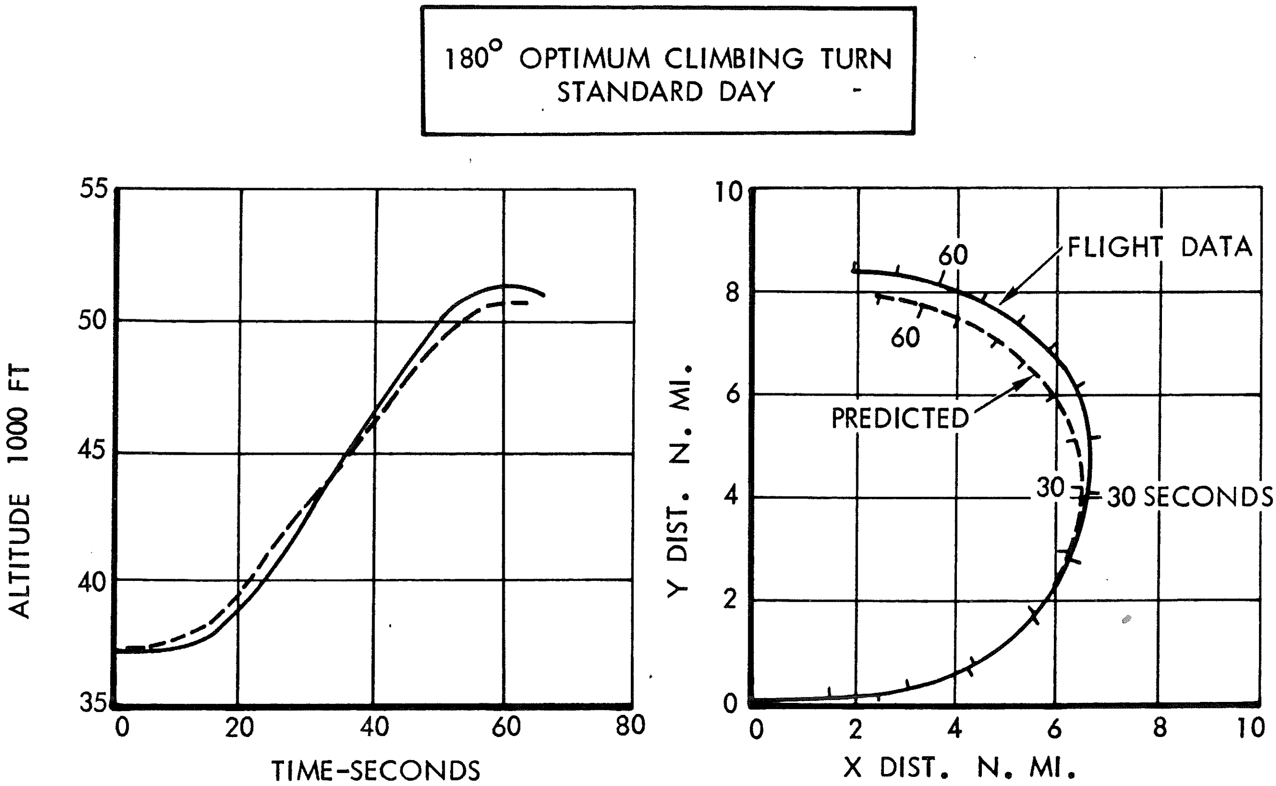
A word of explanation is due in regard to these plots of the control variables. First, the predicted data begins after a five second time history of the flight test profile has elapsed. This is because the computer data starts with the initial bank angle, $\emptyset$, and a load factor, a_n, already established. However, the flight test data shows that from straight and level flight at Mach 2.0, you will need about 5 seconds to establish the bank angle and initiate the turn. After the g load is established, however, look how closely the predicted schedule was followed. Even though the programmed load factor had a smoothly decreasing slope, this is not an easy schedule to follow.

The programmed bank angle was an easier schedule to follow as it called for a rather steady bank angle between 60 to 70 degrees. The dashed line indicates that the oscillograph trace hit its maximum calibrated deflection. But the actual bank angle had to be following very closely to the programmed bank angle as we'll see by the turn radius. I'm of the opinion that the actual bank angle was just at the maximum trace value during this part of the turn. You can see here, as in any chandelle you fly, the primary control parameters are bank angle and load factor. These are the "control variables" that you establish and follow in order to meet the desired end conditions. If you follow the bank angle and load factor scheduling, then Mach number and altitude will fall together to satisfy your requirements. That's just what happened to the ARPS pilots as we can see from these plots of altitude and Mach number:



F-104C FLIGHT TEST COMPARISON
STATE VARIABLES
180° OPTIMUM CLIMBING TURN
STANDARD DAY

See what I mean? By the smooth following of the control variable schedule, the ARPS pilots wound up at their end conditions while exhibiting the predicted change in Mach number and altitude. To fully appreciate the effect of the control variable schedule upon the turn results, look at the following plots of X-Y distance compared with the altitude gain during the turn:



How about that, Ace? The smooth following of load factor and bank angle have combined into a beautiful supersonic chandelle. And just focus an eyeball on the time and distance! It makes that offset point of 22 nautical miles look a little sick, doesn't it? The time to fly the turn is also a winner. In just a little over a minute from the offset point, you're clear up to 50,000 feet!

By looking back at the preceding plots, we can explain why the "representative" chandelle did not turn out to be exactly perfect. From the plot of Mach number and altitude versus time, it shows that generally the pilots tended to relax the turn around the last 90°. This explains the small overshoot on the Y, or offset distance. This relaxing of the turn also resulted in the small increment of higher altitude than predicted. But the critically important point here is that the overall accuracy of the "representative" chandelle proves its practicality in optimizing the intercept turn from the offset point. Even though the final track of the flight path is 1/2 to 3/4 miles outside of the programmed diameter, you are still in an "attack cone" position. My definition of the "attack cone" is any position to the rear of the target from which you can maneuver and overtake the target into the position of the weapon firing ranges. Naturally, the least amount of required maneuvering at overtake is desired so that you can concentrate upon your target tracking. Roughly speaking, the attack cone will lie in the 5 to 7 o'clock position behind the target and at co-altitude or slightly below the target altitude. Since it is a geometric proposition, the farther back you are from the target's position on your roll-out from the turn, the greater the lateral displacement that you can tolerate and still be flying in the attack cone.

"What about pilot technique used during these supersonic chandelles?"

Now there you got me Ace. Since I only flew some experimental segments and not the total profile, I prevailed upon Major Rider to give us a write-up of this project from the standpoint of the ARPS objectives and how they were achieved. So why don't we read what Jim has to say to you about their flight profiles and I'll just act as the friendly Editor.

ARPS

Edwards AFB, California

COMPUTER PROFILE TEST PROJECT

Summary

The Aerospace Research Pilot School (ARPS) conducts Test Pilot courses in which are taught the theory and flight techniques of establishing performance envelopes of airborne vehicles. With high performance aircraft such as the F-104C and the NF-104, the student pilots are also taught classic envelope expansion methods and optimum energy conversion techniques. In conjunction with Lockheed's SURE Project study of profile optimization, the ARPS undertook the Computer Profile Test Project to further investigate the method of teaching classical envelope expansion and to establish optimum energy conversion techniques for accurate zoom path predictability in the NF-104.

The envelope expansion technique is based on computerizing the equations of motion of a given aircraft, its engine, lift and drag characteristics. Then using the information and equations, the computer makes predictions about the aircraft's performance and stability. The flight envelope is expanded about known operating points and compared with the computer's prediction. These initially may not tend to agree too closely; so after each new data point is obtained the computer program is updated. This procedure is continued until the performance or stability limit of the aircraft is reached. As a training tool, the minimum time path computer predictions allow the Aerospace Research Pilot School student to train in making these comparisons between computer predictions and actual aircraft performance.

The use and mastery of an improved energy conversion acceleration profile for zoom climbs was the secondary objective.

Both objectives were realized. In addition the tests showed conclusively that Lockheed's F-104 computer predictions were accurate and could be flown quite easily with a little practice.

This report is divided into the two main aspects of the project, i.e., aircraft acceleration and supersonic turns.

Aircraft Acceleration

We teach in the ARPS that the major factor affecting acceleration is the net excess thrust, or:

$$F_{Net} = F_{Total} - D_{Total}$$

where, F_{Net} = Net Thrust

F_{Total} = Total Engine Thrust

D_{Total} = Total Aircraft Drag

This equation, of course, is affected by many factors and some of them are variable. The most important variable factors are altitude and free air temperature. At the high Mach end of the acceleration, the free air temperature is of primary importance since it dictates the Mach number at which the CIT limit will be reached.

The pilot has some control over these factors since he can choose the best altitude band to make his acceleration. The proper choice can make a big difference on how quickly the aircraft will accelerate. Before going into the recommended technique for picking the altitude band, let me inject one more point which theory predicts and experience bears out. When you make a level acceleration with your aircraft, you increase its total energy since you increase the aircraft's Kinetic energy. But here's the problem which all supersonic aircraft have. Their power plants produce increased total thrust as the aircraft velocity increases, but the drag increases as a function of the velocity as well. In the flight regime from just below Mach 1.0, the drag rises very sharply when going to the supersonic speeds. While the engine thrust is also increasing, it may or may not be sufficient to overcome the drag (depending on other factors such as altitude and configuration). In the F-104, the thrust remains greater than the drag but the margin is moderate until about 1.4 to 1.5 Mach. Above 1.5 Mach, the drag increases much more slowly while the total thrust is still increasing. This results in increased net thrust and better acceleration.

In the ARPS study curriculum, we teach that the aircraft has basically two kinds of energy---potential and kinetic energy. These two energies can be shown as specific energy from this equation:

$$E_s = h + \frac{1}{2}\frac{V^2}{g}*$$

This equation tells us how we can assist the aircraft to accelerate. Rather than trying to accelerate level at the lower altitude of 35,000 feet, climb to between 40,000 and 45,000 feet to increase your potential energy and then start a shallow descent (10 to 15° nose down) and convert the stored potential energy into kinetic energy. This helps the aircraft to accelerate faster through the low net thrust Mach region. The altitude to which you should continue the descent depends upon the atmospheric temperature factor. If the upper air temperatures are known, plan the descent portion so as not to descend below the -50° C level. We discovered a very useful rule of thumb during the computer profile tests and that was: if the ambient temperature is not known, don't descend below the altitude where T_2 cutback started during the A/B climb at 0.9 Mach.

