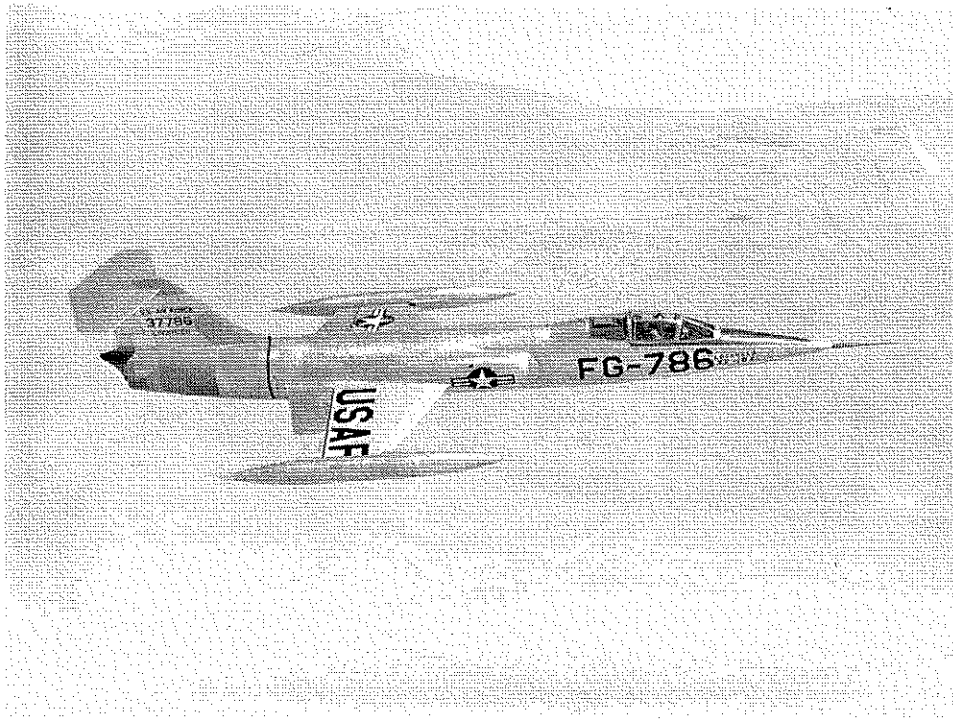


The SURE Project





**STARFIGHTER
UTILIZATION
RELIABILITY
EFFORT**

**LECTURE
5**

THEORETICAL AND PRACTICAL
ASPECTS
OF
SUBSONIC AND SUPERSONIC
AIRFLOW EFFECTS
ON THE
F-104

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

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

REFERENCES

1. T.O. 1F-104G-1 dated 30 April 1966.
2. NASA Technical Note D-3443, "Ground Measurements of Shock-Wave Pressure for Fighter Airplanes Flying at very low altitudes and Comments on Associated Response Phenomena" by Domenic J. Maglieri, Vera Huckel, and Tony L. Parrot July 1966.
3. Technical Material submitted by Jerry Blausey, Dept. 74-31, Lockheed California Company, January 1967.
4. Technical Material submitted by Walt Sheehan, Dept. 76-34, Lockheed California Company, January 1967.
5. "Airplane Aerodynamics" by Professor Daniel O. Dommasch, Commander Sidney S. Sherby, USN and Commander Thomas F. Connolly, USN. Pitman Publishing Corporation, New York, 1951.
6. "Principles of Aerodynamics" by Professor James H. Dwinell, University of Washington, McGraw-Hill Book Company, Inc. 1949.
7. IDC, To: H. C. Spring From: E. J. Marsh Subject: NOSE WHEEL LIFT-OFF F-104 AIRCRAFT dated Sept. 16, 1964.
8. FTC-TIH-64-2007, AERODYNAMIC THEORY, USAF Aerospace Research Pilot School, Edwards AFB, California
9. Aerodynamics for Naval Aviators by H. H. Hurt, Jr. University of Southern California, NAVWEPS 00-80T-80 U.S. Navy 1960
10. FORMATION F-104G, Luke Air Force Base Phase Manual, 111102G Jan. 1966 Rev. 102
11. USAF Manual 105-5, Weather for Aircrew Trainees, Dept. of the Air Force
12. Hangar Flying Vol. VII, No. 2, May 1967 Article by A. W. LeVier

FOREWORD

It is indeed surprising to discover that after all these years of flying supersonic fighter aircraft, there are a large number of pilots who are actually not aware of all the factors of supersonic flight. They literally have been flying in an area of "unknown". This situation was brought to my attention in discussions with the operational pilots during SURE visits to their F-104 bases. In my attempt to find material they could study and refer to, I was appalled at the lack of any pilot-oriented information explaining the various, intricate phenomena of subsonic and supersonic airflow. Any books and written matter on these subjects were based on mathematics and aerodynamics that could only be understood by pilots with an engineering education. And as I have stated in other SURE lectures, the Pilot's Handbook is limited by its main purpose of telling you what to do--not why for or how come. For example, there is only a brief, blunt description of supersonic flight in the handbook, and I can assure you that the supersonic regime opens a whole new world of aerodynamic effects on fighter aircraft.

One of the oldest, proven methods of learning certain characteristics of aircraft (that were due to airflow effects on the design) was the "word of mouth" explanation among pilots. To a certain extent, this method still exists. But aircraft performance has leaped from the simple, basic flight regimes to encompassing vastly different and rapidly growing flight envelopes. The task of informing other fellow pilots of the subtleties and intricacies of these devastating airflow effects becomes therefore correspondingly more difficult. Sometimes before we can even catch up with the performance of the aircraft the designers have given us, we've already blundered into accidents that might have been prevented--had we but known certain airflow characteristics. In my dim memory, as I first started flying, I remember a statement that imbedded itself upon me, "Flying is not inherently dangerous, but the Air, like the Sea, is terribly unforgiving of mistakes". So obviously, without an adequate knowledge of supersonic flight effects, you will be at a loss to understand some of the natural phenomena and you might unknowingly operate the aircraft in the wrong manner. In addition to studying the supersonic regime, there is still a large area of subsonic flight that needs to be explained for a better and more complete knowledge of flight in the Silver Sliver.

In order to fully know the behavior of the F-104 from takeoff to Mach 2.0 and back to landing, it will be necessary for you to study the airflow patterns around the aircraft and their effects on the flying characteristics. Only by this study, will you add a few more "feathers" to your tail. They are the hidden but distinguishable and identifying signs of a professional airman. Therefore, with Lockheed's continuing effort to help you through the SURE project, this lecture has been written to inform you of the important airflow aspects of subsonic and supersonic flight in the F-104 Starfighter. It is to be hoped that the recommendations in this lecture will be absorbed in your Squadron SOP's and Pilot's Information Files. I believe this knowledge will prevent further incidents and accidents caused by lack of awareness of the effects of airflow.

SECTION I

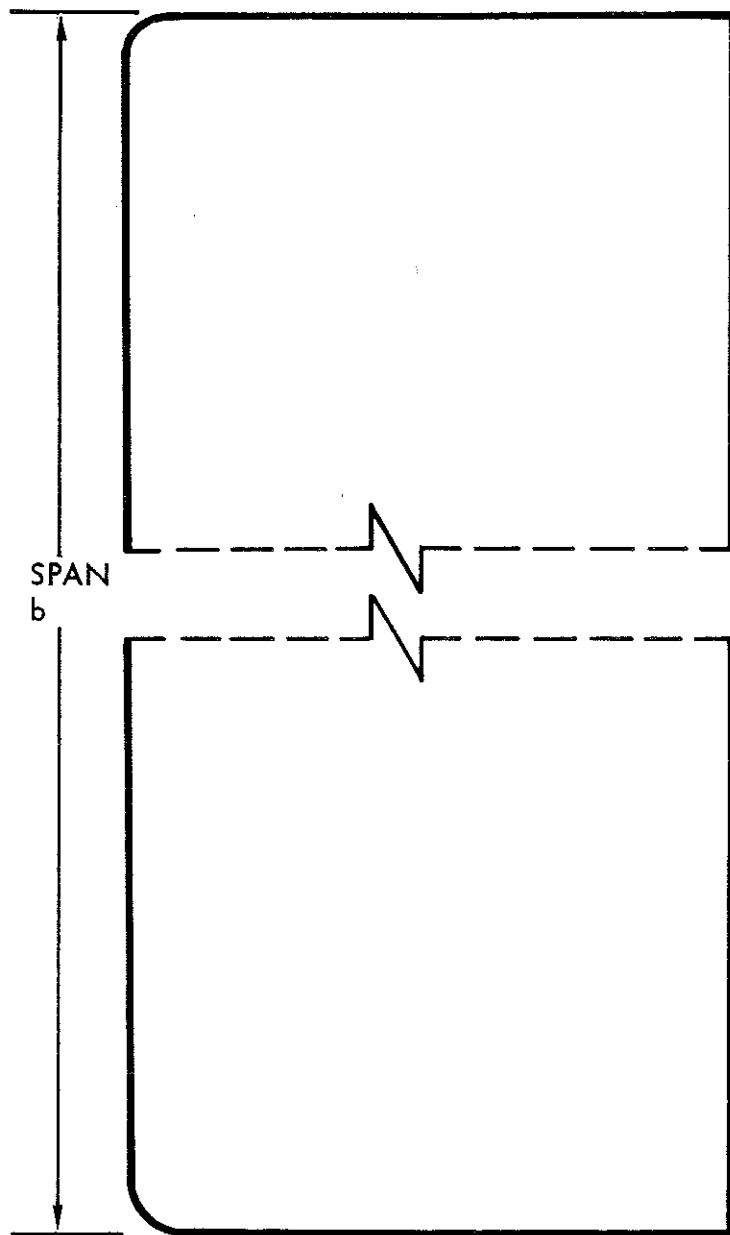
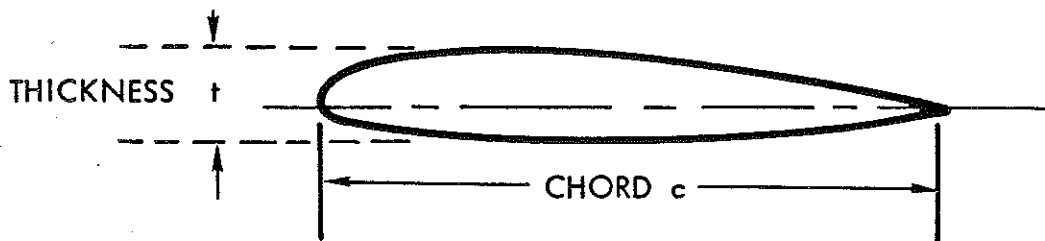
Fundamental Theory of Subsonic and Supersonic Airflow

The atmosphere in which we fly may basically be thought of as composed of large, gaseous blankets that envelop the earth. These gaseous blankets vary in density, pressure and temperature from sea level to outer space. Arbitrarily selected dividing lines have been picked to define the blankets. The first one, closest to the earth, being the troposphere; the next one, the stratosphere; the third, the ionosphere; and the fourth, and outermost, the exosphere.

The troposphere is the region in which most clouds are formed and is characterized by the turbulent conditions that generally prevail. The height of the troposphere varies from about five miles at the poles to approximately ten miles at the equator.

The stratosphere extends from the upper limits of the troposphere, called the tropopause, to approximately fifty to seventy miles above the earth's surface. All flights in the F-104 take place in the troposphere and the lower levels of the stratosphere. The troposphere and the stratosphere have molecules of gas that react in predictable fashion in subsonic flight and supersonic flight. In subsonic flight and well below the transonic region, the motion of the fluid can be assumed as steady, i. e. at any point in the flow, the velocity, pressure and density remain invariant with time. This means that the conditions prevailing at a given fixed cross section of the flow (not moving with the stream) do not change with time. If we consider that any fluid flow is composed of the more or less oriented movement of a large number of discrete fluid particles, we can see that the path which any of the particles follows is characteristic in many ways of the flow in general. Let's call this path a streamline. Using these streamlines, we can illustrate various aspects of subsonic airflow. For instance, we can examine the flow over an airfoil and see what it looks like in this slow speed, laminar flow regime.

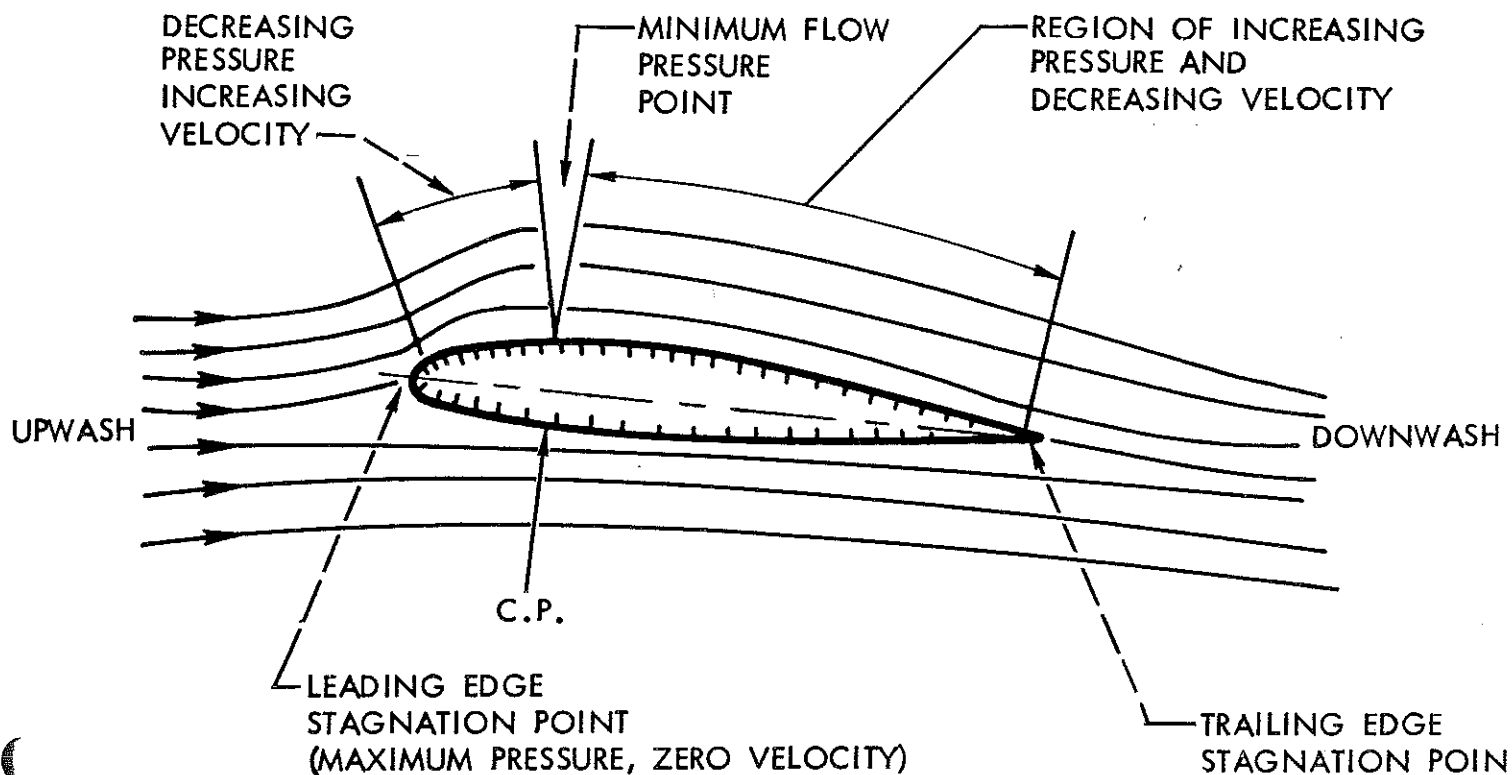
First, let's establish the airfoil and its nomenclature.



As shown in our drawing, the airfoil has a certain Chord length c , wing span b , and thickness t . An important term that we shall use is Aspect Ratio. Aspect Ratio is a measure of the slenderness of the wing and for a rectangular shaped wing, it becomes the ratio of the span to the chord.

$$\text{Aspect Ratio} = \frac{b}{c}$$

If we now initiate a slow speed, laminar flow field over the airfoil section, we can deduce some aspects of airflow for this type of wing section. Our flow picture will look like this.

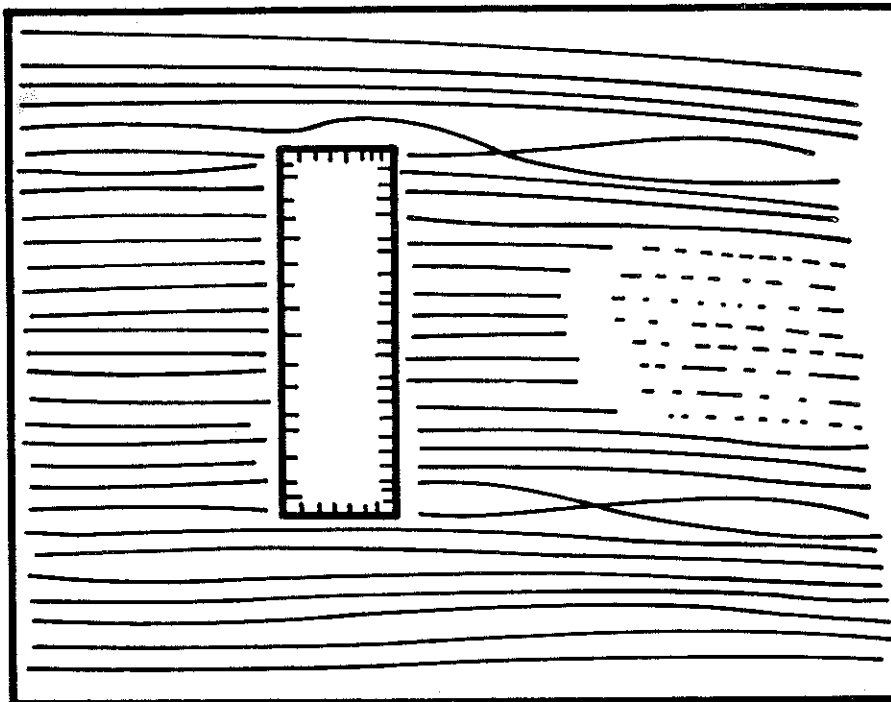


Our investigation of this flow picture shows that:

1. A stagnation point exists at the leading edge.
2. The flow speeds over some portions of the upper surface of the wing must be greater than the free-stream velocity in order that air particles moving over the upper surface may traverse the distance from the stagnation point to the trailing edge in the time that it takes particles to traverse the shorter distance from the stagnation point to the trailing edge along the lower surface, and thus provide continuous flow about the airfoil.

3. The center of pressure point is well forward along about the first 1/4th of the chord.
4. The significant flow pattern consists of upwash in front of the airfoil and downwash behind the airfoil.

Since the velocity and pressure of the two air streams from the upper and lower surfaces which meet at the trailing edge must be identical for steady flow, it follows that, as a consequence of 2. above, an adverse pressure gradient exists aft of the minimum-pressure, maximum velocity point. And we can see that at the minimum pressure point exists a maximum point of lift on our airfoil. Also of interest, is the flow picture in front of our wing and behind the wing. A picture of this flow pattern can tell us what effects are taking place on other control surfaces that lie in the area of flow behind our wing. If we mount a typical, square-tipped wing section in a wind tunnel and generate smoke in front of the wing, we get a picture like this:



SMOKE PICTURE OF WING-TIP VORTICES AND DOWNWASH

From this illustration, we can predict two airflow effects--wing tip vortices and downwash. Both of these effects are influenced by the amount of lift on our airfoil. And speaking of lift, how can it be measured? Any aerodynamic textbook will tell you the equation for lift.

$$\text{Lift}^* = 1/2 \rho (\text{density}) \times V^2 (\text{velocity}) \times C_L (\text{coefficient of lift}) \times S (\text{wing area})$$

Looking at each of the factors, we find:

ρ is a function of our altitude and a property of the fluid we're flying in.

V is our airspeed which is purely a function of movement.

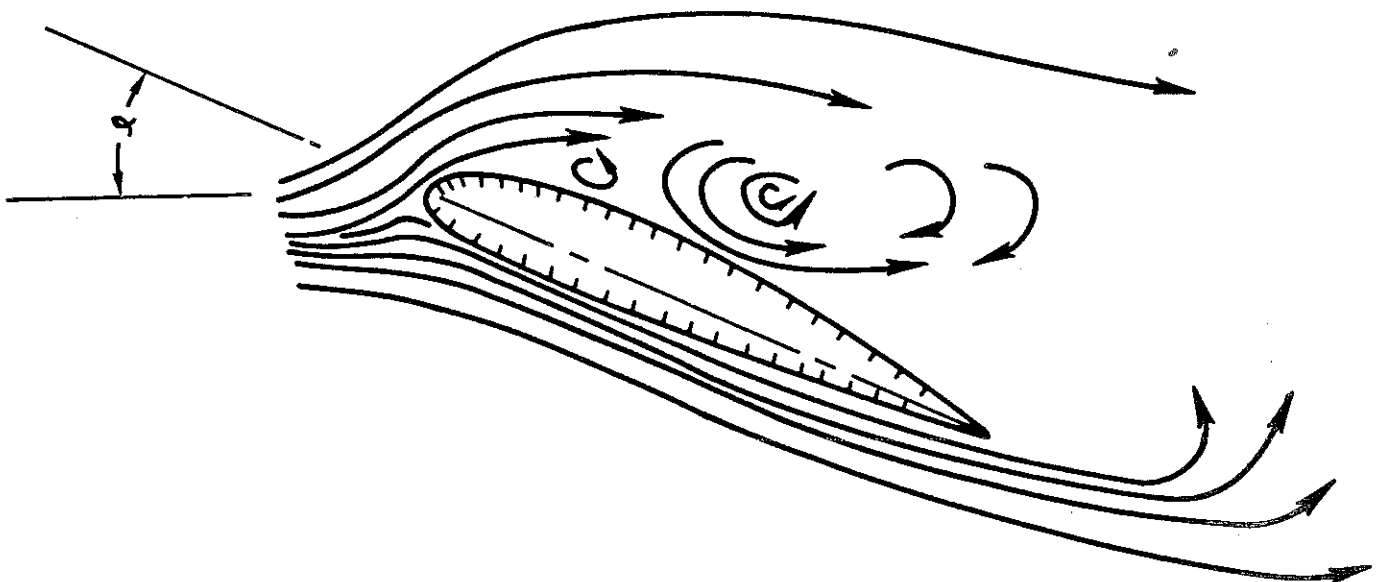
C_L is a function of the geometric shape of our airfoil and varies with α , the angle of attack of the airfoil with respect to the airstream.

S is the total wing area and is a constant factor for fixed wing aircraft that do not have variable sweep mechanisms.

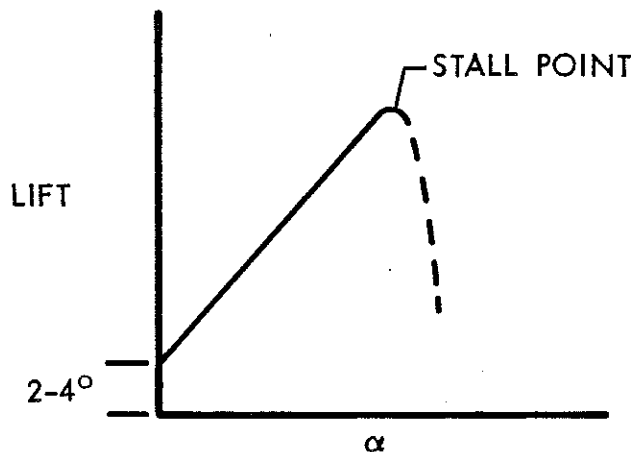
Therefore, by eliminating factors over which we have no control, we see that, in a general sense, lift is primarily dependent upon the shape and area of our wing. Normally the equation for lift is stated as:

$$\text{Lift} = q S C_L, \text{ where } q = 1/2 \rho V^2, \text{ a quantity called dynamic pressure}$$

Note, however, that we stated that C_L varies with α , which means that lift will also vary with α . If, at a cruise speed and at cruise altitude, we pull back on the stick, we will increase our load factor because we are increasing our lift by increasing α . If we pull to an α that is too steep, we now encounter a loss of lift. Why? Because now our airflow over the wing becomes turbulent and uneven. This uneven airflow, which is usually called turbulence, can be displayed as separated airflow.



From our sketch of the airfoil at an extreme angle of attack to the airflow, we can see that the smooth character of the flow disappears and a region of turbulence is generated on the upper surface. There is primarily just a great area of disturbed and separated airflow. This is a pictorial representation of decreased lift and is defined as "stall". Our airfoil is simply not operating effectively anymore. We can plot this transition to show the effect of "stall" on our airfoil in this manner.



With increasing α , there eventually comes a point where the airflow separates and "stall" occurs. As we know from experience, on subsonic aircraft with this type of wing shape, the airplane literally falls out of the sky when full stall is encountered. Of course, the airfoils on the F-104 were designed with one thought in mind--Mach 2.0 capability. So, now you see that "Kelly" Johnson designed for pure supersonic capability and made adaptations to accommodate the subsonic requirements. Now, let's examine our F-104 wing to see its characteristics.

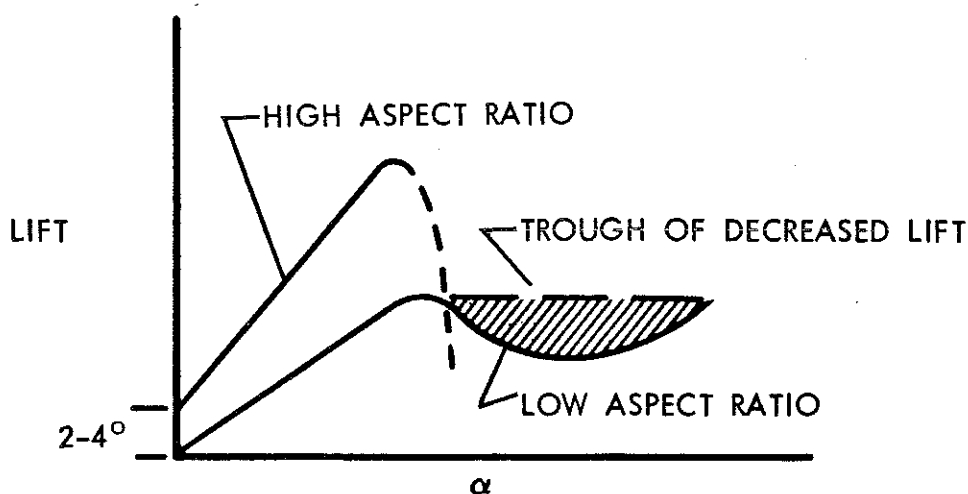
First, the wing shape bears little resemblance to the subsonic wing. It is extremely thin and essentially square-tipped, with sharp leading and trailing edges. Another important point from airflow considerations is that it is a low Aspect Ratio wing, with a high wing loading (airplane weight divided by wing area). A proven rule of aerodynamics is that a low Aspect Ratio wing with high wing loading produces stronger tip vortices and downwash that will give airflow effects that will definitely affect your flight operations. In looking again at the even flow, steady state picture, we can readily deduce some comparisons with the subsonic airfoil.



Since the flow has to deviate very little from the free-stream path, then the changes in pressure and velocity are not as great as on the subsonic wing, when the two airfoils are at the same α . Our F-104 wing then, will produce less lift as the subsonic wing. The main purpose of our thin wing is to reduce transonic and supersonic drag. The aerodynamic drag of an airfoil can be thought of as the penalty you pay to produce lift. And, just like lift it can be measured by the equation;

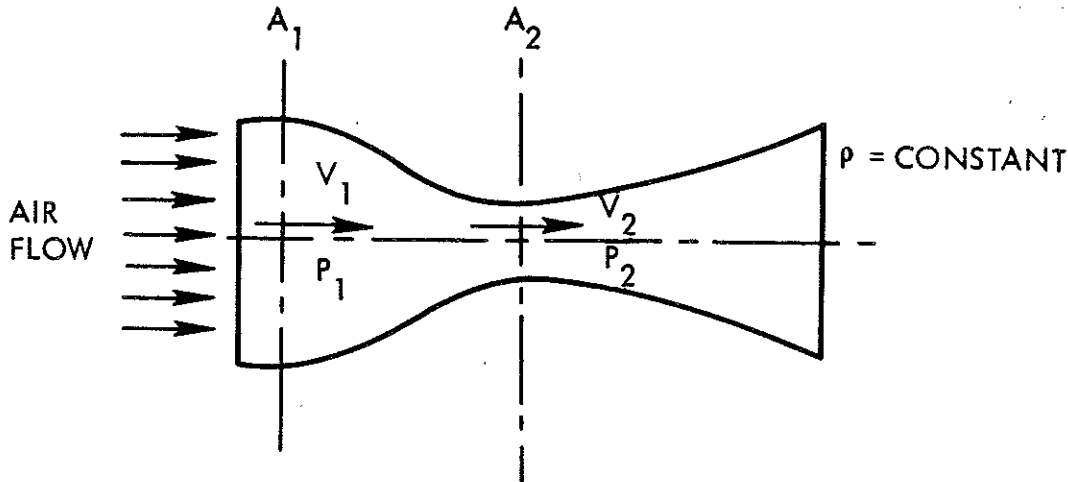
Drag = $q S C_D$, where we now have a coefficient of drag that is primarily dependent on the shape of the wing and also varies with α

For our F-104 low Aspect Ratio wing to produce as much lift as the subsonic high Aspect Ratio wing, it must fly at a greater α . Again, if we pull our supersonic wing up to a steep angle of attack, we should expect to reach a stall point--right? Well, let's carefully examine this aspect because a strange thing happens in this case. With increasing α , our low Aspect Ratio wing produces more and more lift until the outer wing panels begin to stall (giving buffet and turbulence) and our lift factor begins to drop off. But, it does not fully stall as our high Aspect Ratio wing, and in fact, our wing continues to give lift to the airplane. A plot comparison can show this striking difference in these wing characteristics.



Such a major difference in airfoil behavior is bound to affect your flight operations as we shall see later on in this lecture.

Another general theory that we should consider is the venturi effect in subsonic flow. For this, we shall investigate the flow of air through an orifice with a changing cross-sectional area. Our venturi tube looks like this.



From Bernoulli's equation for incompressible flow--*

$$P_1 + \frac{\rho_1 V_1^2}{2} = P_2 + \frac{\rho_2 V_2^2}{2}$$

And from the equation of continuity of flow--

$$A_1 V_1 = A_2 V_2, \text{ since } \rho_1 = \rho_2$$

rearranging,

$$V_2 = V_1 \frac{A_1}{A_2}$$

since the ratio of A_1 to A_2 is greater than a factor of 1.0, then V_2 must be greater than V_1 . Therefore, since V_2 is greater than V_1 , then p_2 is less than p_1 in the Bernoulli equation.

The conclusion that we reach by this study is that for restricted flow areas, the pressure has to decrease and the velocity increases in order to maintain steady, incompressible flow.

Next, let's accelerate the airflow over our wing sections and observe what happens. For the subsonic type airfoil, the velocities and pressures will undergo important changes as the transonic regime is approached. An approximate definition of the Mach regimes has been given as:**

* Reference 5

** Reference 5

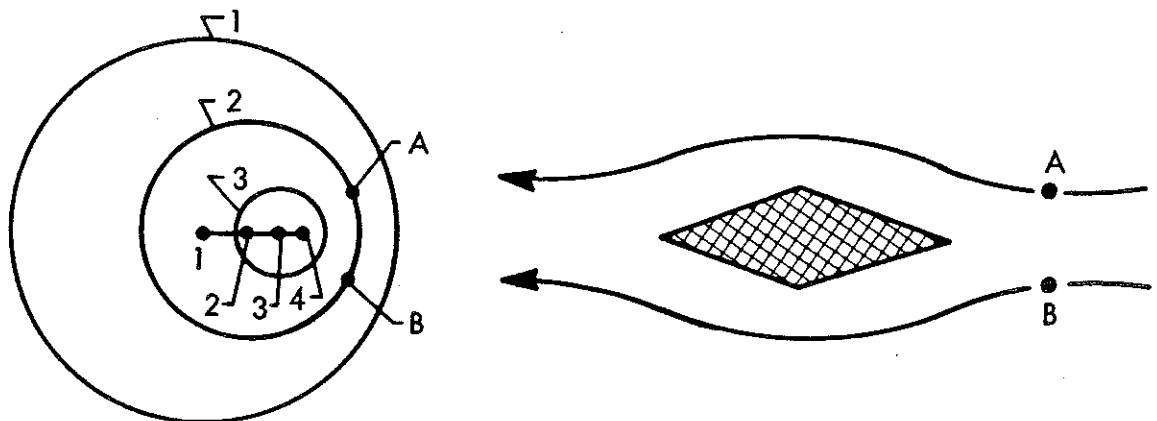
Subsonic,	$M_o < 0.75$
Transonic,	$0.75 < M_o < 1.20$
Supersonic,	$1.20 < M_o < 5.00$
Hypersonic,	$M_o > 5.00$

And Mach number has been defined as the ratio of flow velocity to the local speed of sound.

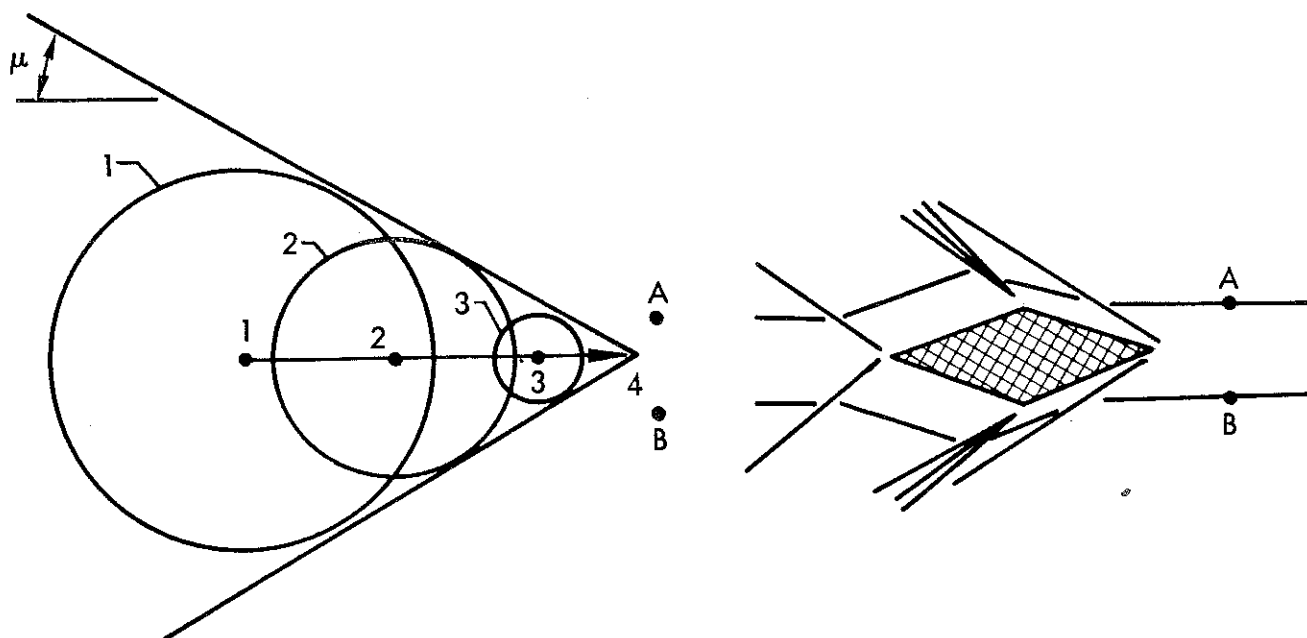
$$\text{Mach number, } M_o = \frac{v(\text{flow velocity})}{a(\text{local speed of sound})}$$

At this point, I think it pertinent that we explain the airflow pattern change from subsonic to supersonic.

In looking at flight in our gaseous blankets, whenever a disturbance occurs, it is propagated at the "speed of sound" in all directions. The speed of sound in a gas depends on the chemical composition and temperature of the gas. If the disturbance is vibratory, within a certain frequency (10 to 15,000 cycles per second), and of sufficient magnitude, we hear it as sound. The disturbance does not have to be vibratory in order to create a propagation in all directions. An object moving through a gas at constant speed creates a disturbance which is sent in all directions through the gas by minute pressure variations. These pressure variations signal the gas molecules of the existence and motion of the object. The gas molecules respond by moving to make way for the oncoming object. However, the speed at which the object is moving affects the signal, which the gas molecules, ahead of the object, receive. If we look at two particular gas molecules, A and B, we'll see how they're affected by the movement of an object coming toward them. As the object starts moving from an initial point 1, it immediately begins to send out circular, balloon shaped pressure waves. These waves are infinite in number but we shall draw only some representative circles to indicate movement of the object in relation to the movement of the pressure balloons. If the object is moving at Mach 0.5, our picture looks like this.



This figure shows the propagation of the disturbance caused by our object moving from left to right at Mach 0.5 (1/2 the speed of sound). The object is presently at point 4. The disturbance created at point 1 has ballooned out to circle 1. The disturbance created at point 2 has ballooned out to circle 2. Continuing this analogy, we can see that our gas molecules, A and B, ahead of the object, have been warned of the approaching object in time to make way for it. They have already sensed the pressure wave of balloon 1 and are now being pushed by balloon 2. An interesting fact about this motion is that the object always remains within the confines of all previously produced disturbance waves; furthermore, each wave must remain within the confines of all waves previously produced. With this type of flow, the movement of the gas molecules to get out of the way of our airfoils has been shown to be smooth streamlines over the airfoils. But what happens if the object moves so fast that A and B have no warning of its approach? For this answer, we'll move the object at a speed of Mach 2.0. The picture now changes to this.

