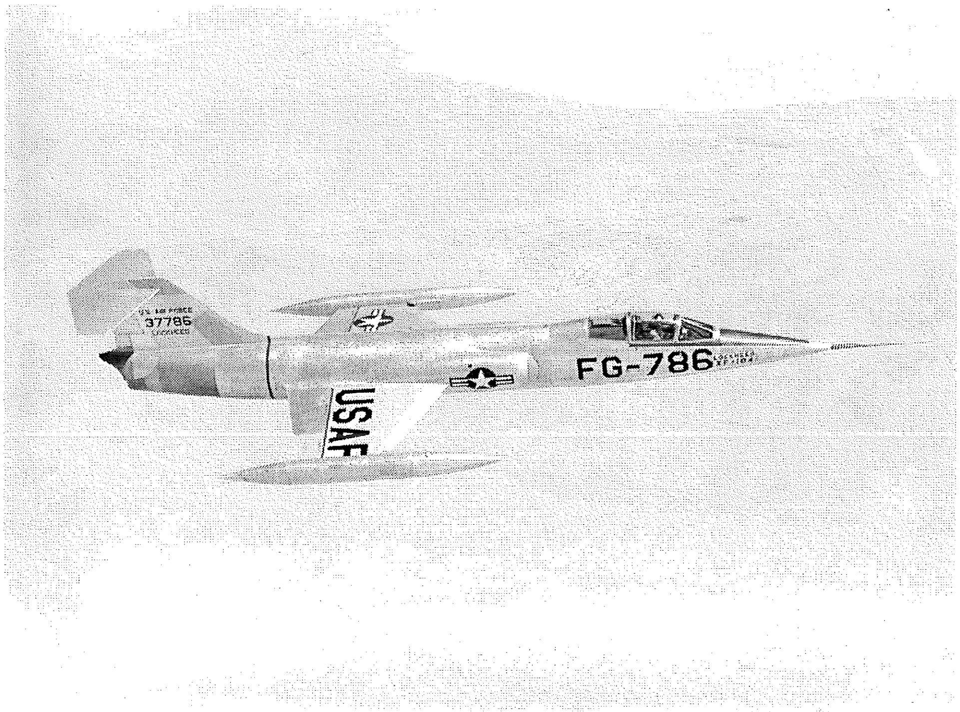
The SURE Project



Lecture – 6/10

STARFIGHTER UTILIZATION RELIABILITY EFFORT

LECTURE 6

THE ENERGY MANEUVERABILITY CONCEPT AND RECOMMENDED AIR COMBAT TACTICS FOR THE F-104

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

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FOREWORD

Ever since that first dogfight occurred, somewhere in the skies over France, arguments and confusion have highlighted discussions about Air Combat Tactics. Due to the fluid dynamic situation of aerial combat, ACT have never remained completely "static" for any prolonged period of time. It is true that between armed conflicts wherein successful ACT were developed at the expense of life and machines, certain earth-bound theorists have attempted to turn Doctrine into Dogma. But human nature has always instigated another war that bred new weapons and new developments in Air Combat Tactics. Also, technological progress dictates to the professional fighter pilot that he constantly conduct open-minded studies to achieve his mission--to shoot down the enemy! The sincerely dedicated fighter pilot knows that not only skill in flying but well planned tactics are his prime tools of trade. Skill can only be acquired by flight experience, but tactics and planned maneuvering begin with study while still on Terra Firma. All studies and planning, however, are limited in scope and cannot cover all possible situations in aerial combat. But, by putting ourselves in "canned" situations and studying the possible tactics, we can prepare ourselves to evaluate situations as they develop. A distressing fact about current literature and training methods is that both are <u>outdated and obsolete</u>. All defensive and offensive maneuvers are based on the assumption that the two competitive aircraft have nearly equal performance. This can result in a revolting development such as training a pilot in a Mach 2.0 fighter to engage a Mach .9 fighter with maneuvers that are strictly advantageous to the slower aircraft. We all know that aerial history is laced with exploits of smart, aggressive pilots overcoming performance deficiencies and shooting down aircraft that have superior performance. Therefore today's tactics and training directly commit a cardinal "sin" of the Rules of Engagement: <u>Do not engage an enemy on his terms</u>.

At the beginning of the large jet aerial battles in Korea, a comparison of the Mig-15 vs. the F-86 led many theorists to prophesy a high Mig-15 kill ratio over the F-86. But past history that was spelled out in those long vanished contrails over the Yalu revealed the error of their thinking. They neglected the most important factors of all--individual pilot courage and skill. Yet the Mig-15 pilots committed the greater error--they engaged the F-86's without taking proper tactical advantage of their superior rate of climb and higher flight ceiling. Too often we look at our opponent's past weaknesses and fall prey to the assumption that our opponent is neither as skilled nor courageous as we are and that he will not fly his aircraft to its maximum. This is fallacious thinking and should be avoided. Any study of ACT should assume just the opposite and that is my posture in this lecture.

In researching information for this lecture, I have discovered two forward thinking tacticians. They are Maj. John R. Boyd and Lt. Col. Everest E. Riccioni of the USAF. Maj. Boyd has done extensive work in performance comparisons and is the leading exponent of the Energy Maneuverability concept. Lt. Col. Riccioni is a thinking-man's fighter pilot, discoverer of and erudite proponent of the Double Attack System.

So that you will be able to properly utilize all of the capability that exists in the F-104, this lecture has been written to answer the questions:

What is Energy Maneuverability?

How can you apply Energy Maneuverability in Air Combat Tactics?

Why does Energy Maneuverability used with the Double Attack System give you the greatest effectiveness in fulfilling your mission?

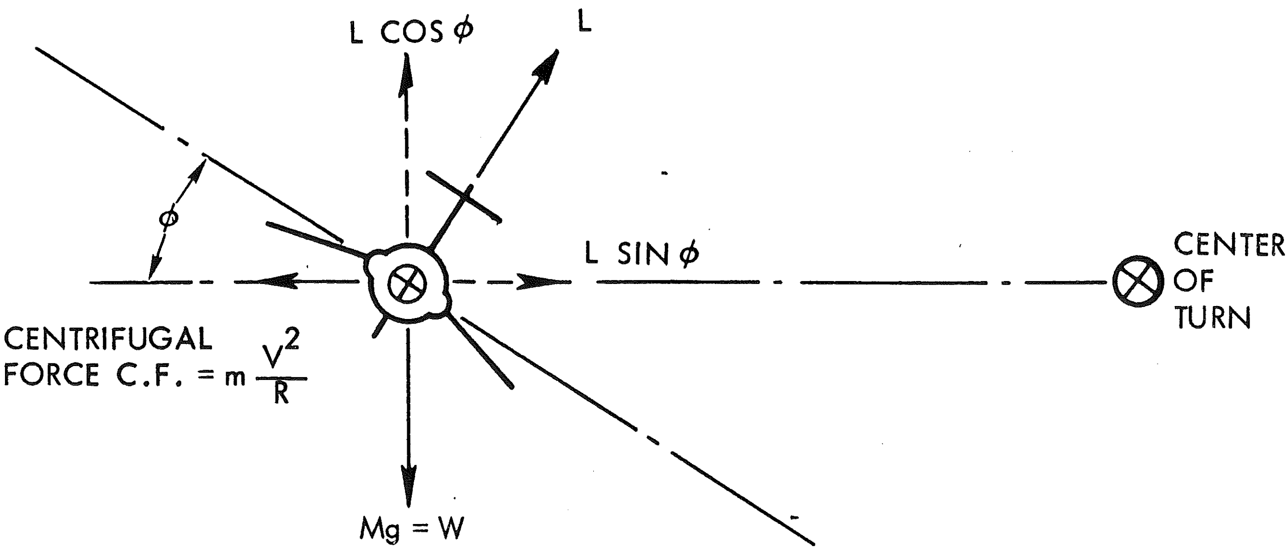
SECTION I

Aircraft Maneuverability in relation to Air Combat Tactics

When you search among fighter pilots for a definition of aircraft maneuverability, you will encounter many terms used to describe this characteristic. Roll rate, pitch rate, wing loading, available thrust, induced drag, turn radius and g capability. From historical records it appears that in the opinion of fighter pilots in World War I and up to the end of World War II, g capability, or turn radius, was their important criteria for aircraft maneuverability. For the combat pilots of those times, just a small advantage in turning was all-important. First, tight turning as a defensive maneuver to lose the attacker and on offense, to pull that slight lead angle needed to "score" when you were on the opponent's tail in a Lufbery. With relatively equal performing aircraft, a turn advantage will always be important if the engagement is one of turning maneuvers. It was not until the closing days of World War II when the ME-262 suddenly appeared that "turn capability" lost its predominance and climb rate along with higher speed became the overpowering factors in the combat picture. Immediately after World War II, the important lessons of higher performance vs. low speed turn capability were forgotten. With the introduction of jet fighters around the world, the schoolroom tactics and flying training again settled into a mold that was based upon aircraft with comparable performance capability. Therefore, turn radius once again assumed a tactically important characteristic for aircraft maneuverability. Korea did not upset the tactician's thinking about the requirement for turn advantage. And even up to today, many pilots are primarily interested in how many g's they can pull at various speeds and altitudes. This type of information is given in all fighter handbooks in V-g plots and they are supposed to depict turn capability in a manner consistent with the pilot's background training and his cockpit instrumentation. But, I will now show you how this diagram, while interesting, is worthless in planning ACT.

Suppose you want to compare the turn radius of different fighter aircraft in order to develop tactics. The first thing we must do is to derive the equation for turn radius. This can be done by drawing our Starfighter in a turn and summing up the forces acting on the aircraft.

TURN AT CONSTANT ALTITUDE AND CONSTANT SPEED



Let: ϕ = Bank Angle
- L = Airplane Lift
- V = Velocity
- m = Airplane mass, $\frac{W}{g}$
- g = Acceleration of gravity
- a_n = Normal load factor
- W = Airplane weight
- R = Turn radius

Summing up the vectors and solving for turn radius as a function of bank angle and velocity, we find:

$\Sigma F_x = 0$, i.e. the summation of forces in the horizontal plane equals zero

$$\text{C.F.} - L \sin \phi = 0, \text{ or C.F.} \left(\frac{mV^2}{R}\right) = L \sin \phi$$

$\Sigma F_y = 0$, i.e. the summation of forces in the vertical plane equals zero

$L \cos \phi - W = 0$, or $L \cos \phi = mg$, and--

$$\tan \phi = \frac{L \sin \phi}{L \cos \phi} = \frac{m\frac{V^2}{R}}{mg} = \frac{V^2}{gR} \qquad \text{Therefore: } R = \frac{V^2}{g \tan \phi}$$

And, by definition, normal load factor is the ratio of airplane lift to airplane lift required for level flight. So --

$$a_n = \frac{L}{L \cos \phi} = \frac{1}{\cos \phi} = \sec \phi, \text{ so } a_n^2 = \sec^2 \phi, \text{ and--}$$

$$(a_n^2 - 1) = (\sec^2 \phi - 1) = \tan^2 \phi, \text{ or } \tan \phi = \sqrt{a_n^2 - 1}$$

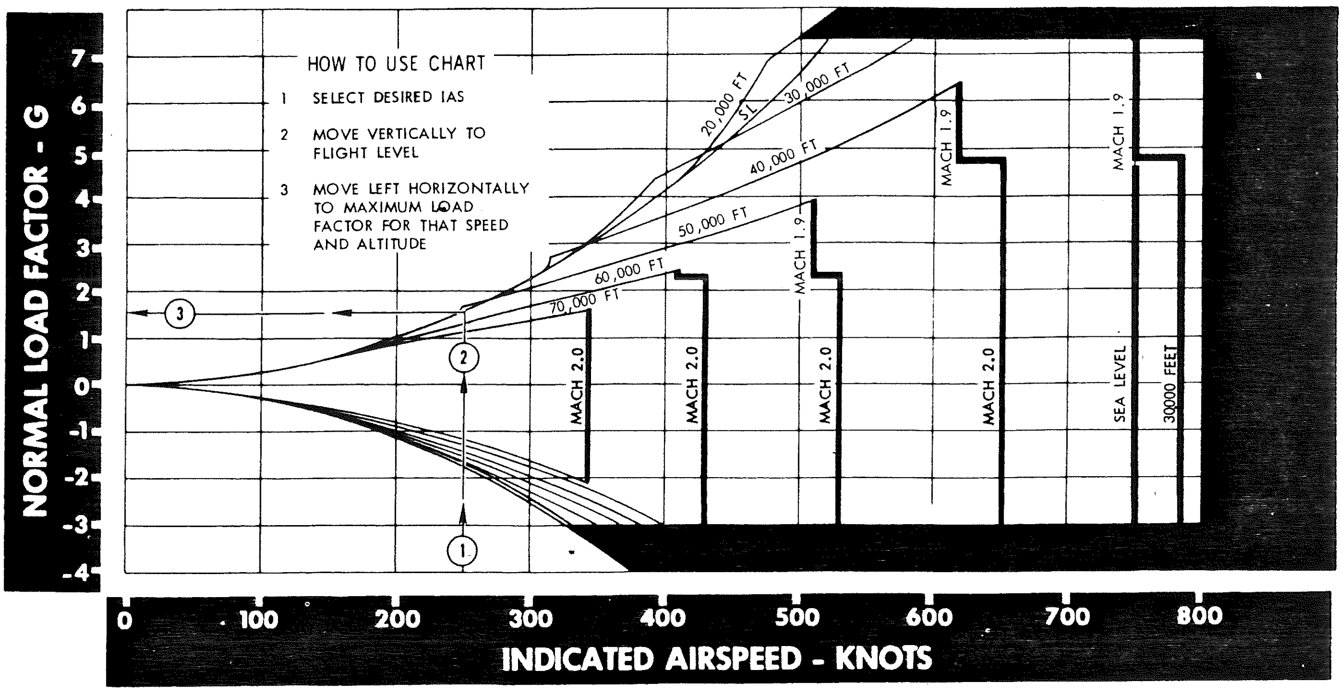
Now, by substituting this expression for Tan ϕ into our equation for turn radius, we have --

$$R = \frac{V^2}{g\sqrt{a_n^2 - 1}}$$

This equation now expresses turn radius as a function of our normal load factor. It appears that now we can go into our V-g diagram in the handbook and solve for turn radius at various speeds and altitudes. For illustration purposes, let's look at a V-g diagram reproduced from the F-104 handbook. *

OPERATING FLIGHT LIMITS F/RF

FOR SYMMETRICAL FLIGHT IN SMOOTH AIR — GEAR AND FLAPS UP
NO EXTERNAL LOAD WITH LESS THAN 5500 POUNDS FUEL REMAINING WITH EXTENDED RANGE FUEL TANK INSTALLED
(4000 LB WITH GUN INSTALLED)
SEE FIGURES 5-7 AND 5-8 FOR ACCELERATION LIMITS AT OTHER LOADINGS



*T.O. 1F-104G-1, dtd 30 April 1966

First of all, I think you will notice that this diagram is quite complex. Not only are there multiple, overlapping altitude lines, but the progressive limits to the right show how the maximum allowable speed is diminished due to the decrease in directional stability level for increasing angle of attack. The sudden step change on the Mach 2.0 lines down to Mach 1.9 is that same point of minimum desired directional stability level that I discussed with you on pages 15 and 16 of SURE Lecture 1.

The next shortcoming of the V-g diagram is its failure to show any effect of maneuvering flaps. And finally, the clincher is that any normal load factor read from this diagram and put into our equation --

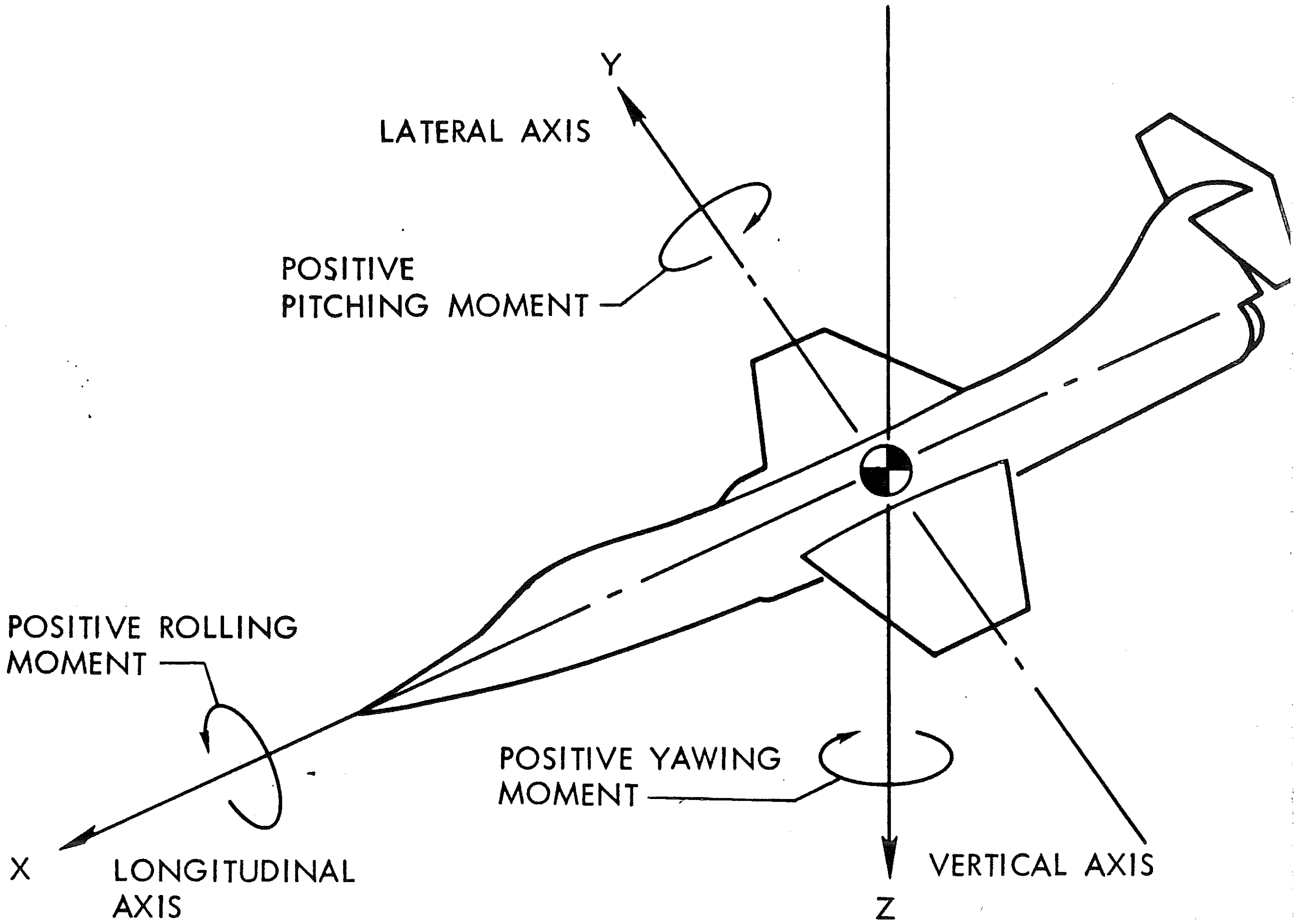
$$R = \frac{V^2}{g\sqrt{a_n^2 - 1}}$$

will only give a relative measure of <u>INSTANTANEOUS MANEUVERABILITY</u>. Any effect of pulling sustained load factors and losing or gaining altitude is not shown on the V-g diagram. For ACT planning, you must be able to analyze the effects of <u>SUSTAINED MANEUVERING</u>. Therefore, we have to refer to Maj. Boyd and his studies and refinements of the Energy Maneuverability concept.

SECTION II

Energy Maneuverability Theory

Maneuverability, in its purest sense, is the ability of an aircraft to translate along 3 axes and rotate around each of these 3 axes, thereby giving the aircraft a theoretical 6 degree of freedom capability. This definition can be illustrated by our drawing of this axis system.



In realistic terms, maneuverability in combat is the capability for proper positioning of our fighter in a spatial relationship to the opponent's position. First, we want to be able to position ourselves, in a manner that will obviate any attacking thrust of the opponent and second, we want to be able to initiate and carry out an effective attack against the opponent. To accomplish this positioning, we must primarily have the ability to change the direction and magnitude of our velocity vector. Therefore, our interest in maneuverability, as applied to ACT, does not encompass all of the theoretical 6 degrees of freedom. The degree of success in our positioning depends upon how efficiently we change the direction and magnitude of our velocity vector. This means that we must know the optimum paths for our positioning. For this, we have to look to Maj. Boyd's applications of an old, well-used aerodynamic equation. This equation has been used for many years but was never conceived of as a key to maneuverability studies until the foresight and imagination of Maj. Boyd resulted in the Energy Maneuverability concept. To understand the E-M theory, you will have to follow me as I explain the mathematics and the laws of physics as they apply to energy.

First, the definition of energy: Energy is defined as the ability to do work. The work required to stretch a spring is stored up as potential energy in the spring. The important principle of the conservation of energy merely states that in any system comprised of a body or system of bodies, the total amount of energy will remain unchanged if the system is neither giving up nor receiving energy. The energy may be transformed from one form to another, such as chemical energy to heat and light energy, but the total amount of energy in the system will remain unchanged. Gravitational Potential Energy is the energy a body has because of its position. Lifting a mass above the surface of the earth stores potential energy in the body, since the pull of gravity drawing the body back to the earth's surface is capable of being used to do useful work. The measure of the potential energy which a body has by virtue of its position is equal to the work spent in lifting the body. The increase in potential energy of a 500 pound weight lifted 10 feet in the air, for example, is equal to 5,000 foot pounds as shown:

Potential Energy = Work spent lifting the weight

P.E. = Force x Distance = Weight, lb. x Height, ft.
P.E. = 500 lb. x 10 ft. = 5,000 ft. lbs.

So in the case of air vehicles, we can see that balloons, helicopters and vertical rising machines are able to achieve levels of pure gravitational potential energy. Such is not the case with our F-104. As we know, we are always in forward motion except before takeoff and after landing. Therefore, while we have gravitational potential energy with our altitude above ground, we also have the energy of our motion. This energy has been defined as Kinetic Energy. The measure of the kinetic energy which a body has by virtue of its motion is equal to the work expended in order to move the body up to a certain speed. In stopping, the body will give up an amount of energy equal to the work done in starting the motion, if losses due to friction, drag and so on are neglected. Thus, the kinetic energy a 500 pound weight would possess because of its velocity of 10 feet per second is 776 foot pounds as shown:

Kinetic Energy = Work spent in accelerating body to velocity V.

$$K.E. = 1/2 \times \text{mass} \times \text{Velocity}^2 = 1/2 \times \frac{\text{Weight, lb.}}{\text{g, 32.2 ft./sec}^2} \times V\ (\text{ft/sec})^2$$

$$K.E. = 1/2\ \frac{500\ \text{lb}}{32.2\ \text{ft/sec}^2}\ (10\ \text{ft})^2 = 776\ \text{ft-lb}$$

One final type of energy that we have in flying the F-104 is rotational energy during our roll maneuvers. Potential, kinetic and rotational are the three types of energy that exist while maneuvering the F-104. As we will see, the Energy Maneuverability concept only takes into account potential and kinetic energy as these values greatly overshadow any contribution of rotational energy. Summing up then, if we want to know our total energy at some defined point within the flight envelope, it can be computed by:

Energy Total = potential energy + kinetic energy

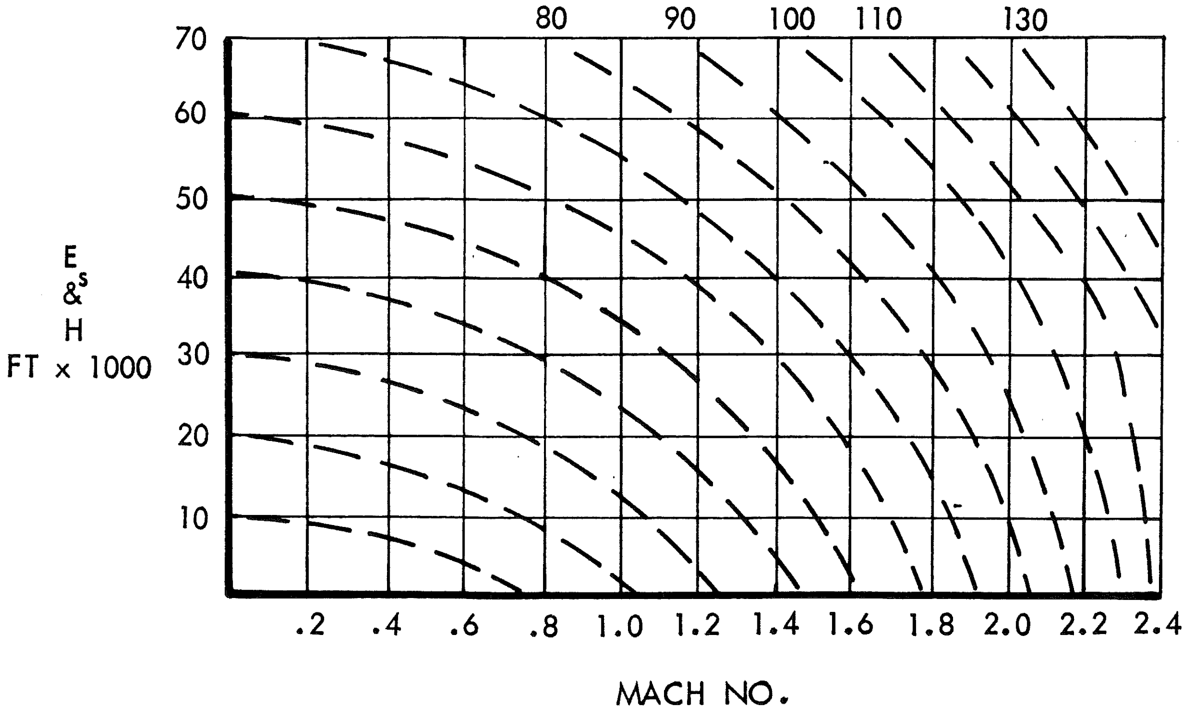
$$E_t = WH + 1/2\ \frac{W}{g} V^2$$

If we divide this equation by the factor of weight, we will have a relationship that is entirely independent of any particular aircraft. Thus --

$$\frac{E_t}{W} = H + 1/2\ \frac{V^2}{g} = E_s$$

This equation is useful in analyzing climbs and accelerations and to deal with energy per pound of aircraft weight. It is called "Specific Energy". The term E_s has units of length only and is often referred to as "Energy Height". This is the height the aircraft could theoretically attain if all of its kinetic and potential energy could be converted to only potential energy. And since this equation is independent of any particular aircraft, we can calculate a series of curves that depict E_s for altitude and Mach numbers. If we pick increments of 10,000 feet E_s, the plot will be:

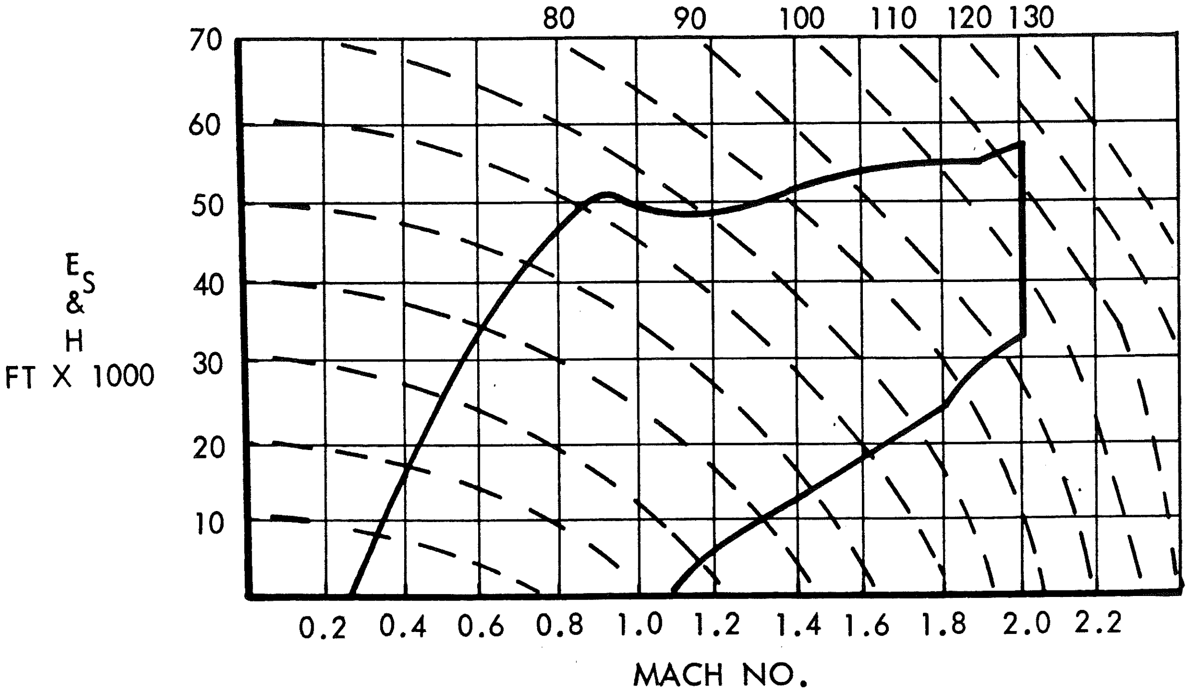
ENERGY HEIGHT CURVES



As the E_s lines start from the left, their values represent pure gravitational potential energy. As the lines move to the right to zero altitude, the values represent pure kinetic energy. In between of course, is the combination of energies, but the lines maintain a constant value of E_s. To use this non-related chart, let's now superimpose the F-104G lg flight envelope* so that we can learn some basic relationships. By placing the steady state flight envelope over the specific energy curves, we can see that all maneuvering will be conducted between a maximum energy level associated with a best altitude-airspeed combination and a minimum energy level associated with zero altitude and minimum airspeed. The boundaries of the F-104 steady state flight envelope are determined on the right by limits of structure, temperature and available thrust; on the left by maximum lift limits; and above by the steady-state ceiling curve, where thrust is equal to drag. By studying this diagram, we can find our maximum and minimum energy points.