So that you will understand our computer profile test flights, let's take a clean F-104C and work through a climb and acceleration from start to finish utilizing our ARPS recommendations. This profile will be an A/B takeoff and climb, followed by an acceleration to Mach 1.8 to 2.0, depending on the temperatures aloft. I'll describe our ARPS procedures for you in steps from the takeoff to our end conditions.

A. Takeoff and climb: Takeoff and subsonic climb data are very well known so won't be discussed here; however, instead of an A/B climb to 35,000 feet followed by a level acceleration, we'll make the A/B climb to 43,000 - 45,000 feet, noting that altitude segment where T_2 cutback starts. Note both the RPM cutback and the CIT reading. You do not want to descend below this altitude during the acceleration.

*Editor's Note: This equation was derived for you on page 7 of SURE Lecture 6.

B. Pushover: At about 40,000 feet, we'll start a gentle, straight ahead pushover to peak out at around 43,000 - 45,000 feet and about 0.5g. Then we'll continue the pushover to 10 - 15° nose down and then holding this attitude, we'll accelerate.

C. Acceleration to level-off: If the -50° C level is at 33,000 feet, which it is for a Standard day, the nose should be slowly trimmed up - not pulled - starting about 36,000 - 37,000 feet so that the aircraft is level at 33,000 feet. In any event do not load up the wing by pulling g's because it's better to overshoot your altitude while maintaining close to 1g. When level, you should be about Mach 1.5 or higher and holding forward stick pressure to stay level. Let the airspeed build to about 625 - 660 knots and staying within this airspeed band and a CIT of 80 - 85° C, start a slight climb. Do not worry about T_2 reset as it will come. But, if you dive on down to the placard limit line of 750 knots EAS just to obtain T_2 reset, then the drag rise is very sharp during the subsequent pull-up and the net thrust to accelerate is again low.

D. Terminal climb: From the condition of 625 - 660 knots and 33,000 feet, a shallow climb should be used at first unless the CIT is building too fast, in which case the climb can be steepened a small amount. The normal ramp to Mach 2.0 is 5 - 7° nose up and only in extreme cases does it get steeper than that. From our tests, the F-104 will accelerate quicker to Mach 1.8 to Mach 2.0 along this path rather than flying a level acceleration at the 35,000 feet altitude. We normally shoot for Mach 1.8 to 2.0 because on extreme hotter than Standard days the CIT limit may be reached about 1.8 Mach number. In any case, you will reach your end conditions at about 38,000 feet and from this position a supersonic cruise can be made to reach the offset point or the minimum time to turn and climb to target altitude can immediately be initiated.

Supersonic Turn

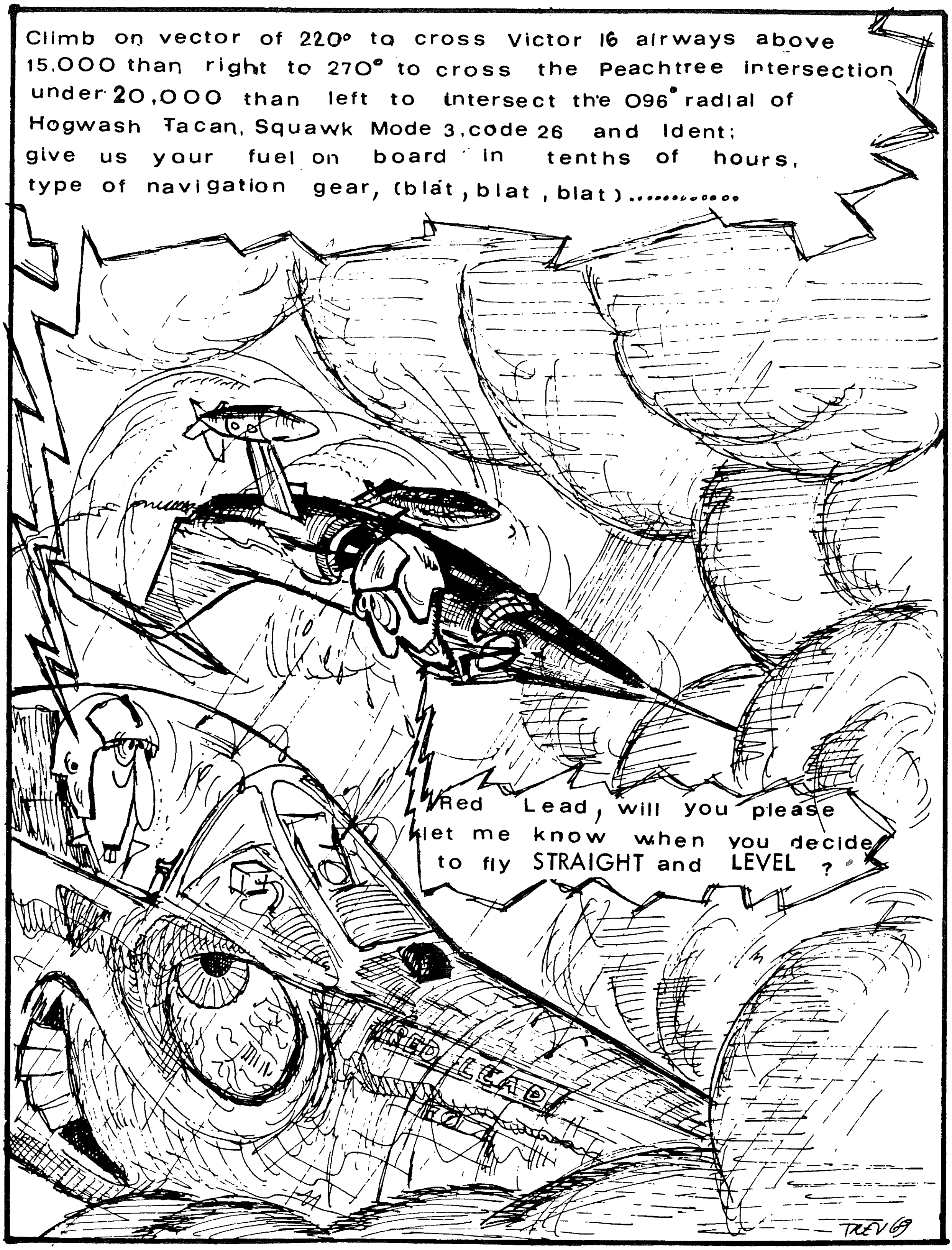
Several methods of minimizing the time to turn were studied. Some of them were very complicated and difficult to perform and tended to exceed the airframe limits (CIT primarily). The one found most optimized and useful was the modified chandelle. This maneuver was easy to perform and required no change to existing aircraft instrumentation. I found that it was much easier to obtain and hold the initially required 4g's by pre-trimming a medium amount of back stick while holding the nose down on the final acceleration phase with forward pressure. With the pre-trimmed aft stick, the turn was made by rolling smoothly to the required bank angle and applying back pressure and additional trim to obtain and hold the required 4g's.* For most of the turns a slowly varying bank angle was used depending on the required altitude gain and a constant 4g until reaching the stick shaker boundary and flying the turn along the shaker boundary. All of the turns performed compared very closely in time, fuel, speed and distance with the computer predicted values. There is one strong word of warning which must be injected at this point about some conditions that could be dangerous if a pressure suit is not being worn. The pilot must insure that the bank angle is 45° or greater before applying the required load factors. All of the pilots participating in the project (except one), simply established the required bank angle of 60 to 70° and then applied aft stick to acquire the programmed, initial 4g's. A faulty attitude indicator and an unclear horizon caused the pilot on one data mission to start the turn at 4g's with only 15 to 20° of bank. This, of course, was very much like trying to perform a loop from 36,000 feet at Mach 2.0 and using 4g's. These conditions, needless to say, caused the aircraft to exceed the desired 50,000 feet by several thousand feet and could have been very serious if the cockpit pressurization had been lost. I can't urge you strongly enough to be sure that you have the proper bank before pulling into the turn - double check both attitude indicator and the outside reference, if it is available---and have more than 45° of bank before applying the load factor.

Another important finding of this Computer Profile Test Project came about as a sort of fall-out. We discovered the best way to reposition yourself if you have missed the target at the top of the supersonic chandelle or if the GCI tells you of a course change by the target just when you reach the offset point. Rather than a level, 180°, Mach 2.0 turn, an optimized course reversal is to still fly the minimum time and distance supersonic chandelle. Then, at the top of the chandelle at 50,000 feet and about 1.2 Mach, change to the new heading, lower the nose and again use the technique of exchanging altitude for speed. You will rapidly reaccelerate to Mach 2.0 in the descent back down to 35,000 - 38,000 feet. This technique can easily be used to turn, reaccelerate to catch the target and then climb to intercept. And, it can be done in less time, fuel and distance than a level turn and pursuit.

finis

*Editor's Note: You will see on page 33 of SURE Lecture 4, a plot of stick movement versus stabilizer deflection. For the F-104C, you will note that it has a longer aft stick movement, 9 inches, versus the F-104G and subsequent models as shown on page 34. Combined with this is the fact that the F-104C has a slower pitch trim rate, 0.72 degrees/second versus the F-104G and subsequent models which have 1.4 degrees/second. In my opinion, the pre-trim technique will not be necessary if you fly the F-104G or a subsequent model.

OK Ace, our computer paths for acceleration have been proven beyond doubt for accuracy and feasibility. The supersonic chandelle has been consistently flown within 10% of offset distance, 1% of altitude and 1% of time and speed. I believe this lays a firm foundation for our final phase of this study. So from this point on, let's focus on just how we can apply the results that have come from the use of our thinking helmet, the IBM 360 and the data from the ARPS flight test profiles. And that will be the optimization of the intercept profiles!



BY FOLLOWING SIMPLE, PRECISE INSTRUCTIONS, YOU WILL ....

SECTION VI

"Happiness is an Optimized Intercept and a Max-range Lock-on!"

With a firm grasp of the tools required for optimizing steps 3 and 4 of the intercept problem, George Dreiling, Burt McCorkle and I then launched upon the final phase of our optimization study. Cranking up our thinking helmets to max RPM, George and I decided to analyze two basic intercept missions and when we had all the problems outlined and the bogies were inbound upon us---Burt scrambled the computer.

"What did it do?"

It scored two outstanding "splashes." Want to see how it flew these two missions?