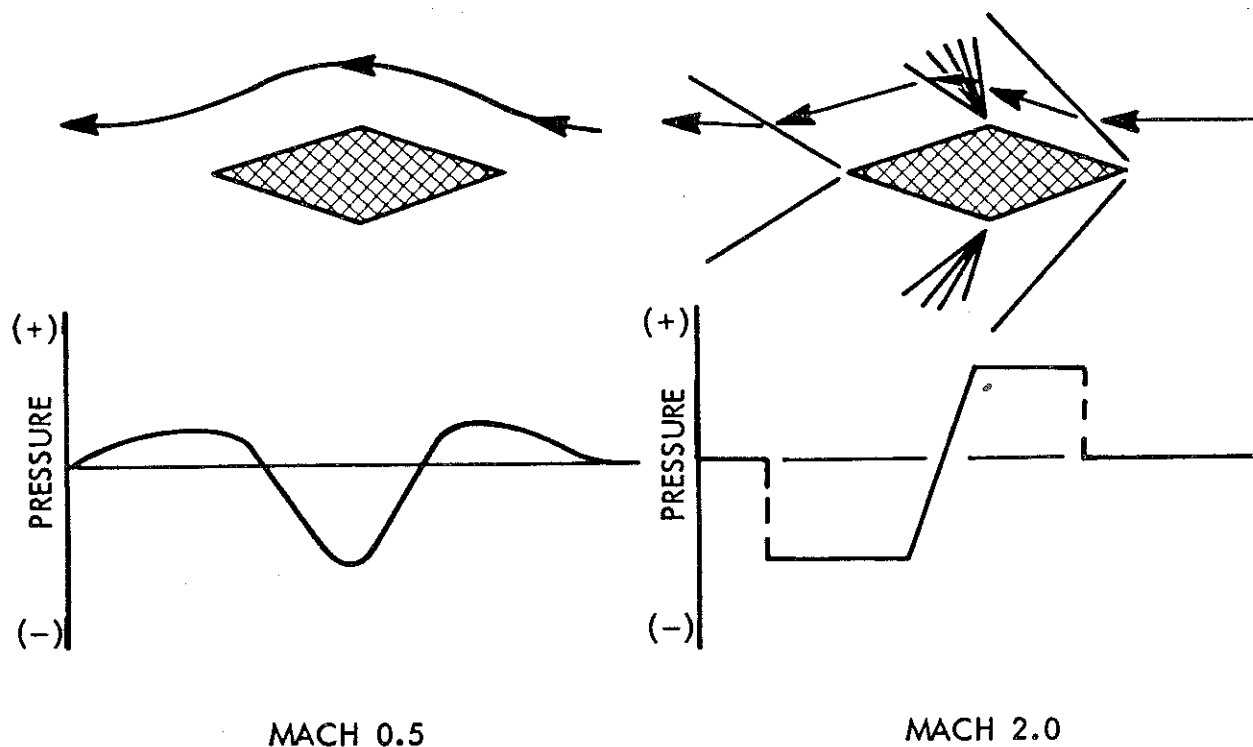


Here, evidently, conditions are radically different from the subsonic case. The object is never within the boundaries of any previous disturbance wave, nor is any previous disturbance wave completely enclosed by a preceding one. The object, which is presently at point 4, has produced disturbance balloons from point 1 to point 3 and is now starting a disturbance at point 4. Furthermore, the tangent to all of the waves produces a conical envelope whose apex is coincident with the object at point 4. This conical envelope represents the leading edge of the pressure variations that warn the gas molecules, A and B, of the approaching object. In this case, molecules A and B have not

been warned of the approaching object and will not be warned until they pass through the leading edge of the pressure variations. Since the warning time is so short, the pressure increase must be large and sudden in order to move the gas molecules, A and B, out of the path of the object. This large, sudden pressure variation is called a "shock wave". Due to the fact that the gas is compressed as it passes through the shock wave, the term "compression wave" is sometimes used. Also, by way of illustration, a weak shock lies at an angle close to the Mach angle defined by μ , which is related to the object's velocity and Mach number in the following manner:

$$\mu \text{ (Mach angle)} = \sin^{-1} \frac{a(\text{speed of sound})}{v(\text{velocity of object})} = \sin^{-1} \frac{1}{M}$$

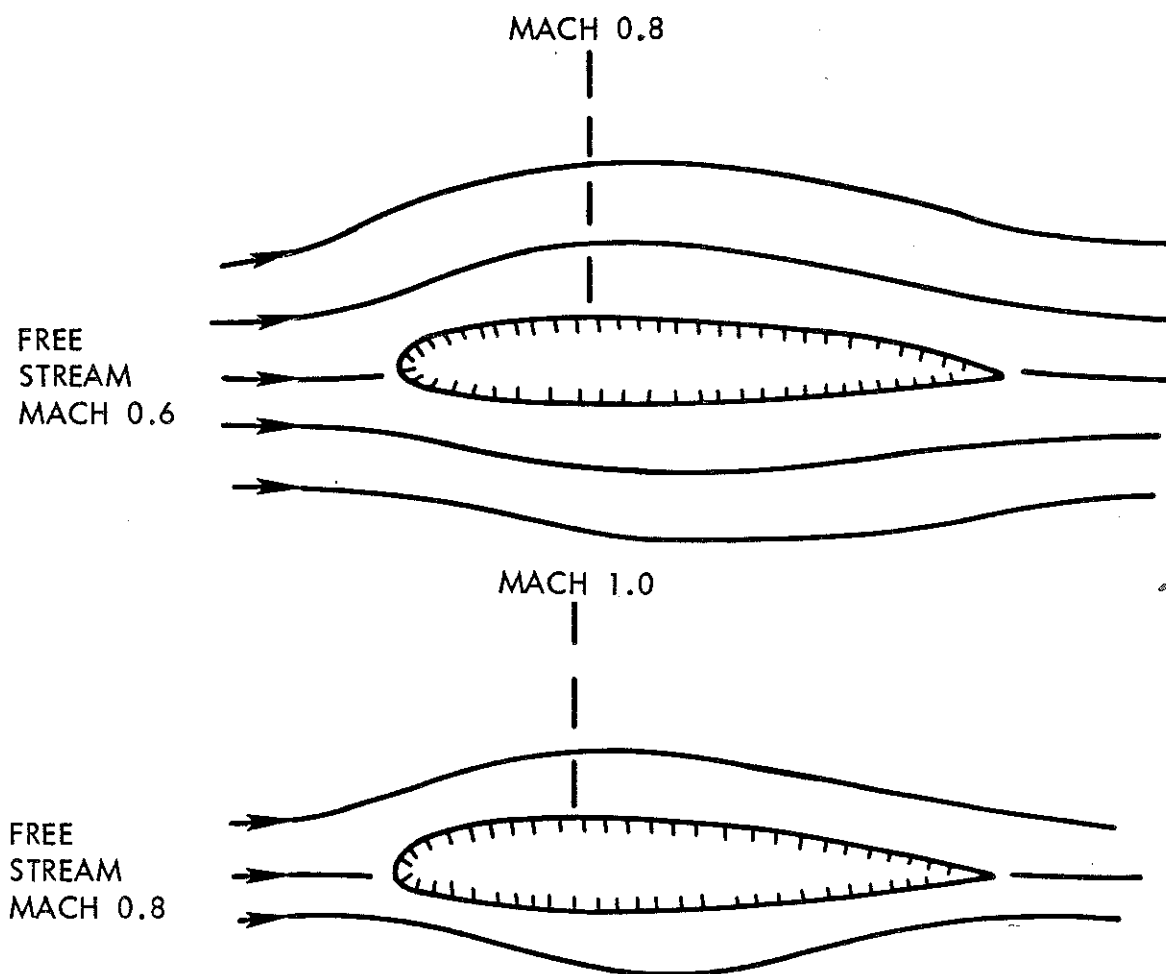
This equation tells us simply that the higher the Mach number, the more acute is the Mach angle, i. e. the faster we go, the conical envelope has a sharper and narrower shape. A strong shock will lie at a larger angle but still sweeps back as the Mach number goes up. We have now developed our airflow theory to the point that we can compare the two basically different fluid worlds of subsonic and supersonic airflow. Their comparisons look like this:



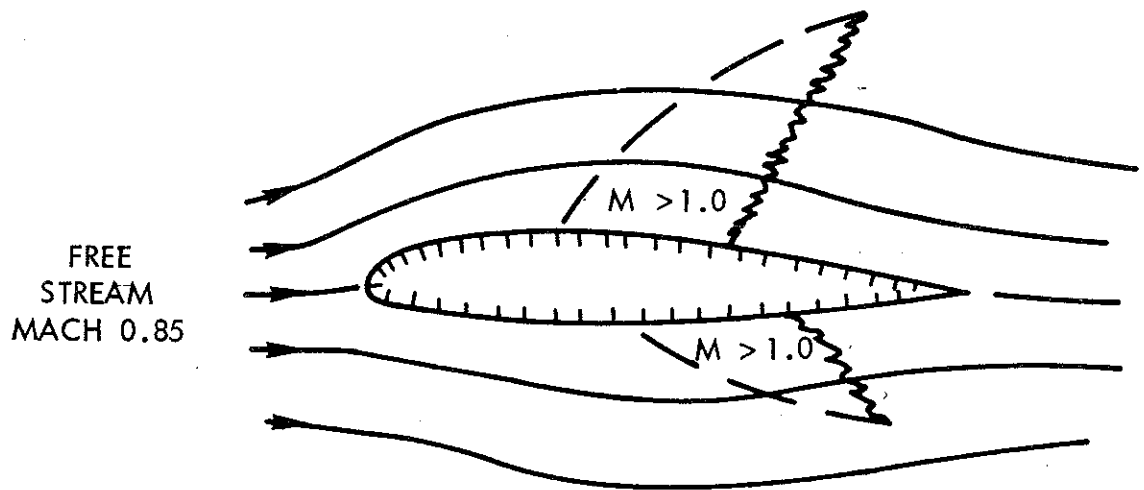
This comparison shows local pressure along a streamline close to a body in subsonic ($M = 0.5$) and supersonic ($M = 2.0$) flow. In subsonic flow, the pressure variations are smooth, while in supersonic flow they are sharp

and discontinuous. In subsonic flow the pressure variations decrease or "smooth out" as the distance from the body increases. However, this is not the case for supersonic flow. The pressure change across a shock wave remains large and discontinuous even as the distance from the body is increased. Returning to the flow over the subsonic airfoil, we find the following developments. The transonic speed regime begins when sonic flow first occurs over the surface of the airfoil and ends when the flow is supersonic over the entire surface (with the possible exception of a small insignificant subsonic region at the leading edge).

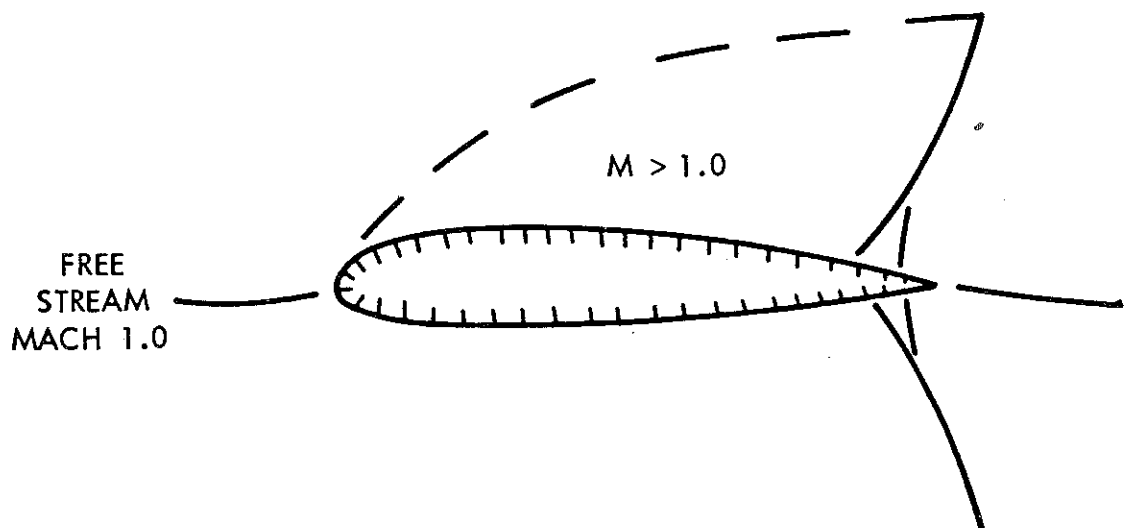
From our streamline diagram, it has been shown that the velocity increases and the pressure decreases as air flows subsonically over the surface of an airfoil. As the Mach number of our airfoil is increased, the flow near the thickest portion of the airfoil increases in velocity and approaches near Mach 1.0 as we can show by our sketches.



As shown, whenever the flow over the thickest part of the airfoil becomes Mach 1.0, then this free stream Mach number is defined as the critical Mach number of the airfoil. If we accelerate our airfoil faster than the critical Mach number, regions of subsonic and supersonic airflow are created on the airfoil as we now show.

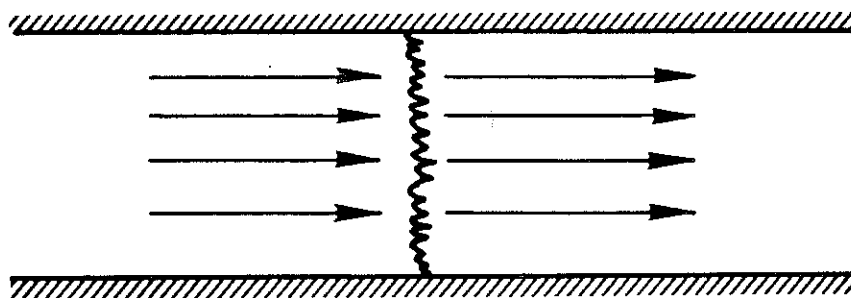


The shock region on the airfoil will remain essentially at one point if the velocity is constant. With increasing velocity, the supersonic region grows fore and aft of the point of maximum thickness until it reaches the leading and trailing edges. A typical illustration of this shock spread can be shown in this manner.

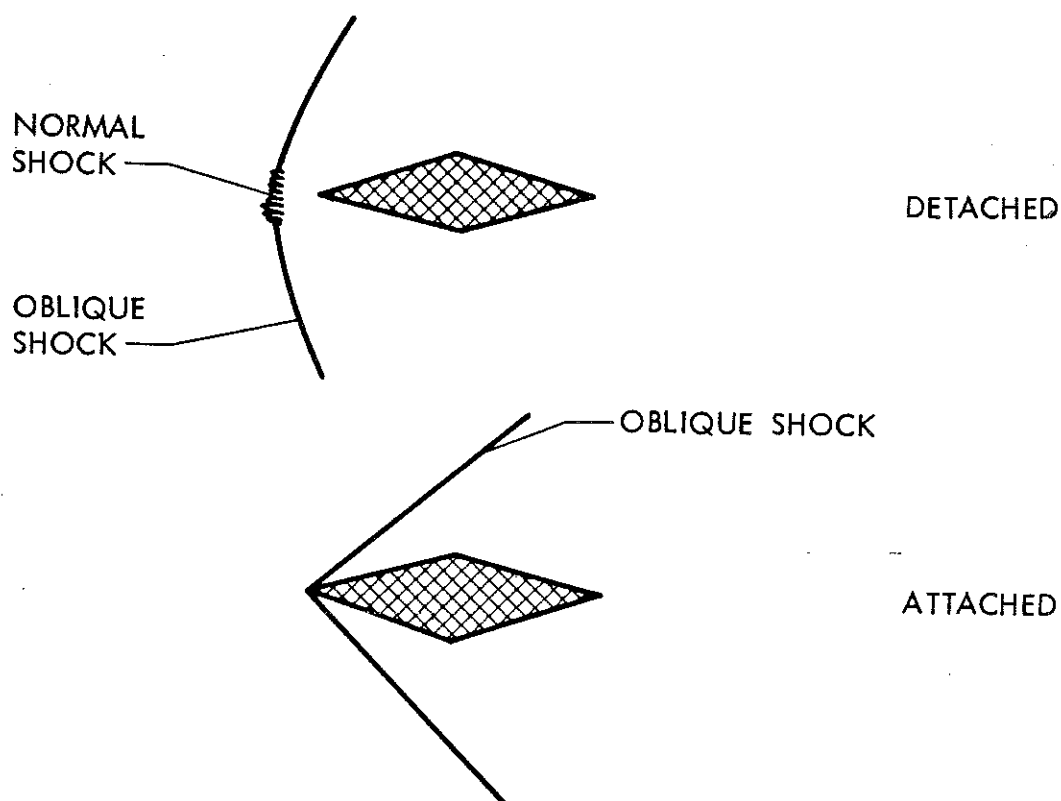


Finally, when the bow shock attaches to the leading edge, the airfoil has left the transonic speed regime and has entered the supersonic regime. It is appropriate now to basically define the various types of shock waves we will encounter in supersonic flight with our F-104. They are:

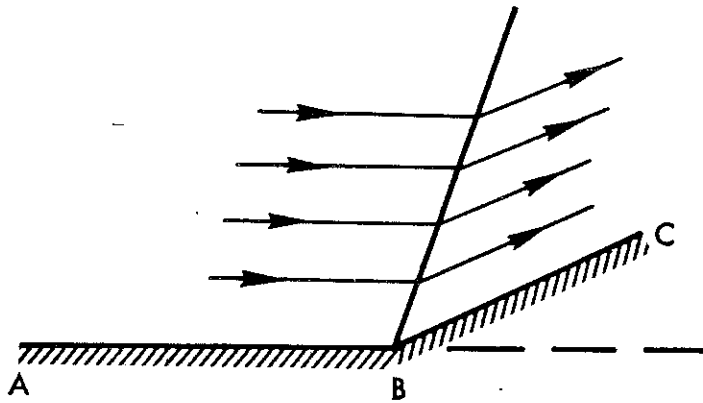
1. Normal shock wave; this wave is defined as one that is perpendicular to the flow path and appears as this.



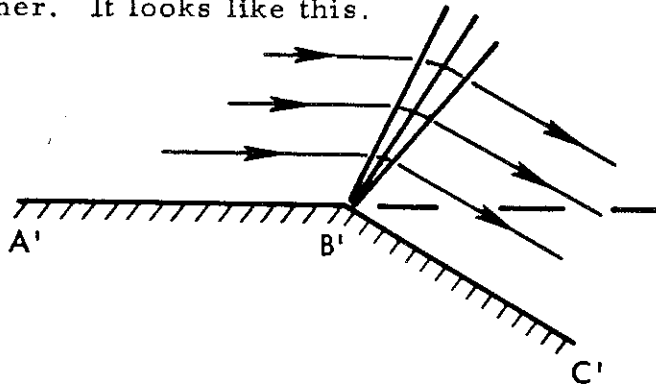
2. Bow shock wave; this is the shock wave that is either in front of the nose of the object (detached bow shock) or in contact with the nose of the object (attached). Technically speaking, however, the so-called bow wave is really a combination of normal and oblique shock (when it is detached) and is a pure oblique wave when it is attached. We can sketch the transition in this manner.



3. Oblique shock wave; this is a wave formed in supersonic flow when the flow is forced to change direction suddenly due to a sharp, convex corner. It looks like this.



4. Expansion wave; this is a wave formed in supersonic flow when the flow is forced to change direction due to a divergent corner. It looks like this.

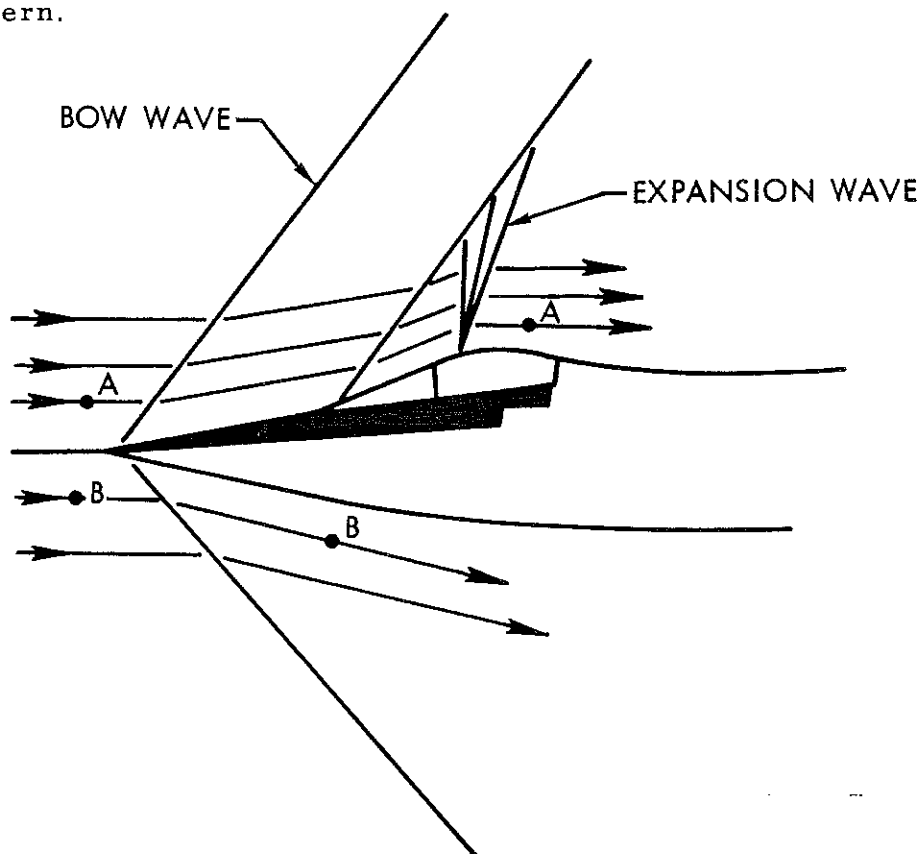


From our reference material*, we find that there are definite physical characteristics of the shock waves and we can list the changes in these properties behind the shock wave.

* Reference 9, page 213

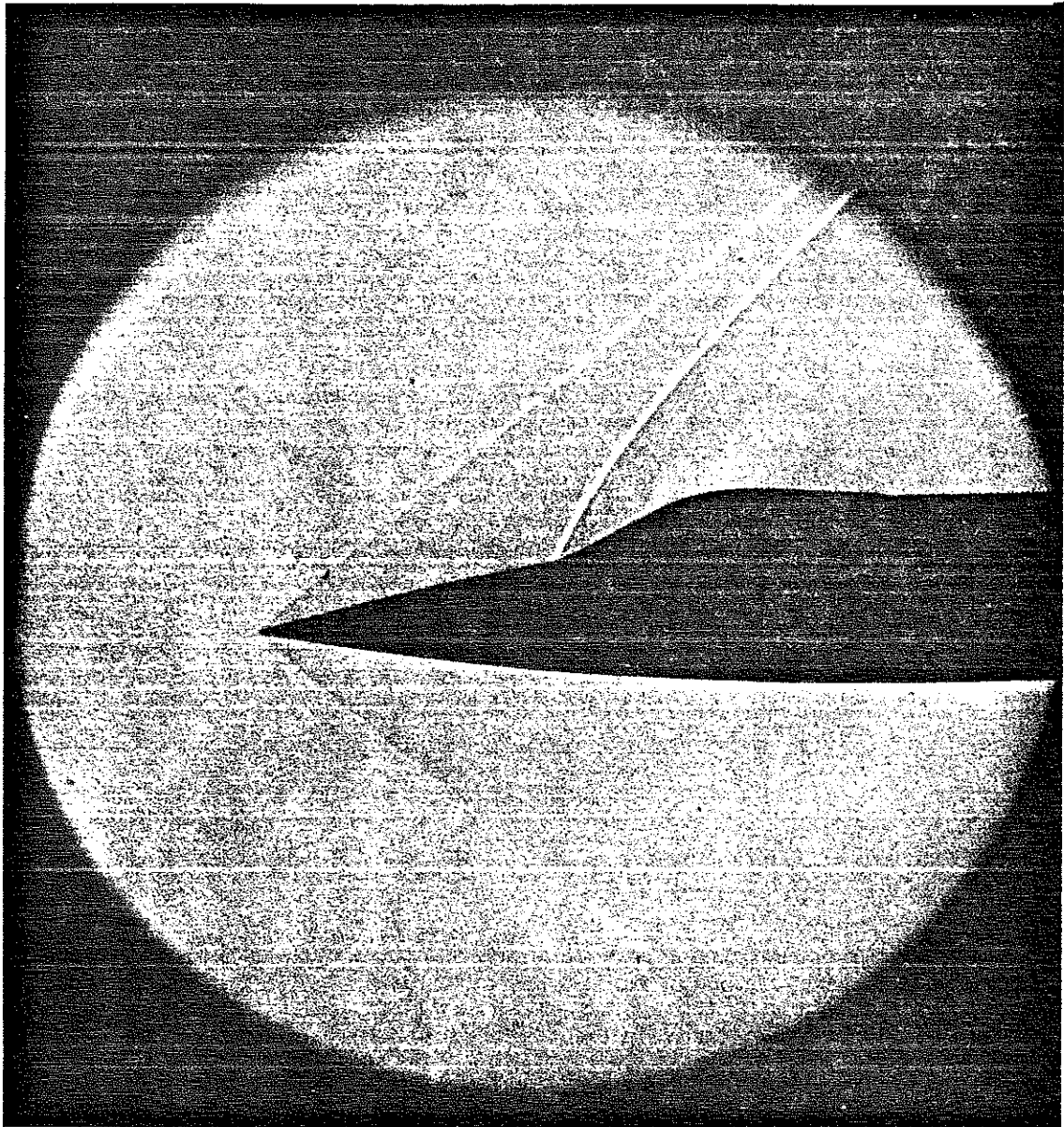
TYPE	Flow Direction Change	Effect on Velocity & Mach	Effect on Static Press. & Density	Effect on Energy or Total Press.
Oblique	"Flow into a corner", turned into preceding flow	Decreased but still supersonic	Increase	Decrease
Normal	No change	Decreased to subsonic	Great Increase	Great Decrease
Expansion	"Flow around a corner", turned away from preceding flow	Increased to higher supersonic	Decrease	No change (no shock)

Considering our nose and canopy area, we should have the following shock wave pattern.



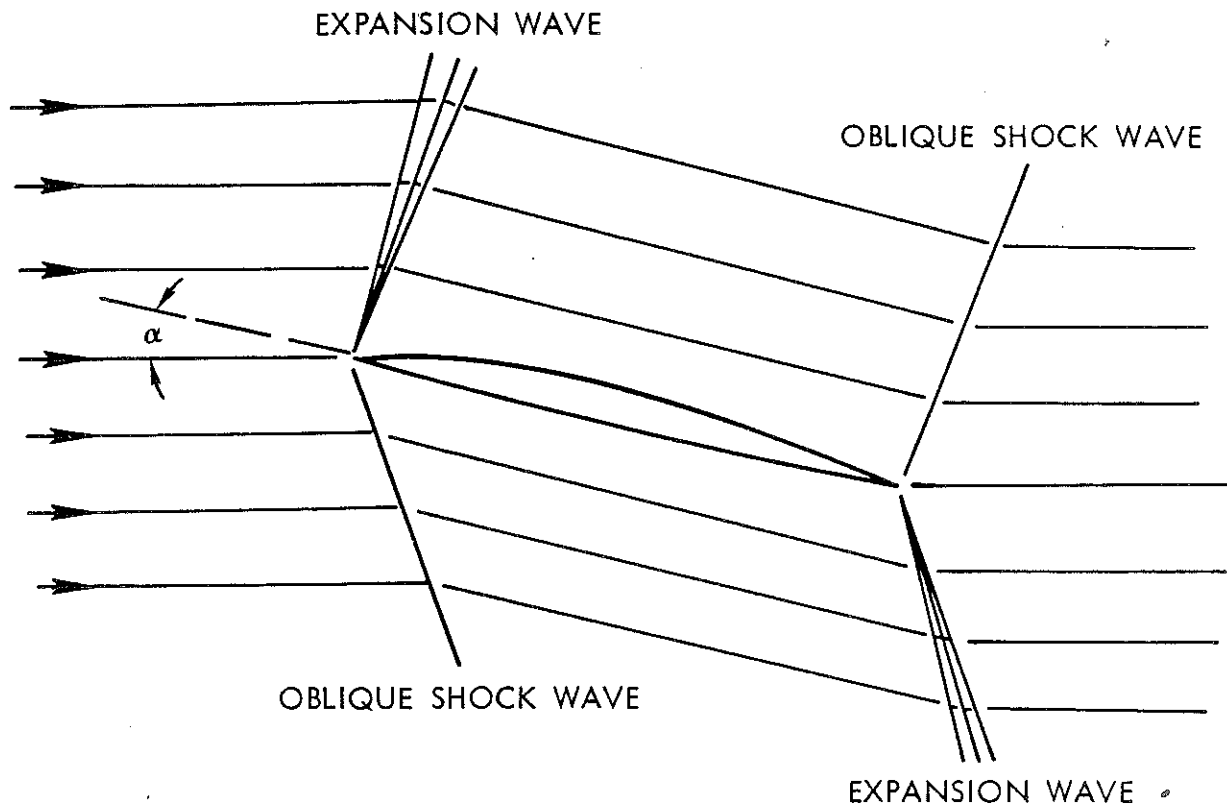
This sketch predicts that molecules A and B will be split by their airflow over the nose. B will go through the oblique, bow wave on the bottom, while A will go through the same bow wave above the nose. But in going on up the nose, A will also go through the oblique wave caused by the corner the flow must turn through, when it meets the windscreen. As A flows over the canopy, there is next an expansion wave that A will flow

through. Checking our table, it shows that A will decrease in static pressure and density behind the expansion wave and in the area just over the canopy. If you're skeptical of my sketch, just check this photograph of actual flow over an F-104 model in Lockheed's Rye Canyon Wind Tunnel.



Just as we predicted, our actual airflow shows the attached bow wave and windscreen shock waves.

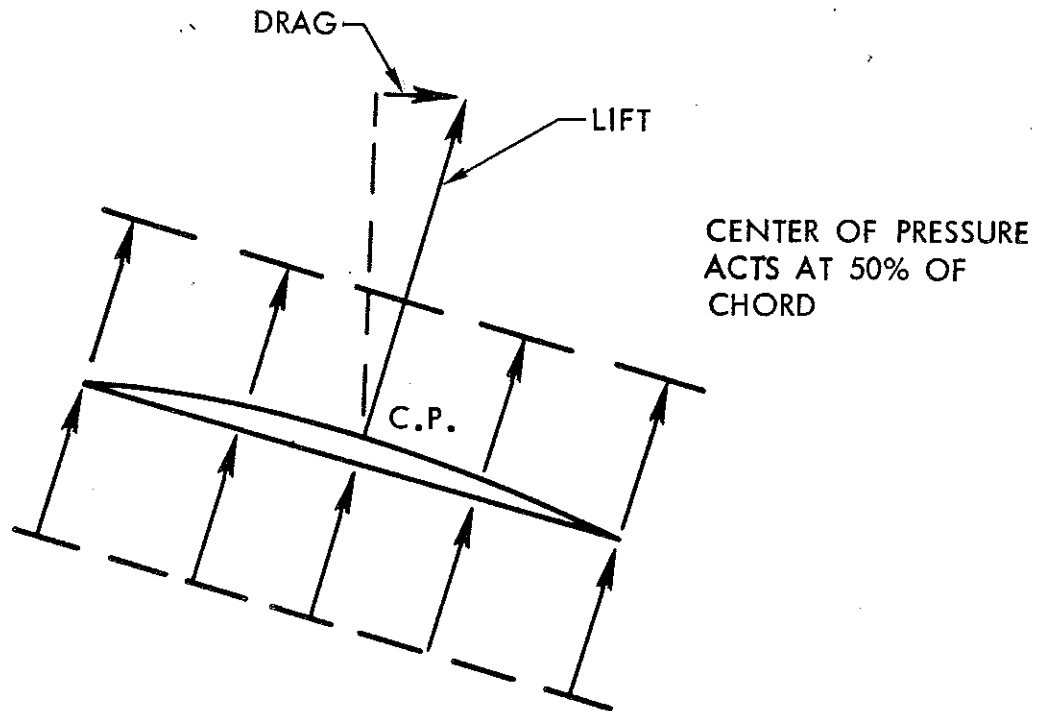
Further back on our fuselage, we can find many other combinations of shock waves. In respect to our wing, with its 3.36% thickness to chord ratio, we can show by our sketch what the shock wave pattern should be.



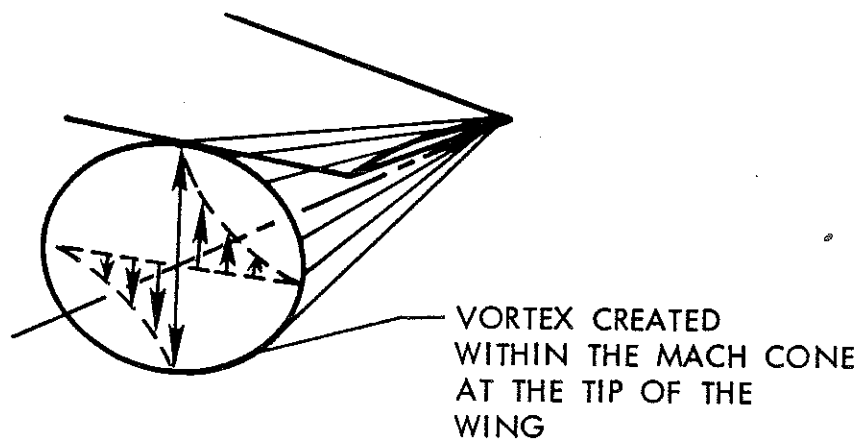
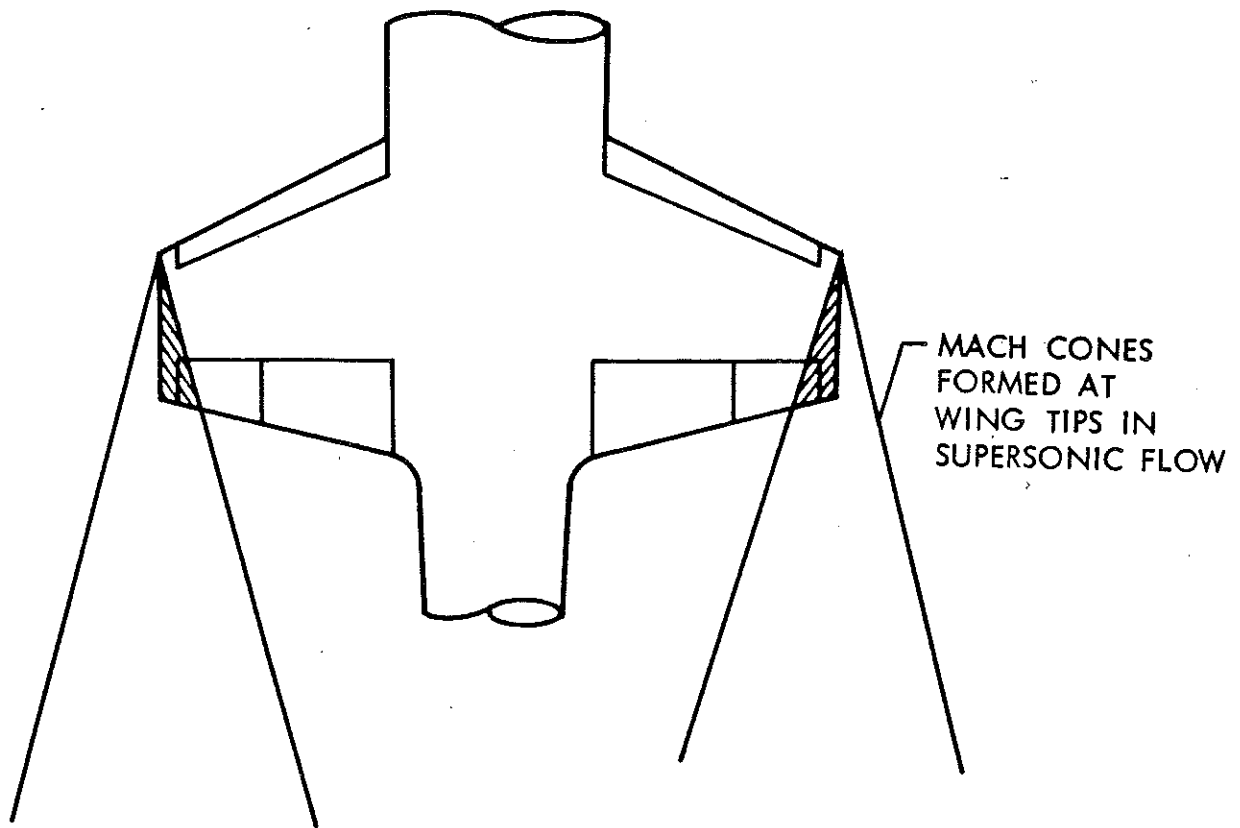
With positive α on our wing, we have an expansion wave off the upper leading edge and an oblique shock wave off the lower leading edge. The combination then reverses itself at the trailing edge. Using our table, we can analyze the changes of the airflow on our wing. We can conclude that:

1. A uniform suction pressure exists over the upper surface, and;

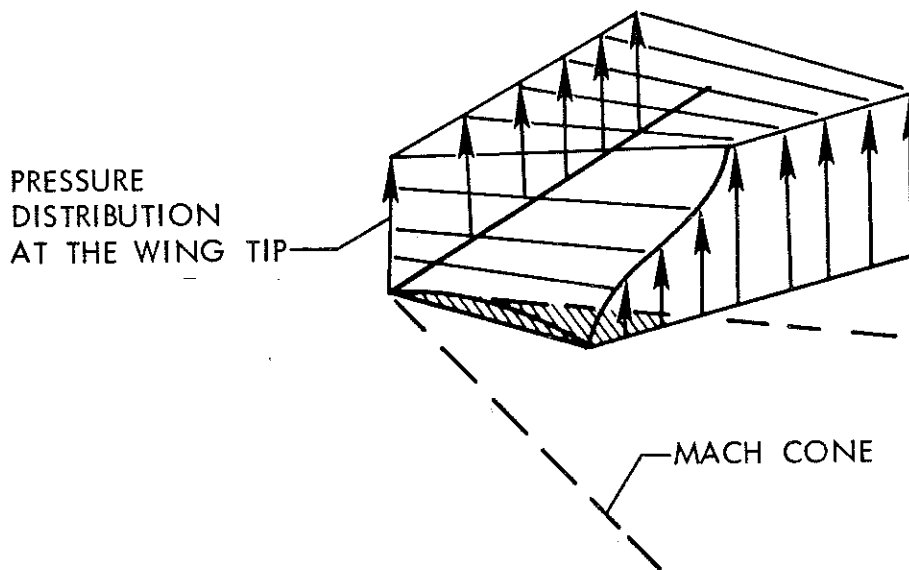
2. There is a uniform positive pressure on the underside of the wing. This distribution of pressure on the surface will produce a net lift and incur a subsequent drag due to lift from the inclination of the resultant lift from a perpendicular to the free stream. Our sketch of this also shows the center of the pressure point.