*Reference 1

MAXIMUM AND MINIMUM ENERGY LEVELS



The maximum energy level for the F-104G is about 115,000 ft. at Mach 2.0 and approximately 58,000 feet altitude. The minimum energy level is located at sea level where the appropriate specific energy contour intercepts the steady state envelope. An established axiom of ACT is that offensive maneuvering advantage will belong to any pilot who can enter an engagement at a higher energy level and maintain more energy than his opponent while locked in a maneuver and countermaneuver duel. But again, we are interested in sustained maneuvering and not a measure of instantaneous capability. Therefore, actual maneuvering involves energy loss and energy gain so a method must be found to show energy rate of change. With this kind of presentation, we will be able to find out how we can gain a maneuvering advantage even when we are forced to enter the engagement at a lower energy level but are capable of increasing the energy level during the course of battle.

In the case of an air-to-surface role, the pilot is not as interested in a high energy state as he is in maintaining energy while maneuvering with a wide assortment of stores. If he cannot maintain maneuvering energy, his choice of tactics becomes limited. In addition, if he is attacked by enemy airpower, his ability to evade or nullify the attack becomes questionable. Observing the correlation of energy with maneuverability, it follows that tactical maneuverability is related to the amount of energy possessed and HOW WELL THAT ENERGY IS MANAGED. For best maneuverability, the fighter pilot must know when and how to move to a higher or lower energy level and how to best conserve his internal energy (fuel) when locked in an air-to-air or air-to-ground encounter. Since we are considering changes of energy then we must develop a presentation that will show energy rate changes. To do this let's examine the factors of non-steady state performance.

Returning to our equation of E_s (specific energy), there is a mathematical method called Differentiation which will give us the rate of change of E_s. Now do not be concerned if you've never studied Calculus and do not feel you understand differentiation. Quite simply this is a tool whereby we take our steady state equation of specific energy and convert it to an equation that shows the effect on the specific energy when its component factors, (altitude and velocity), are changing with respect to time. Also, we only want to establish this equation in this particular form so that we can derive the final equation in aircraft performance terms that we will readily understand. Now, let's take our steady state equation and apply differentiation.

$$E_s = H + \frac{V^2}{2g} \quad \text{(steady state equation)}$$

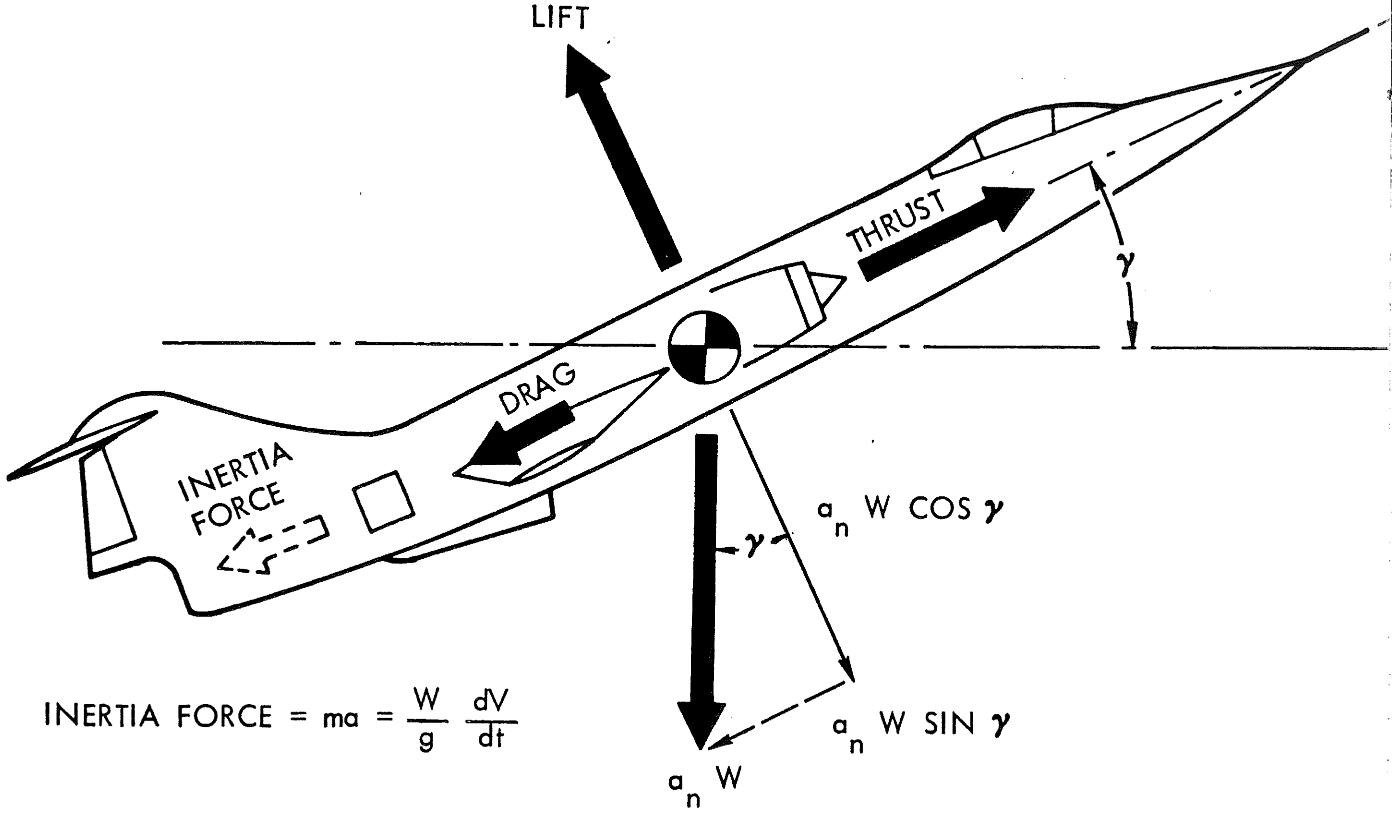
$$\frac{d(E_s)}{dt} = \frac{dH}{dt} + \frac{2V}{2g}\frac{dV}{dt} = \frac{dH}{dt} + \frac{V}{g}\frac{dV}{dt} \quad \text{(rate change equation)}$$

From the standpoint of flying the F-104, the rate of change of specific energy $\frac{d(E_s)}{dt}$ is a measure of the output of the engine-airframe combination at a specified speed and altitude. Obviously we have an almost unlimited capability of changing potential energy to kinetic and vice versa during our maneuvering. So now we need to analyze the various forces contributing to a change in specific energy. Let us establish some guidelines for assumed conditions. These will be:

1. Speed and/or altitude will be changing.
2. Direction of flight will be constant.
3. The load factor will be a selected constant. (1g, 2g, 3g, etc.)
4. The engine will be operating at either Military or Maximum Afterburner power.

The diagram of our F-104 under these conditions, looks like this:

FORCES ACTING ON THE AIRCRAFT THAT CAUSE A CHANGE IN SPECIFIC ENERGY



For ease of calculation, we will now sum up the forces parallel to and perpendicular to the direction of flight. Also, at climb speeds the angle of attack will usually be small and the thrust line is assumed coincident with the direction of flight.

Perpendicular to flight

$$\sum F_y = 0$$

$L = a_n W \cos \gamma$ and we assume lg flight

$$L = W \cos \gamma$$

For forces parallel to the direction of flight, the aircraft may in general be considered to be both climbing and accelerating. Forces opposing the thrust force T will consist of a drag force, a component of the weight and an inertia force. Therefore--

Along the flight path

$$\Sigma F_x = O$$

$$T - D - a_n W \sin\gamma - \frac{W}{g}\frac{dV}{dt} = O$$

since we assume 1g flight, $a_n = 1$

rearranging, then;

$$T - D - W\sin\gamma = \frac{W}{g}\frac{dV}{dt}$$

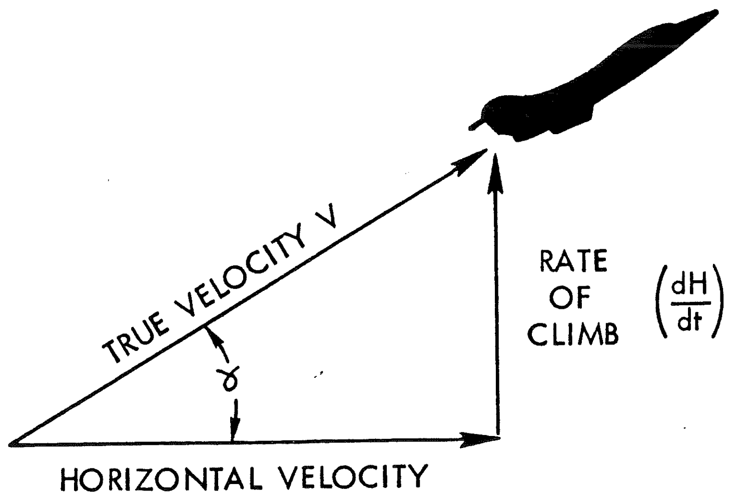
If we now multiply by V and divide by W on both sides of the equation -

$$\frac{V(T - D)}{W} - \frac{VW\sin\gamma}{W} = \frac{VW}{Wg}\frac{dV}{dt}$$

The last step is to transpose $V\sin\gamma$ to the right side of the equation and we have -

$$\frac{V(T - D)}{W} = V\sin\gamma + \frac{V}{g}\frac{dV}{dt}$$

This equation is very similar to our original equation of $\frac{d(E_s)}{dt}$ and if we now consider the relationship of rate of climb $\left(\frac{dH}{dt}\right)$ to velocity V and the climb angle γ as shown by our sketch -



From this, $\frac{dH}{dt} = V \sin\gamma$ and now if we substitute this into our previous equation---

$$\frac{V(T - D)}{W} = \frac{dH}{dt} + \frac{V}{g}\frac{dV}{dt}, \text{ and;}$$

When we look at the differentiated equation of E_s, we find;

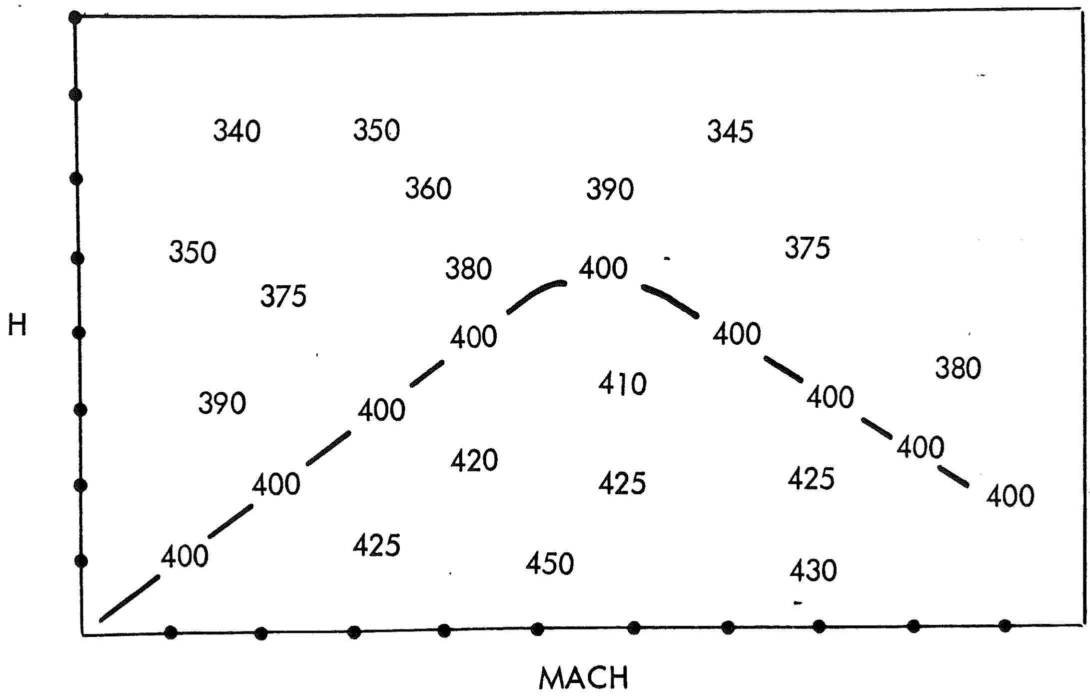
$$\frac{d(E_s)}{dt} = \frac{dH}{dt} + \frac{V}{g}\frac{dV}{dt}$$

So now we have:

$$\frac{d(E_s)}{dt} = \frac{V(T - D)}{W} = P_s$$

And here you have the equation for rate of change of specific energy in terms of easily measurable or calculable aircraft performance. Also from now on, let's refer to the term $\frac{V(T - D)}{W}$ as specific excess power, or P_s. You might have noticed that P_s has units of feet/sec, therefore, it can also be thought of as available climb rate.

The formula for P_s has been used for many years in flight test programs to determine best climb schedules and range profiles. These tests were of the cut-and-try method because of the immense difficulty of calculating all the possible P_s points within the flight envelope. The calculation is easy but depending upon the increment selected to divide the points for calculation, you might have 1,000 to 1,000,000 calculations to make. Now, with modern computer systems, it is possible to develop all the P_s contours within the flight envelope. To understand this, let's look at a matrix of calculated P_s numbers within a selected small square in the flight envelope.



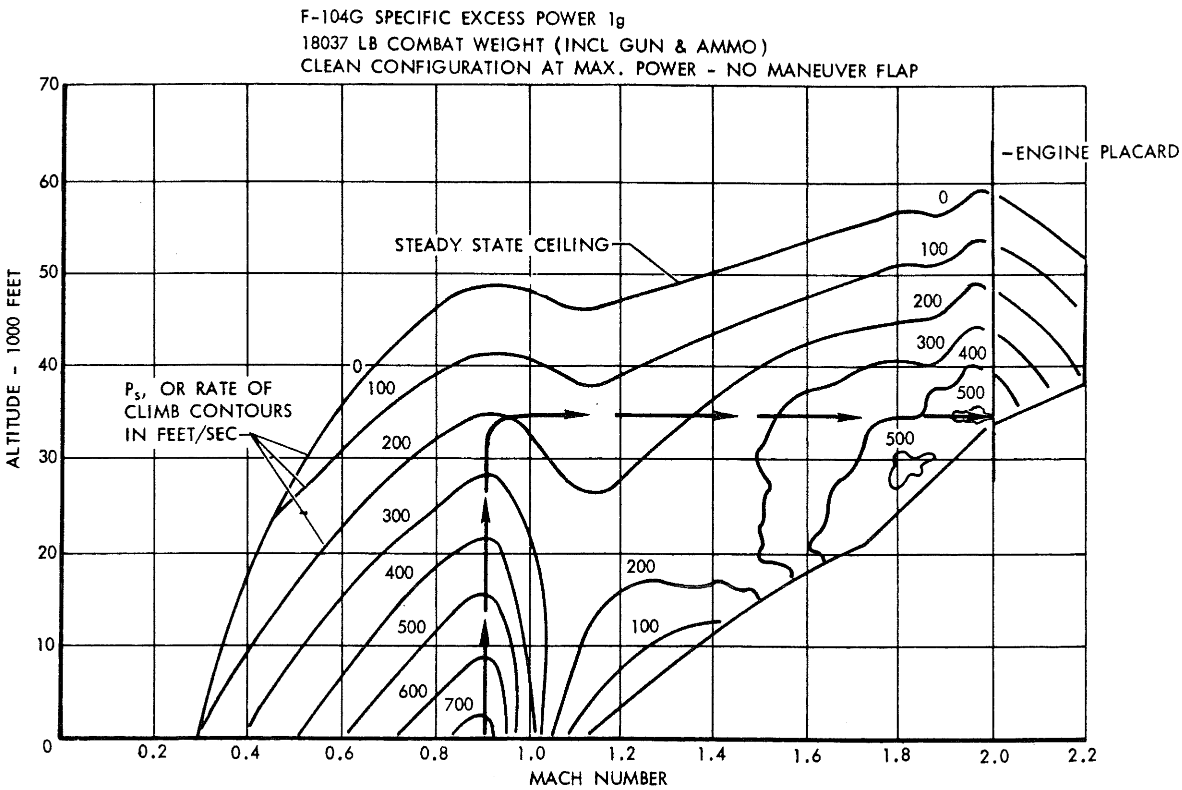
After the computer makes the thousands of calculations for P_s, throughout the flight envelope, we can see within the grid that there are contours of constant numbers and by connecting them we have specific excess power contours. Maj. John R. Boyd, a leading tactician for the USAF was one of the first who realized the importance of the Energy Maneuverability plots. Maj. Boyd's first application of the E-M theory was to tackle the minimum time to intercept problem. When he encountered some diffulties with computer analysis, Mr. Hugo P. Heerman, Research Analyst of Lockheed, collaborated and helped Maj. Boyd. Our Research group at Lockheed, and Mr. George W. Dreiling of Market Engineering, have pioneered various applications of the computer to the Energy Maneuverability calculations and the automatic plotting of the P_s contours.

We are now in the position to investigate these Specific Energy Plots for a better understanding of how to get the most out of our Starfighter in a combat situation.

SECTION III

Energy Maneuverability Applications

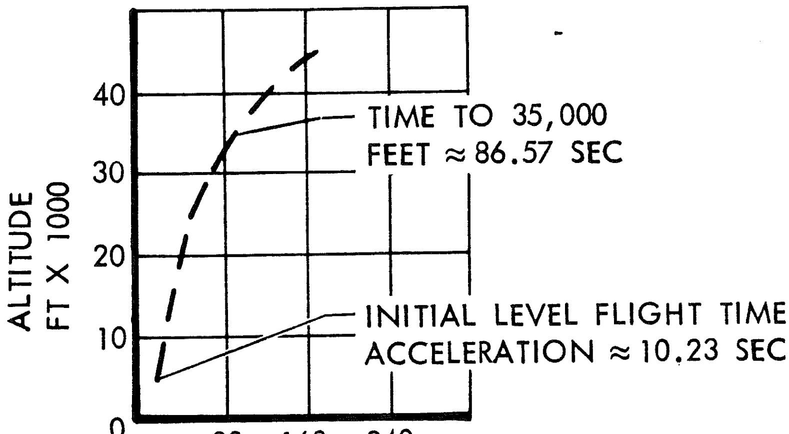
The established performance parameters of a fighter interceptor aircraft are minimum time to climb, minimum time to intercept, maximum possible speed and altitude. The Energy Maneuverability plots will help us extract these performance items for our required profiles. First, let's tackle the classic problem of a minimum time to intercept where the target is inbound at 35,000 feet and we want to scramble, climb, accelerate to Mach 2.0 and make a successful "splash". Up to the contact point our profile will be very close to lg conditions, so let's look at a lg Specific Excess Power plot for our F-104G.



Utilizing the P_s contours in our lg envelope, let's divide the problem into a climb path and an acceleration path. Also, let's look at the established method of a subsonic climb to 35,000 feet and a level acceleration to Mach 2.0.

Remember that I explained that the P_s contours could be considered as rate of climb capability? Well, obviously the subsonic maximum rate of climb path will pass through the peaks of these contours in the subsonic regime. As noted, they give a good solid picture of .90 Mach being the optimum climb Mach number. As you know, your Pilot's Handbook* lists a climb Mach number of .90 or .925 based upon various configuration drag indexes. Our plot now shows why these Mach numbers are recommended. Therefore, a minimum time to climb path to 35,000 feet will lie on the peaks of these P_s contours. Experience has shown that after takeoff, most pilots will smoothly rotate and be on climb schedule around 5,000 feet. By following the recommended climb schedule, a plot can be made that will show the time to climb along the maximum rate of climb path. And it will look thusly --

TIME TO CLIMB ALONG MAXIMUM RATE PATH

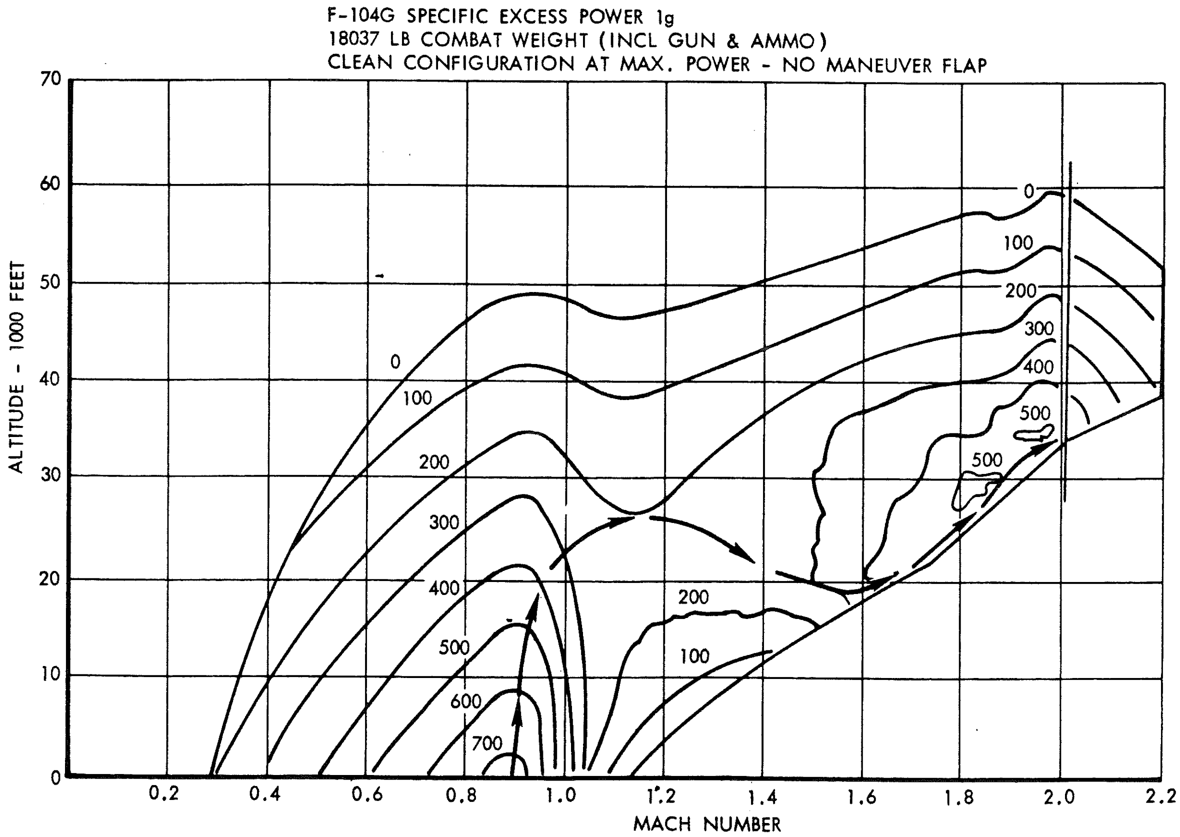


Establishing the optimum climb path starts us on the way to minimum time to intercept by showing minimum time to climb to 35,000 feet. Now we can investigate the level acceleration path. Looking again at our 1g P_s contours, we can see that if we level off at 35,000 feet and accelerate at this altitude, we will cross the 200 P_s contour at Mach 1.4 and the 300 P_s contour at Mach 1.5 and the 400 P_s contour after Mach 1.7 and then hit the highest P_s contour of 500 around Mach 1.9 and this "boots" us to Mach 2.0.

*Reference 1.

Looking closer at the plot, we see that from the 200 P_s contour at .9 Mach we decrease in P_s level to around 130 before we cross the 200 P_s contour again. I'm sure that now many of you are beginning to have some understanding of the questions that can be answered by the Specific Excess Power plots. For instance, why does the F-104 accelerate slower between .90 Mach and 1.4 Mach than between 1.4 and 1.9 Mach? This is easy to understand after looking at our plot. That dip in the P_s contours just before Mach 1.0 reflects the rise in compressibility drag which extends over into the transonic region. The excess thrust (T-D) begins to build up around Mach 1.4 and that's why we experience an increase in Mach acceleration. The varying P_s contours which spell out acceleration capability are also in agreement with the aerodynamic effects of engine airflow as explained before.*

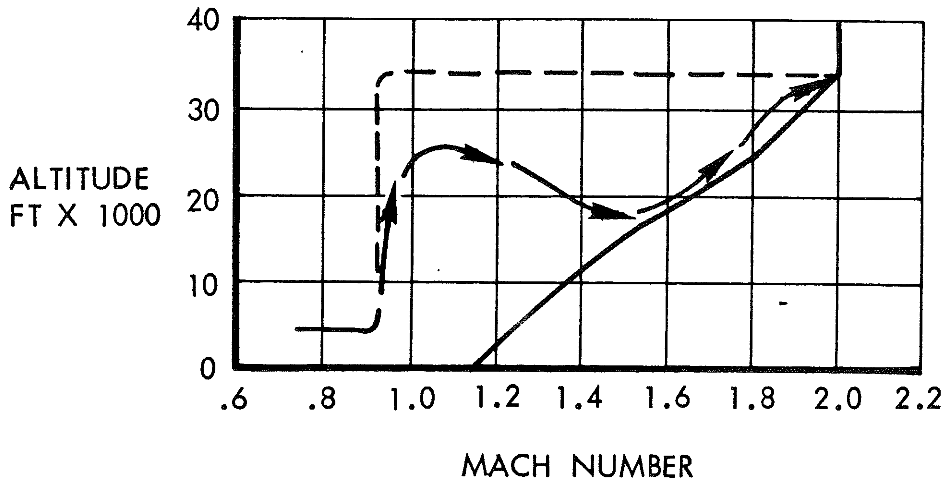
The maximum rate of climb path and level acceleration path breaks down the minimum time to intercept problem into two distinct operations. But I'm sure you've already thought ahead and have concluded that a combined profile is necessary to attain the minimum time to reach a final combination of altitude and speed. By analyzing our Specific Excess Power Envelope once again, we can make a point performance profile that will connect the peaks of the P_s contours and also follow the P_s contours for maximum benefit. This E-M profile can be shown thusly:



*See SURE Lecture No. 5

This E-M profile begins to deviate away from the climb schedule of .90 - .925 Mach at about 15,000 feet and assumes a smooth push over to intercept the 200 P_s contour about 27,000 feet and 1.15 Mach number. From here, a shallow dive to the placard limit at about 17,500 feet and then a gentle climb to Mach 2.0 at 35,000 feet. Hugo Heerman compared the two profiles of the standard path and the E-M path and arrived at conclusions shown in the following diagram:

Standard vs. E-M Acceleration Paths



		TIME - SECONDS
⟶	E-M PATH	194.316
– – – –	NORMAL PATH	251.364

Beginning at a climb schedule intercept around 5,000 feet, the E-M profile shows a reduction in time of 57 seconds or 23% for the total intercept time. This amount of a reduction certainly is profitable and important for Fighter Interceptor F-104's close to critical border areas. From the experimental profiles flown at Eglin and Palmdale, there are some critical factors that must be considered before attempting the E-M minimum time to intercept profile.