"Why do you think I've stuck with you this far?"

OK---now let me lay out the ground rules we used for this study. Here are the aircraft factors:

1. F-104 interceptor configuration.

   A. Weapons: 2 AIM-9B wingtip mounted missiles
   750 rounds of 20mm ammo for M-61 cannon

   B. Fuel: 5,825 lb. internal

   C. Configuration Drag Index: Index of 10 until missile launch then 4 for return to base.

2. Intruder Data.

   A. Medium class bomber with intrusion speed between 0.8 and 0.9 Mach number at a maximum cruise ceiling of 50,000 feet.

Predicated upon these aircraft factors, we accepted the following payoff conditions for a high P_k factor (probability of kill).

1. Interceptor conditions.

   A. Altitude at AIM-9B launch: co-altitude of 50,000 feet.

   B. Mach number during attack phase: 1.2 to 1.3 Mach number.

   C. Tracking requirements: 1.5 minutes of time in the attack cone for detection, lock-on and steering to AIM-9B launch. Time to begin when the interceptor is in trail in the attack cone and from 2,000 feet below target on up to co-altitude at fire point.

Our mission philosophy was derived after some serious head scratching to see if we couldn't solve the two extremes of the Air Defense spectrum that's confronting the F-104 Interceptor units worldwide. This is what we selected as the philosophy behind our two missions which we'll call Mission A and B.

1. Mission A: This mission will apply to those interceptor units faced with close, neighboring border zones and correspondingly short warning time. It will answer the question of how far you can allow an intruder to penetrate into your airspace and still be able to complete a successful intercept and missile launch based upon our selected payoff conditions. For this mission, we'll apply our optimization techniques to the fullest. We will fire at the intruder in minimum time and minimum required distance.

2. Mission B: This mission will apply to those interceptor units who do not have border problems or short warning times but their mission requirement is to fire at the intruding targets as far out as possible and as quickly as possible. For this mission, we'll maximize the distance out at the fire point while still minimizing the elapsed time to the fire point.

So much for our guiding philosophy. For clarity, let's break down the mission profiles into segments. For Mission A, they are:

Segment 1: Takeoff and accelerate to climb speed.

Segment 2: Combined climb and acceleration path to Mach 2.0 and 35,000 feet at the offset point.

Segment 3: Turn from the offset point into the attack cone.

Segment 4: Attack cone phase of 1.5 minutes to missile firing.

Segment 5: Fire missiles.

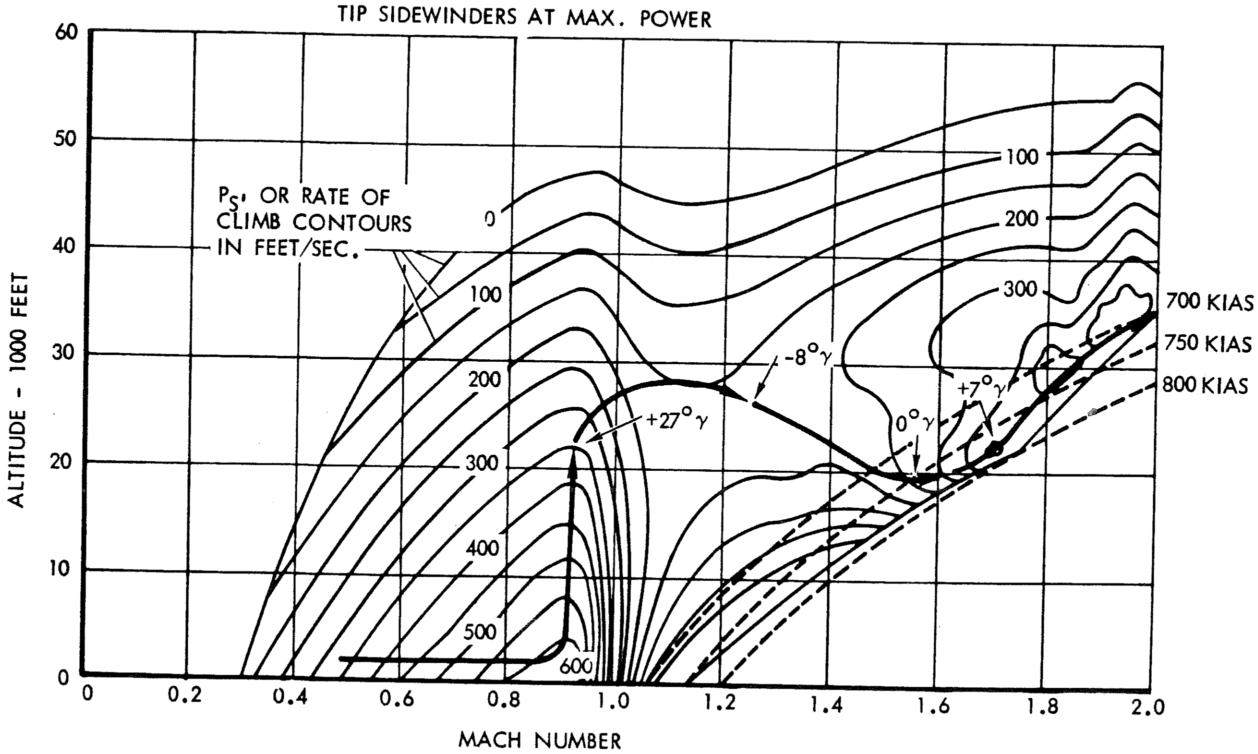
Segment 6: Continue attack with gun or return to base.

Segment 7: Recovery.

From this outline, segments 2 and 3 correspond to steps 3 and 4 of our basic intercept profile. Because these segments are completely different from the prevailing current procedures, I want to explain them in detail.

Concerning segment 2, we will now fly the low altitude E-M path because we're minimizing time and distance. So let's look at the E-M plot and discuss this path. This is our E-M plot of the F-104G with Tip Sidewinders and I've plotted out the climb and acceleration path for you:

F-104G SPECIFIC EXCESS POWER 1G
19184 LB WEIGHT
TIP SIDEWINDERS AT MAX. POWER



As you can see, I've noted some guide points to help you. I discovered these points to be helpful to me on my successful tries at this path. Why don't you follow me through as I describe how you should fly the low altitude path for acceleration.

1. Climb and pushover: The climb path is completely standard up to the 22,000 foot regime. At this point, with a climb path angle of $+27^\circ$, start beep-trimming forward to peak out at 28,500 feet and a level attitude. During this decreasing of the climb path angle to level flight, you can very easily judge and anticipate matching the 28,500 feet to the nose level attitude. The Mach "jump" on the Machmeter will occur during this transition and you'll be around 1.05 Mach number upon reaching level flight. The resulting load factor schedule during most of this phase will be around 0.5g. At the peak of 28,500 feet, you'll be around 0.65g. These small readings would be too hard to try and follow from your g-meter so just smoothly trim to match altitudes and attitudes. Don't worry about small overshoots, just concentrate on smoothness.

2. Descent and level-off: From the level attitude, continue beep-trimming to a nose down flight path angle of -8°. By the time you establish this attitude, you should have about 1.2 Mach and be at 26,000 to 27,000 feet. This is the steepest nose down attitude you should encounter. From this point, start a very gentle, slow beep-trimming attitude change in order to arrive at a level aircraft attitude just under 20,000 feet. At the level-off point, the speed should be 1.55 to 1.6 Mach number.

3. Terminal climb: From the level-off point, continue beep-trimming to a nose up flight path angle of $+7^\circ$. By the time this attitude change is achieved, the altitude will increase to the range of 22,500 to 23,000 feet. The Mach number will also increase to 1.7. An important point to mention is that this entire rotation phase is done very slowly. The elapsed time from changing the nose down flight path angle of -8° to the nose up flight path angle of $+7^\circ$ is approximately 107 seconds. So it's not the tight corner that Loh and Diegmann were flying. And, the maximum load factor encountered during the rotation should not get over 1.2g's. The primary pilot technique that helped me the most was to beep-trim so that <u>small but continuous</u> changes in altitude and attitude were occuring. In this manner, I could smoothly work at matching the conditions that I was aiming for. When established on the nose up flight path angle of $+7^\circ$, you should now encounter increasing Mach numbers---but a decreasing IAS.

From Mach 1.7 and 22,500 feet, you will notice the Mach number holding a steady increase of .05 for every 2,500 feet of altitude increase. For instance, Mach 1.75 at 25,000 feet, Mach 1.8 at 27,500 feet, Mach 1.85 at 30,000 feet and Mach 1.9 at 32,500 feet. Your peak IAS, however, is 775 knots at Mach 1.7. From the lines of constant IAS that I've drawn, you can see that the IAS actually decreases on this terminal climb schedule.

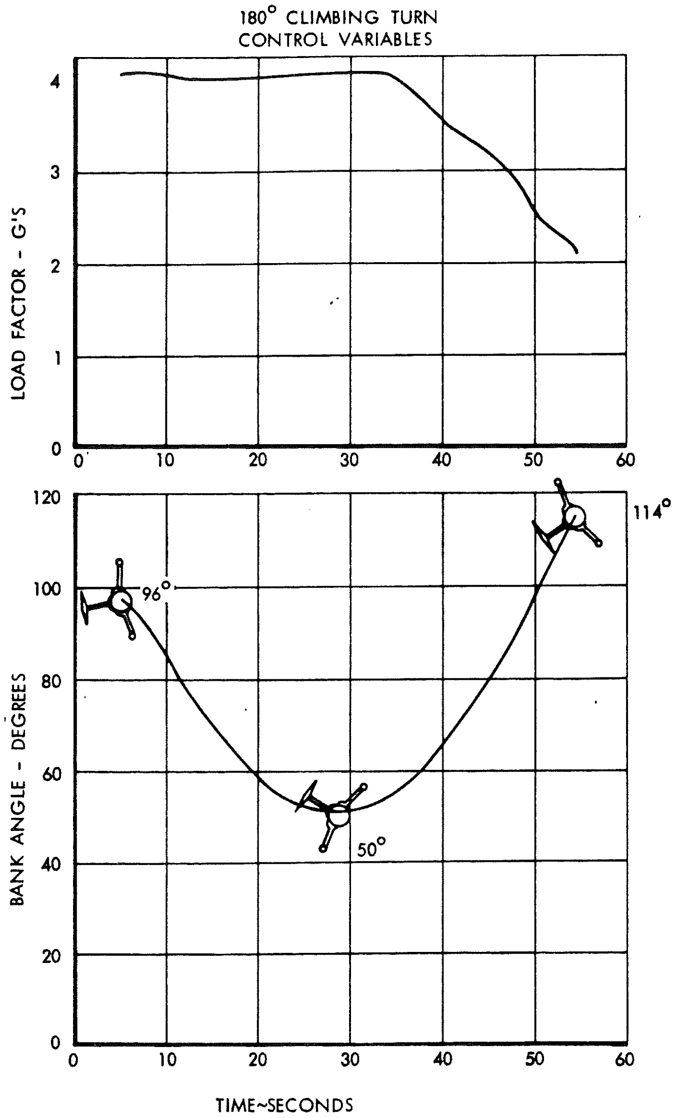
That's all there is to it---it's a smooth, simple path to fly if you follow the guidelines. For our Mission A, we'll assume that as you arrive at Mach 2.0, this position will be the offset point, so you're ready to immediately initiate the turn to attack. And at this point in our study, we turned to the computer as a guide for flying segment 3. Accordingly, George and I gave the payoff conditions and inflight constraints of the Tip-Sidewinder bird to Burt and he "unleashed" his trusty IBM and came back with an optimized turn---but what a turn! I took one look at it and knew that it was just "too optimized."