Here we find a radical shift in the center of pressure point in comparison to the center of pressure point on the subsonic wing. Shock waves will also occur at all movable surface hinge lines causing square pressure distributions on the surfaces and increasing their hinge moments, as I pointed out to you on pages 22, 23 and 24 of SURE lecture 1. An important, distinguishing characteristic of our low Aspect Ratio wing is its square tip. The combination of thinness and square tip brings about an extreme of three dimensional flow in the supersonic flight regime. This amazing flow characteristic can be shown as I've sketched it here.

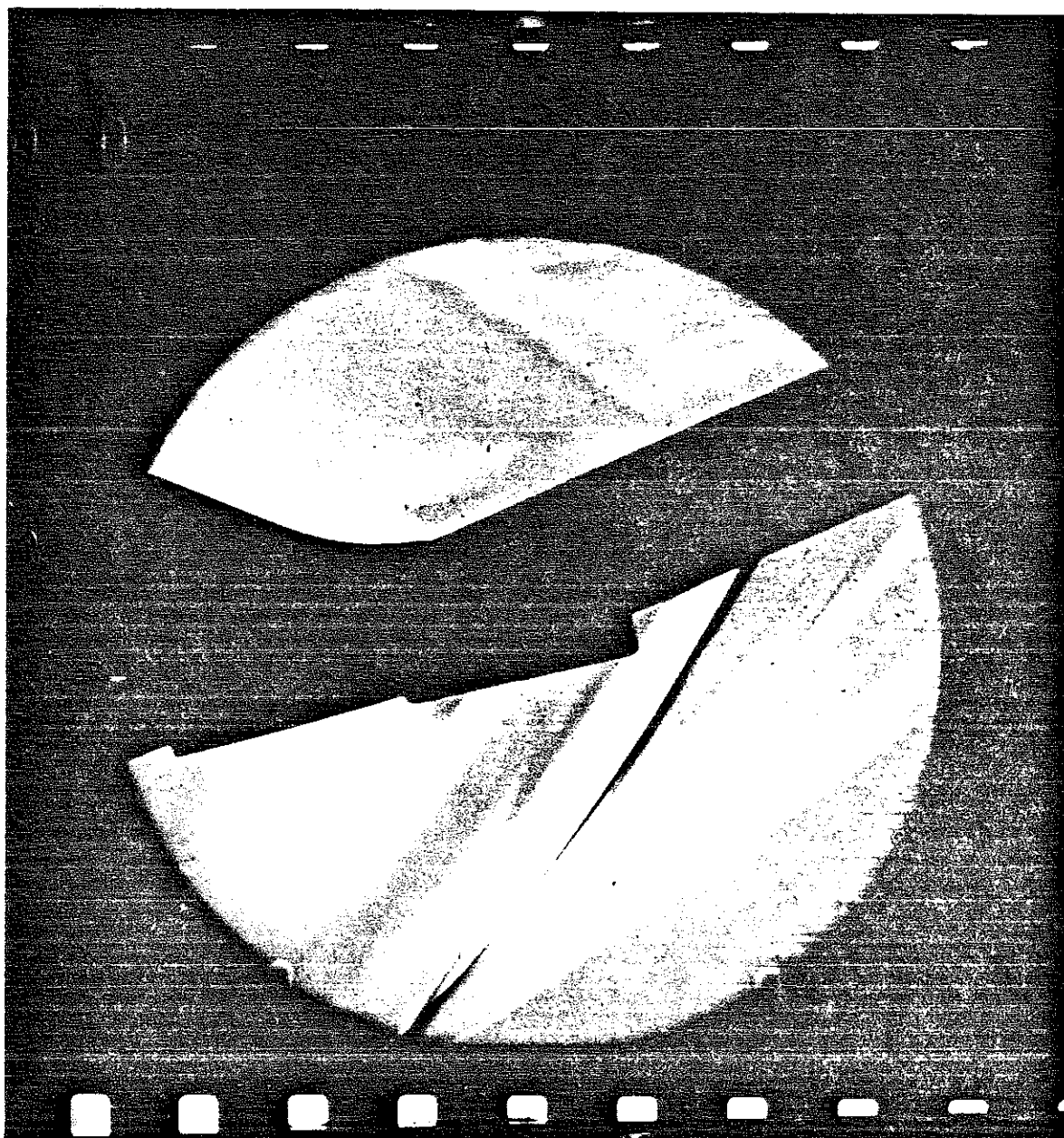


As shown, Mach cones form at the wing tips and affect the pressure distribution on the area within the cone. The vortex develops within the tip cone due to the pressure differential and the resulting average pressure on the area within the cone is approximately one-half the pressure between the cones. Three dimensional flow on the wing is then confined to the area within the tip cones, while the area between the cones experiences pure two-dimensional flow. This has the result of changing the pressure distribution pattern over the wingtip. We can sketch this change thusly.



So in supersonic flight we have Mach cones on the wing tips that give us tip vortices within which the pressure is lowered in relation to the pressure over the rest of the wing. With tip tanks or tip stores, we also have the Mach cone effect that is due to the three dimensional shock wave generated by the nose of the tip tank or tip store. Since the apex of this three dimensional shock wave is forward of the wing tip, its effect upon the two dimensional flow over the wing is more pronounced than the Mach cones generated by the clean wing tip. The external tanks have optimum aerodynamic shapes for minimum drag in the subsonic, transonic and supersonic regime, along with maximum volume and minimum weight.

To show you the composite supersonic flow pattern on the F-104, I have another wind tunnel photograph for your study. If you look closely, you should be able to detect the nose bow wave, the inlet shock wave, the oblique wave and the expansion wave on the leading edge of the wing. See if you can pick them out.



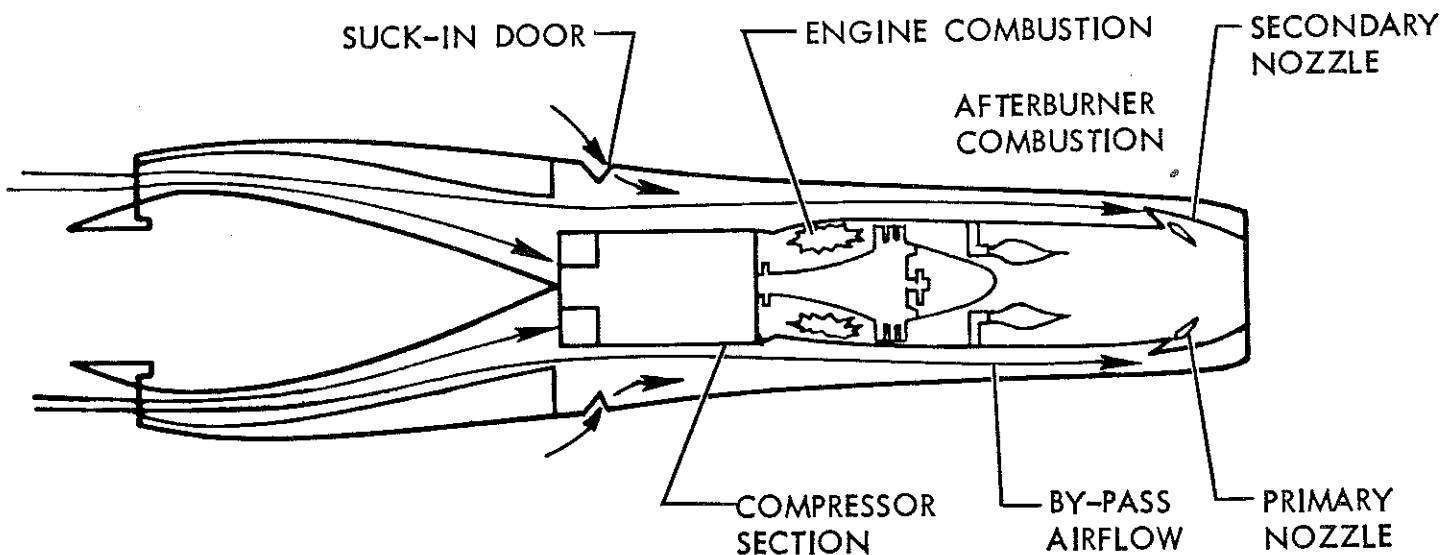
Maybe by now, you are becoming aware of the fact that we fly in two completely different worlds of airflow when we accelerate from subsonic to supersonic flight.

SECTION II

Engine Duct Airflow in Subsonic and Supersonic Flight

The realization of the immense changes that occur between subsonic and supersonic flight prepares us for an important study--that of the airflow through the ducts into the engine. This study, I believe, will yield great benefits in helping you to understand the procedures in your handbook. Also, after completing this Section, I think you will respect the masterful design job by Harry Drell, Ben Rich and John Stroud, Lockheed Design Specialists, in giving us ducts that are simple, yet are wonderfully matched to our engine airflow requirements throughout our huge flight envelope. Instead of designing for moveable ramps and all their associated complexity; we have fixed geometry ramps. The basic design philosophy is to take in all the air that comes into the inlets and then properly distribute the airflow into and around the engine. This simplicity results in our full combat maneuver capability at all speeds and altitudes within the flight envelope. We don't have to worry about roll effects, g loads, accelerations and decelerations and all those critical combat flight factors that have a tendency to confuse sensing mechanisms on moveable type ramps.

To begin our study, let's look at an illustration of our J-79 engine installed in the F-104.



Your first impression of this illustration, or when you take a look at an actual J-79 engine in an F-104, is the snugness of fit and no wasted space. It's a no-nonsense design job with the engine packaged into the airframe for maximum efficiency. To find out how the air is effectively shuttled from the outside all the way through the engine, we need to consider applicable areas of operation.

Ground Operation

As the engine begins to wind up from zero RPM on a ground start, our instinct tells us that it must physically "suck" the air in through the ducts to feed the engine. This suction, within a certain distance from the ducts, has proven many times to be dangerous to the life and limb of our ground crew. Checking our engine illustration, we see that suck-in doors operate to serve as a source for by-pass airflow during ground operation. As long as the engine is running under a condition of zero ram effect into the inlets, it will need every bit of the air that it can swallow into the intake section.

If you start the engine when you're parked with your tail into a strong wind, you will notice some of the engine systems operating to their maximum. This is because the engine is not only trying to suck air into the intake, but the outside air is blowing in the wrong direction. The engine will naturally light-off, but will probably windup slower than you're used to. Also, the EGT will try to rise above 600° C, because of the pressure that the turbines are having to push against in order to eject the exhaust gases. But the nozzles will not allow this so they will go full open and stay there until the engine can overcome this airflow handicap. A strong wind directly into the intakes is beneficial, of course, and will result in a faster, cooler start than you're used to. That's why your handbook recommends it.*

Takeoff Operation

As you go through your pre-takeoff engine checks and take your instrument readings at full Military Power, you might wonder about the amount of thrust you're going to have for the takeoff roll. The handbook** tells you that in Military Power, this engine is rated at approximately 10,000 lbs. of thrust.

* Reference 1, page 2-7

** Reference 1, page 1-5

But wait a minute! It also clearly states--uninstalled engine sea level static thrust. What do they mean by that? Just this. The engine manufacturer runs the engine in test cells where large, bell-mouthed funnels are placed in front of the engine intake. Get the message? There in the test cell, the engine puts out 10 grand of static thrust for Military Power, at sea level on a Standard Day. But here we are -- sitting at the end of the runway and this engine is having to suck air in and around all of the necessary cones and inlet lips that we've put in front of the compressor face. So naturally, we're paying a penalty. How much? An absolutely exact answer involves mathematics beyond the intended scope of this lecture. However, I can give you a gem-dandy rule of thumb to use. At zero ram conditions, we have the following coefficients of thrust or specific fuel consumptions.

1. Military Power - $C_t \approx 1.0$

2. Full A/B - $C_t \approx 1.0$

Our references* tell us that the coefficient of thrust is defined as the ratio of fuel flow to thrust produced. In equation form this is:

$$C_t = \frac{\text{fuel flow (lb./hr.)}}{\text{thrust produced (lb.)}}$$

Now we can do some calculations to determine an approximate figure for the actual thrust we're getting to become airborne. Rearranging our equation for C_t , we get:

$$\text{Thrust produced} = \frac{\text{fuel flow (lb./hr.)}}{C_t} \approx \frac{\text{fuel flow (lb./hr.)}}{1.0}$$

All we have to do now is find some fuel flows and we'll have some interesting answers. On the applicable page of your handbooks**, you will find a chart that will tell you Military Power fuel flows for altitudes and temperatures. In the case of A/B fuel flows, we won't be too far wrong by simply assuming that we gain 50% by going into full A/B at the end of the runway. So, if we take Military Power fuel flow and add 50% to it, this is close enough to use as total fuel flow when we're in full A/B. Using this procedure, I've prepared a table for you to peruse. My calculations were all for sea level conditions.

* Reference 5 & 9

**Reference 1, page 2-12

Temperature Condition	Military Power Fuel Flow <u>or</u> Net Thrust	Total Fuel Flow in Full A/B <u>or</u> Net Thrust
Hot Day - Mil. Std. 210A 103° F.	6550 lb.	9825 lb.
Standard Day 59° F.	7450 lb.	11,175 lb.
Intermediate Cold Day 0° F.	8700 lb.	13,050 lb.

For the answer to how much of a penalty we pay under zero ram conditions, we'll compare our estimate of produced Net Thrust to rated thrust on a standard day.

Military Power

$$\frac{10,000-7450}{10,000} = 25\% \text{ loss}$$

Full A/B

$$\frac{15,800-11,175}{15,800} = 29.3\% \text{ loss}$$

So there you are, Ace, you've had'a thrust indicator in the cockpit all along!

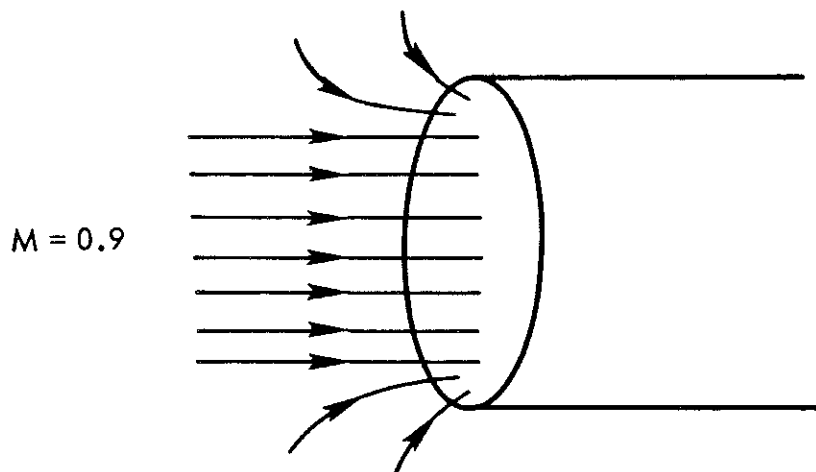
"OK, this is for zero ram conditions--what happens when we start rolling and begin packing some air into the inlets?" Well, next time you bomb down the runway, sneak a peek at the fuel flow indicator and you'll see it rise from the brake release reading to 1000 to 1500 lb./hr. more fuel flow at lift-off. An increase in thrust? Correct! You have an increasing thrust force acting on the airplane from the second you release the brakes. The engine still needs all the air that's being taken in, however, so the suck-in doors continue to operate until about 375-400 knots after takeoff.

Flight Operation

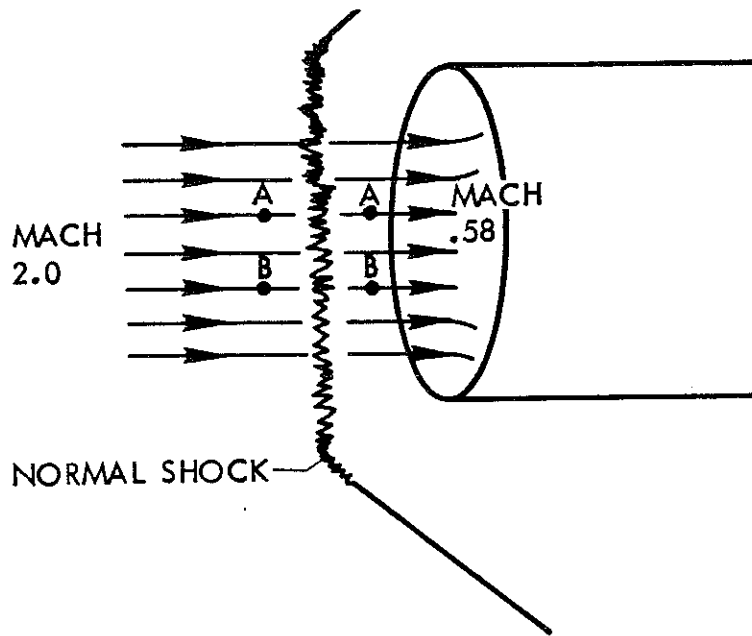
To cover all the aspects of our duct flow in flight, we have to apply some of our newly acquired knowledge about shock waves. And we need to establish some more aerodynamic facts about these shock waves than we listed in our table. Without burdening ourselves with all the complex mathematics, let's review and emphasize some facts the aerodynamicists know:

1. Normal shock waves are perpendicular to the flow and the flow in back of a normal shock wave is always subsonic.
2. The pressure loss through a normal shock wave is considerably greater than through an oblique (conical) shock wave.
3. The angle of an oblique shock wave is established by the wedge or cone angle and operating Mach number.

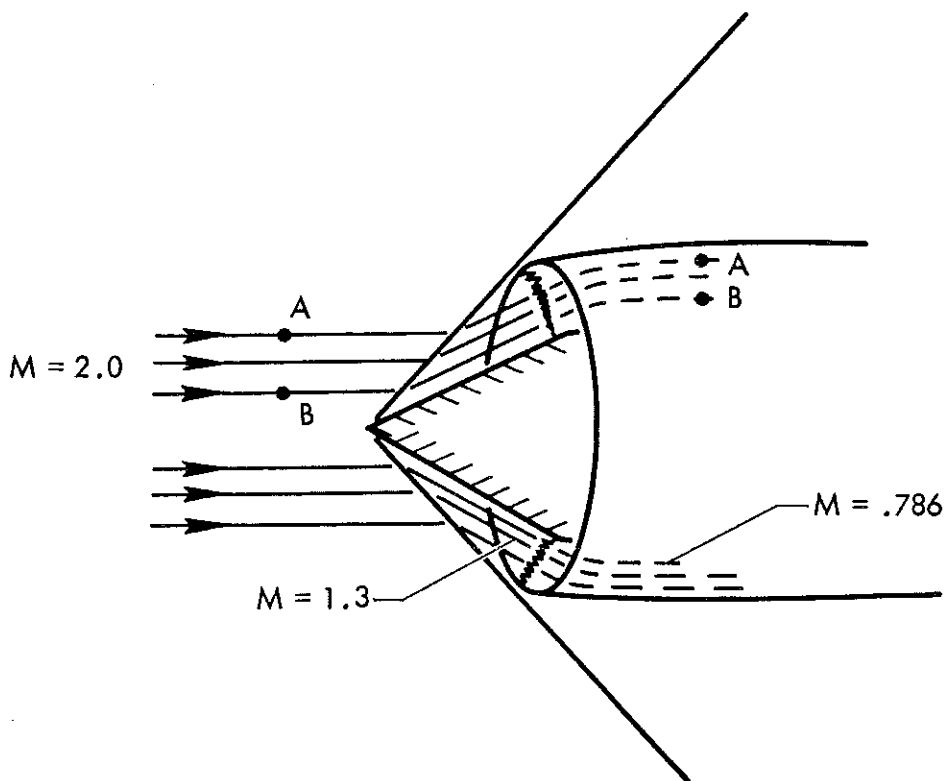
With these facts in mind, and going back to the subsonic area of flight, we know by now that an oval shaped, bell-mouthed intake is the most efficient for subsonic operation. If we design an inlet for a fighter that will cruise for the majority of its time on its missions at 0.9 Mach, it should have an inlet like our sketch. The inlet, of course, will definitely be sized for the airflow requirement of 0.9 Mach number.



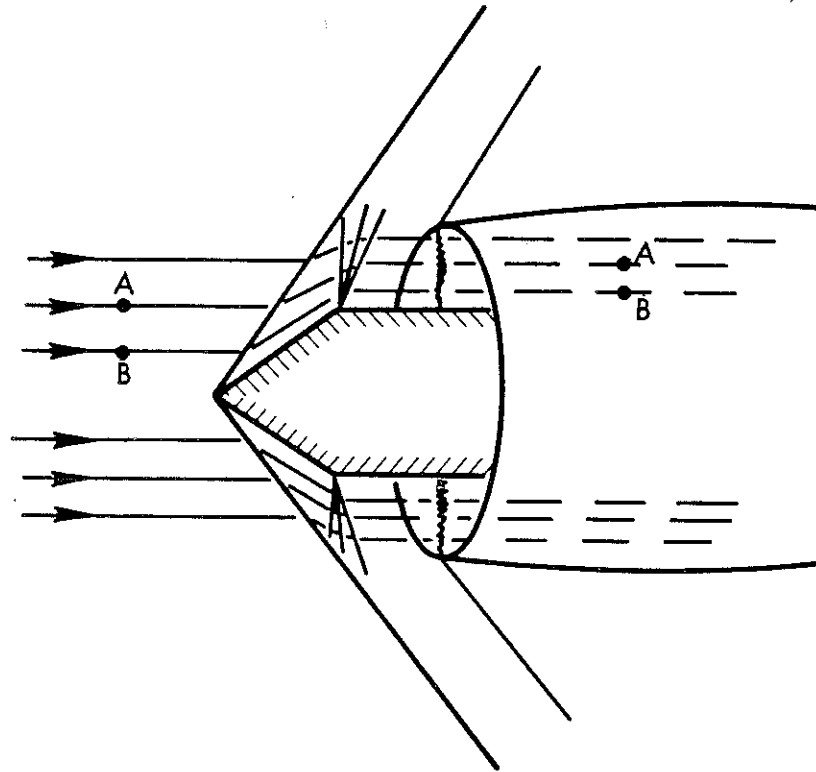
If we had the thrust available to push the inlet out to Mach 2.0, we would have a flow pattern that would consist of a normal shock wave at some distance in front of the duct. We can sketch the flow picture this way.



From our prior study of the path that molecules A and B would undergo, we can understand why they wouldn't like the drastic pressure and velocity change from Mach 2.0 to Mach 0.58--all in one jump! Their disgruntlement at this disturbing change in their conditions would be reflected in the efficiency of their flow into the intake. Comparing the free stream conditions, we find that the theoretical available pressure at the compressor inlet for this flow is approximately 70% of the free stream or available pressure. A "shocking" loss? You bet. There has to be a better way--and there is. Falling back on our shrewd knowledge and innate instinct of airflow (remember the feathers!) we can envision a duct--with a cone in the middle. Using this cone to produce some beneficial shock waves, let's see if we can't become more efficient in scooping in this high Mach flow. A sketch of this flow will tell us if we're successful.

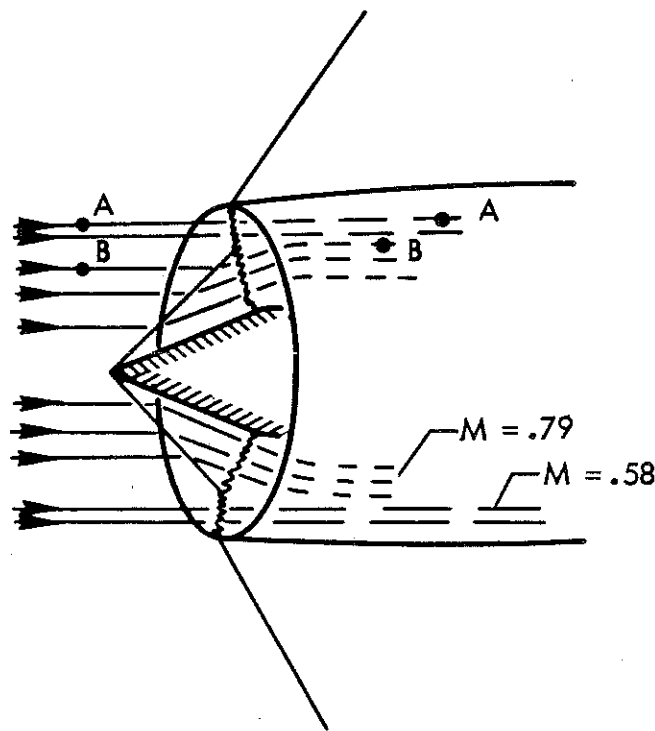


Now we're getting somewhere. Because this configuration results in a theoretical available pressure of approximately 90%. Only a 10% "shocking" loss. But, we must now be careful on our design shape and size. The aerodynamicists tell us that the cone must be in a fore and aft position to obtain a "shock on lip" condition. That is, we must have the oblique shock just hitting the circular cowl lip when we are at our maximum design speed, and for maximum efficiency, hold the shock on the cowl lip for all supersonic flight. If the oblique shock stands out too far, we will pay a drag penalty. This will occur if our cone is positioned too far forward as in the following sketch.



Even though A and B go through an oblique and expansion wave, they must still essentially go through a complete normal shock that covers the whole inlet area. They'll show the same disgruntlement as they did before. We're only a little better off than with the bell-mouth inlet.

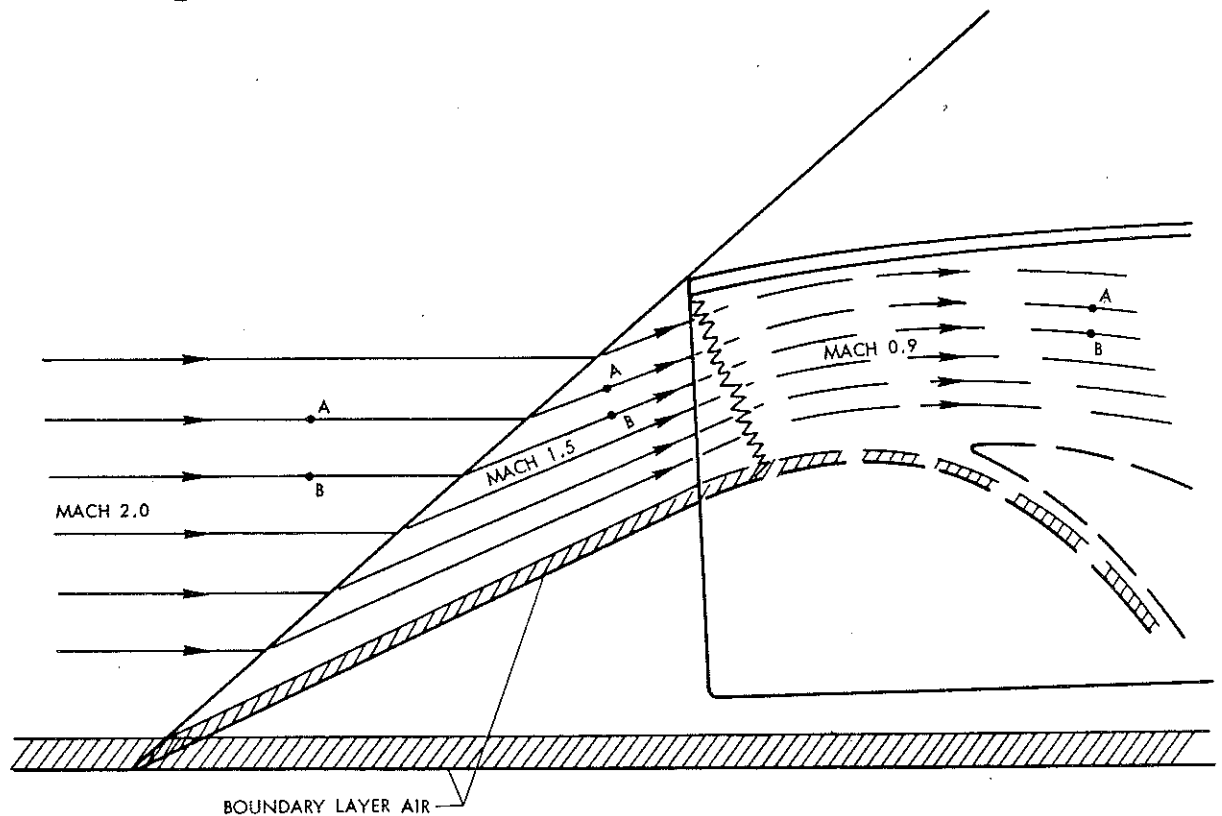
On the other hand, if our oblique shock wave is swallowed into the inlet, we will encounter a pressure loss because of the lingering presence of the solo normal shock wave. The flow pattern looks like this.



Now we are again splitting up the flow of A and B. B will go through a nice, oblique wave and be slowed down before going through the normal wave. B will end up at Mach 0.79 with a high pressure recovery, while A is stuck again with the big "shocking" loss by going directly and impetuously through the normal wave. A will wind up at Mach 0.58. Incompatible flow? You bet.

The care that must be taken to properly size and position the cone is more easily said than done, since one configuration can be optimized for one Mach number (flight condition) only. That is, the inlet size should vary as engine airflow changes as a function of engine RPM and Mach number. The cone angle and position should change with Mach number to keep an optimum inlet shock pattern. To accomplish all this takes space, weight, power and complexity. In the case of the F-104, it was not considered justified when compared to the moderate performance loss associated with a properly designed, external compression, fixed geometry system. With the fixed geometry system, the duct size and shock position are compensated for by by-passing primary duct airflow past the engine inlet. This air is not wasted since it serves to cool the engine and accessories, and provides air to the exhaust nozzle ejector to increase the exhaust nozzle coefficient.

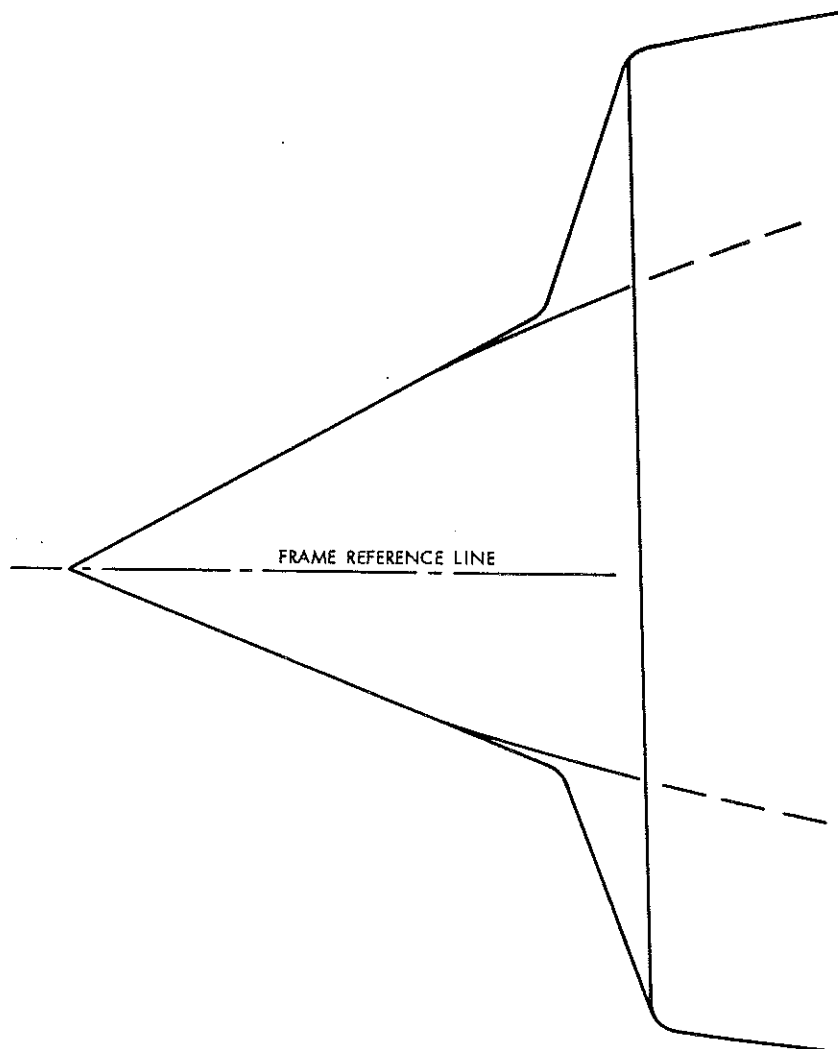
If we again follow molecules A and B through their flow pattern, you'll see the efficiency of our undercut, conical ramp inlets. I've drawn a sketch to show their journey.



As I've shown molecules A and B are shocked through an oblique wave which slows them down from a free stream flow of Mach 2.0 to about Mach 1.5. Then they follow the contour of the 25° angle ramp cones, which provides an on-the-lip geometry with the oblique wave. Continuing, they meet the normal shock wave inside the duct, where they are now slowed down to a subsonic flow of about Mach 0.9. From here, they continue decelerating, due to expanding to fill the larger volume, until they are at a smooth, laminar flow of around Mach 0.3 when they meet the splitter ducts, inlet guide vanes and thence begin their trip through the engine.

"Now, Snake--you keep talking about the fixed geometry of the inlet. Aren't the ducts just symmetrical cones stuck into an inlet?"

No, Ace, they're much more subtle in design than that. I've drawn a side view of the ducts to scale so you'll see what I mean.



If you look closely, you'll notice the lip of the inlet slants back at an angle of about three degrees. This is so that at 35,000 feet and a cruise Mach number of 0.9, the airflow will be directly into the inlet since you'll have an airplane angle of attack of close to three degrees.

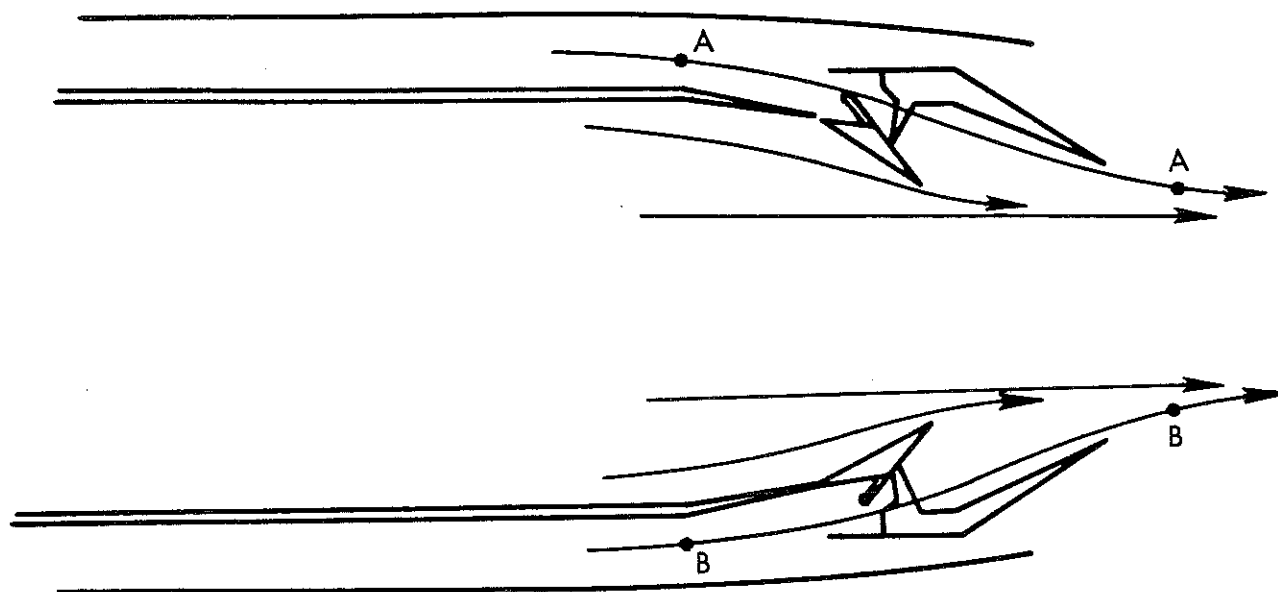
"Wait a minute! If the lip is slanted back, won't we have a wrong oblique wave at Mach 2.0 and not be on the lip?"

No again, because if you examine the cone, you'll see that it has been rotated to correct this. In effect, the whole duct is rotated just the right amount. A brilliant design.