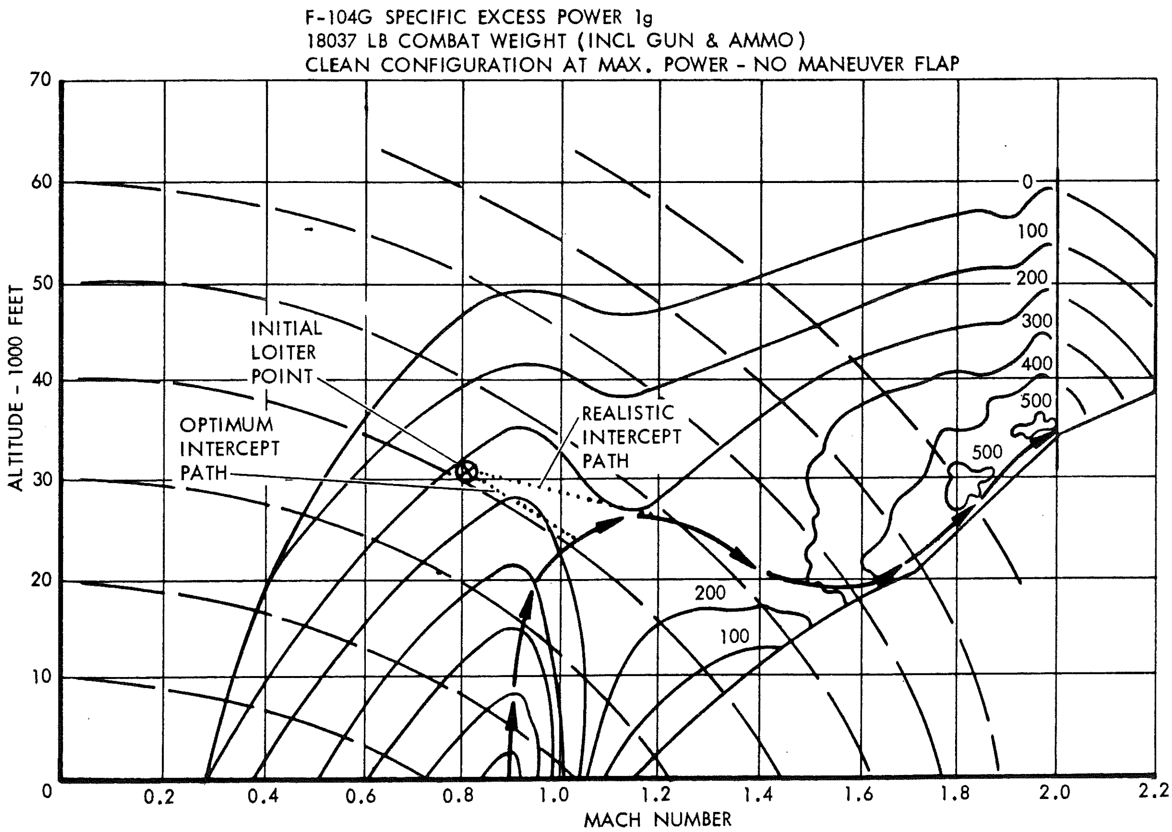
1. Carefully plan and program the profile for key points to achieve but do not worry about small overshoots and undershoots--be smooth and stay close to lg since the profile is based on lg.

2. It is all important that you obtain full T_2 reset and <u>stay</u> in T_2 reset for the supersonic climb from your low point around 17,500 feet. Therefore, a close study of ambient temperature conditions aloft is required before you go up. If you reach your limiting 750 knots EAS and cannot get full T_2 reset, you will probably never be able to attain Mach 2.0 and 35,000 feet faster than the level acceleration method.

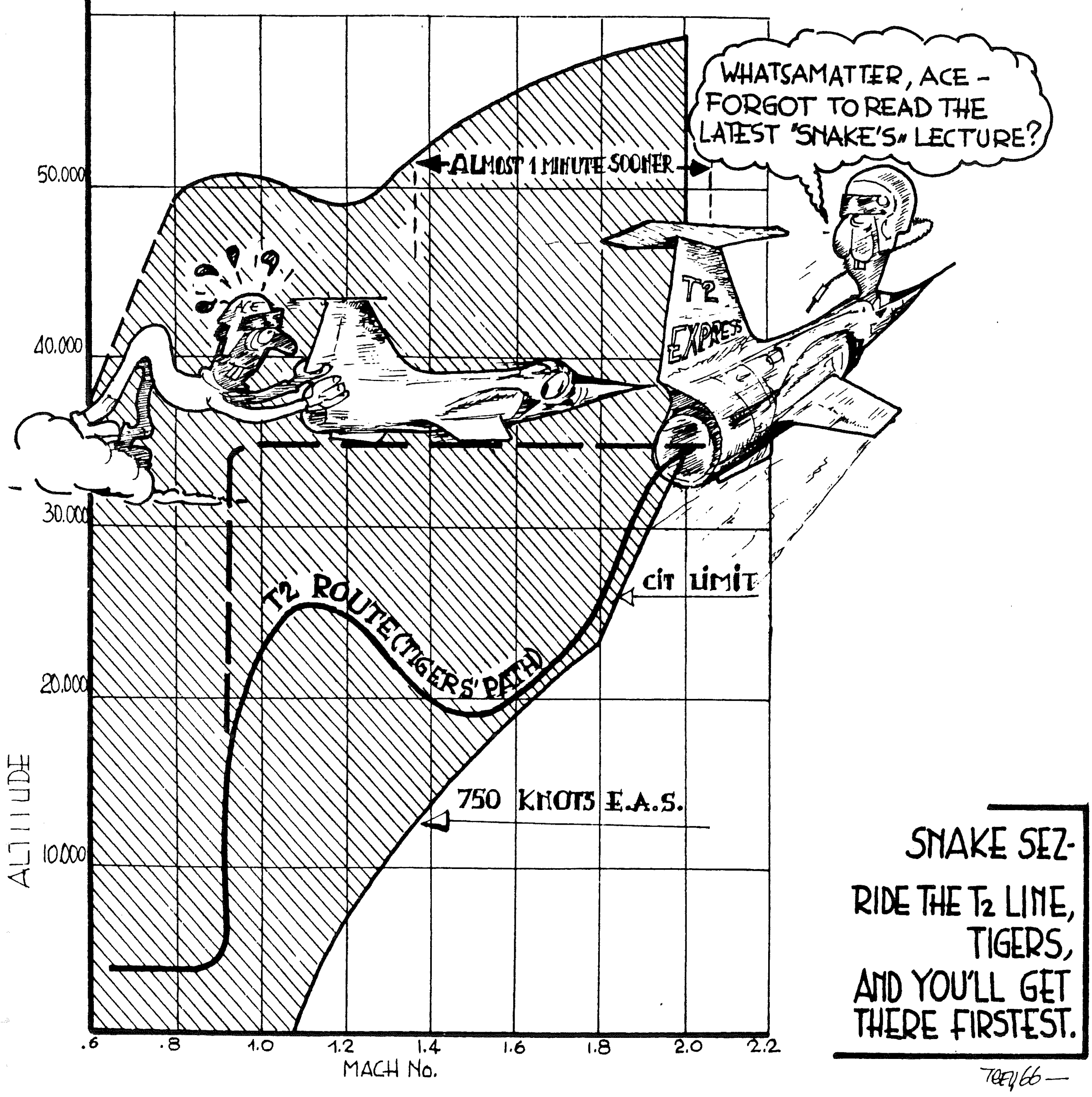
3. The profile will vary for different configurations which changes the Drag and Weight in the $\frac{(T - D)}{W}$ factor in the calculations of P_s. So a particular profile exists for <u>every</u> configuration of weapons loading.

4. This profile will definitely burn more fuel than the level acceleration path since you are optimizing time--not fuel.

So far I've discussed the E-M profile from scramble to "splash" for the minimum time to intercept. Naturally a logical question is "What if I'm at my best cruise or loiter altitude and airspeed and then GCI orders me to perform a minimum time to intercept--how do I get from this point onto the minimum time path in the best manner?" Well, let's look at the P_s envelope again for the theoretical optimum answer to this question. Also, let's now superimpose the E_s lines over the P_s contours, remembering that these lines represent <u>constant</u> levels of specific energy. A solution to our problem now becomes easy if the energy rate, off the minimum time path, inside the steady state envelope is assumed to be zero. Under this assumption, you should move along the E_s line, nearest to your starting point, until intercepting the minimum time path. As an example, let's suppose we're loitering at around 32,000 feet and .82 Mach number. From this point on the envelope, let's see what happens.



INTERCEPT PROFILE WITH ENERGY MANAGEMENT



As we can see, the optimum path is unrealistic due to sharp changes in the flight path. The realistic path is a straight line descent to an intercept of the minimum time path at around 26,000 feet and 1.15 Mach number. The solution for the optimum path to intercept consists simply of following the appropriate E_s line until intercepting the minimum time path. Using this procedure you can determine the best paths from any point in the envelope. Remember though, you might have to alter the "optimum" path to a "realistic" path to intercept the minimum time profile. And it must be pointed out that these paths are approximate for two reasons: (1) Load factor is assumed a constant 1g in developing the basic E-M minimum time path and (2) Energy rate is assumed to be zero in developing the best path from any point in the envelope.

The minimum time to intercept profile is only one application of the P_s contours in the Energy Maneuverability concept. The most important tactical application is the capability to compare different fighter aircraft performance on an absolutely equal "technical" basis. These comparisons are strictly based on known and calculable performance parameters of aircraft capability. But they will act as big signposts in the sky as to the best flight path(s) for your ACT planning.

By now, those of you tigers who have struggled with me so far are probably shaking your heads and muttering--"Old Snake's really a tame tabby if he is only thinking about 1g envelopes". Well chaps, as I said at the beginning, we will have to develop a method of showing sustained maneuver loads on the aircraft. So now, you tigers will have to stick at my six o'clock position and follow me as I explain how we take into account selected g loads at various Mach numbers and altitudes in our calculations of P_s contours. With these envelopes, serious studies of ACT can be made.

Now let's tackle the problem of the mathematics with g loads in our maneuvering flight. Going back to SURE Lecture 5, we saw that the equation for airplane lift was:

$$\text{Lift} = C_L \, q \, S$$

where,

C_L = Coefficient of lift

$q = 1/2 \, \rho \, V^2$, and ρ is the density of air at our altitude and V is our aircraft velocity.

S = Wing area, which is a constant 196 ft^2 for the F-104G.

Turning back to our drawing of the F-104 and the summation of forces acting on it, we find that:

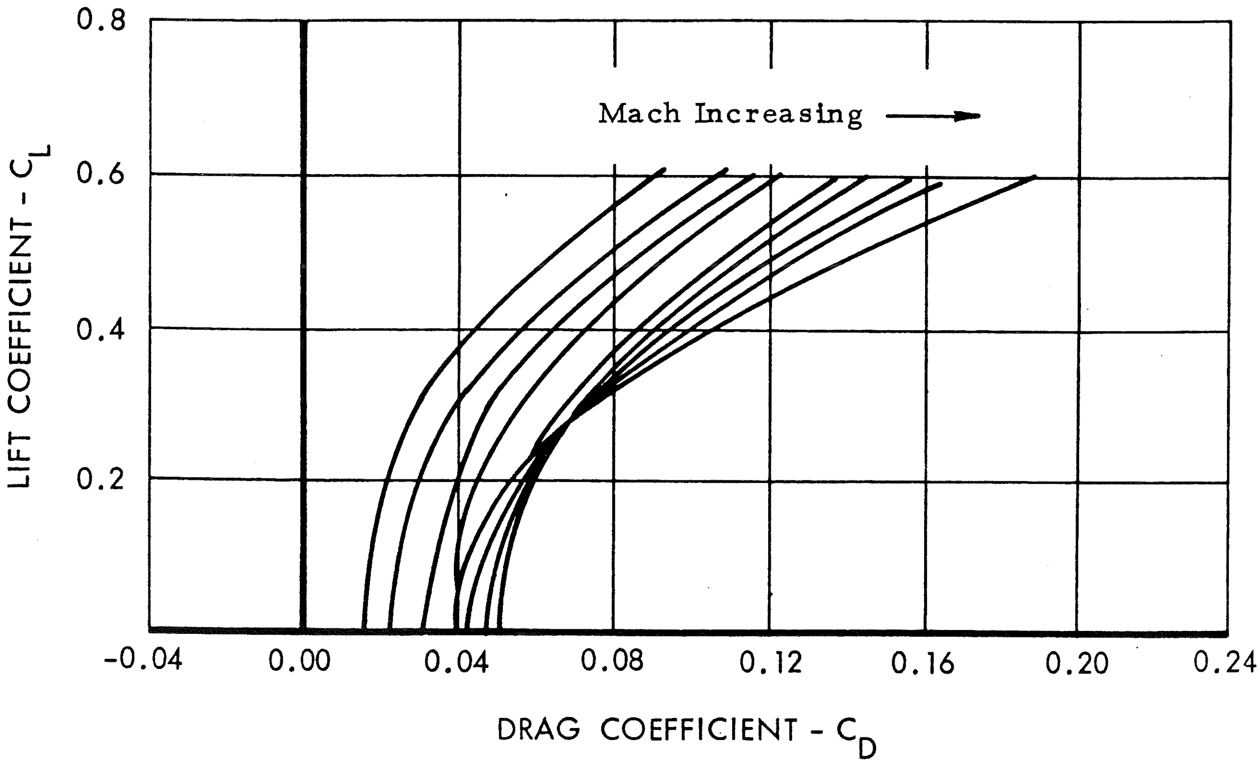
$$\text{Lift} = a_n W \cos \gamma$$

But since the trigonometric cosine value of angles from 0^o to 25^o only varies from 1.0 to .9063, it will greatly simplify our calculations to assume that $\cos \gamma = 1.0$, therefore:

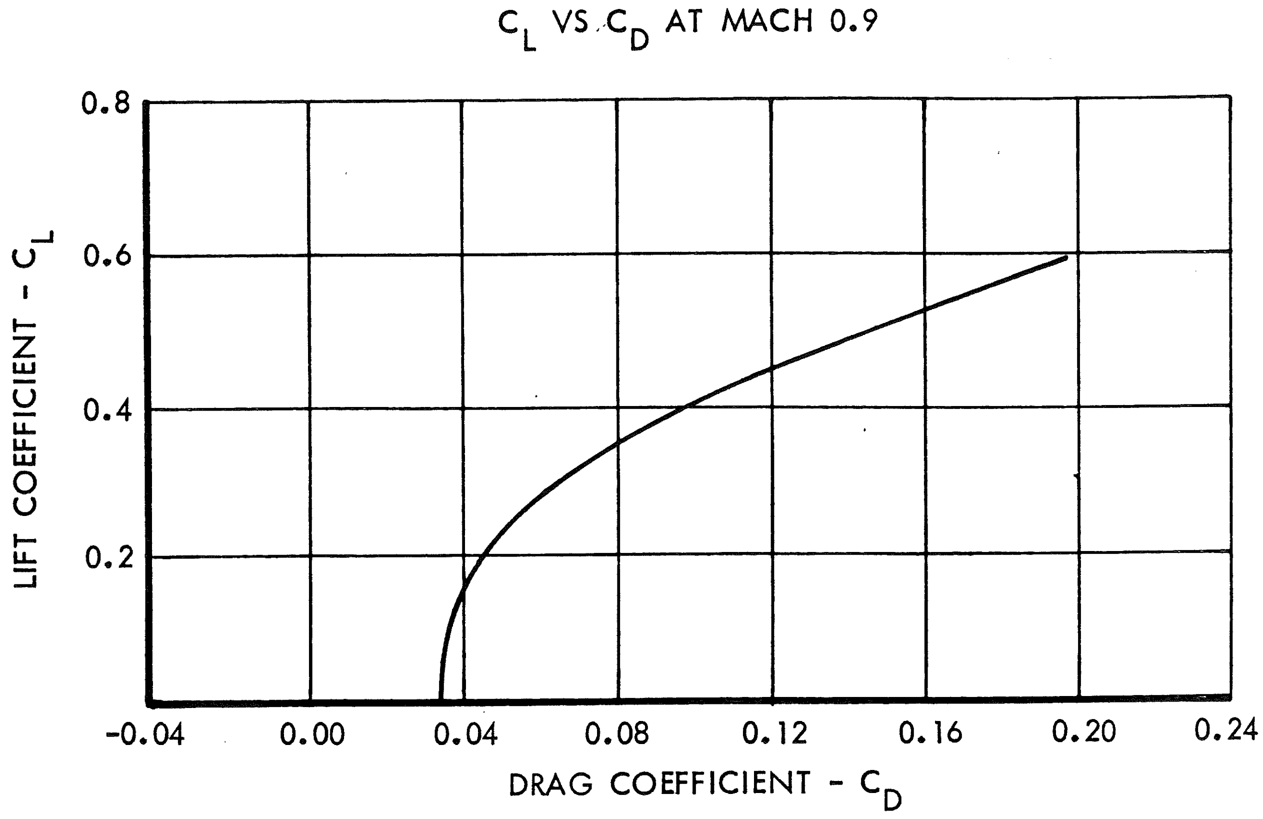
$$a_n W = C_L q S \quad \text{or,} \quad C_L = \frac{a_n W}{q S}$$

Our next step, for a sample calculation, will be to assume some values so that we can establish various E-M envelopes. Since we can pick our own parameters, let's first pull a sustained 3g load factor with 50% fuel, gun and full ammo--in other words, an arbitrarily defined combat weight. By plugging in the selected dynamic pressure q(a factor of Mach and altitude), we can solve for C_L. Let's select Mach 0.9 and 35,000 feet for our example. Solving for the C_L, we now go to our C_L vs. C_D curves to obtain a value of drag coefficient C_D. Our following plot shows the family of curves you obtain with various Mach No's from 0 to 2.0. These curves are obtained from a combination of flight test data and aerodynamic calculations.

C_L VS C_D AT VARIOUS MACH NO.'S



Because the lines get so interwoven, it is easier to individually plot the different curves for selected Mach numbers. And we can read the values more accurately. Since we selected Mach 0.9, let's look at this representative curve.



From this curve, we are able to read off C_D for our calculated C_L. With this value of C_D, we can calculate our Drag, since --

Drag $= C_D \; q \; S$, and we have already calculated qS.

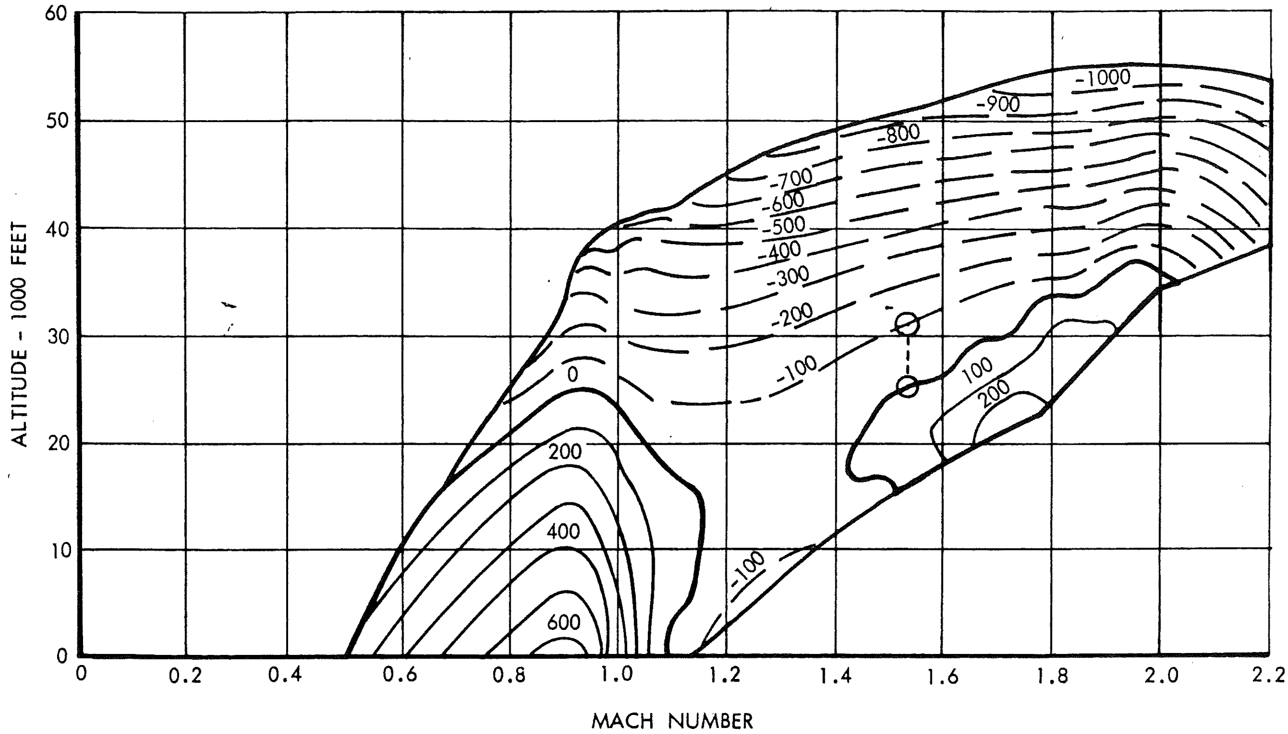
By going back to our equation for P_s, we can calculate entirely new P_s contours because we are accounting for the effect of g load in the value of Drag in the equation for P_s.

$$P_s = \frac{(T - D)\,V}{W}$$

Of course we're facing the requirement of computers again due to the millions of calculations in solving for the P_s values throughout the flight envelope. However, with the IBM 360 doing the bulk of the work for us, we can select a constant g load to be applied throughout the entire flight envelope.

Our experience and common sense tells us immediately that our operating altitudes will decrease with sustained g loads. But only the P_s contours can tell us by how much. So let's look at an envelope where we select a constant 3 g load factor.

F-104G SPECIFIC EXCESS POWER 3g
18037 LB COMBAT WT (GUN & AMMO)
CLEAN CONFIGURATION AT MAXIMUM POWER - NO MANEUVER FLAPS



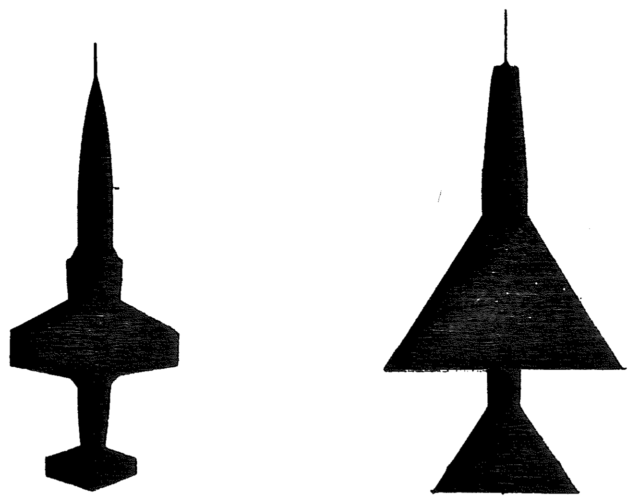
As suspected, we see that by enforcing a sustained 3 g load on our Starfighter, its P_s contours shrink down. And, in fact, we are faced with two separated envelopes of positive P_s values. This doesn't mean there's an area in which we can't fly and pull 3 g but only that we will be losing energy at that rate shown on the negative P_s contours. These negative P_s values are just as helpful as the positive values. For example, if you start at around Mach 1.53 and 31,000 feet and steadily pull 3g, you begin at a value of -100 feet/sec. and if you want to maintain the same Mach number, in this turn, you see that you must begin descending from 31,000 feet and you will have to descend to about 25,000 feet before your energy loss rate is zero. At this point, you could pull 3g's, maintain Mach and altitude until your fuel ran out. Now you might have already made some mental calculations and deduced that you were descending at 6,000 feet/minute, therefore, you could pull 3g for one minute while losing altitude down to your zero rate. Well, that's good thinking, but it ain't quite that simple! Remember that you start at -100 P_s but somewhere between there and your zero rate is a $\overline{-50\ P_s}$, approximately at

28,000 feet. And at this point, you could pull 3g, maintain your Mach number and only lose altitude at the rate of 3,000 feet/minute. So this leads us to a very important conclusion about these Specific Excess Power envelopes. They are point calculations and a static display--they are not a dynamic presentation that can show changing conditions. As of now, there is just no way we can show you a changing situation of varying energy levels.

"Well then, why did we go through all this vector study and the flippin mathematics to get these P_s contours?"

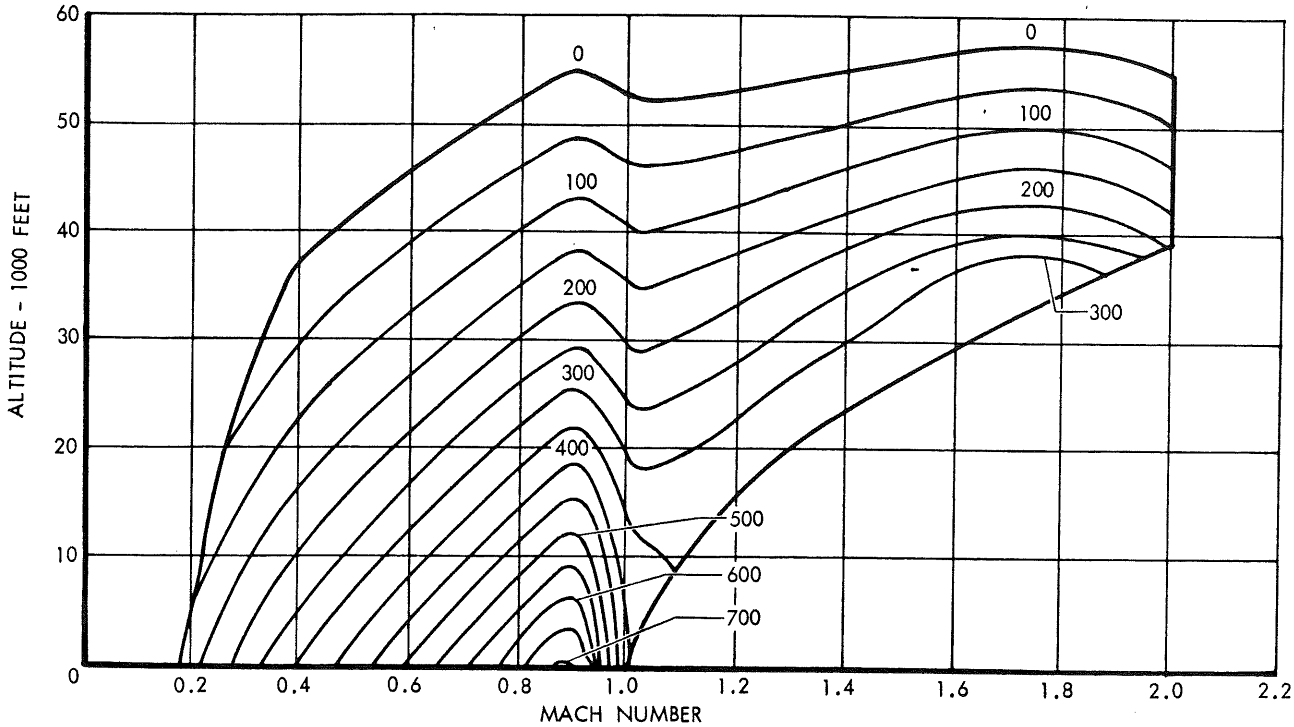
Glad you asked that question, Ace, because it brings me to my next step in E-M applications.

Beginning with my personal experiences of combat with the Mig-15's in Korea and up to the present time with the experiences of my comrades in South East Asia with the later versions of Migs, the USAF and our Free World Allies have been faced with a fighter threat that is quite distinctive. These fighters all have excellent short range, defensive performance in conjunction with operations carried out close to their own airfields. They have not displayed any ability for long range bombing missions and obviously were not designed as multi-mission aircraft. On the other hand, all U.S. designed Mach 2.0 fighters are noted for their high wing loading, heavier airframes, bombing capability, bigger fuel loads and higher strength airframes that can sustain greater airloads. Also, from Korea to th present time, all contacts between these two different type fighters has been typically in the opposition's own "back yard." Since we at Lockheed have a creditable reputation for designing aircraft, we can certainly come up with a fictitious fighter resembling these threat aircraft. George Dreiling has designed for this lecture just such a bird. It is a Mach 2.0 fighter, with a delta wing, conventional tail, light wing loading and high thrust-to-weight ratio with excellent short range performance. We have simply applied their design philosophy to build a hypothetical fighter for comparison purposes. For want of a title, we'll call it Airplane "X". A planform comparison with the F-104 looks like this:



Since we now have a defined threat aircraft, we can apply the same methods we used on the F-104G and obtain for ourselves the P_s contours of Airplane "X". Putting our computer to work, we can look at Airplane "X" under lg and 3g loading.