"It wasn't flying the kicker limit again, was it?"

No---but the scheduling of the bank angle and load factor would be well nigh impossible for you to fly.

"Try me."

OK---you asked for it. First of all, though, let me say that the results of this turn were fantastic! The payoff conditions of a minimum speed of 1.2 Mach and at least 48,000 feet of altitude, after the 180° turn, were both accomplished in a time of 53.5 seconds with a turn diameter of only 8.5 nautical miles! But unfortunately, here's what the bank angle and load factor scheduling called for:



Do you believe me now? The load factor schedule of 4g's was held fairly constant until a little over halfway around and then it started on a declining slope that would not be easy for you to follow. But the really wild part of this turn is that the IBM banked up to 96° to begin the turn and then shallowed out to 50° about halfway around the turn and then it rolled over to 114° at the end of the turn! Burt lassoed the IBM before it went completely inverted. I don't need to tell you that this would be a bear of a schedule to try to follow.

"Man, if you ask me, that's some crazy, flying computer!"

No doubt about it. Maybe now you see another very important constraint that we're faced with in this optimization problem and that's you.

"Me?"

You bet. You're not an IBM computer that can "iterate" back and forth until finding an optimum path and then follow a complicated schedule. You've got to be given clear, simple instructions to follow in order to assure a high factor of success and repeatability.

"I'm with you, but what we gonna do?"

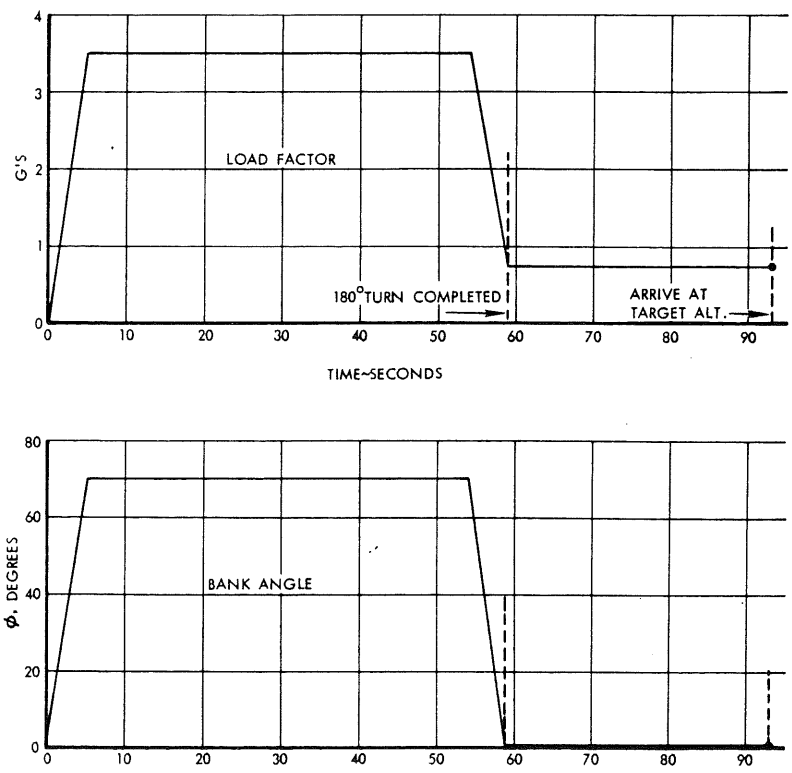
Well, the first thing I did was to convince Burt that we needed to introduce some realistic "pilot-constraints" into the IBM before it snap-rolled itself right off its mounting pad. Now, we both know that jerky, varying aircraft attitudes are undesirable for efficient maneuvering on intercept profiles. So I indoctrinated Burt about the smooth, constant control inputs from the pilot that are needed for a 180^{o} climbing turn. Of course, by operating under the realistic "pilot-constraints," we'll just have to accept the results of our turn in terms of time and distance. But remember that part of our optimization definition that said, "make as functional as possible?"

"Yeah---now I get you. We need a simple scheduling that I can follow with the cockpit instrumentation and be able to repeat the turn with consistency so that the GCI cats can depend on me."

Romeo. That's why Burt had the IBM fly some realistic turns with the same technique that you and I would use, and just like an old Pro, it soon locked onto a beautiful, straightforward chandelle. Here's how the control variables look:

OPTIMUM PATH INTERCEPT

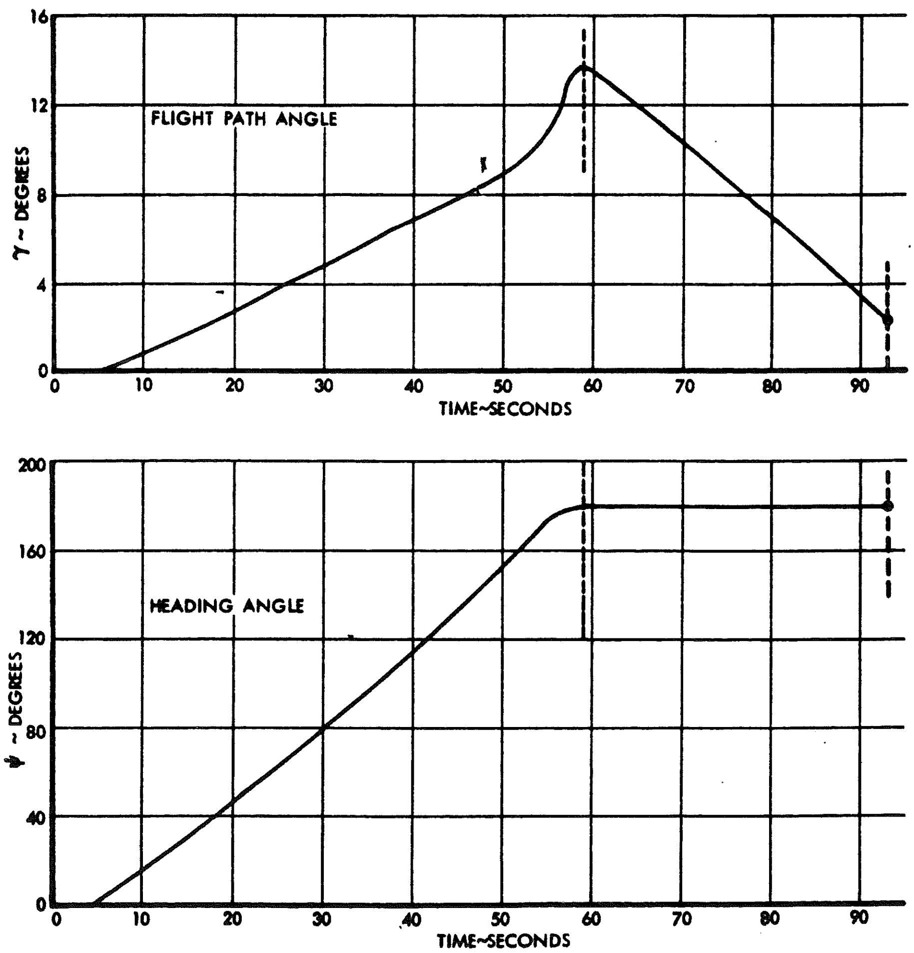
CONTROL VARIABLES



Look at that. It's a schedule of a constant bank angle and a constant load factor to be held simultaneously throughout the major part of the turn--- what could be simpler? You've completed a 180° course reversal in 59 seconds including 5 seconds for the roll-in of the bank angle as you establish the required 3-1/2g load and 5 seconds to rollout and relieve the load factor at the completion of the turn. Depending on your model of F-104, the cockpit instrumentation might be absolutely perfect, where the g-meter is located right alongside the main attitude indicator. In models that do not have this location arrangement, the g-meter is normally located next to the altimeter. There are other instruments that can supplement your guidance throughout the chandelle. For example, your PHI (Position Homing Indicator) in the F-104G and subsequent models is extremely accurate during all maneuvering, subsonic or supersonic. This is because of the instantaneous signals from the LN-3 stabilized platform. Therefore, if you desire, you can cross-check bank angle, load factor and heading indicator during the chandelle. After a few practice runs, the ARPS Drivers were even cross-checking the altimeter. But remember that your primary control parameters for chandelles will always be the bank angle and load factor. For a look at the behavior of our state variables during the turn, let's now look at flight path angle and heading angle.