So the airflow is like shifting gears and it's slowed down with minimum effort and fed into the compressor section in a healthy condition of flow--maximum pressure recovery with minimum "shocking" loss. Looking back at the starting point of A and B, we see that they are also accompanied by a slow moving, sticky layer of air that adheres to our fuselage skin. This brings up an aspect of airflow that we haven't discussed before. And a whole treatise and study could be devoted to airflow on surfaces. For this lecture and your flight considerations, it suffices to point out that in both subsonic and supersonic flow, there is a boundary layer of flow along the skin surface that is viscous and gives drag to the aircraft. "So what do we do with it?" Look at my sketch and you'll see another refinement of our design. Boundary layer removal provisions are made by raising the inlet away from the fuselage, undercutting the cone to obtain a low pressure area to draw the boundary layer from the cone sides. We simply give it a path of least resistance to follow so that it doesn't get into the ducts and cause interference and further drag. The undercut then, will appreciably reduce our boundary layer flow. But visualizing this flow in its true aspect as viscous and sticky, we see that some of it will continue, in a diminished amount, on up the cone--still following A and B. To get rid of this persistent flow, we now slot the cones. Any amount of boundary layer flow that continues up into the duct is bled off by the slot in the cone. To accomplish this, the cone slot is ducted to an area of low pressure at the bottom of the fuselage, which provides a beneficial type of sucking action. This sucks the sticky boundary layer flow to the bottom of the fuselage and removes it from the ducts where it could cause trouble. It's a no-cost, built-in air pump! What could be neater?

One more look at the sketch of the engine in the airframe shows an alternate route that molecules A and B might take instead of going through the engine. That is the possibility that they might be channeled as by-pass air and go around the engine. In this case, they might be used for cooling air on the accessories and then be exited out the tail area around the outside of the nozzles on the engine. Or, more probably, they will be used as flow for cooling air and be selected to exit through the nozzles. The selection of A and B to become by-pass air is not an arbitrary and willy-nilly process. It's all handled by our by-pass flaps, that meet the throat of the engine. There are 10 flaps around the throat. All of the flaps are set to an opening of 1/4 inch that gives an area of by-pass flow of 25 square inches. This condition is for landing gear down, where on takeoff and landing, the engine can use all the air it can suck in. When you raise the landing gear, and as long as the gear is up, two of the by-pass flaps (at the 5 and 7 o'clock position) open further to give a total by-pass

area of 44 square inches. Your handbook* describes this operation very clearly. If A and B are selected for by-pass flow and reach the nozzle area, they are in for a pleasant surprise. Not only does the J-79 engine have a sophisticated air compression process with variable stator blades, and a highly efficient combustion process with augmentation in four stages--it even has an aerodynamic convergent divergent nozzle system. This means that if A and B are exited between the primary and secondary nozzle, they will be serving a most unique airflow function. By a simple drawing of the nozzle area, we can show this airflow process.



With A and B flowing between the primary and secondary nozzles, they are bringing colder, higher pressure flow than the flow in the exhaust. This flow, theoretically, necks down the exhaust flow which later expands, out beyond the tailpipe. The expansion process results in supersonic flow, which yields the Mach diamonds that can be seen in the A/B exhaust pattern at night. In terms of engine thrust, this contraction and expansion of the exhaust flow is beneficial. As I explained before, our by-pass air is used to increase the exhaust nozzle coefficient. Now don't let this term throw you, because it has a very simple meaning. When we compare the actual efficiency of our nozzle against the efficiency of a theoretical "ideal" nozzle, this ratio is called the Nozzle Coefficient. A simple equation tells the story.

$$\text{Nozzle Coefficient} = \frac{\text{Actual Nozzle Efficiency}}{\text{Ideal Nozzle Efficiency}}$$

*Reference 1, page 1-36

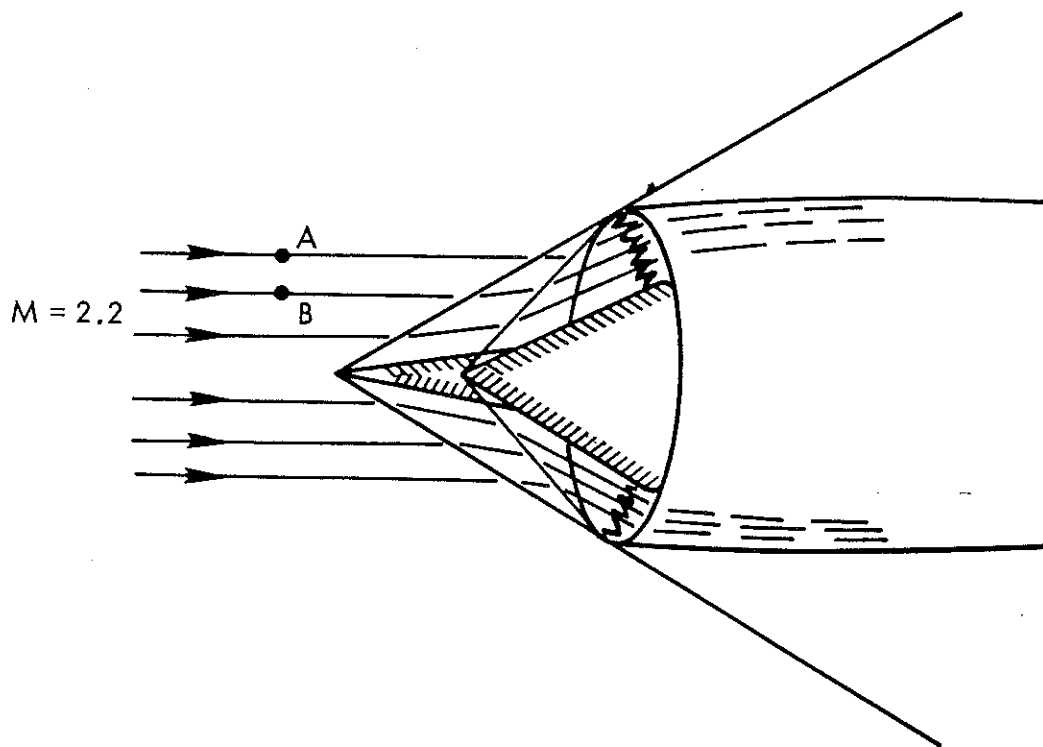
The aim of engine designers is to achieve an exhaust nozzle coefficient of 1.0. With the J-79 in our F-104, we have a very respectable rating of around .9 or a 90% efficient nozzle--a high rating in any league.

A very critical aspect of duct and engine airflow, from the pilot's standpoint, is the airflow effect on engine airstart capability. On pages 1 through 4 of SURE lecture 3, I wrote about the airstart procedure and showed you the huge airstart envelope of the J-79. A primary reason that the J-79, in the F-104, has such excellent airstart characteristics and a large envelope, is the windmilling flow pattern through the ducts and engine. In comparison with all of the other flow possibilities of our molecules A and B, they will have the smoothest ride when going through the ducts and engine, when the engine is windmilling. This flow pattern is smooth because our total induction system is operating generally like an airspeed pitot probe. Due to the low RPM, the engine is neither sucking nor pushing but just rotating at a windmill RPM. In this condition, the pressure recovery in the inlets is nearly 100%, thereby giving A and B a smooth entry into the engine. Of course, any flameout indicates a malfunction of the engine or its associated fuel system. Therefore, the smart move is to get the aircraft back on the ground as soon as you can, after you're successful with your restart attempts. Any wrong move, such as ignoring a critical warning, like a flameout, will probably yield the same results as occurred in Accident Review No. IID on page 13 of SURE lecture 4. Whenever I've encountered flameouts, my first step has always been to head for the nearest suitable landing field and after making an airstart, I LANDED THERE!

From the standpoint of engine airflow, the most critical malfunction is a failure of the Inlet Guide Vanes to the full closed position. If this happens, you will notice a great loss of thrust along with the puzzling situation of all of the engine instruments appearing normal--except for the fuel flow. Pilots have reported that even with 100% RPM, nozzles and EGT indicating Military power, the fuel flow has only been in the 2000 lb/hr range. So, when the IGV's fail to a full closed setting, the airflow is cut off to such an extent that the fuel flow decreases to an amount that yields so little thrust that you cannot remain airborne, unless you are successful with an A/B light. Even with A/B operation, in this condition, you will probably find that you should not retard the throttle out of A/B until touchdown is assured.

Many of you Tigers have asked me about the limitation of Mach 2.0 on the F-104. And you've pointed out that on a colder than standard day, you won't get the "SLOW" light or 100° CIT at Mach 2.0. In SURE lecture 1, I told you about the stability problem and the complexity of displaying it to you. Actually, there's a plain old physical limitation

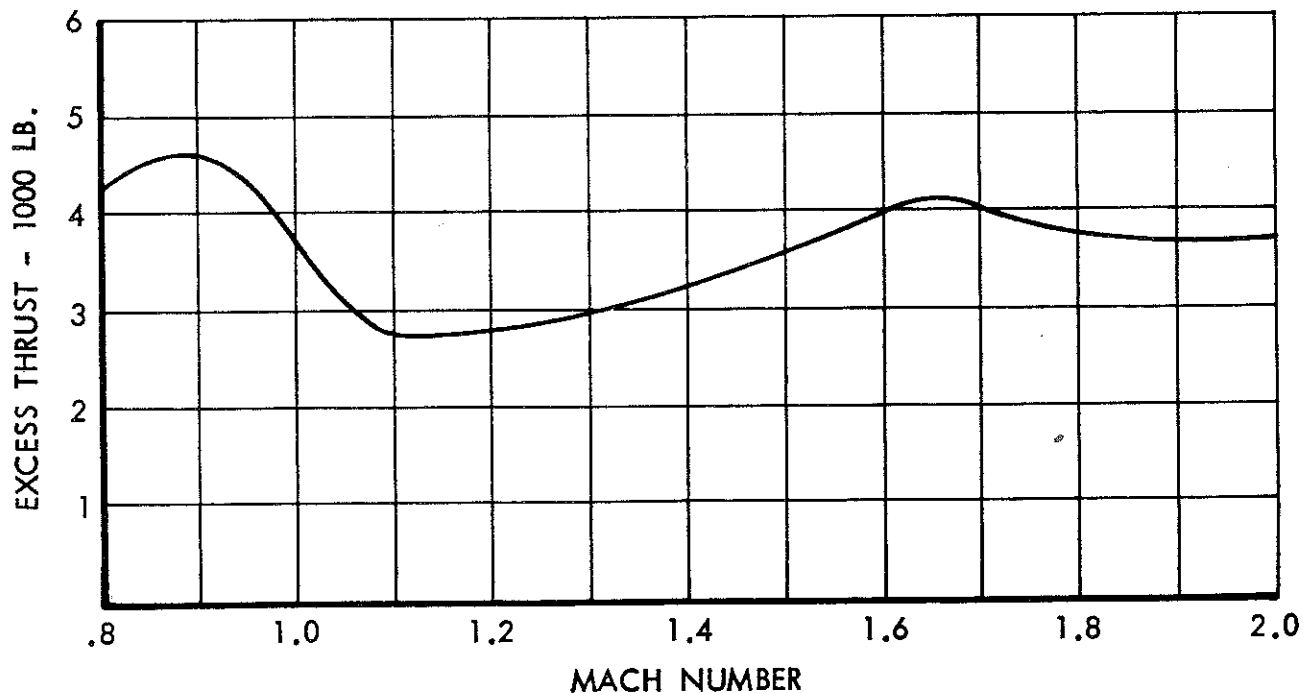
of airflow that should now be knocking in the back of your head. When you go faster than Mach 2.0, the fixed size of our inlets tells us that the oblique shock wave will be swallowed into the duct. Even though you may not have ever been over Mach 2.0, I can tell you what you'll encounter and save you the trouble of curious investigation. As I stated before, the position of the normal shock can be effected by the total airflow of the duct. This is the amount of air that the engine accepts plus the amount of air that is by-passed into the engine bay and is pumped into the exhaust nozzle. If you barrel past Mach 2.0, which is easily done in the F-104, you will probably hear a noise like rocks rolling down the duct. This is caused by the ducts now trying to accept more air than the engine can use and results in excessive spillage. The attendant increased pressure distortion at the engine compressor face may now cause a compressor stall, especially when maneuvering or pushing over to less than 1g. In SURE lecture 1, I have informed you of the Inertia Coupling aspects at less than 1g roll entries at Mach 2.0. The stall will be rather loud, but is normally not accompanied by high EGT and can be eliminated simply by slowing down, returning to straight and level flight or pulling slight positive g's. In order to fly ever faster and higher, Lockheed has studied the airflow problem of flight beyond Mach 2.0 in the F-104, and has designed accordingly. Just as we faced the problem with (then) Capt. Joe Jordan and his world altitude record of 103,395 1/2 feet, we know we can add an additional spike to the existing cone. This will move the first oblique wave out from the inlet as you can see in this sketch.



Later design studies revealed a more efficient way. For the Italian F-104S model and later versions of the F-104, the leading edge of the duct will be cut back to prevent the oblique shock-on-lip from being swallowed. These aircraft will then have true Mach 2.2 speed with full maneuver capability in conjunction with the excellent subsonic performance you're already used to.

For you Tiger's who are real interested in engine performance, I am including a plot of Excess Thrust which primarily proves that even though the ducts were optimized for 0.9 Mach number and 35,000 feet, there is very little loss throughout the supersonic flight envelope.

F-104 EXCESS THRUST
CLEAN CONFIGURATION
35,000 FEET



And for those of you who have that glint in your eye, wondering about how much excess thrust horsepower you would have at Mach 2.0 to maneuver and fight--I am including this sample calculation.

Excess Thrust Horsepower Calculation

Mach 2.0 35,000 feet Clean Configuration

$$\text{ETHP} = \frac{\text{Excess Thrust} \times \text{miles per hour}}{375*}$$

$$V_t \text{ at Mach 2.0} = 662 \text{ mph} \times 2.0 = 1324 \text{ mph}$$

$$\text{Excess Thrust (from plot)} = 3700 \text{ lb.}$$

Therefore;

$$\text{ETHP} = \frac{3700 \text{ lb} \times 1324 \text{ mph}}{375} = 13,000$$

* 1 lb of thrust = 1 HP at 375 mph

Ace, I know I don't have to convince you of the impressive output of the J-79 engine in the F-104. We are fortunate in being in a select group of fighter pilots--those who have felt the exhilarating "kick" and can truly appreciate the airflow utilization of this engine-airframe combination.

SECTION III

Aerodynamics of the Takeoff Roll and Rotation

Well do I remember my first takeoff in an F-104. It was the realization of a great desire that had possessed me ever since I first laid eyes on this classical beauty of a fighter. The heart-stopping acceleration of full A/B gave me a thrill that has now been repeated thousands of times. But this same thrust that pushes you back and "pins" you to your seat can become a nightmare of frustration and confusion--IF THE NOSE DOESN'T COME UP WHEN IT'S SUPPOSED TO! The rate at which you're gobbling up the runway boggles your mind and that barrier at the end of the runway is looming ever larger. If you don't keep a cool head and make the proper moves based upon good judgment--you're facing a major accident! What are your choices? Basically two:

1. Abort.
2. Continue the takeoff roll with further attempts to raise the nose.

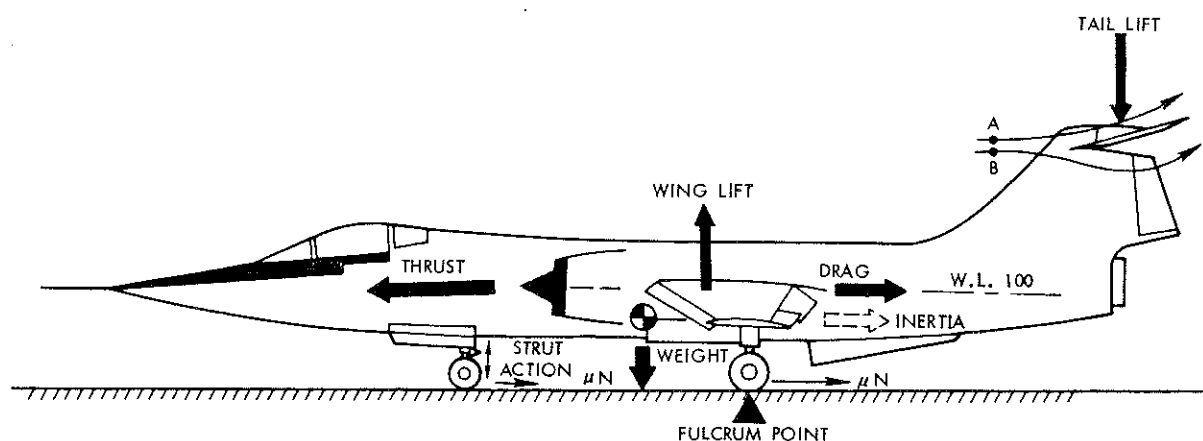
Now I am not so presumptuous as to make the decision for you. If you are faced with this problem in the future, the decision will be yours alone. But you do have a head on those shoulders, so use it for the best and safest action. Also, you might be wondering if maybe old Snake is making a big deal out of a few isolated cases. No, I'm not and records bear me out. From a research of Lockheed files on "reported" incidents and accidents that were directly attributed to difficulty in raising the nose on takeoff, we have the following dismal picture:

<u>Year</u>	<u>Incidents</u>	<u>Accidents</u>
1963	3	
1964	25	1
1965	4	2
1966	22	
1967	8	
	<u>62</u>	<u>3</u>

A total of 62 "reported" incidents and 3 major accidents places this problem definitely out of the isolated category.

Is there a fast, simple answer to those pilots who have hurtled into the barrier and then made confused, red-faced statements of, "I don't know why--but the nose wouldn't come up?" No, there is no simple answer or quick solution. And, there are many, highly qualified pilots

who are among this club of involuntary "barrier testers". No, there is no simple answer, but I do know that an aerodynamic examination of takeoff roll in the F-104 will expose the primary reasons how this revolting situation can occur. And it will tell us how to best accomplish a smooth, assured rotation. With no further blabber and by clapping on a thinking helmet, we can draw our F-104 with ALL of the forces acting on the bird during takeoff roll and the nose rotation phase. By the way--do you know what they are? No sweat--just inspect my sketch and follow me through.



FORCES ACTING ON F-104 DURING TAKEOFF ROLL AND ROTATION

From my drawing, and if we shoot some watts of brain power through our thinking helmet, we can deduce that the forces acting on the F-104, that affect rotation, can be analyzed for two basic phases. First, during the takeoff roll, the forces shall be summed up as acting around the c. g. This analysis will help us to establish the attitude of the aircraft during the takeoff roll and therefore what the attitude is at the instant that rotation is started. The second phase will be analyzed with the forces acting around the main landing gear, which is the fulcrum point for rotation. And for our analysis, let's select a configuration of basic F-104G plus tip fuel plus a 2000 lb. centerline store. On page 36 of SURE lecture 4, you will find that

for this configuration, the aircraft has an approximate gross weight of 25,450 lb. with a c.g. of -5.0% m.a.c. and the chart predicts a takeoff speed of 205 knots. Since I recommend on page 37 to start rotation about 20 knots below takeoff speed, our two target speeds are 185 knots and 205 knots. Now, to obtain a clear picture of the sequence of events, during takeoff roll and rotation, let's reconstruct developments as they occur.

As you release the brakes, the aircraft starts moving down the runway. During the initial phase of the takeoff roll, the primary forces acting on the aircraft are those of weight, thrust and friction and only after an appreciable velocity increase will the aerodynamic forces of lift and drag make known their effects. Therefore, during a normal takeoff, the aircraft accelerates down the runway, initially overcoming the forces of inertia and friction and later, the additional forces of lift and drag. At the proper speed, the pilot introduces an aft stick movement so that the horizontal stabilizer moves from the takeoff trimmed position and increases the downward force of the tail lift. The tail lift must be increased to a value that will rotate the aircraft, with the main landing gear as a fulcrum point, to a positive angle of attack. When the aircraft speed and angle of attack have combined to develop enough lift--the aircraft flies. At the instant of becoming airborne, the aircraft then rotates in pitch around the c.g. So, for the force analysis of the F-104 during the takeoff roll, we can see that the forces acting around the c.g., in a nose down direction, are the thrust line, wing lift and the friction forces on the wheels. A more thorough examination of each force will help to establish their effect on the aircraft attitude during the takeoff roll.

1. Thrust line: On your first takeoff in an F-104, you will notice the characteristic of the thrust line acting above the c.g. As soon as you advance the throttle forward to Military power, while holding the brakes, the bird squats and bows forward. When you release the brakes, the nose rises up toward the static aircraft attitude and you begin accelerating. As you light the A/B and go to full uniform burning, the nose stops its upward movement, settles down and the aircraft again assumes a flat attitude as the pressure in the nose strut works at balancing out the total sum of nose down forces acting on the aircraft. In order to locate force points and moment arms, we shall have to refer to fuselage station points that are units of inches and are numbered consecutively from the nose rearward. Also, we'll use water lines that are units of inches and are numbered consecutively from the landing gear up. For example, the thrust line acts at a fixed position through the fuselage. It passes through fuselage station 510 and water line 105 at a canted down angle of $2\frac{1}{2}$ degrees. For our configuration, the c.g. is located at water line 96.5 and fuselage station 438.5 and since the thrust line is canted down, the moment arm of the thrust line is approximately 5.5 inches. Another facet of this offset thrust line is that the thrust is constantly increasing, during the takeoff roll, as I explained in Section II. So the nose down moment must also be increasing. The rate at which

the thrust/moment is increasing is affected by temperature variation as we saw in our table of thrust variation with ambient temperature. This variation of thrust increase has no effect on nose wheel liftoff speeds, but essentially its main effect is its download on the nose strut, as it attempts to push the nose down to a lower aircraft angle of attack during the takeoff roll. The compression in the nose strut eventually balances out the forces so that the aircraft attitude stabilizes at the static attitude, or at an attitude between the static attitude and a fully compressed nose strut attitude. So our airplane angle of attack at rotation will be dependent upon the condition of our nose strut and its reaction against the total nose down force summation. Therefore, on our preflight inspection, we should check for proper servicing of the nose strut. The nose strut should be checked as extending 2 inches and inflation condition of the tire should be checked. This inspection is important for two reasons. One--if the nose shock strut is serviced so that it extends 2 inches, then the aircraft sits at the proper static attitude of -0.33 degrees nose down. If it does not extend 2 inches, then the aircraft will sit at a greater degree of static nose down attitude. Two--if the nose shock strut does not extend 2 inches, then the Nitrogen pressure in the nose strut is too low for the weight load that has been put on the aircraft. On the takeoff roll, then, the nose down moments will force the nose strut toward a fully compressed condition. A fully compressed nose strut results in a -1.0 degree nose down attitude. On rotation, when a properly serviced nose strut is fully extended, the aircraft is at a positive 1.7 degrees angle of attack. So, in order to keep from going all the way down on the nose strut during the takeoff roll, you need to perform the exterior inspection as outlined in the handbook. If you don't, a "Murphy" oversight can result in a degraded nose strut condition. Even if this happens, however, recent operational tests have shown that nose rotation will still be normal if the proper amount of tail lift is developed.

2. Wing lift: You've probably already figured out that with the flat attitude of the F-104 during takeoff roll, we're not developing a large lift factor on the wings--and you're absolutely right. The small amount of wing lift that is developed acts at one fourth of the wing m.a.c. (mean aerodynamic chord) and this is located at fuselage station 472.5. If we now take the static attitude of -0.33 degrees and an arbitrary in-between attitude of -0.5 degrees and the fully compressed nose strut attitude of -1.0 degree, we can calculate for wing lift at these various aircraft attitudes that realistically will exist just prior to rotation. And also we can calculate for drag to assist in later analysis. Finally, if we calculate wing lift at the aircraft attitude of $+1.7$ degrees, this will encompass the aircraft rotation attitude spectrum. Here's the table of these values:

<u>Airplane</u> <u>Angle of Attack</u>	<u>Airspeed</u>	<u>Wing Lift</u>	<u>Drag</u>
-0.33 degrees	185 knots	2740 lb.	2050 lb.
-0.50 degrees	185 knots	2440 lb.	2050 lb.
-1.0 degree	185 knots	1600 lb.	2070 lb.
+1.7 degrees	205 knots	8120 lb.	2490 lb.

We can make a conclusion from these calculations that if we have a "mushy" nose strut due to improper servicing and during the takeoff roll we proceed toward a fully compressed nose strut condition, our wing lift decays to a very small value. This means that the aircraft will have a less "buoyant" feel than normal, and also has the effect of giving you, in the cockpit, a sensation of the aircraft settling down and a strong impression of no rotational capability.

3. AN forces on the wheels: The friction forces acting on the nose and main wheels are creating a nose down moment around the c. g. during the takeoff roll. These forces are adding to the total nose down moment, but are small in comparison to the offset thrust line moment. From the aerodynamic standpoint, the Normal (N) load is composed of aircraft weight minus lift. But, since our nose remains in a level attitude during the takeoff roll, we've seen that only a small amount of wing lift is developed until there is a positive angle of attack of the aircraft. The Normal load, then, remains close to the aircraft weight value until rotation of the nose.

You can see that these forces all sum up to give the F-104 a flat attitude during the takeoff roll. As the speed increases up to the point for rotation, the aerodynamic forces of drag and tail lift now begin to appear. And, as I pointed out before, the aircraft rotates about the main landing gear axles during the rotation phase. So, it is more pertinent for our analysis, to consider the moments that are acting about the main gear wheel axles. Therefore, this brings us to the next step in our analysis.

After we've accelerated to 185 knots and just as we start an aft stick movement, we must now consider phase two--that of the moments acting around the fulcrum point. Since this is the very important point where we now enter the picture, it will be helpful if we calculate the total summation of nose down moments and nose up moments, at the instant just prior to stick movement. And, by examining my sketch, we can list all of the forces acting on the aircraft and see whether they're against rotation or for rotation.

Against Rotation

Weight force acting through c. g. position
Engine thrust

For Rotation

Wing lift force
Drag force
Inertia force
Tail lift force

Now let's calculate the moments that these forces are subjecting on the aircraft at this point in our takeoff.

Against Rotation

1. Weight force acting through the c. g. position: Assuming that for engine start and taxi-out, the engine has burned about 450 lb. of fuel, then the aircraft gross weight is about 25,000 lb. for the takeoff roll. For our configuration, the c. g. is at fuselage station 438.5 and the axle line of the main wheels is at fuselage station 483.6, so the moment arm is 45.1 inches or 3.75 feet. This gives a nose down moment of 93,750 ft-lb.
2. Engine thrust: In Section II, we established a table that gave us a good approximation of engine thrust for Standard Day and sea level conditions. At the point before releasing the brakes, we had 11,175 lb. of thrust in full A/B. At rotation, though, we figured another 1500 lb. of thrust due to the increasing ram airflow into the ducts. This gives an estimation of 12,675 lb. of thrust at the rotation point. And since the thrust line acts at a canted down angle through water line 105 and our axle line is at water line 53.6, there is a moment arm of 50.25 inches or 4.18 feet, instead of 51.4 inches. The nose down moment calculation for the engine thrust is 52,981 ft-lb.

Our sum total of nose down moments about the main gear, prior to stick movement, becomes 146,731 ft-lb.

For Rotation

1. Wing lift force: The wing lift, that we've previously calculated, acts at fuselage station 472.5, which gives a moment arm of 11.1 inches or .92 feet. And let's assume a static aircraft attitude of -0.33 degrees. In this case, we'll take the most optimistic approach. The wing lift of 2740 lb. multiplied by .92 feet gives a nose-up moment of 2520 ft-lb.
2. Drag force: The drag force, that we've previously calculated, is assumed to be acting rearward along water line 100 of the aircraft. This gives a moment arm of 46.4 inches, or 3.86 feet from the axle water line. So, the nose up moment due to drag is 7913 ft-lb.

3. Inertia: The effect of inertia, for aerodynamic considerations, is acting rearward and along the water line behind the c.g. Inertia force, is the force which opposes the acceleration forces acting on the aircraft during the takeoff roll. Therefore, inertia force is equal to thrust minus drag minus μN . If we have a dry, concrete runway condition, the μ value has been established as .025. And as I stated before, the Normal load is aircraft weight minus lift. Therefore, from our lift calculations, the N load becomes $25,000 - 2740 = 22,260$ lb. So the total μN force is 556.5 lb. The summation figures out to be 10,068 lb. The moment arm from the c.g. water line to the axle water line is 42.9 inches, or 3.57 feet, so the nose up moment due to the inertia force is 35,942 ft-lb.
4. Tail lift: Since, we assumed a static aircraft attitude, for this point, the angle of attack of the horizontal stabilizer becomes -5.33 degrees, (plus a small angle due to wing downwash), as long as we have the proper takeoff trim setting. From aerodynamic data curves, this angle of attack will yield 2000 lb. of lift at 185 knots. Also, this tail lift acts through fuselage station 697.0, thereby having a moment arm of 213.4 inches, or 17.78 feet. So the nose up moment due to tail lift is 35,400 ft-lb.

By adding up the nose up moments on the aircraft, prior to stick movement, we find that the value is 81,775 ft-lb. Now even though we've made educated estimations for some of the factors in our calculations, there's an important point to be learned. A simple subtraction shows that you're way short of a nose up moment value to initiate rotation, as long as there's only a takeoff trim angle of attack on the horizontal stabilizer. So the only way that you're going to make up this deficit is to pull back on the stick. Therefore, I want to tabulate the most important factor, in my opinion, that is for rotation or against rotation.

Against Rotation

For Rotation



Alright now, before you panic and head for the club and a nervous Martini-- just settle down. I know it's disturbing to the tummy to actually discover all the pushings, pullings and tuggings that are trying to keep us from "slipping the surly bonds of earth"--but we should be grown-up enough by now to face some facts of flying.

"AHA! You split tongued Snake--I got you now. Talk about facing facts-- in SURE lecture 4, you stated that from the engineering flight tests made on nose wheel liftoff and aircraft takeoff speeds, we found that the determination of these speeds was based on two factors--Trim position and c.g. and

weight effects. And you didn't say anything about my stick technique being so important".

Very true, Ace--I ain't denying a thing. Only bear with me a bit and I'll explain everything--what you got to lose?

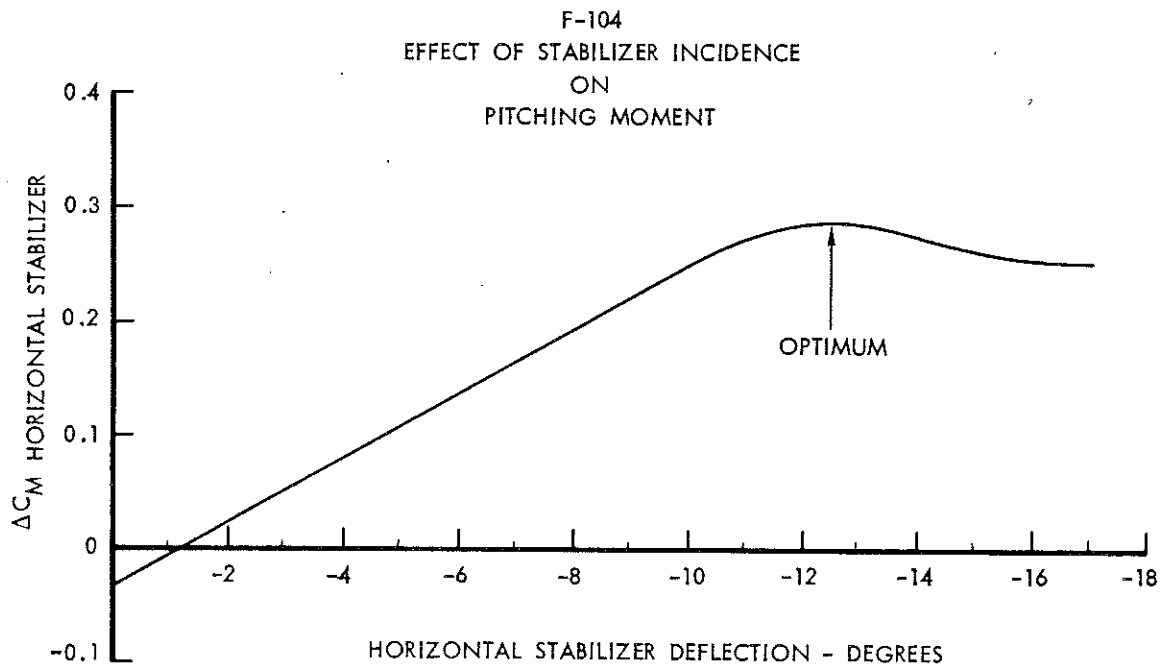
As I have told you troops many times, test flying just isn't exactly like operational flying. And pure engineering considerations tend to eliminate the requirements of pilot technique. After the tests for nose wheel lift-off, and at that time, we did not expect that with certain configuration loadings, pilot technique could possibly become a critical factor. Now, after a more thorough study and with data from a recent wind tunnel program, we've got a more complete story for you. So, put your thinking helmet back on and let's study my sketch once more and carefully examine the key force that is acting to rotate the aircraft. This is the development of tail lift by the flow of molecules A and B around the horizontal stabilizer. The smoothness of the flow of A and B and their development of maximum lift to rotate the aircraft brings us to the crux of my entire disucssion about this subject.

If you want to read until you're cross-eyed, going over all the incident reports as I have, you'll come to the same conclusion that I did. Except for tail lift, every factor that I have discussed, even though some of them are variable factors, they can all be predicted and measured. But what is the one unpredictable, unmeasurable, varying factor in the schmear? -- IT's YOU! With certain configuration loadings, I believe that a bad stick technique can put you on the wrong side of the ledger. How can I say that? First of all, I have never found it necessary to use full aft stick on any configuration--even the heaviest possible loadings--in order to initiate nose rotation. On the fully loaded strike fighter bomber configuration, I noticed that I usually had almost full aft stick at the liftoff point. But I didn't need full aft stick to start the nose up. Secondly, turn up the wattage on your thinking helmet and let's look at some data from a detailed wind tunnel program, just recently completed by the Aerodynamics Group at Lockheed. Although it's wind tunnel data that has not yet been substantiated by a Flight Test program, it is definitely valid and I believe it points the way toward an optimum stick technique. And, since we are obviously interested in the effect of the tail lift to give us a nose up moment around the main landing gear, let's examine a term that is called the aerodynamic pitching moment coefficient of the aircraft. This term is defined as:

$$C_m = \frac{\text{Aerodynamic pitching moment of airplane (ft-lb.)}}{S \text{ (wing area-sq. ft) m.a.c. (ft) } q \text{ (lb/sq.ft)}}$$

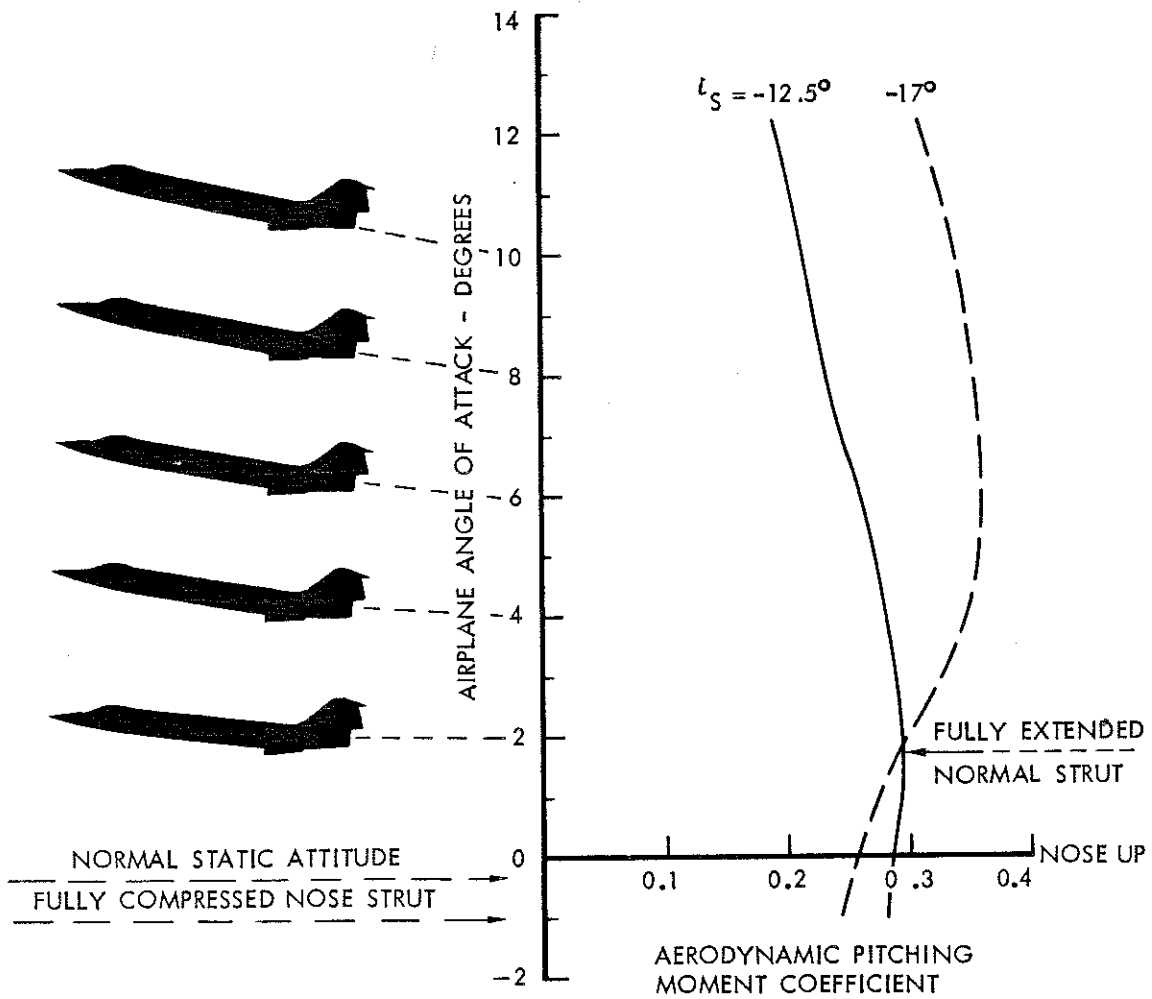
As you can see, this term is dimensionless and when plotted, it will show the aerodynamic pitching moment effect to rotate the aircraft. From our

analysis and flight experience, we've seen that the F-104 retains its flat attitude, until we initiate an aft stick movement. So now, let's see what the wind tunnel data tells us about the pitching moment effect of the horizontal stabilizer at the static aircraft attitude of -0.33 degrees.