AIRPLANE "X" SPECIFIC EXCESS POWER 1g
COMBAT WT 50% FUEL (INCL GUN & AMMO)
MAXIMUM POWER



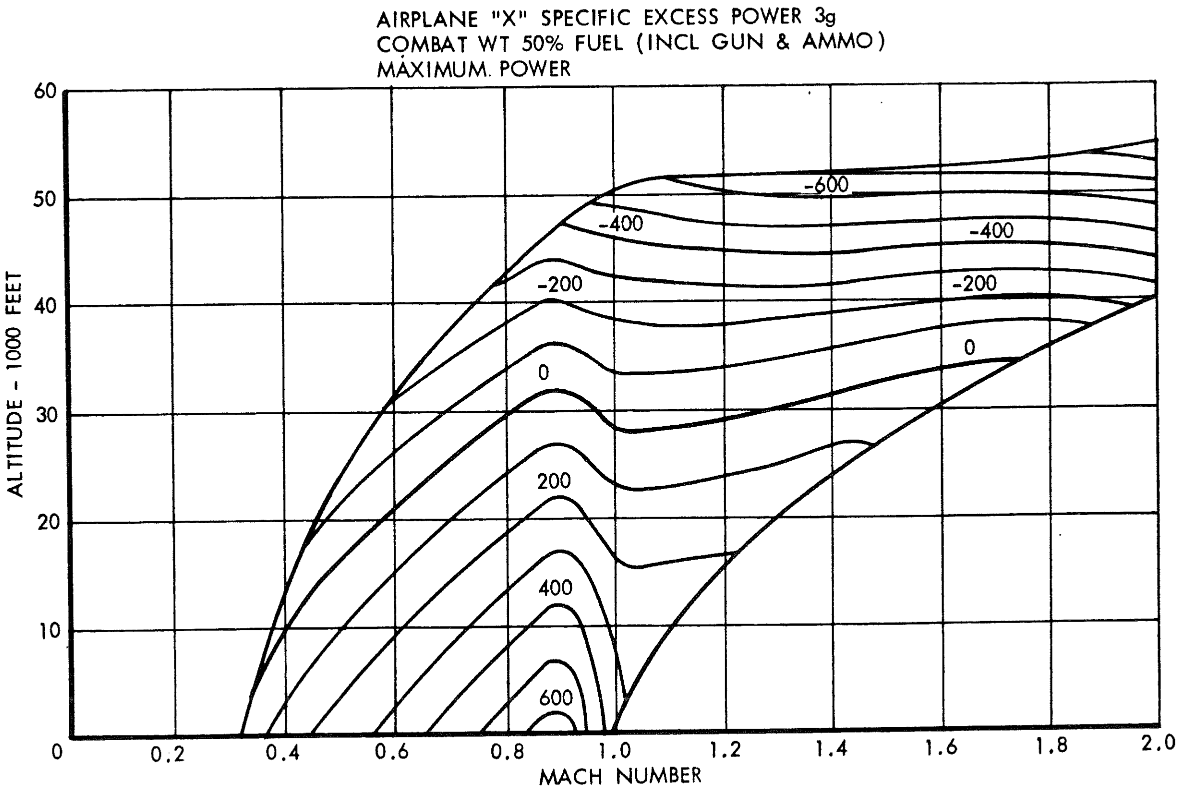
Just like our F-104G, Airplane "X" has boundaries that are determined on the right by structural limit and available thrust; on the left by maximum lift limits; and above by the steady state ceiling curve, where thrust is equal to drag. And now, I believe there comes a glimmer of understanding as to why we've gone through all this exercise. Looking back at the F-104G lg envelope we can immediately make some tactical comparisons:

1. Airplane "X" with its bigger wing and lighter wing loading has a higher steady state ceiling. This is definitely a foregone conclusion because of the inherent differences in the design philosophy of the two birds.

2. Not only does it appear that Airplane "X" has a higher steady state ceiling, but an eyeball comparison indicates that its P_s contours are higher in value at higher altitudes. Again, this is an obvious fact due to the design differences.

3. It looks like there's a big difference between the birds in the lower mid-altitude region and in the supersonic area. We can see the difference by noting the structural limit line of Airplane "X". This aircraft just cannot fly beyond this placard line without risking structural failure due to its lightweight construction. Here is where our threat aircraft is being penalized by its design criteria.

OK, so much for 1g; what about 3g? Again to the computer which grinds and clatters out this envelope.



"Oh boy, now we're getting somewhere, if we just make some plastic over-lays and put the 104 over Airplane "X", then we can--".

Wait a minute, Ace, just throttle back a bit. I know an easier way. Rather than you and I looking at all those squirrely lines and trying to do all kinds of minute comparisons, why not put a few guidelines into the computer and really put that big black beast to work! In particular, let's instruct the computer to overlay the envelopes and search through the calculations of P_s with these rules:

1. Where only one aircraft envelope exists, label that area an exclusive area.

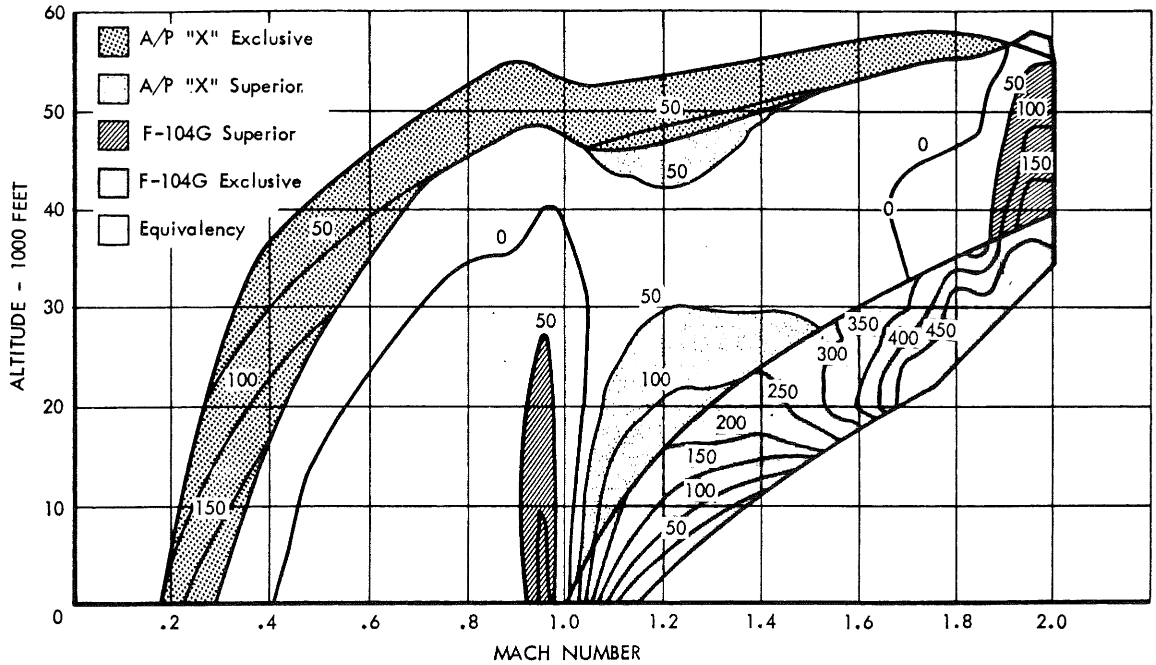
2. Where the P_s values of the two fighters are equal, plot a zero line throughout the common areas of the two envelopes.

3. Where the P_s values of the two aircraft vary by as little as 50 ft/sec, plot an area of equality for the two aircraft. In other words, individual pilot technique could easily cancel out any small advantage of aircraft performance in this close of a comparison.

4. Throughout the rest of the common areas of the envelopes, compare the two values of the aircraft and make a "subtraction" of the P_s values which will give us a differential comparison of the values. This will mean that the differential P_s contours represent the amount of advantage <u>by the amount shown on the contours</u>.

Before we look at the resulting Differential Specific Excess Power Contours though, I want to reemphasize the correct interpretation of these contours. First, they are point to point calculations, assuming that both aircraft are in the same hunk of sky at the same altitude and Mach number with full power. It's sort of a canopy to canopy comparison of who can out-turn or out-climb whom at that particular point in space. Second, the contours do <u>not</u> represent any situations where one aircraft is attacking the other <u>with a</u> high overtake speed and therefore a higher energy level. Third, they do not indicate any acceleration capability in a downward direction or at any other g loading than the constant g that we selected prior to the calculations. We'll look in another direction for a solution to these questions. But for a static point comparison, let's now look at the differential plots.

F-104G vs. AIRPLANE "X" AT 1g
DIFFERENTIAL SPECIFIC EXCESS POWER CONTOURS
CLEAN CONFIGURATION 50% FUEL FULL AMMO MAX A/B



Just as we expected, there are some very clear points of analysis to be made:

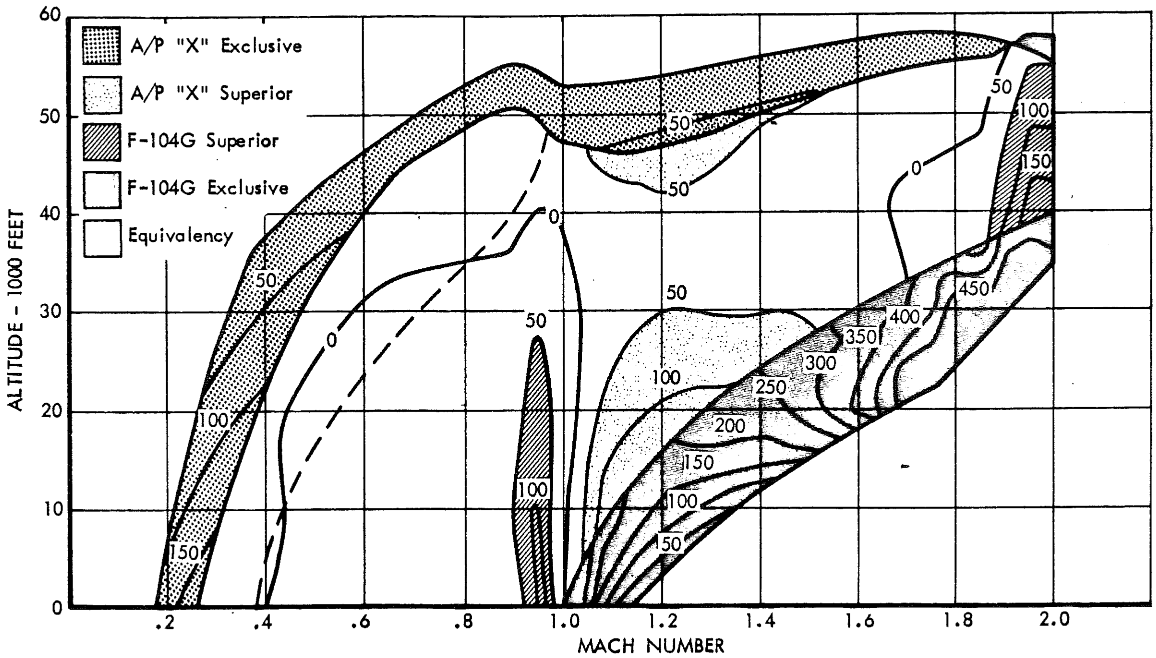
1. Airplane "X" definitely has a higher ceiling due to its design. In fact, it has an area of exclusivity in the slow speed and high altitude, steady state ceiling area.

2. There is a large area of equivalency between the two aircraft that runs from both ends of the common envelopes.

3. The F-104G has an area of exclusivity along the entire span of Airplane "X's" structural limitation and an area of superiority in the Mach 1.9 to 2.0 region from 38,000 to 55,000 feet.

This envelope does not have the effect of Maneuver flaps as you probably noticed. So, to see just what help they might give us, we'll include them in the envelope.

F-104G vs. AIRPLANE "X" AT 1g
DIFFERENTIAL SPECIFIC EXCESS POWER CONTOURS
MANEUVER FLAPS 50% FUEL FULL AMMO MAX A/B



Well, it doesn't appear that Maneuver flaps are going to overcome the bigger wing area and greater lift of Airplane "X". It's true that we've moved the zero line back a little and moved the 50 P_s contour of "X" back, but primarily in this area, Airplane "X" just flat has the point comparison advantage over us. Some of you "sharpies" might have noticed that the actual Handbook* placard line lies to the right of the Maneuvering flap line that we have in the envelope. There is an excellent reason for this in that this line represents the best point of trade-off between flaps in Up or in Takeoff position. In other words, this line shows where the Lift/Drag ratio is equal. Eventhough the placard allows us to leave the flaps in Takeoff position up to higher speeds, the rising drag of the flaps is penalizing us in acceleration with full A/B.

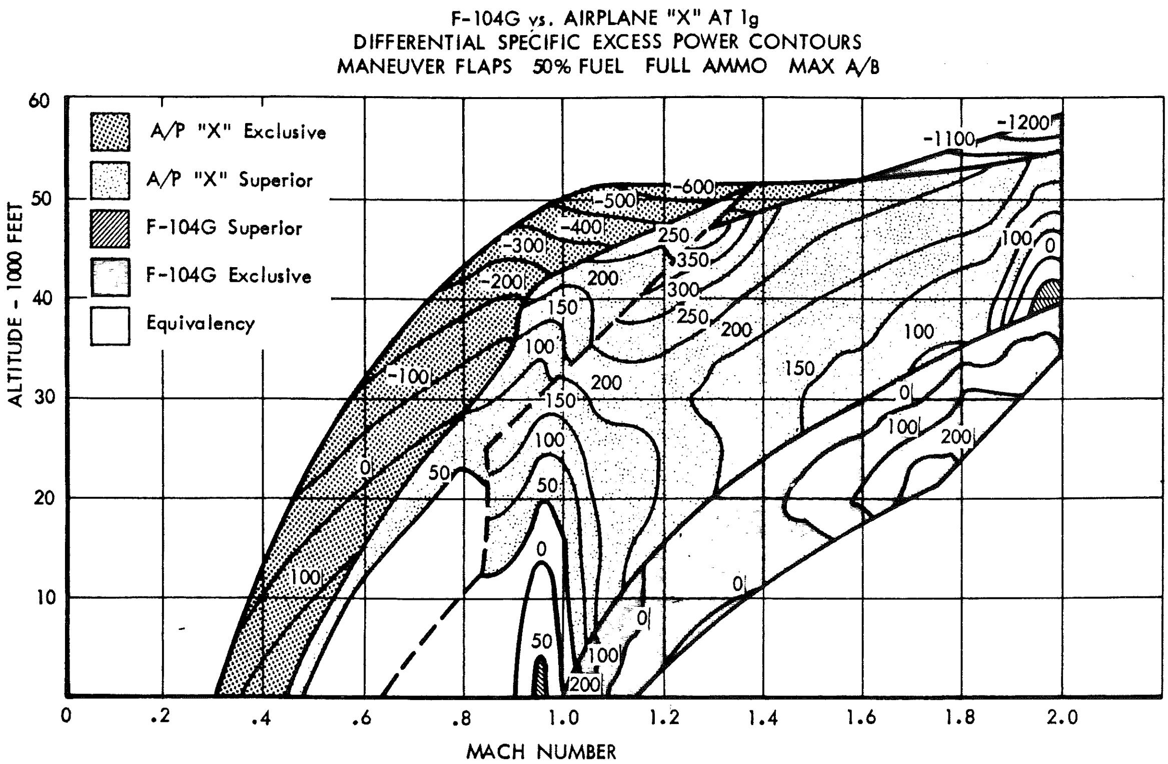
Now, before we check the 3g differential contours, I think you will agree with me that some preliminary conclusions can be made from the 1g contours

1. The advantage area of Airplane "X" appears to preclude our using tactics that involve nose high, low speed, turning maneuvers.

2. The great performance advantage of the F-104G lies beyond the structural placard of Airplane "X".

* Reference 1

In deciding what g load to be selected for comparison, I have picked 3g since I believe it is a realistic sustained g load and will show any trend adequately enough so that there's no reason to go as high as say 5g. Ou plot of 3g on both aircraft looks like this:



Well Ace, I don't think I need to tell you the message of this picture-- Don't fight a high g turning battle against "X"!

Again, our Maneuvering flap line should be explained. The line from sea level to 13,000 feet is the same as on the 1g envelope--the best trade-off between flaps in Up and Takeoff. From 13,000 to 25,000 feet is the placard limitation of .85 Mach number and then on up is the placard limitation of 360 knots IAS. But, the recommended primary area of 3g combat is again out beyond the structural limit line of Airplane "X".

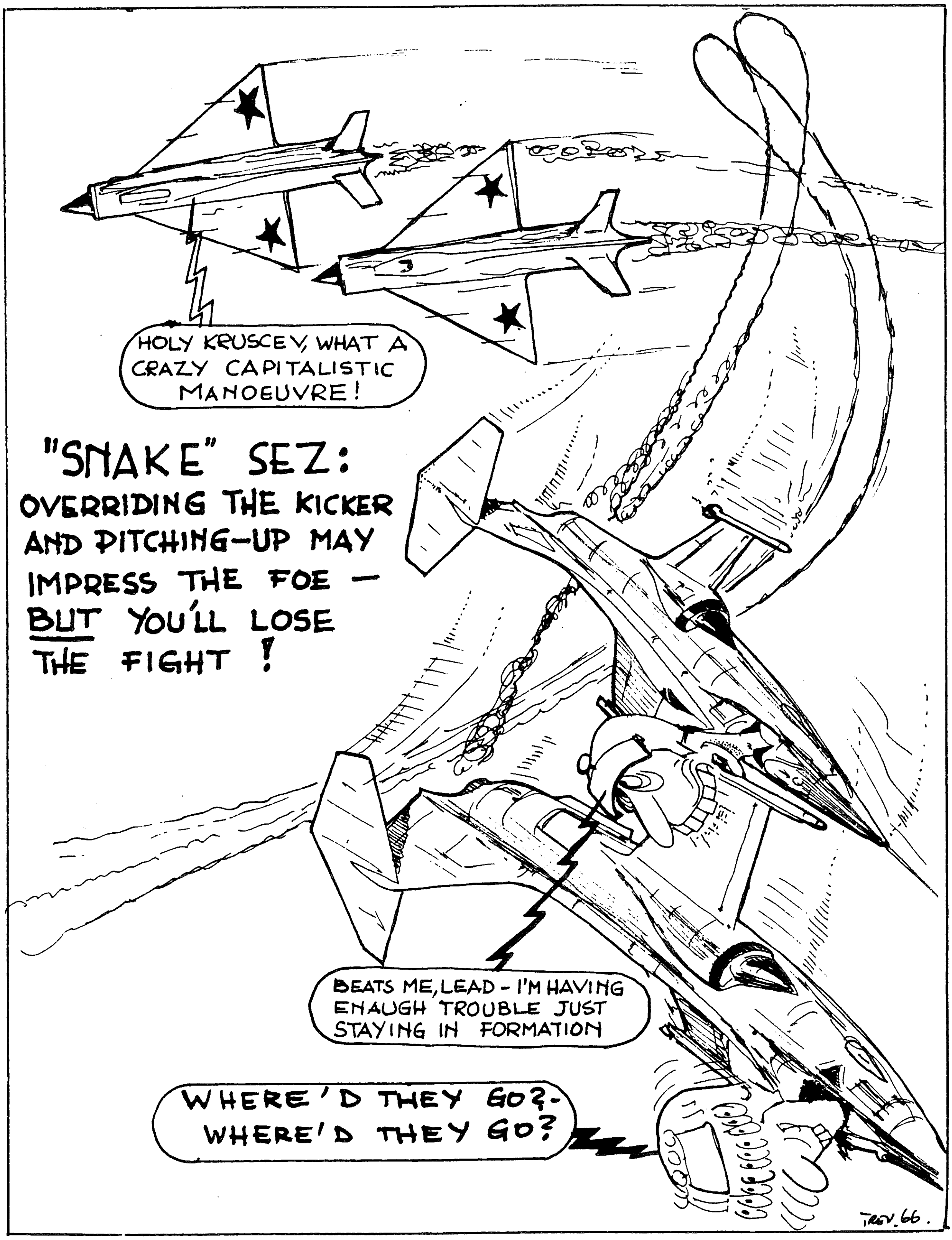
Eventhough I stated earlier that turn capability still was deemed important in World War II, I would like to quote a statement by one of the leading Ac in that conflict to show how it was even then losing its importance. Adolf Galland states "The old fighter pilots from World War I, who were now sitting at the joy stick of the supreme command of the Luftwaffe, with Go at their head, had a compulsory pause of 15 years behind them, during w they had probably lost contact with the rapid development of aviation. Tl were stuck on the idea that maneuverability in banking was primarily the determining factor in air combat. The ME-109 had, of course, much tc high a stress per wing area and too great a speed to have such abilities.

*Reference 10, Chapter 2

And look at where we are today. We still receive reports of pilots attempting to dogfight a slower aircraft by high g turns in the F-104. The resultant pitch-ups and spins graphically portray the uselessness of these tactics.

"OK Snake, now that you've thrown out the scissors, the reverse, yo-yo and all our turning maneuvers--what we gonna do?"

You're going to sweep "X" and his pals right out of the skies, Ace-- and I'm going to tell you just how you can do it.


HOLY KRUSCEV, WHAT A CRAZY CAPITALISTIC MANOEUVRE!
"SNAKE" SEZ:
OVERRIDING THE KICKER AND PITCHING-UP MAY IMPRESS THE FOE — BUT YOU'LL LOSE THE FIGHT !
BEATS ME, LEAD - I'M HAVING ENAUGH TROUBLE JUST STAYING IN FORMATION
WHERE'D THEY GO?- WHERE'D THEY GO?
TREV. 66.

SECTION IV

Air Combat Tactics based upon the Energy Maneuverability Concept

At this point in my discourse, I want to repeat my statement in the FOREWORD that you must constantly conduct open-minded studies to achieve your mission. And that's just what I want you to do right now--because we are going to embark on some ACT considerations that run counter to today's tactical doctrines and training. But, if you will follow me through this I can guarantee that you will learn something that you won't find anywhere else. So latch onto my wing and let's aviate.

DEFENSIVE ACT

In order to make my points absolutely clear to you, I will divide up the ACT, based upon E-M considerations, into a defensive and offensive posture. Quite simply, I want to show you how you can obviate any attack, due to your superior performance, and then how you can reattack and fight on your own terms.

From a defensive posture standpoint the only solution is to assume that we are being attacked and to give the attacker every known advantage at the initial engagement point. Therefore, let's start out with us intruding into the airspace of Airplane "X" so that he has no fuel problem. And we'll be flying at 35,000 feet and at .9 Mach number. This intrusion results in "X" scrambling up and GCI positions him for a nice advantageous attack on us. All of a sudden, at 3 miles away we visually pick up "X" at our 5 o'clock position and he is coming in at 1.2 Mach and has a 2,000 foot advantage on us--a perfect high side pass opportunity. Alright Ace, what are our possible moves? Turn? Nope. Climb? Nope. There's only one thing to do--DIVE IN FULL AFTERBURNER. Are we running away? Nope--we're charging in a different direction. The tactical soundness of this move is corroborated by the following facts:

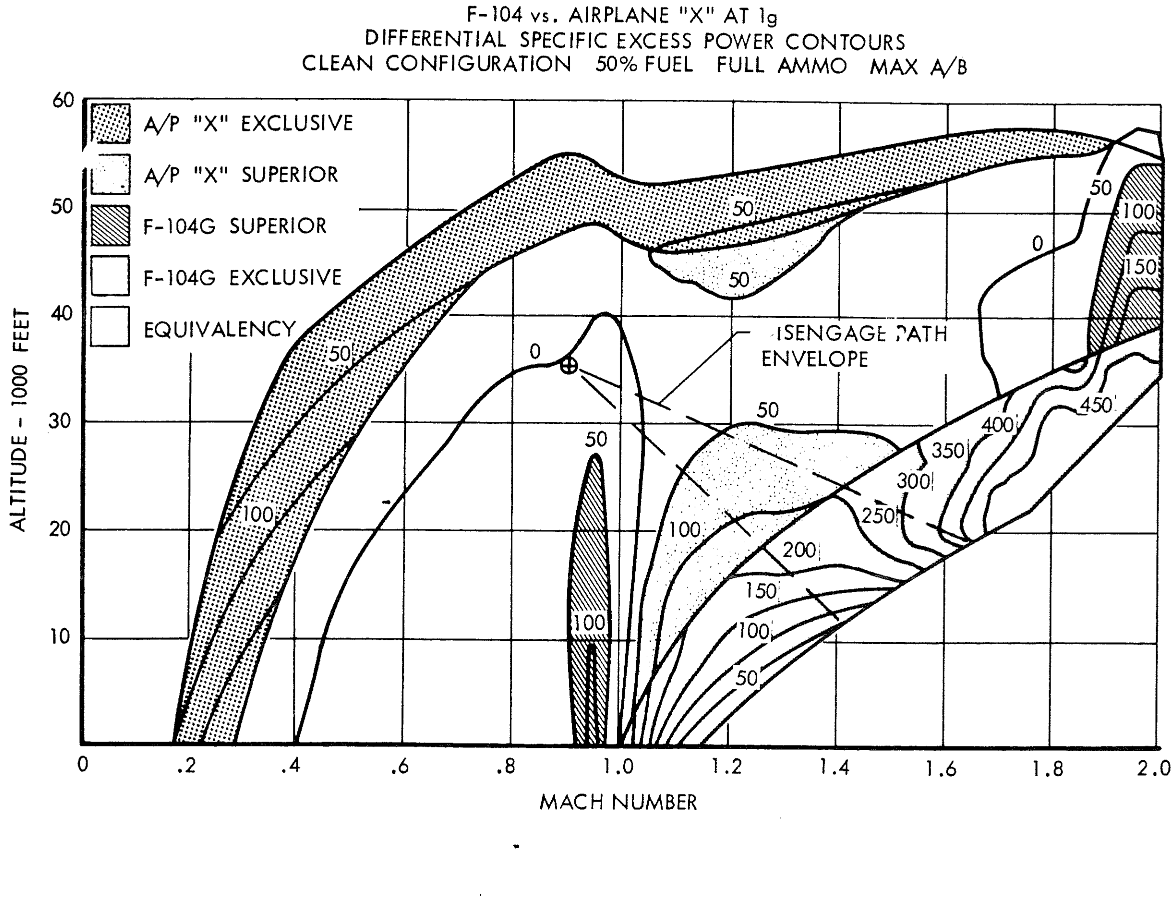
1. You are rejecting all other tactically unsound moves and are flying toward your area of advantage.

2. The attacker is kept out of gun range and you are moving out of missile range by going to the lower altitude region. Also, for heat seeking missiles, you are presenting the problem of the missile looking toward the ground with the high IR diffusion from the earth.

3. As you reach the structural limit line of Airplane "X" his attack is now completely negated due to his risk of aircraft structural failure or loss of control due to diminished stability.

4. Upon arrival in your exclusive area, you are reaching performance levels that will turn the option for attack over to you. How? It's simple.

Accepting for the moment, your ability to disengage from the attack of "X", let's examine the Differential Specific Excess Power Contours in order to better define the disengaging maneuver path.



You can see that your main effort is to strive for 1.4 to 1.6 Mach number between 13,000 and 20,000 feet. And when you get there--now what do you do? CLIMB FOR <u>YOUR</u> ATTACK! Checking the position of 1.7 Mach and 20,000 feet, you have over 20,000 feet/minute climb advantage over

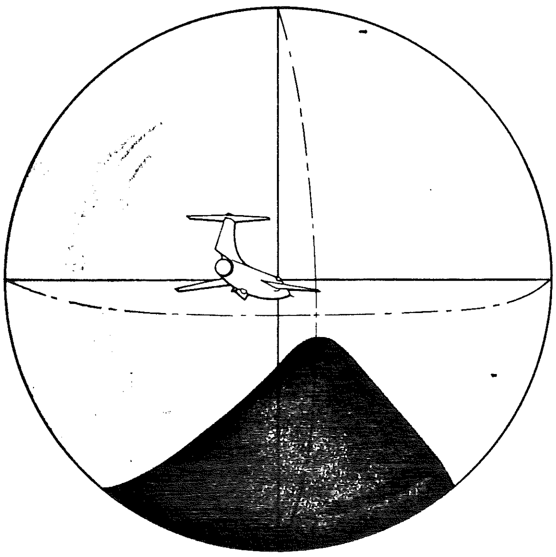
"X", so use it. As you climb skyward, "X" will lose visual contact and for him--the war is over. Because now the option of attack belongs solely to you.

Since this disengaging maneuver is so critical to your survival, when the attacker has all the tactical advantages, I want to go into further detail about technique and performance.

At the point of detecting the attack, you should immediately utilize a nose low .5 to .7 g rolling pushover--away from "X's" direction of turn. As "X" is in a right banked curve of pursuit, this forces him to attempt much greater negative g to keep you in sight. Instead of pushing over violently, in all probability, "X" will half-roll onto his back and pull positive g to maintain visual contact. This move results in your F-104 accelerating under very light g load and "X" trying to track and overtake you with positive g's. Obviously the advantage in acceleration lies with you and your light g load. Flight experience has shown that you will quickly reach Mach numbers of 1.3 to 1.4 and below 20,000 feet you will reach your placard of 750 knots. Visual contact by "X" may be lost during the dive but assuming he retains contact, following you down until both of you are at or near your placard limits, as you climb up, he will lose contact due to your small tail-on view and the great separation range you have now achieved. Of course, if you also lose sight of "X" during your climb, the entire engagement is effectively terminated. But, at least the odds are 50-50 that you will be in a better position at the next contact. With a little practice in utilizing a very slow climbing, low bank angle (30°) spiral at 600 to 750 knots below 25,000 feet or 1.3 to 1.4 Mach above 25,000 feet--you will be able to keep "X" in sight by looking back over your shoulder and playing your spiral climb. This is due to another great design feature of the F-104--its visibility from the cockpit. You are sitting in the absolutely best cockpit of any Mach 2.0 fighter in the world. The following photograph describes it better than I can.

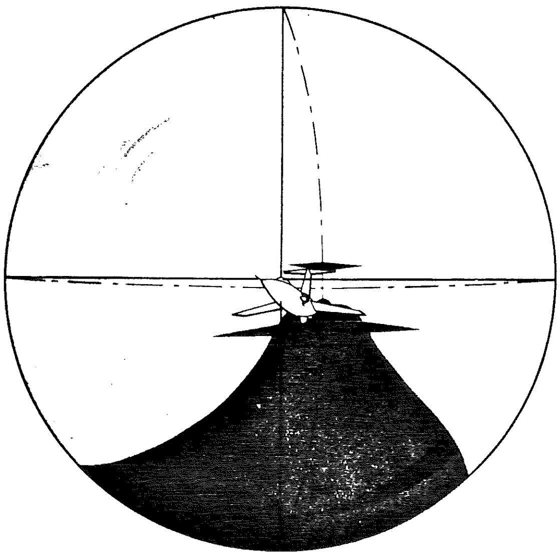
For your ACT studies, I am including a hemispherical plot to show you the angles of visibility available to you from your cockpit.