OPTIMUM PATH INTERCEPT

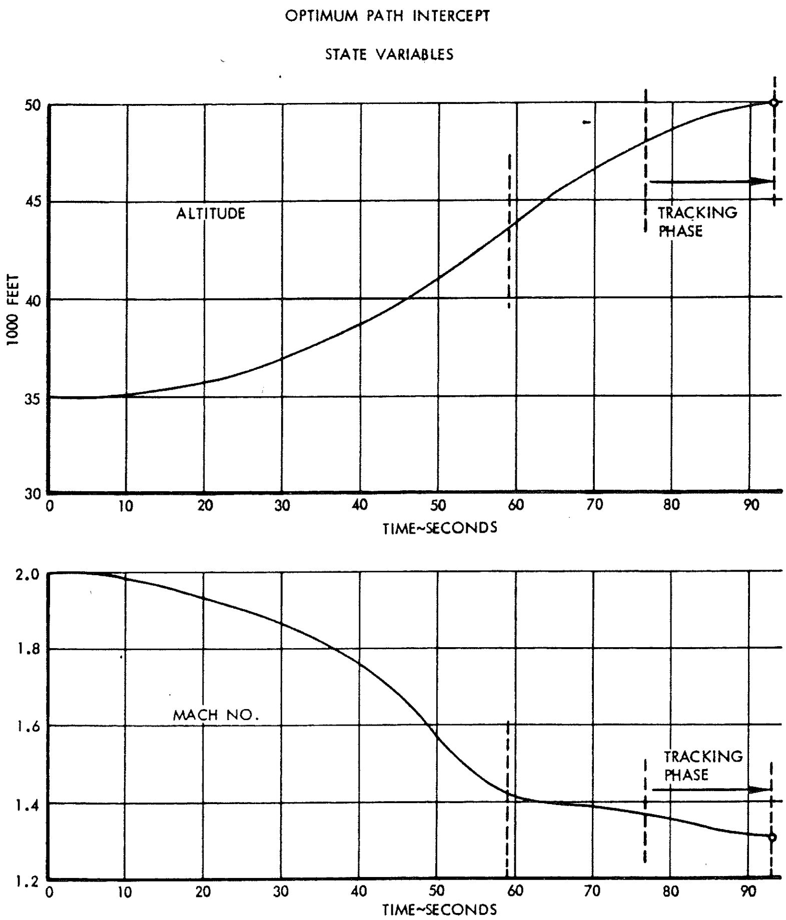
STATE VARIABLES



An impressive result of our constant scheduling of the control variables is the smooth 3 degrees/second change of heading angle from 0^{o} to 175^{o} and then a smooth roll-out to complete the 180^{o} turn. Our flight path angle also has an extremely steady rate of increase up to 11 degrees at 55-seconds into the turn, where we start the roll-out.

> "What is the reason for that hump in the flight path angle beginning around 55 seconds?"

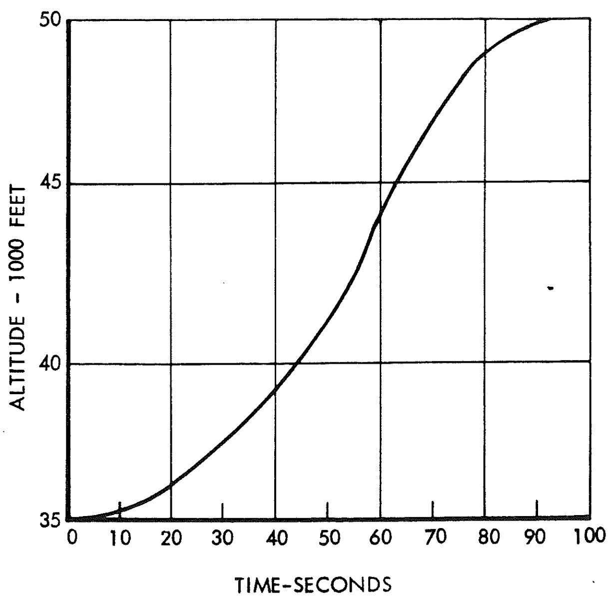
That's simply the transition from the 3-dimensional curved flight path, during the turn, into the 2-dimensional straight ahead climb path after you've rolled out the bank angle. To understand more about all of the state variables during the chandelle, let's go on to the altitude and Mach number plot.

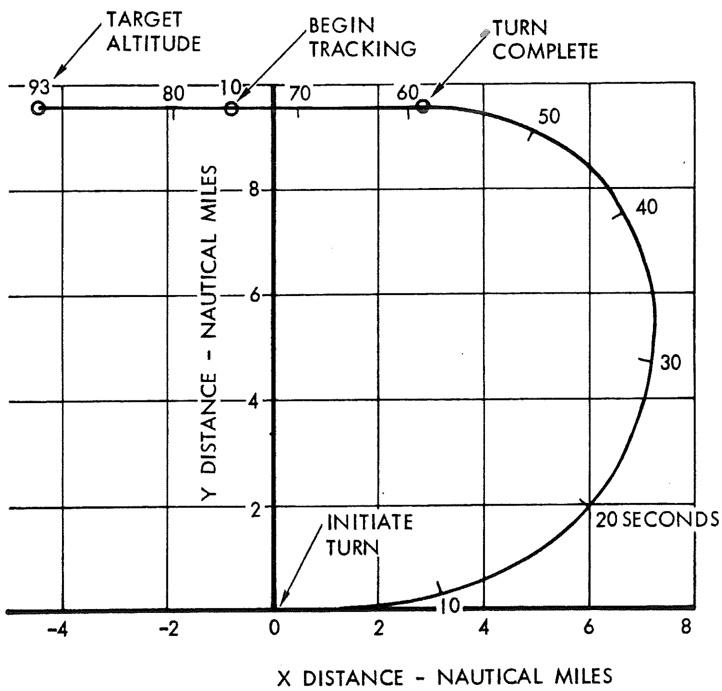


Our Mach decrease has been from Mach 2.0 down to 1.42. This is what we've had to pay for the 3-1/2g schedule during the chandelle. Our altitude gain has taken us up to 43,500 feet at the completion of the 180^{o}. We still have to climb then to arrive in our attack cone and begin the tracking phase. To remain conservative, we've picked the altitude of 48,000 feet as arrival in the attack cone. But do you notice that changing slope of the altitude curve? That means that our flight path angle must be on a decreasing schedule. Looking back at the plot of γ shows how we are smoothly decreasing the flight path angle as we approach the target altitude. Now you can understand the reason for the 0.75g load factor schedule that we have after we've rolled out the 3-1/2g's and the 70° bank angle. If you held 1g, you'd overshoot the target altitude, so you should hold less than 1g to arrive at 50,000 feet and a level flight attitude. My recommendation is to utilize your beep-trimming technique for attitude-altitude matching and you'll have no problem. We arrive at 48,000 feet in 76.5 seconds from beginning the turn and here we start our 1.5 minute tracking phase. At this point, we have an overtake Mach of 1.36 which slowly bleeds off to 1.31 as we level-off at 50,000 feet.

> "Wait a minute, there. If you'll just go back to the 1g E-M plot that you showed me, I find that at Mach 1.3 and 50,000 feet---I'm above my power limited ceiling. Maybe I'm even at a negative P_s value---what about that?"

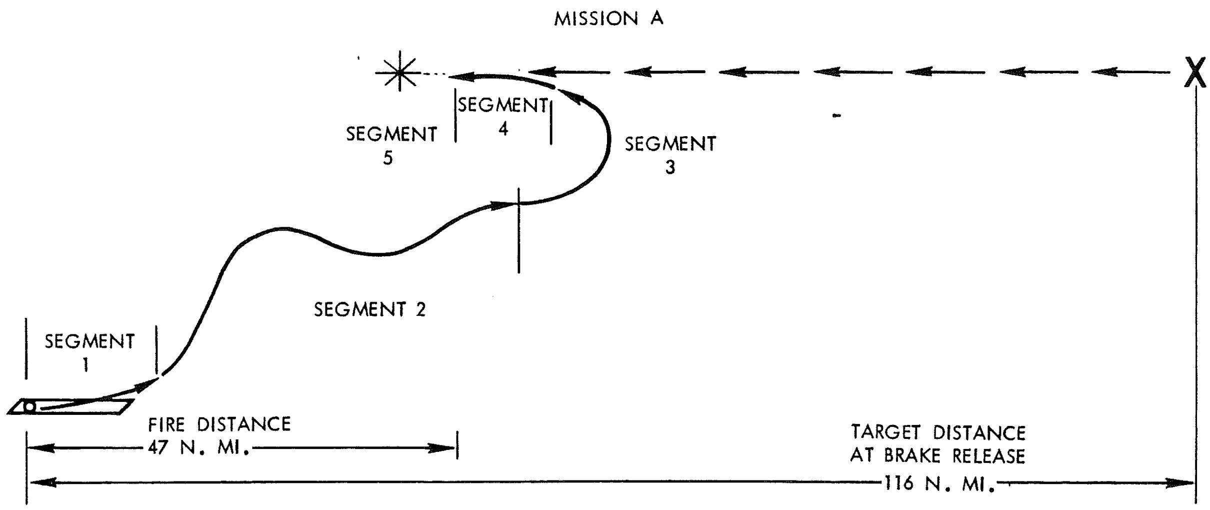
That's alert thinking. But you forgot an important point. That 1g E-M plot reflects the constant weight condition of 19,184 lbs. It shows a static plot then and not the changing weight condition during your profile. The beauty of the IBM is that she's really flying the profile! Every little hunk of burned fuel is immediately subtracted and all the parameters affected by this are upgraded. In fact, the IBM says that at this point on the profile you're still on the positive side of the 0 P_s contour which has climbed in height as our fuel has been expended. You need to maintain full A/B, however, until the missile fire point in order to keep the desired overtake speed. For a real good look at this chandelle, I want you to examine this plot of altitude and the X-Y values.





Look at that, Ace! Our offset distance is only 9.6 nautical miles! And we're in the attack cone in 76.5 seconds, so we really haven't lost a great deal by following our simpler, constant value bank angle and load factor turn versus the complicated scheduling of the optimum turn by the computer.

From the point where you arrive at 48,000 feet, you now have 1.5 minutes of tracking until you fire the missiles. After missile firing, you still have enough fuel to continue with a gun attack, if necessary. In any case, your distance out from home base coupled with your altitude make the remainder of the mission calculations rather academic since in this case there is no critical fuel criteria for recovery. I know you're interested in all the details of this profile, so we've listed the data by segments and in sequential total value columns. Here it is:



	SEGMENT	INITIAL WEIGHT	INITIAL ALTITUDE	INITIAL MACH	SEGMENT TIME MIN.	SEGMENT DISTANCE N. MI.	SEGMENT FUEL LB.	TOTAL TIME MIN.	TOTAL DISTANCE N. MI.	TOTAL FUEL LB.
1	T.O. & ACCEL TO CLIMB SPEED	21,224	0	0	.60	2.0	450	.60	2.0	450
2	CLIMB & ACCEL TO MACH 2.0	20,774	2000	.52	4.92	65.6	2766	5.52	67.6	3216
3	TURN INTO ATTACK CONE	18,008	35,000	2.0	1.20	-0.8(NET)	526	6.72	66.8	3742
4	TRACK FOR 1.5 MINUTES	17,482	48,000	1.36	1.50	-18.9	275	8.22	46.9	4017
5	FIRE MISSILES	17,207	50,000	1.30		FIRE!				