This curve tells us that with an airplane angle of attack of -0.33 degrees, we will realize the greatest nose up moment with a horizontal stabilizer angle of attack of -12.5 degrees. In order to get a broader picture of C_m with various aircraft angles of attack and stabilizer deflections, let's examine this plot from our wind tunnel program.

F-104
HORIZONTAL STABILIZER EFFECTIVENESS
TAKEOFF CONFIGURATION
WITH GROUND EFFECT



I'll attempt to explain this plot as clearly as possible. Our vertical axis represents airplane angle of attack. The horizontal line represents the aerodynamic pitching moment coefficient of the aircraft around the fulcrum point i. e., the axles of the main landing gear wheels, in addition to the lift and drag moments discussed previously. The plot may look difficult to understand, but just think of it this way. Any value read off of the horizontal line is the aerodynamic effect of the airplane to rotate nose up. The plotted curves represent two different conditions of stabilizer deflection. The difference of any values of pitching moment coefficient between the two curves, represents "pure" stabilizer effect to rotate the airplane nose up. To use this plot is very easy. If you assume that you have a properly serviced nose shock strut and a static condition of -0.33 degrees nose down, then somewhere between this airplane angle of attack and the extreme condition of a fully compressed nose strut of -1.0 degree nose down angle of attack, will lie the actual airplane angle of attack--at the nose rotation speed. Our wind tunnel plot tells us that at a stabilizer deflection of -12.5 degrees, our variation of aerodynamic pitching moment coefficient from a static attitude to a fully compressed nose strut attitude is $.282$ nose up to $.278$ nose up. If you have a stabilizer deflection of -17 degrees, the variation of aerodynamic pitching moment coefficient, for the same conditions, is from $.254$ nose up to $.246$ nose up.

"For gosh sakes, what's going on here? -- I always thought that you would have the greatest nose up moment effect by having full aft stick before nose rotation!"

Well, one thing that's going on is that your thinking helmet just shorted out. Don't you remember our curve of increasing angle of attack for a low Aspect Ratio wing? You've just fallen into that same trough of decreased lift with increasing angle of attack. You haven't completely "stalled" the stabilizer but YOU'RE NOT GETTING THE MOST OUT OF IT! OK--is your thinking helmet warming up again? How about accepting an old flying principle of mine? Regardless of your aircraft loading, you can make a real smooth takeoff, if you use OPTIMUM STICK TECHNIQUE.

"Sounds good--what is it?"

Well, I'm not saying that I'm the best--but here's how I do it.

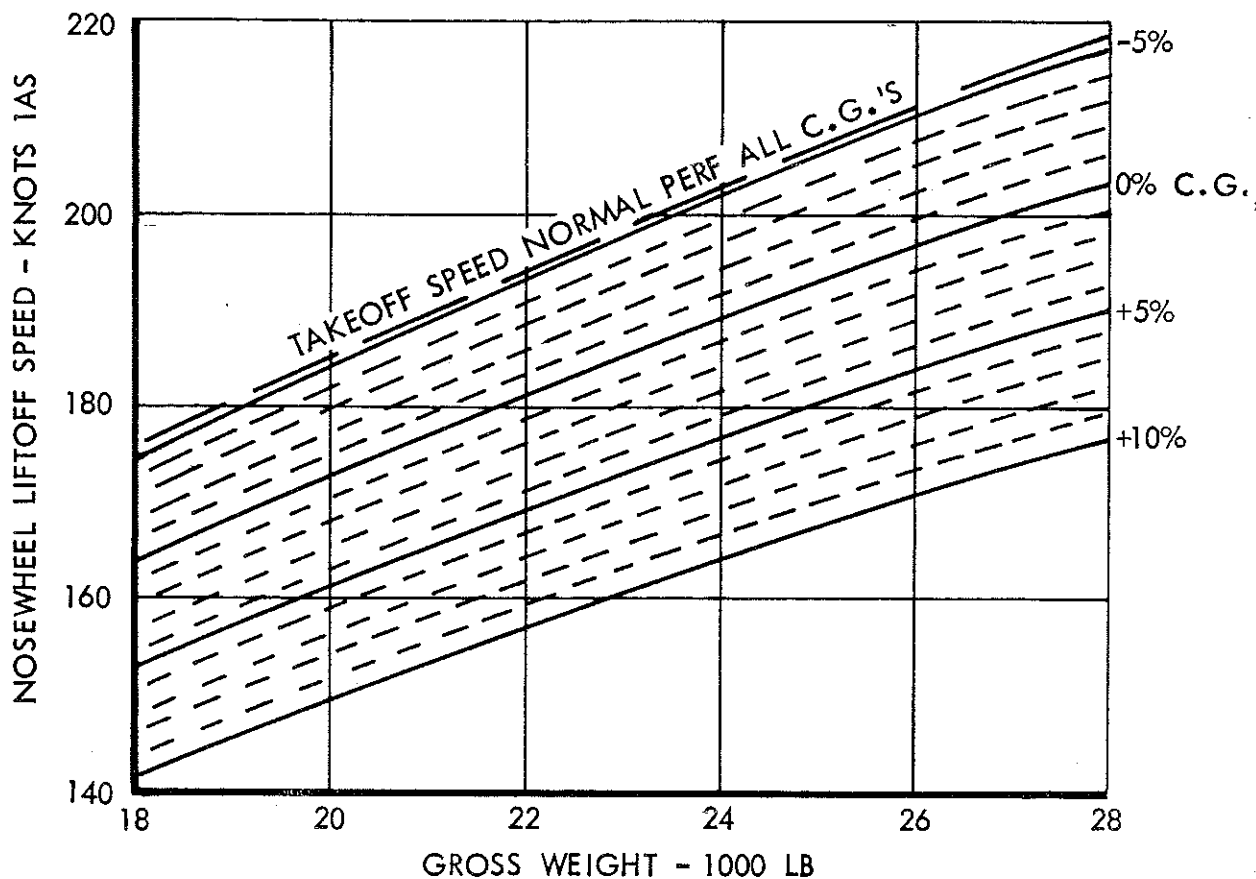
Any pilot's method of stick technique for rotation on takeoff should consider the following:

1. Knowledge of a calculated nose wheel liftoff speed and a calculated takeoff speed. These calculations take into account the weight and c. g. of the aircraft.
2. Knowledge of ambient temperature, surface winds and runway altitude so that calculated line speeds and takeoff roll can be obtained.
3. A thorough check of the aircraft so that you are reasonably certain all conditions are go.

These are the items you need to know in order to plan a smooth takeoff. Now let's consider them individually.

1. The reason for calculating a nosewheel liftoff speed and takeoff speed is so that you have a target number that will alert you when conditions are way off from what they should be. It's not to be expected that you are going to rotate exactly on the number and liftoff exactly on the number. You should use these numbers to assist you and not let them dictate a spastic, jerky technique. To calculate these numbers, I'm including a copy of the same graph as on page 36 of SURE lecture 4. Particularly note that it says minimum nosewheel liftoff speed--not the absolute speed at which the nose must come up. I've already informed you of how to use this plot in my discussion on page 35 of SURE lecture 4. A valid conclusion that can be drawn from our knowledge of aerodynamics and the use of this chart is: for the lighter loadings on the F-104, there is greater latitude of stick technique in order to obtain nose rotation. Whenever you get into the heavier loadings, though, an optimum technique is recommended in order to be assured of nose rotation. My philosophy has always been--"Why not fly at optimum all the time?"

F-104G, G (MAP) & TF 104G
MINIMUM NOSE WHEEL LIFTOFF SPEED
DRY RUNWAY



2. On the applicable pages of your handbook*, you are given the necessary information so you can calculate the takeoff roll. Again, you are not expected to liftoff exactly at this distance. It's another target number. But, we should definitely be alerted to the fact that on a hot day and a high altitude with a heavy load, our takeoff roll will be longer. What does this do to our stick technique? It means a later initial movement and a slower transitional movement than normal. On a real cold day and a light load, we must be alerted for the reverse. A sooner initial movement and a more rapid transitional movement than normal.

*Reference 1, pages A2-8, A2-9, A2-10

3. After our external inspection and with the firm conviction that all is right with our bird, we can now make a beautiful takeoff by using a smooth, optimum technique.

"I'm asking you again--what is it?"

Remember my recommendation on page 37 of SURE lecture 4 to start rotation at 20 knots below takeoff speed?

"I know that by heart, Snake--but it doesn't tell me what to do!"

I agree, so let's really find out what to do for optimum technique.

We've found out that from the wind tunnel tests, -12.5 degrees of stabilizer deflection will give us the maximum aerodynamic pitching moment coefficient at our static and takeoff roll attitude. Even though, for our lighter loads, we may not need this much of a pitching moment--it's still the optimum at that point where we want the nose to rotate. Once the nose starts up and the airplane attains at least a positive 1.7 degrees angle of attack, then our plot shows that if necessary, we can pull the stick right back to our little fat belly, because now the full -17 degrees of stabilizer deflection becomes optimum. An excellent indication of this is when the nose strut is fully extended and the nose wheel is just lifting off the runway. So what do we do for optimum stick technique--just this:

1. On takeoff roll and up to 20 knots less than our calculated takeoff speed, we simply hold the stick in our takeoff trimmed neutral position. This will keep the aerodynamic drag during the takeoff roll to a minimum.
2. At 20 knots below our computed takeoff speed smoothly bring the stick back to obtain a stabilizer deflection of -12.5 degrees. How much is this? Look on page 33 or 34 of SURE lecture 4 for your particular model to find out the proper stick deflection. On page 34 is the chart for F/RF/TF-104G, MAP and Consortium, CF-104/104D and F-104J/DJ. Therefore, for these models for -12.5 degrees of stabilizer deflection, pull back a little over 3 inches. As you smoothly pull the stick back toward the deflection to give optimum aerodynamic pitching moment, the moving stabilizer will actually provide a greater moment than a static stabilizer deflection held at a given setting. Again, this stick deflection figure is a target value for you to have as a guide. The "actual" technique is for you to use your pilot skill and "feel" the tail lift moment for when it's at the maximum effect. Once the nose is definitely rotating up and the nosewheel is lifting off the runway, then you can use all the back stick you want to in continuing your smooth liftoff. But, I do not recommend that you come back with full aft stick prior to positive nose rotation. In all likelihood, you'll just raise the nose

slightly and sit there. As we've shown, you'll fall back into the trough of decreased lift on the tail. And then it becomes an indeterminate proposition about how much more speed and how much more runway you'll need to get airborne.

In the case of the F-104A/B/C/D, we have a different stick throw for stabilizer deflection as we see on page 33 of SURE lecture 4. To obtain an optimum aerodynamic pitching moment coefficient for rotation, you should pull back about 4.5 inches for a stabilizer deflection of -12.5 degrees.

That's all there is to it. And I can guarantee you that a smooth stick technique will not only assure nose rotation, it'll help overcome those Murphy's that crop up and will keep you out of the barrier. Oops--I want to warn you of one last pitfall.

"Trim shift? "

Right--now the helmet's working.

To find out what effect this has on our stick technique, we'll have to once more refer to pages 33 and 34 of SURE lecture 4. Noting from these graphs where our trim limits are and the lines of stick throw and stabilizer deflection, we can deduce the effect on our stick technique when the trim shifts off to full nose up or nose down. This is the analysis in tabular form.

<u>F-104A/B/C/D</u>		
<u>Trim Position</u>	<u>Stick Movement</u>	<u>Stabilizer Deflection</u>
Trim shifted full nose down	4.5 inches aft	5 degrees Trailing Edge Up
Trim shifted full nose up	4.5 inches aft Note: at 3 inches aft, the cylinders will bottom and the next 1.5 inches will be toward the mechanical stops.	17 degrees Trailing Edge Up

F/RF/TF-104G, MAP and Consortium
CF-104/104D F-104J/DJ

<u>Trim Position</u>	<u>Stick Movement</u>	<u>Stabilizer Deflection</u>
Trim shifted full nose down	3.0+ inches aft	Approximately 5 degrees Trailing Edge Up
Trim shifted full nose up	3.0+ inches aft Note: just short of 2.5 inches, the cylinders will bottom and after that the stick will be moving toward the mechanical stop	17 Degrees Trailing Edge Up

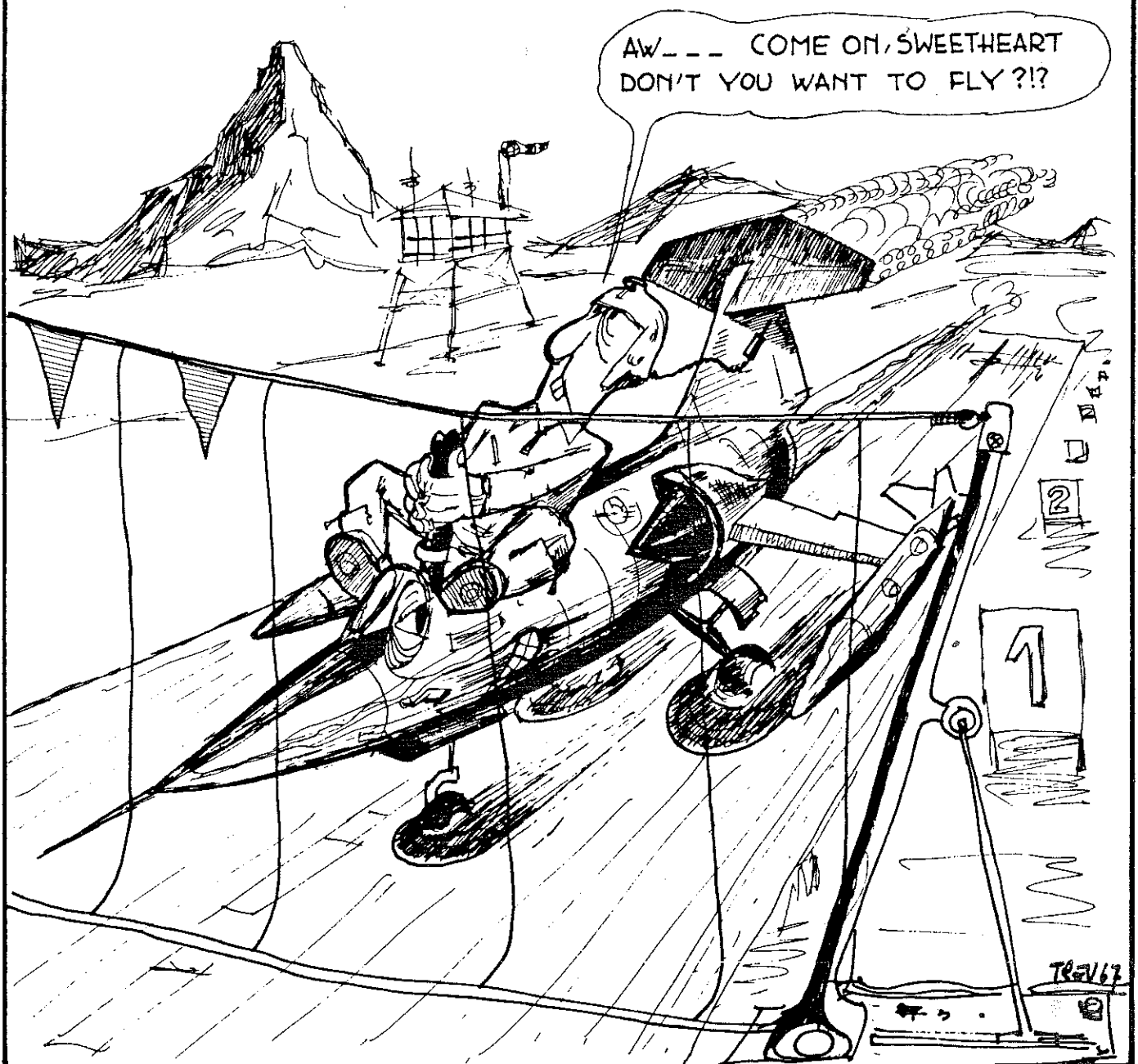
These charts tell us that for all models of F-104's, our optimum stick technique for rotation is affected in the same manner, i. e.

1. Trim shifted full nose down: in this case when we pull the stick back to our estimated throw for optimum pitching moment coefficient, we are far short of the required stabilizer deflection. If no change is made away from this condition, a barrier engagement is likely.
2. Trim shifted full nose up: in this case, we are getting full stabilizer deflection too soon and too rapidly. We're heading right back down into that trough of decreased tail lift.

A simple procedure that I use to preclude this is to give the stick a full pump fore and aft, prior to releasing the brakes to assure myself of no trim shifts. I recommend too, that you familiarize yourself with the pronounced stick "feel" when the trim is full nose up and full nose down. That way, you'll know which way the trim shifted and you can act accordingly.

Enough said, Ace. Many happy takeoffs.

"SNAKE" SEZ: USE A SMOOTH TECHNIQUE, ACE = AND YOU'LL
AVOID THAT "GLUED TO THE RUNWAY" FEELING !



SECTION IV

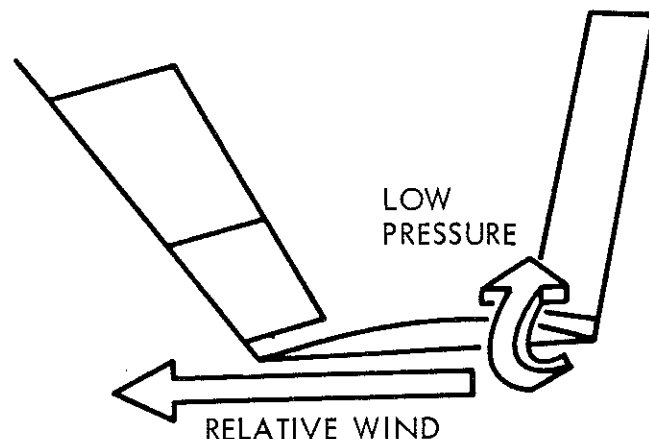
Subsonic Airflow Aspects on Operational Flying

Since the majority of operational flying, in the F-104, takes place in the subsonic regime, a survey of subsonic airflow aspects will help you to discover those areas to avoid.

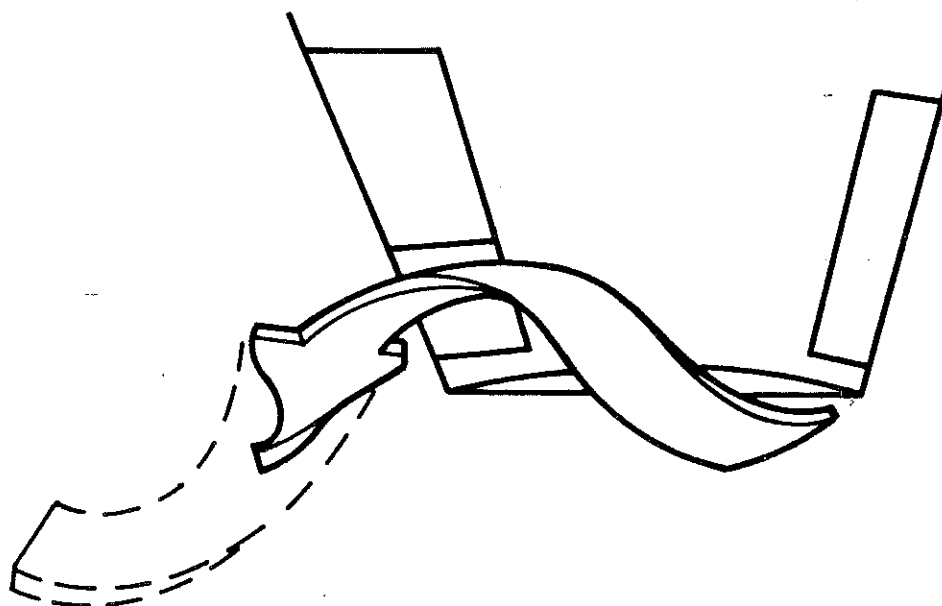
Subsonic Formation Flying

On page 15 of SURE lecture 4, I have given you brief extracts of two accidents that happened in formation flying. I now believe these accidents might have been prevented, if the pilots had been aware of certain subsonic flow patterns.

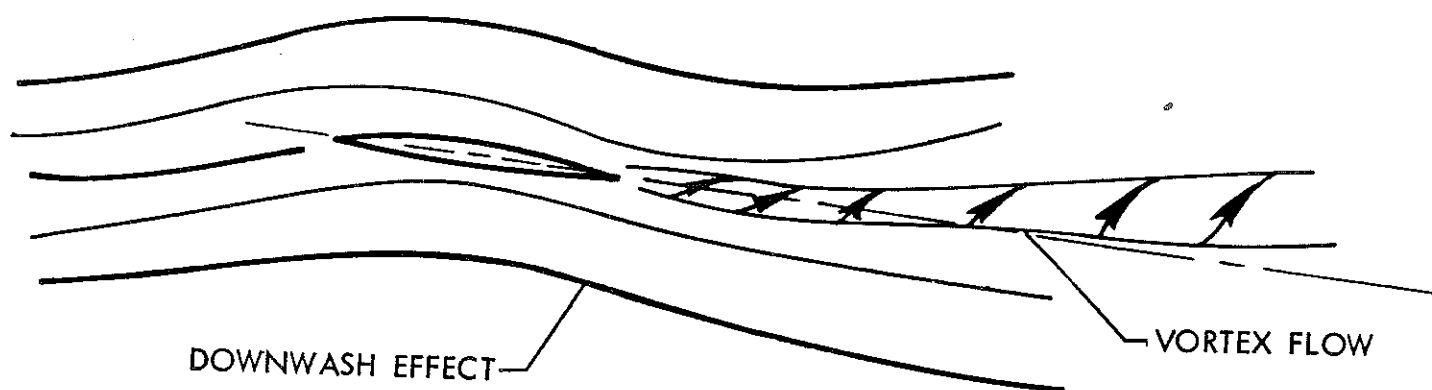
Two main airflow aspects of the F-104 in subsonic flight are wing tip vortices and wing downwash flow that I've already pointed out in Section I. The power of these two aerodynamic forces should not be underestimated. A closer look at wing tip vortices flow development can be shown by this sketch.

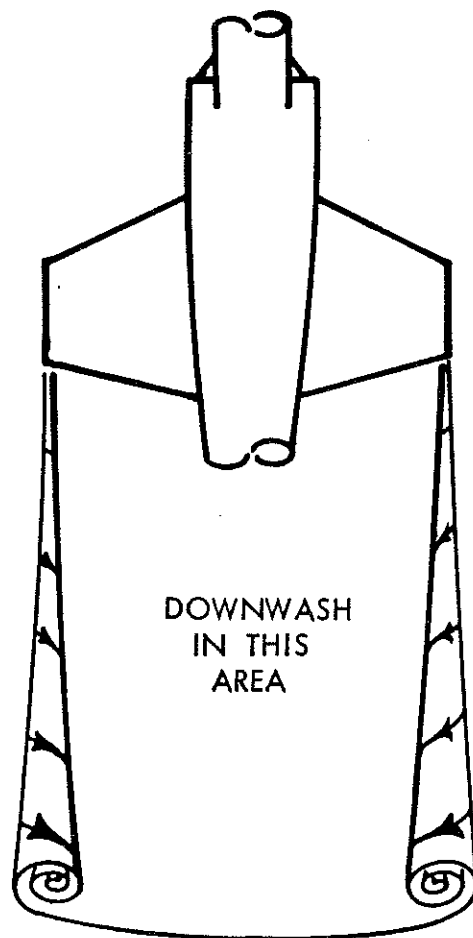


We've already seen how the pressure drops on the upper surface of the airfoil, so the wing tip flow can be visualized as composed of the two forces in our sketch. The resultant flow is a whirling, twisting vortex as we now show.



Taking a look at the F-104, we can sketch the vortices airflow and show the areas to avoid. Looking back in Section I, you'll also find that I stated that a proven rule of aerodynamics is that a low aspect ratio wing with a high wing loading produces stronger wing tip vortices and a greater downwash than a high aspect ratio airfoil. So, here are the areas to avoid when flying wing position with the F-104.

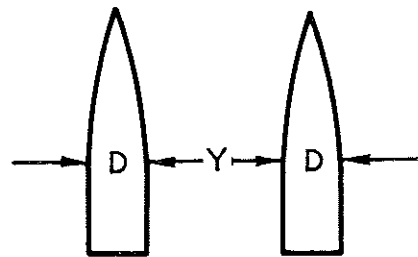
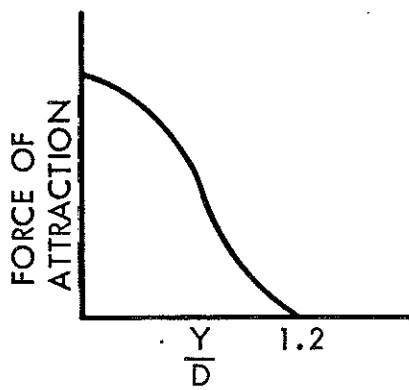




Many of the manuals for formation flying*, give instructions for the position to hold while in formation and warn about maintaining wing tip clearance. If you will now reread Accident Review No. IIC on page 15 of SURE lecture 4, I think you can begin to appreciate the effect of tip vortices. Vortices effects are characteristic in that they act behind the wing tip--not parallel to the wing. For us, this means a line abreast, or a forward position offers no problem. It's when we try to fly too close in a wing tip formation position, that airflow becomes a problem. First of all, the vortex flow results in a wing down movement that turns the wing aircraft into the lead aircraft. This will definitely occur for wingmen who insist in overlapping their wings on the lead aircraft.

*Reference 10, page F-13

Once the wing tip has been deflected down, the wing aircraft moves closer to the lead aircraft and then the overlapped wing moves into the downwash area. Now the combination of vortices and wing downwash can completely overcome the full throw of counter controls on the wing aircraft. As the two fuselages come closer together, another airflow aspect rears its head. In Section I, I discussed the venturi flow and Bernuolli's theorem for incompressible flow. Now we can predict that the flow between the two fuselages will increase in velocity but decrease in pressure. A general indication is that the fuselages must come very close together for this flow to become an attracting force. But the wing tip vortices and downwash are starting you in that direction. Aerodynamic theory tells us that once you're closer than 1.2 diameters, the force of attraction increases rapidly. Pictorially, we can show it in this manner.

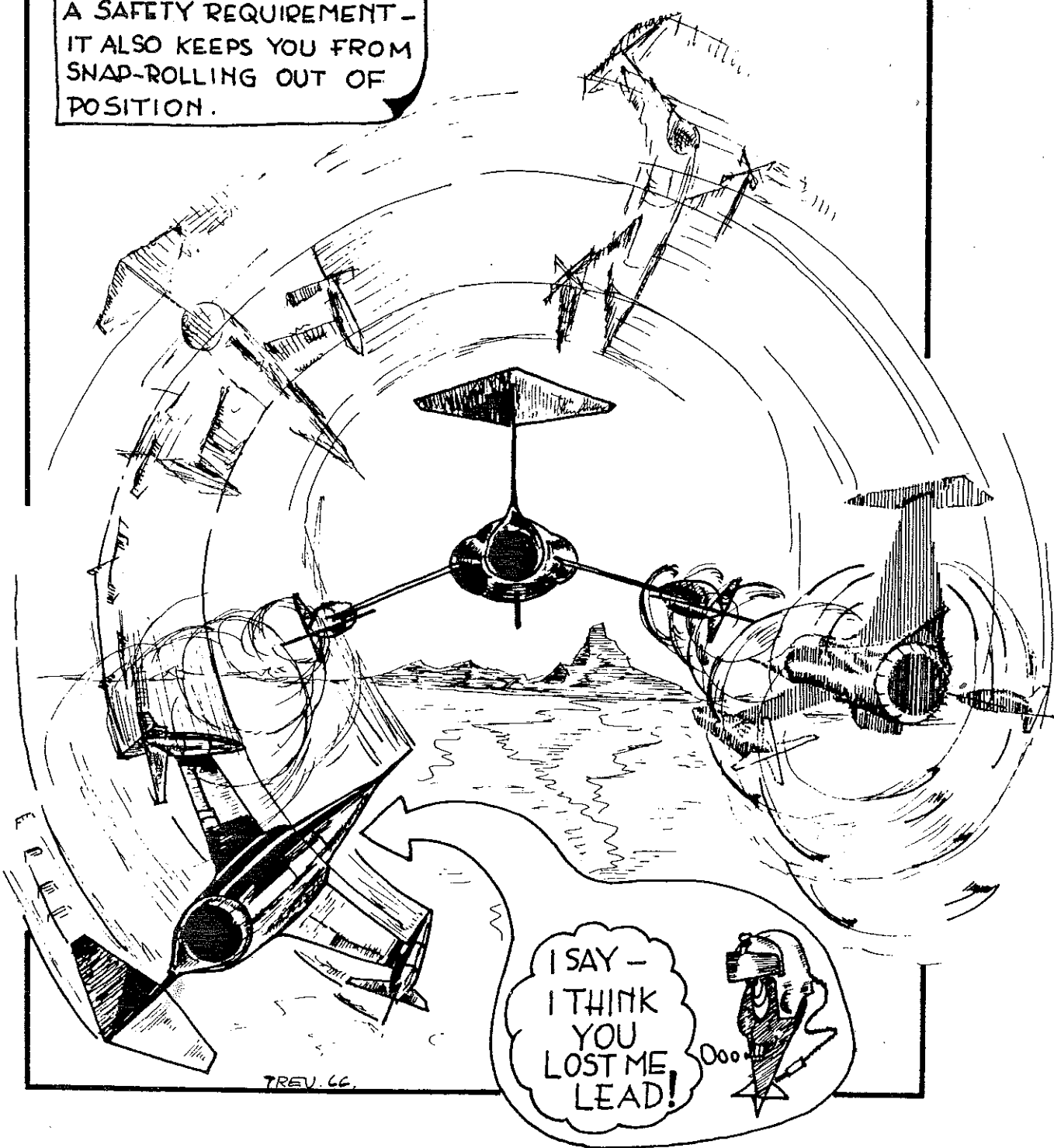


Some of you old heads probably have fond memories of flying the T-Bird or F-86 in formation and almost sticking your wing tip in the lap of the lead. But conditions were different then. You had different airfoils with weaker vortices and wing downwash effect along with longer wingspan with greater available aileron moments. Now, you're flying much closer and in areas of more pronounced airflow effects.

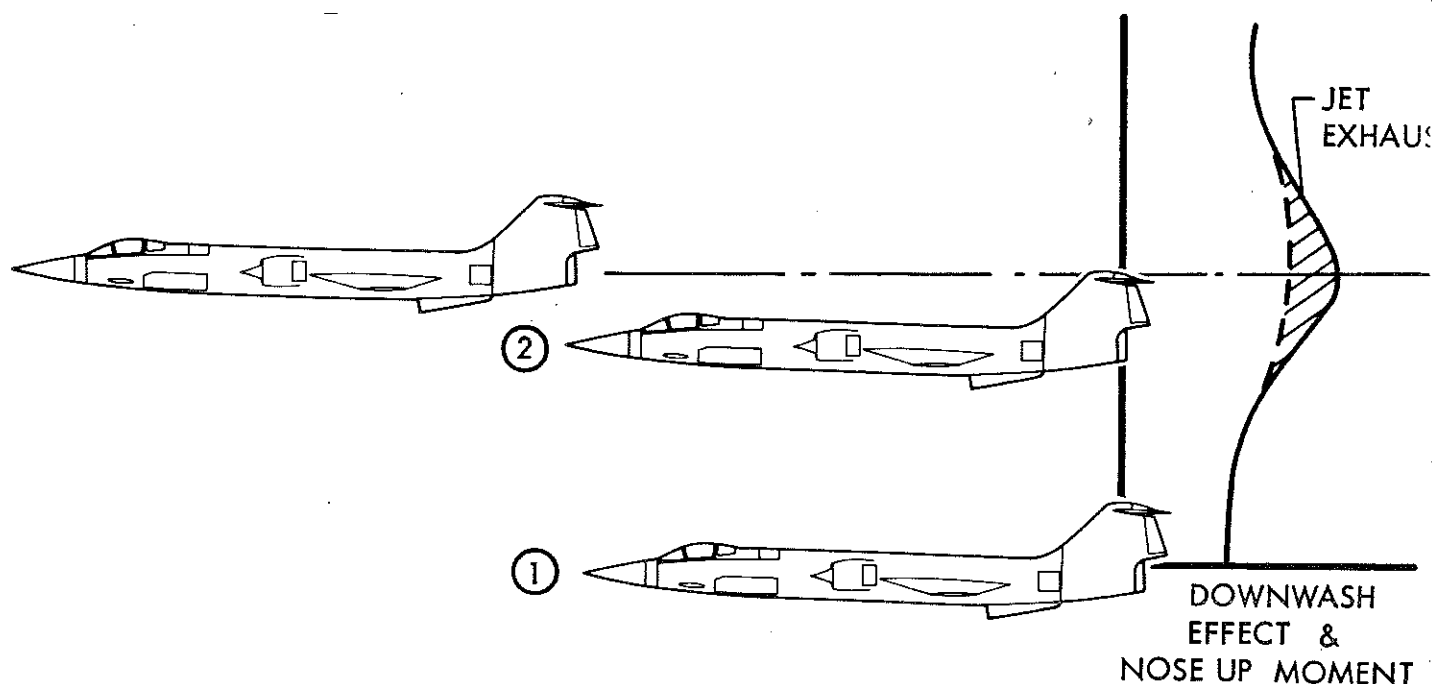
Maybe now a feeling of suspicion is beginning to grow in your head. That Accident Review No. IIC. Could it be that the wingman pressed so close that tip vortices and wing downwash brought him into a flight condition where he couldn't stop the mid-air collision? I think so.

● SNAKE SEZ -
WING TIP CLEARANCE IN
FORMATION IS NOT JUST
A SAFETY REQUIREMENT -
IT ALSO KEEPS YOU FROM
SNAP-ROLLING OUT OF
POSITION.

FORMATION FLYING



Another formation position that has areas of flow that you need to know about is the "trail" or "slot" position. You might be called upon to fly this position in Diamond show formations or close trail for certain combat maneuvers. Again, there are some powerful flow effects that you'd better watch for. Wing downwash is obviously one effect and the other comes from the jet exhaust on our high T-Tail. Let's put two F-104's in this position and analyze what happens.



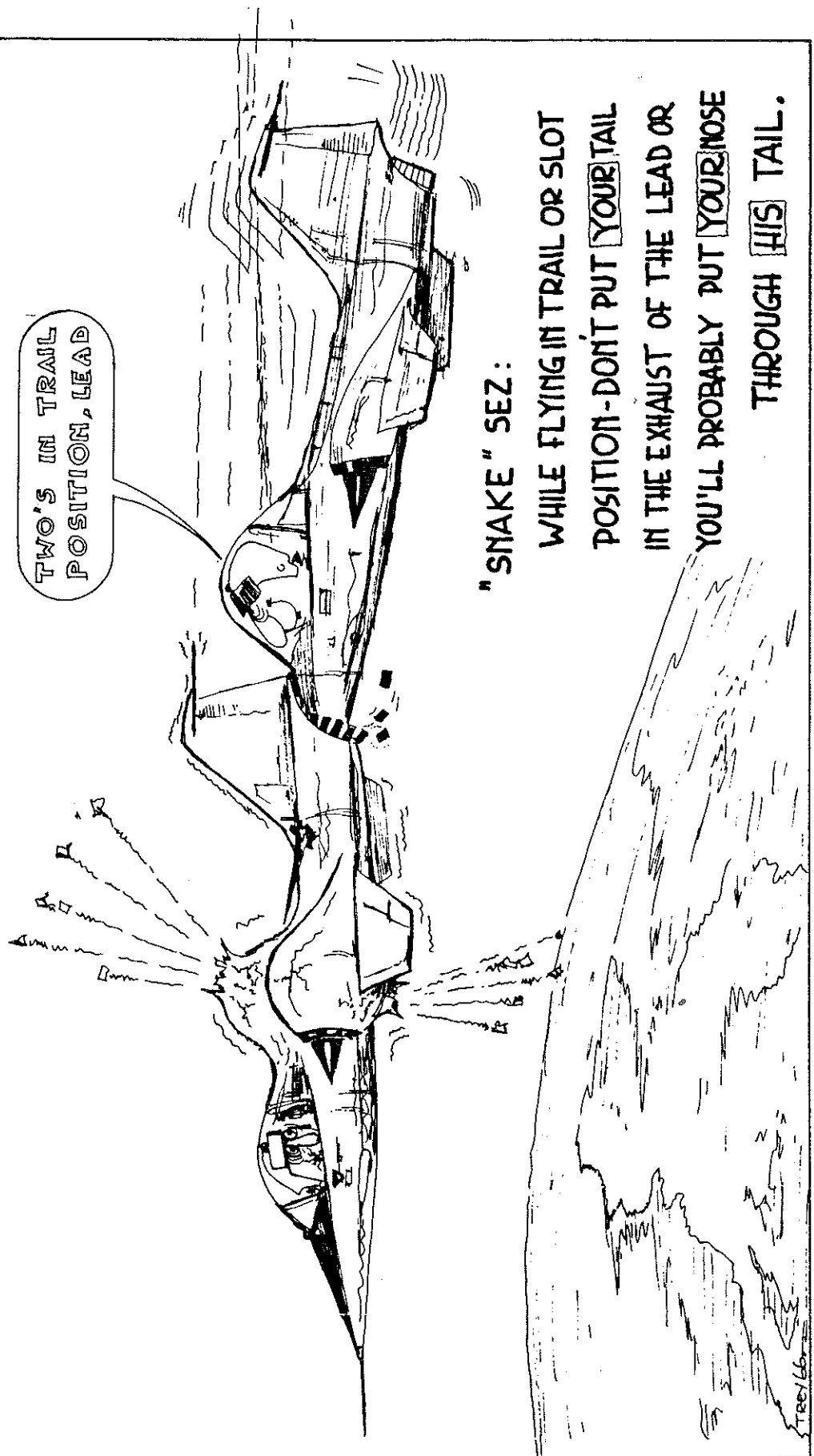
Our drawing shows the downwash pattern directly behind the lead F-104. If we start the trail F-104 at position 1 and move him up to position 2, we should be able to predict the effects on the trail F-104. Of interest to us is the effect on the trail F-104 in the type of flow field in our sketch.