COCKPIT VISIBILITY



FORWARD HEMISPHERE

Visibility is approximately 78.9%



REAR HEMISPHERE

Visibility is approximately 77.5%

This tremendous advantage of cockpit visibility will be completely worthless, though, if you don't keep your head "out" and "on a swivel". Adolf Galland stated this ACT axiom rather clearly when he wrote, "The first rule of all air combat is to see the opponent first. Like the hunter who stalks his prey and maneuvers himself unnoticed into the most favorable position for the kill, the fighter in the opening of a dogfight must detect the opponent as early as possible in order to attain a superior position for the attack."*

If, through your skill and cunning, you kept your eyeballs glued onto "X" during your climb away--you would notice:

1. Consternation at losing sight of what was a "dead pigeon" just a few seconds before.

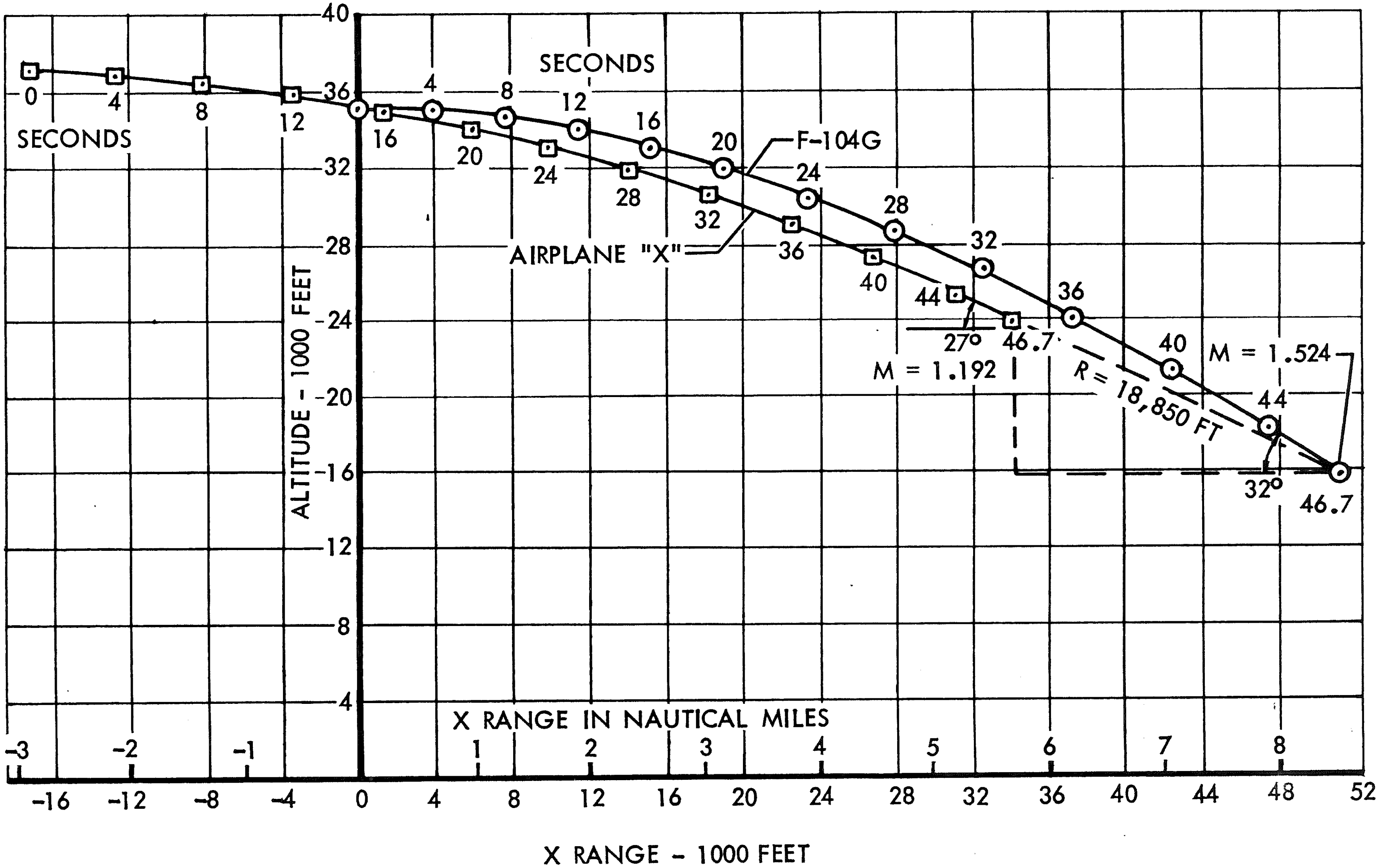
2. Confusion about what to do because <u>"X" can't attack that which he can't catch or can't see</u>!

3. Some type of maneuver that "X" would undertake to definitely break off the engagement. And as "X" begins this maneuver, it is a clear signal that the attack option now lies in your hot little hands.

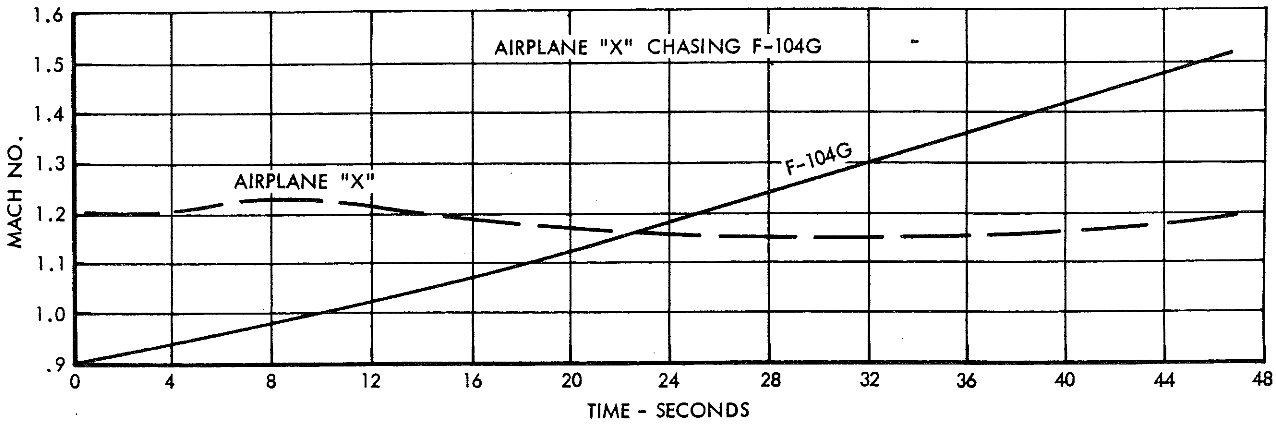
Going back to our disengaging maneuver, I want to thoroughly prove the sound feasibility of this move. If we start at the initial engagement points and plot the displacement of both aircraft through their dives toward their placard limits, we will be able to observe the performance comparisons and therefore prove our capability. To do this, I again had the boys crank up the IBM 360 computer and we had the black beast conduct this phase of the combat. All computers have certain limitations, though, and we were not able to carry out the disengage maneuver under 3-dimensional parameters. So, we'll have to be satisfied with a 2-dimensional solution of the resultant flight paths. Giving "X" every break in the book, we'll see what the computer says will happen if he is 2000 feet above us, 3 nautical miles behind and has an overtake Mach of 1.2 to our cruise condition of Mach 0.9. At this contact point, we go into full A/B, push over and fly a 0.5g flight path until approaching our placard limit. The black beast gives us an x-y plot that is doggone interesting. And here it is with the actual predicted paths plotted to show time, altitude and range separations.

* Reference 10, Chapter 3.

AIRPLANE "X" CHASING F-104G

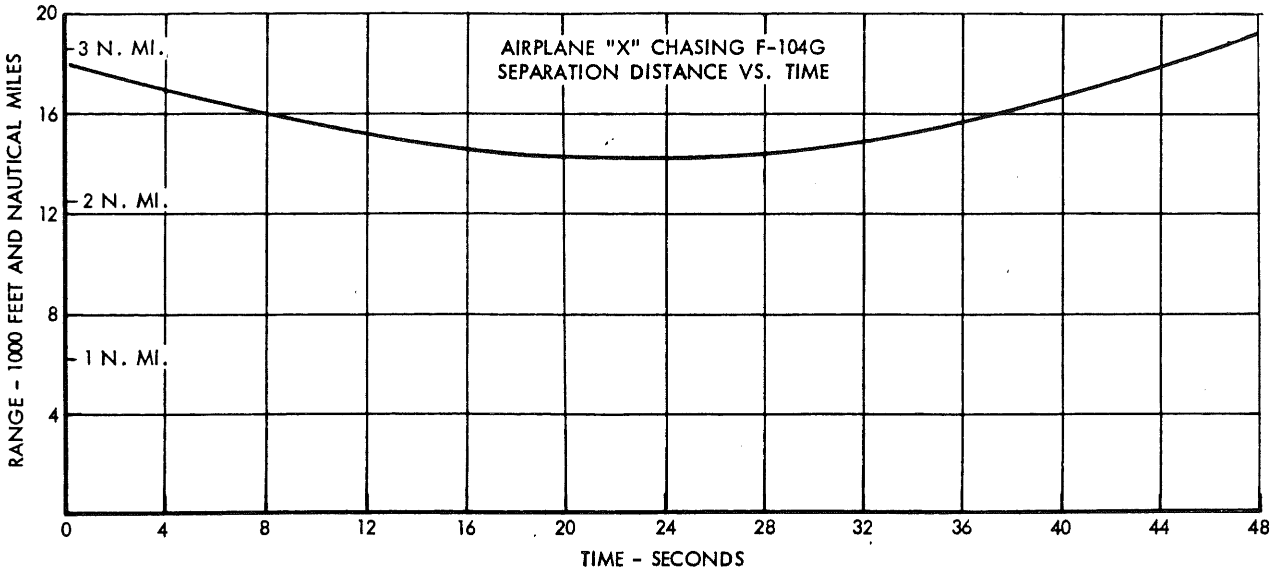


An analysis of this plot is definitely in order. What does it tell us? First, that we have attained an increase in Mach number from 0.9 to 1.524, in 46.7 seconds (assuming that we flew right up to the placard limit, while holding the 0.5g path). Second, during this time we went from a level flight attitude to a 32 degree dive angle where we hit the placard limit. Third, we cover over 8 nautical miles in range while losing 19,600 feet of altitude. And a most interesting development in this resolution of flight paths is that the black beast also predicted that "X" must roll over on his back and pull positive g to be able to track us in pure pursuit during our pushover path. A further analysis of this maneuver comes from plotting critical variables vs. time. For instance, what are the Mach numbers of both aircraft during their relative paths? The computer plot is this.



Look at our steadily increasing Mach number while "X" is <u>not</u> increasing. This definitely means that we are increasing our energy level while "X" is hamstrung by the necessity of pulling an increasing g load to maintain contact and attempt tracking.

Another critical factor is the variation of range separation vs. time. Our flight experience tells us that "X" will close to some minimum range point before our increasing Mach number will begin to take effect and result in an increasing range separation. The computer plot looks like this.



Look at this! "X" never gets closer than 2.3 nautical miles in range, between the altitudes of 29,700 feet down to 28,200 feet, and then he steadily loses range until we're over 3 nautical miles away at the time that we hit our placard limit and "X" is now 18,850 feet behind and 8000 feet above and losing out at a rapid rate. Therefore, we can positively say that we've remained out of gun range during "X's" entire thrust and I leave it up to you to analyze any possibility of "X" being successful with a missile launch. But remember:

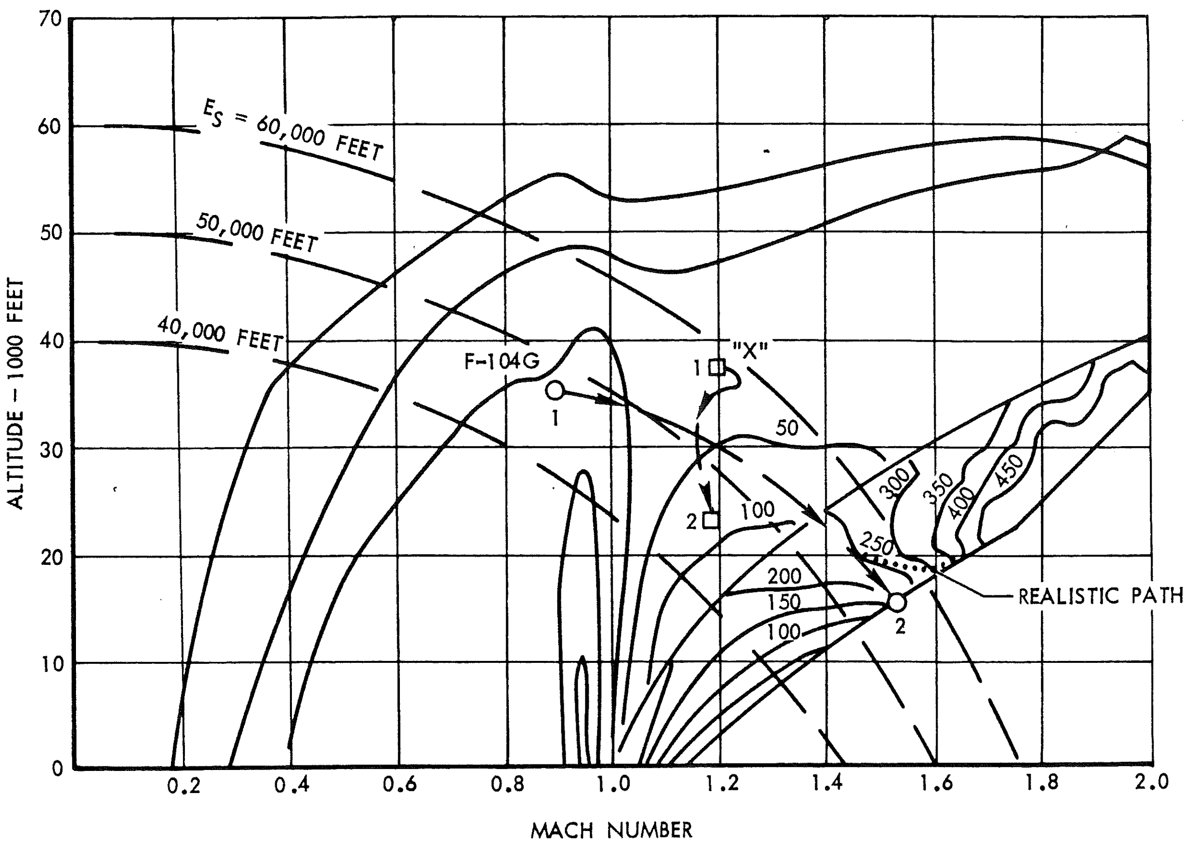
1. You're forcing "X" to look at the ground with the corresponding high IR diffusion.

2. "X" is forced to pull a high positive g load for tracking, and this is very limiting on his missile launch envelope.

3. The range capability of any missiles that "X" has is rapidly decreasing with the loss of altitude.

A final analysis of this maneuver is to plot the paths on a 1g E-M Differential envelope and see what happens. We should note that these paths are approximate in relation to the P_s contours because the two aircraft are not at 1g--but it's a worthwhile comparison, so here it is.

AIRPLANE "X" CHASING F-104G
DIFFERENTIAL SPECIFIC EXCESS POWER CONTOURS
CLEAN CONFIGURATION 50% FUEL FULL AMMO MAX A/B



This now shows us a very important fact, i. e., our 0. 5g pushover path is exceedingly close to the absolute optimum path for intercepting our placard limit line. Back in Section II, I showed you that the best path to follow to get onto the minimum time E-M intercept profile was to follow the appropriate E_s line until you arrived at your desired point on the profile. Our 0. 5g disengage path shows that we are wonderfully close to following the 50, 000 foot E_s line until arriving at the placard limit. But, we don't want to charge out beyond our limit, so the realistic path, again, involves a smooth intercept of the placard line. This is really our best move, because even though we have to pull a few g's to level off, we're increasing our P_s value. And again, you can see that we have over 20, 000 feet per minute climb advantage over "X", so all we gotta do is to pull the nose up.

OFFENSIVE ACT

Our proof of successful disengagement capability and the development of our defensive ACT helps point the way to conduct our attacks on "X". After the separation and you're in the position of altitude advantage over "X", you should now plan your attack to take advantage of all the factors in your favor:

1. Sun position; remember the tried and proven commandment. If possible, always attack from out of the sun.

2. Utilize the cones of darkness of "X's" airplane due to its design.

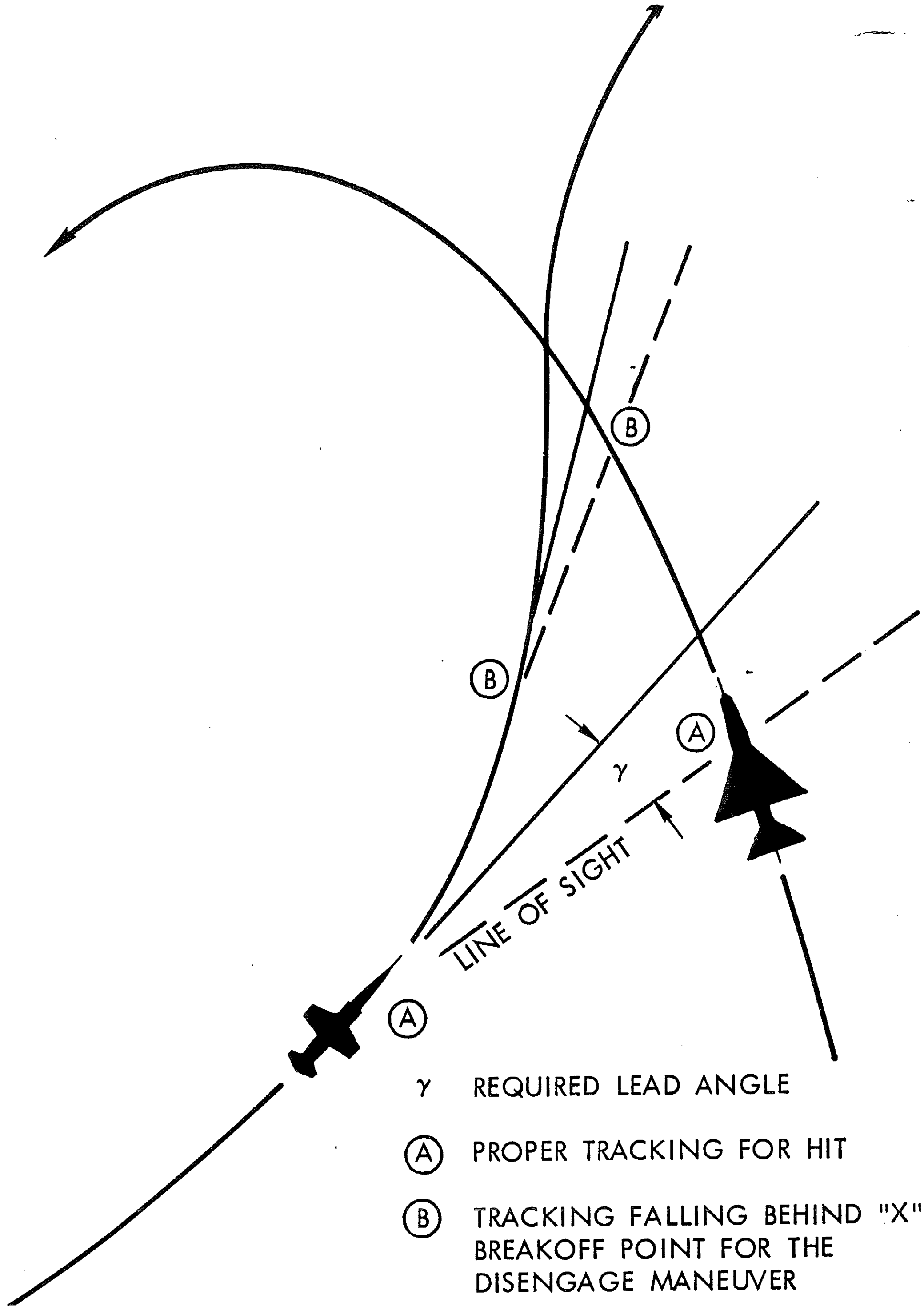
3. Use your high speed closure capability due to your position.

4. Exploit "X's" mental attitude. At this stage of the game, after losing contact with you--he's shook!

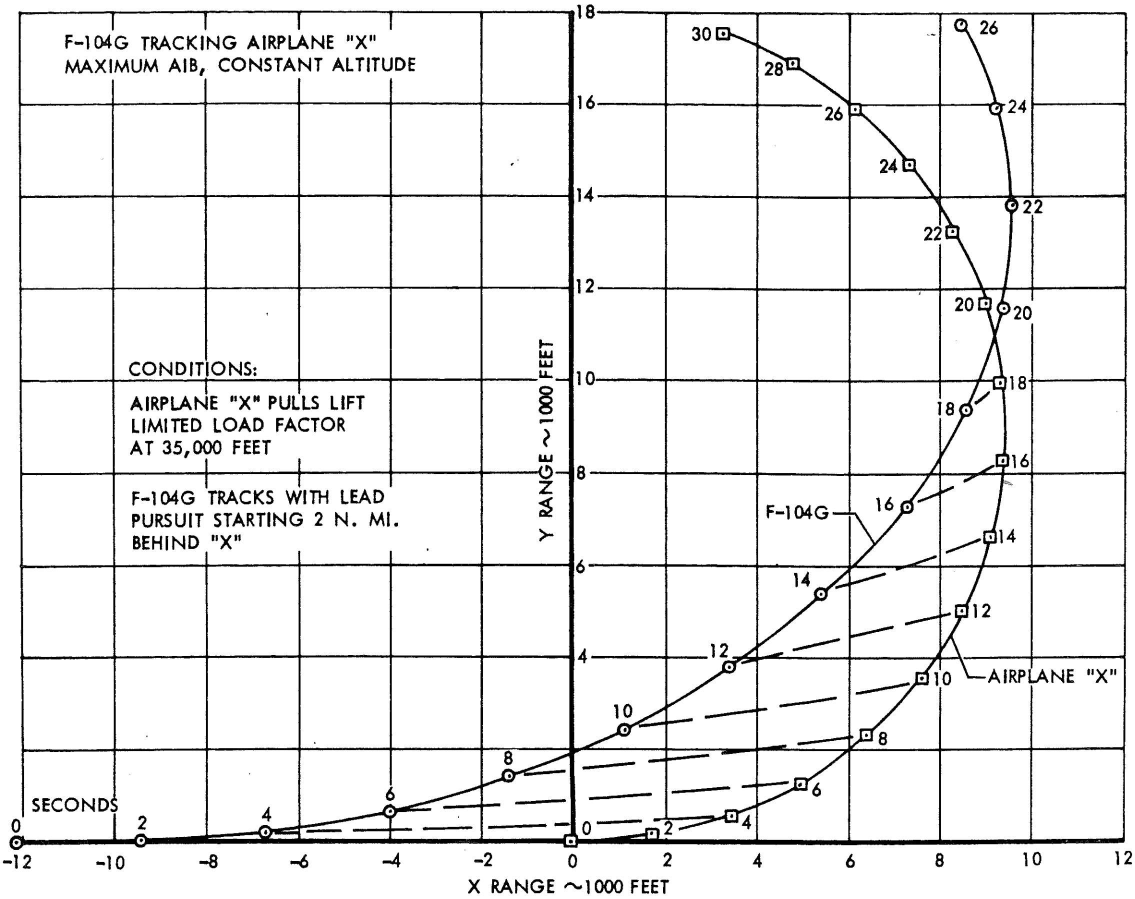
Using these factors you should press your advantages just like a stalking Tiger--pounce when you're sure of your attack.

1. Attempt to gain as much attacking airspeed as possible by utilizing a rolling full afterburner attack. This tactic will result in airspeeds of about 650-700 knots below 20,000 feet and indicated Mach numbers of 1.3 to 1.4 at altitudes above 20,000 feet.

2. Attempt to track "X" on your pass, which should be made from a blind zone. If you're successful in evading his search for you--he'll never know what hit him. If he is warned of your attack or sights you in time to attempt a high g turn to throw off your tracking, keep pressing but only up to a certain point. A simple graphic display can show what we all know from experience, i.e. once your tracking falls behind the turn of "X", you should break off because it's impossible to regain your tracking position.

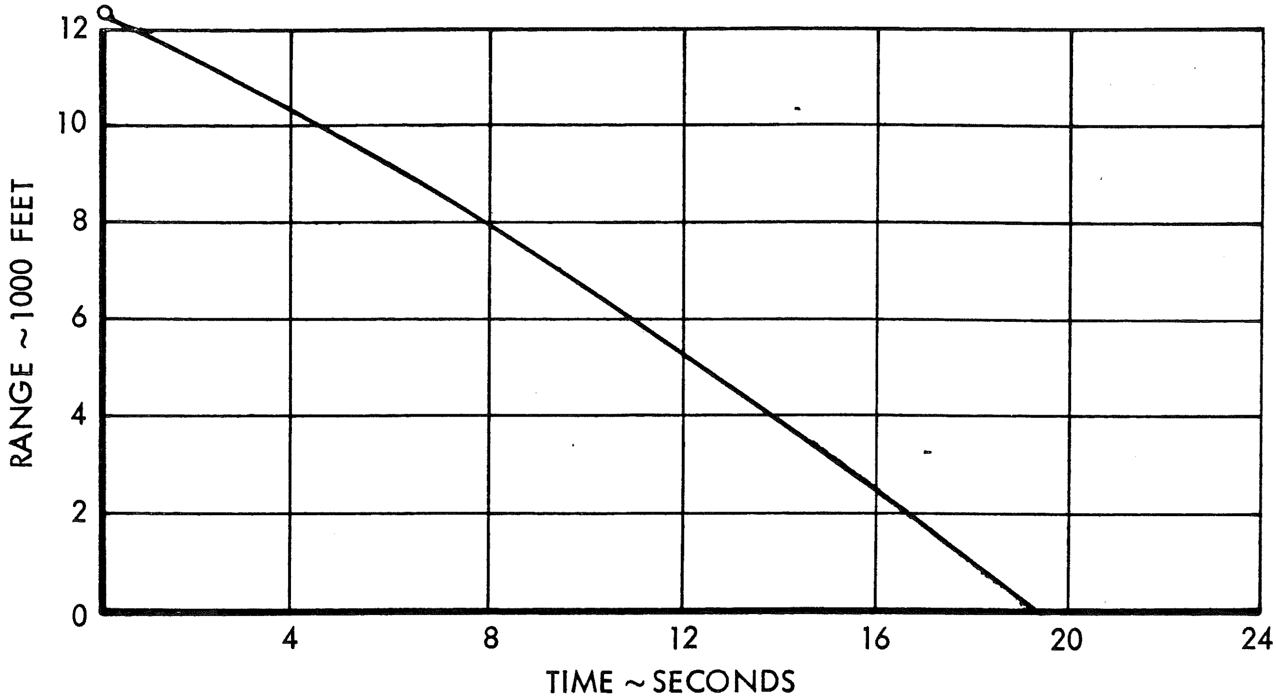


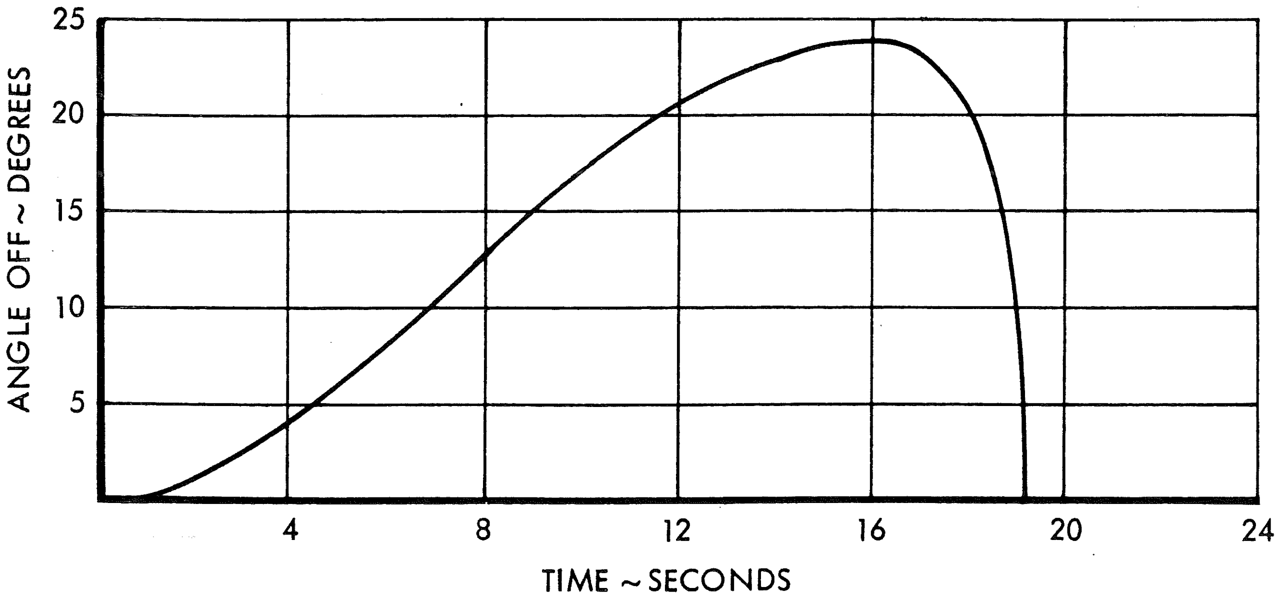
To give you a clear picture of your tracking ability and how to best use it, our IBM 360 computer has been kind enough to give us a tracking plot. Of course, we had to give the computer some parameters, so I selected a starting point of both aircraft at 35,000 feet but we begin at 2 miles behind "X" at Mach 1.4 and "X" is now at Mach 0.9. If "X" sees us coming in on him and breaks left with maximum available load factor, our tracking plot shows that we rapidly reduce the separation range and stay in Missile range before the g load and angle off puts "X" out of our Missile launch envelope. Continuing, you can see that we can still track and close for a short 1 to 2 second gun burst at a range of 2000 down to 1000 feet. After passing behind "X", we should proceed with our next move in our positioning.