The summation analysis of this mission is pretty astounding. An intruder can be as close as 116 nautical miles and flying at 50,000 feet and 0.9 Mach at the time when you release the brakes. But, you can still fire on him at 46.9 nautical miles out in just 8.22 minutes---IF YOU OPTIMIZE THE ACCELERATION PATH AND THE TURN. How about that, Ace?

"I'm some impressed---but suppose that I was faced with an intruder that has a stand-off missile and my requirement is to fire at him when he's still over 100 nautical miles out. How could I do that? "

Mainly by following our Mission B profile. Why don't we list the segments of this profile and examine the other end of our Air Defense spectrum---that of maximizing the distance while minimizing the time. Here's Mission B:

Segment 1: Takeoff and accelerate to climb speed.

Segment 2: Combined climb and ARPS acceleration path to Mach 2.0 and 35,000 feet.

Segment 3: Mach 2.0 cruise to offset point.

Segment 4: Turn from offset point into the attack cone.

Segment 5: Attack cone phase of 1.5 minutes to missile firing.

Segment 6: Fire missiles.

Segment 7: Descent to optimum cruise altitude.

Segment 8: Cruise to descent point.

Segment 9: Descent and recovery.

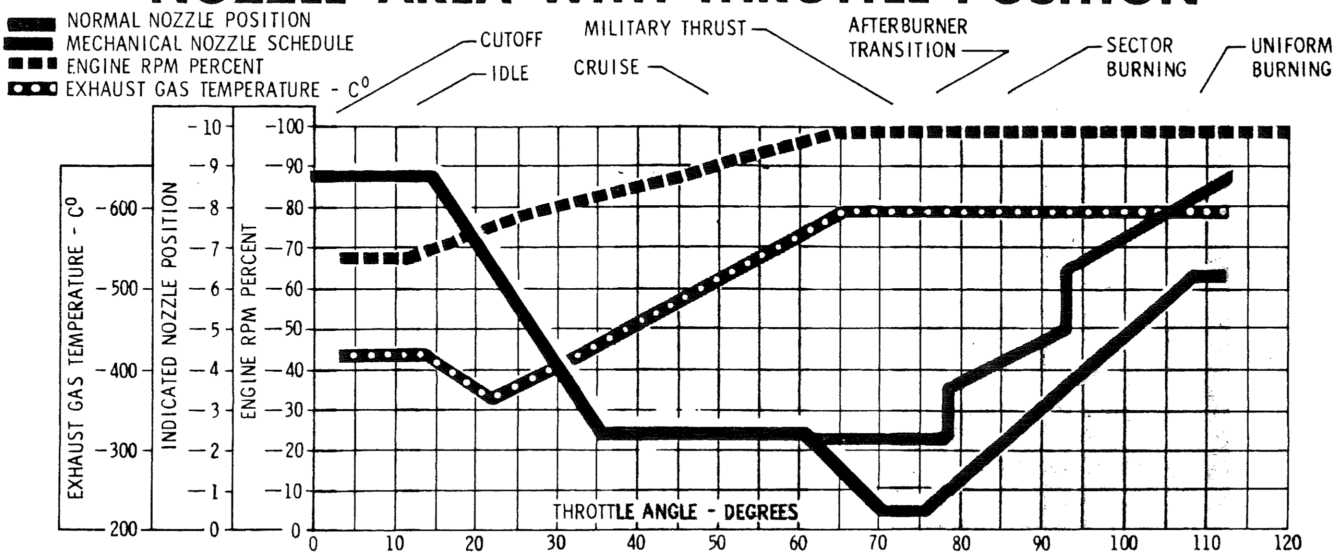
For this mission, segments 2, 3 and 4 correspond to steps 3 and 4 of our basic intercept profile. Because we're maximizing distance, we'll use the high altitude ARPS path for acceleration. This path gives us a savings in fuel at a slight cost in time, versus the low altitude path, that we can use for added range. I don't think that I need to describe the acceleration path or the turn from the offset point as I've covered them already. In between these segments, though, we now have a supersonic Mach 2.0 cruise segment. This is to fulfill the philosophy of our mission.

"I got a question about that. The Handbook* has a series of curves shown in figures A9-97 through A9-107 for Afterburning Cruise Performance. But I don't have any idea about the throttle position required for this Mach 2.0 cruise. Can you tell me about that? "

Be glad to. And to help you with this problem, let's reproduce Figure 1-30 from the Handbook* since it gives us throttle angle versus various engine parameters.

*Reference 1.

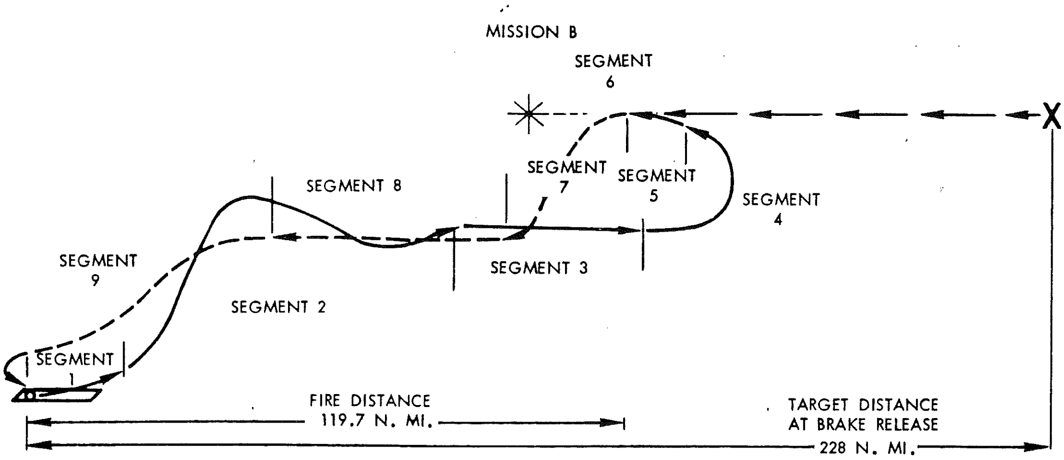
VARIATION OF ENGINE RPM , TEMPERATURE AND NOZZLE AREA WITH THROTTLE POSITION



This figure shows you the throttle angle span from idle to maximum A/B. You've undoubtedly studied this figure before and noted the nozzle changes from Military power to minimum A/B and from secondary sector burning to primary uniform burning. But it too is limited, in that it does not correlate any fuel flow for certain throttle angles. So that the computer could take into account the varying thrust levels from the engine, we installed an engine deck that the computer can utilize to figure thrust and total fuel flow amounts for the different A/B quadrants. This is a tabular listing of the four A/B quadrants for Mach 2.0 and 35,000 feet.

Afterburner Quadrant	Throttle Angle-degrees	Installed Engine Thrust-lbs.	Total Fuel Flow-lb/hr.
Maximum A/B	113	15,124	33,346
Primary Uniform	101	13,401	28,239
Secondary Sector	90	11,111	23,131
Minimum A/B	78	9,010	18,023

To initially maintain your Mach 2.0 cruise, our calculations indicate that you need the output thrust of the Secondary Sector stage of A/B. From figure 1-30, the 90° throttle angle can be found by retarding the throttle from full A/B to just below the switch-over point from uniform to sector burning. From this initial throttle position, you simply make any minor adjustments required to maintain Mach 2.0---got it? OK, as you approach your offset point, though, you should remember to push the throttle back up to full A/B as you roll into the turn. The turn and tracking for Mission B is the same as for Mission A. But since we're down to a lower fuel state after missile firing, we'll have to return to base with optimum cruise conditions. How about looking at our layout of Mission B?