Beginning with the trail F-104 at position 1 and trimmed for flight in this position, let's have the trail F-104 move up closer to the lead. As the stabilizer of the trail F-104 moves vertically up in the flow field behind the lead F-104, our plot shows an increasing downwash which results in a down load increment. This increment produces a nose up moment, resulting in an increased airplane angle of attack which causes

the trail F-104 to accelerate upward. If the trail F-104 goes up far enough, his stabilizer comes up into the flow field effect of the jet exhaust from the lead F-104. Our "tail feathers" instinctively tell us that with our fuselage in one flow field and our tail in another, we have a situation of imbalance. The increased tail lift causes a maximum nose up effect that must be countered by forward stick to go nose down. So we see that the initial motion of the trail F-104 has now resulted in an increasing upward velocity that is greater than expected by the pilot. As the pilot of the trail F-104 senses the increasing upward movement with no input on his part, he will initiate control movements to go back down. As he initiates the downward movement, his airplane is leaving the stronger area of flow and going down into the weaker area of flow. So again--his move in the downward direction results in an unplanned for acceleration. Basically, any pilot initiated movement of the aircraft, up or down, in this type of flow field, results in unexpected accelerations that can result in diverging oscillations in pitch. This is definitely an unstable flight condition and requires careful pilot attention to maintain a constant position relative to the lead airplane.

By rereading Accident Review No. IIIB on page 15 of SURE lecture 4, we might now come to a different conclusion than what we originally thought. Instead of only considering a misjudgment of closure rate, what if the wingman passed under the lead aircraft so close that he encountered the maximum nose up effect of the flow field from the lead aircraft? In this position, a quick and unexpected nose up movement could easily result in a nose-tail collision.

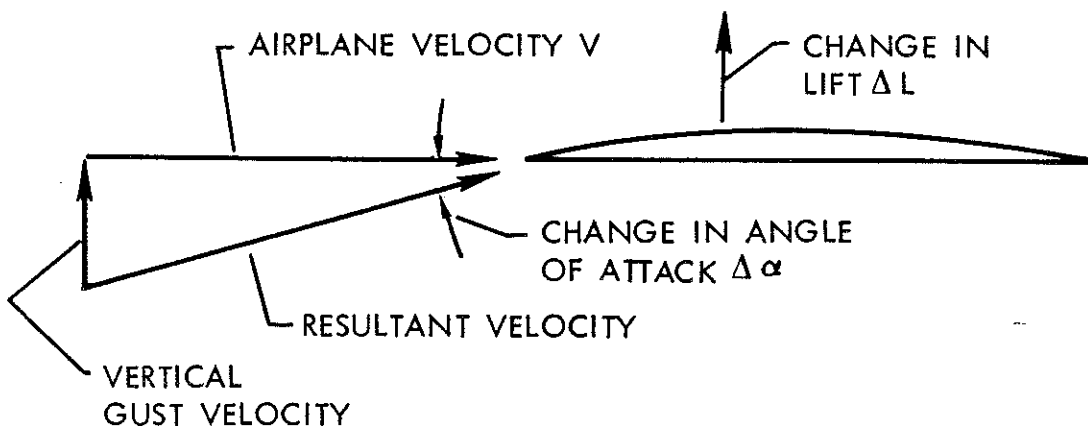
FORMATION FLYING



Atmospheric Effects

The ocean of air that molecules A and B float around in and through which we fly is not always in a calm and stable condition. In fact, it's quite the opposite--stormy, turbulent, ever shifting and flowing with high pressure areas chasing low pressure areas like fighter pilots running after the showgirls of Moulin Rouge. So rather than placidly floating around, waiting for us to come flying along and disturb them--usually they are already in a state of agitation when we arrive. With the freestream flow in agitated motion, our flight path will be anything but smooth. Gusts, shear flow, jet-streams, CAT (Clear Air Turbulence)--they're all a part of the flow picture we have to contend with in our flying. From your progression through flight training, you probably noticed that as your aircraft got bigger and heavier, the effects of the atmospheric turbulence seemed to decrease. They were still there, but just didn't bother you as much as before. Don't think that since you are in a bigger, heavier bird you can now ignore the effects of these atmospheric phenomena. If anything, they need more study. So let's consider the characteristics of CAT and gust load factors.

During flight, when you encounter gusts and turbulence, you experience bodily movement in the cockpit that you naturally relate to g loads. Any sudden vertical force registers on the g meter and you read the force as an indicated g load. The airplane structure, however, senses total load which is not always registered on the g meter. By definition*, gusts are associated with the vertical and horizontal velocity gradients in the atmosphere. A horizontal gust produces a change in dynamic pressure on the airplane but causes relatively small and unimportant changes in flight load factor. The more important gusts are the vertical gusts which cause changes in angle of attack. We can portray this increase with this drawing of a vertical gust on our wing.



*Reference 9, page 332

The vectorial addition of the gust velocity causes the change in angle of attack and change in lift. The change in angle of attack at some flight condition causes a change in the flight load factor. The extent to which this gust load will affect us is greatly dependent on two airplane properties, wing design and wing loading. Back in Section I, I drew a lift comparison plot of our low Aspect Ratio wing to a high Aspect Ratio wing. The steepness of the lift curve with increasing angle of attack is called the slope of the curve. You can see that the lift curve slope of our low Aspect Ratio wing is not as steep as the high Aspect Ratio wing. The lift curve slope relates the sensitivity of the airplane to changes in angle of attack. An aircraft with a straight, high Aspect Ratio wing would have a high lift curve slope and would be quite sensitive to gusts. On the other hand, our low Aspect Ratio wing has a low lift curve slope and is comparatively less sensitive to turbulence. The apparent effect of wing loading (Weight of aircraft/Wing area) W/S , is at times misleading and is best understood by considering our own F-104.

When we encounter a gust at lower than ordinary gross weights (down around landing weight), the accelerations due to the gust condition are higher. This is explained by the fact that essentially the same lift change acts on a lighter mass. The high accelerations and inertia forces magnify the impression of the magnitude of turbulence. If we load up our Starfighter to the Basic configuration plus tips, pylons and the store, and then encounter the same gust factor, the accelerations due to the gust condition will be lowered, i.e., the same lift change acts on the greater mass. As we sit in the cockpit, we primarily sense the degree of turbulence by our bodily movements that come from the accelerations and inertia forces. Therefore, our personal estimate of their magnitude can be wrong due to this misleading impression of strong effects with light weight loads and weak effects with the heavier loadings.

A major operational problem with CAT appears when we're flying low level missions. CAT can normally be predicted* on the lee side of large mountain ranges and under the lenticular clouds and roll clouds. A severe control problem can now occur if we fly low level and high speed through this area. It's due to the turbulence plus the little floating wings on our nose. Remember?--The APC vanes. With your knowledge of the APC (Automatic Pitch Control) system and applying some aerodynamics, this problem can be easily understood.

*Reference 11, page 82

As we encounter turbulence with vertical gusts, the airplane will experience the change in angle of attack and lift as has been shown. Also, the gusty turbulence results in up and down, rapid load factor changes. The vertical airflow with its rapidly changing directions causes deflections of the APC vanes. As the airplane undergoes the up and down oscillations, the pitch rate signal (from the pitch gyro) is sent to the APC computer and combined with the angle of attack signal. These two are summed up to determine shaker and kicker operation. Obviously, the rapidly changing signals will give alternate shaker and kicker operation. This cycle, once it starts, makes you pull back on the stick to override the kicker. Your stick input added to another quick gust of turbulence will quickly put you out of phase and you're soon headed downhill--fighting the repeated kickers. Later versions of F-104's incorporate a time delay in the APC circuitry to prevent this. But you should be alerted for turbulence effects when entering a region of expected CAT, at low level and high speed.

Another atmospheric turbulence area that affects us is the problem of thunderstorm penetration. The handbook* lists procedures that take into account engine-duct airflow problems connected with the rapidly varying pressures and temperatures in thunderstorm penetrations. An important consideration for formation penetrations is the maximum availability of control authority to overcome those gusts that could cause a formation collision. This means that a judicious step would be the pulling of the rudder limit control circuit breaker prior to entering the area of heavy turbulence. This same thought should be given to formation GCA approaches in turbulence and the attendant risk of collision with the limited control authority (for applicable F-104 models) prior to lowering the landing gear.

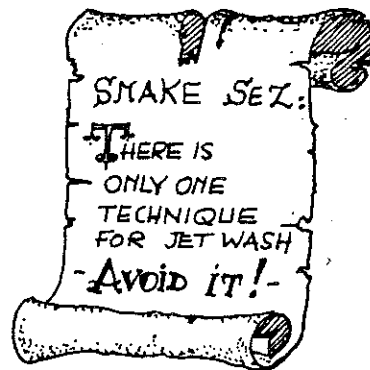
Jet Wash Effect

The ironic twist of the jet wash effect (in consideration of landing approaches) is the absence of gusty, turbulent atmospheric airflow. These disturbances sweep out and continually change the flow pattern over the runway. So even though you may be sweating out a healthy, gusting crosswind condition on final approach, you have the satisfaction of knowing you won't be facing old man jet wash. Any of you, who have had the experience of whipping through the jet exhaust of the lead airplane, up at altitude, have a good feeling for this effect down on the runway. Just imagine those uncontrollable floppings, back and forth, taking place five feet above the runway. When you start out with a calm, placid atmospheric condition and have a jet fighter

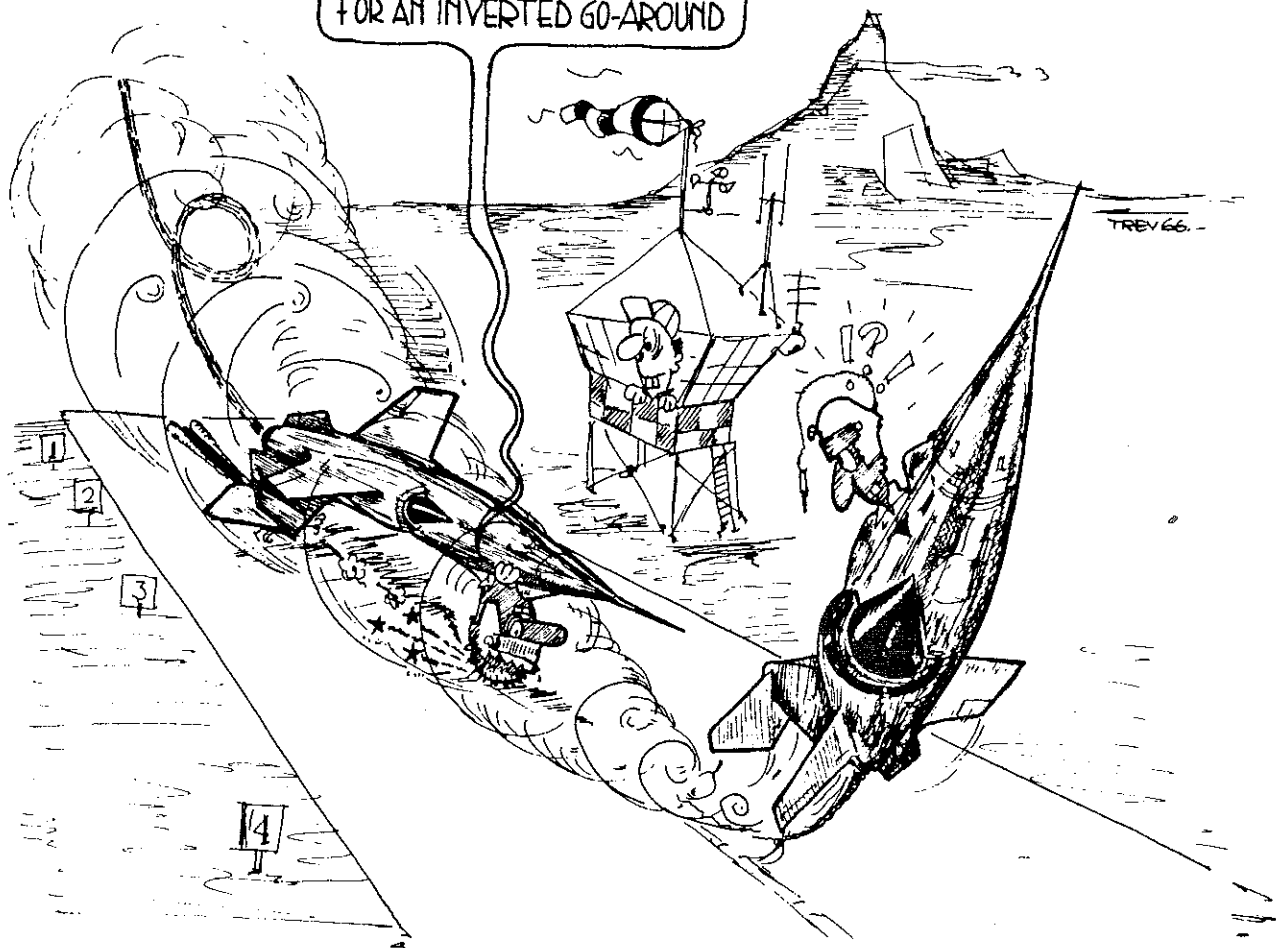
*Reference 1, pages 9-3 and 9-4

roll down the runway in full power--there's a bad airflow situation waiting for any airplane that's on a short final approach. This condition will give you the "heebie-jeebies" on flare and landing since it's the most unpredictable and wildly varying flow pattern you can ever cope with, much less right on the flare and touchdown. Jet wash, in a technical sense, is a misnomer, because the total disturbance is a combination of jet engine exhaust and wing downwash along with our old friend wing tip vortices. This flow has a tendency to linger and roll upward behind the departing aircraft. Jet exhaust, with its high temperatures, has a tendency to rise in the atmosphere. Its rate of rise is dependent on the ambient temperature. Therefore, we can predict, that on a hot, muggy, windless day--any approach for landing immediately behind a departing F-104 is going to spell one thing--TROUBLE!

JET WASH



... UHHHH...
TOWER, IS No. 2 CLEARED
FOR AN INVERTED GO-AROUND



Gun Firing Effects

The handbook* describes the systems operation for the gun firing. These systems operations are based upon airflow requirements that are necessary for safe, reliable gun operation. The stringent design requirements of gun operation at our extreme speeds and altitudes have been met and we now have exceptional accuracy and ease of operation.

Many years back, I encountered an airflow effect on Air-to-Ground gun firing that was a real mystery at that time. The 479th Tactical Fighter Wing was developing a team to enter the scheduled William Tell Meet at Nellis AFB. After stiff trials of competition, they selected four eager pilots and began strenuous practice. Pretty soon, my phone was ringing and a perplexed, irate Colonel was on the other end. His comment was short and succinct. "Why in H---aren't my boys hitting the target?" Needless to say, I hustled over to their airpatch to find out what was happening. The story was this. These four top gunners had been picked by their scores from a normal, rectangular gunnery pattern and firing the standard 1 second burst. All of their scores had been in the respectable 80 to 90% range. From skillful intelligence probing, they had found out that under the rules of the meet they would have only one firing pass on the target for scoring. Their practice then took on the approach of starting gun firing at maximum range and holding the trigger down until crossing the foul line. Their thinking, naturally, was to get the maximum number of holes and the highest score. But now--these hotshot gunners were down to 15 and 20% scores (ratio of hits to rounds fired). Looking at the gun camera film, we noticed a remarkable similarity in all the strafing passes. All of the pippers were starting in the high middle part of the panel targets, at the beginning of firing. Then they steadily walked off the panel to the left and down. Heated conversation with the pilots disclosed no clues about the reasons for the wandering pippers. Thoroughly confused about it all, I turned the problem over to the experts and a bright aerodynamicist promptly came up with the answer. To wit:

- Any gun firing conducted longer than two seconds increases the drag on the left wing, which yaws the nose to an imperceptible degree but moves the piper visibly left of the target.

*Reference 1, page 4-89

Really simple when you think about it. That gun blast wave you're popping out there really shakes up molecules A and B and you can see how this heavy pressure wave will cause increased drag as the wing passes through it.

SECTION V

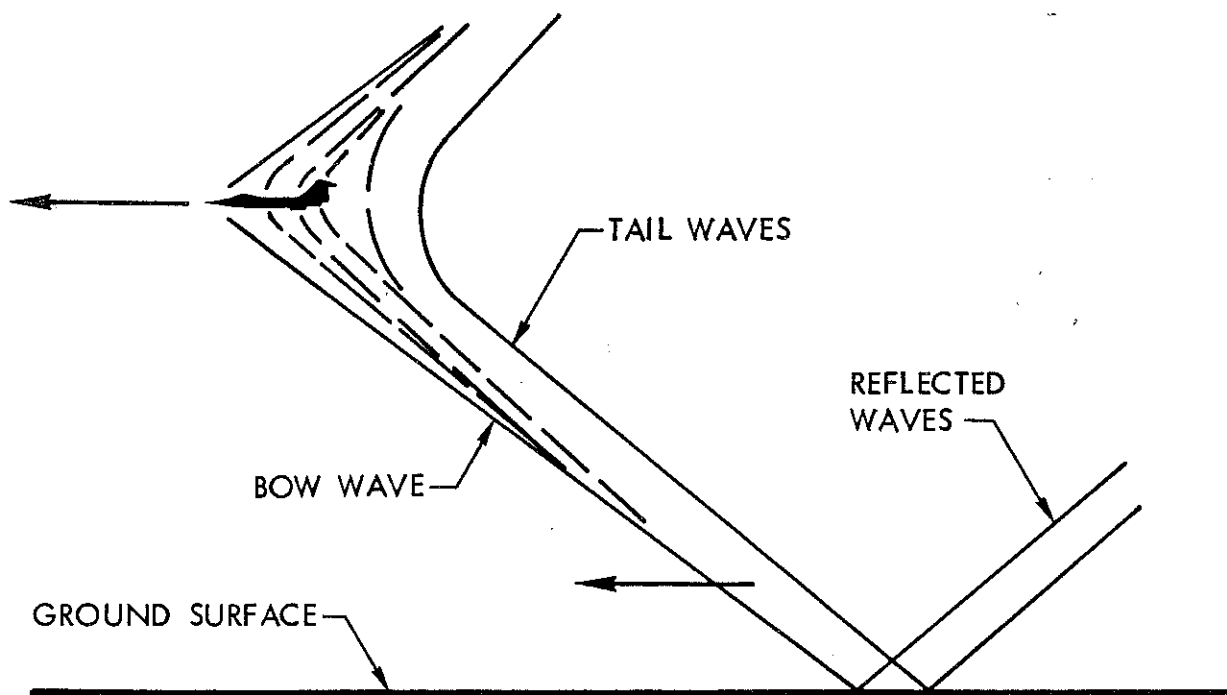
Supersonic Airflow Aspects on Operational Flying

From that day when Col. Chuck Yeager gave the throttle to his X-1 rocket aircraft and punched through the so-called "sound barrier" till today--molecules A and B have repeatedly become embroiled in shock waves that smack upon the ground and are known as sonic "booms". These sonic "booms" mean different things to different people. The populace, or general public, will never look upon the sonic boom as anything but a nuisance. A few, patriotic minded, citizens might look upon the thunderous noise with benevolence and a feeling of security with the knowledge that they're our sonic booms. But, in the main--the local population don't like sonic booms. A surprising factor, among people who are constantly subjected to sonic booms, is that a full understanding of the sonic boom gives them a higher tolerance level. In spite of your protests and reluctance, you will find yourself on the defensive with the public in attempting to substantiate the need for sonic booms in your operations. Even though it doesn't fall in your area of responsibility--you better learn how to be a public relations man in explaining the necessity for and the harmlessness of sonic booms. Maybe you can use the following explanation for this airflow phenomena.

When an airplane is in supersonic flight, the local pressure and velocity changes on the airplane surfaces are coincident with the formation of shock waves. The pressure jump through the shock waves in the immediate vicinity of the airplane surfaces is determined by the local flow changes at these surfaces. Of course, the strength of the shock waves and the pressure jump through the wave decreases rapidly with distance away from the airplane. While the pressure jump through the shock wave decreases with distance away from the surface, it does not disappear completely and a measurable, but very small, pressure wave will exist at a considerable distance from the airplane. So we can say that the sonic booms are the pressure waves generated by those shock waves formed on the airplane in supersonic flight that are still strong enough to make their presence felt on the ground.

We can illustrate how our F-104 is a source of sonic booms with this drawing.

F-104 IN SUPERSONIC FLIGHT



When we are in level flight at a high Mach number, a pattern of shock waves is developed which is dependent on our configuration and flight Mach number. At a considerable distance from our F-104, these shock waves tend to combine along two common fronts and extend away from the airplane in a conical envelope, as we discussed in Section I. The intensity of the propagated "boom" will be dependent on many factors. The main factors are:

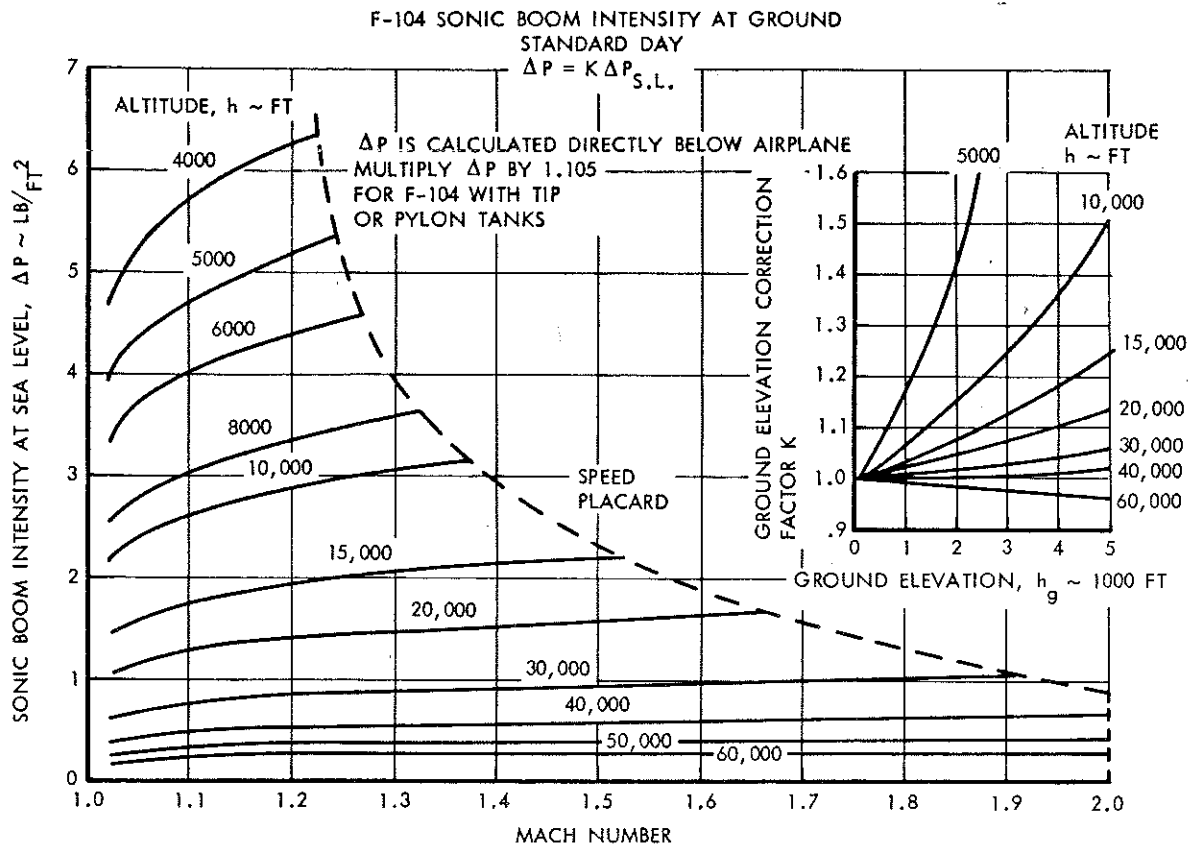
1. Terrain contour over which we are flying.
2. The size and shape of the aircraft, in our case the F-104.
3. Our flight Mach number.
4. Our flight altitude.
5. The ground elevation.
6. Atmospheric conditions.

These factors, in particular, are influential in these ways.

1. Terrain contour will dictate the reflection and attenuation of the sonic boom.
2. Our small F-104 shape generates a very small shock wave since we're transferring a small amount of energy to the air mass.

3. Our flight Mach number obviously is indicative of the degree of intensity of the shock waves.
4. Our flight altitude has an important bearing on boom intensity since at high altitude the pressure jump across a given wave is much less. In addition, at high altitude a greater distance exists between the generating source of the pressure disturbance and the ground level and the strength of the wave will have a greater distance in which to decay.
5. The higher the ground elevation where the boom is encountered, then obviously the stronger will be the effects since the high ground elevation is nearer the source.
6. The variation of temperature and density plus the natural turbulence of atmosphere will tend to reflect or dissipate the shock wave generated at high altitude. However, in a stable, quiescent atmosphere, the pressure wave from the F-104 in high supersonic flight at high altitude may be of an audible magnitude at lateral distances as great as 10 to 30 miles.

To assist you in establishing the true facts about sonic boom complaints, I have a plot that you can use to calculate the exact pressure load created by the F-104 for any sonic boom.



An example will show you how to use this diagram. Assume that an F-104 conducted an intercept at 30,000 feet and Mach 1.7. From the large plot, this shows that at sea level, the F-104 would have created an overpressure of 1 lb/ft². If a complaint was made about the sonic boom and the person lived at 5,000 feet elevation, then we go to the small plot and find our elevation factor k, of 1.05. Now from our formula:

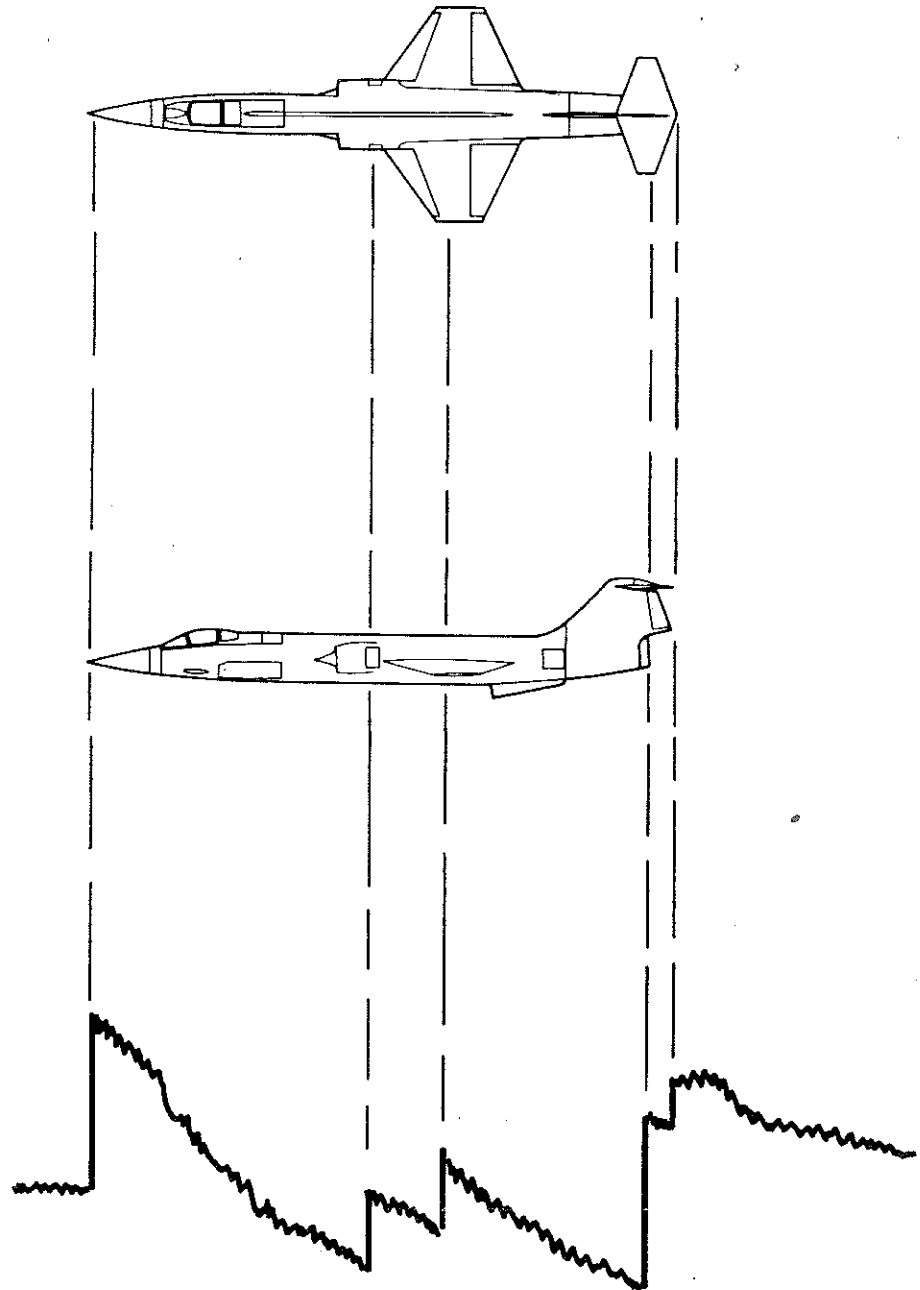
$$\Delta P = k \Delta P_{S.L.}$$

then,

$$\Delta P = 1.05 \times 1.0 = 1.05 \text{ lb/ft}^2$$

Now, you can thoroughly explain how much overpressure was generated by the sonic boom.

To determine the characteristics of sonic booms at extremely low altitudes, NASA conducted some tests at altitudes between 50 to 1000 feet above the terrain. From these tests, it was learned that every supersonic airplane will leave a particular, identifying pressure-print. From these tests*, were established the pressure-print of the F-104 that I've included in this lecture for your interest.



PLANFORM AND SIDE VIEWS OF F-104 WITH A TYPICAL TIME HISTORY OF SHOCK NOISE PRESSURE

*Reference 2

Supersonic Formation Flying

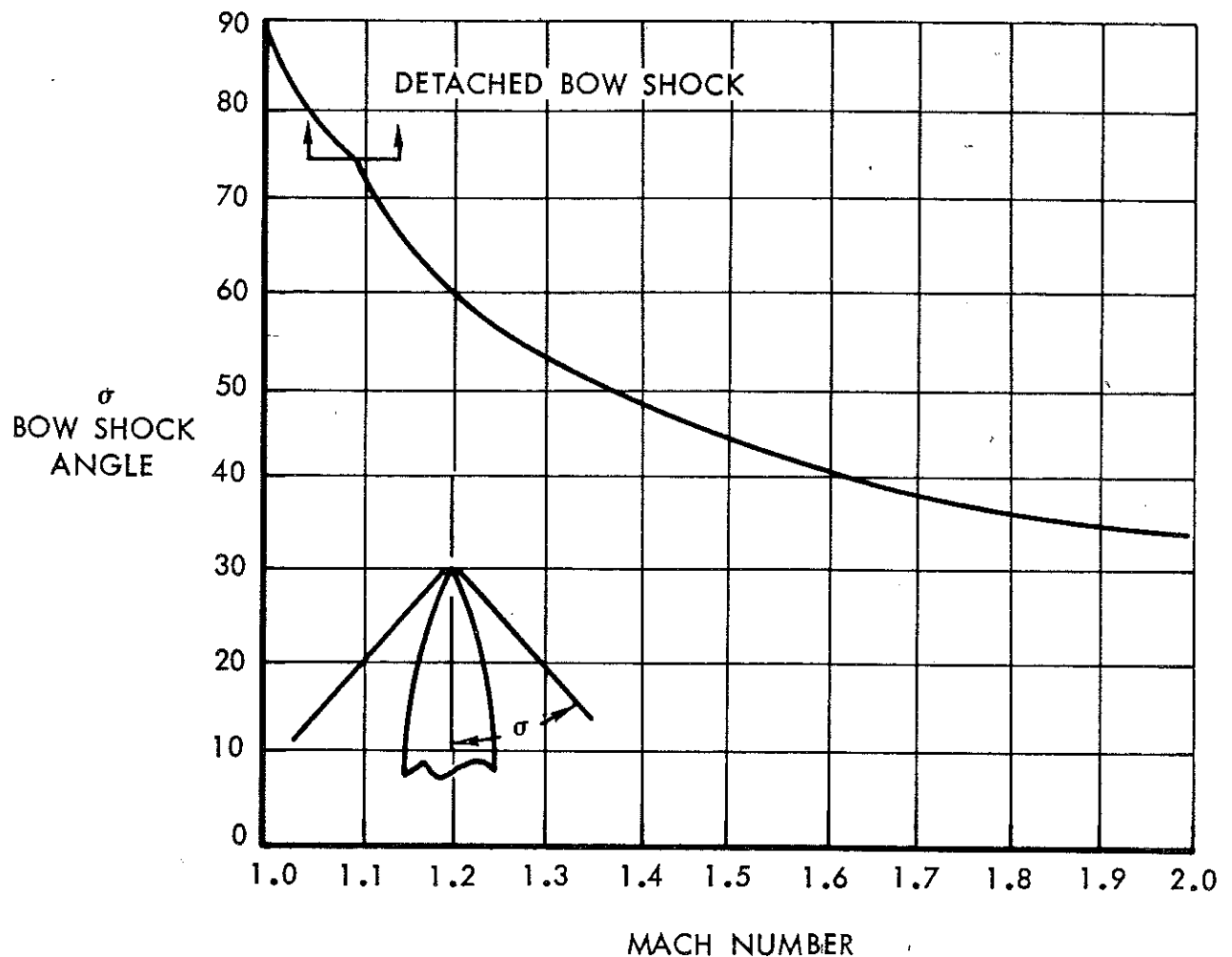
Your handbook* talks about lateral directional oscillations that can be experienced in the Mach 0.94 to 0.98 range. They explain that the oscillation is due to formation of unstable shock patterns on the empennage at these speeds. Now that you know about the development of sonic flow over airfoils, I'm sure you can understand the imbalance on our vertical fin in this speed range if the points of sonic flow are not acting equally. These lateral oscillations will only cause difficulty to you and your wingman, therefore, the duration of time in this flight regime should be kept to a minimum.

Your handbook** also describes for you the small trim changes required for level flight during accelerations to Mach 2.0. After your study of the wind tunnel photos, now you can understand that the trim changes are a result of the changing shape of the pressure loads on the airfoils and therefore require slight trim changes on the control surfaces. In regard to supersonic formation, your handbook*** discusses the effects of passing through the shock wave pattern of a lead aircraft. The first question that is always asked about supersonic formation is--"What position should I fly to stay out of the bow wave effect?" To answer this, I've drawn a curve that shows you the predicted angle of that bow wave you saw in the wind tunnel photo. This wave angle is plotted against Mach number and is good for all altitudes. Using this plot in your planning, you'll be able to brief on where to fly in order to stay either in front of or behind the wave and avoid the cycle of oscillations that will occur if you pass through it.