For more accurate planning of our capability under these conditions the following two plots will yield more exact information on range and angle off.

F-104G TRACKING AIRPLANE "X"
MAXIMUM A/B CONSTANT ALTITUDE

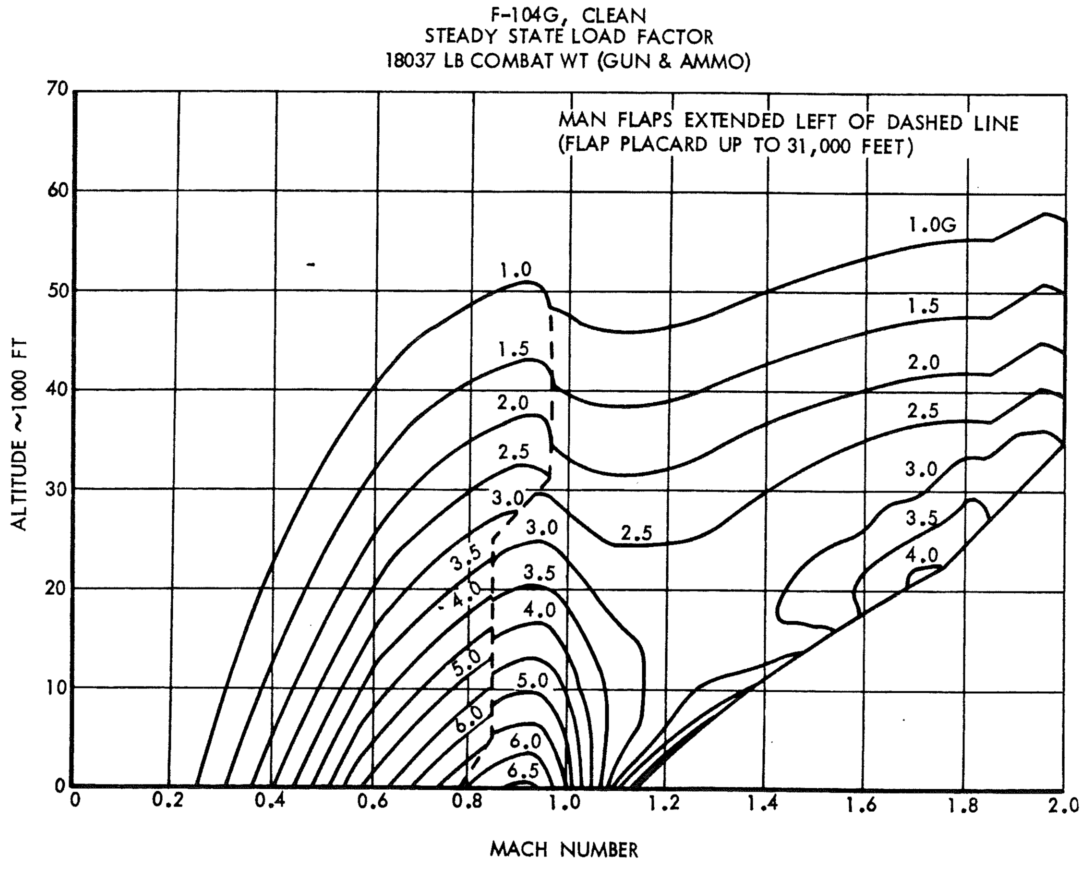




3. Your next step should be obvious; disengage again by a rolling pushover away from the direction of "X's" turn. This will again give you missile/gun separation before "X" can reverse his turn and attempt to track and fire. In all probability, "X" will even lose visual contact again in your dive away and the spiral climb back to altitude. A climb into the sun will help assure loss of contact.

After this, a thoroughly demoralized "X" will be heading for home, nervously looking back and wondering where you're going to come from next. It's up to you to put him out of his misery.

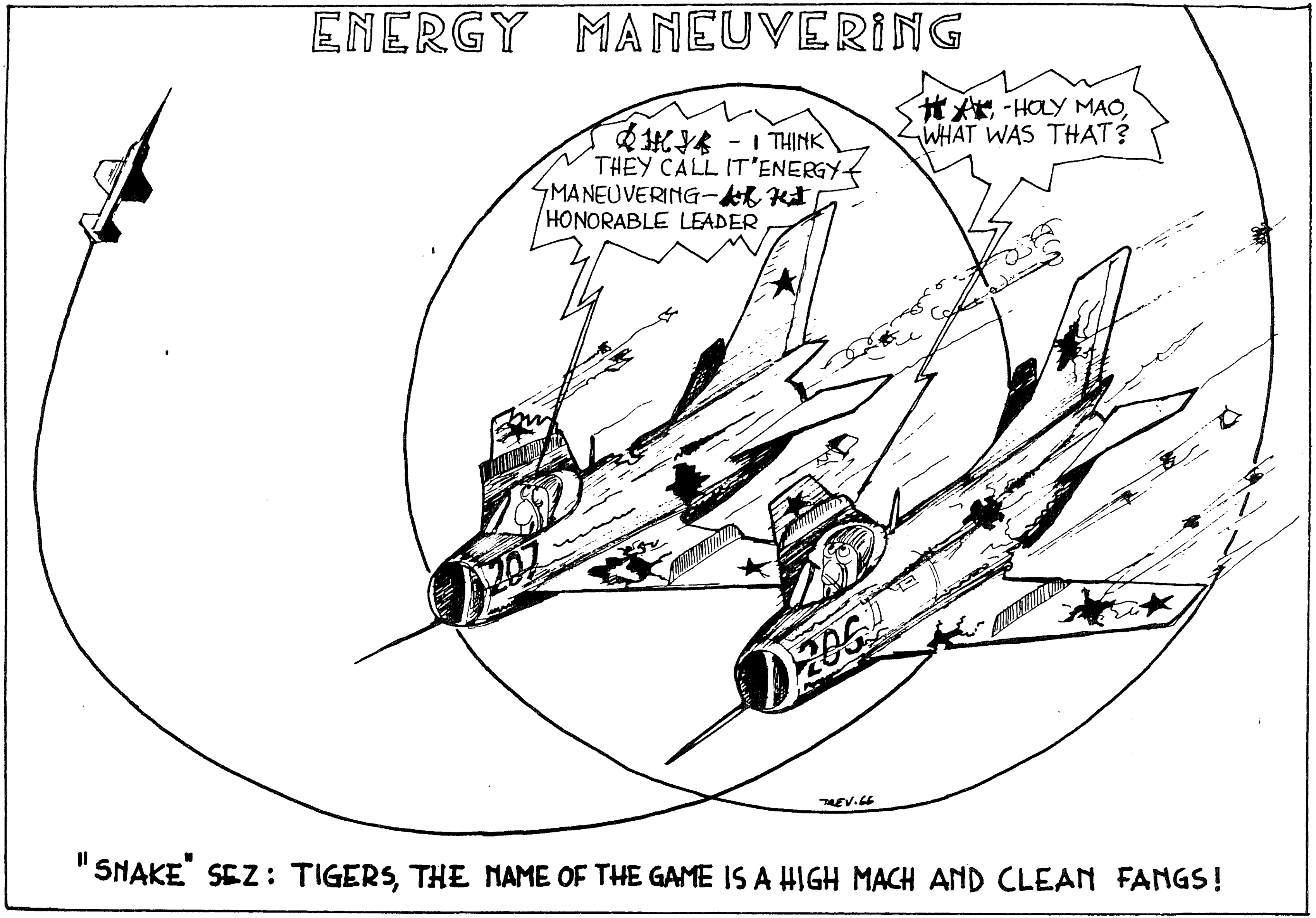
To cover other situations of altitude and airspeed where you might meet up with "X" and be making a tracking pass, I now give you an F-104G sustained g load flight envelope to study. This plot, I'm sure, will endear me to those of you who are still adamant about pulling the airplane around as tight as you can. My purpose though, is to show you the area where you should use maneuvering flaps in your tracking of "X" throughout the flight envelope.



This plot will give you some excellent guidelines about when to use the maneuvering flaps. Essentially, any time you are to the left of the dashed line on the plot, you are better off by using the maneuver flaps with full A/B in your tracking of "X". But, even so, if "X" uses his full turn capability, you will eventually fall behind on your tracking pass and at that time, you should proceed with your disengage maneuver.

This cycle of disengaging and reengaging is exactly what I meant when I pointed out earlier that by utilizing the E-M concept, we could find out how to gain a maneuvering advantage even when we are forced to enter the engagement at a lower energy level but are capable of increasing the energy level during the course of battle. But, I will be the first to agree with you that the limitations of the E-M Differential Specific Excess Power Contours preclude their being the entire answer to analyzing ACT. A distinct limitation is the inability to show, during the course of battle, the fuel loss (internal energy) of each airplane. If this could be shown, then we could plan ACT wherein we could utilize the fuel flow efficiency of our engine to its best advantage against "X". In the initial stages of contact, judicious use of the afterburner, with primary emphasis on Military Power maneuvering, might eventually force "X" into the position where he can't go into A/B and still get home. In this case, "X's" high performance, short range fuel situation can "backfire" on him.

Offensive ACT are, of course, aggressive attacks carried out until the enemy is destroyed. Once you are in the attack phase, you must be relentless until your mission is fulfilled. Anything short of this is unacceptable. For a more thorough analysis of pure tactics, we now need to study the Double Attack System.


ENERGY MANEUVERING
- I THINK THEY CALL IT 'ENERGY MANEUVERING- HONORABLE LEADER
-HOLY MAO, WHAT WAS THAT?
207
206
TREV. 66
"SNAKE" SEZ: TIGERS, THE NAME OF THE GAME IS A HIGH MACH AND CLEAN FANGS!

SECTION V

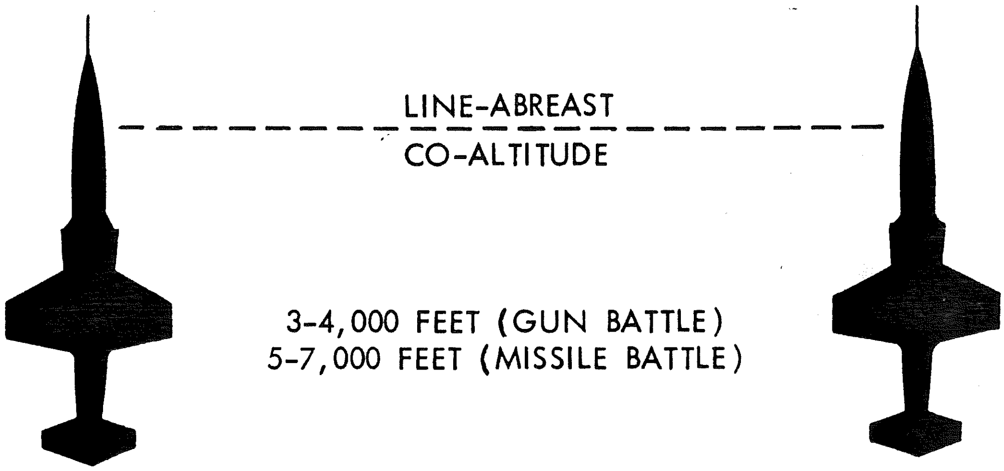
The Double Attack System

Lt. Col. Everest E. Riccioni, Associate Professor of Astronautics at the USAF Academy, is in my opinion the modern day "Oswald Boelcke" of the United States Air Force. Years ago, he rightfully deduced that the great disparity of performance between two fighter aircraft, such as the F-100C and Mark VI Sabre, demanded tactics other than those flown at that time. After dogged analysis and many experiments in ACT, he evolved a system that fulfills all of the Military Principles of Combat and is so logically sound that it practically begs for acceptance in the fighter squadrons around the world. In the unpublished manuscript of his book, "TIGERS AIRBORNE", Lt. Col. Riccioni has thoroughly and concisely analyzed all features of the aerial fighter operation. It should be required reading for anyone who professes to be a fighter pilot. I shall not repeat the brilliant arguments that Lt. Col. Riccioni makes for the Double Attack System (DAS) versus the Fluid Four, which is currently taught and practiced. Instead, I intend to inform you of the reasons for my firm conviction that a "marriage" of tactics based upon Energy Maneuverability and the Double Attack System will be next to impossible to defend against, especially if your opponents persist in flying the Fluid Four with all its built-in limitations.

In order to explain to you, in this lecture, about the beautiful manner in which the E-M concept complements the tactical effectiveness of the DAS, Lt. Col. Riccioni has kindly permitted me to reproduce the main points of his DAS along with the various applications of the DAS. OK, let's set the attack posture of the Double Attack System. Just where do we fly and what does it give us?

First of all, we fly in that effectively simple grouping--two aircraft. And these two fighters, as we shall see, split and weave so that full performance capability is utilized at all times. The DAS fighters are flown essentially in patrol spacing, line-abreast, co-altitude position. Pictorially, it looks like this:

THE DAS FLIGHT POSTURE



Referring back to our visibility diagrams, we can see that this flight position of our F-104's eliminates any area of darkness from which we may unsuspectingly be attacked. The distance separation allows practically continuous searching by both DAS pilots. All of you tired wingmen in the Fluid Four who spend at least 80% of your time watching the lead, to anticipate his next turn, will appreciate the freedom and application of two pairs of eyes searching 100% of the time for "X". In the Fluid Four lead element, for example, there is only one pair of eyes searching 100% of the time and the other pair searching for maybe 20% of the time. Once combat maneuvers begin, the wingman's searching, in the Fluid Four, reduces to zero--a small number!

"Well, what are the requirements of this Double Attack System?"

As usual, it requires understanding, precision and teamwork that comes from conscientious practice. And--oh yes--ample and propitious use of the UHF radio.

"And if we adopt this Double Attack System, what will it give us?"

Well, Chaps, Lt. Col. Riccioni has summed up the answer thusly:

The attack formation of the Double Attack System:
is the BEST DEFENSIVE FORMATION, is the BEST MISSILE/GUN ATTACK FORMATION, is the BEST FIGHTER ATTACK FORMATION, is the BEST BOMBER ATTACK FORMATION, is the BEST SUPERSONIC ATTACK FORMATION,

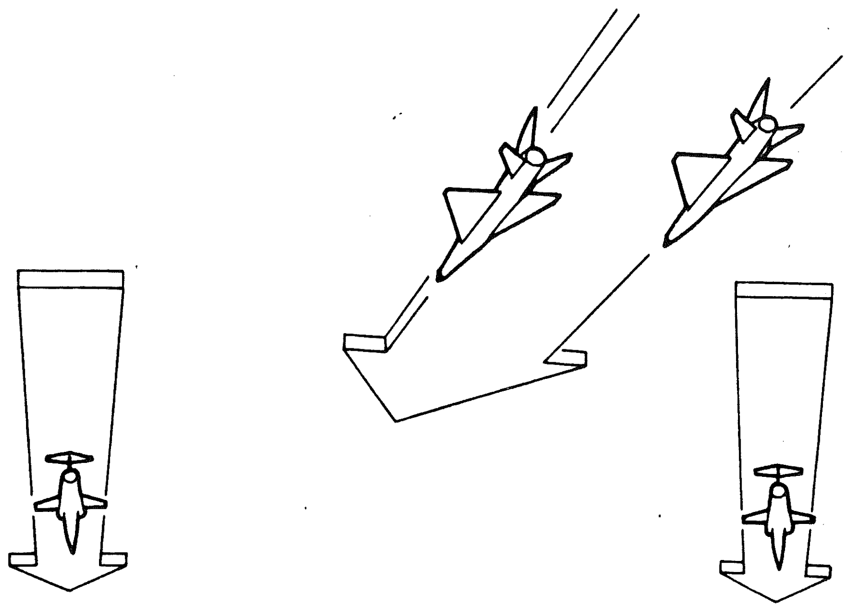
"Wowee--what a hunk you've bitten off there!"

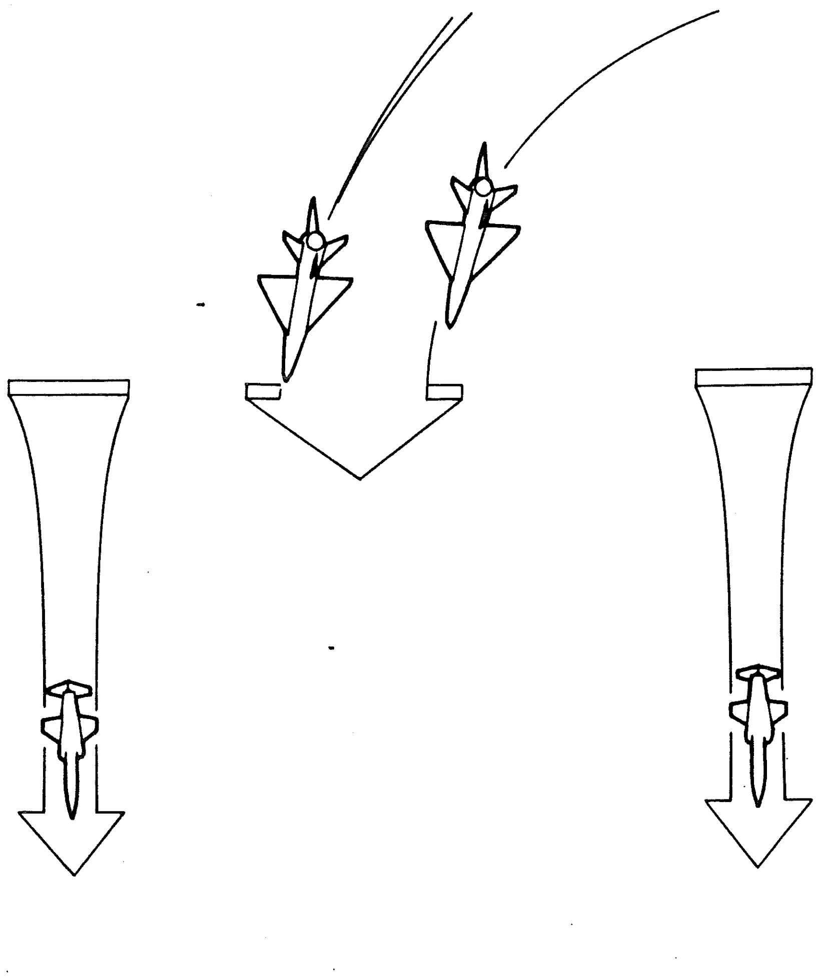
Right, and it can be proven if you'll crank up your thinking helmet and follow me.

The DAS Is The Best Defensive Formation

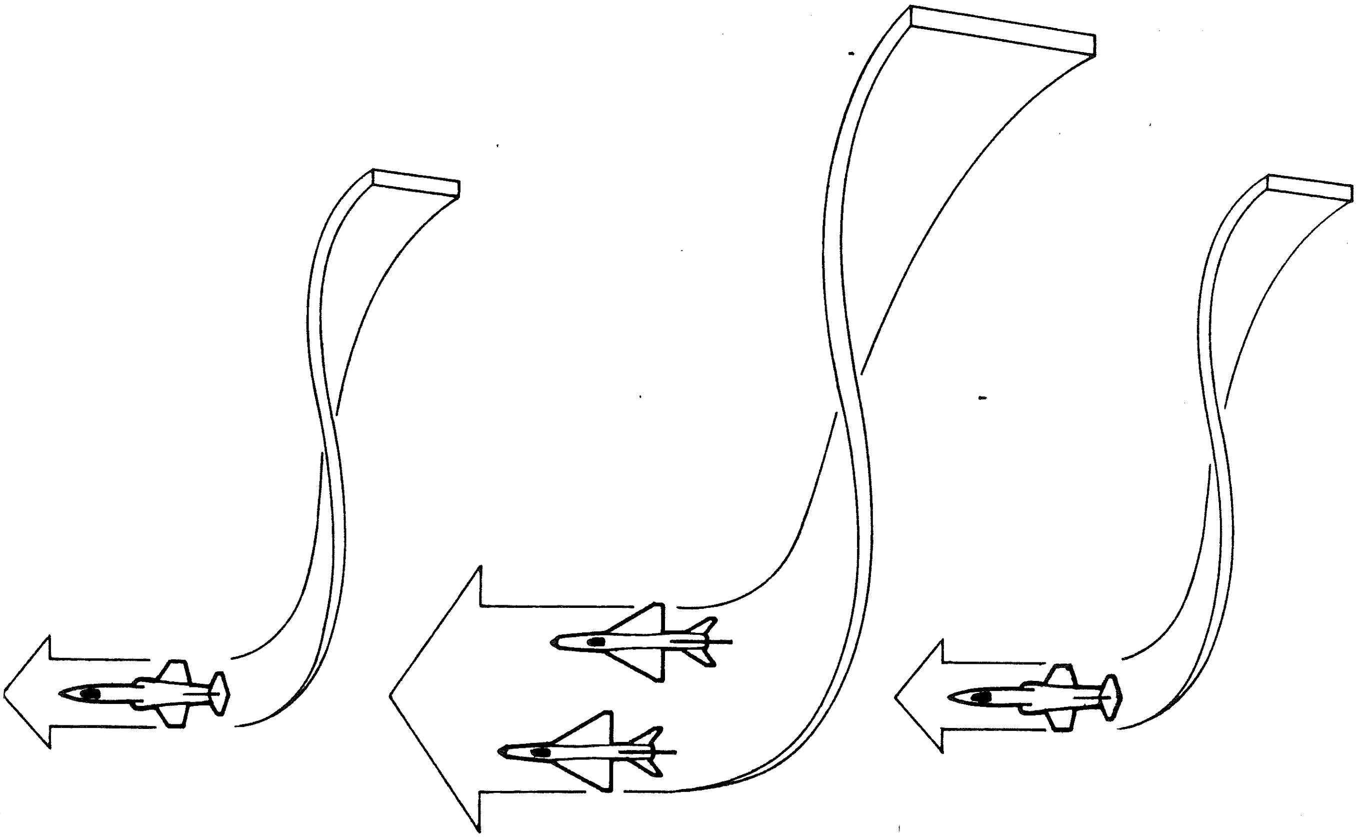
Our postulation of this precept of the DAS will be to return to the point of our being attacked by "X" and this time we'll give him a friend. And we'll assume that they are going to fly strictly by the rules of an element flying the Fluid Four tactics. Since we are now flying the DAS posture, we can exercise some tactical options. For instance:

1. The Sandwich: this tactic can be performed in the following manner. Since "X" and his wingman are attacking with an initial overtake rate, we must push over, go into full A/B and accelerate at least to a matching speed. This phase can be shown by our sketch.





Assuming that "X" chose to attack the left aircraft of our DAS flight, then a left 90° break will result in sandwiching the attackers between the two DAS fighters. The Sandwich tactic can be shown in this sketch.

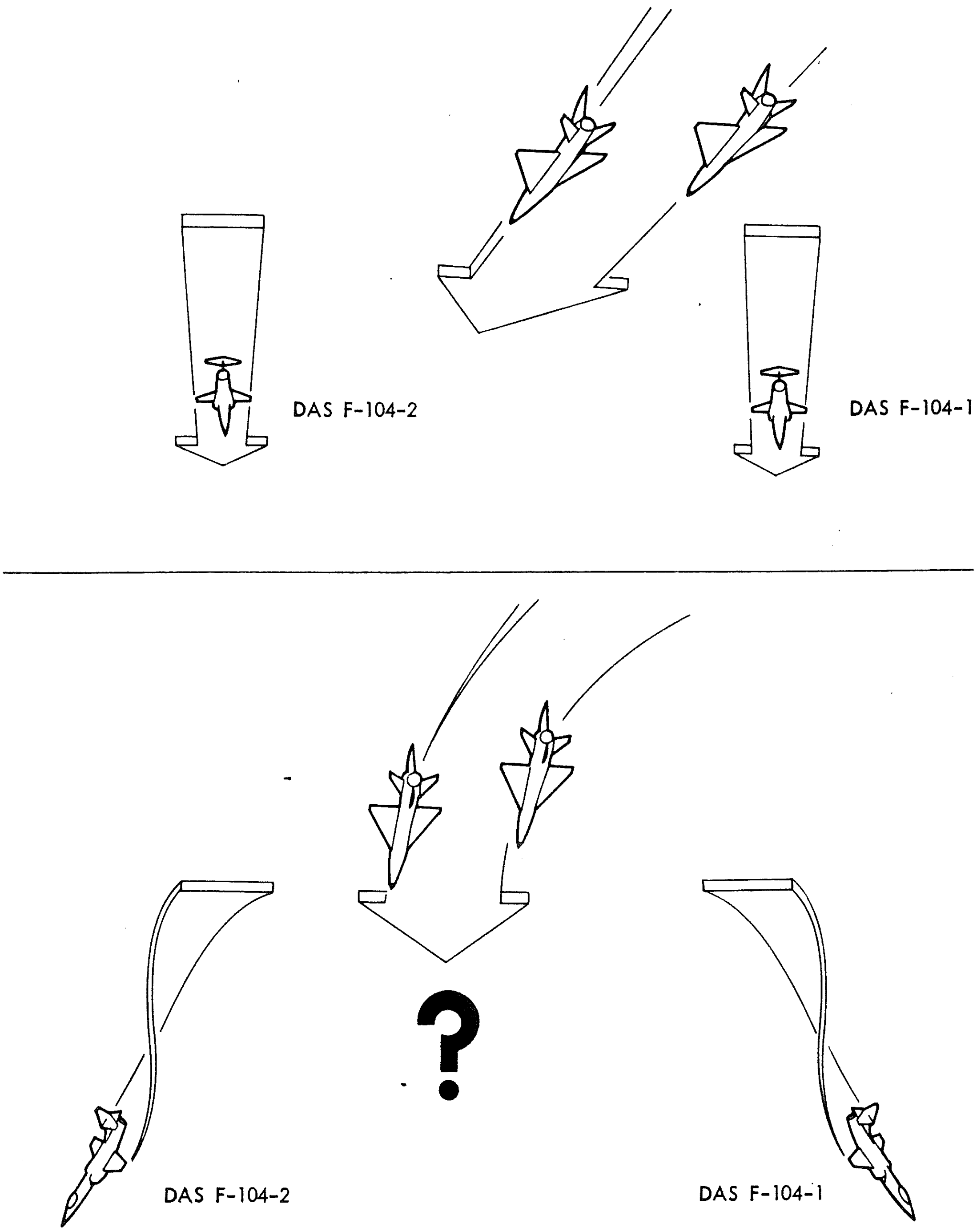


THE SANDWICH

I'm sure you are already discounting this maneuver as your best tactic. It's true that we now have one of our DAS fighters in an attacking position, but the other DAS fighter is unnecessarily exposed to a possible missile/gun attack by "X" and wingman before the attacking DAS fighter can make his presence known and force a break by "X" and wingman. A far better tactic would be to again perform the E-M disengage maneuver with follow-on DAS tactics. So--

2. The Defensive Split: using this maneuver, the DAS fighters push over in full A/B, as the attack is launched, and roll <u>away</u> from each other on diverging 35-45° headings. This move forces "X" and wingman to make an immediate choice of which DAS fighter to attempt to follow. Both DAS fighters accelerate to their placard limits and then begin climbing, while turning back toward each

other on a 30-45° converging course. Regardless of which DAS fighter that "X" and wingman attempt to follow, they will be unable to complete their attack as shown before. Our sketches will show this defensive split with both DAS fighters able to disengage.