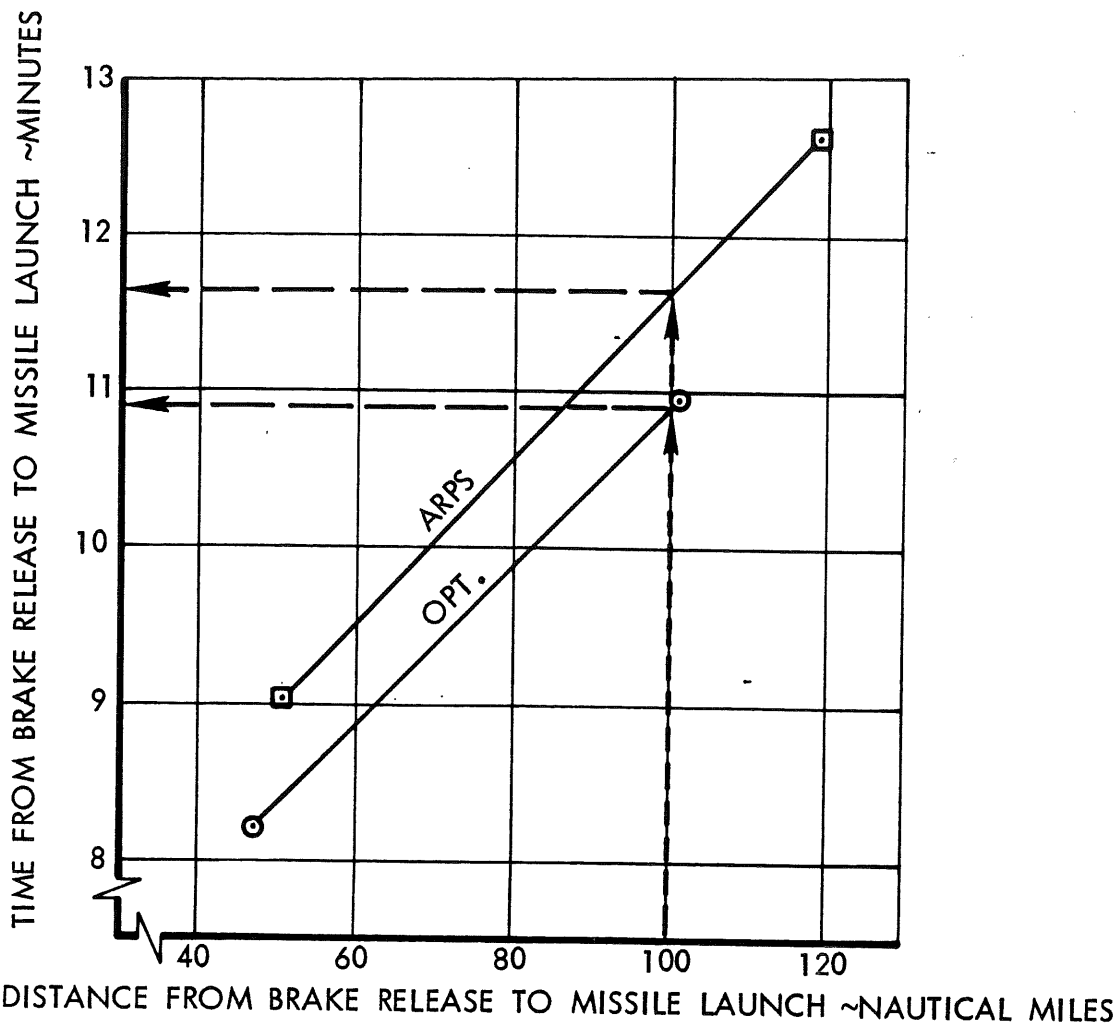
				SEGMENT			TOTAL		
SEGMENT	INITIAL WEIGHT	INITIAL ALTITUDE	INITIAL MACH	TIME MIN.	DISTANCE N. MI.	FUEL LB.	TIME MIN.	DISTANCE N. MI.	FUEL LB.
1 T.O. & ACCEL TO CLIMB SPEED	21,224	0	0	.60	2.0	450	.60	2.0	450
2 CLIMB & ARPS ACCEL TO MACH 2.0, 35000 FT	20,774	2000	.52	5.76	68.3	2339	6.36	70.3	2789
3 MACH 2.0 CRUISE TO OFFSET POINT	18,435	35,000	2.0	3.59	69.1	1452	9.95	139.4	4241
4 TURN INTO ATTACK CONE	16,983	35,000	2.0	1.20	-0.8(NET)	526	11.15	138.6	4767
5 TRACK FOR 1.5 MINUTES	16,457	48,000	1.36	1.50	-18.9	275	12.65	119.7	5042
6 FIRE MISSILES	16,182	50,000	1.30		FIRE!		12.65	119.7	5042
7 DESCEND TO OPT CRUISE ALT	15,872	50,000	1.30	2.03	-18.0	18	14.68	101.7	5060
8 CRUISE TO DESCENT POINT	15,854	34,600	.89	5.69	-54.7	250	20.37	47.0	5310
9 DESCENT & RECOVERY	15,604	34,600	.87	7.33	-47.0	73	27.70	0	5383

RESERVES: 10 MINUTES LOITER @SEA LEVEL, 441 LBS.

Check these results! If you release your brakes when the target is 228 nautical miles out, you'll fire at him at 119.7 nautical miles out and in just 12.65 minutes! This mission truly epitomizes the results of optimizing our intercept profiles. Agreed?

> "I'm sold. Say, Snake---something in my headbone tells me that there should be an area of overlap between Missions A and B. In other words, don't I have the option of using the low altitude optimum path or the high altitude ARPS path if the target range at brake release is between the extreme ranges that you used in Missions A and B?"

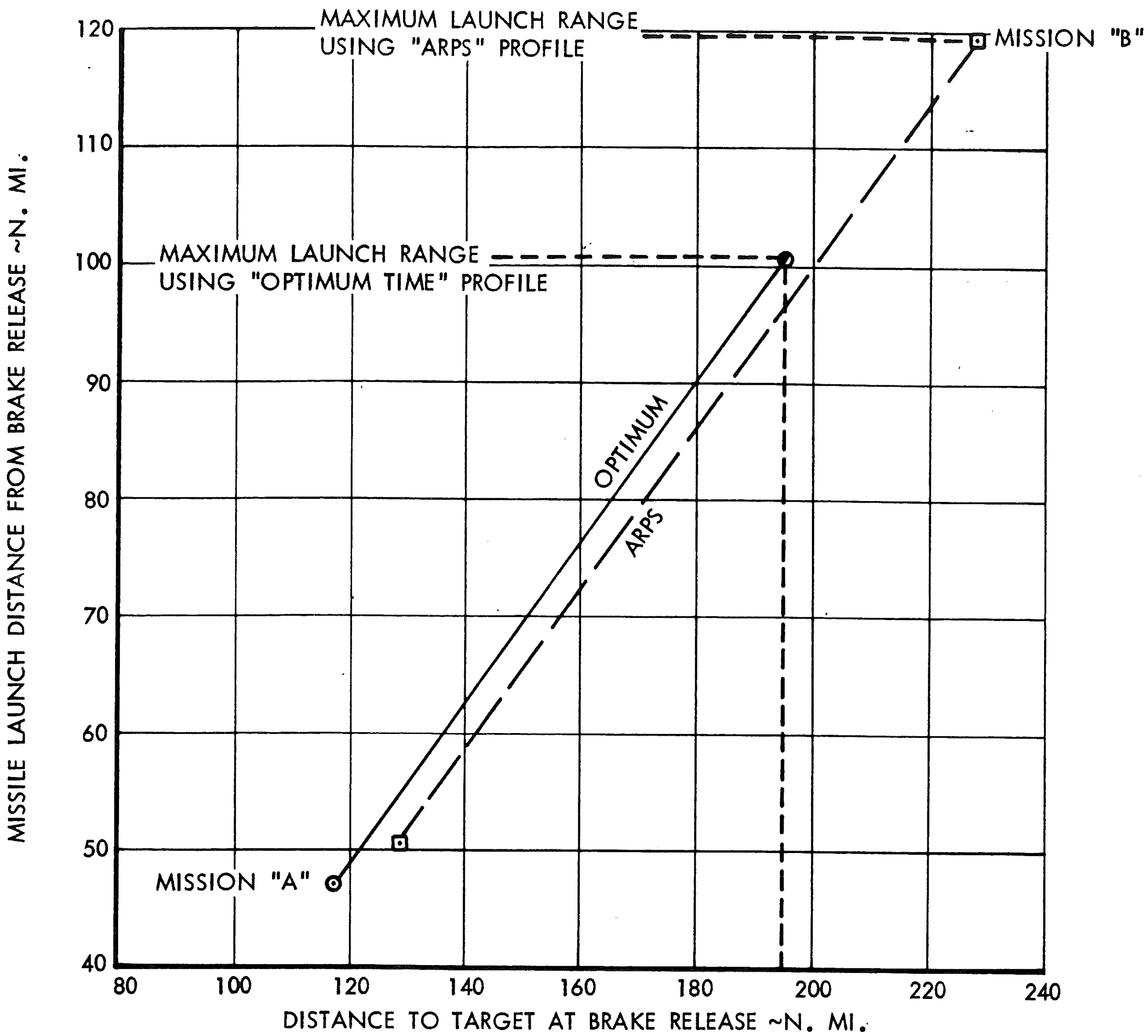
Sure. We can show you this by a plot of time from brake release versus net distance from brake release to missile launch. Here it is:



This plot tells us that any missile launch distance between 51 and 100 nautical miles out is a range where you can fly either acceleration path and still splash the target. But you can see that for the same missile firing range, within this bracket, the ARPS path takes about .75 minutes longer than the optimum path. This is because the optimum path will get you to Mach 2.0 faster and then you cruise out to the offset point at Mach 2.0. Beyond a missile firing range of 100 nautical miles, however---you have no choice. You must fly the ARPS path in order to gain the required added range.

> "But when could I make the decision as to which path to fly and how could I make it?"

For that, let's examine a plot of missile launch distance from brake release versus distance to target at brake release. This plot should give us the answers.



Here you see that if the GCI reports that the target range is more than 195 nautical miles as you roll down the runway, then you should automatically plan on the ARPS path. If the target range is less than 128 nautical miles---again, you got no choice---you should definitely fly the optimum path. Now let me qualify this statement. Our plot shows that for any target distance at brake release between 128 and 117 nautical miles, you can missile fire at 50.4 and 47 nautical miles respectively, whenever you fly the optimum path. If you fly the ARPS path for acceleration when the target is less than 128 nautical miles, you will be forced into a longer tracking time than 1.5 minutes to the missile fire point. This is because you will be further behind the target after roll-out of the turn and you will use more time and distance to catch the target. It's conceivable that he might even be back over your air base---so you'd better fly the optimum path under these close target ranges.

For the ranges where the two paths overlap, you can check that by flying the optimum path, you will be about 4 nautical miles further out at fire point versus the ARPS path. Again, this is due to a longer segment of Mach 2.0 cruise whenever you fly the optimum path. All squared away?

"No---I got another question. It appears to me that you've been talking all along about a single ship attack against this intruder. But what if I complete the turn and just as I'm about to fire, this bomber jock takes an evasive maneuver with a hard bank? At that high altitude and only 1.3 Mach, I might not be able to pull enough g's to track him and fire---what then?"

First of all, you got me all wrong, Ace. I have not limited the optimization to just one interceptor. And as for your question---have you forgotten about SURE Lecture 6 and our study of Riccioni's Double Attack System? Here is a beautiful case just made to order for it. Remember the basic theme that Riccioni expounds?