* Reference 1, page 6-16

** Reference 1, page 6-17

***Reference 1, pages 6-23 and 6-24

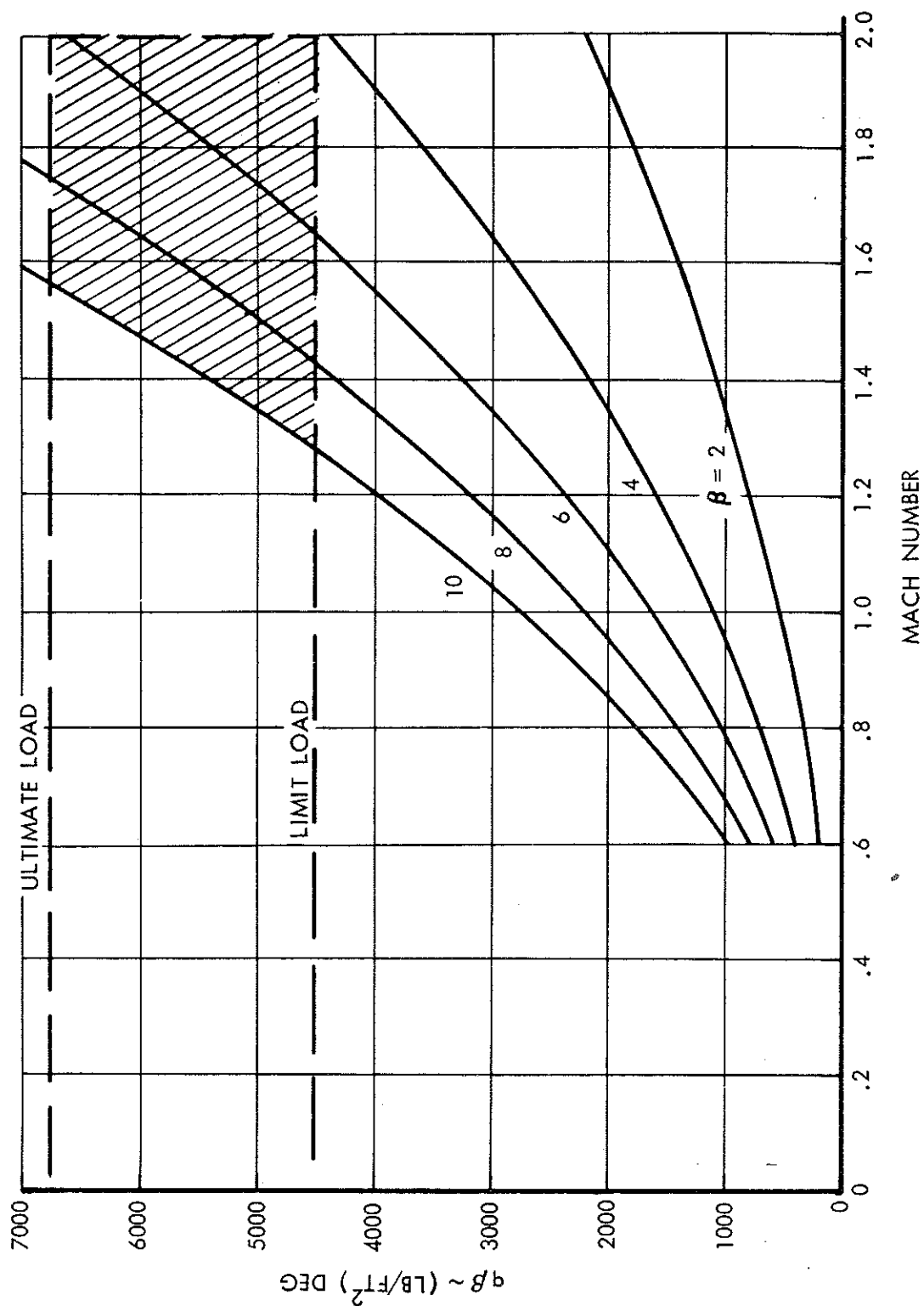


The next question that is normally asked is--"If I get caught in the bow wave, can I possibly encounter structural failure?"

To answer this question, you should first review pages 5, 10 and 25 of SURE lecture 1 where I explained the build-up of airloads on the vertical stabilizer and the reasons for the limiter on the powered rudder. Next, the handbook describes the yaw oscillations to expect when you pass through the bow shock wave, so you know that the aircraft will yaw and therefore build up the pressure load on the vertical stabilizer. To give you an idea of the critical yaw angles to stay away from, I have a plot from our reference material* that tells us an important story.

*Reference 3

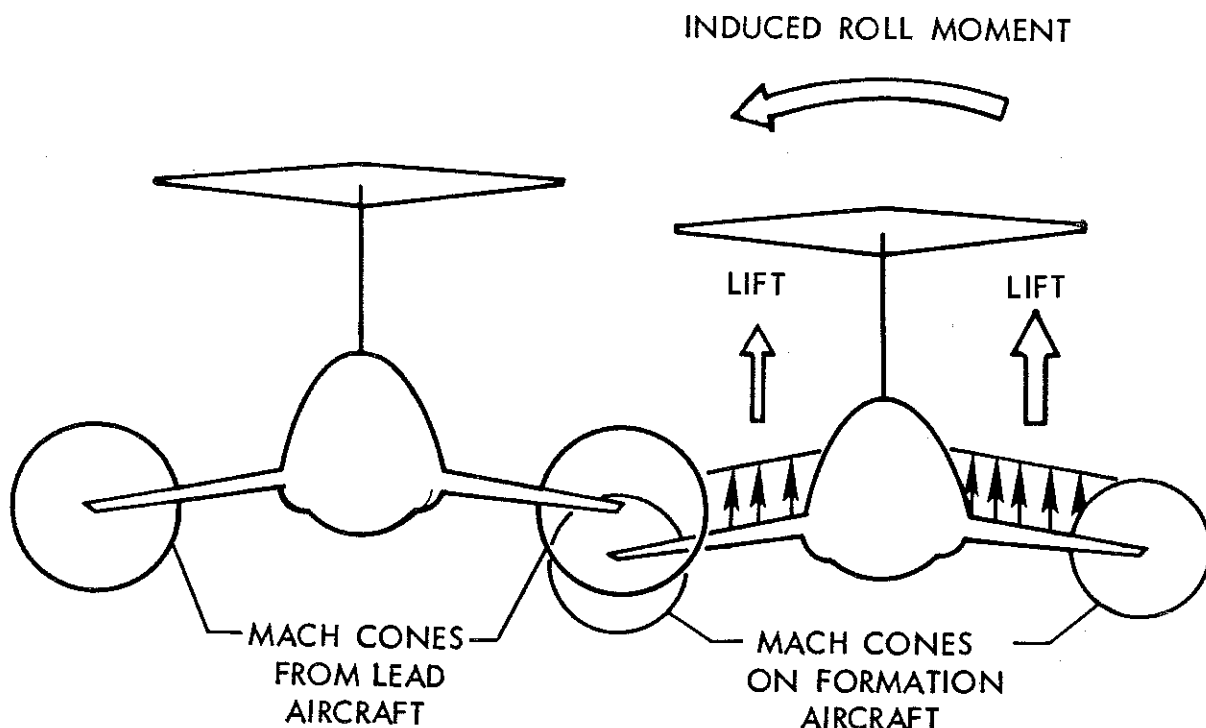
F-104
EFFECT OF SIDESLIP ON VERTICAL TAIL LOADS
H = 40,000



From this diagram, we have a critical area for any sustained yaw angle above 4 degrees between 1.3 Mach number and Mach 2.0, when we're flying at 40,000 feet.

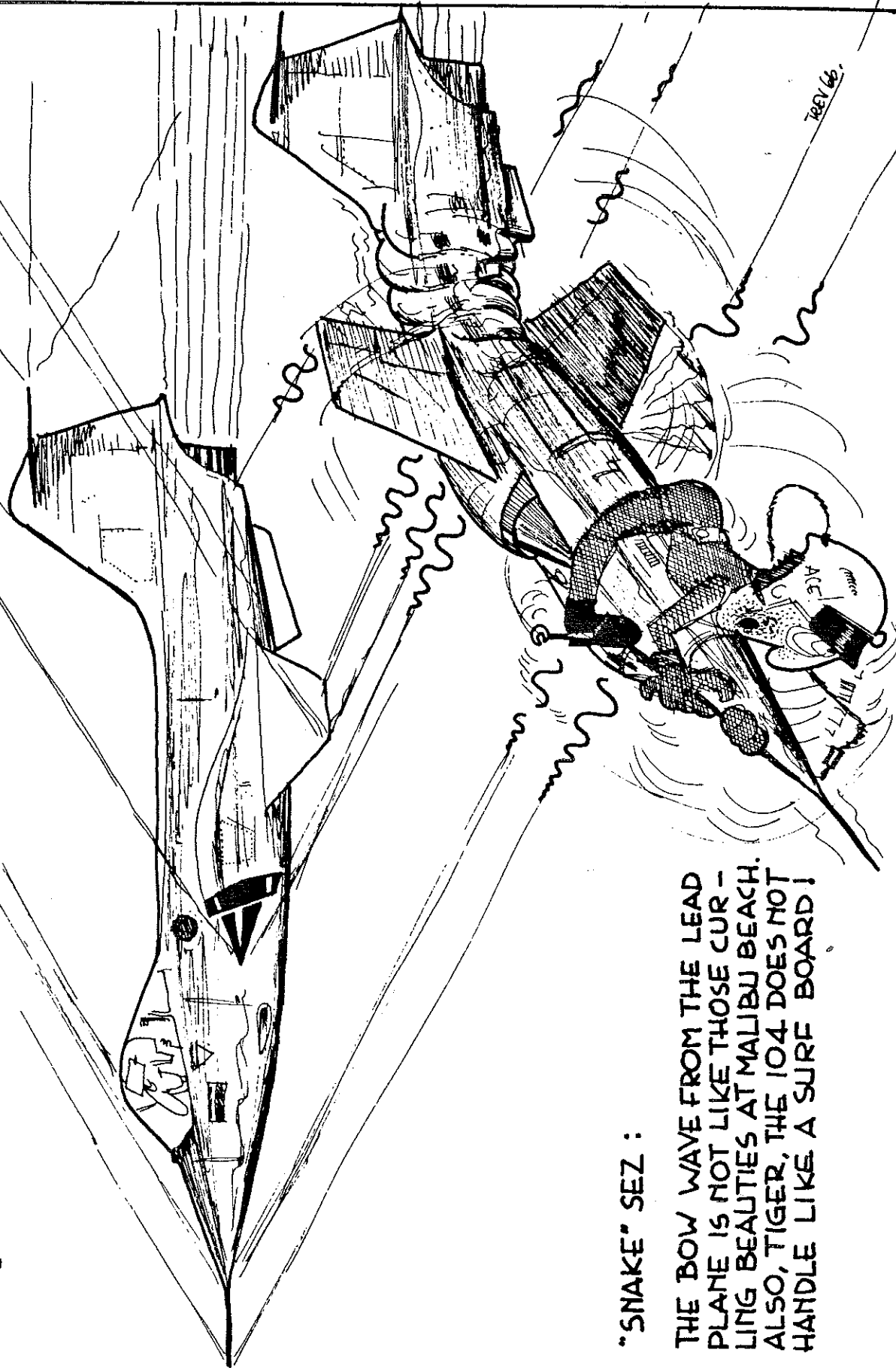
"Hold the phone, Snake! Based upon the direction of the supersonic airflow just behind the bow wave, wouldn't I actually be turning into the flow direction, when I yaw toward the lead aircraft and thereby be decreasing the actual yaw angle and the tail load?"

Say man--you're really turned on with that thinking helmet. You're absolutely right--as long as you're just behind the bow wave. But remember, if you pop out in front of the wave--then you've jumped into another flow field direction and that could put you again into that critical area of yaw angle and Mach number. It's best to not mess around with the bow wave effect of the lead aircraft when you're flying supersonic formation. And just in case you're thinking about flying a close show formation position to avoid the bow wave, let me remind you of that wingtip Mach cone in supersonic flight that we discovered in Section I. I know--there isn't any twisting flow that will hit the overlapped wing tip and force it down--but remember there was a low pressure area in the vortex cone that caused a loss of lift at the wing tips. If you now overlap your wing tip with the lead aircraft, there will be an even greater lowered pressure over the overlapped wing tip. This will cause an unbalanced lift on the wing airplane as I've sketched for you.



So that's it--a different airflow picture but the same effect. Your rule of wing tip clearance is mandatory in both subsonic and supersonic flight.

SUPERSONIC FORMATION



"SNAKE" SEZ :

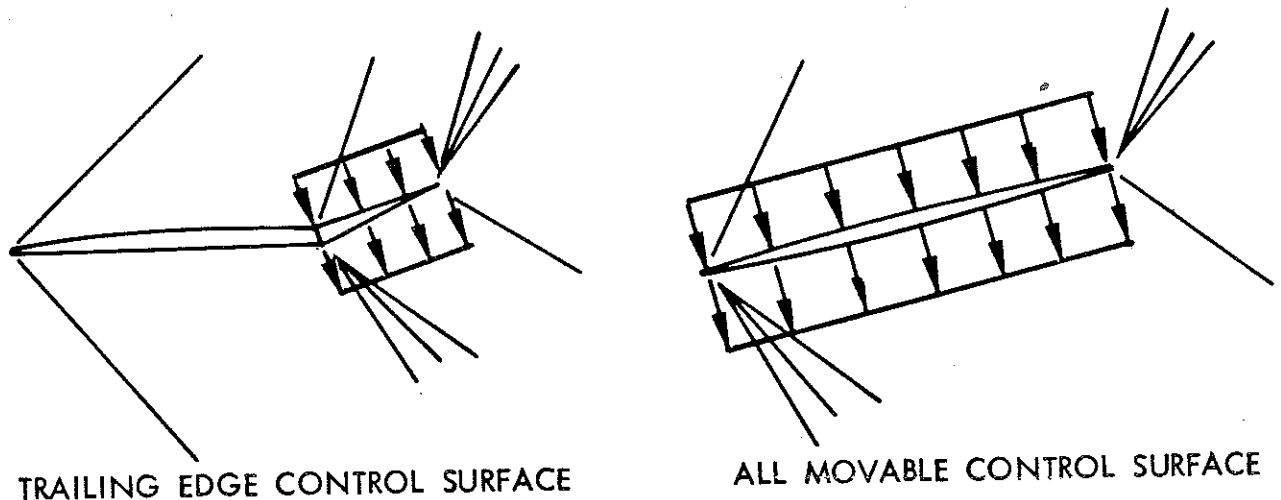
THE BOW WAVE FROM THE LEAD PLANE IS NOT LIKE THOSE CUR-LING BEAUTIES AT MALIBU BEACH. ALSO, TIGER, THE 104 DOES NOT HANDLE LIKE A SURF BOARD!

Control Aspects of Supersonic Flight

A specific area of "unknown" that pilots have encountered since the inception of supersonic operational flying is the unknown area of airflow effects on the airfoils and control surfaces. They've heard various terms to describe some of the effects, but no adequate, informative material has been made available to them. After you've finished studying the information I have for you, I hope your area of "unknown" will be greatly diminished.

With your well developed knowledge of supersonic airflow from Section I, let's examine the airfoils and control surfaces of our F-104 in supersonic flight. We know that our horizontal stabilizer is an all movable control surface while the ailerons and the rudder are trailing edge control surfaces. In regard to the rudder, there's no useful maneuvers that I know of that require its application in supersonic maneuvering. Therefore, let's realistically confine our study to the horizontal stabilizer and the ailerons.

From our reference material*, we can sketch the supersonic airflow over these control surfaces and look at the pressure patterns.



*Reference 9, page 237

Plainly, our horizontal stabilizer is undergoing the same shock wave pattern of our wing when it was at a positive angle of attack. Except that for the horizontal stabilizer, the angle of attack is negative so the shock wave sequence is reversed and also the pressure pattern is reversed. On page 4 of SURE lecture 1 and page 1 of SURE lecture 2, I explained the design criteria that "Kelly" was after when he designed the high horizontal stabilizer on the empennage. It's now apparent why his design is so effective in pitch during our supersonic maneuvering.

The ailerons, however, have a noticeable reduction in their effectiveness in transonic and supersonic flight. During subsonic flight, molecules A and B are always warned about the deflections of the ailerons in their flow over the wing. So the deflections of the ailerons at low subsonic speeds alters the pressure distribution on the fixed portion of the wing as well as the pressure distribution over the area of the ailerons. But our supersonic flow is completely different. In supersonic flow over the wing, a deflection of the aileron cannot (due to supersonic flow properties) influence the pressure distribution in the supersonic area ahead of the aileron. In fact, in high supersonic flight, as we've drawn, supersonic flow exists over the entire chord and the change in pressure distribution is limited solely to the area of the aileron surface. Obviously then, our aileron effectiveness decreases in supersonic flight.

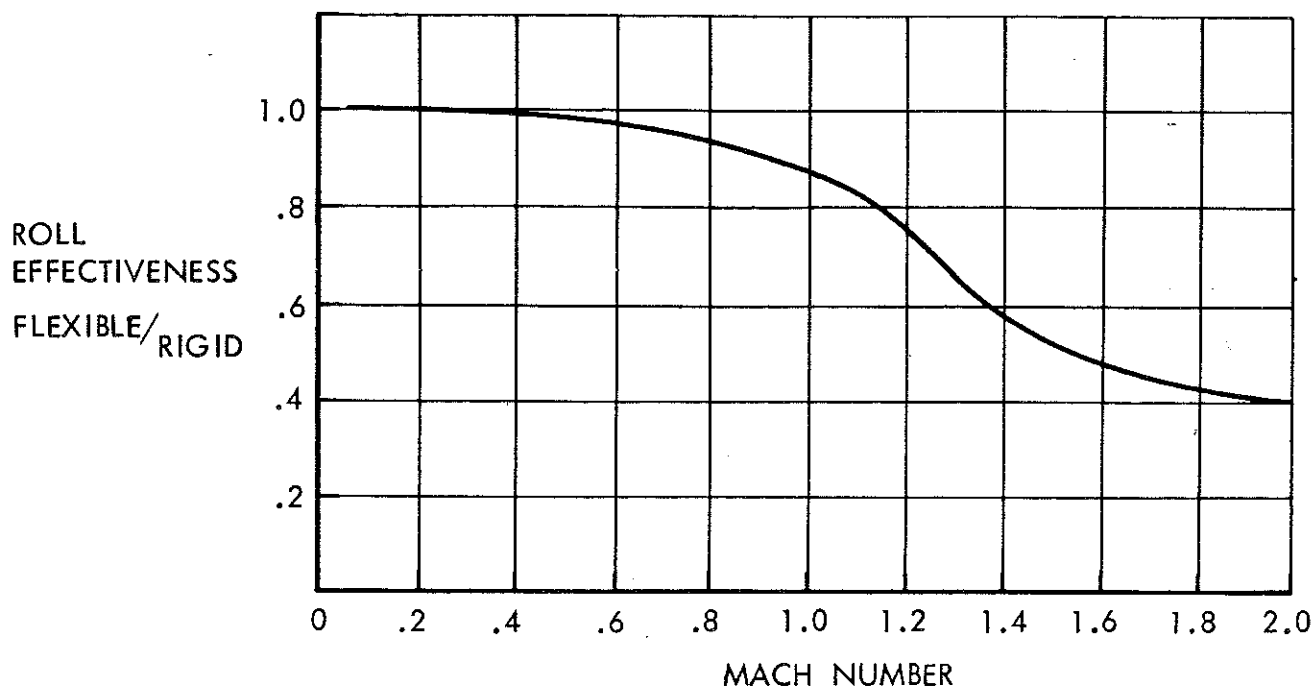
"You mean--?"

Yeah--that's basically why you don't roll as fast with full aileron throw at Mach 1.5 as you can at Mach 0.9. And that ain't all. Our sketch shows a rosier picture than actually exists. We've got enough tail feathers by now to know that our airfoils have to flex and bend under the various pressure loads we subject them to in our maneuvering. I know--it doesn't seem possible that the F-104 wing will flex one iota. But it does. It's natural to misconstrue strength for stiffness. Our wing is plenty strong, as you know, but let's distinguish between strength and stiffness. Strength is simply the resistance to load while stiffness is the resistance to deflection or deformation. Of course, strength and stiffness are related, but it is necessary to appreciate that adequate structural strength does not automatically provide complete resistance to deflection. The flexure of our airfoils is due to a certain amount of unavoidable aeroelastic effects. Establishing the fact that our wing has flexure and deflection under pressure load, we can now investigate another control aspect called aileron reversal.

Aileron reversal is a phenomenon peculiar to high speed flight. When in flight at very high dynamic pressures, the wing torsional deflections which occur with aileron deflection are considerable and cause noticeable change in aileron effectiveness. The deflection of an aileron on the rigid wing (which we've assumed, so far) creates a change in lift and produces a rolling moment. In addition the deflection of the aileron creates a twisting moment on the wing. When our actual elastic wing is subjected to this condition at high dynamic pressures, the twisting moment produces measurable twisting deformations which affect the rolling performance of the aircraft. We can illustrate the two wings in this manner.

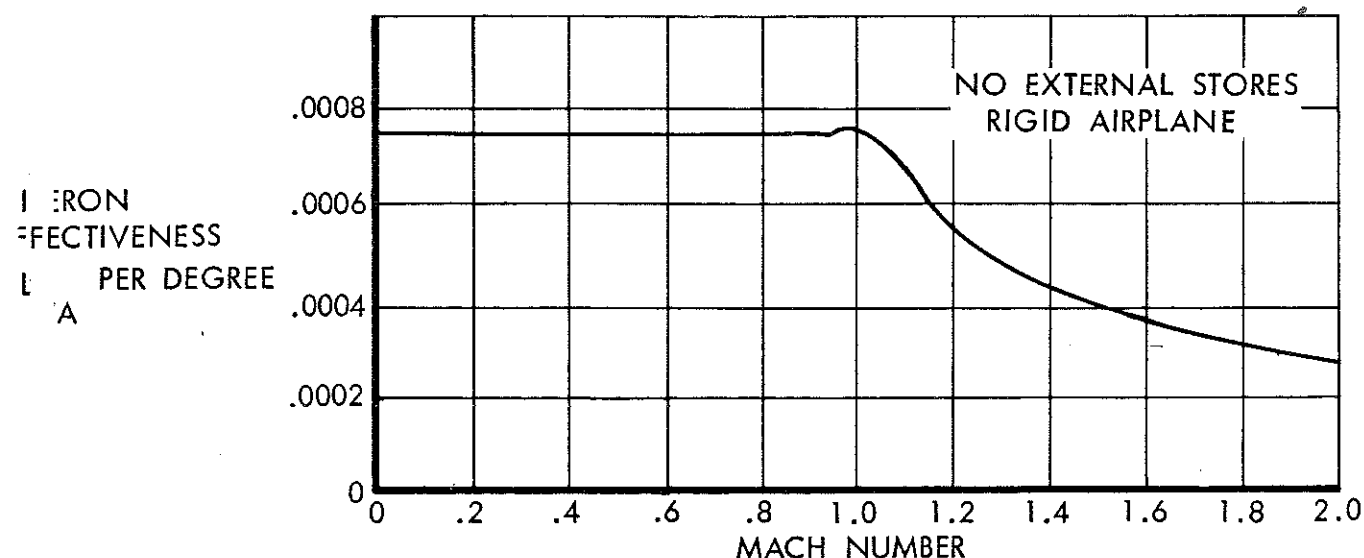


Our actual wing has to react to the displacement of the aileron so the wing will twist around a point called the elastic axis of the wing. As the wing twists, the aileron effectiveness goes down. If the twisting deformation becomes great enough, it will completely nullify the effect of aileron deflection and their control effectiveness becomes zero. Flight at speeds higher than this point will create rolling moments opposite to the direction we move the control stick, so this point is called "aileron reversal speed". As you know, from your flight experience in the F-104 and from the handbook, there is no point of "aileron reversal speed" with the F-104 in all of its flight envelope. In SURE lecture 1, I explained to you all of the aspects of inertia coupling due to the high available roll rate of the F-104. In order to demonstrate the strength and stiffness of our F-104 wing, let's compare the theoretical rigid wing roll effectiveness to our actual F-104 wing roll effectiveness. Just like the engine manufacturers trying for a nozzle coefficient of 1.0, we aircraft builders try for an aileron roll effectiveness of 1.0 throughout our flight envelope. Here is the plot.

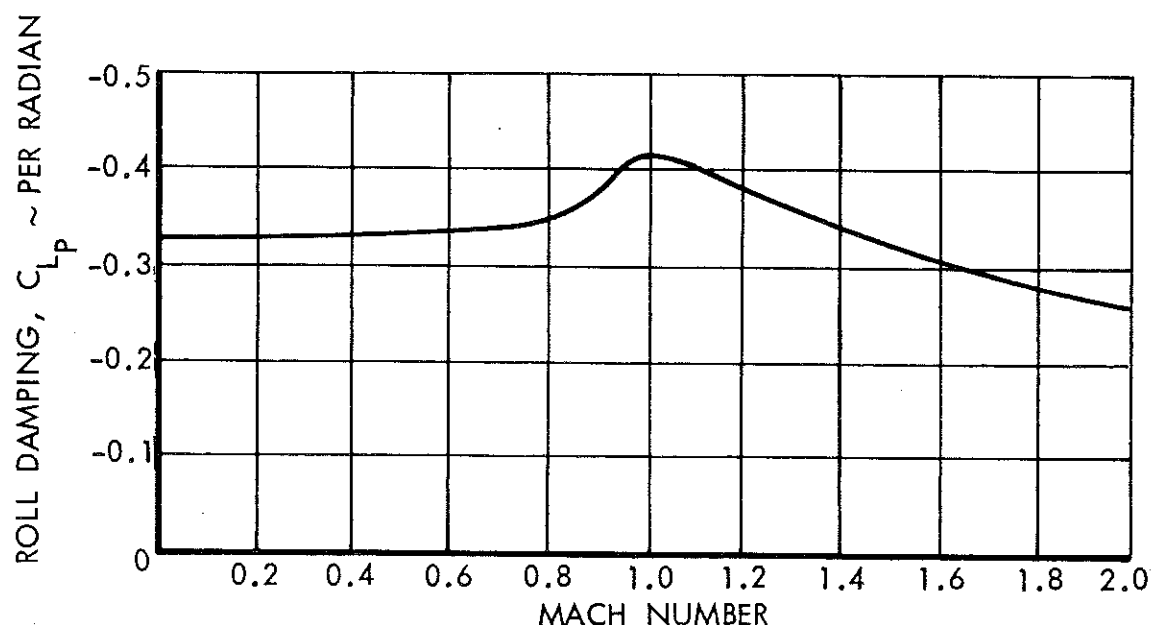


Even though this plot indicates that aileron reversal does not occur in our flight envelope, the effects of reduced aileron effectiveness definitely exists. So a study of F-104 supersonic aileron roll effectiveness will shed more knowledge on just how much roll effectiveness we have.

The peak, or maximum steady state, roll rate depends on two aerodynamic moments; the rolling moment produced by the ailerons, and the roll damping moment which comes largely from the wings. Assuming a rigid wing, we can plot the aileron effectiveness in this manner.



This graph shows the decrease of aileron effectiveness above Mach 1.0, that comes even with a rigid airplane, because of the change in pressure distribution over the wing in supersonic flight. Now if you will imagine the wing movement just at the instant of beginning a roll, you can picture that the wing tip will have moved a certain amount that has given it a change in angle of attack and therefore, lift. At the wing root, however, it will have moved much less and therefore have a smaller angle of attack and lower lift. During the rolling motion that the ailerons have imparted to the wing, there is also the resistance to rolling from the wing that is due to the variation of local angle of attack along the span of our rolling F-104. This roll damping can also be plotted against Mach number so that we can see its variation.



This curve shows the resistance to rolling and is plotted against Mach number. We have two rolling moments that oppose each other so the peak roll rate will be reached when they are of equal magnitude, or--

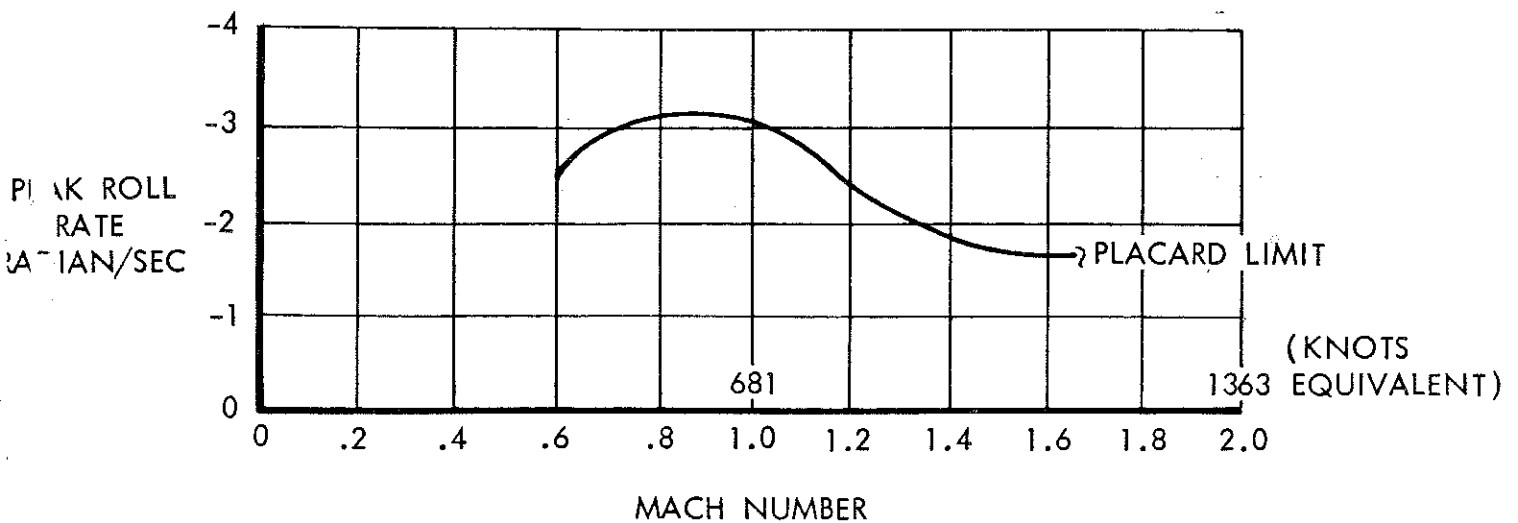
$$\text{Aileron Rolling Moment} + \text{Roll Damping Moment} = \text{Zero}$$

If we use these two curves in conjunction with our equation and take into account the flexibility of our wing, we can arrive at a curve that shows our available peak roll rate.

F-104 ROLL RATE

$$\delta_A = \pm 10^\circ$$

NO EXTERNAL STORES H = 20,000 FT



The key point from this study is to recognize the fact that you have a decreased aileron effectiveness when you're flying beyond Mach 1.0. This can be very critical under certain circumstances. In your handbook* is a warning not to exceed Mach 0.9 with an asymmetrical tip tank fuel load. Why not? Three pilots of different nationalities made supersonic acceleration runs with one tip tank empty and the other tip tank full. Two of them are dead and the third one will tell you a right hairy tale of loss of adequate aileron effectiveness and winding up in a graveyard spiral at a high Mach number! The weight imbalance coupled with the decreasing aileron effectiveness all added up to disastrous effects. Ace, we flat can't afford to ignore the firmly established physical aspects of airflow.

Gun Firing Effects

A look at either one of our wind tunnel photographs tells us that in the case of supersonic gun firing, we encounter some very complex airflow problems. Due to the physical properties of supersonic airflow, our gun blast cannot get out in front of the bow wave and due to the high speed, the left inlet swallows the hot blast wave almost immediately upon firing. In order to maintain proper engine operation, a combination of events occur when you squeeze the trigger. These events are:

The electrical signal for gun firing comes from the depression of the trigger switch. This electrical signal goes through the landing gear up switch, through the weapons selector switch which must be circuited to the gun, through the purge pressure switch;

*Reference 1, page 6-22

then into the gun relay box which takes care of purge timing, the start of the engine dual ignition and the IGV closure of 5 degrees. The gun purge pressure is maintained for approximately 12 seconds after the trigger has been released. The reason for this is that the gun fires all of the rounds in the barrel of the gun after trigger release. This is a safety function that prevents the shells from auto-igniting because of their hot barrel environment. Therefore, we need the additional gun purge function for this time duration which is approximately 12 seconds.

Even though our engineering features can accommodate a large number of the airflow problems of gun firing, there are still some critical areas that could cause A/B blowout and a possible compressor stall. This is the area of high altitude (45,000 feet and up) and the lower supersonic Mach numbers with an associated high angle of attack. Now, our systems are faced with three problems. First, the inlet air flow has been distorted by the gun blast. Second, the airflow now is too rich in its mixture. Third, the engine is faced with too high an inlet temperature. This combination is tough to handle, so you might encounter some undesirable engine reactions if you gun fire under these critical conditions.

Cockpit Pressurization Aspects

A very startling occurrence is the sudden loss of cockpit pressurization, the Master Caution light popping on and the Canopy Unsafe light illuminating on the annunciator panel--all at about Mach 1.8 and 40,000 feet! The sudden charge of adrenalin in your blood flow will be quite stimulating and your natural reactions will cause you to chop the throttle to idle, extend the speed brakes and then all of a sudden as you're slowing down--"whoof",--the warning lights go out and the cockpit pressurization comes back with a tremendous surge against the ear drums. Everything has happened so fast that you're wondering what to write up for the maintenance crew. Again--it's all due primarily to a supersonic airflow effect which in this case is the airflow over our canopy. Remember that beautiful expansion wave above the canopy. Well, right behind that wave, the pressure goes down and that increases the differential of our pressure inside the cockpit to the pressure just above the canopy. So then what happens? If those cockpit pressurization switches, located on the right sill, are on a marginal setting--you'll go through the little story I just reiterated. As the pressure keeps decreasing with the high Mach flow, eventually the switches break contact and dump the pressurization and then they re-contact as you slow down. It's an interesting experience.

SECTION VI

Aerodynamics of the Approach and Landing

Beautiful landings are never accidents! They are artistic creations that result from untold hours of practice and concentration. And to our bitter chagrin, they can only be fully appreciated by a minority--our ever critical and grudgingly praiseful, fellow pilots. Due to its very requirements, any successful landing is a precise maneuver--no matter how it turns out. It's only that some landings are better than others. But what is a landing?

According to the Dictionary--it's the act of alighting upon the earth. In the case of our fine feathered friends--the birds--there's never a worry about where to alight upon the earth. Because essentially, the whole earth is a landing field for them. Tain't so with us in our aluminum crates. We are limited to particular nestling places with specific directions for approach and fixed lengths to set down in and all the time, we are completely at the mercy of the changing atmospheric conditions such as fog, rain, wind, and snow. Are we better at landing than the birds? In consideration of our restrictions--yes. But we're better only so long as we don't scuff our tail feathers and ding our machine during the approach and landing. To prevent this nauseous occurrence, we must really study our airflow and its effects upon us during this most critical maneuver. Since your handbook* already has excellent information on technique and procedures, I shall only point out some particular airflow aspects on approach and landing with further explanations of why certain procedures are recommended.

Approach Phase

Many years ago, I stated in an issue of Lockheed's Hangar Flying that: "A well thought out professional approach always brings a better chance of success--be it with an airplane, or more delicate equipment." This emphasis on the approach phase has not failed me yet--in my flying. I believe that the smoother and more exact that you plan your approach, the easier will be the flare and touchdown. I've never liked anything in my flying to be unnecessarily difficult and taxing. Why not help yourself to make it nice and easy by making a smooth approach? Now, it just might be that my experience and technique could possibly help you--so I'm going to describe how I fly the pattern and approach.

In coming up to the initial, I have found that all models of the F-104 have an RPM setting that seems to naturally maintain my traffic pattern altitude and an initial speed of 325-330 knots. For the lighter models (F-104A through F), this seems to be about 88-89% at the normal landing weight.

* Reference 1, pages 2-19, 2-20, 2-21, 2-22, 2-23, and 2-24.

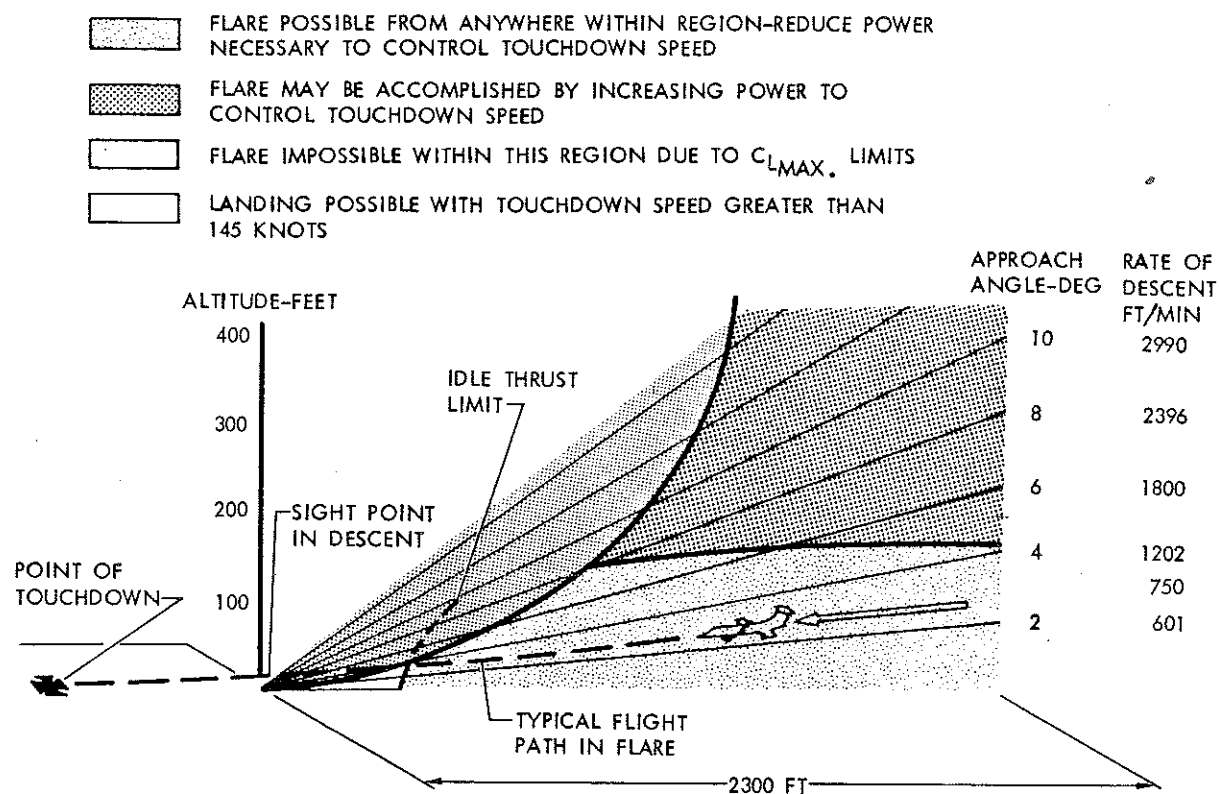
This power setting is a "natural" for the initial and on the overhead break. As I make the pitch-out and lower Takeoff flaps, I carefully check the indicators, flap movement in the rear view mirrors and control feel while I leave my hand on the flap handle. This is to make sure that I can quickly counteract any roll-off tendency--like a split flap condition. As I make the overhead break, I pull enough g's to start bringing the airspeed smoothly down toward 260 knots. By leaving the power setting alone, I can adjust my airspeed bleed-off to match up with 260 knots just as I roll out on the downwind leg and opposite the approach end of the runway. The amount of bank angle and g load is varied on the overhead break to compensate, in the proper direction, for any large crosswind components that may exist. The extension of the landing gear, at 260 knots, will take 5 ± 1 second and during this time the airspeed will decrease to 240 knots, which is the Land flap extension airspeed. If I consider the crosswind to be too severe for a Land flap landing, then I continue with only Takeoff flaps and maintain 240 knots on the base leg with shallower, flatter turns and the pattern becomes larger in radius by extending my downwind leg. At this point, an increase in power setting is needed to keep the proper rate of sink and maintain 240 knots. From base leg turn to final I strive for a definite $2 \frac{1}{2}$ degree glideslope interception and begin stabilizing on 190 knots final approach airspeed. The distance from the end of the runway at the start of the final approach should be at least 6,000 feet.