THE DEFENSIVE SPLIT

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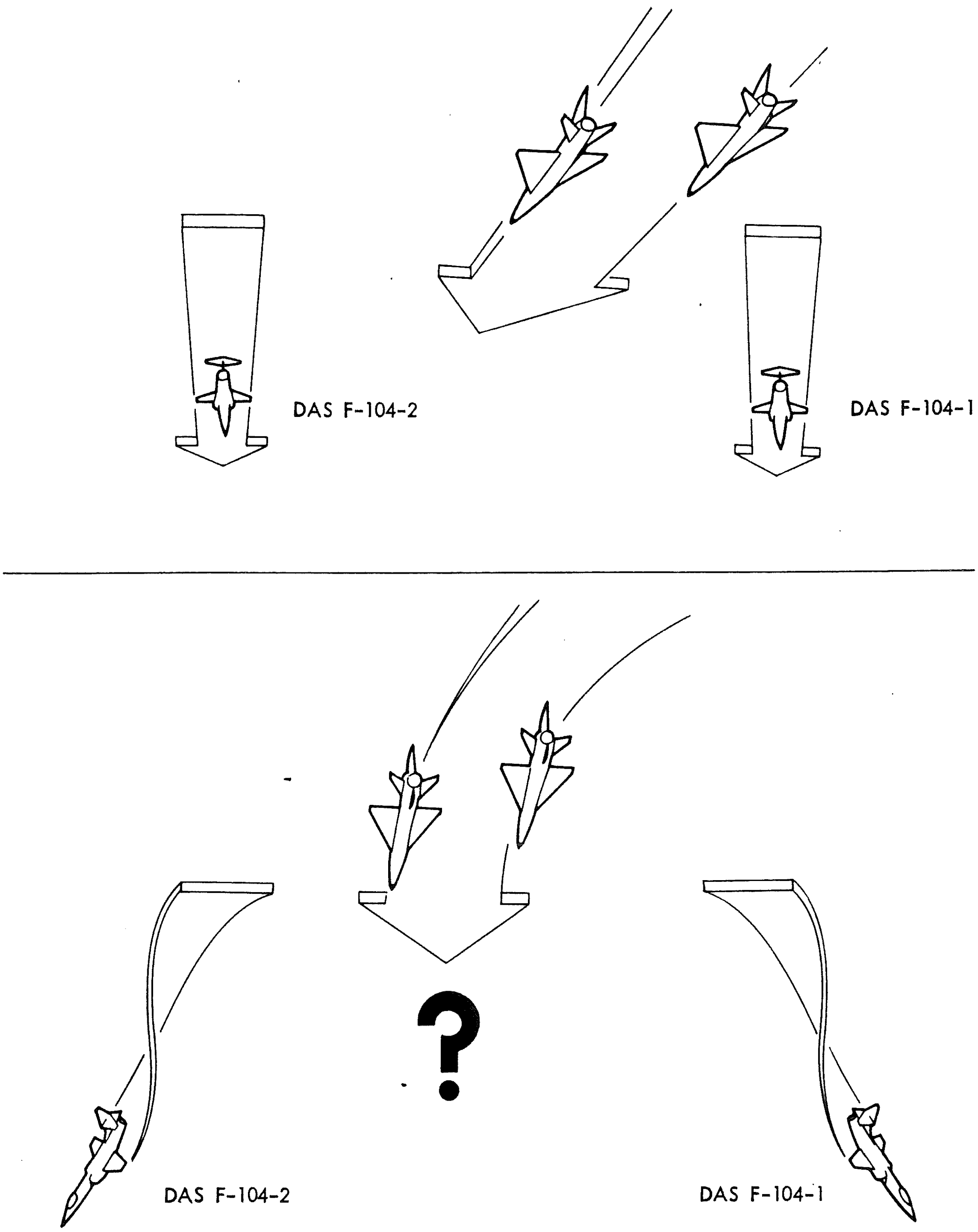
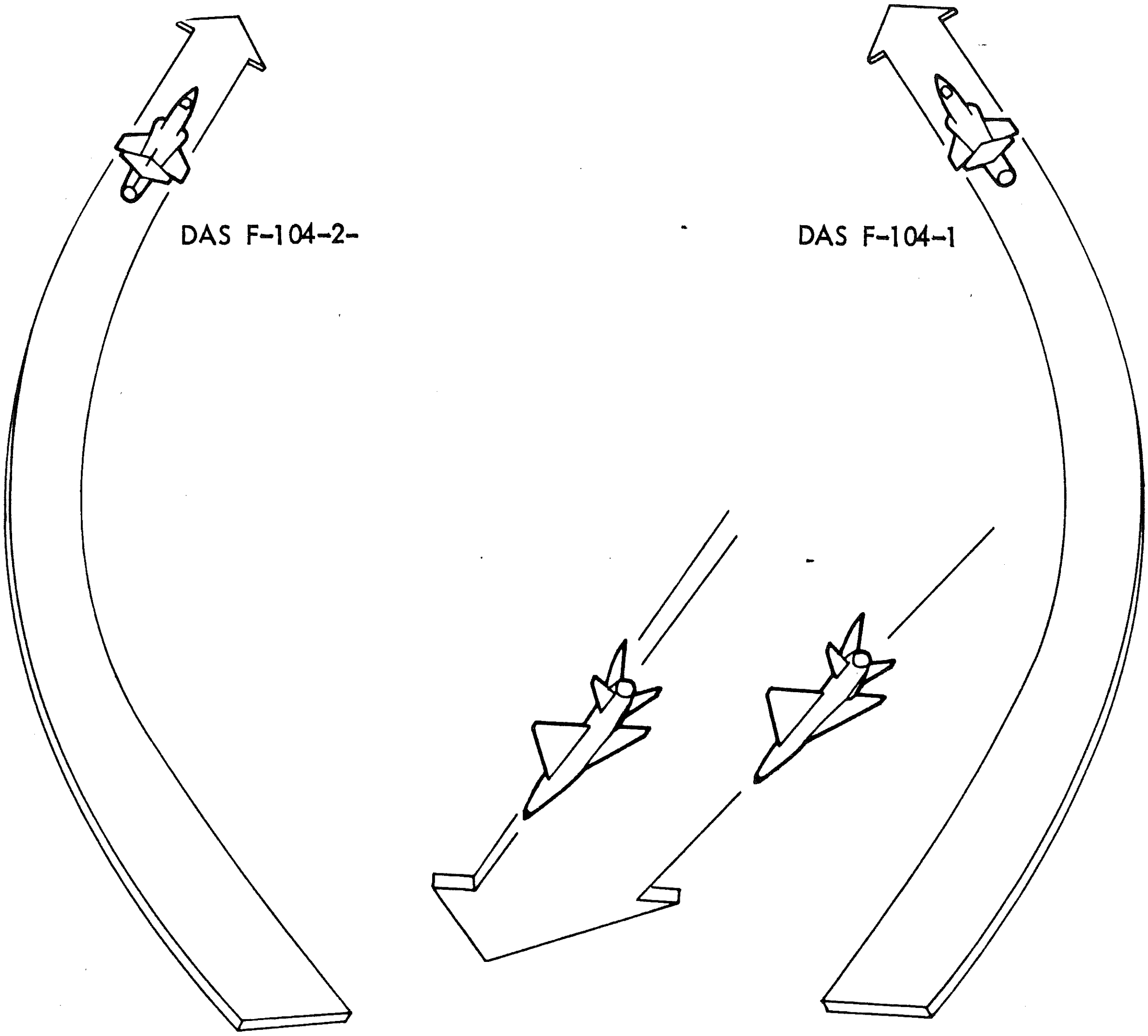


THE DEFENSIVE SPLIT



THE CLIMB AND REJOIN

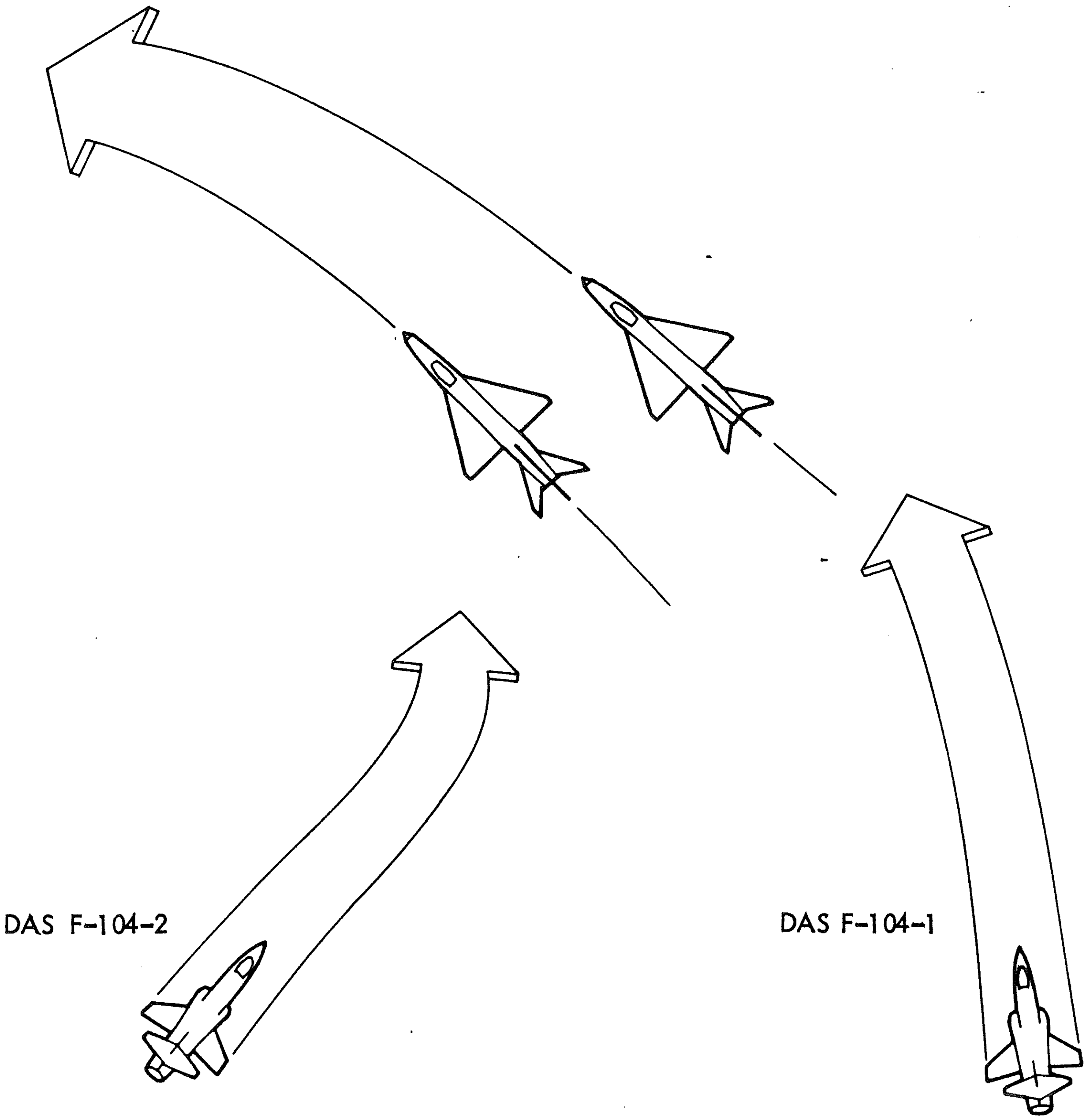
This development results in both DAS fighters disengaging and rejoining for the combined attack on "X" and wingman. All of the factors we discussed before, on offensive ACT, are in effect with a much greater attack capability as we shall see.

The DAS Is the Best Missile/Gun Attack Formation

I shall include both missile and gun attack together in this lecture because it is not my intention to go beyond the basic tactics of defense and offense. There are many excellent manuals that fully inform you of the details and technique for firing the missiles and gun. Some of the listed references are strongly recommended for your study.* They will tell you the procedures of firing--I want to help you get into that position!

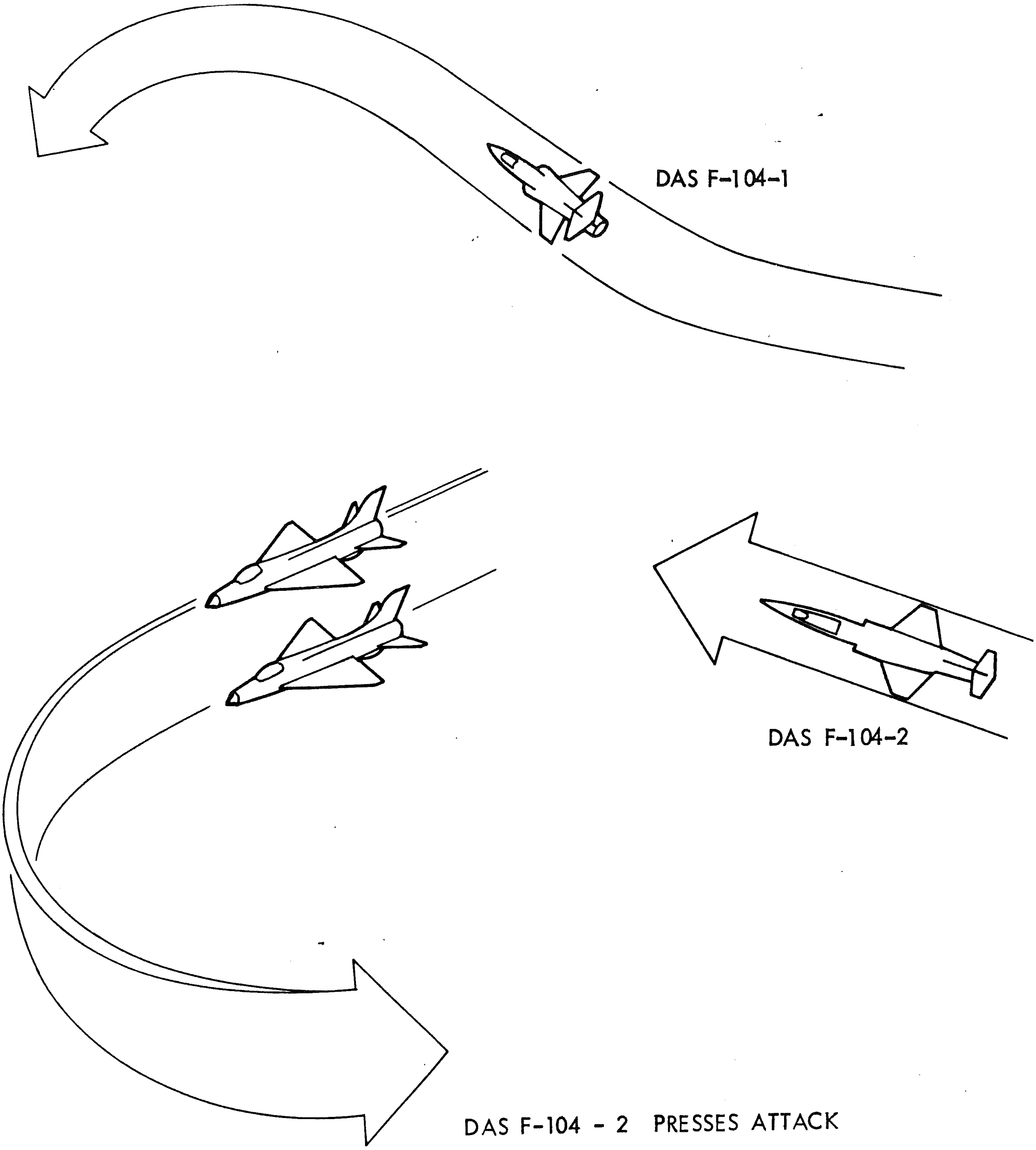
So, back to the dogfight, where our DAS fighters have disengaged and are converging back together on their shallow, high Mach climb. Since "X" and wingman are still together, thereby presenting a larger target, and with the freedom of search (and two pairs of eyeballs), there exists a greater chance that one of the DAS pilots can keep "X" and wingman in view. And that's all you need to now actuate the DAS Pincer attack. Again, we can expect a loss of visual contact by "X" and wingman since only "X" can be looking. And that yields exactly the same situation as before when "X" lost out when he was alone. Whichever one of the DAS pilots retains visual contact should verbally guide the other into the attack until both have "X" and wingman in view and then they can initiate the Pincer as shown.

*References 4 and 5

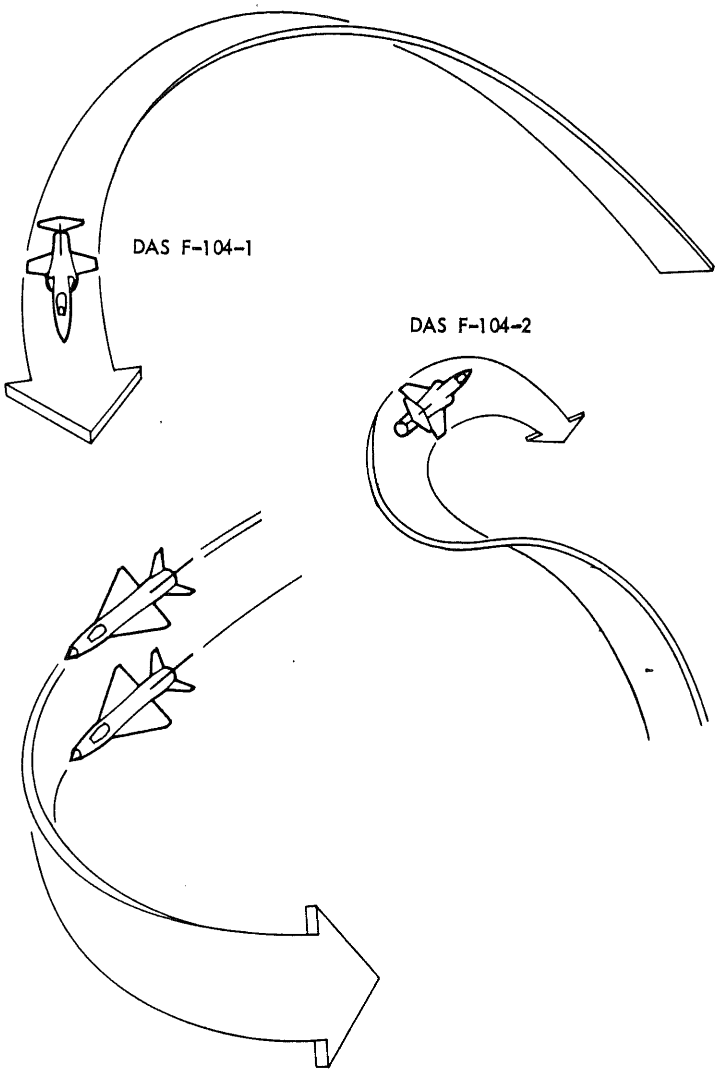


THE PINCER ATTACK

As our DAS fighters close in on "X" and wingman, they may launch missiles if they are not detected in their approach. If, however, "X" and wingman spot the DAS fighters and break hard in a turn (left or right), they will still be attacked by one of the DAS F-104's! The DAS F-104 that is not in position to continue tracking "X" and wingman zooms for repositioning and reattack. The other DAS F-104 presses the attack as shown in our sketch.



Assuming that "X" and wingman broke hard left, the DAS F-104-(2) still presses the attack. As his tracking begins to fall behind "X" and wingman, he simply breaks off and notifies DAS F-104-(1) that he is clear to come in. When DAS F-104-(1) comes in, he is lined up for a devastating 6 o'clock position attack while "X" and wingman have, in all likelihood, tried to keep their eyes on DAS F-104-(2) that broke off due to the tight left turn. The tactic can be shown by our sketch.



DAS F-104 - 1 PRESSES ATTACK

By using the Double Attack System, our F-104's have made three effective thrusts at "X" and wingman. And to the consternation of "X" and wingman, they haven't been in a firing position yet! Lt. Col. Riccioni has tersely stated this axiom. "No defender can cope with a simultaneous thrust from two different directions because an aircraft can only go in one direction at a time." At this stage of the game, our DAS F-104's would have accomplished one of the following:

1. Shot down both "X" and wingman.
2. Shot down either "X" or his wingman. Or---
3. Broken up the flight integrity of "X" and wingman and routed them from this hunk of sky. Since they could not defend themselves against the thrusts of the DAS F-104's when they were together, they definitely would not stay and try to fight alone. If they proved to be this foolish, then accomplishment 1. or 2. above, would be the inevitable result.

Just in case you might be wondering and thinking that the DAS allows the fighters to operate independently of each other--you're wrong. If this is your thinking, you don't understand the concept. The description of the Double Attack System that is given by Lt. Col. Riccioni is that the two fighters are a coordinating entity linked by sight, by radio, a common target and a formal system of attack. With this in mind, let's now prove the next precept.

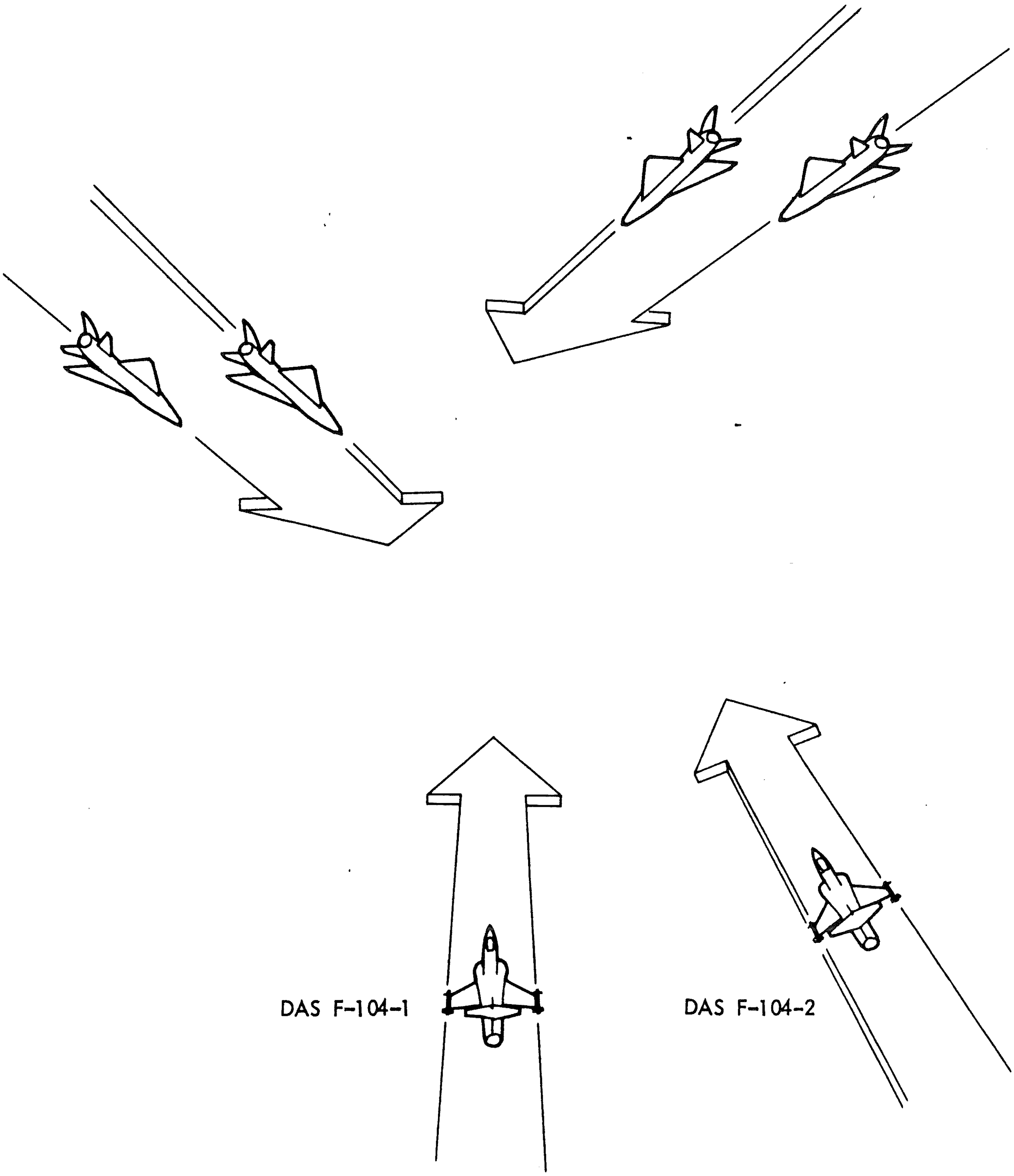
The DAS is The Best Fighter Attack Formation

There is only one real good test to apply to the DAS in order to prove this statement. And that is to have our two DAS F-104's attack "X" when he is leading a flight of four aircraft. The test given to the Double Attack System is to effectively attack and destroy a force that is superior in number. If this can be done, then we shall have proven our point. I believe that after we study this phase of the DAS, you will agree with me that the DAS is the only tactical system that you can use and confidently expect results when you're outnumbered. But don't misunderstand me--there's one absolutely vital ingredient always needed. That's two fearless, aggressive, mean and sharp fighter pilots. The Double Attack System is not for bomber pilots or the weak of heart. If you fall in this category, read on at your own risk. For those of you who want to blast "X" clear out of the sky--join up.

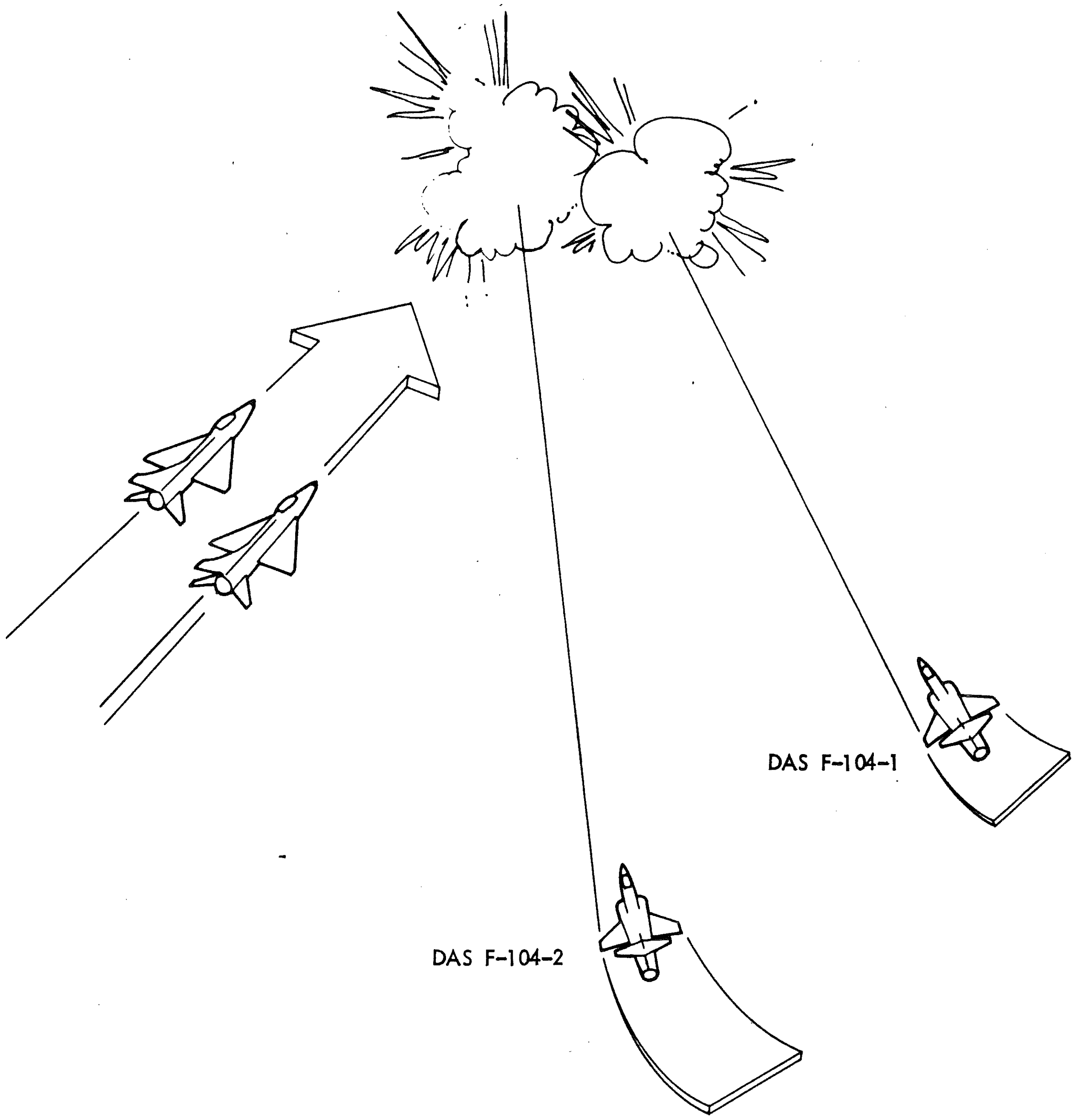
Given a clear option to attack "X" and flight as they are cruising at 40,000 feet and .9 Mach, I recommend the following:

1. Attack from the 6 o'clock low position at about 35,000 feet and a Mach number of at least 1.4.

2. Judge your supersonic, climbing attack to accomplish a torpedo from below attack on the high element of "X's" flight. Making full use of the element of surprise, you should be able to launch missiles from this blind spot of "X's" flight. Missiles are the weapon for this phase of your attack, because once that "X" and flight are made aware of your presence, they will undoubtedly begin maneuvering at high g's that will obviate missile launches. Further, the 6 o'clock position yields the optimum success potential for missile attack. Our sketches show this opening phase of the attack.

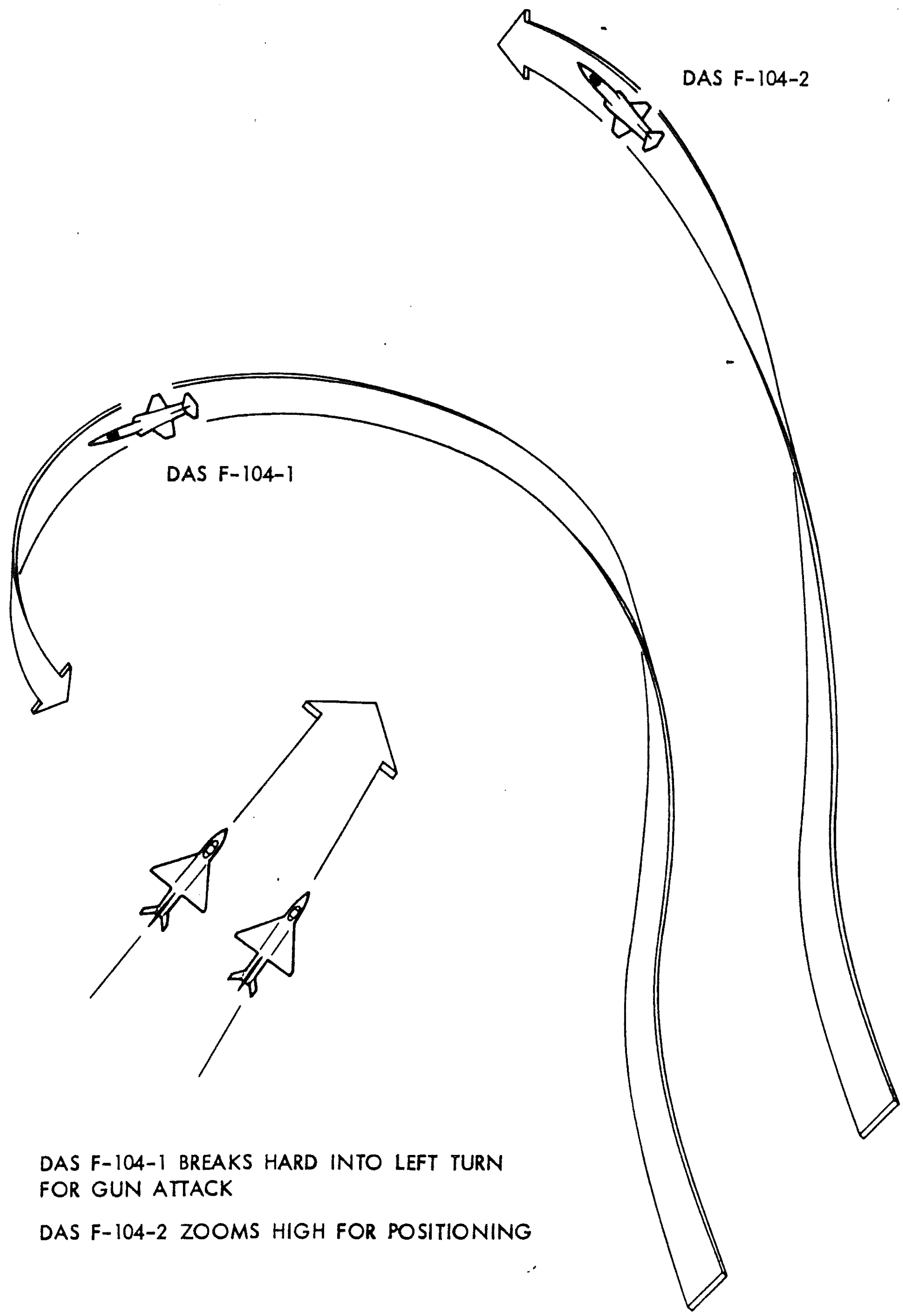


DAS F-104'S VS. FLIGHT OF FOUR



THE MISSILE ATTACK

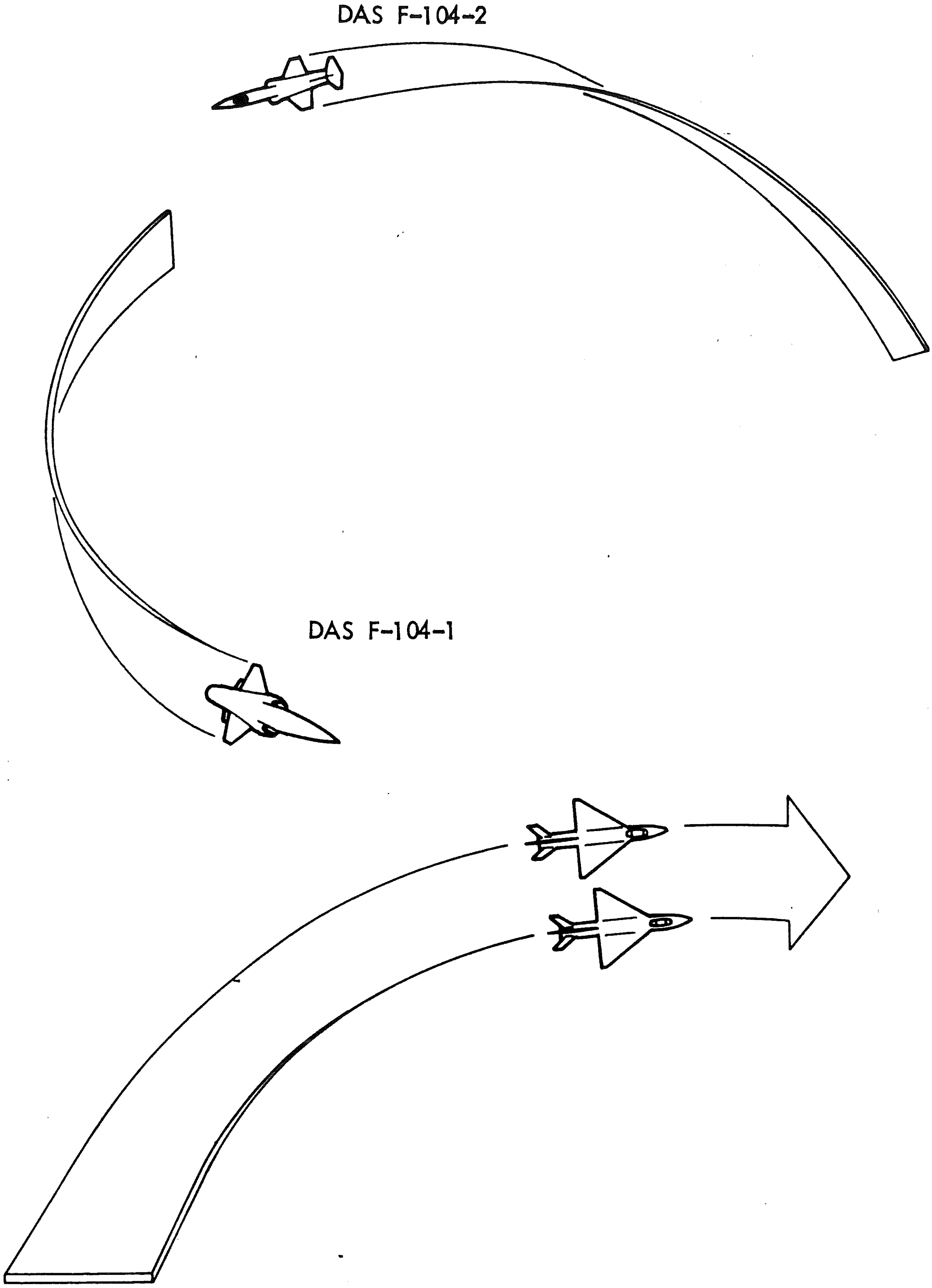
After the missile attack, continue your climb with DAS F-104-(2) zooming high for positioning and observing. DAS F-104-(1) should use his excess speed to turn tightly to the left for an immediate gun attack on "X" and wingman. The action now looks like this.



DAS F-104-1 BREAKS HARD INTO LEFT TURN FOR GUN ATTACK

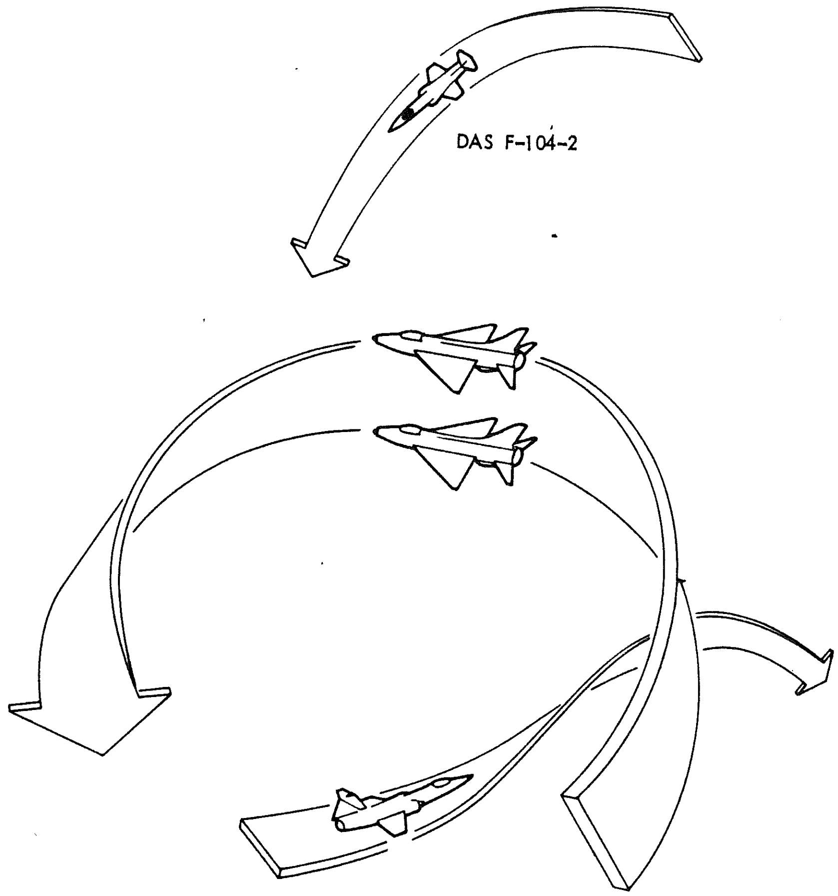
DAS F-104-2 ZOOMS HIGH FOR POSITIONING

"X" is now faced with one of two choices. Quite simply, he can break either left or right. If he breaks right, then DAS F-104-(1) is in excellent position to continue his gun attack. Our sketch can show what occurs if "X" breaks right.



DAS F-104 - 1 PRESSES ATTACK

More logically, "X" would react like all Standardized pilots and break left into the attack of DAS F-104-(1) just like he's been taught to do. As he breaks left to negate the attack by DAS F-104-(1), DAS F-104-(2), who zoomed high for positioning and observing, will now roll over and down into his gun attack pass from "X's" 6 o'clock position. Our sketch shows this action very clearly.



DAS F-104 - 2 PRESSES ATTACK

Since DAS F-104-(1) could not track the turn that "X" and wingman created with their hard left break, he breaks off into the disengaging maneuver, calling in DAS F-104(2) to attack while he repositions. We can see that essentially "X" and wingman, again, cannot cope with the thrusts from different directions. Their disappearance from the battle arena is inevitable. Q. E. D.

Note that with the Double Attack System, the DAS fighters never get trapped into trying to maneuver with the more maneuverable aircraft. You use your performance in the proper way with the proper tactics--and you kill your enemy.

Next, we come to a precept of the Double Attack System that clutches at my heart strings.

The DAS Is The Best Bomber Attack Formation

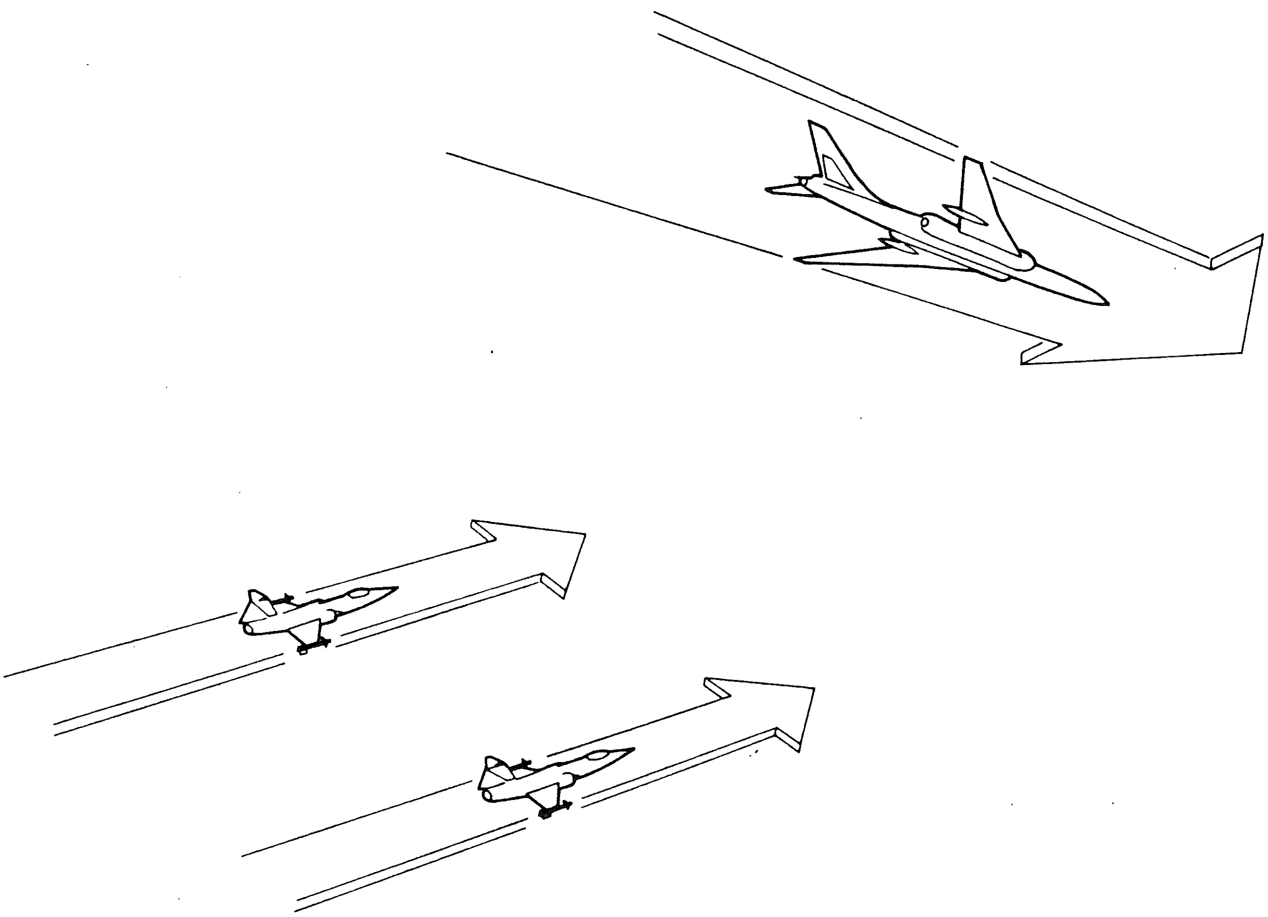
At the risk of exposing my age and ignorance, I shall tell you of a dreadful, humiliating experience. Picture, if you will, in 1948, a bright-eyed, bushy tailed 2nd Lt., fresh out of flying school, assigned to a jet fighter squadron equipped with the latest--F-84D's. Hot? Man--I smoldered! There was nothing, absolutely nothing, in the skies that I and my Flight Commander, 1st Lt. Joseph McConnell, could not conquer. When we couldn't find any Navy cats or neighboring squadron birds to bounce--we squared off and fought each other. Aggressive? Damn right. Fearless? We took on anyone. Mean? We broke every rule in the book. Sharp? Forget it. We were strictly from hunger when it came to understanding tactics. We blindly bounced our foes with throttles bent and eyes bulging. And then came the day of reckoning. Sickening, nauseating defeat at not being able to accomplish our mission--that we had thought would be so easy. Worse yet--it was the who and the what, that smashed our egos and sent us limping home like puppy dogs, that still makes me grind my teeth when I think about it. It was a cotton-pickin, sharp bomber pilot in a B-36! That city block long hunk of aluminum, churning through the blue was the downfall of the two hottest fighter pilots in the world. How did he do it? He just turned at exactly the right time.

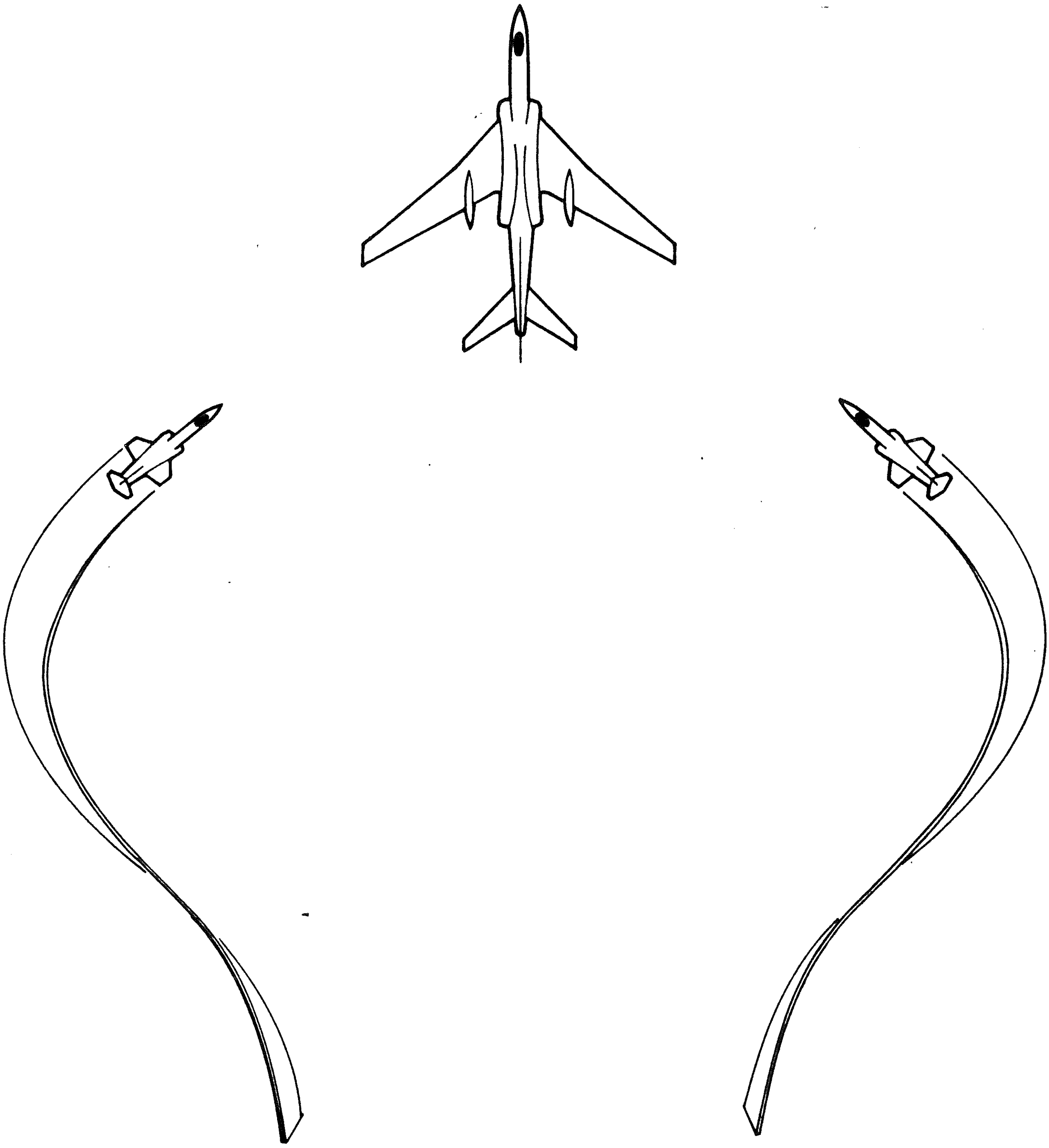
When the Wing Commander briefed us for our mission, we were like two cats licking our whiskers over a bowl of cream. Jump into those mighty jets, he said, and go up yonder and bring me back some camera gunnery film of that big muthah. That's all--just get some film of that big monster. Almost guiltily, Joe and I briefed for the mission and "had at it". Our first shock was when GCI informed us that during our climb-out and struggle up to 38,000 feet, the B-36 pilot had already completed his practice bomb run over San Francisco and was on his way out of the target area. Our next shock was the agonizingly slow overtake speed as we literally crept up to a high side, gun perch position. Still aggressive, still fearless and now mad as could be--we flipped the camera switches on, dove down and pegged the Machmeters. Then, just when the pipper was tracking smoothly and gun firing range was scant seconds away--the city block banked up and turned out of our windscreens! The final shock, as we mushed by on the outside of the turn, was noticing the smooth tracking of the radar-aimed, remote controlled gun turrets. Yep--you're right. Our film was blank--but they got beautiful pictures of us.

This exposure of our weakness--tactics, started Joe and I to thinking, eating and sleeping tactics. His later kills in Korea, I feel, were due in part to his development of ACT that complemented the performance of his aircraft and his skill. The point of my story, for you, is that the DAS used against the bombers will stop them from getting through your defenses and laying their eggs. It works like this:

1. Bomber intrusion at high altitude; for reasons of clarity, let's assume that we are faced with individual intrusions and not massed bomber formations. Although the DAS would be employed in the same manner against massed bombers, it is easier to illustrate the individual attack.

   If our intruder is at a respectable altitude, say 45,000 to 50,000 feet, you should attack from below and behind. Accelerate to at least 1.4 Mach number, then perform a full A/B, climbing torpedo-from-below attack. During the climb-up, the DAS fighters should diverge and then converge in the climbing pincer movement. Our sketches show these steps.





TORPEDO FROM BELOW WITH PINCER ATTACK

As you close the pincers, the smartest bomber pilot in the world cannot negate both attacks by turning or even diving. One--maybe. Both? Negative. One of the DAS fighters will surely be successful with either missile or gun.

2. Bomber intrusion at low altitude; in this case, the intruder will definitely be solo. You just don't hedgehop with a formation of these big machines: Locating and intercepting the intruder is a problem not to be covered in this short treatise. Assuming you make contact and your target is at low altitude, you now use the DAS, but attack with the pincer movement out of a nearly horizontal plane. The intruder, not being able to dive and greatly restricted in turning, is obviously very limited in negating any attack. Both DAS fighters should have a "smashing" success.

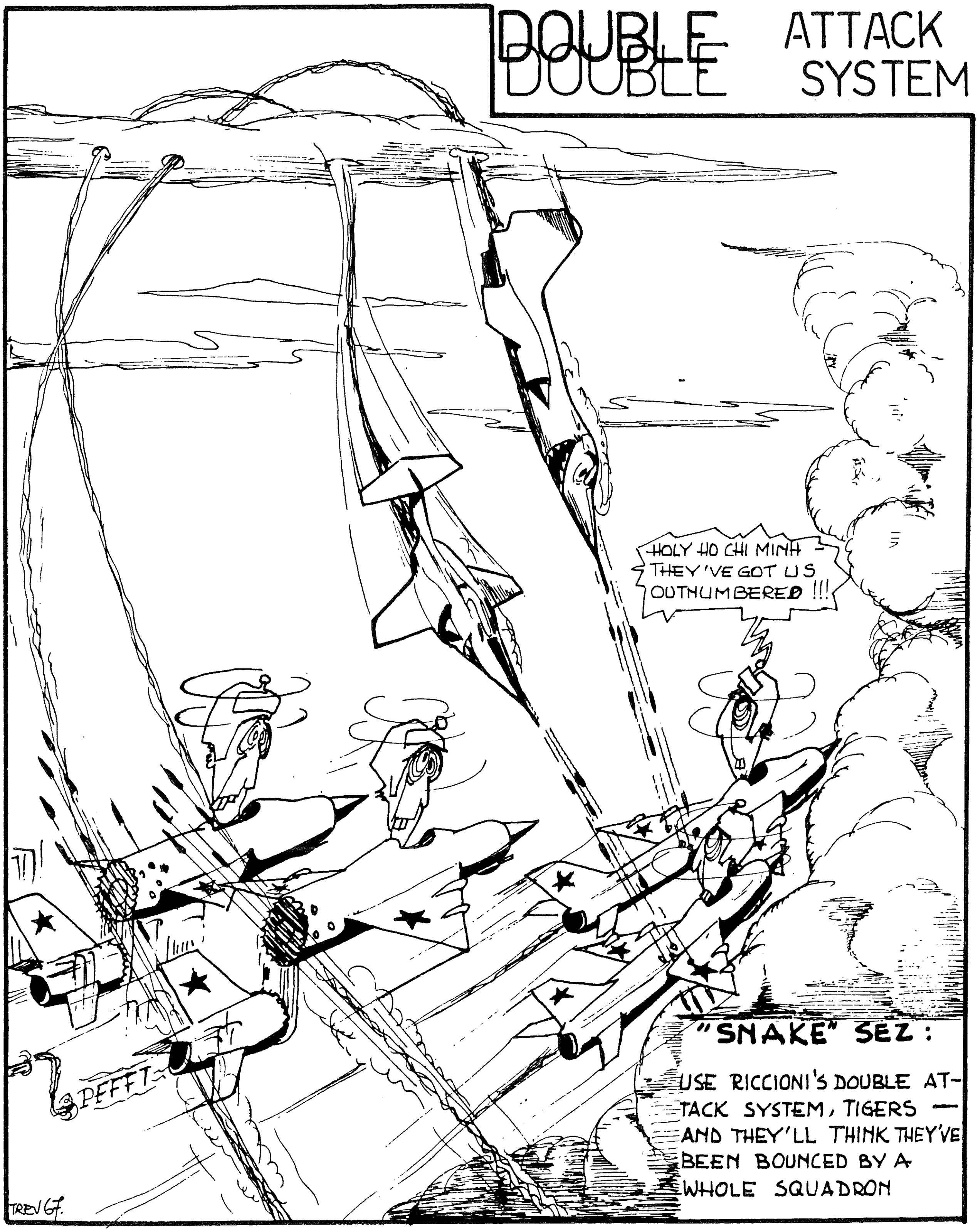
Finally, we come to the last precept of the Double Attack System and one that is a requirement for two fighters to even stay in formation due to the physical laws of supersonic aerodynamics.

The DAS Is The Best Supersonic Attack Formation

I stated in SURE lecture 5 that we fly in two completely different worlds of airflow as we go from subsonic to supersonic flight. I expect, that you have already deduced that the Fluid Four is strictly a subsonic formation--and not worth a hoot for supersonic combat. If you still persist in trying to fly in the 5 to 7 o'clock position as a wingman in the Fluid Four--you better keep all your maneuvers subsonic. Otherwise, old man bow wave is going to flip you neatly out of position and you'll probably lose the lead, which makes him very friendly and full of compliments about your flying ability. But, if you'll fly the DAS position, you won't have a worry in the world about those shock waves--cause they're all behind you. So there's no dodging the fact that the DAS is mandatory for supersonic formation attacks.

In summary, I want to emphasize what I stated earlier. Due to the dynamically fluid situations in Air Combat, ACT will never remain "static" for any great length of time. As you read and study what I have compiled for you, new tactics and various modifications are being formulated and experimented with. If I have aroused your thinking, you might already be considering better applications of the Double Attack System for your mission. My experience in studying ACT has made me adopt the following rules. Hold fast to that which is true, firmly reject that which is false, keep an open mind so that you will be able to see the best answer to a problem and never be afraid to test your ideas.

For too many years, I have listened to pseudo-qualified persons proclaim that the F-104 could not turn with other fighters and therefore was not an air superiority fighter. But you and I know different, Ace. She's as misunderstood as she is lovely and all too few people really know the true performance of our little thoroughbred. Let's hope the enemy never finds out. That way we can make it a surprise party!


DOUBLE DOUBLE ATTACK SYSTEM
HOLY HO CHI MINH — THEY'VE GOT US OUTNUMBERED !!!
PFFFT
"SNAKE" SEZ:
USE RICCIONI'S DOUBLE ATTACK SYSTEM, TIGERS — AND THEY'LL THINK THEY'VE BEEN BOUNCED BY A WHOLE SQUADRON
TREV 67.

CONCLUSION

One of my firm, unshakable beliefs is that the saga of Air Combat and the further development of Air Tactics will occupy pages of history for decades to come. There'll always be fighter pilots--even in Hypersonic rocket craft that will gobble up hundreds of thousands of feet in chandelles and Immelmans. There'll always be short-sighted "experts" who will want to tame, shackle and standardize the beast. There'll always be self-proclaimed analysts who will righteously expound Dogma that flies in the face of cold reason and mounting military losses. Hopefully, there'll always be the Boelckes, Mitchells, Chenaults, Boyds and Riccionis to analyze and experiment for better Air Combat Tactics. The carrying out of those tactics will always be the responsibility of you Tigers. This earnest effort of mine is intended primarily to stir you to studying ACT. There's an old cliche that says, "you're never too old to learn". But consider the flip side, Ace, "you're never too young to learn". Never blindly believe that your youthful aggressiveness can overcome better executed tactics. Old Tigers with cunning and experience are just as deadly as the powerful, young, eager cats. Remember that your combat effectiveness will always be the sum total of three ingredients that exist within you--your knowledge, courage and skill. It depends upon you how high that effectiveness level can be today or will become tomorrow. Yes, there'll always be fighter pilots. Independent in thinking, competitive by nature, supremely confident from individual achievement--the fighter pilot is the absolutely irreplacable military weapon.