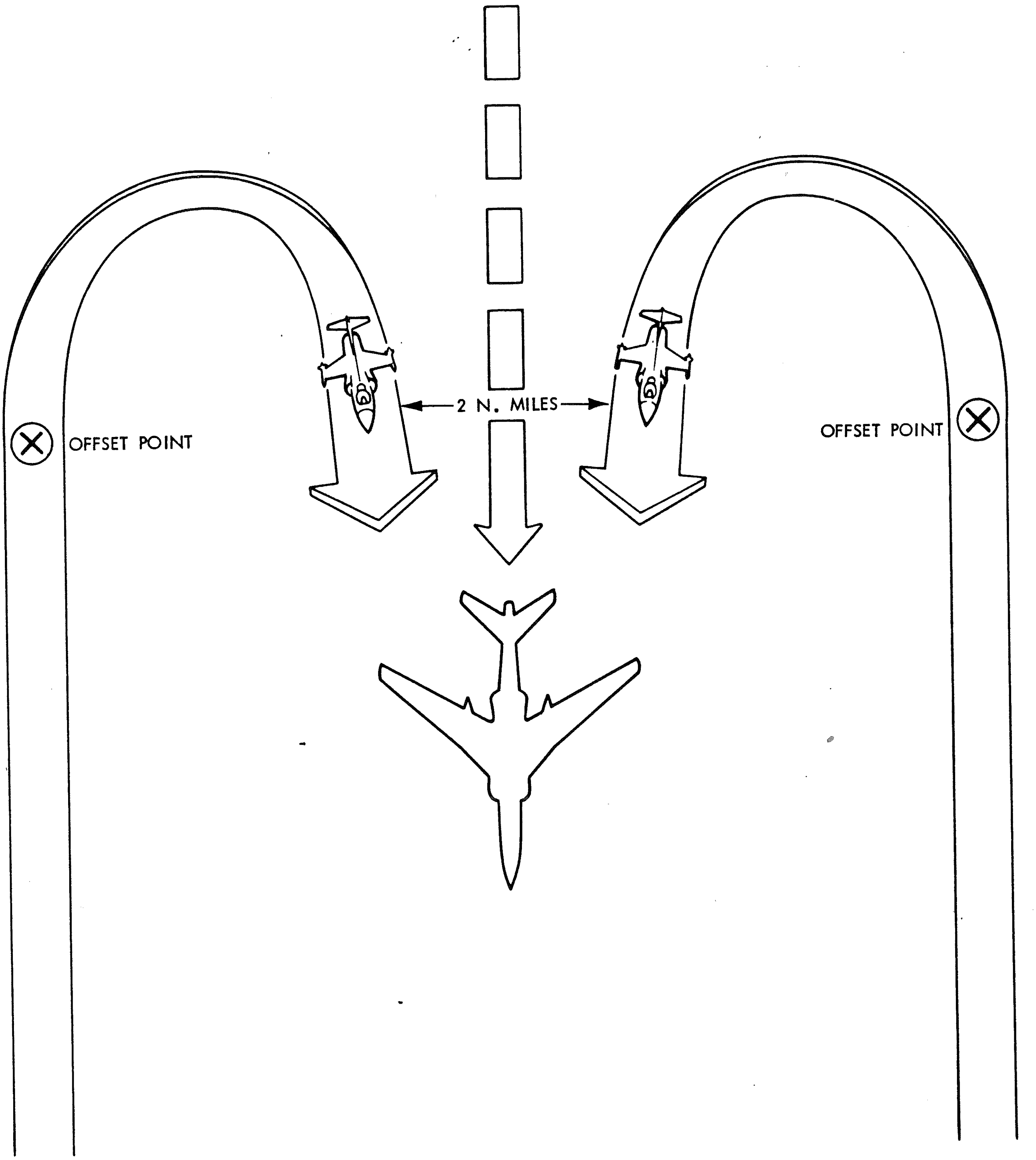
"Brief me again."

OK. To put it short and sweet---all fighters use maximum power during attacks. They fly individual, maximum-maneuver paths, but while flying different maneuver paths---they do <u>not</u> act independently. They are tied together by their common target and their radios.* In the case of our intruder, the proper tactical deployment of our F-104's would be to definitely scramble two birds. But the GCI would direct them on two paths so that at their offset points, they'd be on opposite sides of the bomber.

"Opposite.......?"

Naturally. From these opposite offset points, they both make climbing turns so that they end up in the pincer attack position as shown on page 69 of SURE Lecture 6. This sketch will show what I mean:

*Reference 7, pp. 172 - 185


2 N. MILES
OFFSET POINT
OFFSET POINT

Now you've got him cornered. I haven't mentioned anything about the tactical possibilities of evasive turns of the target while you're out-bound. But again, you can imagine the potential countermoves by the interceptors---if they're sent outbound on both sides of the target's inbound track. Even though many tactical units flying the F-104's around the world have adopted the DAS for ACM (Air Combat Maneuvering), I'm convinced that we haven't even begun to penetrate the envelope of tactical capabilities of the DAS. It can readily be incorporated into the Air Defense role along with the optimization of the intercept profiles---what you got to lose?

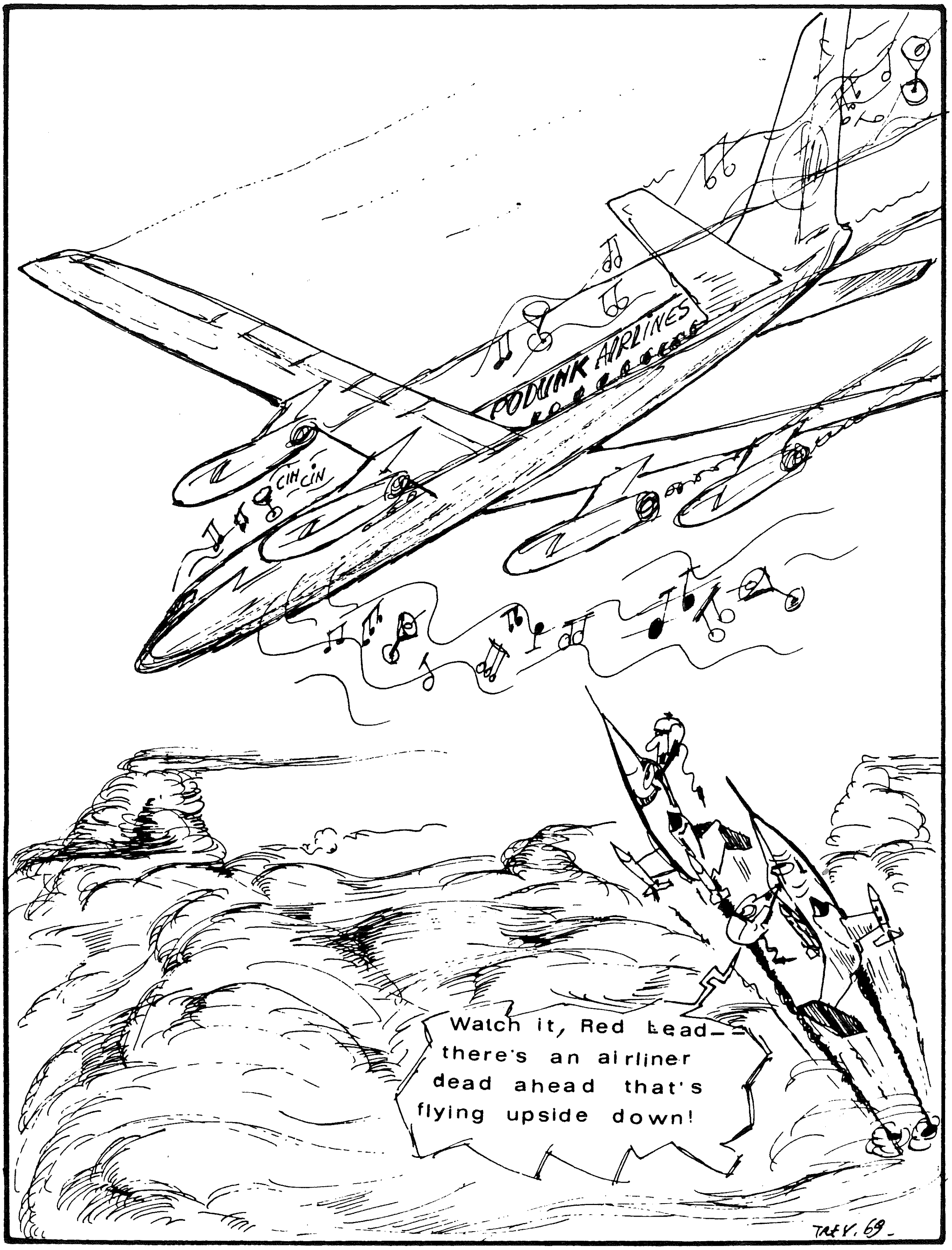
> "Say---how about some profile comparisons so I can see how much I'll gain by optimizing steps 3 and 4?"

I knew you'd ask me that. But this time I'm forced to disappoint you, Ace, because there just ain't no way to compare the optimized steps of our profiles to what you're doing now. It's the case of apples to oranges and there's no basis for valid comparison, because of our different approaches to steps 3 and 4. How about you accepting a challenge, though? You take your intercept methods for a 0.9 Mach target at 50,000 feet and the ranges that we've used and fly your present, standard profile and see how you stack up to the results of our recommended optimization profiles. <u>It may be a real eye-opener to you.</u>

In summary, I believe that you have to agree with me that with the results of Missions A and B, we have achieved the maximum expected output of man and machine. There are, of course, intercept profiles too numerous to mention in this short study and we've only applied the optimization philosophy to two "canned" intercept problems. But the application of optimization to <u>any</u> intercept problem yields results too important to ignore. Any possible decrease in required time and any possible increase in distance out at the fire point must be relentlessly pursued. To do less would be dereliction on our part. Quite simply put---you have the weapons system and the assigned mission. We, at Lockheed, have the computer that can help you to optimize your F-104 intercept profiles. Why don't we get together?

> "What should we do?"

I would suggest that your first step should be a conference with your GCI experts to learn just what their "constraints" are in relation to controlling you on maximum performance missions. Target blip size on skin-paints, accuracy of height finding gear---all of the problems should be analyzed by a Task Group. Once you've outlined the profile requirements, then negotiations with Lockheed can result in the IBM giving you detailed flight paths that you can fly and practice to perfection so that you can get your bogies in minimum time and maximum distance out. I'll ask you again, Scramble---Anyone?



..........................FIND ALL THOSE AIRLINERS THAT ARE OFF-COURSE BECAUSE THE CAPTAIN IS FLIRTING WITH THE STEWARDESS.

CONCLUSION

It is not inconceivable that in the near future, Interceptor pilots will receive automatic guidance for maximum optimization of man and machine capabilities. Since no computer can ever replace the fighter pilot in the cockpit---you will always be there, Ace. The ability to survey the battle scene and make the critical judgment to fire will always be yours.

Lockheed's development of the F-104S which exploits the head-on attack capability of the Sparrow missile yields yet another highly fruitful area of optimization study. The combination of optimized profiles and forward hemisphere attack will increase the effective envelope twofold. Maximized distance out will increase by the addition of the missile range to the aircraft range. Also, the intruder can be even closer in at scramble time and the minimum-time, minimum-distance head-on launch of the Sparrow can still negate the accomplishment of his mission. With the supplemental Sidewinder armament, the F-104S will have an air defensive capability second to none. But remember Ace, that in terms of air warfare, a perfect weapons system utilized in an imperfect manner will only yield imperfect results. You must ever strive for optimization.