For a Land flap approach, the pattern is only slightly different. On the downwind leg where I'm opposite the approach end of the runway, I lower the Land flaps, again checking the indicators, watching the flap movement in the rear view mirrors and assessing my control feel while I hold my hand on the flap handle. I'm prepared and alerted for an immediate return to Takeoff flaps if I encounter a marginal flap rig or BLC (Boundary Layer Control) roll-off. During the extension time of the flaps from Takeoff to Land, there's always a definite slight nose down tendency due to the increasing aerodynamic forces on the Land flaps. By aft stick movement and trim change, I cancel out this slight nose down effect and by the time the flaps are in the Land position, the airspeed has bled off to 220 knots. As I turn on the base leg, there is now a need for increased power. Normally, a power setting of 93-94% will enable me to turn, with a rate of sink of about 1500-2000 feet per minute so that I wind up on the final approach at 170 knots and a $2 \frac{1}{2}$ degree glideslope at a minimum distance of 6000 feet from the touchdown point. The power is now reduced again to maintain 170 knots. Once I stabilize on this approach--that's it! I don't mess with the angular line to touchdown, unless I see that I'm short. And that requires immediate action on any type of approach. But normally, as I roll out on final approach and stabilize--I am now in a groove that I don't dare change--without bad repercussions. Many pilots who transition from the venerable T-33 to the F-104 are not aware of the immense aerodynamic changes between the two basic types of aircraft. If we compare the two birds on an aerodynamic basis, we'll see the striking difference.

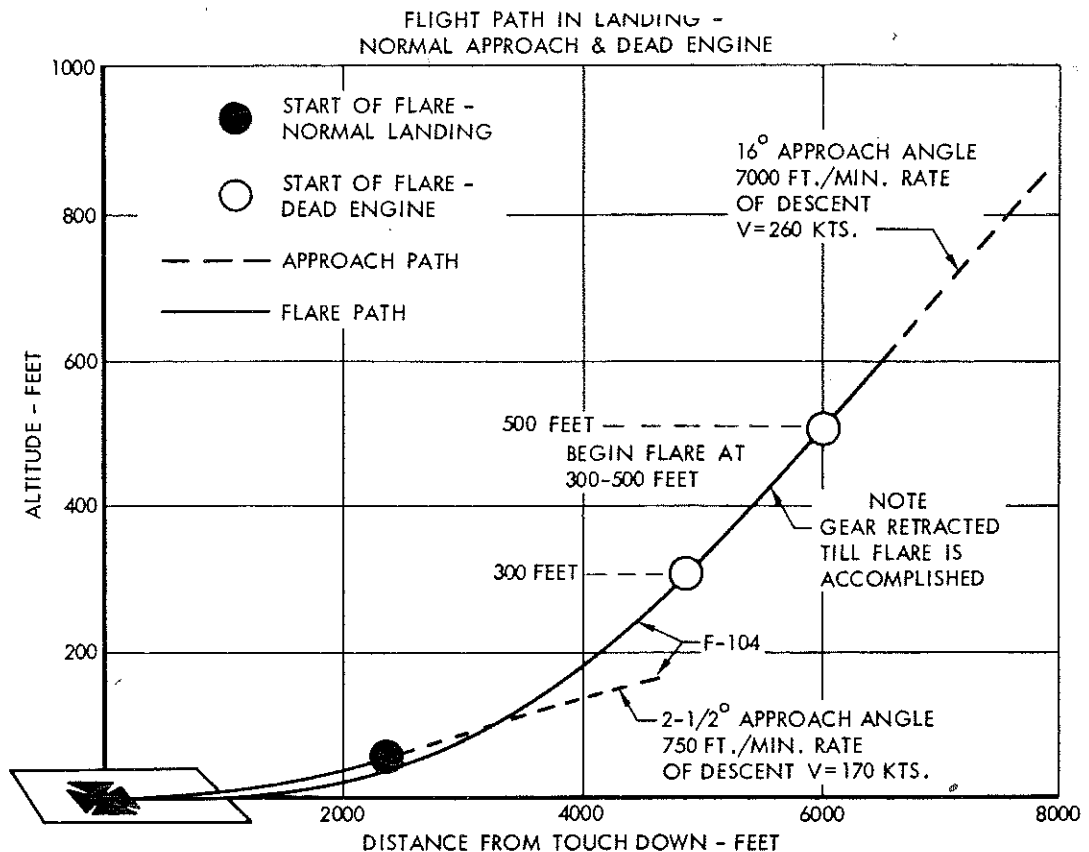
Comparison of T-33 with the F-104 in Landing Configuration

	<u>T-33A</u>	<u>F-104</u>
Aspect Ratio	6.0	2.5
Wing Loading W/S lb/ft ²	45.7	78.9
C _L max. (useable)	1.7	1.13
(W/S) ($\frac{1}{C_L}$ max.)	26.0	69.8
Approach speed-knots	118	170
Touchdown speed-knots	104	145 Minimum

The whole picture tells you that with the T-Bird, you've got a much greater latitude for approach and a larger margin for error and still be able to make a successful approach. That's not true with our small skinny wing on the Starfighter. Our low Aspect Ratio wing has to work its hardest to obtain the greatest amount of possible lift from the airflow of molecules A and B. This means that we don't have any large margin to play with. Our approach has to be "wired" far enough out on final so that we are in the proper envelope for flare capability. To impress you with the proper approach, here is a display of the recommended approach envelope.



A study of this envelope shows you that the recommended 2 1/2 degree glideslope puts you in the groove for flare and landing. If you try to pull a real tight pattern with a steep, power-off final approach at 170 knots, you can see that as you approach the flare point, any angle of approach greater than 4 to 6 degrees and a sink rate more than 1202 to 1800 feet per minute puts you in an area where you can rotate the aircraft--but you won't stop the sink rate before impact with terra firma. And a real important point to remember is that this envelope holds for all approaches. That definitely includes the SFO pattern and the Precautionary pattern. If you don't get my message, then you better study this presentation of the normal flight path and the SFO flight path--on approach to flare.



This presentation shows exactly what I said. Even though you're coming in with high speed (and a high sink rate), you must still get in the groove of the 2 1/2 degree glideslope for the proper approach to touchdown. You should start this flare at 300-500 feet altitude in a wings level attitude, and then you should smoothly flare to intercept the 2 1/2 degree approach path to the runway for the gear extension and touchdown.

Flare Phase

By grooving yourself on the approach, the flare can be made more easily and naturally. The flare phase of an F-104 landing is not the flare you're used to when flying subsonic fighters. You do not chop the throttle, raise the nose and stir the stick as you "feel" for the runway. In fact, if you're

on the proper glideslope you actually only have to do one thing, and that's to slowly retard the throttle. In essence, you're matching up a decreasing lift force on the aircraft with a touchdown speed. The aircraft is actually in a landing attitude on the final approach but it's a rather flat attitude, so most of the pilots raise the nose slightly as they retard the throttle so that they're sure of touching down on the main landing gear with the nosewheel still in the air. This slight raising of the nose is termed "flare", but it actually is only a small pitch change from the approach attitude.

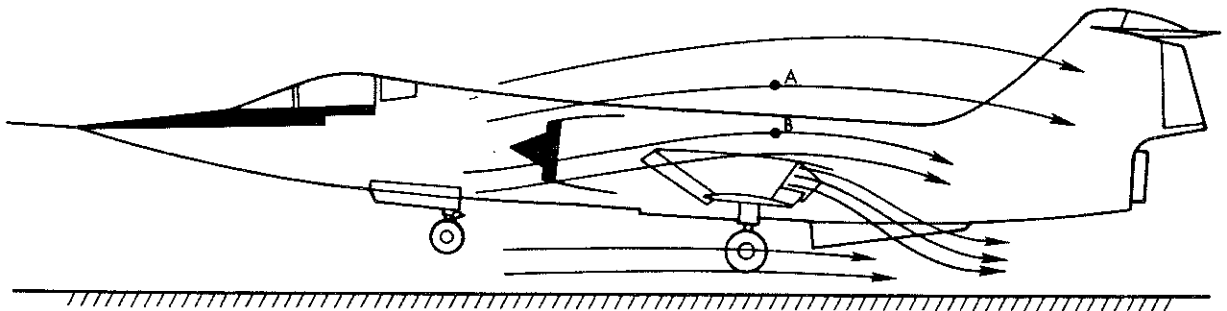
If you're making a Takeoff flap approach, you will more closely approximate the flare of subsonic fighters. It's a more positive and greater nose up attitude rotation and of course, you can bring the throttle back to idle, during the flare, and you will probably float a short distance before touchdown.

The Land flap approach attitude, however, is changed very slightly during the flare to touchdown. This very small change in attitude is due to the combination of two airflow aspects--ground effect and BLC airflow. From our references*, we can discover some general results of ground effect on our F-104 during the flare.

When we approach the runway in our flare phase, a change occurs in the three dimensional flow pattern because the local airflow cannot have a vertical component in its flow path along the runway. This alters the flow of molecules A and B over our wing. They have to reduce their upwash in front of the wing and their downwash behind the wing in comparison to their freestream flow over the wing at altitude. Also, the wing tip vortices are reduced by the ground effect. As a result of this changed flow pattern, the wing will behave as if it has a greater Aspect Ratio. In order for ground effect to be of a significant magnitude, however, the wing has to be very close to the runway, or ground plane. A general rule is that when the wing is at a height equal to the span ($h/b = 1.0$), the reduction in induced drag, due to ground effect, is only 1.4%. But, when the wing is at a height equal to one-fourth the span ($h/b = 0.25$), the reduction in induced drag is 23.5%. Since our wingspan is 21.94 feet, then we will not experience any noticeable ground effect until our wing is at an effective height above the runway of 5.48 feet. Because of the negative dihedral, we have to say an effective wing height. A general assumption could be the mid span point of the wing which will be about 4.5 feet high when the main wheels are just touching the runway. Therefore, we will experience an appreciable ground effect only when our main wheels are at about a height of 1 foot above the runway. Mainly, it's just prior to touchdown that we'll encounter any ground effect which will have little or negligible effect on the touchdown. By far, the most important airflow effect on flare and touchdown is the BLC airflow. Its flow pattern can best be shown by this sketch.

* Reference 9, pages 379, 380, 381, and 382

TYPICAL AIRFLOW PATTERN OF F-104 LANDING WITH BLC AIRFLOW



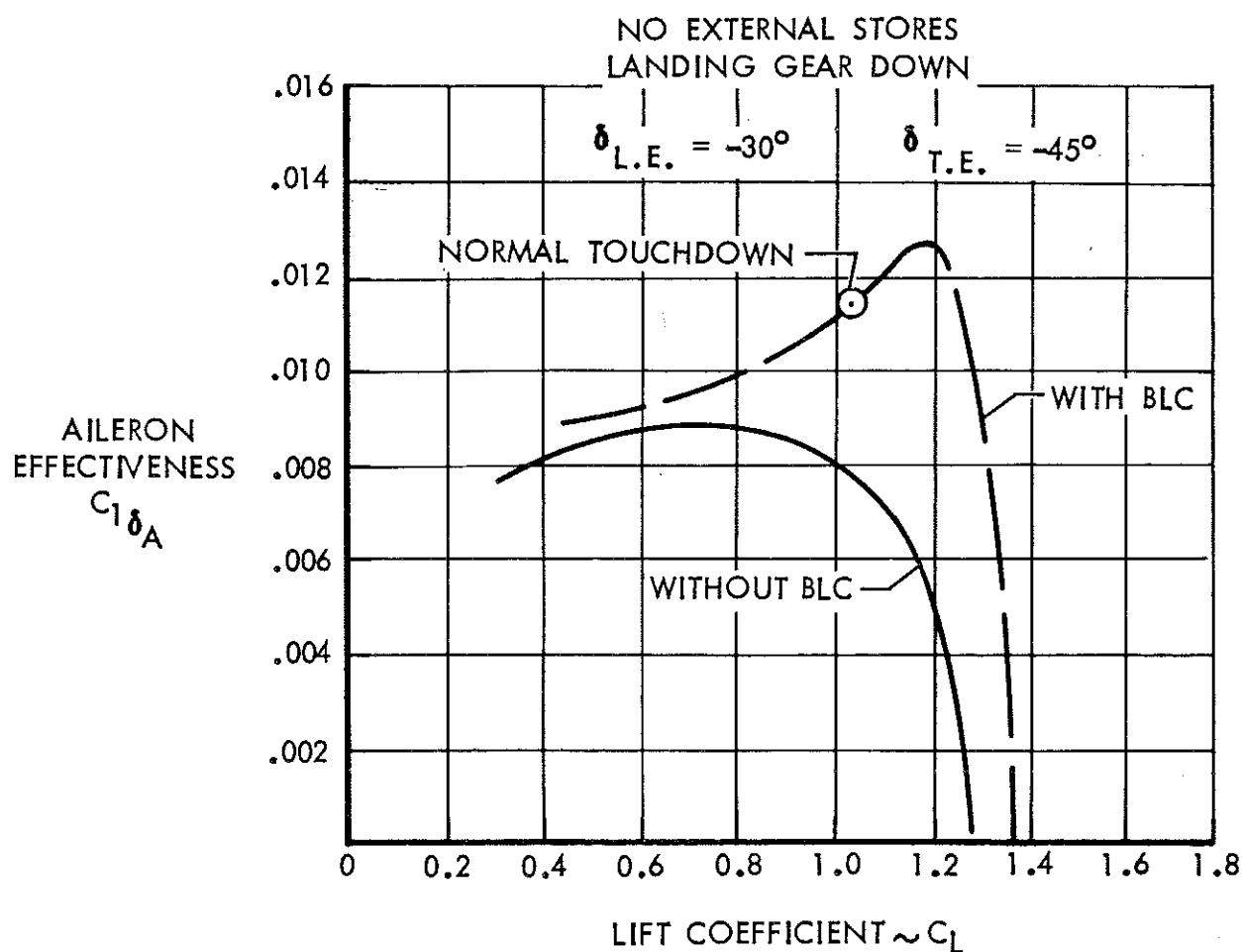
By analysis of the effects of BLC, we find that it gives us the following benefits that we wouldn't have if we just used the Land flap setting and did not introduce any BLC flow.

1. Increased lift on the wings.
2. A reduced airplane angle of attack on the approach and flare.
3. Increased stability by holding smooth stable flow past the empennage.
4. Increased aileron effectiveness by holding the wing flow straight back over the Land flaps and preventing flow separation over the wing.

To grasp this amazing airflow picture, I want to itemize each benefit so you can see how it makes up the composite flow pattern.

1. Increased lift: At the Land flap hinges, 17th stage bleed air from the engine, flows out of the BLC manifold over the upper surface of the Land flaps as I have sketched for you. This air has been translated from high pressure to a high velocity flow pattern. As you know from Bernoulli's theorem and the venturi effect I discussed with you in Section I, anytime we increase the velocity of flow in a continuous stream, the pressure goes down. And, by using your thinking helmet, you can see that the BLC flow develops a low pressure area all around the lower rear empennage section. The outer freestream flow (being of a higher pressure), then curves in all around the BLC flow pattern and this gives the venturi effect in this region of airflow. Therefore, as molecule B flows along in the freestream path above the wing, the flow field forces molecule B to curve down and adhere to the curvature of the Land flaps. Separated airflow then does not take place which would cause a decrease in lift.
2. A reduced airplane angle of attack: It follows that with the BLC flow holding over the wing, that if we did not have this flow, and separation occurred, we would be forced to fly at a higher angle of attack in order to obtain the lift required for the capability of approach speeds of 170 knots and a 145 knot touchdown speed.
3. Increased stability: This factor is probably the least understood and appreciated benefit of BLC airflow. If we did not have the BLC airflow and flew at the higher angles of attack with separated airflow over the wing, there would be a different flow path for molecules A and B. They would both become involved in the separated airflow behind the wing and then they would flow past the vertical stabilizer in a turbulent condition. This would decrease the vertical stabilizer efficiency and cause directional instability. This is the same effect of directional instability that develops in a subsonic lg stall approach that I explained to you on page 3 of SURE lecture 2. But, with BLC flow, molecule B is held in a smooth flow over the wing and so molecule A flows smoothly past the vertical stabilizer and therefore, a higher directional stability level is maintained for flare and touchdown.
4. Increased aileron effectiveness: Since the decreased pressure in the BLC flow pattern results in a three dimensional venturi flow effect around the aft section of the empennage, the spanwise flow over the wing has a less tendency to flow outward over the aileron and wash off the wing tip. Also if we did not have BLC flow, the same turbulent, separated airflow over the Land flaps would spread outward and this turbulent flow would cover the inboard portions of the ailerons. This is also proven by wind tunnel tests that show that aileron effectiveness is improved in our landing configuration with BLC airflow.

AILERON EFFECTIVENESS VS. LIFT COEFFICIENT



Touchdown

The touchdown of a landing is really only an outcome of the preparations that preceded this climactic point in your flight. Just like the French Chef and his intricate preparations before lighting the fire under his gastronomic masterpiece--without the proper mixture, the soufflé falls flat as crepe suzettes. If you've followed all the proper technique and procedures up to this point, the only thing between you and a smooth touchdown is the landing gear. And for you to have a rough touchdown in the F-104 calls for a hard landing on the verge of structural failure. Why do I say that? Because the design of the F-104 main landing gear is practically unique and one of a kind. It's designed to give you those landings that feel like you touched down on a bed of feathers. And to top it off, it's an extremely rugged and durable design.

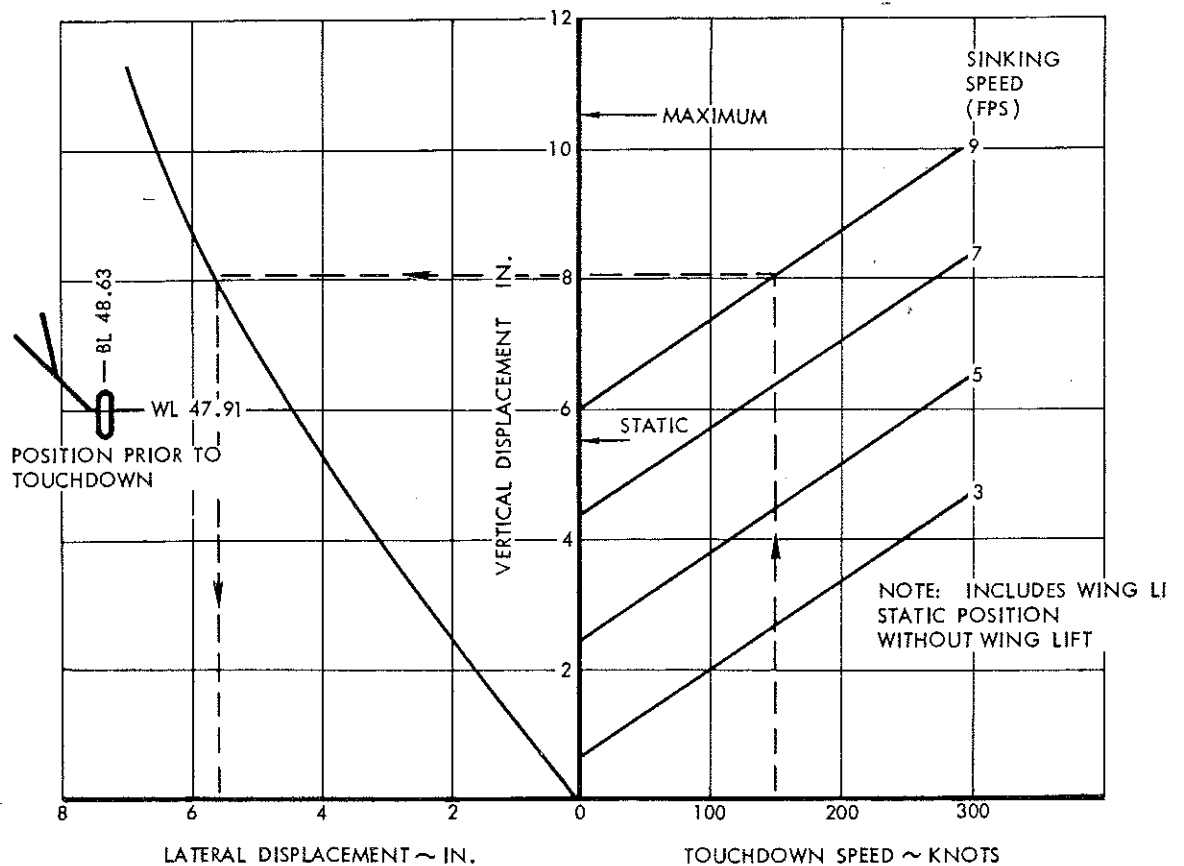
It all began in the initial design stage of the airplane when the main landing gear obviously could not go into the wings and had to be tucked into the belly of the fuselage. This dictated the cantilever suspended, forward folding design. What it means to us is an unusual main landing gear and, therefore, few pilots really understand its action on touchdown. If you've closely observed any touchdowns of the F-104, you should have noticed a main landing gear functioning in a completely different manner than on other fighters. With the main landing gear extended, prior to touchdown, the main wheels are hanging at a cocked-in position with the main landing gear legs hanging at a more acute angle from the fuselage than when the aircraft is sitting on the ground. At touchdown, a complex cycle of motions and loads occur. To analyze the touchdown, let's examine each part of the main landing gear and observe its cycle of operation.

1. Main wheels: At touchdown, the tires have to spin-up to the speed of rotation for rolling down the runway. If the aircraft skips back airborne, the wheels will now overspeed and then upon the second touchdown, the wheels will give a spin-back to the tires. As the aircraft weight settles down upon the wheels, they go through the motion of moving sideways--

"What!--SIDEWAYS?"

Sure--sideways, until they have accepted their full load of the aircraft weight. They actually oscillate back and forth in this sideways motion until stabilizing. During this time, the wheels are also translating from the cocked-in position, prior to the touchdown, to a vertical position as they accept their loads. And of course, the main wheels have to go through a vertical motion as the aircraft settles on the runway. To give you a better understanding of this main wheel motion, here is a plot from our Structures Group for you to study.

MAIN LANDING GEAR WHEEL MOVEMENT DURING LANDING TYPICAL



I've selected an example of a touchdown speed of 150 knots and an extremely hard touchdown sink rate of 9 feet per second. This results in an initial vertical wheel displacement of 8.1 inches and an initial lateral (sideways) movement of 5.5 inches. Then after stabilizing and as wing lift is lost, the wheel returns to the static position of 4.1 inches lateral displacement from the extended position.

2. Main landing gear legs: At touchdown, the ΔN force on the wheels gives a rearward force that tends to bend the leg back. The drag strut goes through an extension and then pulls the leg forward. So the initial spring-back becomes a spring forward. Depending on the type of touchdown, the legs may go through several cycles before stabilizing.

The main landing gear, of course, has been designed to accept loads well beyond any loads resulting from normal touchdown sink rates. The F-104G was designed to meet the following different load conditions.

Main Landing Gear Load (per side)

<u>Condition</u>	<u>Critical Gear Position</u>	<u>Vertical</u>	<u>Drag</u>	<u>Side</u>	<u>Load Factor</u>
Level landing 2 wheel spin-up	Extended	15210	7000	0	More than 1g
Level landing 2 wheel spin-back	Extended	15210	-5550	0	More than 1g
Drift landing	Extended	7610	0	4570 (outboard) 6090 (inboard)	More than 1g
Braked roll	Static	14380	7900	0	1g
Reverse braking	Static	14380	-11500	0	1g
Unsymmetrical braking	Static	10160	8130	±2440	1g
Taxi	Compressed	22450	0	0	2g

Note: In the extended position where landing loads are experienced, one pound of vertical load and one pound of side load are equal to 2.3 and 2.4 pounds respectively in the critical members.

From this table, you can see that the strength of the landing gear for vertical and side loads is essentially based upon the taxi condition (with 2g on the aircraft), which is the heaviest load that the main landing gear has to accept. The strength of the main landing gear for drag loads is essentially based upon the Reverse braking and 2-wheel Braked roll conditions. The sinking speed capability of the F-104G has been demonstrated to be 5 feet per second for any configuration involving pylon tanks, 5 feet per second for any configuration involving full tip tanks and 9 feet per second for any configuration involving empty tip tanks or no tip stores. If you exceed these sink rates-- you'd better go back and learn how to make a proper approach and flare-- or have your eyes checked for depth perception!

Roll-out

After all three landing gear are in contact with the runway, the nosewheel steering should be engaged and the drag chute deployed immediately. In Section I, I pointed out that Drag could be measured by the value of $C_D q S$. And since q is $1/2 \rho V^2$, you can see that the effect of the drag chute varies as the square of the deployment speed. For the greatest effect, then, it should be deployed as soon as possible but under the handbook limit of 180 knots. Upon deployment and full opening, the drag chute does have a twisting motion back and forth that causes slight yaw oscillations of the nose, but the nosewheel steering will easily control this yaw motion. Nosewheel steering should be used to maintain directional control throughout the roll-out.

This covers the various phases of a normal landing, but since we're limited to specific directions for approach, many times we're facing the problem of a crosswind landing. And this is really a tough nut to crack--so I want to belatedly tell you a story and offer my apologies.

Crosswind Landing

Many years ago, in the very first stage of F-104 flying, I had a long discussion about the main landing gear design with my boss, the Dean Emeritus of Test Pilots, A. W. "Tony" LeVier. At that time, we were flying without BLC and using only Takeoff flaps for landing. When we began trying to land in crosswinds, many of us experienced some bouncing back and forth on the main landing gear, and this did not set well with our professional pride. Finally, after this talk with Tony, I took an audacious step and experimented with a full crab approach and landing. The rest of my colleagues were dubious at first of my enthusiasm and reports of an effective, simple technique. One by one, though, they all agreed with me that the F-104 was a no-sweat bird in a crosswind landing. It was considered such a minor problem, we hardly even gave it a thought in writing up the first F-104A handbook. A few years later, when some of the operational types began encountering difficulty with crosswind landings, I attended a handbook review and attempted to institute a write-up recommending the crab approach and landing. After my speech, a Lt. Col. stood up and just like Hugh Hefner would say (if you tried to date a Playboy Club Bunny), he told me, "Sir--you just don't do things like that!" Beginning with that rebuff to this date, we at Lockheed have had little success in selling the crab method for crosswind landings in the Starfighter. I was even influenced by the Manuals people to the extent that on pages 38 and 39 of SURE lecture 4, I went along with them and advocated a combination of wing down and crab for crosswind landings. Also, I pulled a faux-paus and wrote down

one aerodynamic term when I meant to write down another term. A lulu of a boo-boo. No way out of it. On page 39 of SURE lecture 4, paragraph 2 should have read :

2. Sideslipping the aircraft is very effective but, unfortunately, the rudder will hold its effect only for a short time. Then, the directional stability of the long fuselage takes over and even with full rudder the aircraft will slowly straighten out and will not hold the sideslipped attitude.

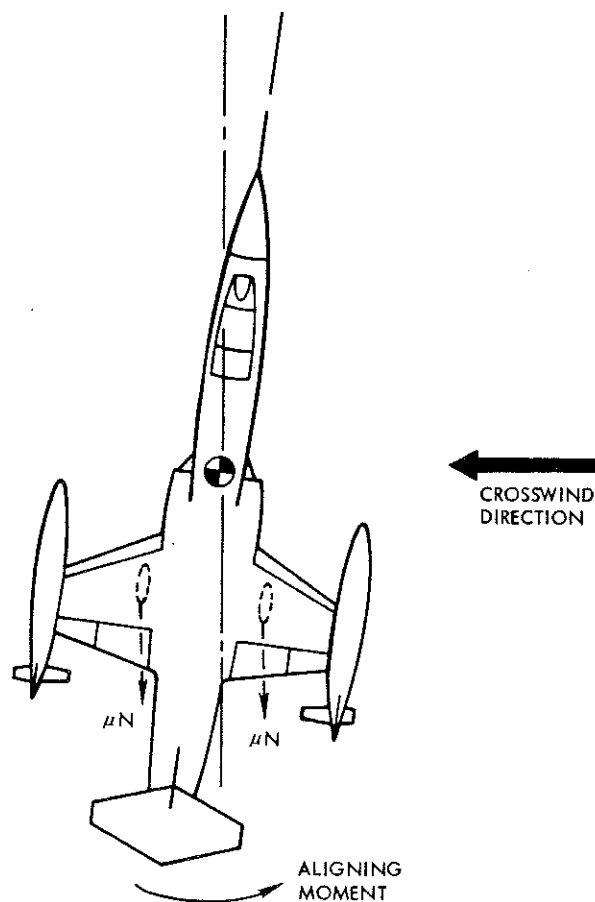
Sorry about that Ace, looks like you've got a drink at the club coming from the Snake. Anyway, maybe now you get my meaning. The combination or wingdown method is quite effective, and can be done by experienced pilots. Many F-104 jocks will still swear this method is adequate. But an easier way, believe me, is the full crab method with Takeoff flaps. Now before you fling this book down and disgustedly head for the 'Fridge' and another cold beer--just bear me out, because I have proof that those who've tried it are now real believers.

Anyone who reads Accident Review No. XIIA on page 38 of SURE lecture 4, cannot help but be impressed by the pilot's loss of control on his crosswind landing attempt. If this pilot had even suspected that he would have had that much difficulty, I'm sure he would have been willing to try a Takeoff flap, crabbed approach and landing. And this brings up the key danger of gusting, strong crosswinds. By the time you realize that your technique and method are inadequate--it's too late, because you've already lost control. If the runway is wide enough, you might stagger off in a go-around while mumbling some apt phrases to the Control Tower and Mobile Control. Too many pilots have wandered off the runway with the resulting damage to their aircraft. There's only one safe attitude to take when the situation arises where you must land in a crosswind. Since you face a possible loss of control, you should give yourself every possible advantage. And to me, that means Takeoff flaps and a crab landing. Now why do I shy away from Land flaps and BLC? Well, one very important limitation of BLC is the requirement of direct freestream airflow over the wings. All those "goodies" that we get with BLC on a normal landing were predicated on the proper freestream airflow of molecules A and B. In a strong crosswind, the degradation of BLC airflow works against us as I have explained on page 39 of SURE lecture 4. The only way to eliminate this unwanted

effect of BLC is to stop it by using Takeoff flaps. You're not hurting yourself at all because you'll fly the approach only 10 knots faster (190 vs. 180) for a 20 knot, 90 degree crosswind landing, and you'll gain added aileron effectiveness. In regard to the crab, it's the most natural way that the airplane wants to fly in a crosswind, so it will assume the crabbed attitude with no cross-controlling on your part. The controls will stay in the neutral position. It's an aerodynamic fact that the airplane wants to fly in a crab whenever it's subjected to a crosswind, so this is definitely the easy way to do it. If you hold this crabbed attitude right down to touchdown, you'll only have 6 1/2 degrees of crab at a touchdown speed of 170 knots. And then what happens? Well, I've already shown you the movement of the main wheels in a normal touchdown so the tires won't even know whether it's a crabbed touchdown or a straight ahead landing. They'll go through their sideways motion regardless. What about loads? OK--our table showed the loads for a drift landing which is the condition you encounter on touching down in a crab. Based upon the note about loads in the critical members--here's what they can take:

<u>Vertical</u>	<u>Side</u>
20,547 lb.	10,968 lb. (out board)
	14,616 lb. (inboard)

This is more than ample strength to handle the small loads of a crabbed touchdown. Directional control? As I've pointed out, the aircraft wants to maintain the crab attitude into the crosswind but a force sketch on our main wheels at touchdown shows that a moment is developed from the μN forces that wants to align the aircraft with the runway heading.

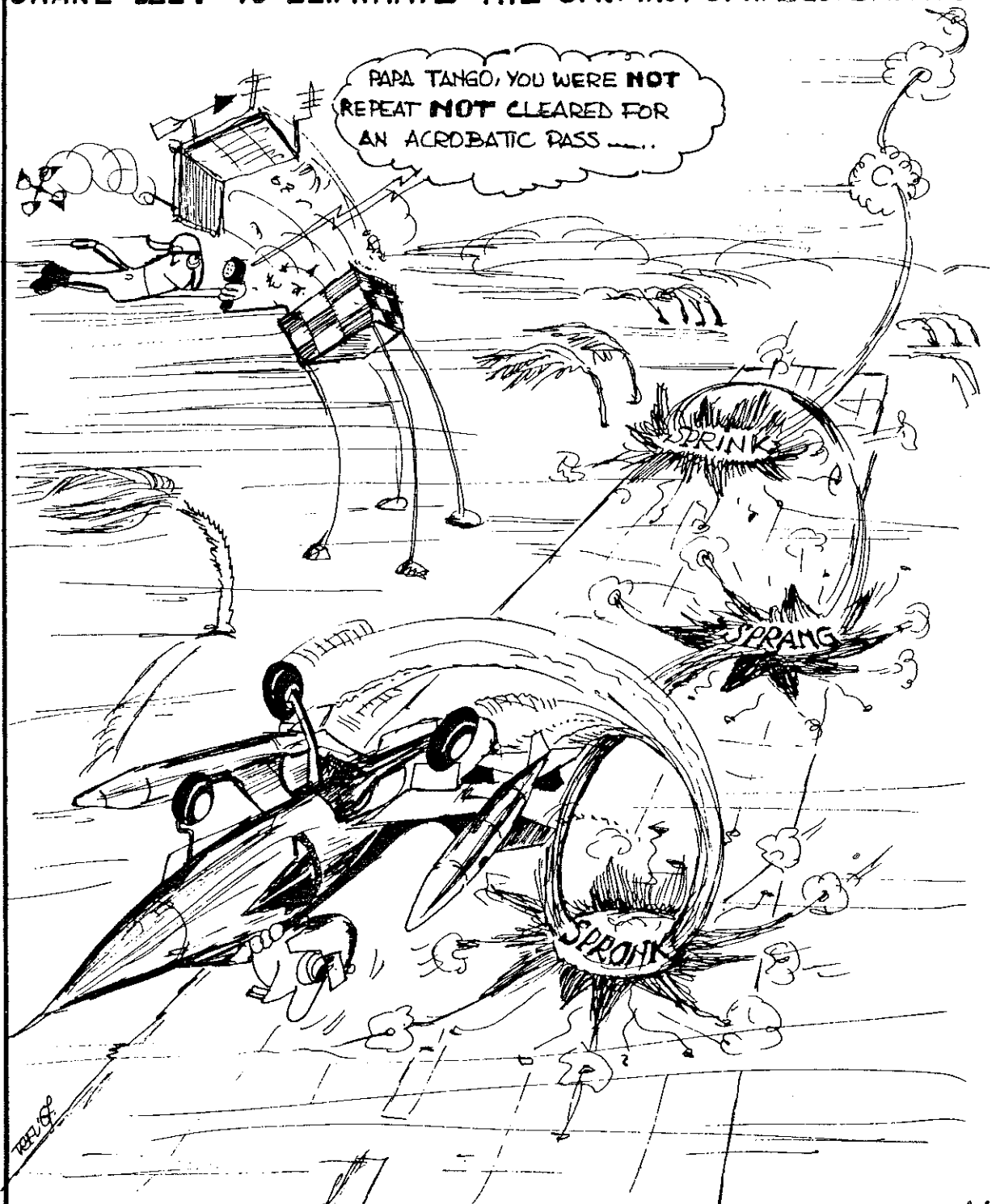


Relationship of forces acting on F-104 when touching down in a crab - prior to lowering nose gear.

From my experience in using this method, the two forces normally cancel each other so it's up to you to use rudder control to straighten out the aircraft, then lower the nose to the runway. As you put in rudder to straighten the aircraft, now come in with control stick and aileron into the crosswind, to prevent the upwind wing from rising. After the nosewheel is on the runway, make a positive engagement of the nosewheel steering for directional control during roll-out. From this point simply follow your recommended procedures.

During my years of SURE visits to operational bases, I have personally recommended this method and now there are many letters on file with overwhelming approval by those who have tried it. Why not you?

1 SNAKE SEZ: TO ELIMINATE THE "SPRINKS, SPRANGS, SPRONGS"



2 OF A CROSSWIND LANDING - JUST SET HER DOWN FLAT - IN A CRAB !!

SECTION VII

With your arrival at this Section, I must congratulate you as a hardy, inquisitive soul with a burning desire for learning everything it takes to become a fighter pilot in the F-104. No matter how long it took you or how much head scratching was involved, the main thing is that you've finished this lecture and I hope it's with a little more understanding of the airflow phenomena that affects your flight operations. And as a reward for your integrity and perserverance, I have a small surprise for you. Those molecules--A and B--just who are they? And why do they insist on flowing together through life on the turbulent, stormy and sometimes placid Sea of Air? Here's why:

