Walt Lounsbery

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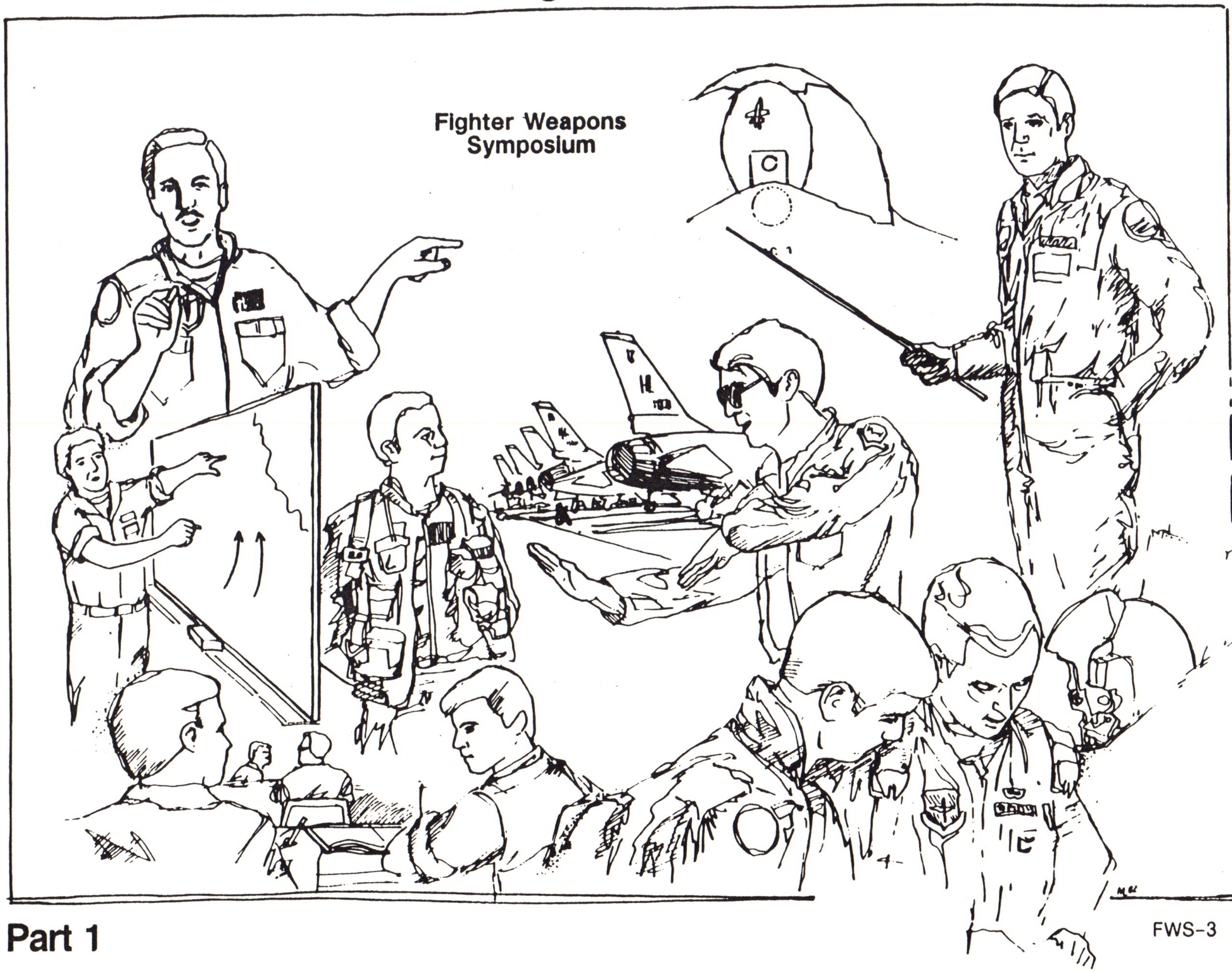
Teaching and Learning



Part 1

Teaching and Learning

- **Fighter Weapons Schools Prepare Their Graduates to Present Tactical Training Lectures in Their Squadrons and Commands**

- **Graduation from a Fighter Weapons School Is Generally a Prerequisite for Tactical Command in Most Air Forces**

- **Properly Presented Briefings Result in Higher Retention of Details and Good Morale in the Classroom**

- **Special Attention Must Be Given to These Areas:**
  - **Materials Preparation**
    - **Substantive Research**
    - **Medium, Articles, and Equipment**
  - **Location of Lecture (Course)**
  - **Timing of Lecture (Course)**
  - **Organization of Presentation**
  - **Techniques of Effective Communications**
  - **Training Aids, Facilities, and Equipment**

Teaching and Learning (Cont'd)

- A Fighter Weapons Syllabus Must Emphasize the Basics of Weapon System Utilization and Classical Tactics, but a Degree of Flexibility Must Be Maintained So that Changes in Threat and Tactical Doctrine Are Assimilated
  - Schools that Remain Rigid Havé Eventually Lost Credibility with Front Line Units and Ultimately Become an Extension of the Advanced Training Command
  - Accept the Fact that the "Flavor" of the Syllabus Becomes Personality Dependent, but "Substance" Usually Remains if It Is Current, Pertinent, and Tactically Correct
  - Schools that Have Become Saturated with too Senior, and Permanently Based Instructors Lose Their Appeal with Front Line Commanders. THE FIGHTER WEAPONS SYLLABUS SHOULD BE DIRECTED AT THE IMMEDIATE NEEDS OF THE FRONT LINE SQUADRONS
  - The Syllabus Must Be Tailored to the Capabilities of the Class, and Classes Should Be Formed by Personnel with Equivalent Experience Levels

Recognized Schools of Tactical Air Combat

US Navy Fighter Weapons School
Topgun
NAS Miramar, California 92145

USAF Fighter Weapons Center
57th Fighter Weapons Wing (FWW)
Nellis, AFB, Nevada 89191

USN Adversary Squadrons

VF-126	NAS Niramar, California
VA-125	NAS LeMoore, California
VF-43	NAS Oceana, Virginia
VF-45	NAS Key West, Florida

USAF Aggressor Squadrons (TFTAS)

64 TFTAS	Nellis AFB
65 TFTAS	Nellis AFB
527 TFTAS	RAF Bentwaters
26 TFTAS	Clark AFAB

USMC Fighter Weapons Center
MAWTS-1
Marine Air Weapons & Tactics Squadron 1
MCAS Yuma, Arizona

VMFT-
MCAS Yuma, Arizona

MAJOR EXERCISES AND COMPETITIONS

Red Flag	Nellis AFB
Maple Flag	Cold Lake CFB
William Tell	Tyndall AFB
Gunsmoke	Nellis AFB
Green Flag	Eglin AFB
Cope Thunder	Clark AFB
Red Star	RAF Bentwaters

NATO Tactical Air Meets (TAM)

Combat Commander's School (CCS)
Pakistan Air Force
Sargodha Air Base
Pakistan

Air Weapons & Combat Instructor's School
Royal Jordanian Air Force
Azraq Air Base
Jordan

ROCAF Air Tactics & Weapons School
Republic of China Air Force
Baitung Air Base
Taiwan

NATO Tactical Leadership Program
Jever Air Base
The Federal Republic of Germany

EURO/NATO Fighter Weapons Instructor Training (FWIT)
Belgium/Denmark/The Netherlands/Norway
Bi-Annual Fighter Weapons Course

Panther Squadron (Retired since 1983)
Israeli Air Force
Etiam Air Base
Sinai Region, Israel

Japanese Self Defense Air Forces
Aggressor Training Squadron
Nyudary Air Base, Japan

Teaching and Learning (Cont'd)

- **A Fighter Weapons Syllabus Will Vary According to Type of Aircraft and Mission Objectives**
  - (1) Graduate Level Air Combat and/or Intercept Tactics Instructor Course
  - (2) Aggressor/Adversary Pilot Training Course
  - (3) Squadron Air Combat Tactics Instructor Certification
  - (4) Combined Arms Weapons Instructor Course
  - (5) Squadron Pre-Development Upgrade and Operational Certification
  - (6) Large Scale Exercises Utilizing Realistic Scenarios
  - (7) Joint-Test Exercises of Various Scales
  - (8) Strike Planning and Weapons Employment Course

- **All of These Activities Expose Personnel to Realistic Threat Training Environments Which Include Demanding Flight Sorties, Resulting in a Stronger Pilot Capable of Leading Through Example. A Corresponding Comprehensive Ground School Helps to Prepare the Pilots to Teach and Participate in Tactics Development**

Teaching and Learning (Cont'd)

A. LECTURE PREPARATION:

1. Who Gives the Lecture?
    a. Willingness
    b. Experience
    c. Credibility
    d. Excellence
    e. Enthusiasm

2. Initial Preparation
    a. Use Varied Sources if Possible Both Classified & Unclassified; Current Data Counts
    b. Track Sources by Author and Subject – Be Alert to Follow-On Work
    c. Write It All Down
    d. Seek to Understand the Subject – Don't Just Read and Recite
    e. Every Subject that Would Be Utilized in a Fighter Weapons Syllabus Is Virtually a Science in Itself. Get to Know Contemporaries Who Deal in the Same Subject Areas & Stay in Touch
    f. Establish a Format Early that Will Absorb Changing and Accumulating Data
    g. Closely Supervise the Preparation of Graphics or Training Aids. What You Present, Directly Reflects on Your Credibility and Inspires or Exhausts Your Audience

3. "Murder-Board" the Finished Product with Your Peers ("Round-the-Table" Discussions)
    a. Dry Runs with Staff for Completeness and Correctness
    b. Don't Be Shocked if You Actually Are Good
    c. Tape Record and Critique Yourself
    d. Be as Demanding on Time Schedule as Management Insists Upon

4. Prior to Each Presentation:
    a. Dress to Impress, but Set the Mood
    b. Prepare the Facilities in Advance
    c. Have Back-Ups for Everything Mechanical if Possible
    d. Be Prepared to Do It All on a Blackboard
    e. Be as Formal as Necessary, Always Be Professional
    f. Never Start Late, Never Give Excuses

Teaching and Learning (Cont'd)

B. LOCATION OF PRESENTATION
   1. Squadron Operations Areas and Traditional Ready Room Facilities Are Not the Best Learning Areas
      a. Phone and Radio Interruptions
      b. Key Officers Are Always Interrupted
      c. General Lounge Atmosphere Inspires Sleep
      d. Wall Decorations Attract Wandering Eyes
   2. Dedicated Training Classrooms Are the Best
      a. Quiet, Well Lighted, with Minimum Interruptions
      b. Proper Seating and Acoustics
      c. All Facility Requirements for Visual Aids Available
      d. If Not Available . . . Change the Ready Room

C. TIMING OF THE LECTURE
   1. Avoid Having Meetings Scheduled During Briefing Periods
   2. Senior Officers Must Commit
   3. Start Early, End Early
   4. Beware After Lunch
   5. Don't Compete with Higher Priority Events
   6. Give Adequate Time for Questions
   7. Make Yourself Available Afterwards

D. ORGANIZATION OF THE PRESENTATION
   1. Lecture Must Be Vital and Necessary for All. Isolate Those from a Group that Do not Require the Training
   2. Physical Layout of Lecture Should Be Consistent with Others and Logical
      a. State Topic and Objectives
      b. Motivate by Indicating Value to Each Individual
   3. Avoid Apologies and Negativity

Teaching and Learning (Cont'd)

4. Body of the Lecture
    a. Logical Progression and Understandable
    b. Continuity
    c. Simple Yet Substance to the Degree Desired
    d. Avoid Confusion with Miscellaneous Unrelated Data
    e. Impress by Thoroughness, Depth of Knowledge, Sincerity and Enthusiasm
5. Conclusion Should Stand Alone as an Executive Summary
    a. Gives the Meaning and Purpose
    b. What Should Be Remembered in Summary
    c. Why It's Important
    d. Solicit Feedback

E. TECHNIQUES OF EFFECTIVE Communications

1. Be Prepared and Know Your Subject
2. Give Assurance to the Group that You Know the Subject
3. Be Physically Direct
    a. Posture
    b. Eye Contact
    c. Avoid Distracting Movements/Sounds
4. Don't Abuse the Dignity of the True Professional
    a. Avoid Out of Context Profane Language
    b. Tackiness in Training Aids is Unnecessary
    c. Convey Honesty and Sincerity
    d. Don't Lose Your "Cool" with Tough or Controversial Questions
5. Tolerance and Fairness Always
    a. Respect Individual Questions No Matter How Important They Do or Do Not Seem. Use the Question to Re-Emphasize Key Points of the Lecture
    b. Talk with Individuals, Not at Them
    c. There Are Only "Good" Things and "Other" Things

Teaching and Learning (Cont'd)

6. Voice Control
   a. Needs to Carry Meaning and Feeling
   b. Talk Loud Enough for Everyone to Hear
   c. Don't Trail-Off at the End of a Sentence
   d. Monotones Bore an Audience, Emphasize when Stressing a Point

7. Keep Your Sense of Humor But Do not Force It. If You Have Natural Humor Let It Flow So Other People Can Enjoy It

8. Don't Hide Your Enthusiasm. Generate Interest and Motivation Among the People You Are Lecturing. It Can Be Contagious

9. Lecturer Should Attentively Look For:
   a. Boredom: Can Be Detected through Continuous Moving Eye Contacts
   b. Puzzlement: Can Destroy Interest. Individual Could Be Confused, or You May Have Made an Error. Correct the Situation
   c. Approval/Disapproval: Can Be Recognized by the Nodding or Shaking the Head in a Positive/Negative Way
   d. Weariness: Is a Result of Excessive Sitting Time. Time Your Breaks so You Do not Exceed 50 Minutes at Any One Session. If Necessary, Split the Time

10. Strive to Be Extemporaneous: This Will Result if You Are Adequately Prepared. Practice Makes Perfect

    Don't read from notes unless you are emphasizing an exact quote

11. Avoid Annoying Mannerisms

Teaching and Learning (Cont'd)

F. TRAINING AIDS

1. The More Senses Brought to Bear on a Subject, the More Effective the Lecture. Movies to Illustrate the Performance of a Missile Will Improve the Importance of the Missile

2. Visual Aids Should Be Correct, Current, Colorful and Are Considered a Significant Part of Every Lecture

3. Function of Training Aids
   a. Makes for Easier Note Taking
   b. Stimulates the Senses
   c. Recollection Through the Use of Visuals Is Almost Four Times Better than Spoken Words
   d. They Supplement Your Own Discussion

4. Types of Training Aids
   a. Blackboards Are Good for Group Discussions
      - Use Quality Blackboards that Will Erase. If It Is of Poor Quality, Refinish It
      - Keep It Clean
      - Use Colored Chalk or Pens
      - Use Proper Lighting So It Can Be Seen
   b. Easel with Paper
      - Accessible
      - It Is Easy to Use
      - Use Colored Pencils or Markers
      - Good for Initial Attention Getter
      - Use the Most Current

Teaching and Learning (Cont'd)

d. Charts and Maps
- All Members Should Have a Copy for Reference
- Make Sure It Is the Graphic Needed. Should Not Have Excessive Information on It

e. Overhead Projector
- It Is Very Easy to Put Too Much on a Single Viewgraph
- Have Viewgraphs Prepared and in Order
- Do Not Spend Time in Class Making Viewgraphs
- Use Grease Pencil on Viewgraphs Only When It Makes a Point

f. Slides
- Most Professional and Most Popular
- They Are Easy to Store and Transport
- Numbers and Numerous Copies Cause Classified Control Problems
- Low Cost and Easy to Create

g. Models Are Excellent for Briefing and Debriefing
- Models Should All Be the Same Scale
- Keep Them in Good Repair
- Have Representative of All the Important Aircraft

h. VCR Video Machines and Displays
- Conversion of All Other Types – Just by "Filming" It with a Portable Camera
- Cut and Dub Very Easy and Imaginative
- Mix in Aircraft Video

Teaching and Learning (Cont'd)

G. SUMMARY

1. Utilize Creditable, Enthusiastic Individuals for Instructors and Given Them the Budget, Flexibility, and Time to Grow with Their Subject

2. Don't Overcorrect Personality Quirks. Everyone Knows Your Bad Habits and Expects to See Some of Them. Just Avoid the Most Distracting Items

3. Summarize Every Lecture Presented. Some People Only Recall What You Summarize

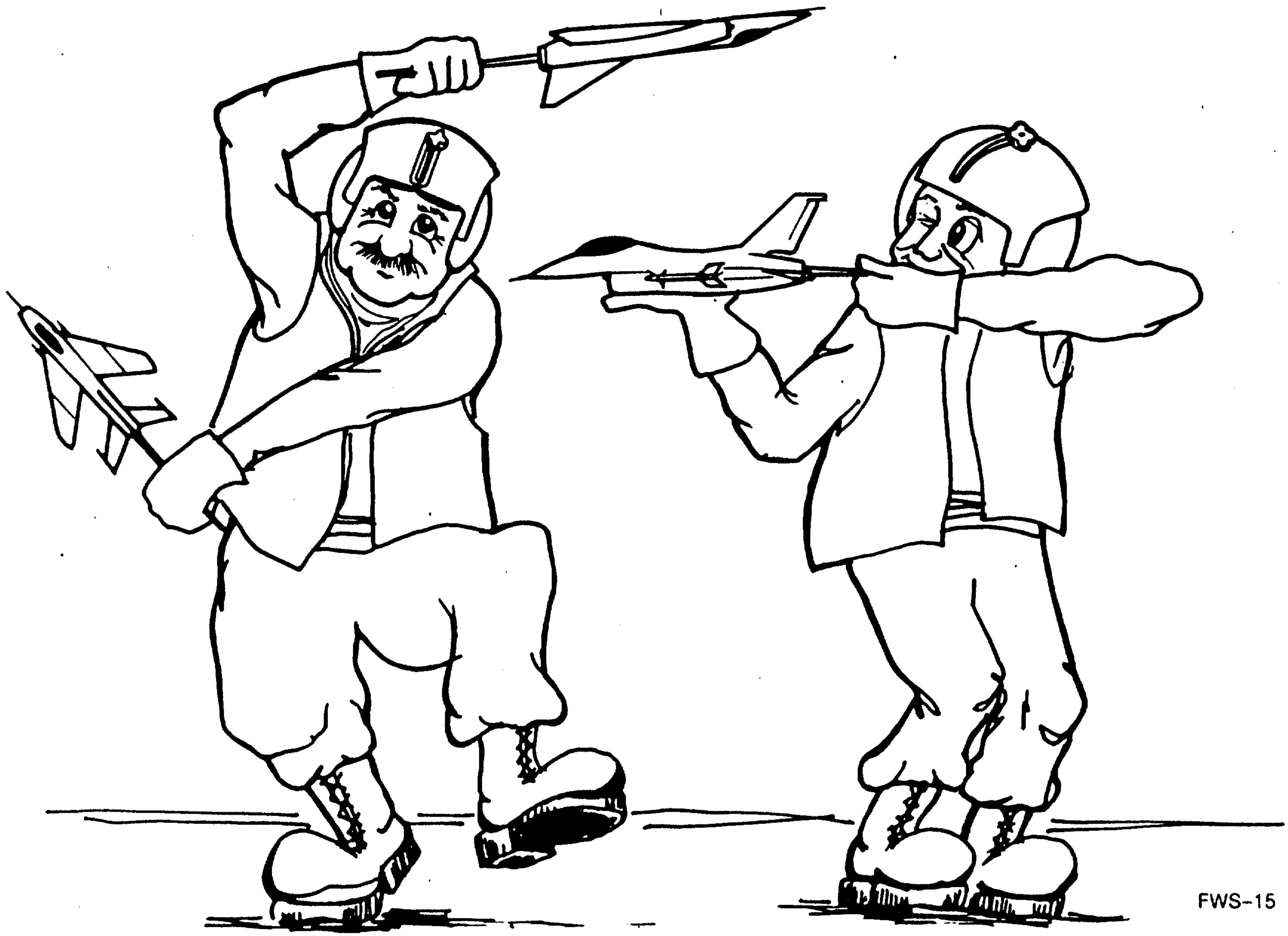
4. Training Aids Are the Most Valuable Tool for Mental Retention. Use Them! Slides and Viewgraphs Can Be Produced Using Simple Techniques and Your Imagination

5. Be Forceful When Necessary, Remember that as a Fighter Weapons Instructor You Represent the Information and Demonstration Link Between Updated and New Tactical Information. The Lives of Your Contemporaries Depend Upon How Well You Prepare, Fly, and Get Across Information

6. Always Strive for
   a. Newer Techniques
   b. Newer Information
   c. Peer Inputs
   d. Better Presentation

7. Never Be Satisfied with the Quality of Your Presentation

Briefing and Debriefing



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Part 2

Briefing and Debriefing

- Without Professional and Thorough Briefings and Debriefings It Will Be Hard to Improve Upon Individual or Squadron Capabilities. It Is Self-Evident that Repeated Mistakes, Both in Training and Combat, Result in Higher Loss Rates

- Commanders and Fighter Weapons Instructors Are Challenged to Inspire Professional and Standardized Briefing and Debriefing Procedures for All Flight Evolutions

- Air Combat Training Demands a Complex Style of Briefing and Debriefing. The Dynamics of Energy and Geometry Create Rapidly Changing Situations and Alternatives Which Affect the Pilot's Decision Processes

- Briefing and Debriefing Factors
  - Tools and Techniques of the Trade
  - Standardized Briefing Issues
  - Rules of Engagement
  - Situation Awareness
  - Remembering the Flight
  - ACM Analysis
  - Administrative Details
  - Coordination of All Players

Briefing and Debriefing (Cont'd)

A. TOOLS AND TECHNIQUES OF THE TRADE

1. Standard Operating Procedures (SOP):
   Every squadron has its own SOP that covers all administrative areas of flying operations such as man-up, preflight, start, taxi, join-up, recovery, non-tactical emergencies and lost systems. SOPs also reflect local area and base regulations as well as requirements imposed by higher authority. By following standard procedures, briefing times can be cut 10-20 minutes and allow longer time for tactics discussion

2. Briefing Guides:
   Are short yet precise guides that are tailored to the mission being flown and serve as an outline or checklist of those key areas required to be addressed. References to squadron SOP are used whenever it applies
   - Safety Items
   - Emergency of the Day
   - Departure, Out of Control Recovery
   - Weapons Arming and Checks
   - Communications

   } Covered in the Administrative Portion of Each Briefing

3. Rules of Engagement (ROE):
   ROEs are designed as standardized rules that maximize safety in realistic training environments; minimum altitudes, crossing distances, airspeeds, etc, are all adhered to rigidly by all participants. Some ROEs may be graduated due to participant skill levels but all members of each flight must review them prior to each evolution

4. Colored Chalk or Marking Pens:
   Inexpensive but extremely valuable for all briefs and debriefs. The use of one color on a complex flight debrief tends to be confusing and hard to follow

Briefing and Debriefing (Cont'd)

5. Blackboards

   Should be reserved for briefing and debriefing periods in designated areas. It is hard to debrief on a blackboard that is full of messages. Many squadrons now have the white formica variety that utilizes marking pens. The colors are bright but the pens dry out. It took 30 years to get enough chalk. Hopefully the pens will be properly stocked as a high consumption item.

6. Voice, Cine, and Video Recording Systems

   All new aircraft are being configured with on-board video/voice recording systems that provide at least radar/sensor and HUD replay with audio. But personal records utilized with gun camera film still serve as valuable training aid. Some pilots still carry personal recorders for continuous commentary during complex training evolutions, even when equipped with aircraft recorders.

   Advanced Flight Recording Systems have been developed that can be placed into a ground-based computer system, after the flight, and a full ACMI type debriefing activity can be created. Video/Voice, flight data off the central mux-bus, and sensor data all are being better utilized to provide a full range of mission debrief capabilities

Briefing and Debriefing (Cont'd)

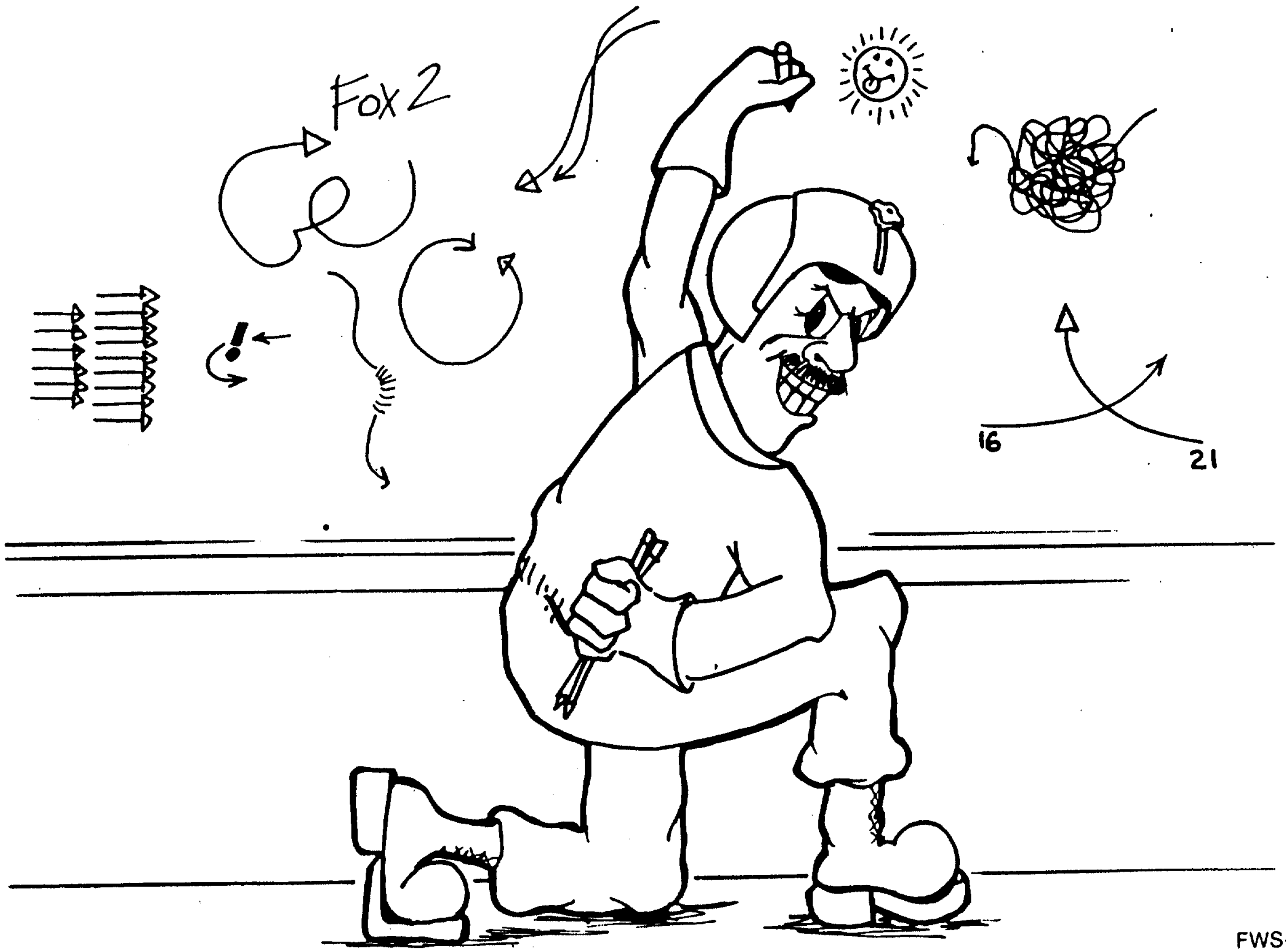
7. Symbology: To Avoid Confusion, a Standardized Set of Symbols Should Be Utilized

   a. Writing on the Board (General Suggestion)

      - It Is Best Graphically to Set the Board with North at the Top
      - Off to One Side Write the Line-Up of Participants in the Color That Will Represent Their Aircraft. In Complex Debriefs Utilize the Same Color for Each Flight for Flights or All Support Aircraft Such as Tankers or ECM
      - Draw One or Two Turns at a Time Avoiding Clutter Yet Discussing in Detail All Major Learning Points
      - Remember, There Are Only Good-Points and Other-Points, Be Constructive in Your Criticism
      - If You Are the First One to the Debrief Room Set Up the Board But Don't Draw Out the Entire Engagement, Wait for the Other Crews
      - Write Large,Neat, and Make Turns Realistic. Avoid Shrinking the Fight into a Small Area
      - Tabularize Lessons Learned and Shots Taken. Analyze Shots for Their Learning Merit. Under Most Training Conditions Kill-Removal Is Not Critical

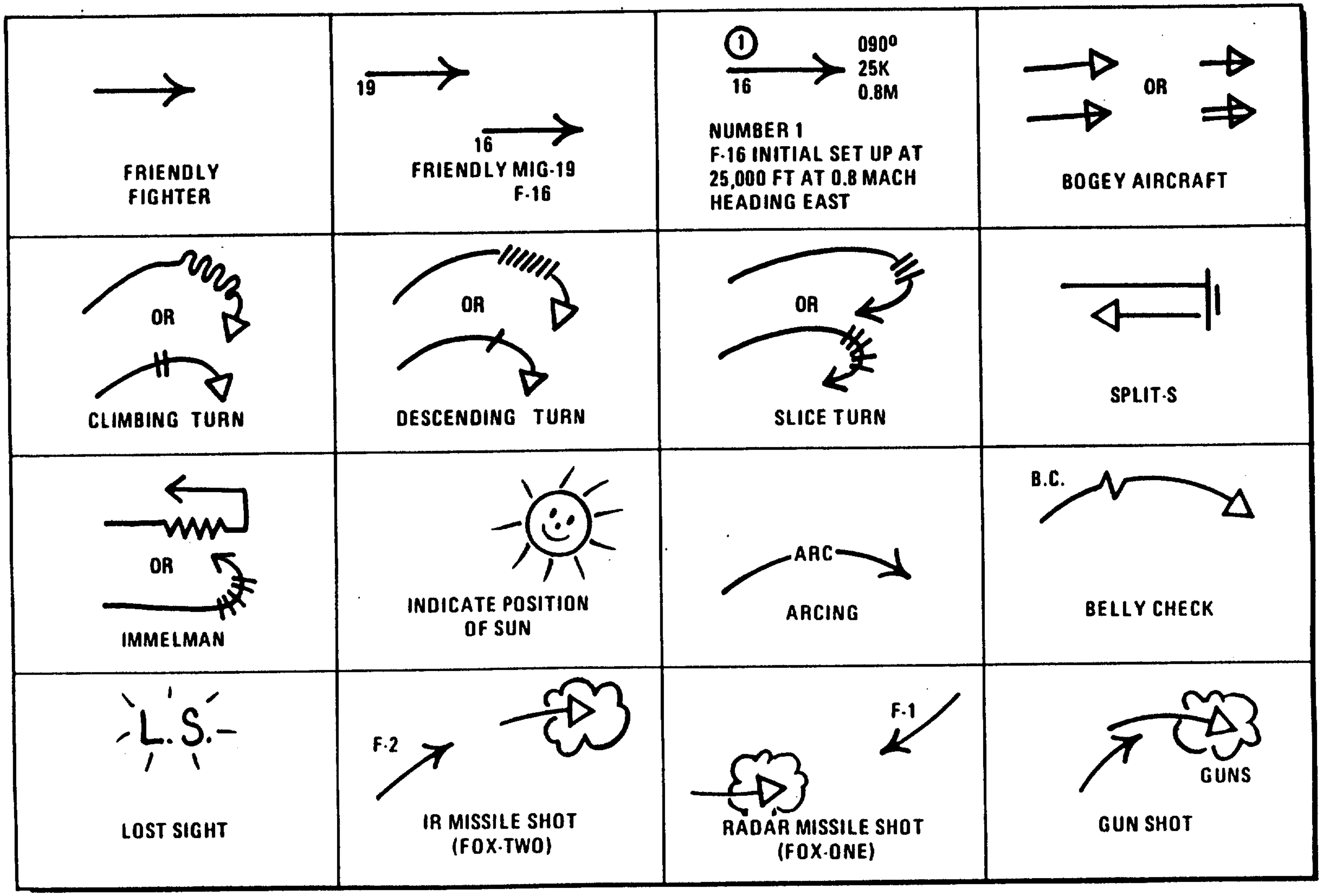
Briefing and Debriefing (Cont'd)

7. Symbology: To Avoid Confusion, a Standardized Set of Symbols Should Be Utilized Throughout All Squadrons

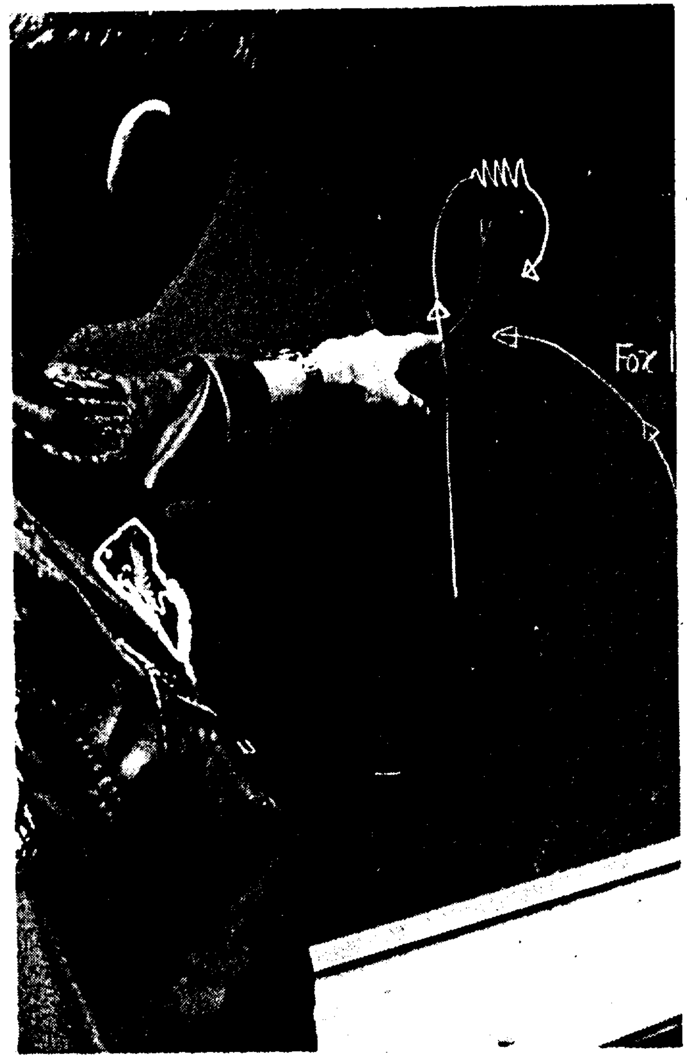


Briefing and Debriefing (Cont'd)

b. Some Recommended Symbology: Blackboard Represents a Top View



Briefing and Debriefing (Cont'd)



DO IT RIGHT!

Briefing and Debriefing (Cont'd)

C. ENGAGEMENT RECONSTRUCTION TECHNIQUES FROM COL HUGH MORELAND (USAF Retired)

(i) INTRODUCTION

After having sat through an Aggressor Debriefing or two, you may by now have wondered just how they are able to reconstruct an engagement as accurately as they do. If you think the basic instructor comes ready-equipped with an advanced Art Degree or possesses some cosmic drawing ability you are wrong; (face is few of them can even sign their names legibly!). Their ability with the chalk comes simply from a awareness of some basic techniques and practice - lots of practice. Given this, anyone can do it. The objective then of this discussion will be to present some of these techniques and show how they can be used to put together an engagement on the blackboard. Armed with these skills, the quality and accuracy of your debriefings should, hopefully, be improved.

(ii) RECORDING THE FLIGHT

Obviously, any good reconstruction requires that you have a fairly good idea of what happened out in the area between "Fights On" and "Knock-It-Off." Without this your diagrams will probably resemble a pile of spaghetti and prove to be a waste of chalk. The problem then is this; how do you record the events as they happen during an engagement and later transform them into a 2-dimensional drawing. If you have a photographic memory and total recall, this part is easy. Unfortunately, few of us have this ability and are forced to rely on some other means to do this; usually notes scribbled on the back of a lineup card or the tape recorder. Notes are fine but in the air they tend to be more of a distraction than they are worth. This leaves the tape recorder and VTR, which aside from an ACMI, are about the best tools available to capture an engagement for reconstruction purposes.

(iii) CARE AND FEEDING OF TAPE RECORDER AND VTR SYSTEM

The tape/VTR should be considered a piece of personal equipment and treated as such. Preflight it before you takeoff and make sure it works once you get in the cockpit. Every aircraft should have one or both on board in order to provide a backup in case of failures, (just because the mission is scheduled for the ACMI don't assume it is always going to be up and working). Once established in the working area, don't forget to turn them on before the engagement begins. This can be prevented by incorporating this step into your inbound and outbound check list. If you elect to do this, use cassettes with at least 20 min/side capacity so you don't have to worry about running out of tape.

Talk to the recorder in the air, when you can, but don't let it distract you from your ability to fly the aircraft. Remember, your primary duty in a fight is to kill your opponent, not gather data for the chalkboard. Without losing sight of this, there are, however, several places during an engagement where a few words directed at the recorder will payoff later on in the debriefing. Without question the first place occurs prior to the start of the engagement. Here its a good technique to "set the stage," by directing the start conditions: i.e. get down on tape your attack formation and the position of individual players, your initial heading, altitude, the position of the sun, cloud conditions, etc - basically anything you can think of which will assist you in establishing an accurate starting setup in the debrief. Accurate starts are essential to a good reconstruction.

Another good place to get some data on the tape is between engagements while you are setting up for the next flight. He you should try to recap in words as much of the fight as you can, as soon as you can. Besides recording the details, this drill tends to fix the events in your own memory banks a little better and makes them easier to recall later on.

Briefing and Debriefing (Cont'd)

(iii) CARE AND FEEDING OF TAPE RECORDER AND VTR SYSTEM (Cont'd)

During the actual engagement you'll probably have to rely, for the most part, on inter-fighter transmissions for reconstruction information. Concentrate on flying the machine and making good radio calls. You'll find that good concise directive and descriptive commentary will not only assist the conduct of the fight but will also help later on in its reconstruction. Practice and more practice will in time enable you to direct a word or two at the recorder during the fight describing significant events and making pertinent observations as they occur. The resulting "running commentary" can then be easily transformed into a two dimensional drawing during the debriefing. This does, however, take a lot of concentration and mental discipline to do properly. Remember, the bottom line is this: fly the airplane - first, last, and always - anything else is gravy.

After the mission take time to listen to your tape, even if it means delaying the debriefing by 5 to 10 minutes. By doing so you will have better control of the debrief and the reconstruction. Take some notes, if necessary, as you listen to it the first time through, but don't get hung up on the nits at this point. You are looking for a general overview of the fight to make sure your perception of what happened is as correct as possible. While doing this, it is advisable to jot down the engagement start and stop points on the footage indicator. This will save time and prevent delays searching for the engagement in the debriefing.

During the debriefing, limit the number of recorders being used to two; one from each side. Keep control of this. Human nature being what it is, people want everyone else to hear their tape. This is time consuming and often contributes little to the objective at hand. As a flight lead perhaps the best technique is to use your tape for the initial construction then play the other side for clarification, if necessary. Beware of people sitting at the table with a recorder glued to their ear - they are not listening. Stop the debrief until they give you their full attention.

Briefing and Debriefing (Cont'd)

(iii) CARE AND FEEDING OF TAPE RECORDER AND VTR SYSTEM (Cont'd)

Perhaps the best way to use the recorder in the actual reconstruction is to play the tape up to a significant event, turn it off, draw the engagement up to that point, debrief it, then start the recorder again; playing, and reconstructing the entire engagement in segments. This will also help maintain the continuity of the debriefing.

(iv) ROE AND BASIC SYMBOLOGY SUGGESTIONS

Before leaping off into your first 4v4 dissimilar reconstruction using both hands and eight different colors of chalk, lets first of all establish some basic ROE and blackboard symbology. The following is by no means the best or most complete listing available, but the concepts they present will get you started in the right direction.

- ROE

A. North Always Lies at the Top of the Blackboard

The quickest way to get your flight members out of their chairs is to start a North/South engagement by orienting it East/West on the blackboard. (If they're still upright after the first turn, get your eyes checked! You've stumbled into the wrong briefing room.)

B. Assign Each Aircraft a Different Color

Doing so will result in a more understandable drawing. Be consistent with these colors throughout the reconstruction. Changing colors in midstream is confusing. (Note: In complex multisection engagements, the preferred solution is to assign each Two Ship A single color to simplify the drawing.)

Briefing and Debriefing (Cont'd)

(iv) ROE AND BASIC SYMBOLOGY SUGGESTIONS (Cont'd)

C. Be Humble

Folks are much more receptive to a tactful approach versus an exercise in humiliation. Most people will recognize when they've had their brains gunned out and don't need reminding.

D. Say Something Nice About the Opposition

If they did nothing right except show up in the area - say so. It will tend to put them in a better frame of mind for what else you have to say.

E. Be Honest

If you porked it, say so. It is as much a learning experience for the debriefer as the debriefee, and should be treated as such. Your credibility is at stake, so don't blow it.

• RECONSTRUCTION SYMBOLOGY

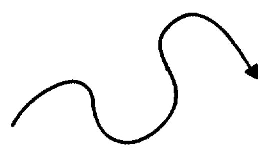
A. Aircraft

Close attention should be given to the size and shape of the aircraft symbol you are planning to use in your diagrams. Generally speaking, a small tapered arrowhead is much more manageable than a large shovel shaped wedge. Big wedges are like big airplane - they are as clumsy on the blackboard as they are in the air.

Briefing and Debriefing (Cont'd)

B. Flight Paths

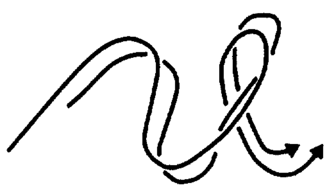
The basic flight path depiction should be a smooth, continuous flowing line, drawn in a deliberate, positive manner.



GOOD

BAD

Where flight paths cross each other, its good technique to leave a break in the line. This will deconflict the diagram and prevent it from becoming a tangle of worms.



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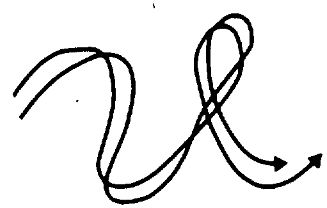
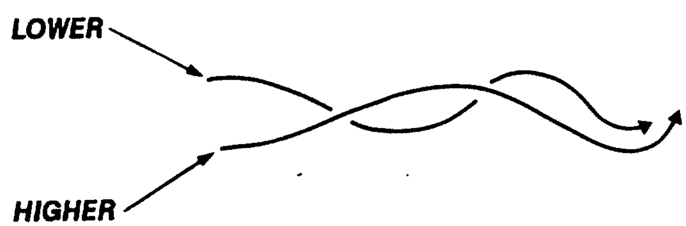


BAD

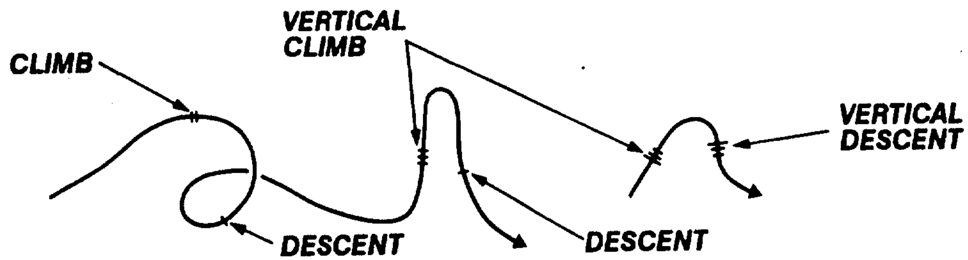
Since an engagement reconstruction is a planform view of the fight from above, the "breaks" and "solid" flight path segments can also be used to denote which aircraft is higher or lower than the other: i.e. the solid line is higher than the flight path with the break in it.



Briefing and Debriefing (Cont'd)

B. Flight Paths (Cont'd)

The effect of comparative height can be further stressed by the addition of hash marks on the flight path line. A single mark can mean either "low" or a "descent," whereas a double has denotes "high" for a "climb." Three marks are used to depict a vertical climb. Regardless of which technique or combination of techniques you elect to use in the drawing, it always good to emphasize the positions of the aircraft with your hands to breath some 3-dimensional life into your 2-dimensional picture.



Individual Flight Paths should also be representative of each aircraft's airspeed and turn capability.

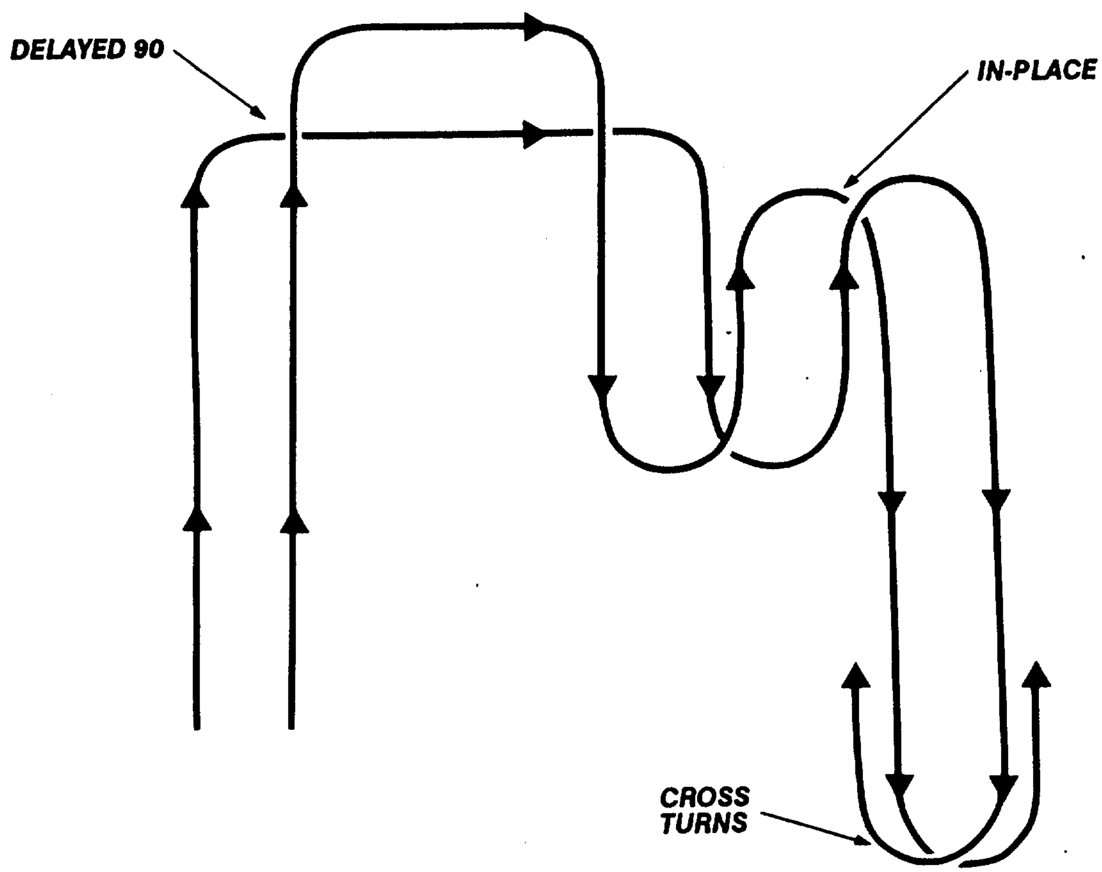
In any reconstruction, you must keep in mind that the position of the aircraft on their individual flight paths identify a specific point in time for each of those aircraft. Therefore, each A/C symbol on a given flight path line should have a corresponding A/C symbol on all of the other lines indicating simultaneous time positions. It follows then that the total number of A/C symbols should be the same on all fight paths. Pay attention to this. Extra uncorrelated aircraft tend to muddy the water and make the drawing more difficult to understand.

Briefing and Debriefing (Cont'd)

C. Miscellaneous Symbology

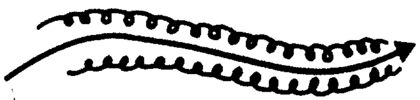
The usage of the following symbols and drawing techniques is by no means mandatory, but they can be used to add detail to your reconstructions.

(1) Tactical Turns



Briefing and Debriefing (Cont'd)

(2) Other

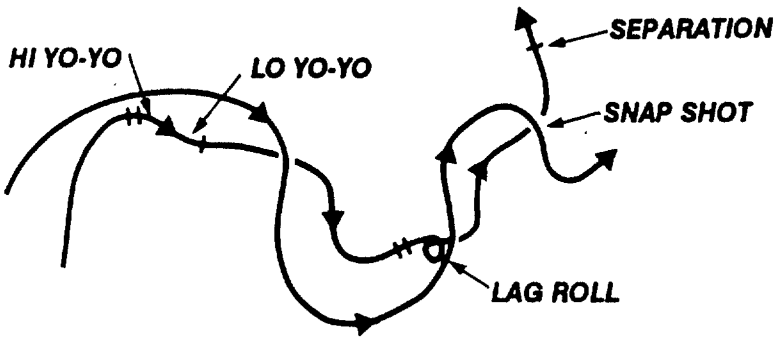


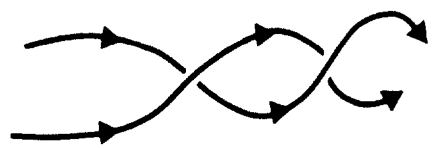
CONTRAILS

CHAFF

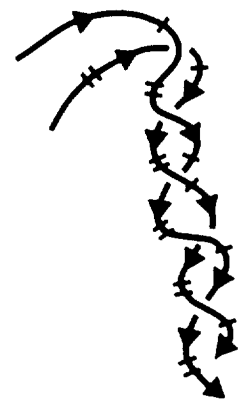
RADAR LOCK/CONTACT

AILERON ROLL

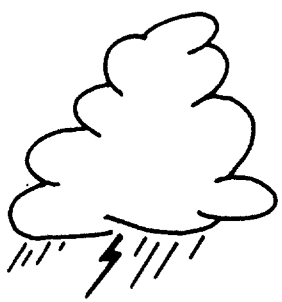




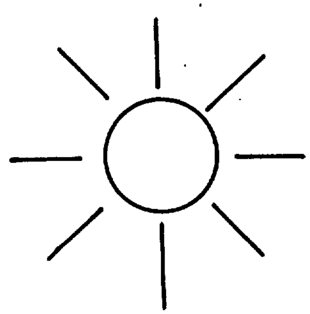
FLAT SCISSORS



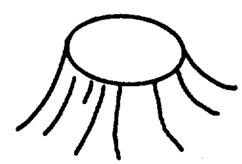
VERTICAL ROLLING SCISSORS



CLOUDS



SUN



MESA/MOUNTAINS

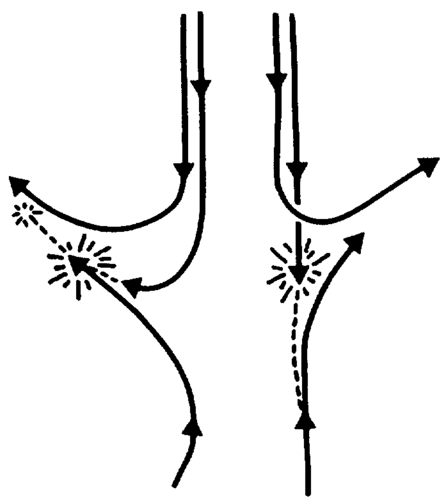
Briefing and Debriefing (Cont'd)

D. Putting It Together

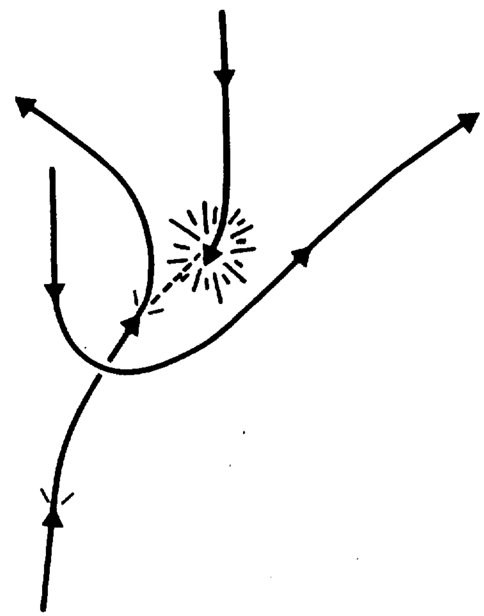
With the foregoing basis in mind let's now take a look at how to go about reconstructing a full blown air-to-air engagement.

For the sake of continuity its a good idea to develop the drawing in sequences until the entire engagement is on the board. This will result in a more logical depiction and serve as a point of reference for summarization purposes at the end. In order to accomplish this its necessary to do two things before starting:

(1) Take a look at the length of the fight and the number of players involved. This will determine the scale and proportion to be used without overloading the available chalkboard area. (Obviously a 2v4 will require a smaller scale than a 2v1.)



2V4



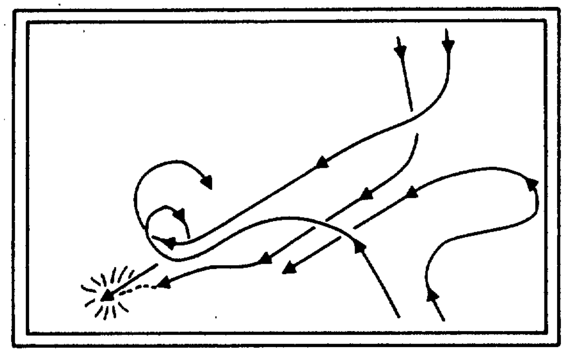
2V1

Briefing and Debriefing (Cont'd)

D. Putting It Together (Cont'd)

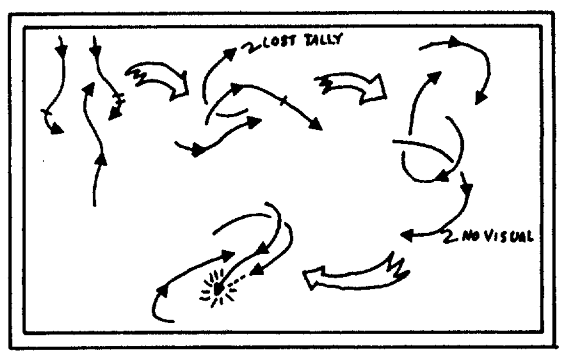
(2) Select a start point on the chalkboard based on the directional flow of the engagement – i.e. did the fight go in a specific direction after the merge or did it become more or less stationary. If it continued to move, choose a start point which will accommodate the entire fight without running off the edge of the board.

RIGHT-TO-LEFT FLOW



If the fight does become stationary you might as well start in the upper left hand corner of the board and lay it out sequentially to the right (*NOTE: Do not stack the engagement sequences on top of each other. When the picture starts to become cluttered its time to start over with a new sequence.*

STATIONARY FIGHT



**(Notes made directly on the diagram as it is developed will also help you to summarize the fight at the end.)*

Briefing and Debriefing (Cont'd)

Summary

In sort, the amount of detail which goes into the reconstruction should be determined by the objective of each mission. For example, a 1v1 BFM sortie involving an new inexperienced pilot should demand close attention to every twist and turn, whereas a continuation training hop involving two experienced pilots may not. Similarly, the emphasis in a tactical mission involving multiple players should be on the effectiveness of game plans and the relative position of opposing players instead of agonizing over each and every "flick and blend." The bottom line then to any reconstruction is this: How much detail is required to adequately determine whether or not the learning objectives spelled out in the briefing were accomplished. If these objectives were not accomplished, your depiction should show why not. Anything less is short changing your flight in terms of training.

Briefing and Debriefing (Cont'd)

8. Kneeboards:

   There are many light and usable styles of kneeboards available. Two of the major factors when considering kneeboards are that they have a hard back surface on which to write, and a velcro patch for a pencil. It is a good idea to tie a string from the kneeboard to the pencil. It also helps to develop your own shorthand. Tape recorders and VTRs, even though they are very helpful, should never preclude the extensive use of kneeboard notes or pre-written cards. Short notes become invaluable at the debrief.

9. Models:

   Can be much more than just debriefing tools, particularly if all the models are of the same scale. The 1/72 scale models are good because they are readily available and inexpensive. You should ensure your squadron has at least one model of each type of aircraft you may encounter. They should be placed firmly on sticks and hung up to keep them in workable condition. In addition a "repair/maintenance" officer should be appointed and given all spare parts to ensure they stay in an up status. Since all models are of the same scale and very accurate, you can readily see such things as relative size or, if no pictures exist of new aircraft (such as MIG 23 Variants, MIG 27, etc) you can compare them to other models for size and special recognition features, new paint schemes can be tried; and lastly, range and size estimations can be made.

   1/72 = 1 Inch = 6 Feet (1cm = 0.72m)
   1 Foot = 72 Feet (1m = 720m)
   14 Feet = 1000 Feet or a F-5 or MIG in Gun Range
   42 Feet = 3000 Feet or a Bogey at 1/2 Mile

   You can move models around at those distances and see what different aircraft look like, nose on, planform, etc.

Briefing and Debriefing (Cont'd)

10. Air Combat Maneuvering Ranges

a. Air Combat Instrumented Ranges with Real Time Tracking Systems for Reasonable Numbers of Aircraft Have Been Available for the Last Decade. Today These Ranges Are Located in Almost All Countries Serving Numerous Air Forces
- Range Tracking System
- Debriefing Subsystems and Facilities
- Pod Carried on Aircraft

b. Many Features Have Been Added to These Ranges Which Have Benefited Aircrew Debriefing Quality, Safety, and Data Reduction for Long Term Analysis

c. Future Improvements Are Focused on –
- Extended Range Size, Shape, and Active Players
- Incorporating Surface-to-Air Threats in the Range Area
- Create Missile Fly-Out Capability, with Kill Removal, for SAM and Air Launched Missiles

d. Adapt Flight Recording Systems for Non-Range-Dependent Debriefing Tools with Similar Capabilities Except for Real Time Play for Range Control

Briefing and Debriefing (Cont'd)

B. ATTITUDE;

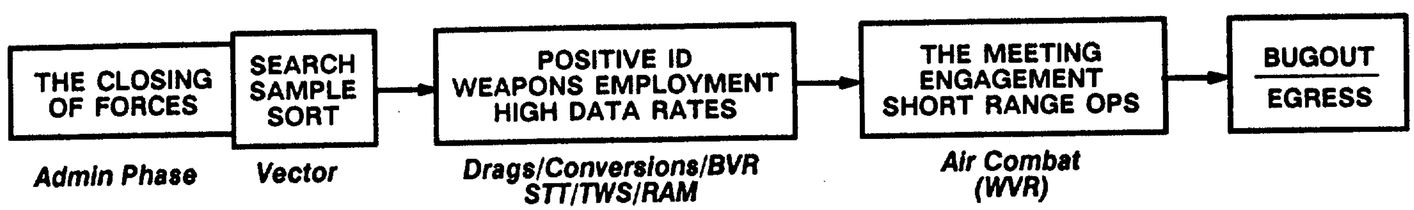
Professional and upbeat at all times, especially during periods of national crisis when great demand is placed on readiness. Be positive and do the best you can.

C. COURSE OBJECTIVES:

There are overall course objectives that are based on a building block approach. The so-called "learning curve" in a Fighter Weapons School environment must be sharp. Flights and academics must rapidly achieve advanced levels in order to maximize the time allotted.

D. OTHER BRIEFING ISSUES:

1. Cockpit Switchology
2. Intercept Tactics/GCI Controller Interface
3. Initial Moves
4. Communications Management and Countermeasures Plan
5. Missile and Gun Envelopes
6. Lessons Learned on Previous Missions
7. Bugout Criteria and Tactics
8. Never Be Satisfied with "Well, in the Real-World I Wouldn't Have Done That."
   You Fight Like You Train, So Train Like You Fight.



Briefing and Debriefing (Cont'd)

E. SPECIFIC DEBRIEFING CONSIDERATIONS:

1. Where:
   Quiet place, with blackboard, models, VTR or gun camera display, and debriefing system

2. When:
   Immediately after hop. No errands except maintenance debrief

3. Attitude:
   Professional and positive learning attitude. Every participant should be there, ideally including the GCI controller. Make learning points, criticize only to the degree justified by experience level

4. Philosophy:
   How and why, not who. "(My wingman shot your wingman before he shot me and I shot you before you shot him, therefore we won" . . . End of Debrief!) Search for the reasons, not the individuals

5. Style:
   Tactful. Be positive and constructive. If you antagonize the flight they will neither be receptive nor actively participate in the debrief

6. Something New:
   Carefully and thoroughly analyze any surprises, determine tactical significance and applications

Briefing and Debriefing (Cont'd)

7. What's Important
   a. Breakdown in Game Plan
   b. Loss of Mutual Support
   c. Loss of Situation Awareness
   d. Shots
      - Envelope Determination on Kills
      - Launch Rule of Thumb
      - ROE Requirments: Min/Max
      - Heart of Envelope Scoring
      - Necessary-Unnecessary Backup Shots
      - Mechanization Verification
   e. F-Pole Analysis
      - Drags
      - ECM
      - Time-of-Flight/Time-to-Kill
      - Kill Removal
      - Flight Coordination
   f. Command and Control Contribution
      - During BVR/WVR Periods
      - Help/Hinder SA
      - Identification of Target

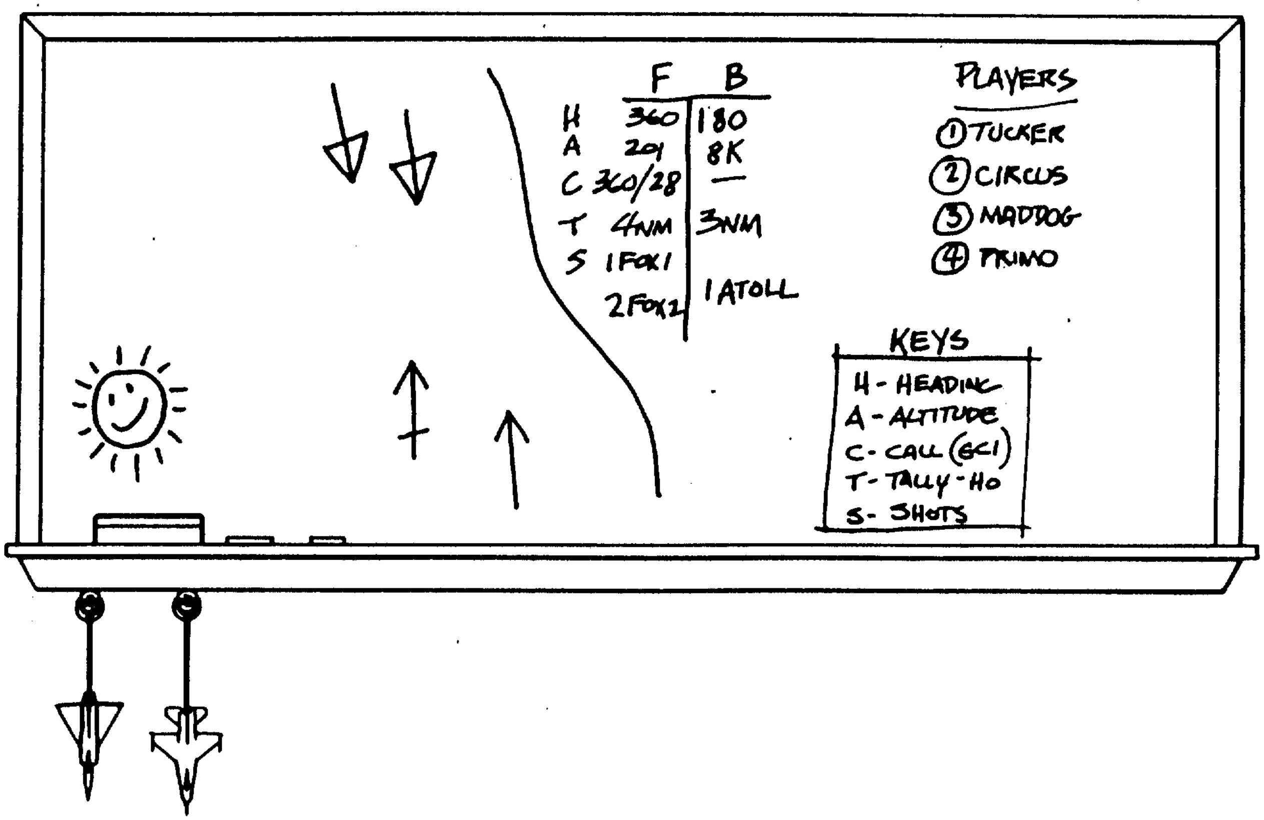
Briefing and Debriefing (Cont'd)

F. CONDUCT OF THE DEBRIEF:

1. Do not Draw the Entire Flight on the Board, Rather Step Through It Point by Point While Everyone Is Present

2. Set the Blackboard Up, i.e., North, Players, and HACTS. It Should Look Like This:

SUGGESTED FORMAT



Briefing and Debriefing (Cont'd)

3. Have the Ground or Airborne Controller Brief What He Saw, Why He Made the Calls He Did (Formations, Altitude, Etc)

4. Eyeball Pilot Brief the VID/Intercept
   a. Prebriefed Plan
   b. Actual Positions on Run-In
   c. UHF/ICS
   e. Problem Areas
   f. The Pass

5. Engaged Pilots Should Take Over at Tally-Ho
   a. Engaged Plan
   b. Engaged UHF/ICS/GCI (Listen to Tape)
   c. Energy – Kts
   d. Pressure on the Bogey
   e. Shots – Type and Quality (Continue or Not)
   f. Shots Called on You, Defensive Reaction
   g. Bugout

MEASURES OF MERIT
- *Unnecessary and Necessary Back-Up Shots*
- *Breakdown of Mutual Support*
- *Breakdown of Situation Awareness*
- *Weapons Opportunities*
- *Time-to-Kill*
- *Heart-of-the-Envelope Employment*
- *Advantage vs Disadvantage Time*

6. As Flight Lead:
   a. Encourage Group Participation
   b. Solicit Opinions (Especially from Junior or Silent Members and Controllers)
   c. Acknowledge Good Moves/Calls (Everyone Likes Pate on the Back) – Debriefing Is Not Just Pointing Out Bad Things but Reinforcing Good Things
   d. Don't Ever "Fake It." You're not Expected to Remember Every Turn of Every Flight
   e. Admit Your Own Mistakes (It Shows that You Are Human and Creates an Open Atmosphere)
   f. Leave No Misunderstanding Unclarified

Briefing and Debriefing (Cont'd)

G. REMEMBERING THE FIGHT

1. Kneeboard Is the Best Method in Coordination with Everything Else

2. Try to Use Only One Card Per Engagement

3. Set Card Up Prior to Man-Up, Usually at Briefing

4. Work to Recall Key Points, Tactical Issues, and Measures of Merit
   a. Wingman's Formation and Positioning During Intercept, and VID
   b. Initial Tally and First Pass
   c. Validity of Shots
   d. Effectiveness of Bugout
   e. Highlights of Interest

5. Write Down What You Remember on the Way Back to Station or the Next Set-Up. Do not Return at 450 Kts Etc., Zoom Up, Set a Cruise Setting, Take a Breath, Coordinate with Your Wingman and Flight Members, Write Down as Much as You Can Remember, Talk into "the Tape" (yours or the VTR),Then Get Your Next Engagement Card Do not Waste Time Getting Things Done, but Don't Rush So Much that Nothing Gets Done.

6. Make the Use of the Tape Recorder and VTR a Part of Your Hot-Vector and/or Combat Checklist. On the Deck Review the Tape to Refresh Your Memory and Fill in the Gaps for the Debrief. Choose the Places on the Tape Where You Need to Make a Point. Remember the "Good" and "Other" Approach. After Three Points Its Worth a Refly, Don't Loose the Value of the Moment. After the Debrief then if There Is Time Review the Entire Tape Under a More Casual Atmosphere

Briefing and Debriefing (Cont'd)

H. SOME INSIGHTS ON ACM ANALYSIS:

1. We Are Not Human Air Combat Ranges. Reconstructing the Fight for Reconstruction Sake Is Worthless. They Key Is to Identify and Correct Deficiencies and Be Able to Suggest Alternate Moves. Recognize Weak and Strong Points

2. Use the "Good"/"Other" Method to Earmark Strengths and Weaknesses. A Log Should Be Kept by Each Individual of His "Goods" and "Others" to Establish Trends. Remember, ACM Is not Learned in a Day. Only One or Two "Other" Points Should Be Stressed to Be Improved Upon for the Next Sortie Vice 10 or 15 Items Which Is Just Too Many to Try and Correct at One Time

3. Situation Awareness (SA), that Is the Capability to Recreate in Your Mind the Events and Nature of the Flight, Is a Skill that Requires Many Flights and Fights to Develop and Daily Sorties to Keep Proficient

   Effectively Improving the Performance of a Student/Wingman Demands Superior SA, Professionalism and Leadership

4. The Trademark of Any Fighter Weapons Graduate Is Superb, Professional Flying Skills and Being the Best Briefer and Debriefer in the Squadron. Always Strive to Improve and Motivate

Mission Management

Part 3

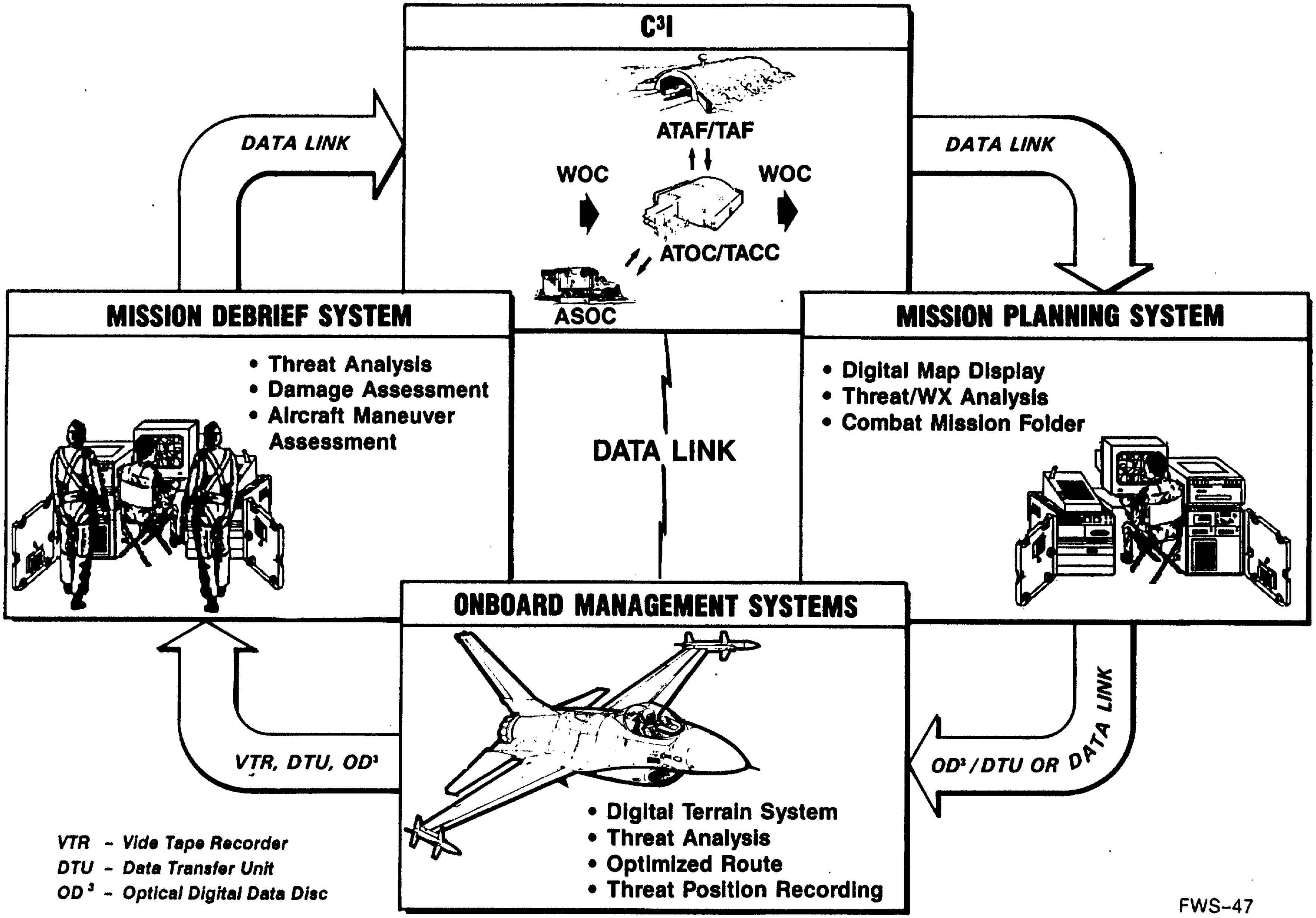
Mission Management Definition

- The Integration and Correlation of Information with Flight Planning, from Initial Tasking Through Debrief, to Provide a Greater Probability of Mission Success and Survival

- It Is Increasingly Obvious that Accurate and Timely Mission Planning Positively Enhances Survivability and Mission Success

. . . It Simply Means Being at the Right Place at the Right Time with the Right Stuff

Mission Management



VTR - Vide Tape Recorder
DTU - Data Transfer Unit
OD3 - Optical Digital Data Disc

FWS-47

The Reason for Mission Management

THREATS

- Mobile
- Accurate
- Lethal
- Fortressing

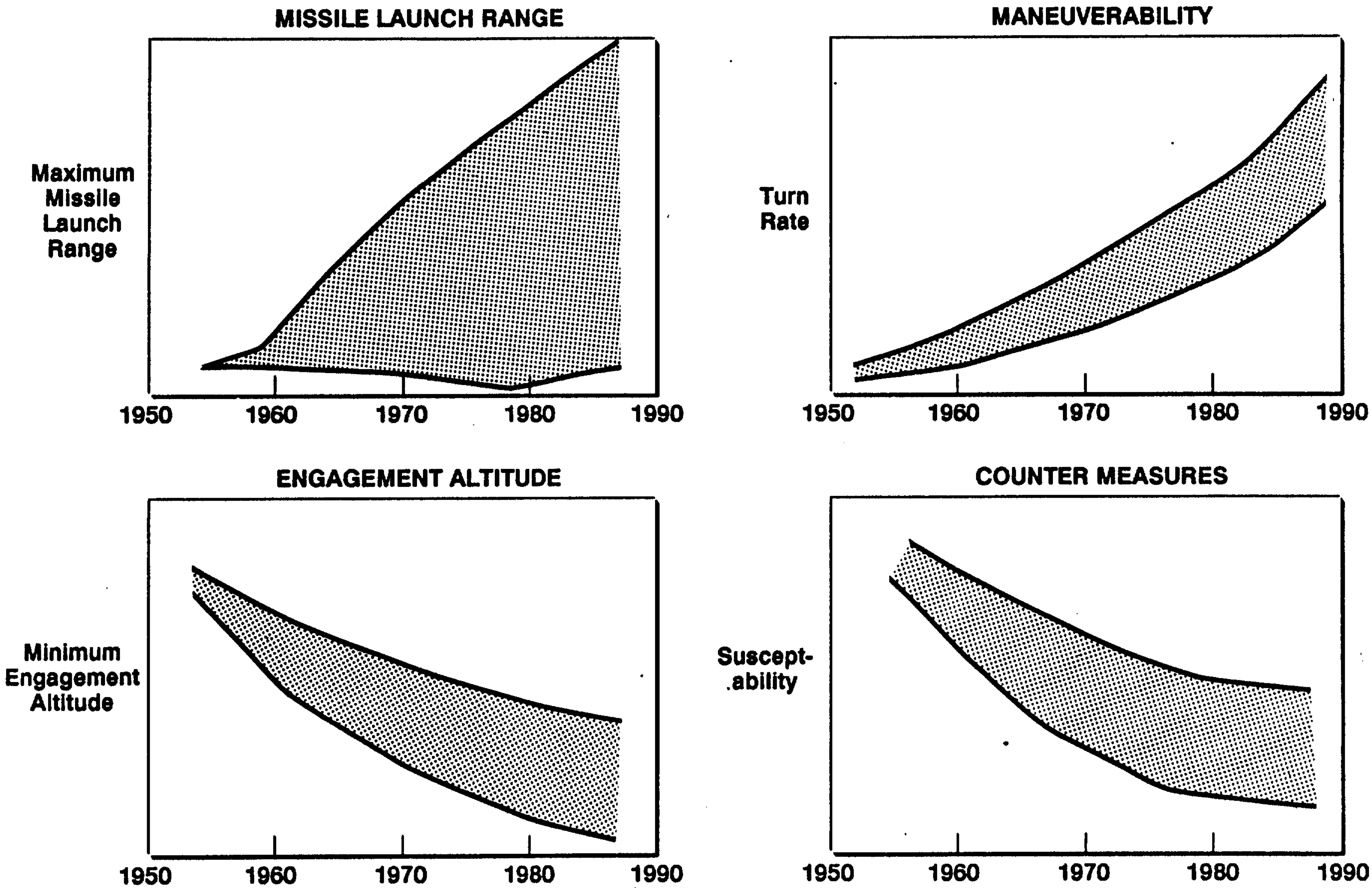
TIME COMPRESSION

- Ground Flight Planning
- Mission Redirect
- Target Area Problems
- Threat Encounters
- Mission Debrief
- Force Tailoring

Mission Completion Requirements

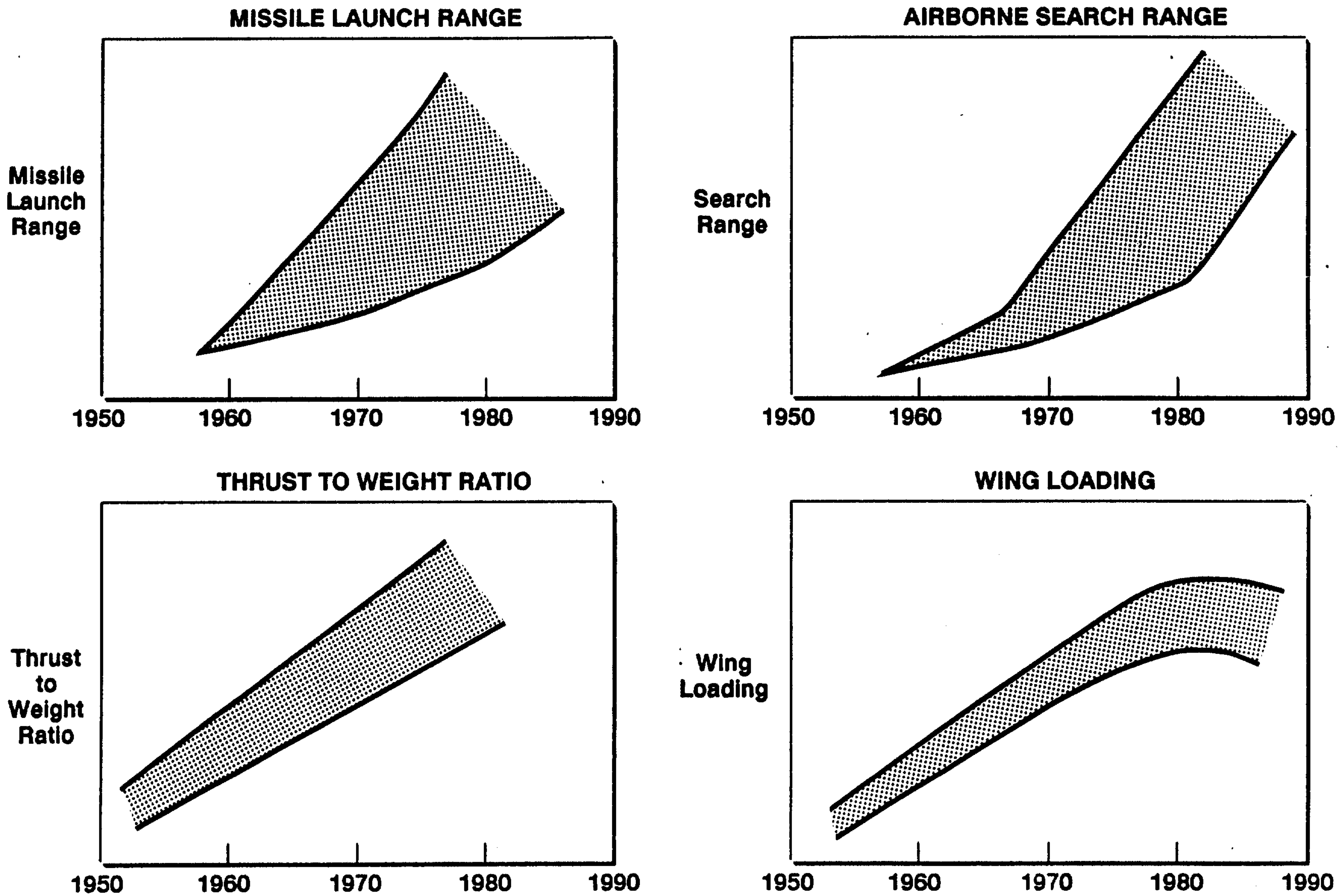
SURVIVAL (Threat Defeat)		TARGET DESTRUCTION		
ACTIVE	**PASSIVE**	**TARGET**	**WEAPON**	**AIRCRAFT**
• Threat Location – Preflight Mission Planning – Data Link – Moving Map Display – RHAW – Voice (e.g. from Wingman) – Visual Aids - IR System - Low Light System - HMD • Weapons – Antiradiation Missile – Mavericks – Hyper Velocity Missile – Hydra 70 – CR-7 – Gun • Radiated ECM • Chaff • Flares • Towed Decoys • Coordinated ECM (Multi-Ship)	• Threat Location – Preflight Mission Planning – Data Link – Moving Map Display – RHAW – Voice (e.g. from Wingman) – Visual Aids - IR System - Low Light System - HMD • Moving Map Display • Digital Terrain • Accurate Aircraft Position • Inflight Path Optimization • Aircraft – Hardness – Agility – Speed – Pilot Visibility – Observability - VCS - RCS - IR Signature - RF Emissions - Acoustic Signature – Altitude – Handling Characteristics • Saturation • Predictability	• Hardness • Orientation • Mobility • Contrast • Size • Shape • Density (#/Area) • Surrounding Obstructions • No. Critical Components	• Weapon Effects – Explosive Charge Type – Casing – Number • Fuse • Guidance Package • Boosting	• Moving Map Display • Accurate Aircraft Position – DTS – INS – GPS • Accurate Target Position – Data Link – Flight Planning – Voice (i.e. from the FAC) • Weapon Delivery Accuracy • Speed • Attitude • Altitude • Threat Acquisition – Aircraft Position – Target Position – Target Queing – Flight Planning

SAM Threat Trends



FWS-50

Air Threat Trends



Strike Planning Considerations

B-17 Flying Fortress crew during pre-flight briefing for a precision daylight bombing mission over Berlin. East Anglia Airfield, England 1944.

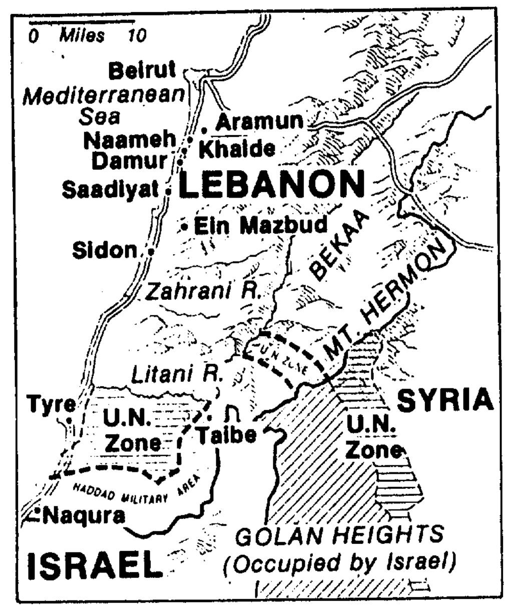
The Strike Planner's Checklist
(LCdr Nichols, USN Strike Warfare School)

1. Objectives
   - Military Expectations
   - Physics, Geometries, & Dispositions
   - Times and Routes
2. Intelligence Sources & Requests
   - Within Your Command
   - Within Your Theater
   - National - Technical
3. Friendly Forces Information
   - OB, Sit, & Disposition
   - Strike Package
   - ROE
   - Systems Requirements
4. Enemy Forces Information
   - Air Defense Capabilities
   - Surveillance & Early Warning
   - Countermeasures Plan
   - Path Analysis
   - Air Threats & Realities
   - Psych & SAR Factors
   - Tactics & Trends
   - Attitudes & Behavior
   - Reactions to Losses
5. Weaponeering
   - Numbers & Types of Weapons
   - Delivery Modes & Limits
   - Fuzing & Handling
6. Suppression of Enemy Air Defenses (SEAD)
   - Avoidance & Path
   - Lethal & Non-Lethal Means
   - Self Protection Systems
   - Surprise
7. Strike Composition
   - Force Numbers by Task
   - Formations & Tactics
8. Launch, Ingress, & Target Area
   - Go/No-Go Criteria
   - Emcon and Sensor Management
   - Tactics, TOTs, & Mutual Support
   - Support Coordination
9. Egress and Recovery
   - Rally Points, Routes
   - Safe SYS, Hung Ord, & Damage Assessment
   - Route/IFF Procedures
   - BDA & Debrief

21 April 1982:
IAF Coordinated Strike Package into Southern Lebanon

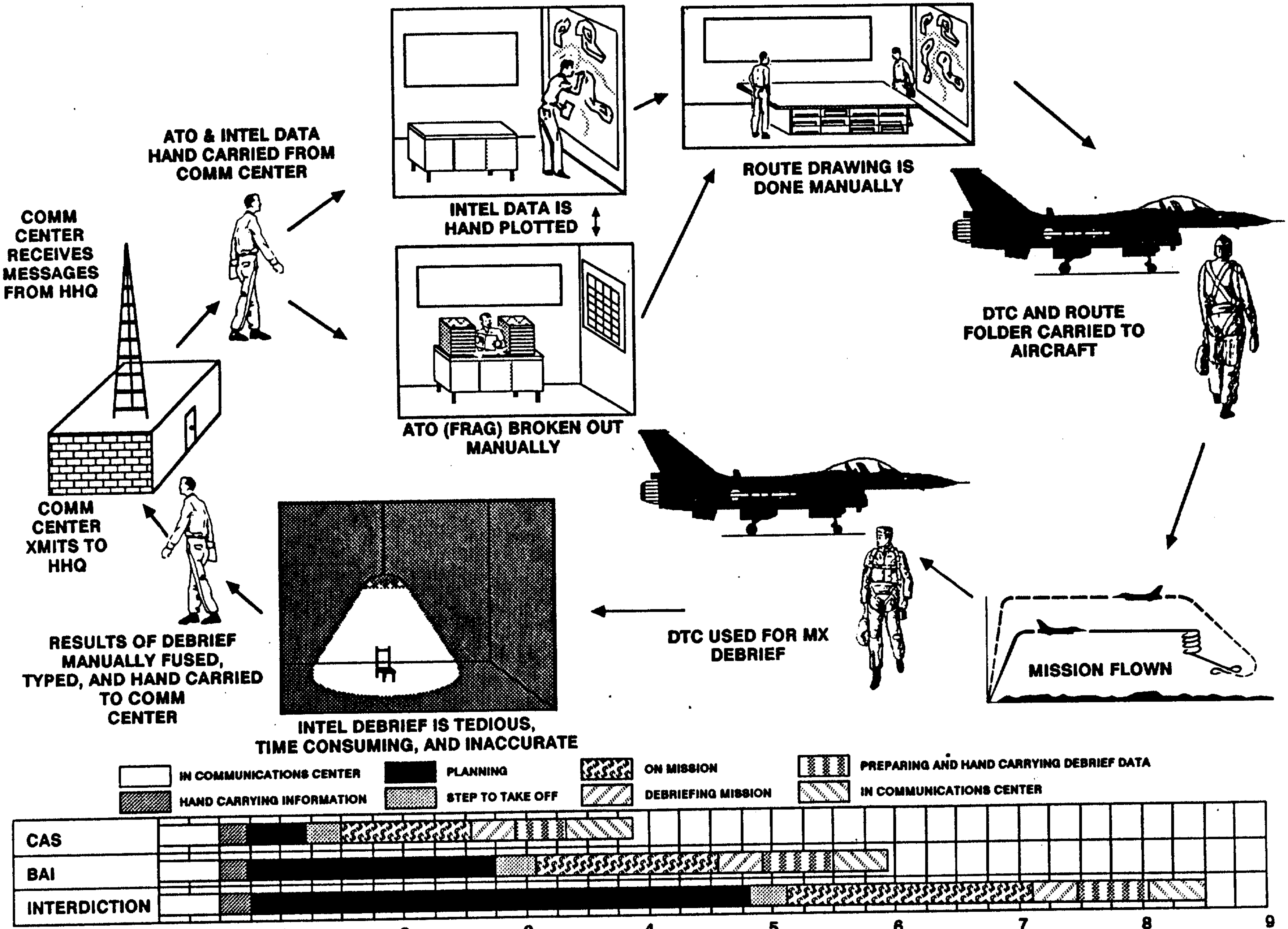
- 58 Aircraft "Package" Experimented with by IAF Strike Planning Branch
- Highlighted Renewal of "Air Campaign" Against Terrorist Groups in Retribution for Continued Violations of July 1981 Cease-Fire
- Aircraft Executed Three Evolutions that Lasted Over Two Hours
- F-16's Down (2) MiG-23 Floggers Vectored on the Strike Package

(4) F-15	Fighter Sweep
(4) F-15	Barcap "High-Cover"
(8) F-16	Tarcap "Low-Cover"
(4) F-4	Flak-Suppression
(2) F-4	Wild Weasel
(2) A-4	Iron Hand
(8) F-4	Precision Strike
(12) KFIR	Visual Strike
(4) COBRA	Visual Strike
(4) MD-500	SAR Escort
(2) UH-1E	SAR Alert
(1) E-2C	C3 Support
(1) RC-707	Elint/Comint Support
(1) ARVA	Comm Jamming Support
(1) RF-4E	Post Stike Recce



PLO Target Camps

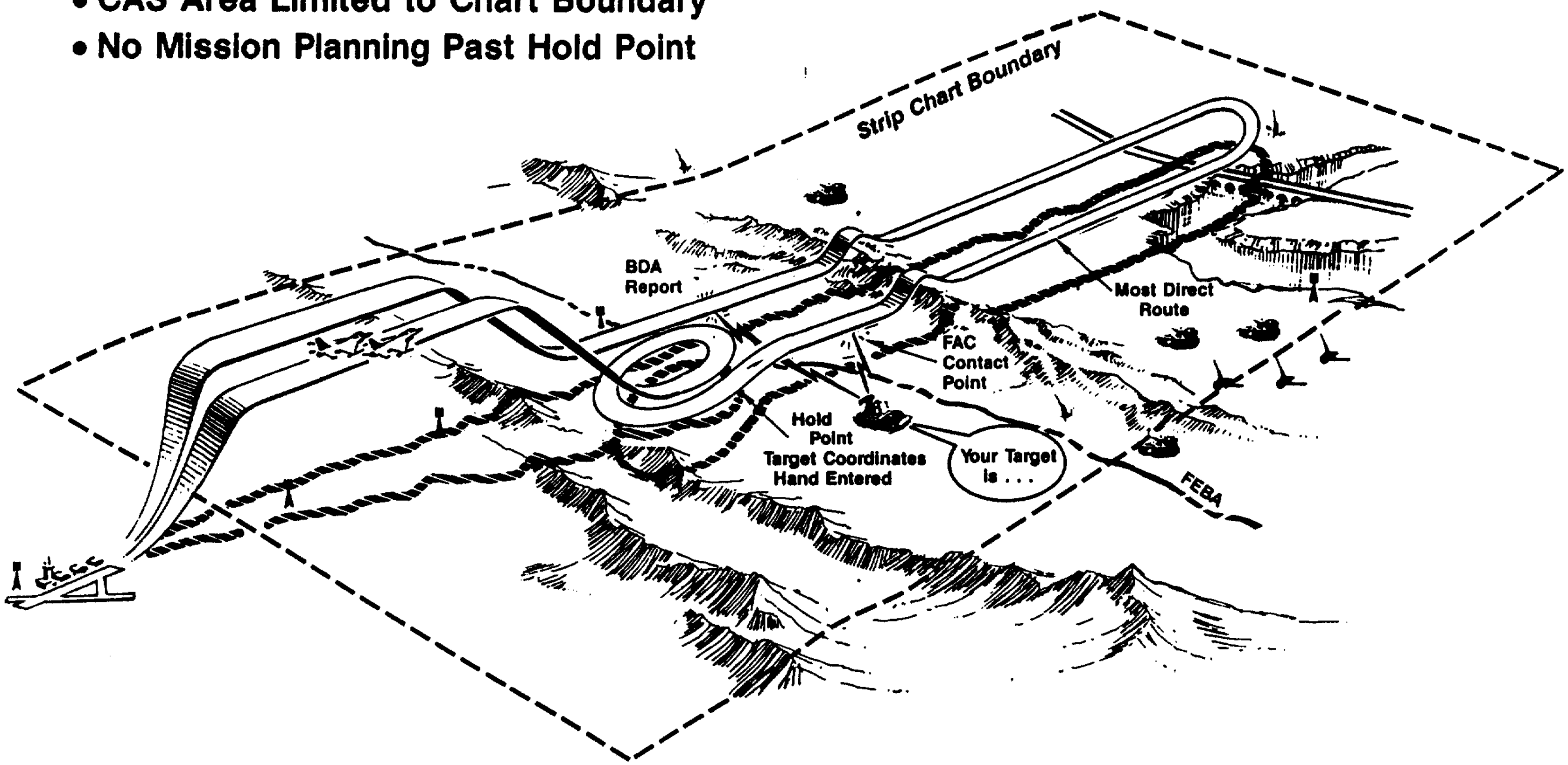
Today's Flight Planning



FWS-55

Today's CAS Mission

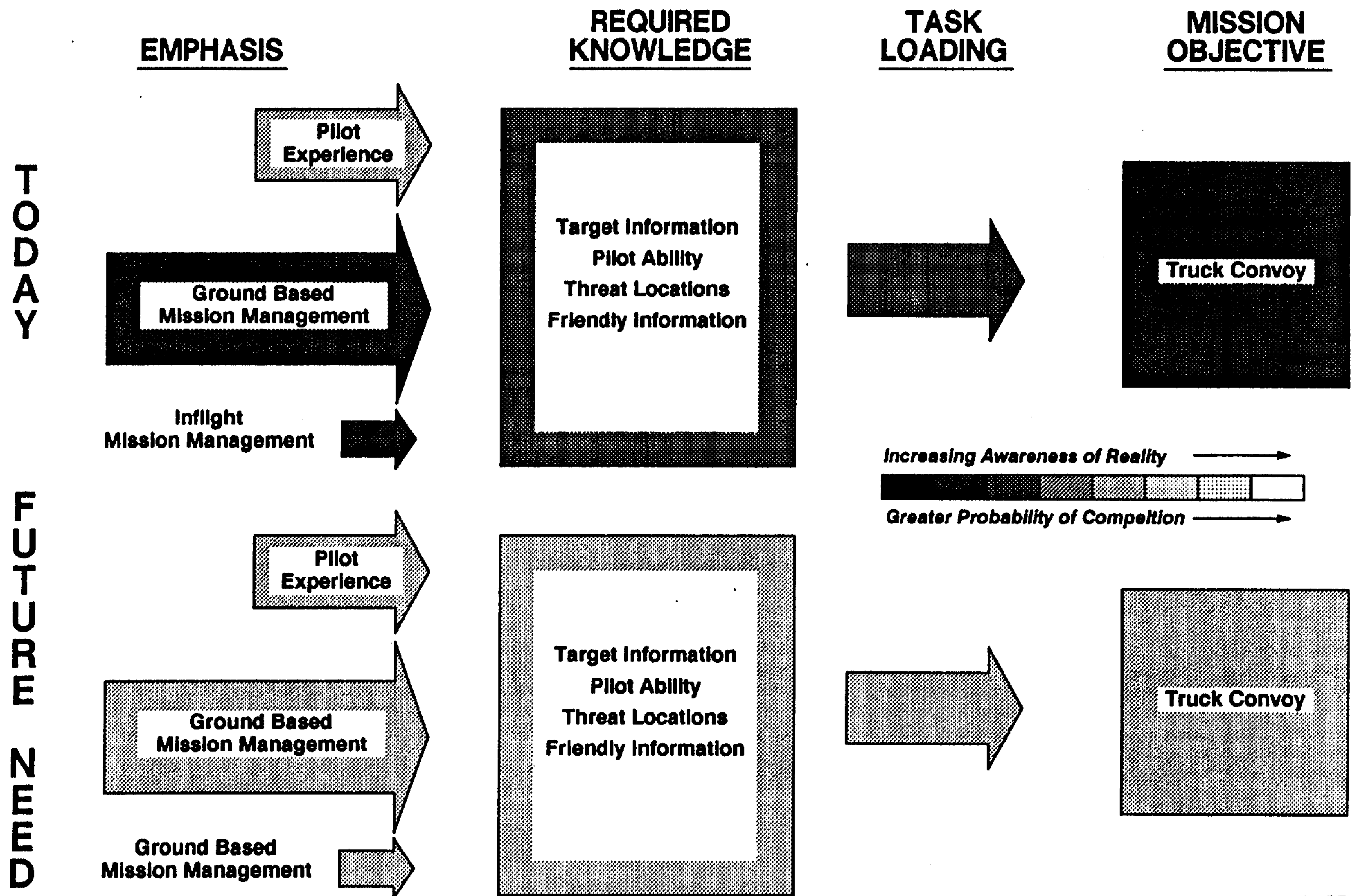
- CAS Area Limited to Chart Boundary
- No Mission Planning Past Hold Point



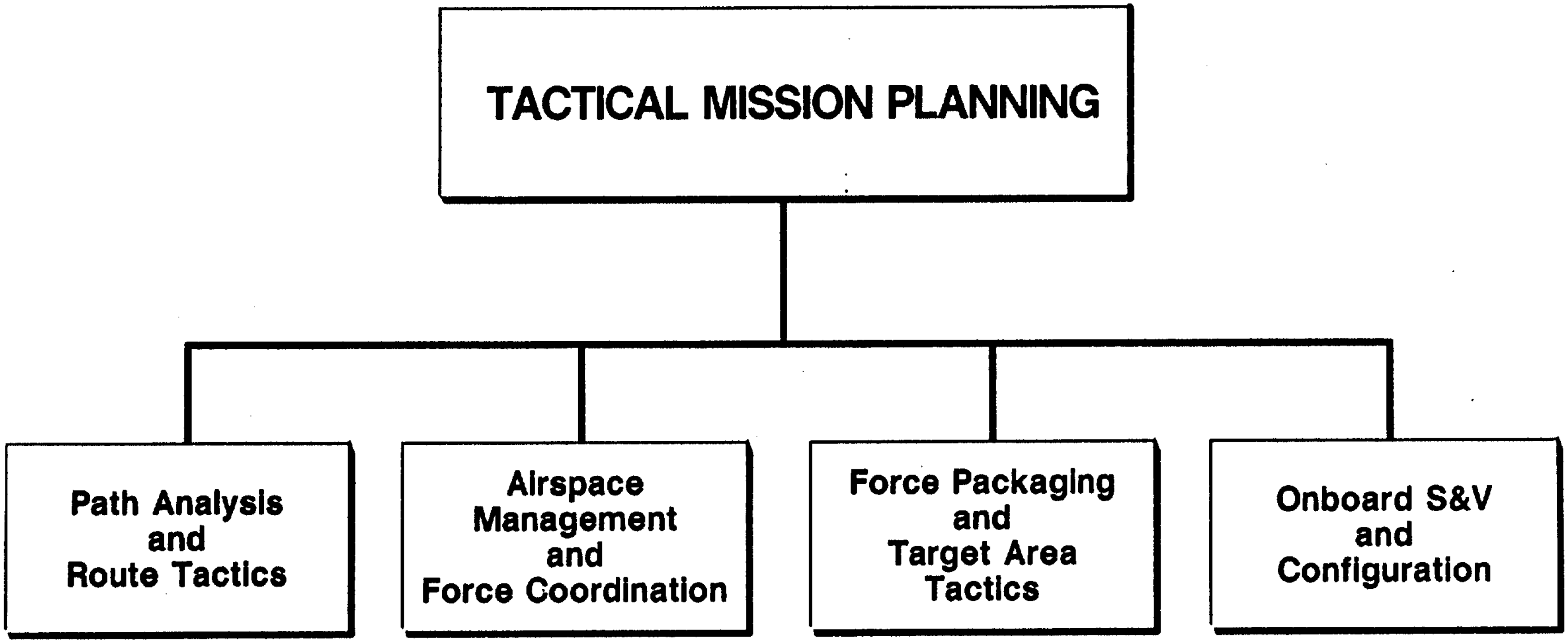
THREAT INFORMATION
- Only for Area on Chart
- Usually Old (>4 Hours)

Mission Management

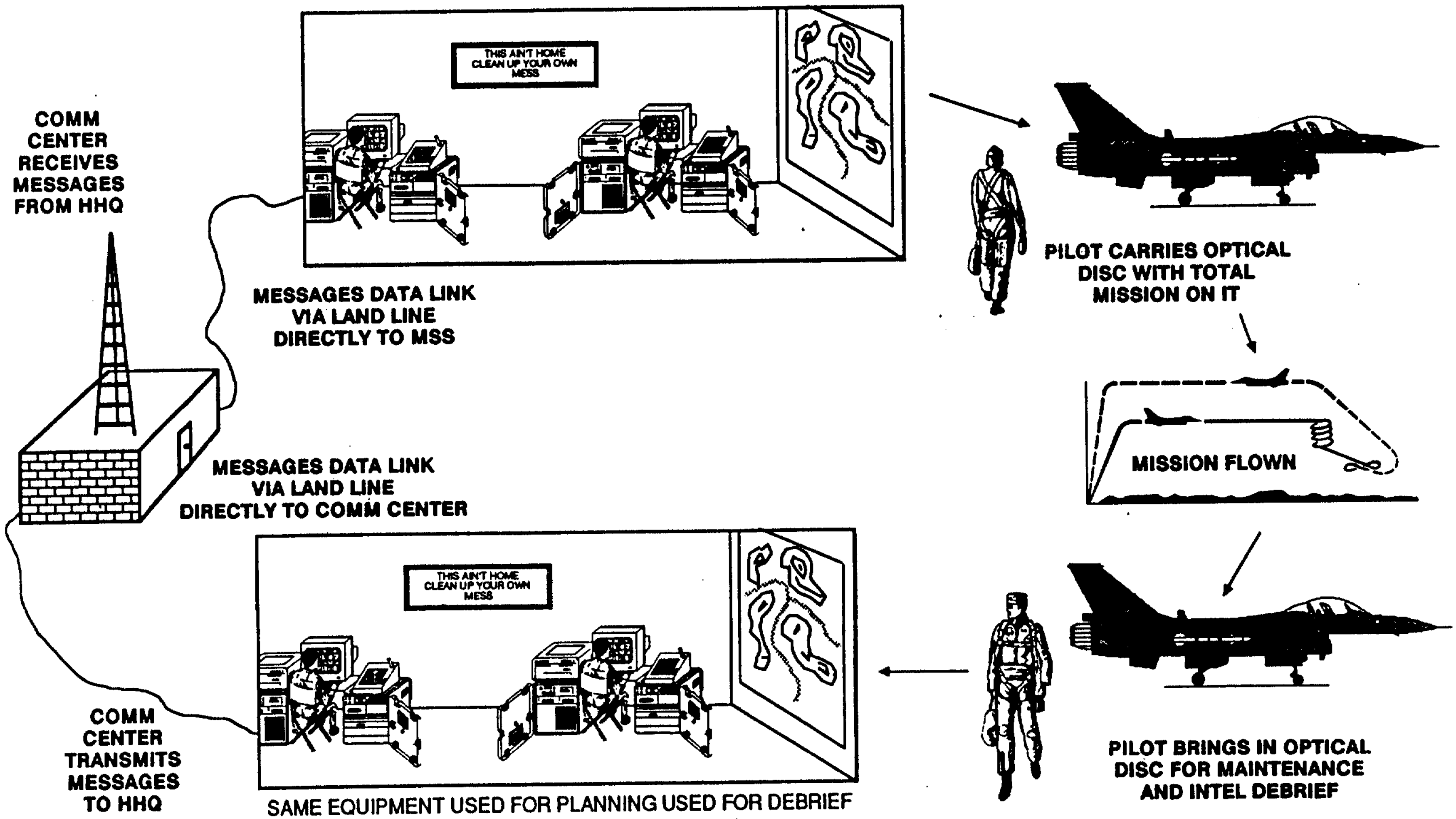
A Change of Emphasis

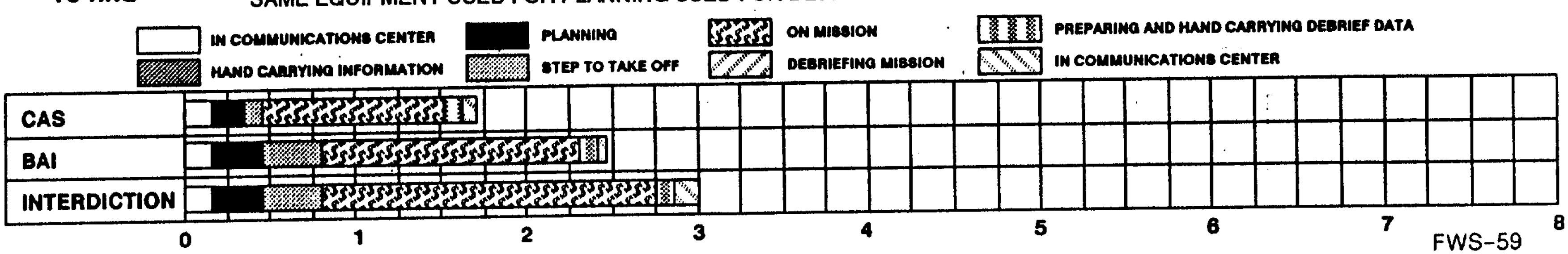


High Threat Environments Demand Centralized Mission Planning



Mission Managed Flight Planning





Inflight Mission Management

DIGITAL DATA STORAGE

- Auto Router
- Data Bases
  - Terrain
  - Cultural
  - Threat
  - Threat Reaction

DATA LINK

- Air-to-Ground
- Air-to-Air
- Ground-to-Air

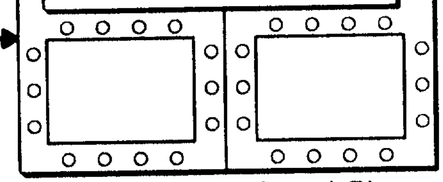
- Correlation of
  - Threat RWR
  - Track Data
  - Path Data
- Pictures & Words
- Positions & Waypoints
- Flight Member Deconfliction

FIRE CONTROL CENTRAL COMPUTER

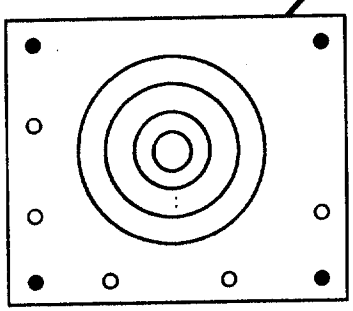
NAVIGATION EQUIPMENT

- GPS
- DTS
- INS

COCKPIT DISLAYS



- Color Map (Chart/3D)
- Overlays
  - Threat
  - Target
  - Route

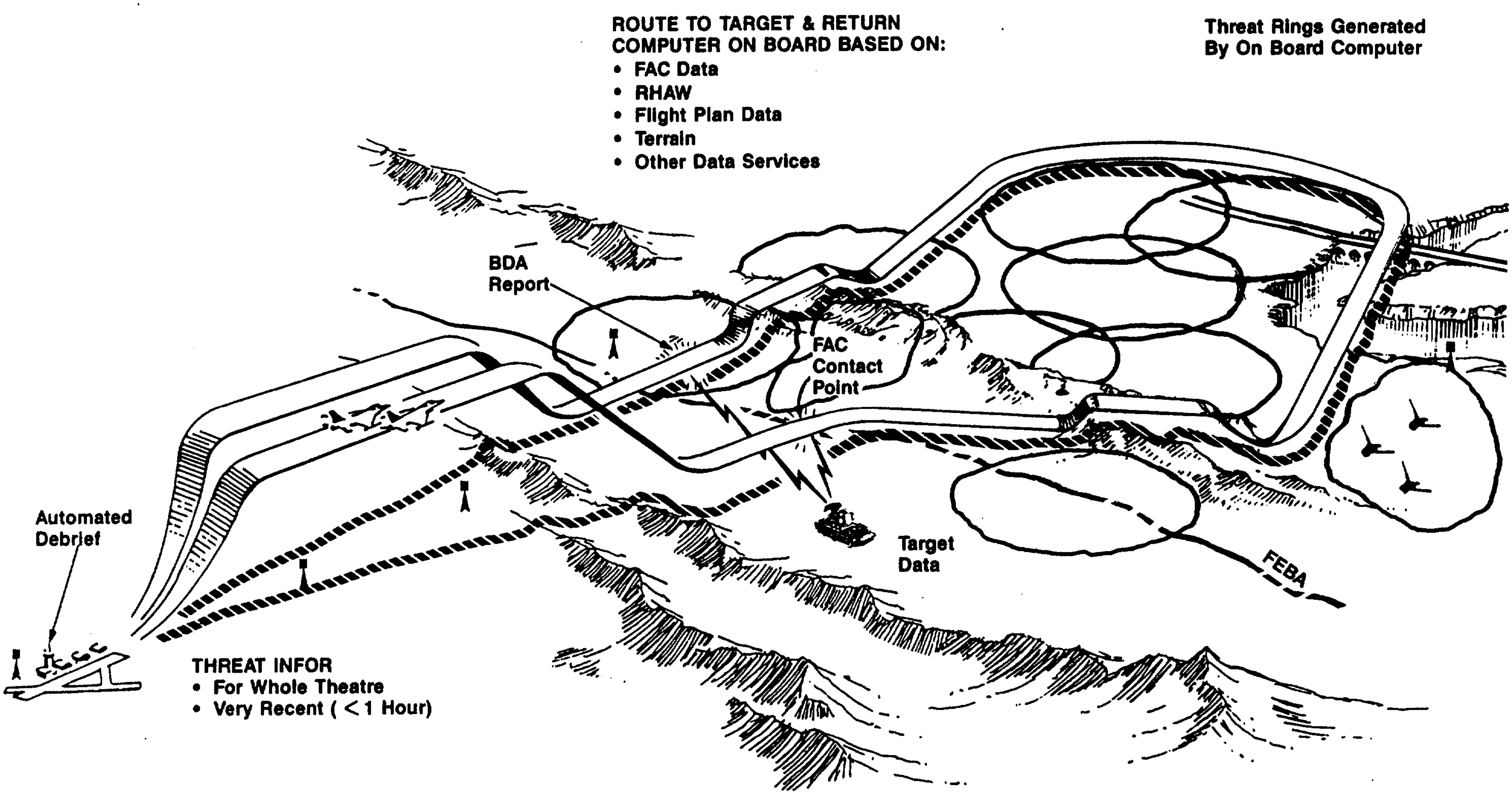


- RWR
  - Threat Type
  - Threat Priority
  - Threat Density

HELMET MOUNTED DISPLAY (HMD)

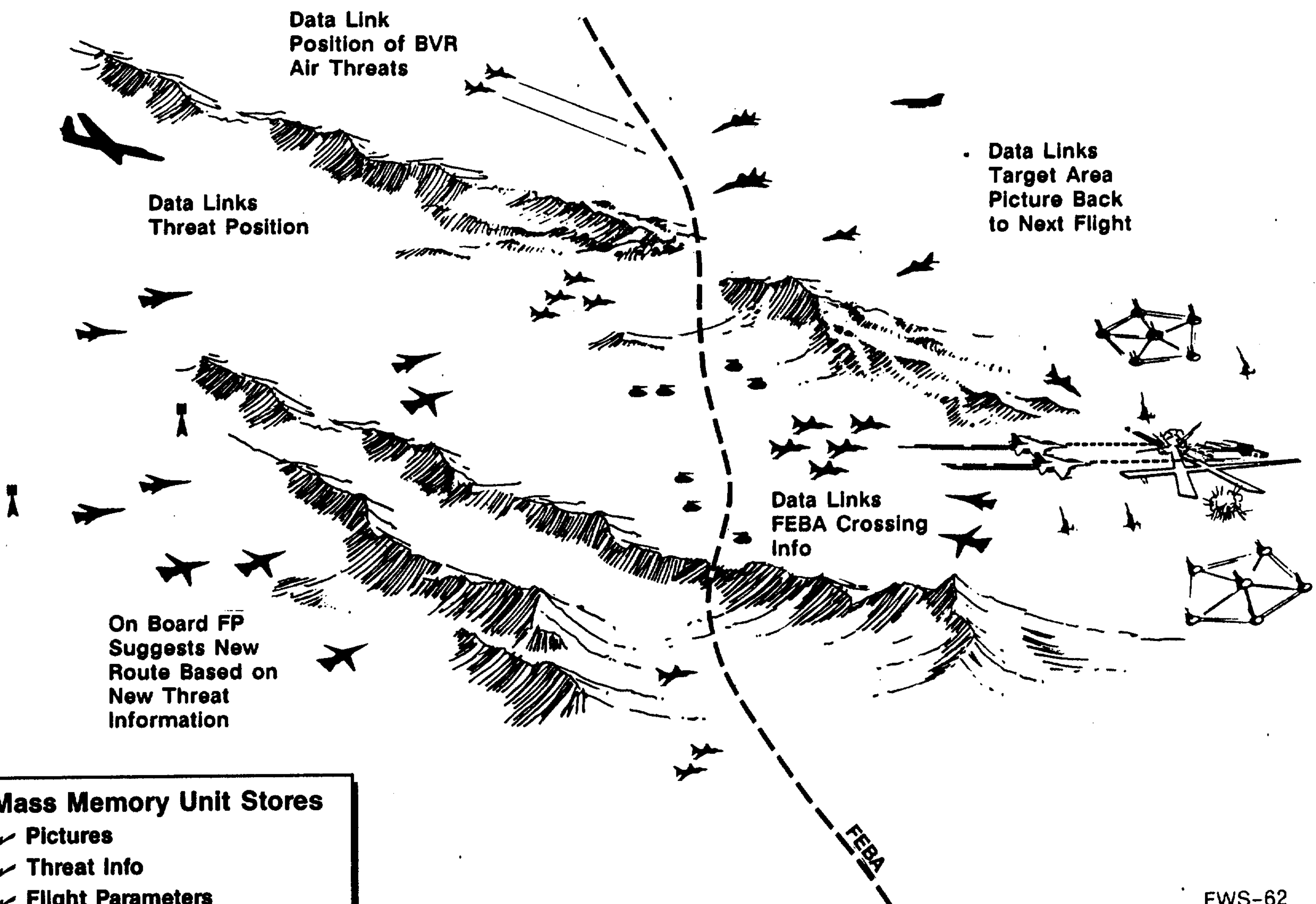
- Today's HUD Information
- Laser Eye Protection
- RWR Bearings
- Suggested Maneuvers

Mission Managed CAS Mission
(Redirect)



Mission Managed Interdiction Mission

(Route Optimization)



- **Mass Memory Unit Stores**
  - ✓ Pictures
  - ✓ Threat Info
  - ✓ Flight Parameters

FWS-62

Requirements
for Mission Management While on the Ground

- 20 Minutes from Mission Input to Complete Mission Package
  - Flight Information Card (USAF Form 70)
  - Chart with Threats and Route IAW AFR 55-40
  - Optimized Route Based on Threats and Desired Effects
  - Alternate Safe Passage Corridors

- Work Station to Aircraft Data Transfer
  - Route
  - Threats
  - Digital Terrain for Flying Area
  - Cockpit Settings
    - Master Modes
    - Radio Frequenices
    - SMS
    - Displays
    - Sensors
  - Programs
    - RCM
    - RHAW
    - OFP
    - Radar
  - Codes
    - Radio
    - Data Link
    - IFF
    - Laser
    - GPS

- Aircraft to Workstation Data Transfer
  - Maintenance Debrief
  - Threat Locations
  - New RF Parameters
  - Flight Data Recorder Information

Requirements

for Mission Management While Airborne

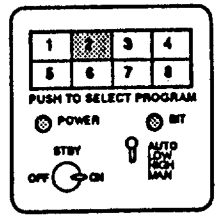
- Situation Awareness Display(s) that Can Depict:
  - Moving Map
  - Route
    - Preflight
    - Optimized for Present and Next Leg Based on Newest Data
  - Air and Ground Threats from:
    - Preflight
    - Data Link
    - Onboard Sensors Find
      - Airborne Threat Position to Within 1° Cone
      - Ground Threat Position to Within 5% of Actual Range
  - Display Airborne Threat (On Situation Display and HMD)
  - Display Ground Threat (On Situation Display and HMD)
  - Target
    - Preflight
    - Newest
- 300-600Mb Data Storage
  - Threat Position by Type and Position
  - RF Parameters
  - Aimpoints
  - Flight Parameters (ACTES)
- Resolve Airborne Threat Position to 0.10 n.mi with 2 Data Linked Aircraft
- Data Link Compatible with Army and Air Force
- Intra-Flight Data Link
- Coordinated Intra-Flight ECM
- Navigation Good to Within 0.01 n.mi

Integrated Inflight Mission Management

DATA LINK

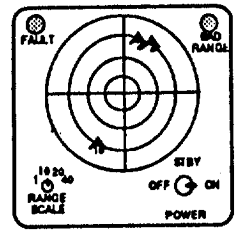
Supplies target and threat information to:

- HUD (from data link)
- MMU (from data link)
- MMD (from data link)
- Data Link net (from aircraft)



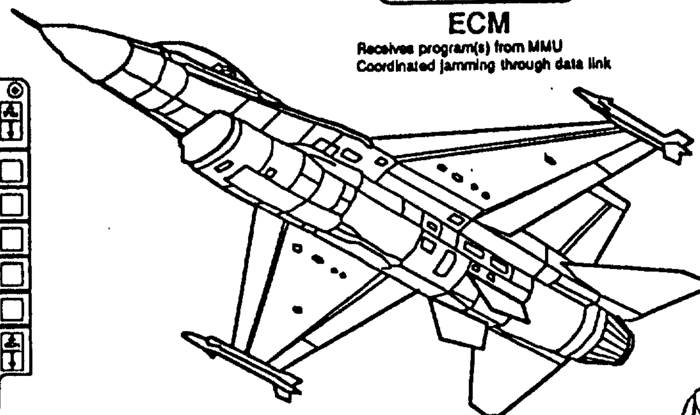
ECM

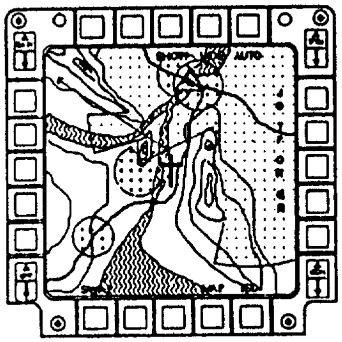
Receives program(s) from MMU
Coordinated jamming through data link



RHAW

Performs HOMING and warning
Sends unknown RF parameter to MMU
Processes range to 3% of actual range
Sends ground threat positions to MMU and MMD
Displays air threats to 1°
Receives programming from MMU

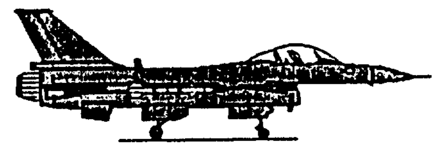


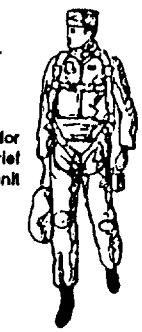


SITUATION DISPLAY

Displays:

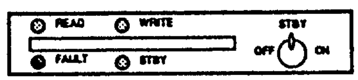
- Map
- Line of sight threats from RHAWS
- Beyond line of sight threats from MMU
- Threat rings based on threat and altitude AGL
- Best immediate flight path
- Applicable data link information





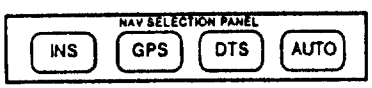
After mission, pilot returns to MSS for automated flight & intel debrief using mass memory unit

Before mission, pilot carries mass memory unit to aircraft



MASS MEMORY UNIT

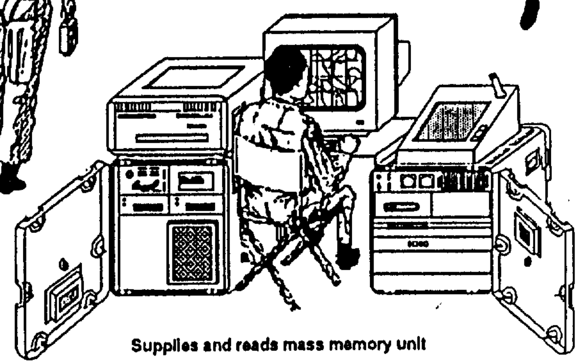
Supplies:	Records:
ECM programs	Aim points
RHAW programs	ACTES information
Radar programs	New RF data from RHAW
Data Link codes	Maintenance information
GPS codes	Threat locations from RHAW
IFF codes	Chaff/flare events
Laser codes	
Display modes	
Master modes	
Sensor modes	
SMS data	
Way points	
Digital terrain data base	
Automated checklist	
Target area photo	



ACCURATE NAVIGATION

Navigates within 30 meters of actual position
Maintains altitude within 10 feet of actual altitude

Good mission management starts on the ground



Supplies and reads mass memory unit

Fighter Performance

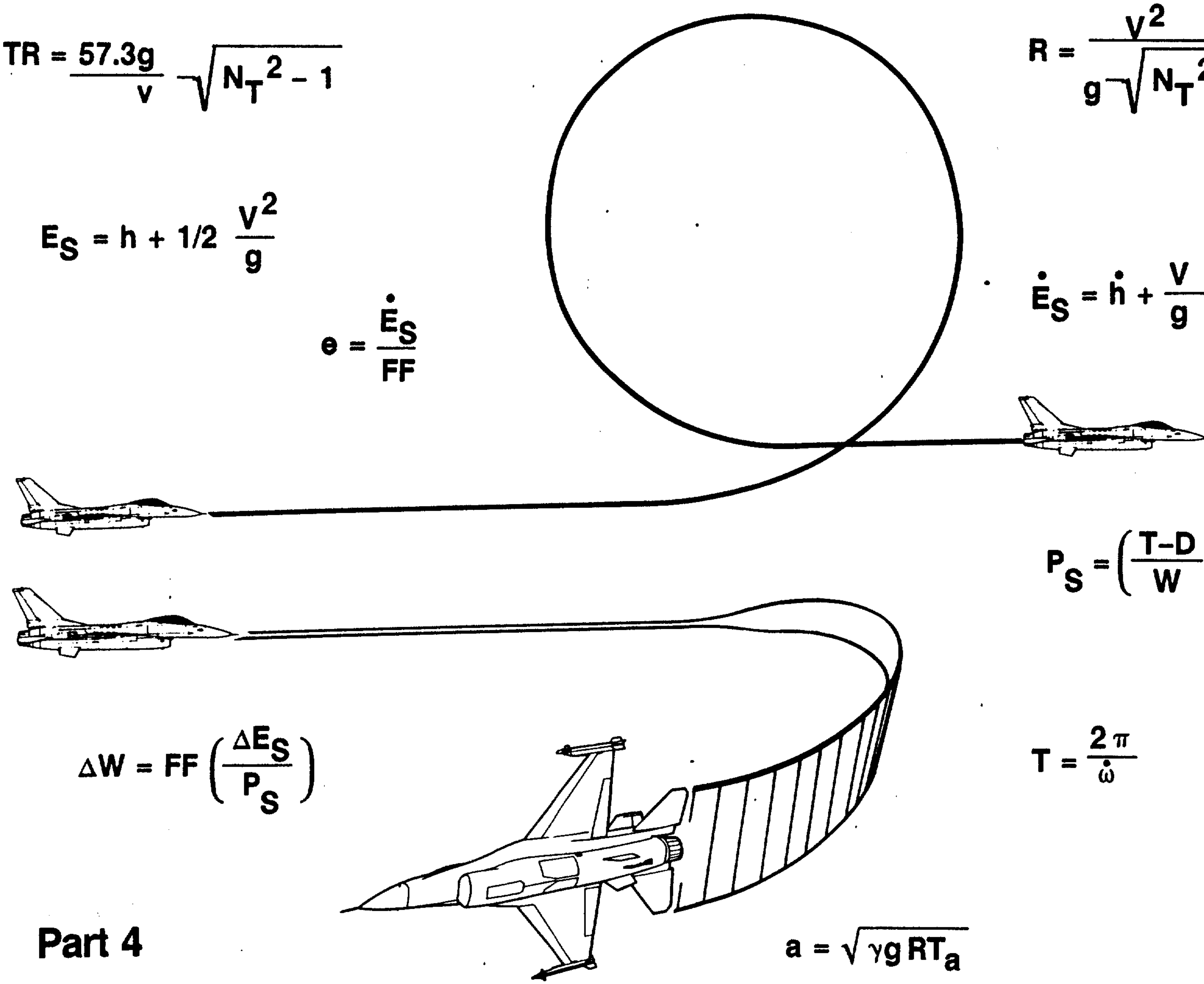
$$TR = \frac{57.3g}{v}\sqrt{N_T^2 - 1}$$

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

$$E_S = h + 1/2\,\frac{V^2}{g}$$

$$\dot{E}_S = \dot{h} + \frac{V}{g}\,\dot{V}$$

$$e = \frac{\dot{E}_S}{FF}$$



$$P_S = \left(\frac{T-D}{W}\right)V$$

$$\Delta W = FF\left(\frac{\Delta E_S}{P_S}\right)$$

$$T = \frac{2\pi}{\dot{\omega}}$$

$$a = \sqrt{\gamma g R T_a}$$

Part 4

Fighter Performance Table of Contents

Fighter Performance

I. GENERAL CONSIDERATIONS FROM A PERFORMANCE POINT OF VIEW

"Performance Means Initiative – the Most Valuable Moral and Practical Asset in Any Form of War."

Maj Sholto Douglas, RAF

NOTE: Perhaps One of the Most Authoritative and Interesting Readings on Fighter Performance Can Be Found in the Appendix to Robert L. Shaw's Book on "Fighter Combat: Tactics and Maneuvering," Naval Institute Press 1985, Where This Quote Was Found.

Fighter Performance (Cont'd)

I. GENERAL CONSIDERATIONS FROM A PERFORMANCE POINT OF VIEW

- Trends in Air Combat
  - Classical Air Combat:

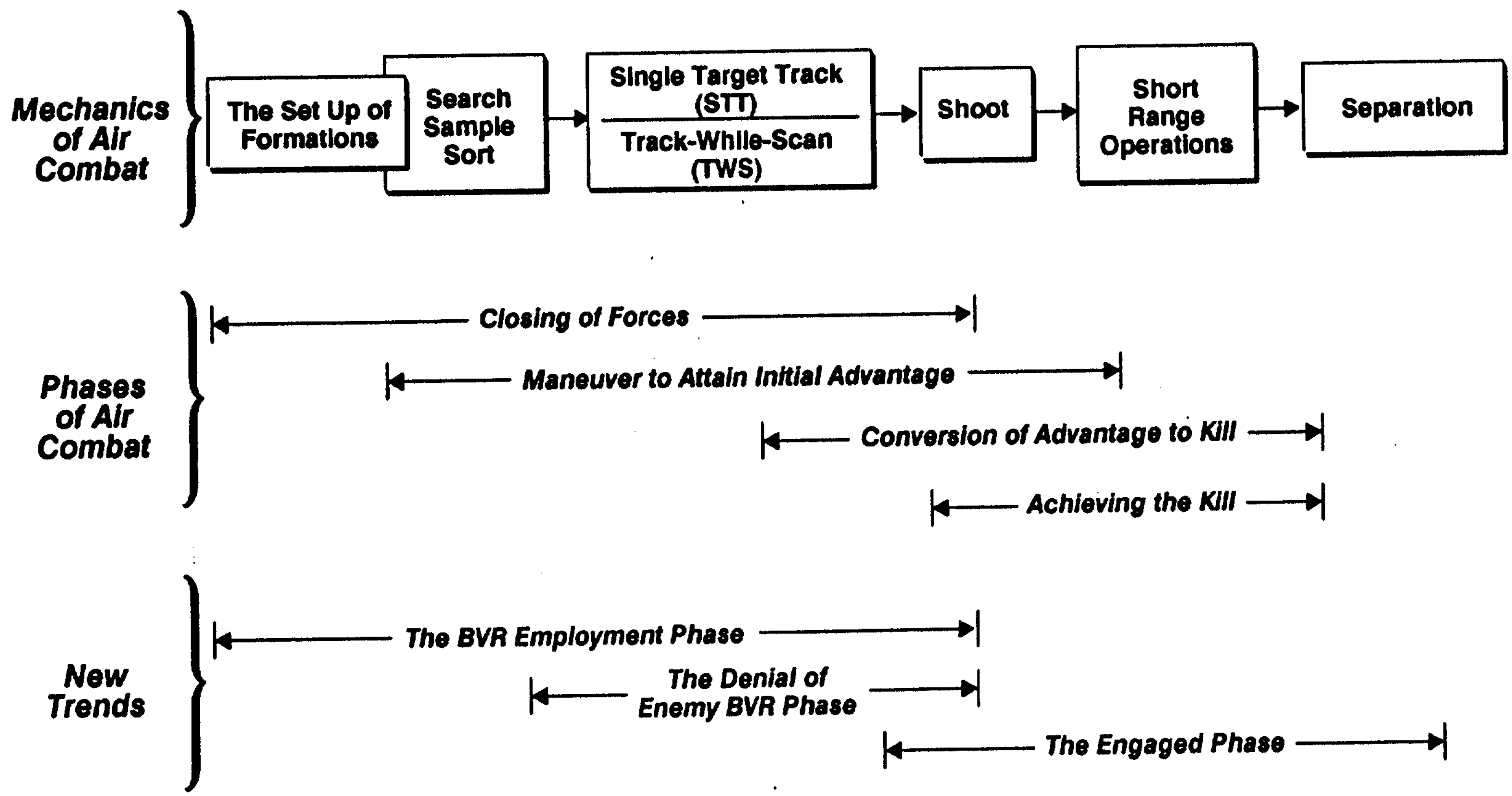
    Has Always Been Associated with "Guns Only" Air Combat Situations Where the Key Performance Concern Was for the Ability of the Aircraft to Change the Direction and Magnitude of its "Velocity Vector" in All Dimensions to Attain Nose-to-Tail Positional Advantage Over an Engaged Opponent. Advantage Can Be Measured by Angular Values or Predicted by Relative Energy States. Generally the Fighters Would Use Energy but Due to Available Performance It Always Progressed "Down-Hill." Since the "Dogfight" of the WWI Biplanes Is Still Executed by Today's Modern High Performance Jets, the "Classical" Guns-Only Concepts Remain Unchanged Except to Include the Dynamics Brought About by the High Thrust-to-Weight Machines and High Angle of Capability of the Lead Computing Gun Sights.

  - Modern Air Combat:

    Has Extended the Positional/Energy Contest Arena Far from the "Smelling Distance" Between Two Aircraft, as the German Ace Galland Would Say. It Now Seeks "Launch Windows" for Complex Missiles or "Opportunities" to Engage Based on Numerous Factors of Force Numbers, Relative Performance, and Weapon Capabilities All Magically Being Assessed by Complex Equipment Onboard and External to the Fighter. We Find Modern Air Combat Entering in Phases: the Set-Up and Closing to the Search/Sample/Sort of Opponents to the Employment of "Beyond Visual Range" (BVR) Weapons and then the Eventual Merge of Players into Short-Range Operations "Within Visual Range" (WVR) Ending with the Escape or "Bugout." The Lethality of These Modern Long Range and Short Range Missiles Continuously Rises and Their Capacity to Kill From Any Aspect Gets Better. The Performance Demands on the Modern Fighter Are Great. He Must Take Heavy Loads at High Speeds Over Long Distances and Maneuver with Them Under High "G" Conditions. The Rates of Change from One Axis to Another Must Be Right at the Limits of Human Capabilities. Today's Dogfight Could Begin at 50 NM with Radical Turns ("Drags") to Reduce the Enemy's Radar Capabilities, At 25NM Additional Hard Maneuvers Could Be Employed to Reduce the Enemy's Capability to Launch BVR Missiles. All the Way down to Visual Range Hard Maneuvering and Rapid Accelerations May be Required to Deny the Use of These Complex Weapons to the Enemy. Once Visual the All-Aspect Short Range Fight Starts, But Once the Fighters Have Merged to a Minimum Crossing Pass the "Classical" Side of Air Combat Make an Appearance Again.

Fighter Performance (Cont'd)

- **Future Air Combat:**
  Offers the Same Demanding Environments as the Present but Will Provide the Ultimate in Responsiveness with Pilot-Aircraft-Weapon Integration. Signatures Will Be Manageable and C^3I Will Be Totally Immersed in the Aircraft Mission Capabilities. Performance Will Be "On Demand" and Will Cover the Entire Spectrum of Low/Slow to High/Fast. Pilot Limitations Will Hold Back Radical Changes in G Capability. High Lethality of Weapons Will Keep High Interest in the BVR Offensive and Defensive Capabilities.



Fighter Performance (Cont'd)

Oswald Boelcke's Rules for Air Combat (1916)

- Try to Secure Advantage Before Attacking. If Possible Keep the Sun Behind You.
- Always Carry Through an Attack When You Have Started It.
- Fire Only at Close Range and Only When Your Opponent Is Properly in Your Sights.
- Always Keep Your Eye on Your Opponent and Never Let Yourself Be Deceived by Ruses.
- In Any Form of Attack It Is Essential to Assail Your Opponent from Behind.
- If Your Opponent Dives on You, Do Not Try to Evade His Onslaught, but Fly to Meet It.
- When Over the Enemy's Lines, Never Forget Your Own Line of Retreat.
- Attack on Principle in Groups of Four or Six. When the Fight Breaks into a Series of Single Combats, Take Care that Several Do Not Go for One Opponent.

"I Fly Close to My Man, Aim Well, and Then of Course He Falls Down."
. . . Capt Oswald Boelcke

Fighter Performance (Cont'd)

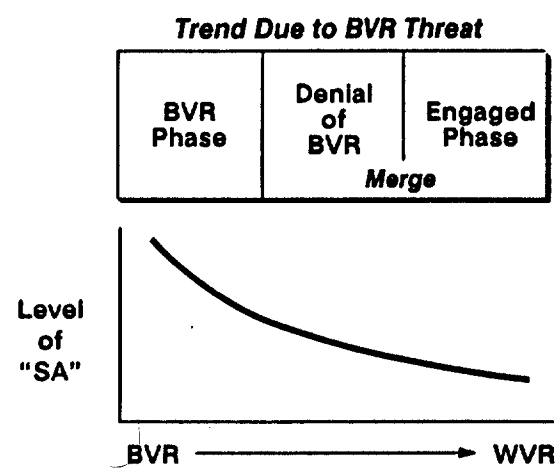
- TACTICS AND STRATEGY
  - When Opponents Are Equal, a Small Advantage in Relative Rates of Change of the Velocity Vector Can Significantly Change Advantage, but Generally Only for a Short Duration
  - All Aircraft Have Regions of "Superiority" and "Inferiority" Over Other Aircraft. The Trick Is to Know Them and Keep the Fight in Your Best Arena
  - Multiple Aircraft Engagements Change the Importance of 1v1 Performance. Saturation by Numbers Somewhat Offsets Superiority of Performance or Weapons up the Point Where the Numbers Are Incapable of Central Control.

- SKILL AND AIRMANSHIP
  - The Pilot: The Overall Dominant Factor, Incomparable to Any Other
  - Aggressiveness: Initiative, the Will to Win, Bravery and the Striving for the Final Goal . . . the Kill
  - Experience: Knowledge and the Use of All Systems, Weapons, Flying Qualities, and Tactics
    All at the Right Time
  - Coordination and Mutual Support: Teamwork and the Optimal Use of Numbers
  - Gunnery: The Final and Ultimate Goal Having Translated Through Known Missile Opportunities
  - Airmanship: The Mastering of Skills that Become More and More Important as the Battle Becomes More Dense and Lethal
  - Conditioning: Mental and Physical Alertness
  - Situation Awareness: A "Good" Feeling About Events Unfolding. Not Necessarily Indicative of Success but a Sense of Relative Time, Space, and Events That Can Be Anticipated for the Sake of Improving Your Situation and Assure Survival

Fighter Performance (Cont'd)

- FACTORS IN SITUATION AWARENESS
  - Key Factors Exploited by Good SA
    - A Good First Start – Beginning with an Advantage in
      - *Speed*
      - *Angles*
      - *Altitude*
      - *Acquisition*
      - *Surprise*
      - *Numbers*
      - *Fuel State*
      - *Weapons*
      - *Aggressiveness*
    - Useful GCI and RT
    - Weather, Clouds, Overcast, Contrail Layers, Etc
    - Visual Cues (Burner Puff, Contrails, Strake Vortex, Smoke, Etc)
    - Sun Position and Visibility – Vertical and Horizontal
    - Surface-to-Air Threats
    - ROEs and Command Requirements/Decisions
    - Presence of Additional Unknown Aircraft
    - Bugout Fuel and Heading
  - "SA" Encompasses Larger Boundaries Once the Threat Goes Beyond the "WVR" to the "BVR" Arena
  - The Longer You Are in One Particular Place, the More You Need "The Big Picture"

A. The Closing of Forces
B. Maneuvering to Gain Advantage
C. Converting Advantage into a Kill Position
D. Achieve of the Kill



Fighter Performance (Cont'd)

- **WEAPON SYSTEM FACTORS**

  An Opponent's Weapon System Can Both Help and Hinder His Performance Against You. Know His Systems, Exploit Weaknesses, and Devise Tactics Against His Strengths. Your Aircraft's Performance Determines Much of What Options You Have.

  - Radar Search/Track Capabilities: How Susceptible Is the Adversary's Radar to ECM? Can He Use His Radar at Low Altitude? Can He Shoot Looking Down? Will His Radar Illuminate Your RHAW? Does He Have Passive Track Systems?
  - Missile Capabilities: Know the Maneuvering and Nonmaneuvering Envelopes for the Adversary's Missiles. Be Aware of Fuzing and Warhead Types and Capabilities/Limitations. How Susceptible Is the Missile to Chaff or Flares? Are There Any "G" Limitations for Employment of the Missile? How Many Missiles Can/Does the Adversary Carry? Do They Fire Off-Boresight? Can You Out Turn It or Run From It?
  - Gun/Gunsight: Does His Aircraft Carry an Internal Gun? What Caliber? What Is His Rate of Fire, Muzzle Velocity, and Number of Rounds Carried? What Type of Gunsight Does the Aircraft Employ? Is There a Stabilization Period, or Is It "G" Limited? At What Range Can He Effectively Shoot?
  - Switchology: Does His Radar and/or Armament Control System Require Heads In the Cockpit to Employ? What Are the Effects of His Situation-Awareness When He Is Forced to Change Modes and Switches? Can He Acquire Off-Boresight?
  - ECM/Defensive Electronics: Does His Aircraft Employ Any? Know the Performance of His RHAW Passive Warning System. Does Your Aircraft's Radar Illuminate It? How Accurate Is It?

Fighter Performance (Cont'd)

II. THE COMBAT ARENA

- Historical Perspective

  1. World War I

     - Aircraft Averaged About 110 mph in Speed
     - Faster Aircraft or Speed from a Height Advantage Would Allow Attacking Aircraft to Separate for Safety
     - Speed Became the Focus of "Superiority" While "Turn" Made the Legends
     - Maximum Operational Speeds Grew to 140 mph by 1918
     - Gunnery Through the Propeller Enabled the Gun to Become an Extension of the Pilot's Eye
     - Air-to-Ground Bombing Required Stronger Wings and Motors

Fighter Performance (Cont'd)

- Historical Perspective (Cont'd)

  - Basic Fighter Maneuvers Developed During World War I
    - Pursuit Curves: Lead, Pure, and Lag
    - Displacement Rolls
    - High and Low Speed Yo-Yo's
    - Lead Turns
    - One Circle (Nose-to-Nose) Turns
    - Two Circle (Nose-to-Tail) Turns
    - Lufberry
    - Immelmann
    - Flat Sissors
    - Defensive Spirals
    - Defensive Spins

2. Between World War I and II

   - Engines and Airframes Were Developed to Win International and Speed Competitions Such as the Schneider Cup Trophy Race

   - Military Aviation Received Spurts of Encouragement from "Cameo" Wars in Manchuria (1931), Latin America (1932), Ethiopia (1935), Spain (1936), and Finland (1939)

   - The Unique Circumstances of Each "Cameo"Confused Aviation Requirements. None of the WWII Powers Was Prepared for the Strategic Range Requirements that Would Be Necessary to Win the War

   - Fighters Were Seriously Under-Powered, Under-Armed, and Unreliable. Point Design Work Usually Resulted in an Aircraft with One Good Characteristic

Fighter Performance (Cont'd)

- Historical Perspective (Cont'd)
  3. World War II:
     - A Universal Demand for More Speed and Range
     - Who Ever Had a Speed Advantage Would Dictate the Tactics of the Fight and Have the Freedom to Separate
       - To Get Height and Sun-Positional Advantage Fighters Needed Higher Ceilings
       - Light, Plywood Constructed, Mosquito Bombers Cruised at 330 mph Which Made It Difficult to Be Attacked by 300 mph Fighters
       - Me-109s Were Out-Turned by the Spitfire but Could Get Away from It in a Dive
     - Visual Sight of the Enemy Dominated Success
     - Numbers Became Important Once Pilot Losses Could Not Be Replaced
     - By the End of WWII Range Requirements Had Been Met and the First Jets Were Introduced, Whose Greatest Asset Was Their Speed Advantage (About 100 Knots) Over Mustangs and Jugs

  4. The Korean War:
     - Swept-Winged Jet Aircraft Dominated the Air-to-Air Arena While Straight-Winged Prop and Jet Aircraft Dominated the Air-to-Ground Work
     - Although the Afterburner (Re-Heat) Was Developed, It Did not Exist on Any Operational Aircraft
     - F-80s and F-84s Were Limited to Around 0.80-0.85 Mach, While the F-86 and MIG-15 Approached Compressibility in a Dive, with Average Capabilities of 0.90 to 0.95 Mach
     - Almost All Air Combat Took Place Over 20,000 Feet and Aircraft Generally Flew at Full Power All the Time
     - The MIG-15s Performance Advantages Over the F-86 Were Heavily Outweighed by USAF Pilot Skill Factors (14:1 LER) and the F-86 Powered Horizontal Tail
     - Inferior Weapons Again Limited Kills During Peak Seasons
     - Speed and Weapons Dominated Lessons Learned

Fighter Performance (Cont'd)

- Historical Perspective (Cont'd)
  5. From Korea to Vietnam:
     - Afterburners Became Available
     - First Generation IR Guided and Radar Guided Air-to-Air Missiles
     - The "Century Series" of High Performance Fighters Evolved
     - All Were Supersonic, Most Mach 2.2 Capable
     - Weapons Priorities Shifted to Missiles at the Expense of Basic Aircraft Maneuverability
     - Pilot Skill Overcame, Again, Deficiencies in Aero-Performance Capabilities Needed for Dogfighting as Evidenced by Israeli Mirage III Dominance Over the More Agile MiG-21
     - Interceptor/Fleet Air Defense and Nuclear Strike Requirements Drove Fighter Designs
     - No Sophisticated Surface-to-Air Defenses Were Encountered nor Did Advanced Soviet Aircraft Show Any Real Tactical Capabilities

F-100 Super Sabre	(North American)
F-101 Voodoo	(McDonnell)
F-102 Delta Dagger	(Convair)
F-104 Starfighter	(Lockheed)
F-105 Thunder Chief	(Republic)
F-106 Delta Dart	(Convair)
F-110 Phantom II	(McDonnell)

  6. The Vietnam War:
     - The Main Combatants Were F-105, F-8, and F-4 Series Aircraft Against Various MiG-17, MiG-19, and MiG-21 Models
     - All US Fighters Were Supersonic Capable, Vietnamese MiG-21 Was the Only Enemy Mach 2.0 Aircraft Whereas the MiG-19 Was Transonic
     - US Fighter Aircraft Flew Over 100,000 Dedicated Air Superiority Sorties
       - Not One Second of Combat Time Over 1.8 Mach Was Recorded
       - Only a Few Seconds of Combat Was Logged Over 1.6 Mach
       - Only a Few Minutes of Combat Was Logged Over 1.4 Mach
       - Only a Few Hours of Combat Was Logged Over 1.2 Mach
     - Almost All Air Combat Was Conducted Below 1.2 Mach and Below 20,000 Feet of Altitude
       - Max Turn Rates Occur at Low Altitudes and Subsonic Speeds
       - Full Afterburner Fuel Consumption Was Four Times Normal Military Power

Fighter Performance (Cont'd)

- Historical Perspective (Cont'd)

  - Summary Matrix Effectiveness Criteria

✓ = *What Was Important*

	PHASES OF COMBAT	SURPRISE	TEAMWORK (Mutual Support)	MANEUVER-ABILITY	WEAPONS
Beyond Visual Range	Set-Up	✓	✓		
	Search/Sample/Sort	✓	✓		
	STT/TWS	✓	✓		✓
BVR/WVR Transition	Shoot	✓	✓	✓	✓
Within Visual Range	Short Range Ops		✓	✓	✓
	Separation		✓	✓	

Surprise:
- 80-85% of All Kills Were Surprised by Their Attacker
- Most Came Out of the Sun or from Below in the Rear Quadrant

Teamwork:
- Prevents Surprise and Maximizes Offensive and Defensive Tactics
- Gang-Up with Numbers at the Right Place/Time

Maneuverability:
- 10-15% of All Kills Were from Seriously Committed Dogfights

Weapons:
- 5-10% Have Been Killed Just by the Pure Capability of the Weapons

  - From WWI Through to Vietnam These Trends Have Prevailed. Only in Recent Middle East Air Activities Had Statistics Changed, but Heavily Influenced by "Near-Perfect" Intell & C^2 Systems

Fighter Performance (Cont'd)

- Historical Perspective (Cont'd)

  - How the Aces Won

    1. Attack Without Being Seen, Have a Game Plan, and Retreat On Schedule
    2. "Maneuver" Is an Option Because You Did Not "Surprise." Don't Press a Bad Start – Live to Fight Another Day
    3. "Separation" Is an Option Whenever Things Are Not Going Your Way

  - Good Advise from History

    1. Use the Sun
    2. Only Engage with an Advantage (Angles/Energy/F-Pole/Number, Etc)
    3. Don't Fight Alone
    4. Use the 10-15 Sec Rule Engaged, Beyond It Survival Decreases Exponentially
    5. Check Six, Three/Nine, and Twelve
    6. Stay Off the Horizon and Don't Be Obvious Around Clouds
    7. Have an Altitude or Speed Advantage or Both

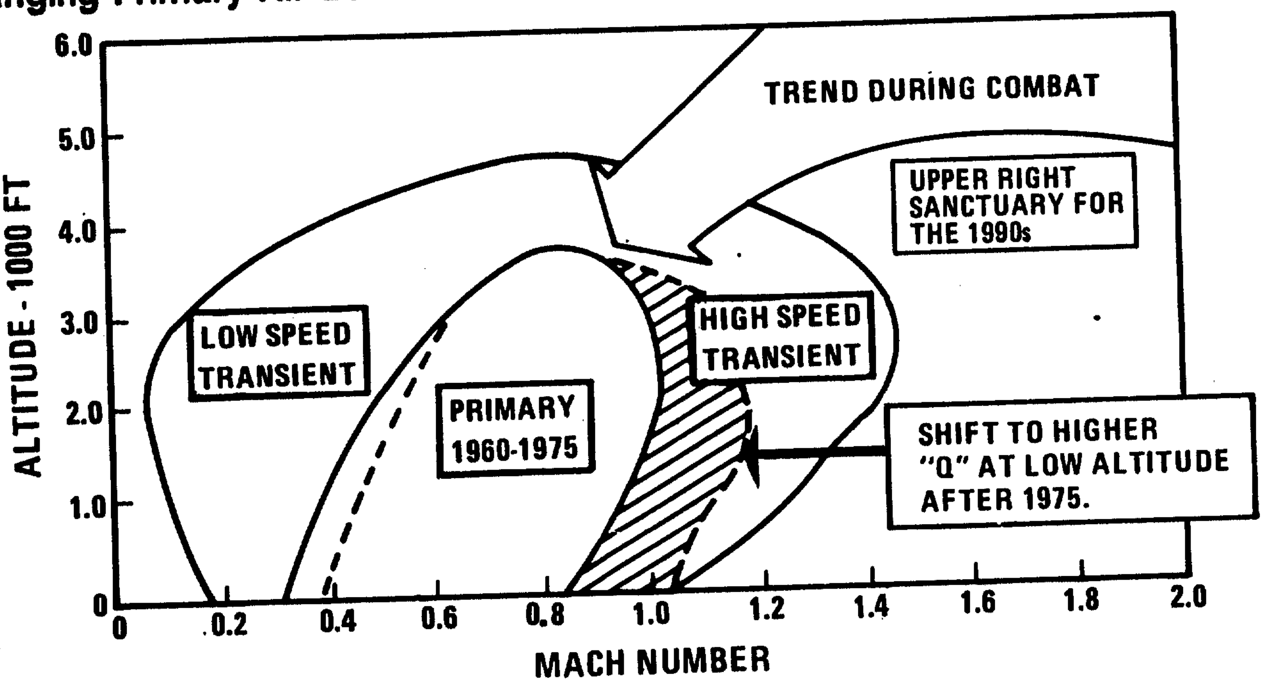
Fighter Performance (Cont'd)

- CHANGING TIMES
  - As We View the Threat Environment of the 80s, Some Changes Have Occurred that Modify These Generalities:
    - Where Mach 2.0 May not Have Been Necessary All the Time, High Speed Flight on the Deck in Excess of 700 Knots Has Been Realized (Sea Level Supersonic Plus)
    - Where Once Complexity Meant Increased Size, Today's Digital Systems Have Become More Powerful, Compact, and Reliable
    - Where Aircraft Sustained "G" Limitations Prevented Higher Speed Turns, Today's Aircraft Are Much Better by a Factor of 2, Pilot Factors at High G's Are in Question
    - Where Type and Nature of Weapons Once Committed the Aircraft to Engage to Kill, Today's Off-Boresight, All Aspects Systems, and Rapidly Pointing Aircraft Allow More Tactical "Options" and "Opportunities" to Kill While Preserving Energy Longer
    - What Once Was "Maneuvering to a Kill Envelope," Has Evolved "to Maneuvering to an Opportunity," While Reducing Your Own Signatures to a Minimum
    - Previous Surface-to-Air Threat Environments Generally Left Someplace to Fly, Today's Integrated Air Defense Environments Actually Challenge the Very Nature of Tactical Airpower Resulting in More Pre-Emptive Philosophies; More Reliance on Night and in Weather Flying and, Has Required Maneuverability with Heavy Loads
    - The Very High, Very Fast, Look-Down, Shoot-Down World Is the Only "Free" Space Left and the Threat Is Demonstrating Significant Interest There, Particularly in Countering C^3I Targets Such as AWACS
    - Fuel Is Still a Problem at High Speed but Some Aircraft Are More Efficient and/or Carry More in Relation to Aircraft Weight
    - Weapons Are Now Available to Aid in High Speed Flights with Numerous Encounters in the Forward Hemisphere. All-Aspect Weapons Have Returned the Dogfight to a Place of Honor Since it Takes Place Generally Inside of Minimum Range
    - Larger Air Battles with New Capable Aircraft and Systems Have Proven Extremely Lethal to All Players, Especially Those Who Are Committed to Classical Turning Fights in the "Primary" Arena
    - Enhanced ID, Visual and Electronic, Are Making BVR Opportunities "REAL"
    - BVR Weapons Can Offset Numbers
    - Lethality Is on the Rise

Fighter Performance (Cont'd)

- CHANGING TIMES (Cont'd)

  The Changing Primary Air Battle Arena



- In General, There Still Exists the Same Trend but the "Primary" Arena Is Shifting to the Right and Still Staying Low for the Engagement.
- The Greatest Leverage in a Combat Situation Is to Have the Ability to Achieve Kills Before the Enemy Can. Technology Has Helped in Attaining this Goal Through Improving
  - On the Reduction of Time-to-Kill
  - Situation Awareness
  - Lethal Range and Envelopes
  - Vulnerable Signatures of the Aircraft

Fighter Performance (Cont'd)

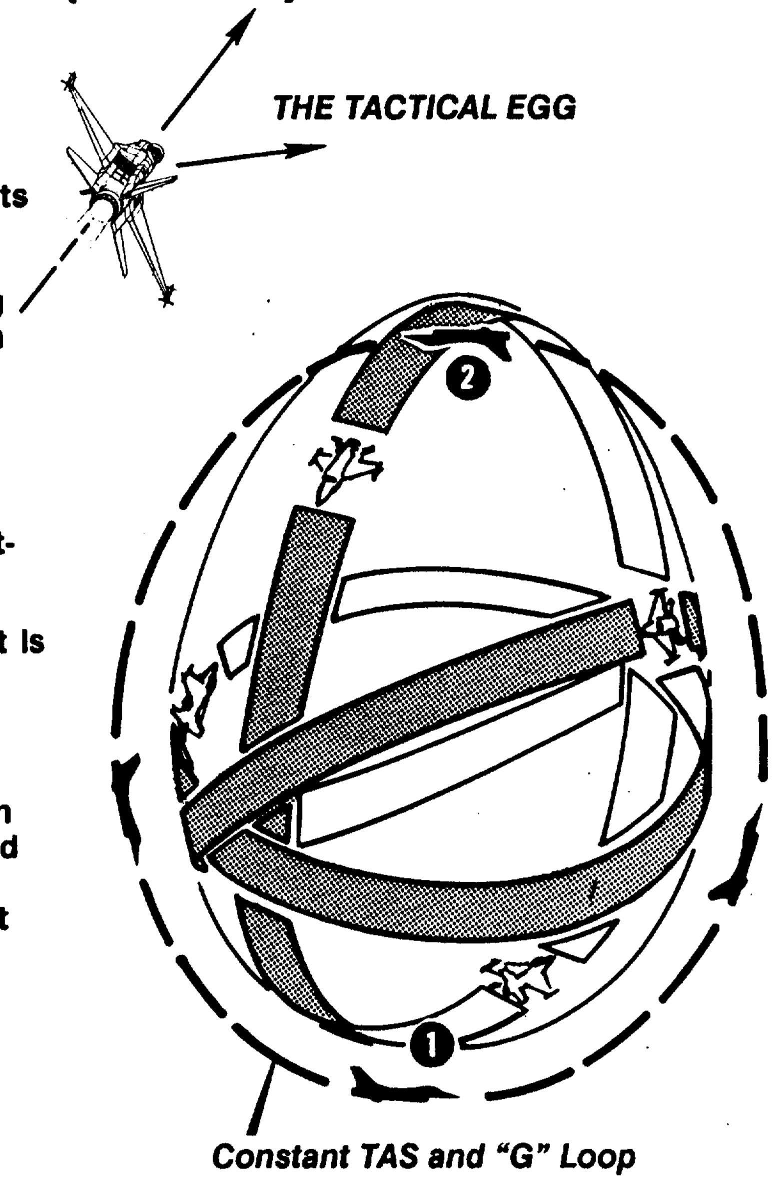
CHANGING TIMES (Cont'd)

- Historical Perspective:
  - In Reviewing Air Combat with Jet Aircraft Significant Analysis Has Been Made of the Korean War, the 1965 and 1971 Indian-Pakistan Wars, the Arab-Israeli Wars, the Three Phases of the Vietnam War and a Continuous Monitoring of Present Engagement Activities World Wide.

- Despite the Starting Conditions, Most Aerial Combat Has Degenerated Rather Quickly into What Has Been Called the "Primary" Maneuver Region of 0.5 to 1.0 Mach Below 30,000 Feet. It Has Been Shown that Even When the Combatants had a Mach 2 Capability Very Little Maneuvering or Turning Ever Took Place Above 1.4 Mach and the Terminal Phase of the Engagement Took Place in the "Primary" Arena. These Results Were Primarily Due to the Poor Turn Capability and Large Corresponding Turn Radii of These Aircraft Which Precluded a Visual Fight. Fuel, and Therefore Combat Time at These Speeds, Was Very Short.
  - From this Initial Analysis it Was Concluded that Capabilities Above 1.5 Mach Were not Necessary for an Air Superiority Fighter and that Weapon System Complexity was Thwarted by the Realities of Visual-Identification Requirements.
  - The Arrival of New Soviet Fighters (MiG-29 and Su-27) that Are Capable of F-16/F-15/F-18 Maneuvering Performance, but Also Have Significantly Improved (BVR-Capable) Weapon Systems and Full Mach 2.0 Envelopes, Has Complicated the Issue Over a "Turning-Threat," "High-Speed/Alt Threat" or "Both."

Fighter Performance (Cont'd)

- THE TACTICAL EGG
  - If an Aircraft Maintains a Constant True Airspeed and a Constant Indicated "G", an Egg-Shaped Envelope Results from the Effect of Gravity. The Force of Gravity Degrades Turning Performance When the Aircraft Lift Vector Is Above the Horizon (point 1), and Aids Turning Performance When the Lift Vector Is Below the Horizon (point 2).
  - In Flight, the Aircraft Accelerates in Dives and Decelerates in Climbs, Accentuating the Vertical Envelope, as Depicted in the Tactical Egg. Therefore, for Maximum Turn Rate, Maneuver so that Gravity Is Favorably Affecting the Thrust Vector and the Turn.
  - It Should Be Obvious, Therefore, that When the Aircraft Is Below Maneuver Speed and the Lift Vector Is Oriented Below the Horizon, Both Rate and Radius of Turn Are Enhanced.
  - When Turning, While Faster than Maneuver Speed, Turn Performance Is Limited by Velocity at Constant "G", and Is Rapidly Degraded as Speed Increases. Therefore, Turns in this Regime Should be Made Nose-High, or Out of Afterburner, or Both.
  - The Pilot, Through Control of Entry Energy, Can Maneuver Effectively and Vary the Size and Shape of the Field of Maneuver, Constrained Only by Aircraft Limits. Aircraft Will Always Turn Shorter Inverted Providing Speed Is not Increasing.



Fighter Performance (Cont'd)

III. AIRSPEED AND ATMOSPHERE RELATIONSHIPS

Fighter Performance III (Cont'd)

- 1976 U.S. Standard Atmosphere Table

GEOPOT	TEMPERATURE		PRESSURE		SPEED OF SOUND		Q/M ^{2}	DENSITY	GEOM
ALT FT	DEG F	DEG C	PSF	IN HG	FPS	KTS	PSF	SLUG/CU FT	ALT FT
0	59.00	15.00	2116.2	29.921	1116.4	661.5	1481.4	0.002377	0
5,000	41.17	5.09	1760.8	24.896	1097.1	650.0	1232.6	0.002048	5,001
10,000	23.37	-4.81	1455.3	20.577	1077.4	638.3	1018.7	0.001755	10,005
15,000	5.508	-14.72	1194.3	16.886	1057.3	626.4	836.0	0.001496	15,011
20,000	-12.32	-24.62	972.49	13.750	1036.8	614.3	680.8	0.001266	20,019
25,000	-30.15	-34.53	785.32	11.104	1016.0	602.0	549.7	0.001065	25,030
30,000	-47.99	-44.44	628.44	8.885	994.7	589.3	439.9	0.0008893	30,043
35,000	-65.82	-54.34	497.96	7.041	972.9	576.4	348.6	0.0007365	35,059
36,089	-69.70	-56.5	472.68	6.683	968.1	573.6	330.9	0.0007061	36,152
40,000	-69.70	-56.5	391.69	5.538	968.1	573.6	274.2	0.0005851	40,077
45,000	-69.70	-56.5	308.01	4.355	968.1	573.6	215.6	0.0004601	45,097
50,000	-69.70	-56.5	242.22	3.425	968.1	573.6	169.6	0.0003618	50,120
55,000	-69.70	-56.5	190.47	2.693	968.1	573.6	133.3	0.0002845	55,145
60,000	-69.70	-56.5	149.78	2.118	968.1	573.6	104.9	0.0002238	60,173
65,000	-69.70	-56.5	117.79	1.665	968.1	573.6	82.45	0.0001760	65,203
65,617	-69.70	-56.5	114.34	1.617	968.1	573.6	80.04	0.0001708	65,824

**For Geopotential Altitudes Up to 65,617 Feet, Same As: 1954 ICAO, 1959 ARDC, 1962 US STD, 1974 ICAO, and 1975 International Standard Atmospheres*

Fighter Performance III (Cont'd)

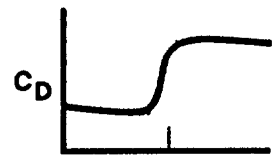
- **Mach Number Defined**

1. Named for Ernst Mach, an Austrian Physicist and Philosopher

Ernst Mach

2. Defined as the Ratio of Aircraft Speed to the Local Speed of Sound, ($M = \frac{V}{a}$) and Is Used to Define Flight Regimes

   - Subsonic: Below 0.75M
   - Transonic: 0.75 = 1.2M
   - Supersonic: 1.2 – 5.0M
   - Hypersonic: Above 5.0M



3. The Speed of Sound Is a Direct Function of Absolute Temperature and Varies with the Altitude Because Temperature Varies with Altitude

$a = \sqrt{(\text{const})\ (°R)}$, $°R = °F + 459.7$

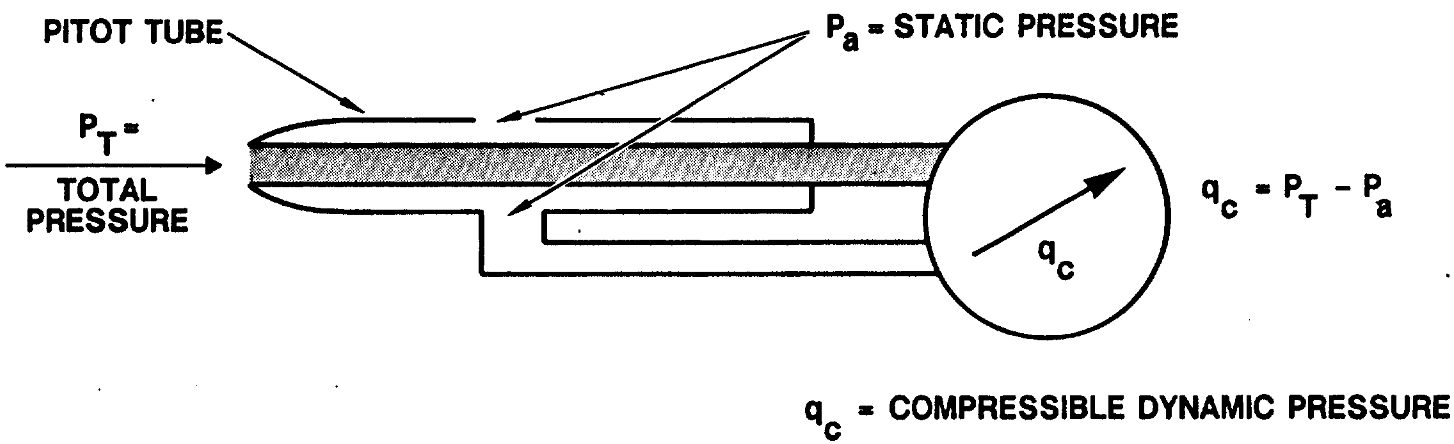
Temperature = f(altitude)

ALTITUDE	TEMPERATURE		SPEED OF SOUND
FEET	°F	°C	KTAS
Sea Level	59.0	15.0	661.47
5,000	41.2	5.1	650.03
10,000	23.3	-4.8	638.32
15,000	5.5	-14.7	626.41
20,000	-12.3	-24.6	614.31
25,000	-20.3	-34.5	601.94
30,000	-48.0	-44.4	589.30
35,000	-65.8	-54.3	576.40
36,089	-69.7	-56.5	573.56
40,000	-69.7	-56.5	573.56
50,000	-69.7	-56.5	573.56
60,000	-69.7	-56.5	573.56

Fighter Performance III (Cont'd)

- **Airspeed Measurement**

1. Total and Static Pressures Are Obtained from the Pitot-Static System:



and a Pressure Gauges Measures the Difference, q_c

2. This Gauge Is Then CALIBRATED to Indicate Airspeed in the STANDARD SEA LEVEL AIR MASS

3. This Speed Is Named CALIBRATED AIRSPEED (V_c)

Fighter Performance III (Cont'd)

• True Airspeed (V_T) Defined

1. True Airspeed = Speed of a Body Through the Air with Respect to an Axis System at Rest in the Air Mass

2. For $M \leq 1.0 \left(\frac{q_c}{P_a} \leq 0.893\right)$

$$V_T = a\sqrt{5\left[\left(\frac{q_c}{P_a}+1\right)^{2/7}-1\right]}$$

From Bernoulli's Equation for Compressible Fluid Flow (Not Valid When Shock Forms in Front of Total Pressure Probe)

3. For $M \geq 1.0 \left(\frac{q_c}{P_a} \geq 0.893\right)$

$$q_c = P_a\left[\frac{166.9216\, V_T^{7}}{a^2\left(7V_T^{2}-a^2\right)^{5/2}}-1\right]$$

From Rayleigh Pitot Formula
– Valid for When a Shock Forms in Front of Total Pressure Probe for Relating P_T to P_a

This Equation Must Be Solved for V_T by Iteration Because It Cannot Be Solved Explicitly for V_T

4. These Equations Are Dependent on Ambient Atmospheric Properties:
   - Speed of Sound (a), and
   - Static Pressure (P_a), as well as
   - Differential Pressure (q_c)

Fighter Performance III (Cont'd)

- Calibrated Airspeed (V_c) Defined

1. An Airspeed Indicator Measuring Differential Pressure, q_c , Can Be Calibrated to Read True Airspeed at Only One Atmospheric Condition

2. Standard Day Sea Level Condition Was Selected by the U.S. Army and Navy in 1925

3. In 1952, the U.S. Army and Navy Redefined These Values:

   $a = a_{SL} = 660.889$ Knots, $P_a = P_{SL} = 2116.2$ PSF

4. For $V_c \leq 660.899$ Knots

   $\left(\frac{q_c}{P_a} \leq 0.893\right) \qquad V_c = a_{SL}\sqrt{5\left[\left(\frac{q_c}{P_{SL}}+1\right)^{2/7}-1\right]}$

5. For $V_c \geq 660.899$ Knots

   $\left(\frac{q_c}{P_a} \geq 0.893\right) \qquad q_c = P_{SL}\left[\frac{166.9216\ V_c{}^7}{a^2\left(7V_c{}^2 - a_{SL}{}^2\right)^{5/2}} - 1\right]$

Fighter Performance III (Cont'd)

- Equivalent Airspeed (V_e) Defined

1. $V_e = V_T \sqrt{\sigma}$ $\quad \sigma$ = Density Ratio $= \rho / \rho_{SL}$

2. V_e Is Useful for Comparing Aerodynamic Data Because It Is a Direct Measure of Dynamic Pressure, q

3. $q = \frac{1}{2} \rho V_T^2$

$$= \frac{1}{2} \rho \left(\frac{V_e}{\sqrt{\sigma}}\right)^2 = \frac{1}{2} \rho \frac{V_e^2}{\sigma} = \frac{1}{2} \not{\rho} V_e^2 \frac{\rho_{SL}}{\not{\rho}} = \frac{1}{2} \rho_{SL} V_e^2$$

= Constanat V_e^2

4. Hence, Constant V_e Corresponds to Constant q
   For Example: V_e = 300 Knots at SL Yields the <u>Equivalent</u> (Same) q as V_e = 300 knots at 30,000 Feet

Fighter Performance III (Cont'd)

- **Mach Number Measurement**

1. A Machmeter Can Be Indicated to Read M Using Differential Pressure (q_c) and Static Pressure (P_a) Measurements from the Pitot-Static System

2. For $M \le 1.0 \left(\frac{q_c}{P_a} \le 0.893\right)$

$$M = \sqrt{5\left[\left(\frac{q_c}{P_a}+1\right)^{2/7}-1\right]}$$

From Bernoulli's Compressible Fluid Flow Equation

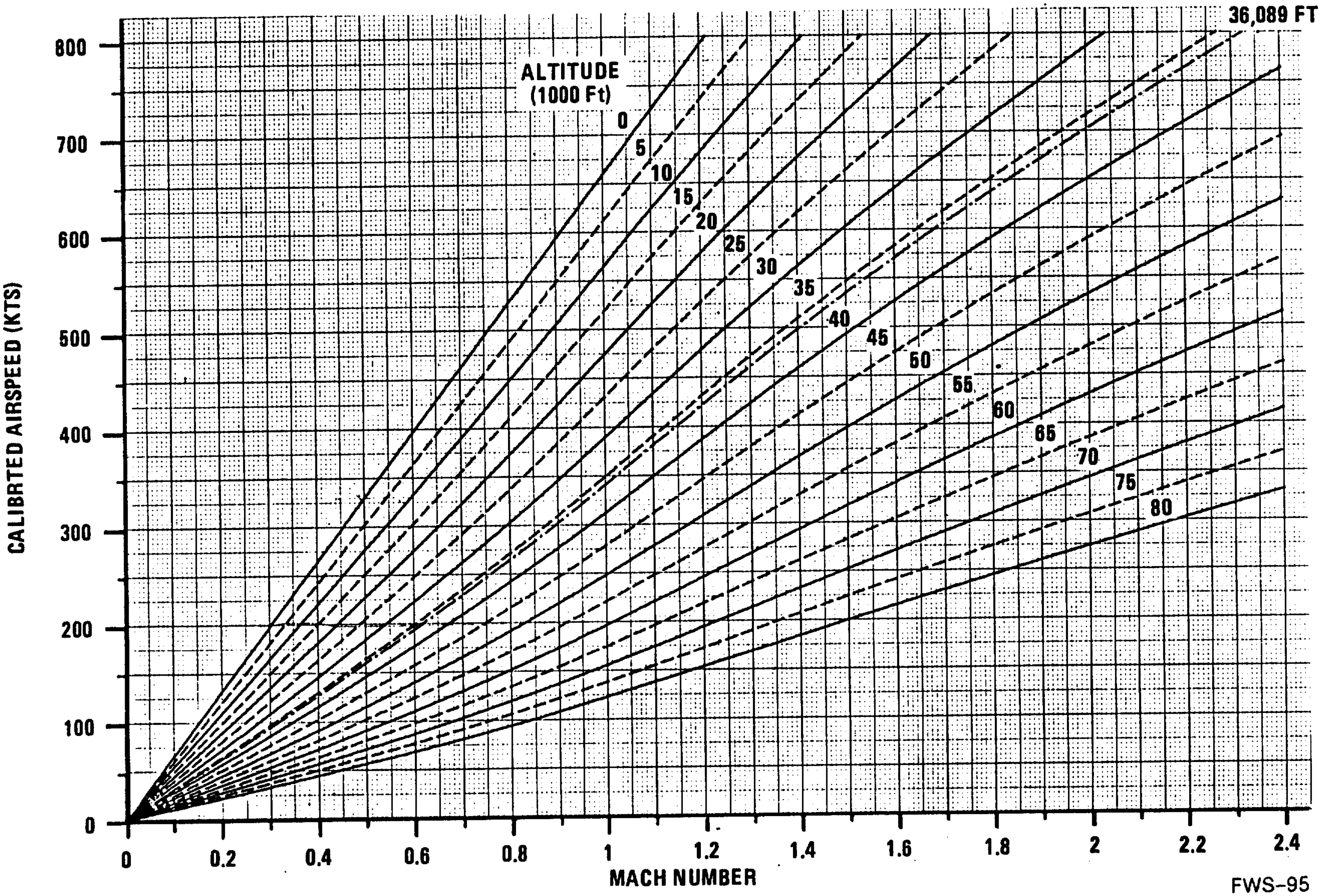
3. For $M \ge 1.0 \left(\frac{q_c}{P_a} \ge 0.893\right)$

$$q_c = 1.2M^2\left[\frac{7.2M^2}{7M^2-1}\right]^{5/2} -1$$

From Rayleigh Pitot Formula

Fighter Performance III (Cont'd)

- Calibrated Airspeed Vs Mach Number



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Fighter Performance III (Cont'd)

- **Mach Number Measurement**

1. **A Machmeter Can Be Indicated to Read M Using Differential Pressure (q_c) and Static Pressure (P_a) Measurements from the Pitot-Static System**

2. **For $M \leq 1.0 \left(\frac{q_c}{P_a} \leq 0.893 \right)$**

$$M = \sqrt{5\left[\left(\frac{q_c}{P_a} + 1\right)^{2/7} - 1\right]}$$

From Bernoulli's Compressible Fluid Flow Equation

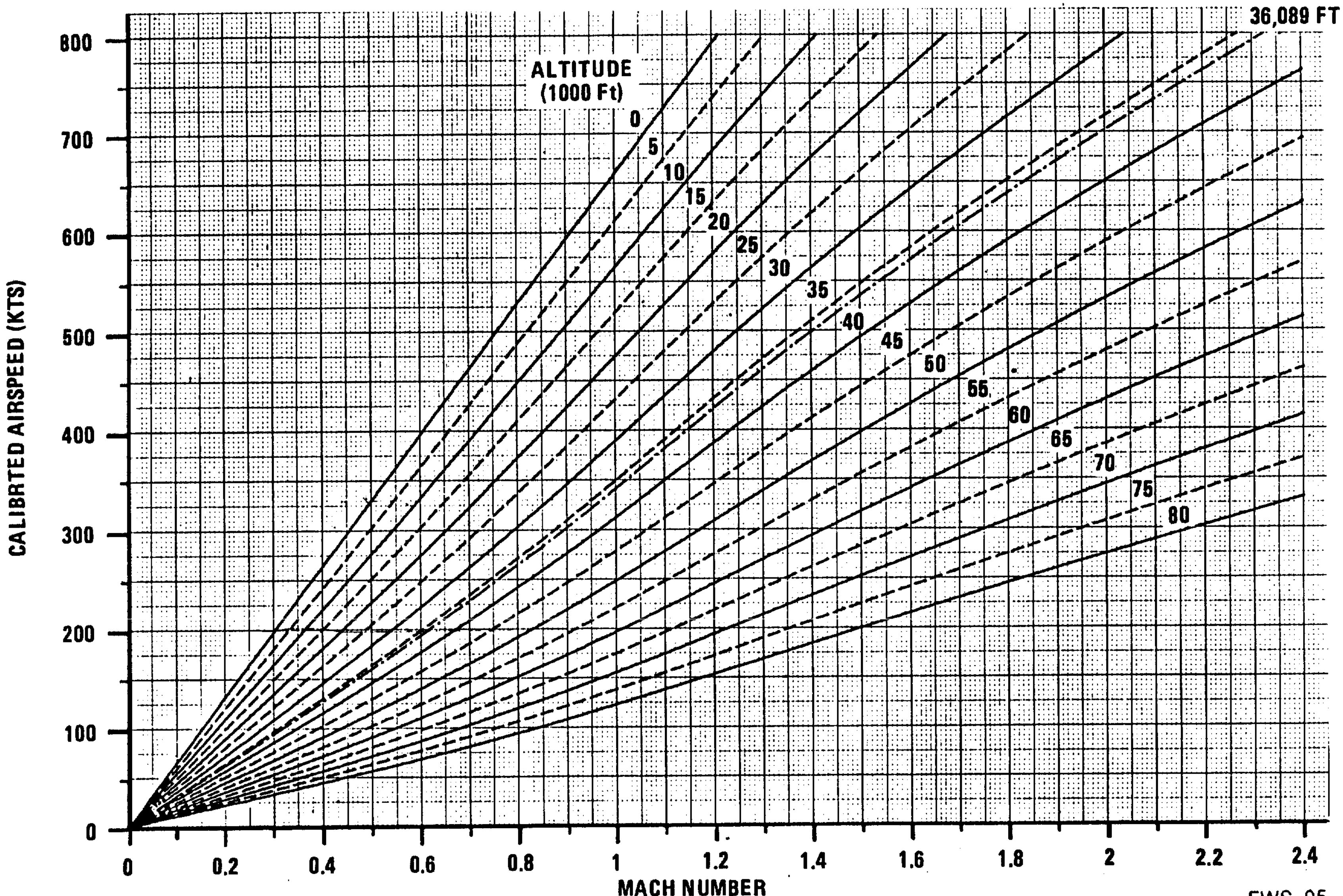
3. **For $M \geq 1.0 \left(\frac{q_c}{P_a} \geq 0.893 \right)$**

$$q_c = 1.2M^2 \left[\frac{7.2M^2}{7M^2 - 1}\right]^{5/2} - 1$$

From Rayleigh Pitot Formula

Fighter Performance III (Cont'd)

- **Calibrated Airspeed Vs Mach Number**



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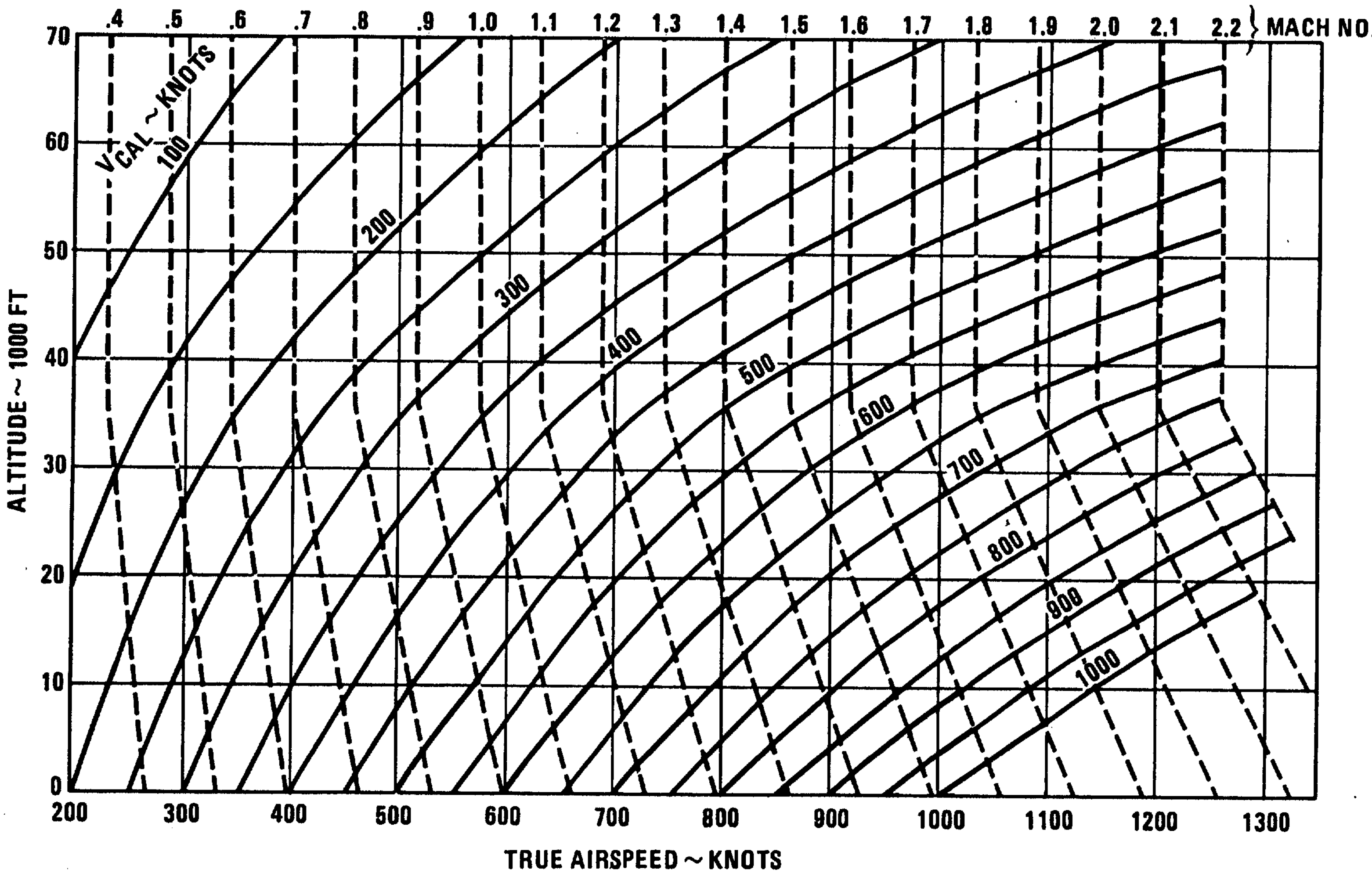
Fighter Performance III (Cont'd)

- Calibrated Airspeed Vs True Airspeed



Fighter Performance (Cont'd)

IV. AERODYNAMICS AND DESIGN

- The Forces Acting on an Aircraft Are Thrust (F), Weight (W), Lift (L) and Drag (D). The Interactions and Changes Between These Forces Define the Motion of the Aircraft

- The Design of Tactical Aircraft Presents Unique Problems Because of Numerous Operational Requirements that Are Imposed on the Same Airframe

- Today's Tactical Aircraft Is Configured for Multiple Design Points. The Performance Requirements Are Specific and Require Optimization in Design for a Multiplicity of Flight Conditions. The Aircraft May Be Required to Take Off in a Short Distance and Perform an Efficient Subsonic Cruise to a Designated Point of Loiter or Reconnaissance, and it May Be Required to Accelerate Rapidly – to Either Escape or Overtake the Adversary – and May Have to Penetrate Supersonically to Reach an Interior Target and, then, May Be Required to Maneuver, Execute an Efficient Turn, and Return After Weapons Delivery.

- Design Goals for a Tactical Weapons System Must Include Efficient Cruise at Both Subsonic and Supersonic Mach Number, Superior Maneuverability at Both Subsonic and Supersonic Mach Number, and Rapid Acceleration. And, or Course, the Aircraft Must be Controllable Throughout the Flight Spectrum. Also, Since Weapons Delivery Is a Key Feature, Low-Drag Weapons Carriage and Accurate Release and Delivery of Those Weapons Is a Prime Consideration. Further, the Problem Is Complicated by the Requirements for Invisibility – From Electronic, Optical, and Thermal Signatures.

Fighter Performance (Cont'd)

A. Lift and Drag:

1. Lift $= \frac{1}{2}\rho V^2 C_L S$

   Where

   ρ = Air Density
   V = True Airspeed
   C_L = Coefficient of lift
   S = Lifting surface area
   P = Ambient Pressure

   The quantity $\frac{1}{2}\rho V^2$ is called dynamic pressure and is represented by Q

   Thus $Q = \frac{1}{2}\rho V^2$ and
   Lift $= QC_LS$

2. Similarly, drag can be expressed as follows:

   $D = \frac{1}{2}\rho V^2 C_D S$

   Where

   C_D = Coefficient of drag
   Drag $= QC_DS$

Note: $Q = \frac{1}{2}\rho V^2 = 0.7\,PM^2$

In: $Q = \frac{1}{2}\rho V^2$

Substitute: $V = Ma$

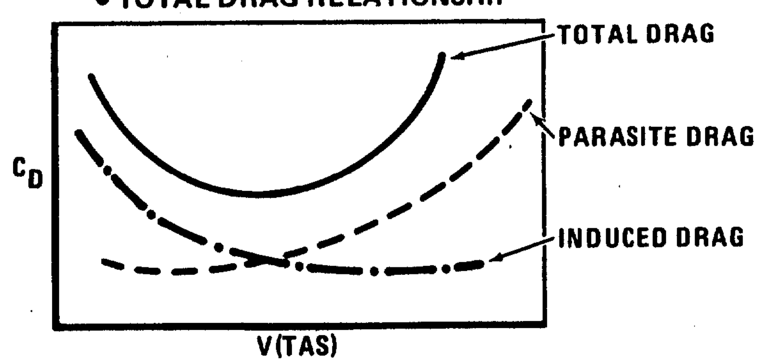
$a = \sqrt{\gamma g R T}$

$\rho = \frac{P}{gRT}$

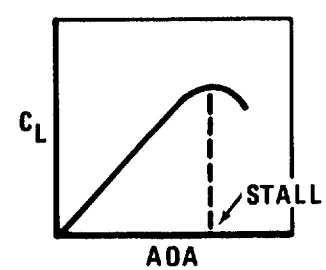
Then: $Q = \frac{1}{2}\gamma P M^2$

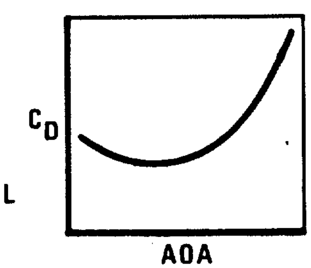
Or: $Q = 0.7\,PM^2$, where $\gamma = 1.4$ for Air

- TOTAL DRAG RELATIONSHIP



- FOR A GIVEN WING, C_L AND C_D VARY ONLY WITH ANGLE-OF-ATTACK (AOA)





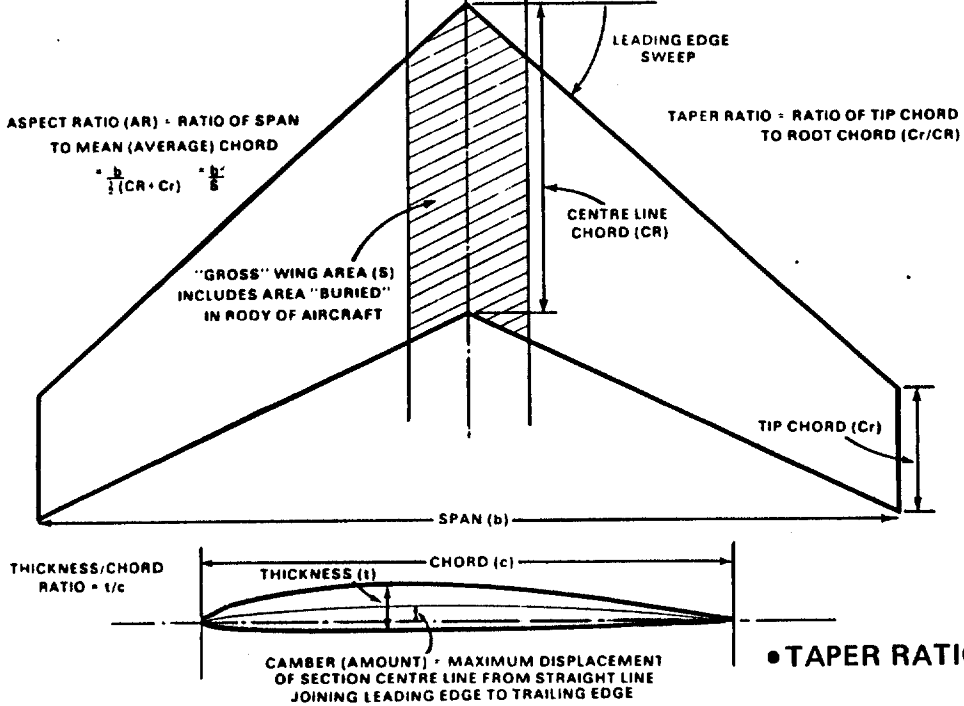
NOTE: $C_D \cong C_{D_0} + K_1 C_L{}^2$

Where $C_L \cong \text{Const.}(\alpha) \cong K_2(\alpha)$

$C_D \cong C_{D_0} + K_3\alpha^2$

Fighter Performance (Cont'd)

B. Wing Parameters:



- **ASPECT RATIO:** $AR = \frac{b}{c} = \frac{b^2}{s}$

  Where b = length of wing span from tip to tip
  c = average chord length
  s = wing reference surface area

  It can also be shown that: Induced drag is inversely proportional to AR

  $$C_{Di} = \frac{(CONST)\, C_L^2}{AR}$$

  The higher the aspect ratio the lower the induced drag. From this we can see why aircraft designed for low speed/high C_L flight (gliders) are always designed with high AR wings. Aircraft designed for high speed flight have lower AR wings because of sweep and structural considerations. Low AR also provides a smoother ride at low altitude, high speed flight.

- **TAPER RATIO:** (The ratio of the tip chord length to the root chord length) affects the local lift distribution. It has been shown that tapered wings reduce bending loads but cause more intense pressure loading on the outer part of the wing which tends toward tip stall.

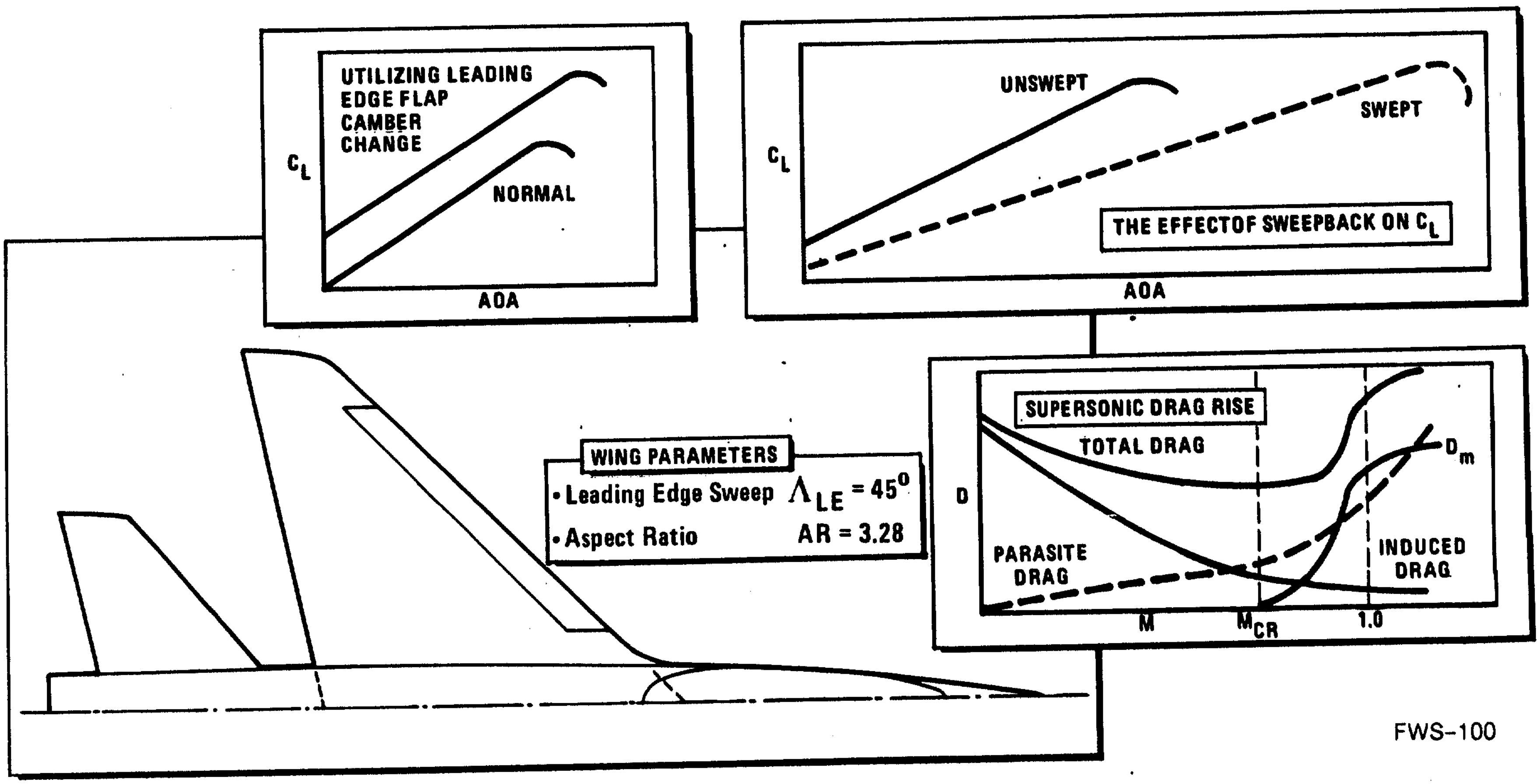
- **THICKNESS RATIO:** Thickness to chord ratio (t/c), high t/c (up to 12%) gives maximum subsonic lift, but at supersonic speeds wave drag is proportional to thickness squared. Generally, thickness for subsonic flight, thin for supersonic and trans-sonic flight. The thickness to chord ratio can be traded for sweep angle.

- **SWEEP:** Reduces wave drag, but has high drag due to lift. At high incidence, strong tip vortices form to give greatly increased lift, good for high instantaneous g's. But high drag rapidly decelerates the aircraft acting like a large speed brake.

Fighter Performance (Cont'd)

C. Wing Design:

1. Wings for Fighter Aircraft Pose a Formidable Design Task Since the Planforms Are Often of Low Aspect Ratio, Are Highly Tapered, and Are Small Relative to the Fuselage Size.
   - Flaps: There Are Many Types for Leading and Trailing Edges. In All Cases the Effect Is More Lift and Increased Drag with a Corresponding Shift of the Stall AOA Upwards
   - Sweepback: Designed to Reduce Drag at Higher Speeds, i.e. It Delays the Critical Mach Number and Total Drag Rise



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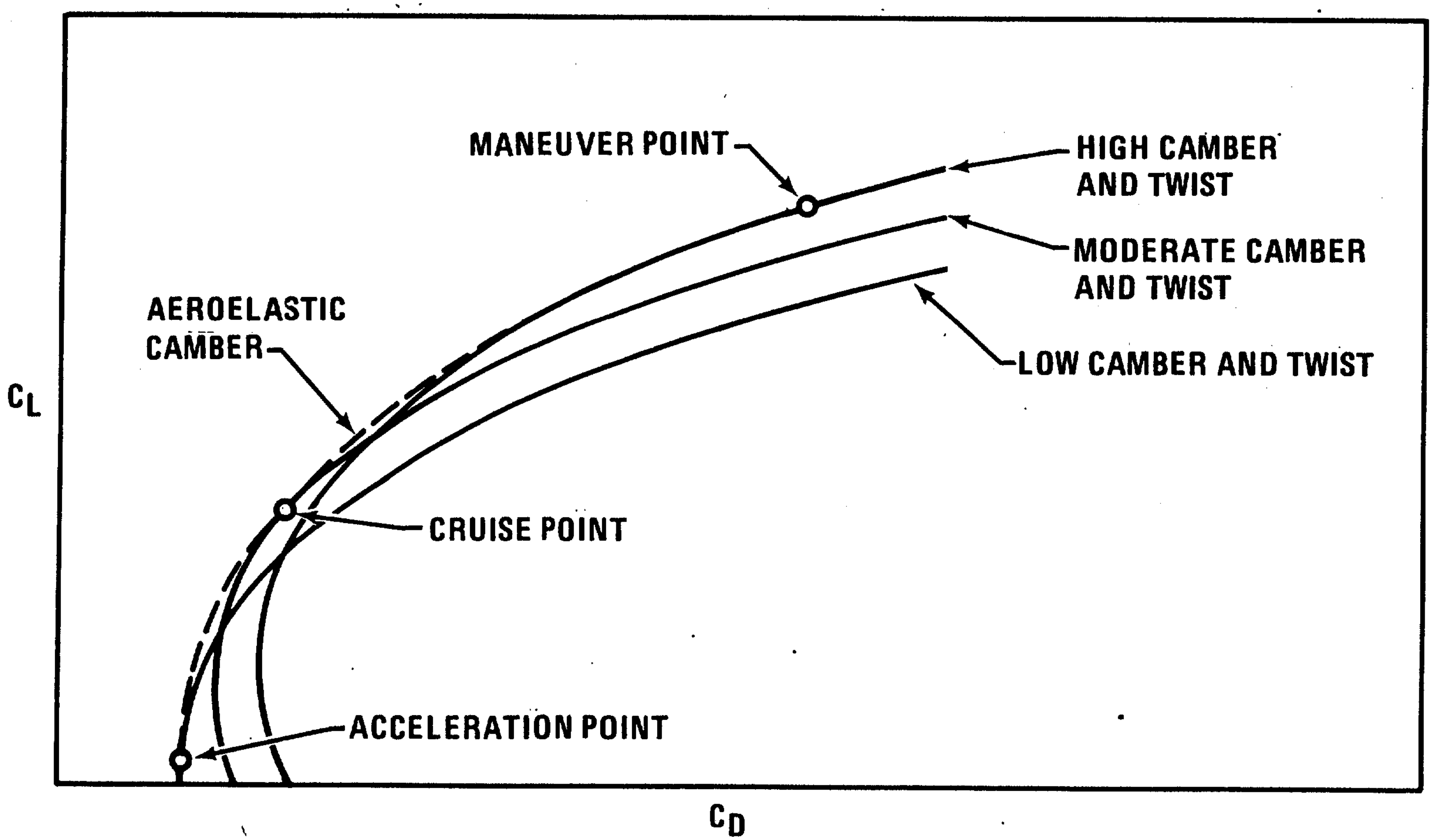
Fighter Performance (Cont'd)

D. **Aeroelastic Tailoring:**

- **The Use of Aeroelastic Tailoring Results in Considerably Less Compromise by Providing the Capability to Obtain Camber and Twist Under High-Load Maneuver Conditions While Not Paying the Weight or Camber/Twist Drag Penalty at 1-g, Cruise, and During Acceleration.**

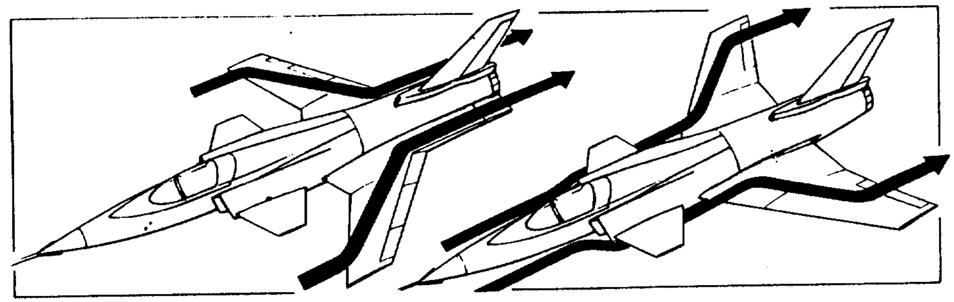


Fighter Performance (Cont'd)

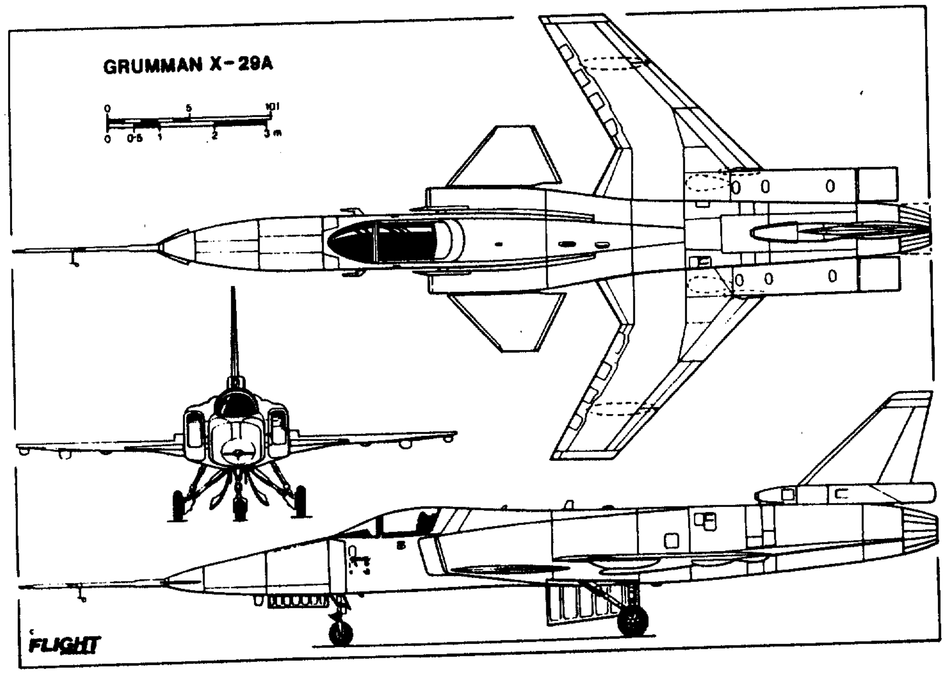
F. The Forward Swept Wing

- Advantages
  1. Higher Usable Lift
  2. Lower Supersonic Drag
  3. Better Low-Speed Handling
  4. Reduced Wing Bending
  5. Better Area and Volume Distribution

- Disadvantages
  1. Root Stall
  2. Structural Divergence



Forward Swept Wings Reverse Airflow Drift Over Wings



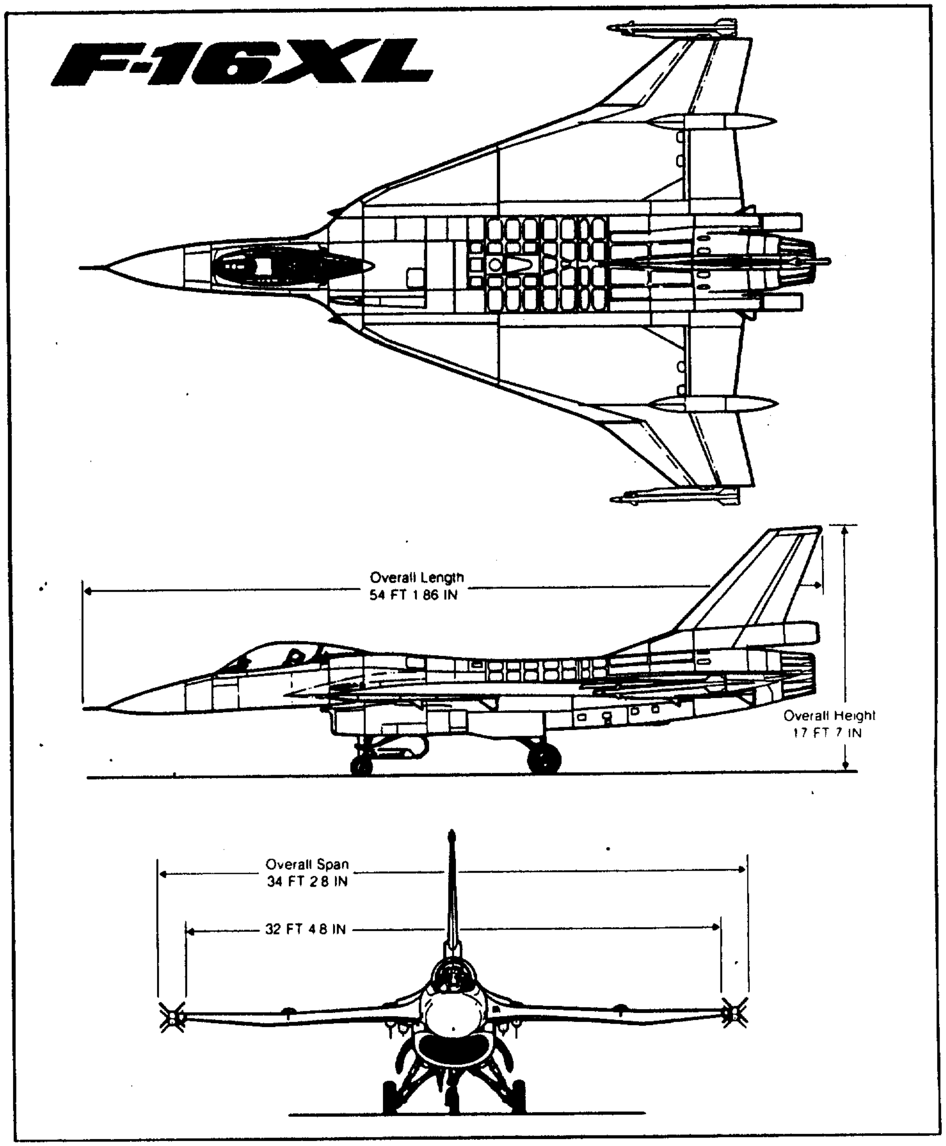
- The Tendency of Forward Swept Wings to Twist the Leading Edge of the Wing "Up" Has Been Corrected Through the Increased Strength of Composite Carbonfibre Laminates.
- Wing Structures Created with Composites Utilize Aeroelastic Tailoring that Resists the Nose-Up Twist Under Loads by a Built-In Twist That Delays Divergence.
- Full Span Trailing Edge Flaperons Are Used Symmetrically for Pitch and Assymmetrically for Roll.
- The Three Section Flaperons Also Are Camber-Changing Devices.

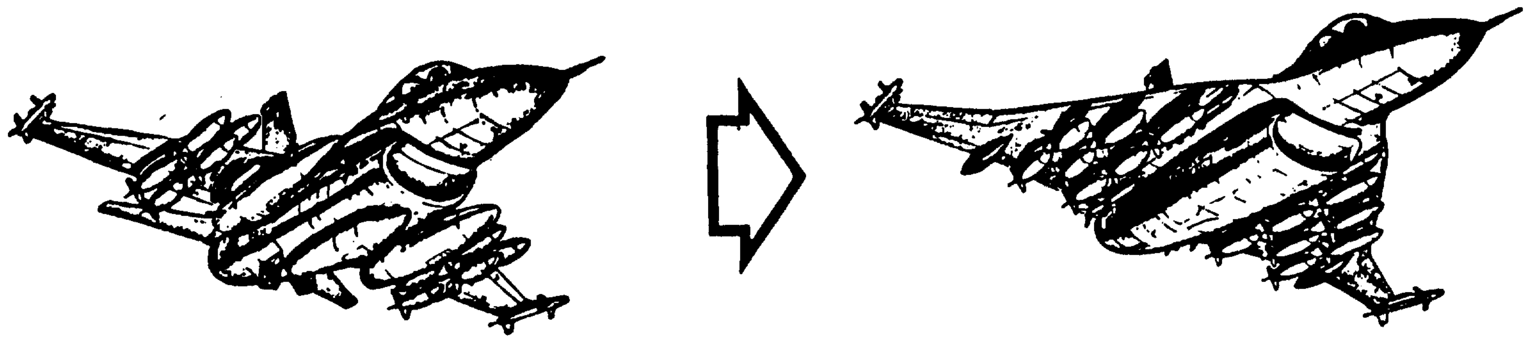
Drawings from Flight International Magazine 16 June 1984

Fighter Performance (Cont'd)

G. The Cranked Arrow Wing Concept

- The Cranked Arrow Wing Was Introduced into the F-16 Design as a Logical Choice to Substantially Improve Range, Payload, and Performance Across All Mission Areas.
- The Cranked-Arrow Wing Retains the Advantages of the Delta-Wing for High Speed Flight, While Overcoming its Disadvantages in Excessive Bleed Rate and Stability by Having the Outer Wing Portions at a Reduced Sweep Angle.
  - It Also Retains Excellent Low Speed Characteristics and Minimizes Trim-Drag Penalties Common to Tailless Delta Wings
  - Wing Skins Are Made of Advanced Graphite Composites for Strength and Stiffness
  - In-Board Aft Control Surfaces Are for Pitch and Out-Board Surfaces for Roll
- Increased Wing and Fuselage Volume Allows for 80% Internal Fuel Increase Which Greatly Increases Range and Provides for Semi-Conformal Weapons Carriage
- Double F-16 Wing Area
- Increased Skin Friction (Wetted Area) Drag But Reduced Wave, Interference and Trim Drag for Overall Net Decrease
- T/W Lower But Excess Thrust Greater
- Higher Penetration Speeds
- Reduced Signatures





Cranked-Arrow Wing Has Significant Benefits

LOWER DRAG
- 14% Lower-Clean
- 36% Lower-With Weapons

INCREASED CRUISE EFFICIENCY
- 11% Higher @ M = .85
- 25% Higher @ M = 1.6
- 40% Better Mi/lb Fuel

IMPROVED FLYING QUALITIES
- Stable at All Conditions and Loadings

GOOD RIDE QUALITY
- Equal or Better Than Already Demonstrated on F-16A

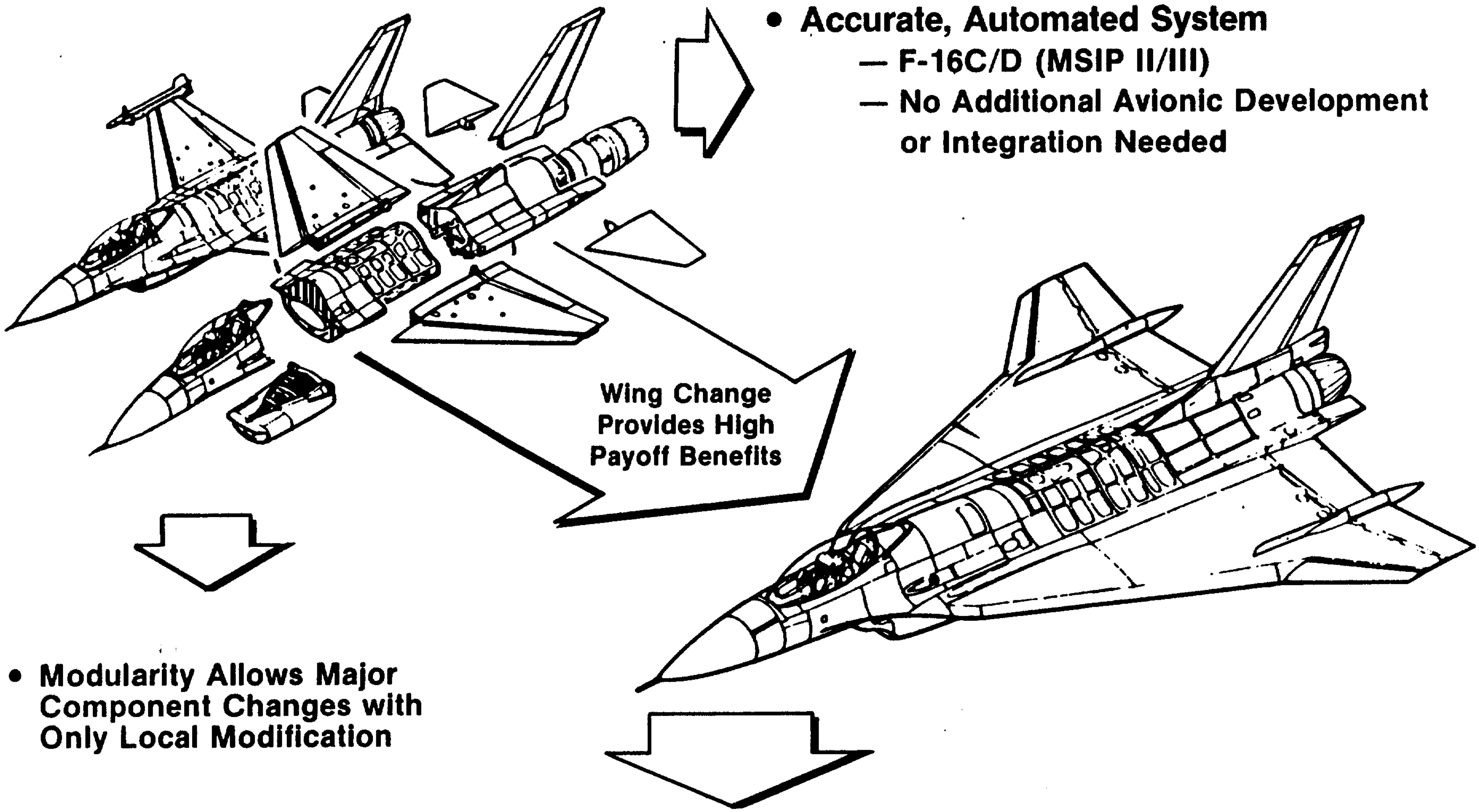
INCREASED INTERNAL FUEL
- 82% More Fuel Volume
- Reduced Dependence on External Tanks

LOWER WEAPON CARRIAGE DRAG
- Semi-Conformal
- 60% Lower Drag
- No Flying Quality Degradation
- Reduced AME/WRR

LOWER RADAR SIGNATURE
- 50% Lower Due to Shape

Design Objective Approach

- **Accurate, Automated System**
  - **F-16C/D (MSIP II/III)**
  - **No Additional Avionic Development or Integration Needed**



- **Modularity Allows Major Component Changes with Only Local Modification**

PERMITS INCREASED MISSION GROSS WEIGHT WITH . . .

- **Lower Wing Loading**
- **Lower Drag**
- **Higher Strength**

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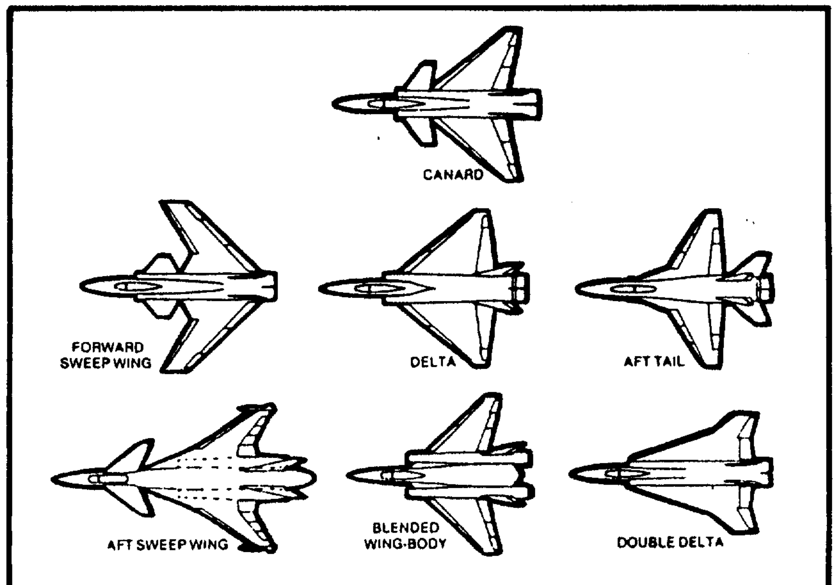
Fighter Performance (Cont'd)

H. Entering the Arena of the "Advanced Tactical Fighter"
(Col. A. C. Piccirillo's Article in Aerospace America, Nov 84, pg 74)

- **Due to Enter the USAF Inventory in the Mid-1990s**
- **Must Defeat Emerging and Postulated Threats (MiG-23/25/27/31, Su-15/27, "MiG-2000")**
- **A "Total Mission Effectiveness" Approach that Will Weigh the Elements of Performance, Supportability, Risk, and Cost**
- **Key Aspects of the ATF Design**
  - **(1) Advanced Structures & Materials**
  - **(2) Integrated Fight/Propulsion Controls**
  - **(3) Advanced Engines**
  - **(4) Improved Aerodynamics**
  - **(5) Enhanced Crew Station Durability and Survivability**
  - **(6) Maximum Use of Artificial Intelligence and Cockpit Modernization**
  - **(7) Advanced Sensors and Systems**
    - **Positive ID of Targets**
    - **Passive Track of Targets**
    - **Advanced BVR Missiles**
    - **Integrated Countermeasures**
    - **Signature Reductions**
    - **All-Weather Attack**



Many Wing Designs Are Being Evaluated

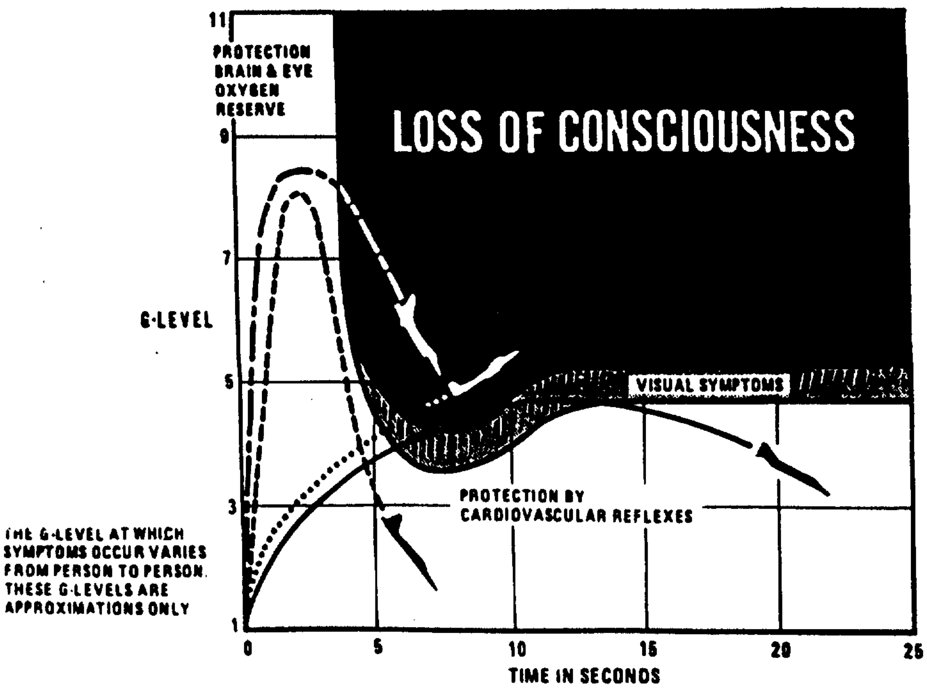
Fighter Performance (Cont'd)

I. New Frontiers in Crew Station Enhancements

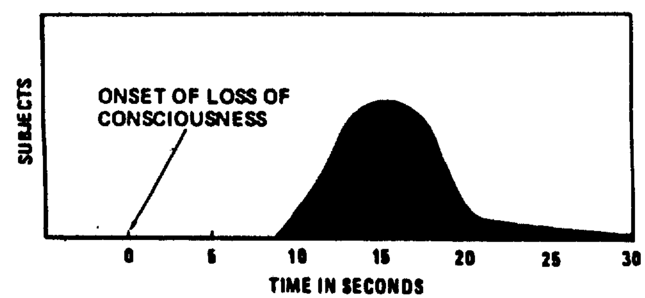
(1) "Gravity-Force-Induced Loss of Consciousness" (GLC) Is the Loss of Consciousness Attributed to the Lack of Oxygen in the Brain Due to a Rapid Onset of Above Normal G-Forces or After a Series of Several High-G Maneuvers with Minimum Time Between

- "G" Value, Duration, and Pilot Stamina Seem to Be the Key Factor
- Pilots Are Now Participating in Classroom and Centrifuge-Simulator Training to Learn How to Withstand and Cope with the High "G" Forces Necessary in Modern Air-Combat

Physiology of G-Induced Loss of Consciousness



G-Induced Loss of Consciousness



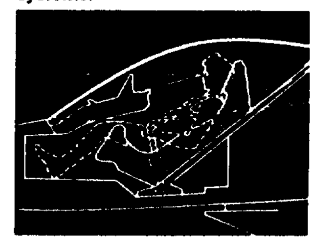
- Duration of Effective Incapacitation

Fighter Performance (Cont'd)

(2) Sine G Tolerance Is Directly Proportional to the Angle Betweeen the Head and the Heart, Cockpit Seats that Are Tilted-Back, or Are Articulating, Have Been Proven to Increase Pilot G-Load Tolerance by as Much as 50% Throughout the Flight Envelope

- Expanded Envelope of the ATF Will Require Improvements in High Altitude, High Mach and Low Altitude High "Q" Ejections.

ATF tactical operating envelope calls for improved crew protection and escape systems.



(3) Voice Command Systems Are Being Evaluated to Reduce Pilot Workload

(4) Advanced Integrated Control Systems Are Bringing the Flight Control and Weapons Control Systems Together

- ATF Requirements Will Further Blend the Propulsion System in This Arrangement

(5) Advanced Fighter Technology Integration (AFTI) Demonstration Aircraft (F-16/F-111/F-15) Have Been Evaluating Advanced Digital Flight Control Techniques

- Six Degree of Freedom Maneuvers Form Into Flight Translations Along Any Axis that Can Point or Slide the Aircraft

- Air-to-Air and Air-to-Ground Applications Appear Promising and at Times Exotic

Fighter Performance (Cont'd)

V. Aircraft Handling Qualities:

Good Flying Qualities Will Ensure the Full Utilization of the Aircraft's Design Performance and Flight Envelope. They Will Also Permit Heads Up Operation and Allow for a Fast Pilot Learning Curve. The Following Flying Qualities Can Severely Limit the Theoretical Performance into Any Aircraft.

A. Longitudinal Instability or Uncontrolled Oscillations

B. Lateral and Directional Instability

C. Stall Characteristics that Are not Predictable or Noticeable

D. Spin Characteristics that Are not Consistent or Known

E. Roll Rate/Time to Change Bank Angle that Is Excessive in Control Response

F. Stick Forces that Are Excessive or Unnatural

G. Full Range Engine Operation Under Loads that Is Limited or Causes Concern Over Stall/Stag Problems

H. Engine Spool-Up Time to Max Power that Is too Long

I. Out-of-Cockpit Instrumentation (HUD) and Stick Feel that Is not ACM Comfortable

J. Guns-Tracking Ease and Agility that Is not There

K. Excessive Heads-In Time to Review Displays for SA

Fighter Performance

VI. Fighter Performance Comparison Factors

A. Parameters that Describe the Maneuver and Energy Capabilities of an Aircraft. Specifically There Are "Turn Measures" and "Energy Measures" that Are Interrelated to Result in Position Advantage of One Aircraft Over Another

- Instantaneous and Sustained "G"
- Turn Radius and Rate
- Acceleration and Deceleration
- Specific Energy and Specific Power
- Max Speed and Altitude

B. Advanced Technology Breakthroughs in Today's Fighters Have Been Created to Achieve Greater Lift-to-Drag and Thrust-to-Weight Ratios on a Scale Never Achieved Before

- High Tech Engines of Modular Construction
- Blended Wing and Fuselage Lines
- High Lift Strakes, Chines, Extensions, Cranks
- All Maneuvering Surfaces Programmed for Optimal Operation
- Relaxes Static Stability
- Fly-by-Wire and Minimal Hydraulics
- Composite Structure

Fighter Performance (Cont'd)

B. Energy Maneuverability (EM): Is the Name Given to a Process of Energy Management, Whereby Comparisons Are Made of the Energy and Power of Competing Aircraft. It Shows an Aircraft's Total Energy in Terms of Altitude and Velocity at a Given Configuration.

- Based on Principles of Mechanics and Developed by John R. Boyd and T. P. Christie in March 1966 in Order that Combat Comparisons Could Be Made of the F-4C and MIG-21F, and to Improve USAF/USN Exchange Ratios in the Sky Over North Vietnam

- Specific Energy (E_S): The Sum, Per Unit Weight, of Potential and Kinetic Energy in Feet. "E_S" Can Be Completely Converted to Potential Energy (Theoretically) to Produce an Overall Potential Energy Height

Total Energy (TE) = Potential Energy (PE) + Kinetic Energy (KE)

W = Aircraft Weight (LBS)

H = Aircraft Altitude (FT)

m = Mass (W/G) (LBM)

G = Force Due to Gravity (32.2 FT/Sec^2)

V_t = True Air Speed (FT/SEC)

TE = PE (Altitude) + KE (Velocity)

$$TE = WH + 1/2mV_t^2$$

$$TE = WH + \frac{WV_t^2}{2G}$$

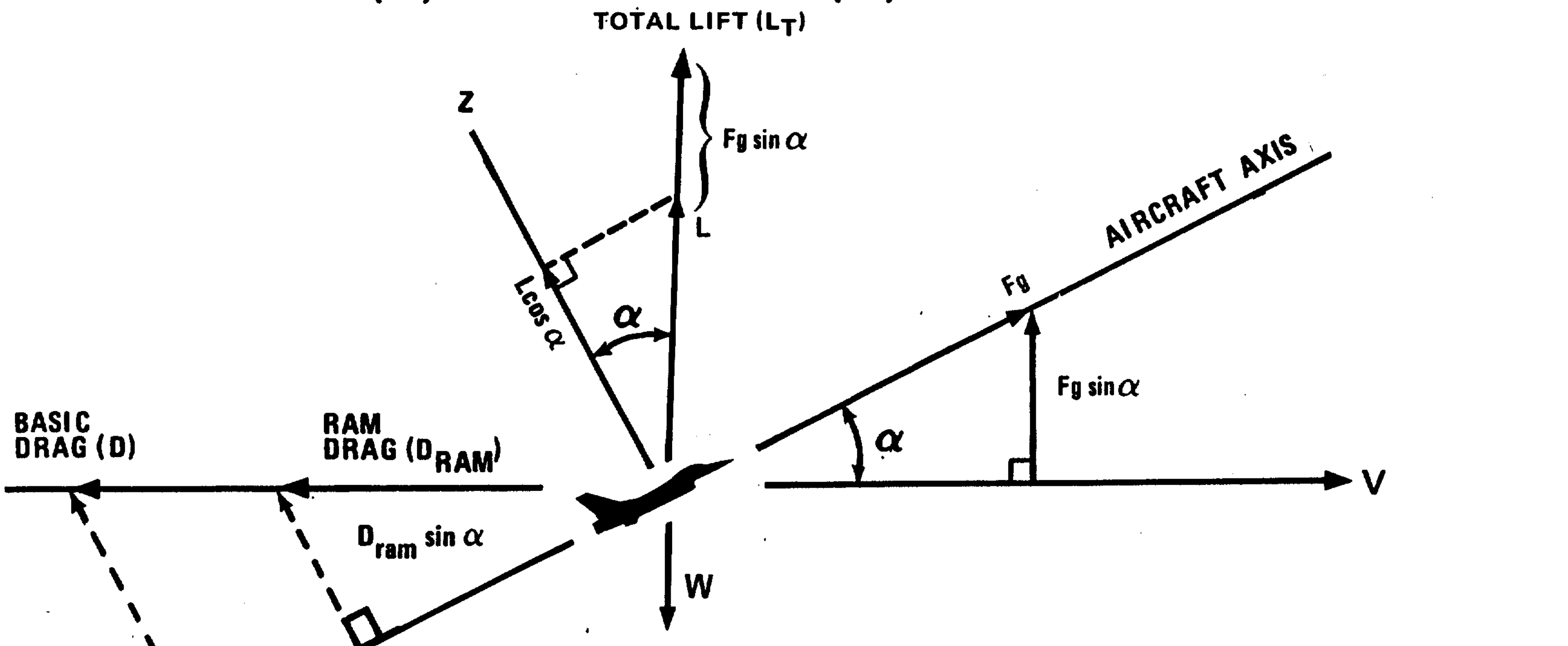
$$E_s = \frac{TE}{W}$$

$$E_s = H + \frac{V_t^2}{2G}$$

Specific Energy State of the Aircraft

Fighter Performance (Cont'd)

C. Normal Force (Nz) and Turn Load Factor (NT) Derivation



Z= PERPENDICULAR COMPONENT TO THRUST ALONG AIRCRAFT AXIS

$Z = L\cos\alpha + D\sin\alpha + D_{ram}\sin\alpha$

N_Z= THE STRUCTURES LOAD FACTOR, NORMAL TO THE AIRCRAFT AXIS = Z/W

$$\frac{L\cos\alpha + D\sin\alpha + D_{ram}\sin\alpha}{W} = N_z$$

L_T = AIRCRAFT LIFT VECTOR, PERPENDICULAR TO THE AIRCRAFT VELOCITY VECTOR

$L_T = L + Fg\sin\alpha \quad = W$ (For Constant Altitude)

N_T= TURN LOAD FACTOR, THE "G" FORCES NORMAL TO THE VELOCITY VECTOR = L_T/W

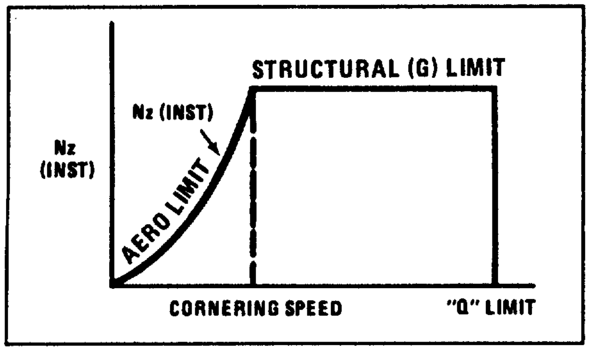
$$\frac{L + Fg\sin\alpha}{W} = N_T$$

Fighter Performance (Cont'd)

D. Performance Factors:

$$Nz = \frac{C_L \cos\alpha + (C_D + C_{D_{RAM}}) \sin\alpha}{W/QS} \quad \text{(Perpendicular to Body Axis)}$$

1. INSTANTANEOUS "G" (Nz INST):

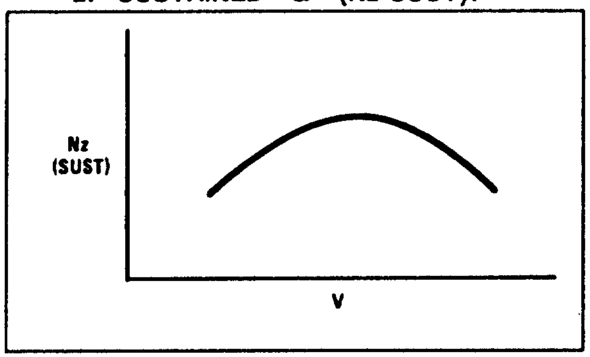


Maximum Instantaneous "G" Is a Result of the Airframe/Wing Characteristic. It Occurs at the Maximum Lift the Wing Can Generate. Instantaneous "G" Can Be Increased at Any Airspeed by Decreasing Wing Loading (W/S). Instantaneous "G" Can Be Found on V-N and Turn Rate Diagrams.

The Airspeed Where the Maximum Nz (INST) Line Intercepts the "G" Limit of the Aircraft Is Defined as the Aircraft Cornering Speed. This Is the Lowest Speed at Which Max Instantaneous "G" Is Available.

$$\text{Maximum Nz (INST)} = \text{Nz AT } C_L = C_{L_{MAX}}$$

2. SUSTAINED "G" (Nz SUST):



Maximum Sustained "G" Is the Maximum "G" that the Aircraft Is Capable of in a Constant Airspeed Level Turn. Sustained "G" Is Dependent on Both Engine and Airframe Characteristics. In order to Sustain a Flight Condition You Must not Be Accelerating or Decelerating (T = D). Sustained "G" Increases with Both Increases in Thrust to Weight and Lift to Drag.

N_z (SUST) = N_z when Thrust = Drag ($F_g \cos\alpha = D + D_{RAM}$)

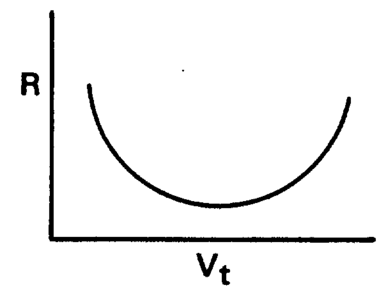
$$= \frac{L \cos\alpha + (D + D_{RAM}) \sin\alpha}{W} = \frac{L \cos\alpha + Fg \cos\alpha \sin\alpha}{W}$$

Fighter Performance (Cont'd)

3. Turn Radius (R): **Is the Distance that Your Aircraft Displaces Laterally in a Turn. From this It Can Be Seen that an Aircraft Pulling High "G's" at Low Airspeed Has a Small Turn Radius**

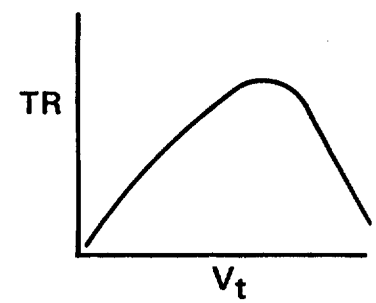
$$R = \frac{V_t^2}{G\sqrt{N_T^2 - 1}}$$

V_t = TAS (ft/sec)
G = 32.2 ft/sec^2
N_T = Turn Load Factor
R = Radius in Feet



4. Turn Rate (TR or θ): **Turn Rate in the Horizontal Plane Equates to Pitch Rate in the Vertical Plane. It Can Be Expressed in Degrees per Second.**

$$TR = 57.3 \frac{G}{V_t} \sqrt{N_T^2 - 1}$$



NOTE:
The Speeds for Max Sustained "G," Max Instantaneous "G," Max Sustained Turn Rate and Min Sustained Turn Radius Are All Different. Relative Speeds May Be as Important as the Absolute Value of the Performance Factors When Doing a Comparison.

Fighter Performance (Cont'd)

5. Acceleration (a):

$$a = \frac{(T - D)\,g}{W}$$

Heavily Dependent Upon Thrust-to-Weight but Also Linearly Dependent Upon Drag.

NOTE: On Lower T/W Aircraft the Reduction of Drag Through Unloaded AOA Is Important to Gain Acceptable Acceleration Rates.

6. Deceleration (-a):

A Sometimes Difficult Capability for Low-Drag Designed Fighters but an Important Tactical Tool. Throttle Back, Speed Brakes, and Loaded Flight Most Common Techniques, Each Having its Respective Tactical Benefits and Shortcoming. Particularly Be Aware if They Can Be Observed, Protruding or Colored Paint Inside Structure.

7. Specific Energy (E_S):

The Total Energy (Potential + Kinetic) per Pound of Aircraft Weight $E_S = H + 1/2\, V_T^2/g$

8. Specific Excess Power (P_S):

Time Rate of Change of E_S per Pound of Aircraft Weight

$$P_S = \left(\frac{T - D}{W}\right) V$$

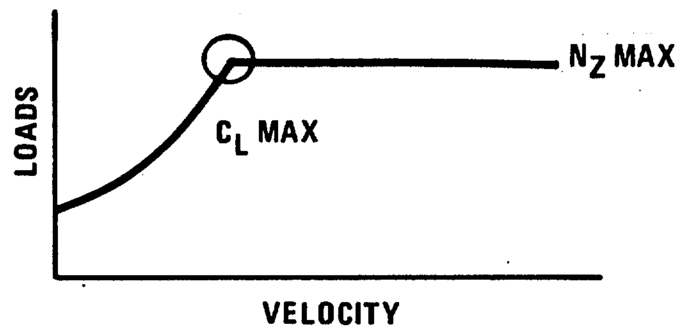
9. Maximum Speed and Altitude: Speed and Altitude Conditions at $P_S = 0$

Fighter Performance (Cont'd)

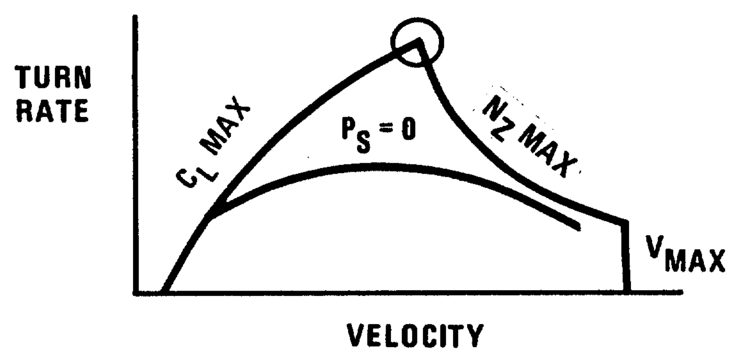
F. Corner Velocity

THE VELOCITY AT WHICH AN AIRCRAFT ATTAINS ITS LARGEST INSTANTANEOUS TURN RATE WITHIN THE G-LIMITS OF THE STRUCTURE

(1) Corner Velocity shows up as a "corner point" on the V-N Diagram.



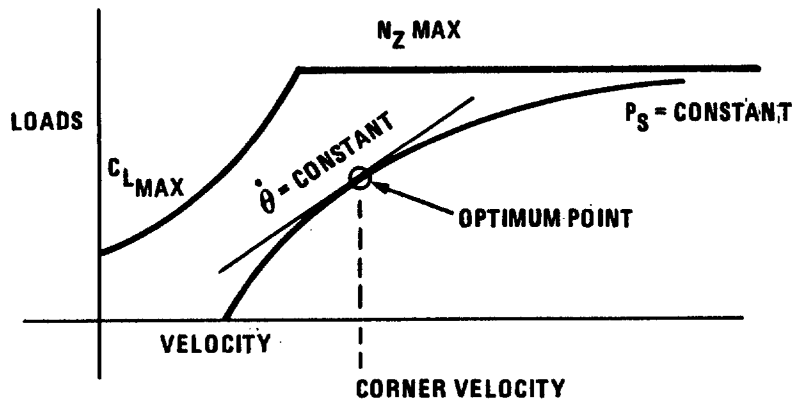
(2) It also shows up in the Turn-Rate Diagram



Fighter Performance (Cont'd)

3. Corner Velocity Is Also Considered the Speed at Which Minimum Time Turns Can Be Made at Constant Altitude

   - The Application of the "Pontryagin Minimum Principal" to Define Conditions for Minimum Time Turns Has Shown that Constant Altitude Min-Time Turns Occur at the Load Factor and Flight Condition Where a Constant Energy Rate (Ps) Line Is Tangent to a Line of Instantaneous Turn Rate



   - Physically, This Is the Condition at Which Energy Is Expended at a Uniform Rate in Order to Attain a Maximum Instantaneous Turn Rate. This Always Occurs Close to, or at the Corner Velocity. Therefore, Corner Velocity Also Represents the Flight Condition that Achieves Min-Time Turns at Constant Altitude

Fighter Performance (Cont'd)

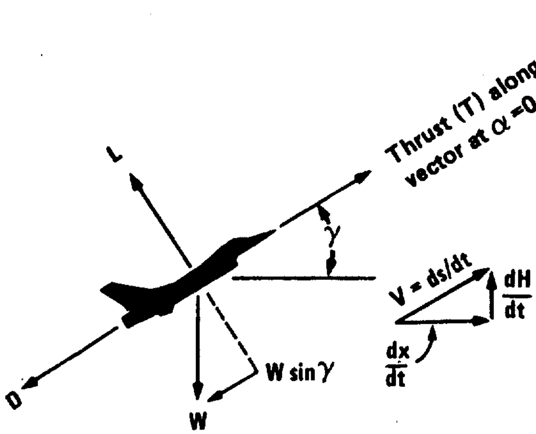
VII. Energy Maneuverability

A. History of Energy Relationships of Aircraft

- The Concept of Energy-Height (Potential Energy) Was First Applied to Aircraft Climb Performance Estimations in Germany During World War II
- Subsequently Serious Analysis Was Done on Aircraft Performance by Kaiser, Rutowski, Lush, and Others. Primary Focus Went on the Development of Parameters that Would Optimize Climb Performance.
- In the 1960s, Boyd Extended the Energy-Height Approach to Cover Maneuvering Flight and Evolved Maximum Maneuver Concepts Which Had Considerable Impact on Fighter Design. With Christie, Boyd Created a Concept of an Energy-State that Considered the Aircraft's Total Energy not Just Its Potential Energy. In Essence, Energy Trades Can Be Examined Where Speed, Load Factor, Height, and Acceleration Can Be Exchanged
- The Following Will Develop the Concepts of Specific Energy and Specific Excess Power

Fighter Performance (Cont'd)

• **SPECIFIC POWER (P_S):** Is the time rate of change of E_s which characterizes an aircraft's ability to change energy levels (climb, acceleration, pulling G's).



$$\sum F_{\text{along flight path}} = ma = m\frac{dV}{dt}$$

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

solve for $\frac{dV}{dt}$ and substitute into → $P_s = \frac{dE_s}{dt}$, $\quad P_s = \frac{dH}{dt} + \frac{VdV}{Gdt}$

$$\frac{dH}{dt} = V\sin\gamma$$

PLUG-IN →

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

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

T = thrust (LBS)
L = lift (LBS)
D = drag (LBS)
W = mg = weight (LBM)
γ = climb angle (°)
V = velocity

✔ P_S IS A FUNCTION OF AN AIRCRAFT'S EXCESS THRUST, NET THRUST – TOTAL DRAG (T-D), AT A CHOSEN AIRSPEED, ALTITUDE, POWER SETTING, AND WEIGHT

✔ STEADY STATE CONDITIONS ARE AT P_S = 0, WHERE THRUST = DRAG

✔ ALL OTHER VALUES ARE INSTANTANEOUS SINCE THRUST & DRAG ARE NOT IN EQUILIBRIUM AND THE AIRCRAFT WILL BE CHANGING ITS AIRSPEED, ALTITUDE OR BOTH

Fighter Performance (Cont'd)

Re-Examining the P_S Derivation

$$T - D - W\sin\gamma = \frac{W}{G}\frac{dV}{dt} \quad \left(\begin{array}{c}\text{Divide by W \&}\\ \text{Rearrange}\end{array}\right)$$

$$\frac{T-D}{W} = \sin\gamma + \frac{1}{G}\frac{dV}{dt} \quad \text{(Multiply by V)}$$

$$\left(\frac{T-D}{W}\right)V = V\sin\gamma + \frac{V}{G}\frac{dV}{dt} = P_S = \frac{dH}{dt} + \frac{V}{G}\frac{dV}{dt}$$

Therefore: P_S = Instantaneous Rate of Climb at $\frac{dV}{dt} = 0$ (a = 0) or Get Instantaneous Acceleration in the Following Way:

$$\sin\gamma + \frac{1}{G}\frac{dV}{dt} = \frac{P_S}{V} \quad \left(\begin{array}{l}\text{Divide by V}\\ \text{SIN } \gamma = 0 \text{ for Level Flight}\end{array}\right)$$

$$\frac{dV}{dt}\left(\begin{array}{c}\text{Instantaneous}\\ \text{Acceleration}\end{array}\right) = \frac{P_S G}{V}$$

$$\boxed{a_{INST} = \frac{P_S G}{V}}$$

P_S in Feet/Second Can Be Converted to KTAS/Second of Instantaneous Acceleration Which Gives a Better Indication of Energy Gain or Loss.

See Page FWS-104B for Table of Conversion to KCAS/SEC.

Example at 0.9M, 15,000 Feet

V = 564 KTAS = 952 Ft/Sec

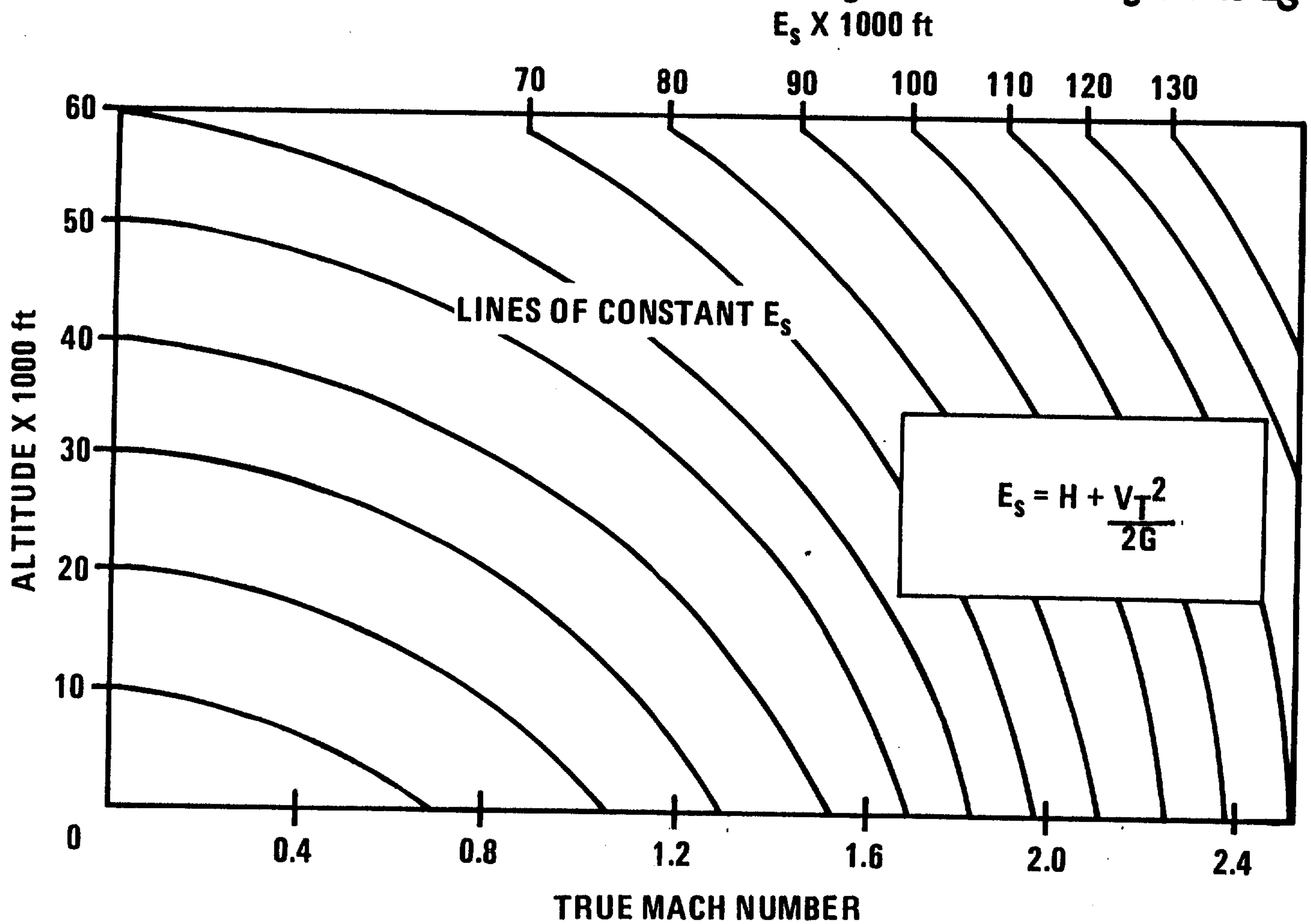
G = 32.2 Ft/Sec^2

P_S (Ft/Sec)	a_{INST} Ft/Sec^2
100	3.4
200	6.8
300	10.1
400	13.5
500	16.9
600	20.3
700	23.7
800	27.1
900	30.4
1000	33.8

Fighter Performance (Cont'd)

C. Height-Mach (HM) Diagrams: The H-M Diagram Is One Tool to Compare Aircraft. With the Knowledge of P_S and E We Are Ready to Build an H-M Diagram. It Is Important to Specify Engine Types, Configuration, Load Factor ("G"), and Combat Weight, Since All of These Effect the Terms In $P_S = \frac{V\ (T\text{-}D)}{W}$.

The First Thing on the H-M Diagram Is E_S Contours.

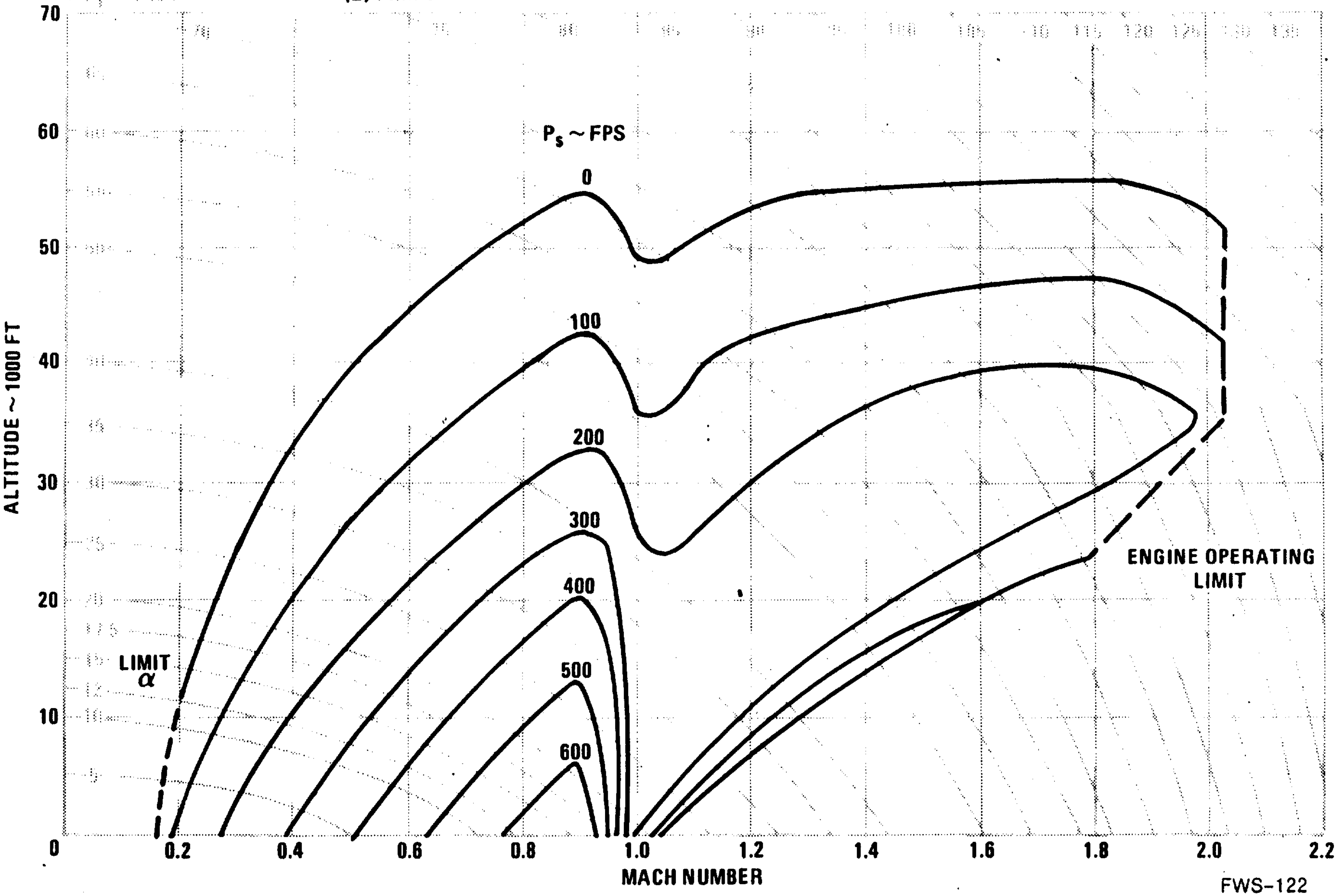


FWS-121

Energy Rate for 1g Operation With V$_{Max}$ Power

- ENERGY RATE FOR 1G OPERATION WITH COMBAT PLUS THRUST

G. W. = 21940 LBS ≈ 50% FUEL
(2) AIM-9



FWS-122

Fighter Performance (Cont'd)

D. Conversion of P_S in FT/SEC to KCAS/SEC

$$\frac{dV_c}{dt} \bigg/ P_S \sim \frac{\text{KCAS/SEC}}{\text{FT/SEC}}$$

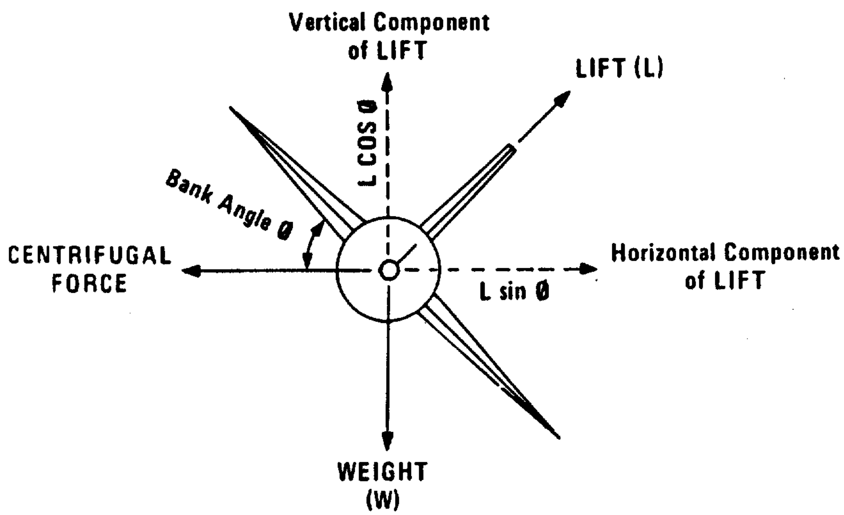
MACH NUMBER	5,000 FT	15,000 FT	25,000 FT
0.2	0.0808	0.0720	0.0635
0.4	0.0407	0.0366	0.0325
0.6	0.0274	0.0251	0.0226
0.7	0.0236	0.0219	0.0198
0.8	0.0208	0.0194	0.0178
0.9	0.0186	0.0176	0.0163
1.0	0.0168	0.0161	0.0151
1.2	0.0135	0.0128	0.0122
1.4	0.0115	0.0103	0.00970
1.6	0.0100	0.00880	0.00788
1.8	0.00890	0.00778	0.00681
2.0	0.00801	0.00699	0.00607
2.2	0.00728	0.00636	0.00550

Fighter Performance (Cont'd)

VIII. Maneuvering in the Horizontal Plane

A. Theoretical Derivation

To Maintain Constant Altitude (Level Flight) During a Banking Turn the Vertical Component of the Lift Vector Must Equal the Magnitude of the Aircraft Weight Vector

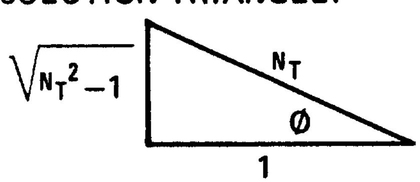


$L \cos \phi = W$ (level turn)

BUT: N_T (TURN LOAD FACTOR) $= \frac{L}{W}$

THEREFORE: $N_T = 1/\cos \phi$

SOLUTION TRIANGLE:



$\cos \phi = 1/N_T$

$\sin \phi = \frac{\sqrt{N_T^2 - 1}}{N_T}$

- Therefore

  L cos Ø must Just Equal the Weight for Level Flight

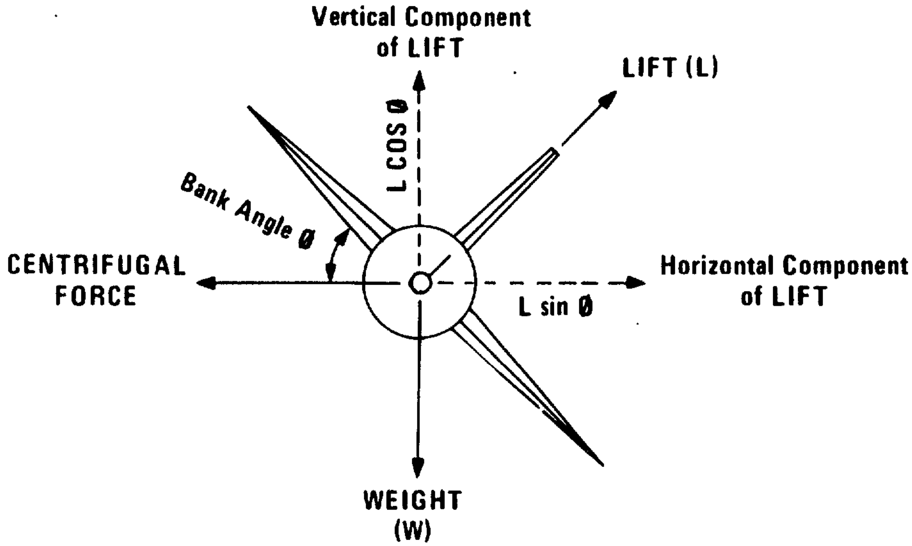
- Concerning Lift:

  Total Lift $L = L_a + T\sin\alpha$ Where:
  L_a = Aerodynamic Lift
  $T\sin\alpha$ = the Component of Thrust (T) in the Lifting Plane Due to Angle of Attack (α). At Low AOA, $\sin\alpha$ Approaches Zero and Cancels the Thrust Component

- Concerning Load Factor:

  A Constant Altitude Turn Therefore Requires a Specific Value of Turn Load Factor (N_T) for a Specific Bank Angle (Ø) and Since Induced Drag Generally Varies as the Square of C_L the Effect Can Be Put in a Table.

Fighter Performance (Cont'd)



Bank Angle (Ø)	Turn Load Factor (N_T)	% Increase in Induced Drag From Level Flight
0	1.000	0
15	1.036	7.3
30	1.154	33.2
45	1.414	100.0
60	2.000	300.0
90	∞	∞

$$N_T = \frac{L}{W} = \frac{1}{\cos \emptyset}$$

$$R = \frac{V^2}{g\sqrt{N_T^2 - 1}} = \frac{V}{\dot{\theta}}$$

$$\dot{\theta} = \frac{V}{R} = \frac{g}{V}\sqrt{N_T^2 - 1}$$

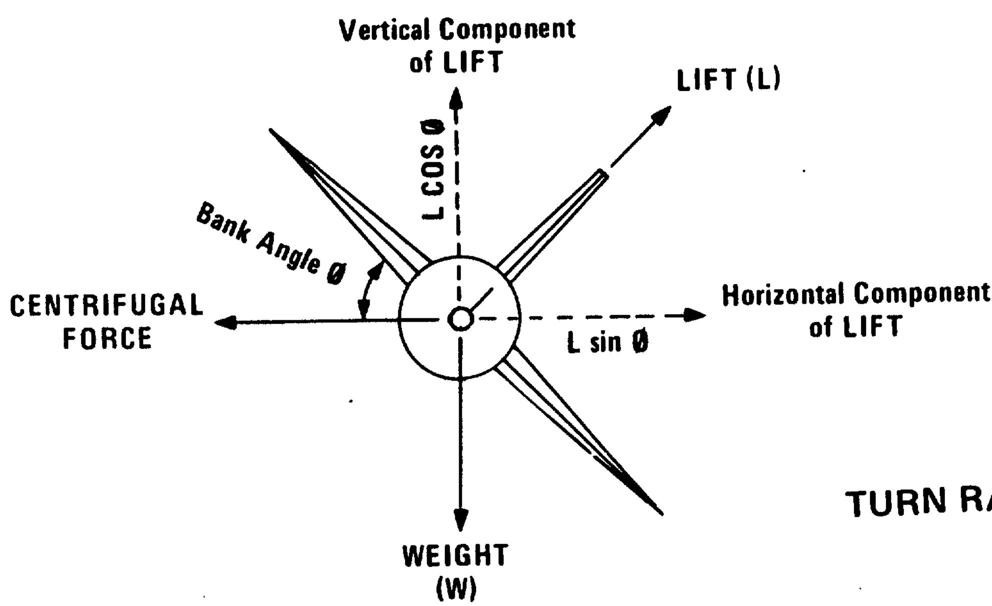
- To maintain a Steady Turn (constant radius) the horizontal component of the Lift Vector must offset the effects of the outward pulling Centrifugal Force:

CF must at least equal L sin Ø

$$CF = L \sin \emptyset = \frac{WV^2}{gR}$$

Fighter Performance (Cont'd)

- IN SUMMARY FOR A LEVEL TURN



TURN LOAD FACTOR $N_T = \frac{L}{W} = 1/\cos \emptyset$

TURN RADIUS $R = \frac{V^2}{g\sqrt{N_T^2 - 1}} = \frac{V}{\dot{\theta}}$

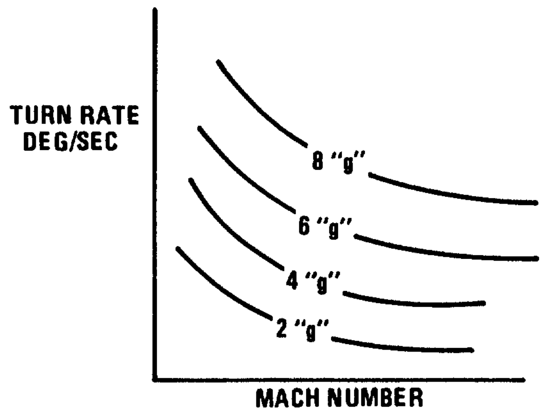
TURN RATE $\dot{\theta} = \frac{2\pi}{\text{time}} = \frac{2\pi}{\left(\frac{2\pi R}{V}\right)} = \frac{V}{R} = \frac{g}{V}\sqrt{N_T^2 - 1}$

CENTRIFUGAL FORCE $CF = L \sin \emptyset = \frac{WV^2}{gR}$

- These relationships can be used to develop Constant Altitude TURN RATE DIAGRAMS

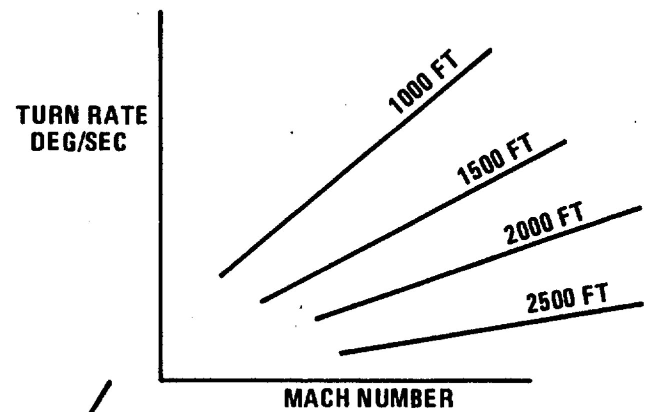
Fighter Performance (Cont'd)

CONSTANT LOAD FACTOR LINES

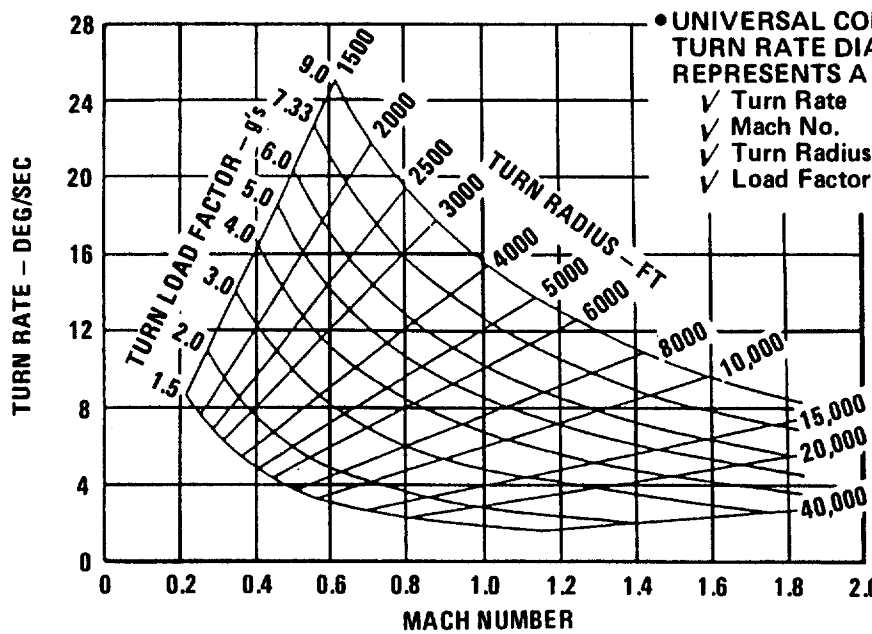


$$\dot{\theta} = \frac{g}{V}\sqrt{N_T^2 - 1}$$

CONSTANT RADIUS LINES



$$R = \frac{V}{\dot{\theta}}$$



- UNIVERSAL CONSTANT ALTITUDE TURN RATE DIAGRAM THAT REPRESENTS A MAP OF TRADEOFFS
  - √ Turn Rate
  - √ Mach No.
  - √ Turn Radius
  - √ Load Factor

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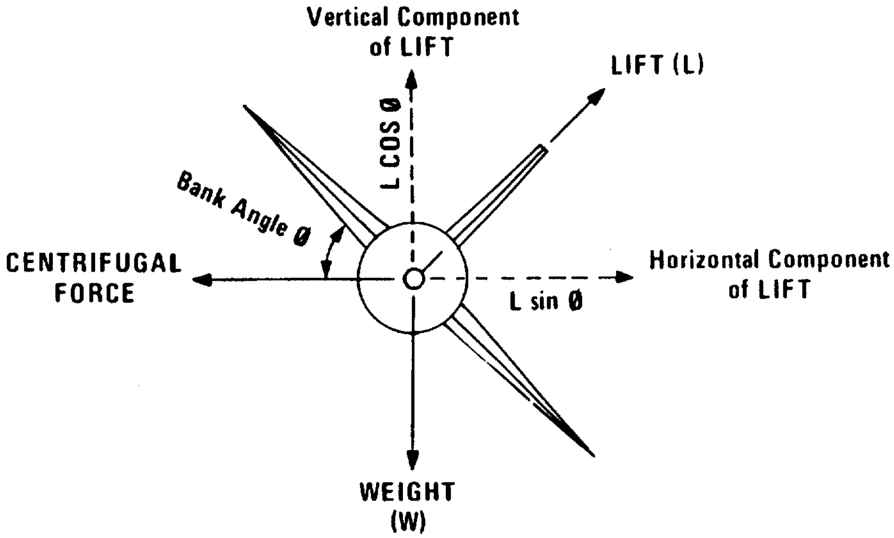
Fighter Performance (Cont'd)



- AN AIRCRAFT'S MAXIMUM TURNING CAPABILITY IS DEFINED BY:
  1. MAX LIFT CAPABILITY
  2. OPERATING STRENGTH LIMITS
  3. THRUST LIMITS

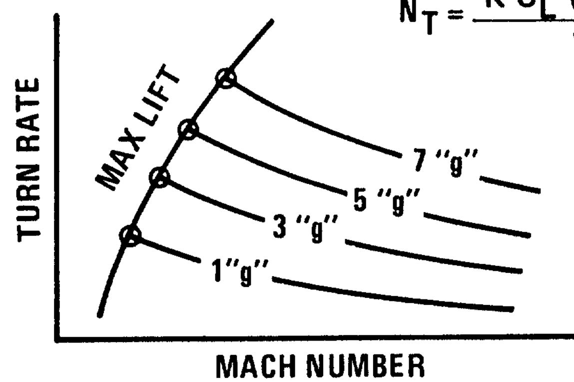
$$N_T = \frac{L}{W} = \frac{1}{\cos \emptyset}$$

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

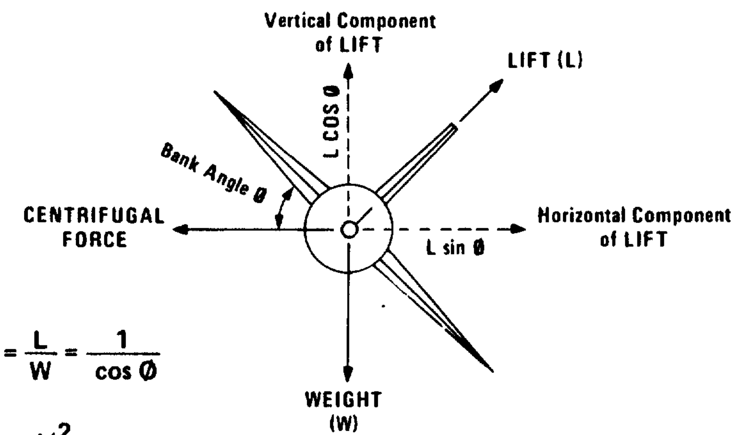
$$\dot{\theta} = \frac{V}{R} = \frac{g}{V}\sqrt{N_T^2 - 1}$$

- ON A CONSTANT ALTITUDE TURN RATE DIAGRAM MAXIMUM LIFT CAPABILITY DEFINES THE LOW-SPEED LIMITS ON THE CONSTANT LOAD FACTOR LINES

$$N_T = \frac{K\, C_L\,(MAX)\, V^2}{W}$$



Fighter Performance (Cont'd)



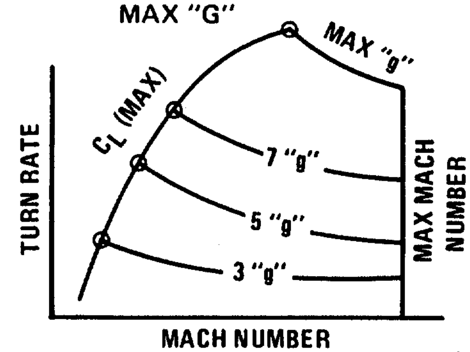
$$N_T = \frac{L}{W} = \frac{1}{\cos \phi}$$

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

$$\dot{\theta} = \frac{V}{R} = \frac{g}{V}\sqrt{N_T^2 - 1}$$

- ON A CONSTANT ALTITUDE TURN RATE DIAGRAM, OPERATING STRENGTH LIMITS CAN BE DEFINED BY THE MAX ALLOWABLE "g" AT ALL GIVEN MACH NUMBERS UP TO THE LIMIT OF THE AIRFRAME.

THE MAXIMUM ATTAINABLE TURN RATE IS DEFINED BY THE POINT AT THE INTERSECTION OF MAX C_L AND MAX "G"

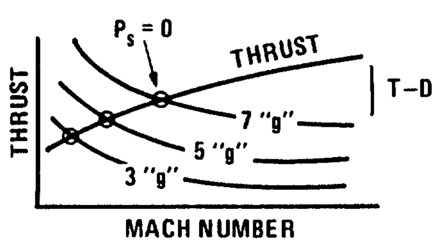


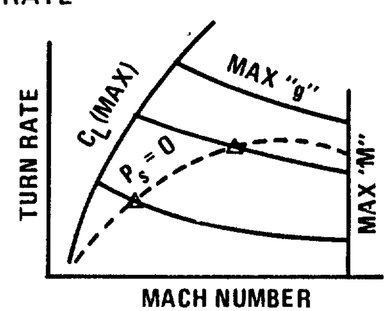
- ON A CONSTANT ALTITUDE TURN RATE DIAGRAM THRUST-LIMITS DEFINE SPECIFIC ENERGY VARIATIONS WITH LOAD FACTOR AND SPEED

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

$$\text{DRAG} = f(L) = f(N_T, V) = f(\dot{\theta})$$

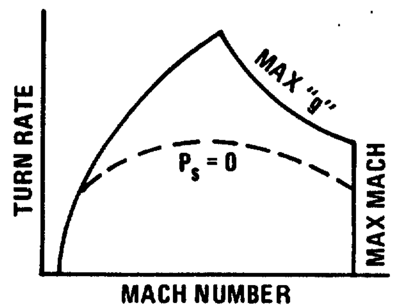
THE $P_s = 0$ VARIATIONS WITH LOAD FACTOR AND SPEED DEFINES MAX SUSTAINED TURN RATE

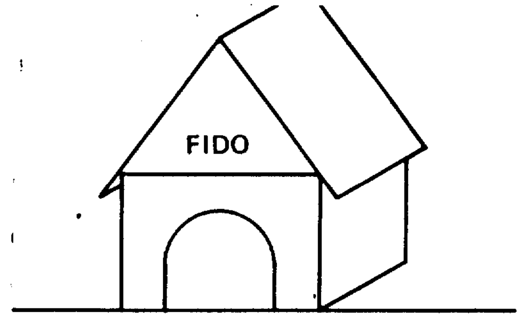




Fighter Performance (Cont'd)

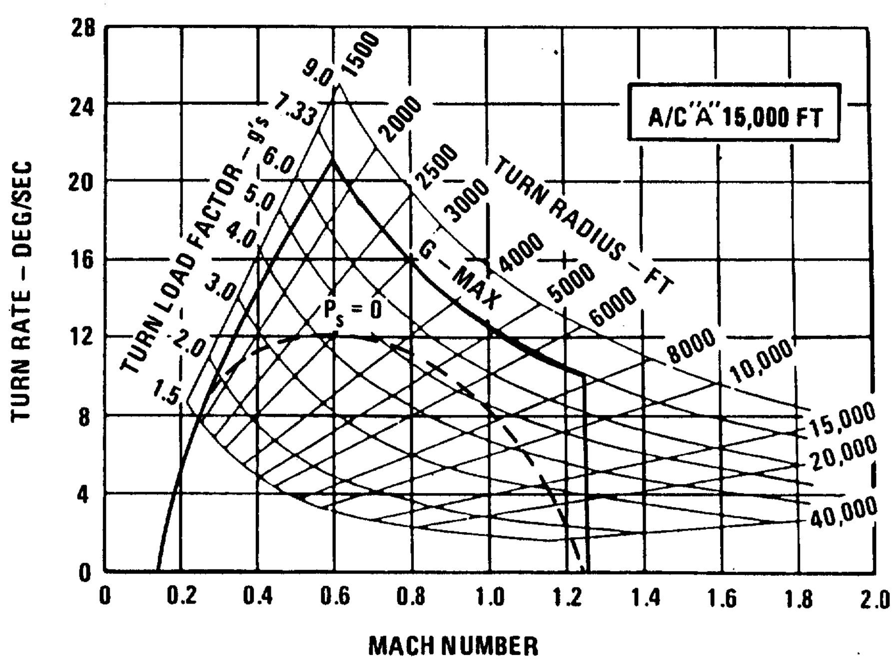
- The Constant Altitude Turn Rate Performance Limits Look Like a "Doghouse," Hence the Name "Doghouse Plots" to Imply Turn Rate Diagrams





- The Doghouse Plot Can Be Placed on the Constant Altitude Universal Turn Rate Diagrams to Yield Turn Radius and Load Factor Information Associated with the Limits and Specific Excess Energy for a Specific Aircraft:

THE "DOG HOUSE" PLOT FOR 15,000 FT (4572m)



Fighter Performance (Cont'd)

VIII. Maneuvering in the Horizontal Plane (Cont'd)

B. Basic Uses of the "Doghouse Plots"

- Turn Rate Diagrams: Turn Rate (TR) Is One of the Most Tactically Significant Measures of Performance Comparisons Since It Relates Directly to the Time Needed to Accomplish a Given Displacement of the Aircraft's Lift Vector

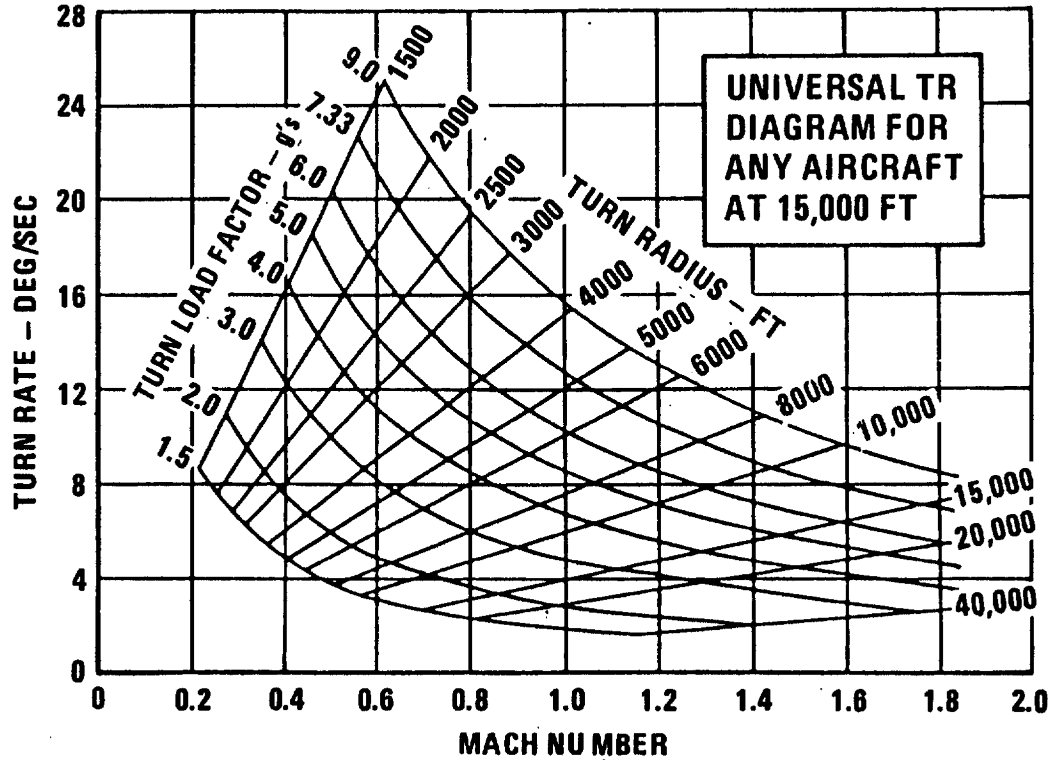
$$\dot{\theta} = TR = 57.3\frac{G}{V}\sqrt{N_T^2 - 1} \text{ (Degrees/Sec)}; \quad RADIUS = \frac{57.3V}{\dot{\theta}} = \frac{V^2}{G\sqrt{N_T^2 - 1}}; \quad N_T = \sqrt{\frac{V^2\,\dot{\theta}^2}{(57.3\,G)^2} + 1}$$

  - Utilizing Turn Rate vs Mach No. at a Given Altitude and Power Setting, Allows P_S Curves to Be Plotted Thus Placing the Performance of that Particular Aircraft in a Capsule Form Called a "Dog House"

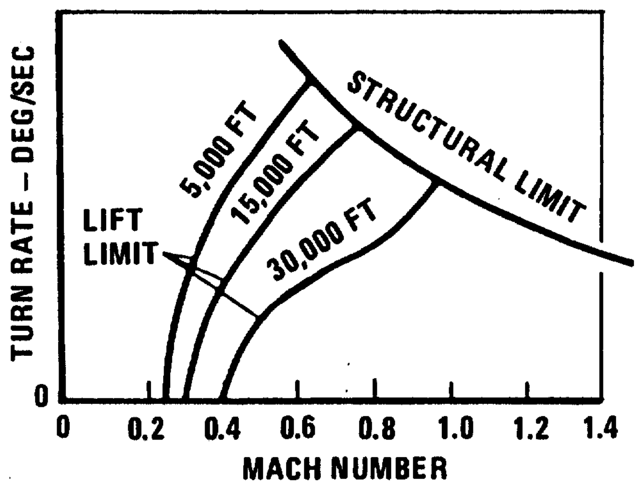
  - The Best Use of Turn Rate Diagrams Are in Comparing Two Aircraft for Their Turn-Values

Fighter Performance (Cont'd)

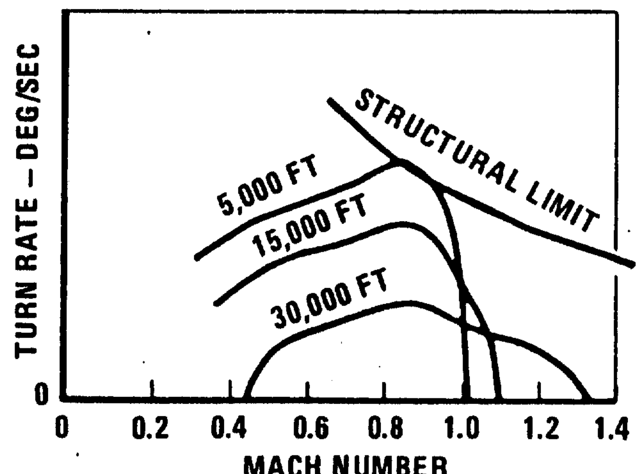
THE UNIVERSAL TURN RATE FORMAT FOR 15,000 FT (4572m)



INSTANTANEOUS TR AS A FUNCTION OF ALTITUDE



SUSTAINED TR AS A FUNCTION OF ALTITUDE



FWS–132

Fighter Performance (Cont'd)

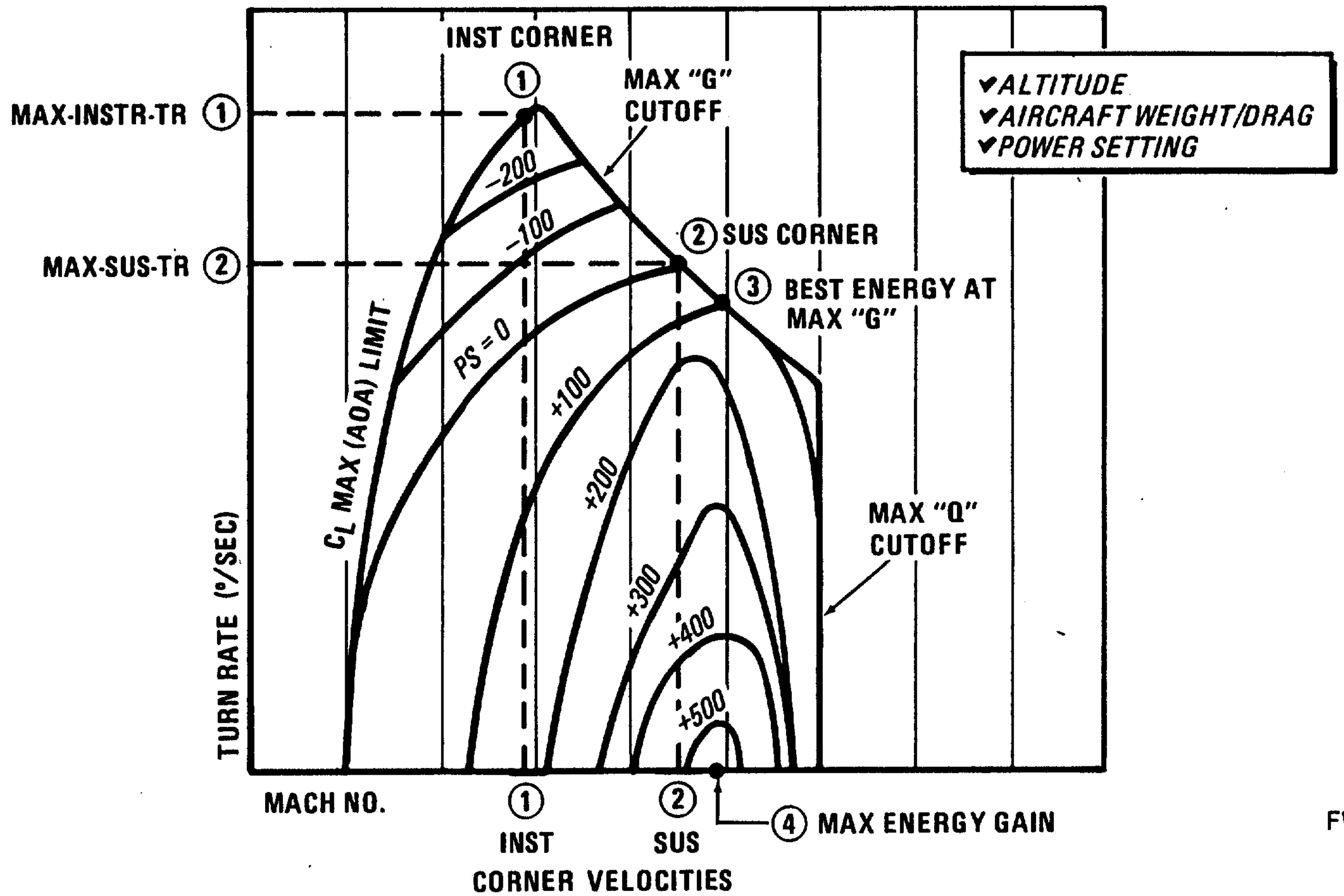
- **Examining the Maneuver (Turn Rate) Diagram "Dog House:**

  (1) **Max TR at Maximum Lift Limit is the Max-Inst-TR. The Minimum Speed at Which Max "G" Can Be Obtained is the Inst-Corner Vel**

  (2) **Maximum Sustained TR is Reached at the Steady State Condition ($P_S = 0$) Where T=D. The Minimum Speed at Which Max-Sus-"G" is Reached is the Sus-Corner-Vel**

  (3) **Best Energy Rate at Max "G" is the Speed Where the Highest P_S is Achieved Pulling Max "G".**

  (4) **Max Energy Gain is at Straight Level Flight at the Speed Where Highest P_S Rests.**



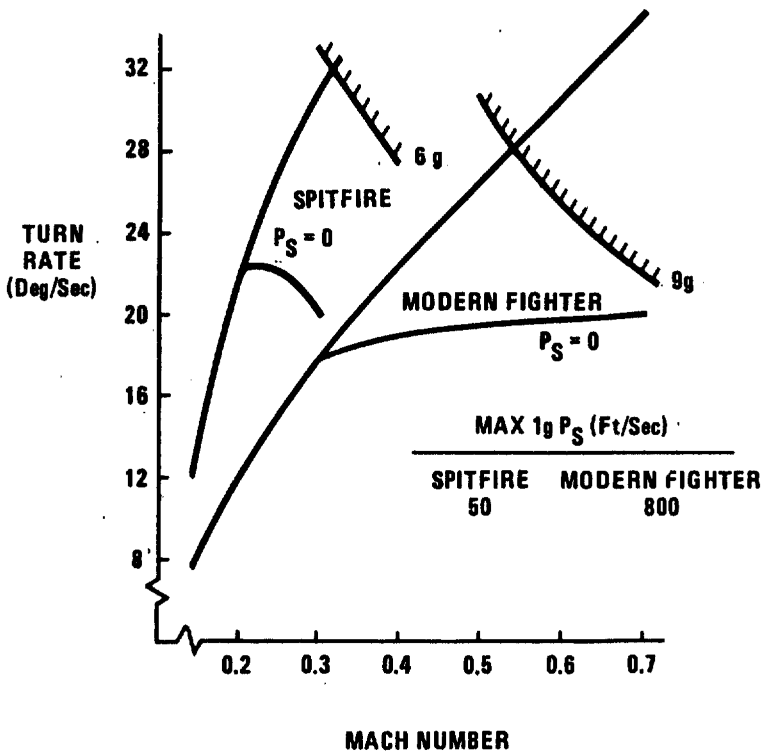
FWS-133

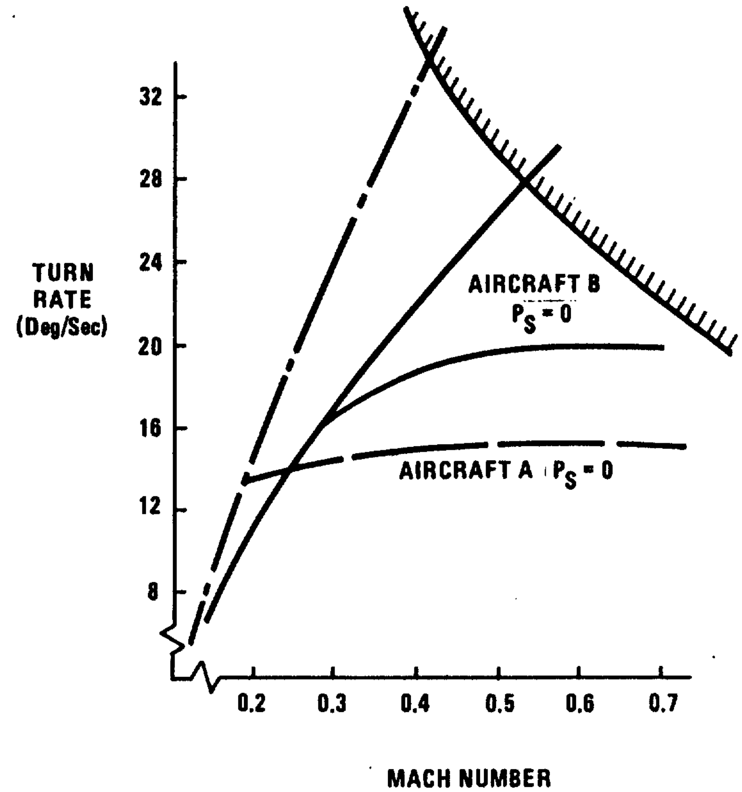
Fighter Performance (Cont'd)

- **How to Use the "Dog House" Turn Rate Diagrams**

The Dog House Chart Is a Superb Information Source for Comparing Two Fighter Aircraft at Constant Altitude. The Dog House not Only Reveals One Aircraft's Performance Advantage, but Also in What Manner It Could Be Exploited

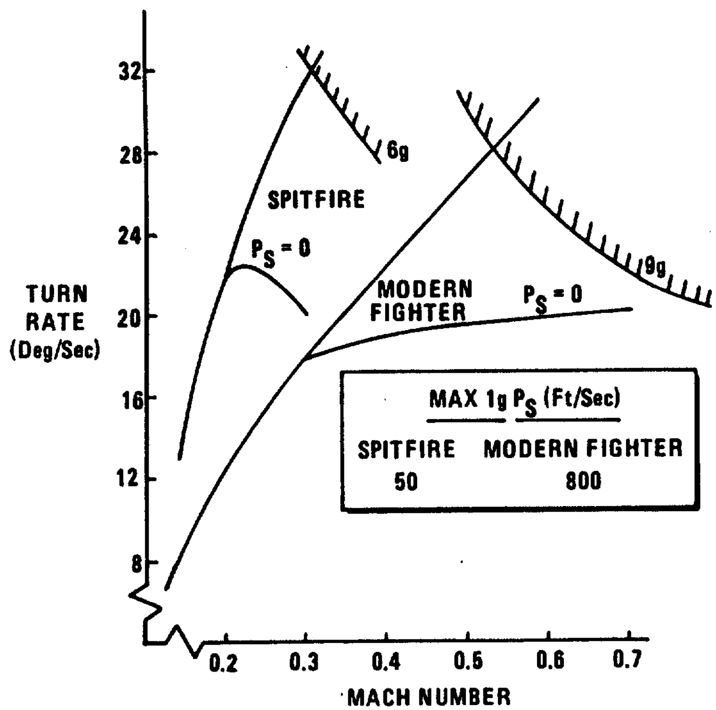
Two Examples Are Shown Herein. One Compares a WW II Fighter with a Modern Fighter, and the Other Compares Two Modern Fighters





Fighter Performance (Cont'd)

- EXAMPLE ONE: A Spitfire Is Compared with a Modern Jet Fighter, Each Being Armed with Guns and (2) IR Missiles

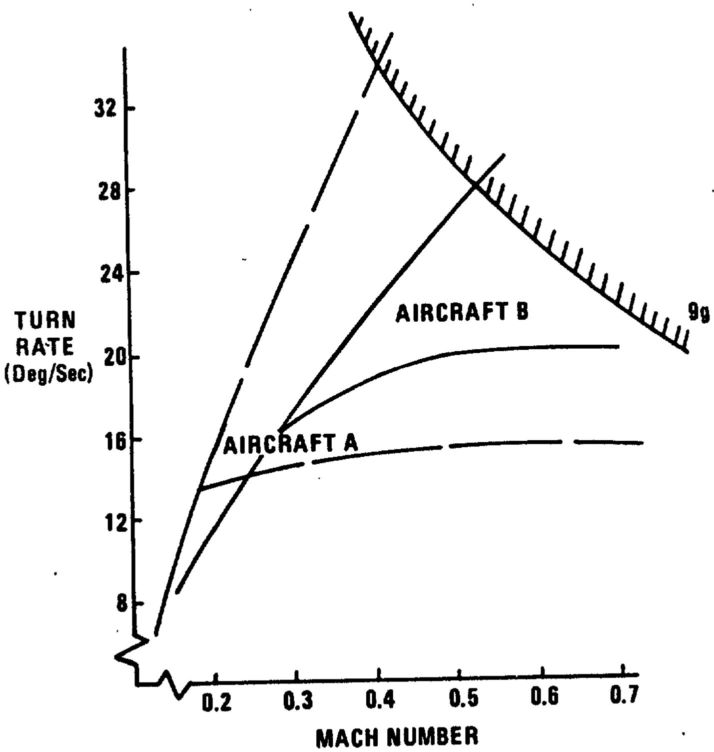


The Spitfire Exhibits a Higher Sustained and Instantaneous Turn Capability, but Over a Small Speed Range. The Modern Fighter Attains its Best Capabilities at Higher Speeds (Mach Number) and Secures an Enormous Specific Excess Power (P_S) Advantage

From a Neutral Head-On Pass, Where Both Aircraft Commit to a "One-Circle" Canopy-to-Canopy Turning Fighter, Each at His Best Speed to Maximize His Degrees/Second Turning Capability, the Spitfire Would Eventually Pull Inside and Behind the Wing Line of the Modern Fighter. Even with Great P_S Advantage, the Modern Fighter Would Lose. Now if the Modern Fighter Would Take the 750 Ft/Sec P_S Advantage and Convert it to 45,000 Ft/Min Climb Rate and Rotate Out of Plane with the Spitfire He Would Force the "Spit" to Either Stay Where He Is or Attempt to Climb and Slow Down More Losing His Best Turn. The Conversion of Excessive P_S in the Modern Fighter Allows Him to Take Himself Out of a Bad Two-Dimensional Fight into a More Advantageous Three Dimensional Fight.

Fighter Performance (Cont'd)

EXAMPLE TWO: Two Modern Fighters with Different Wing Characteristics (Sweep and Aspect Ratio) Are Compared



- Aircraft "A" Has an Obvious Advantage in Instantaneous Turn at Speeds Below 0.5 Mach. Aircraft "B" Exhibits Better Sustained Turn at All Speeds
- "A" Is at a Sustained Turn Disadvantage, but Could Use His Instantaneous Advantage for Nose Pointing or Last-Ditch Defensive Breaks
- Notice at Around 13°/SEC, "A" Is Doing the Best He Can Sustain Wise. At the Same Turn Rate, "B' Will Be Able to Climb or Accelerate
- It Would Be in "A's" Best Interest to Slow the Fight Down and Keep it Horizontal, While "B" Would Seek a Faster Fight with Nose-to-Tail Separation that Is Three-Dimensional

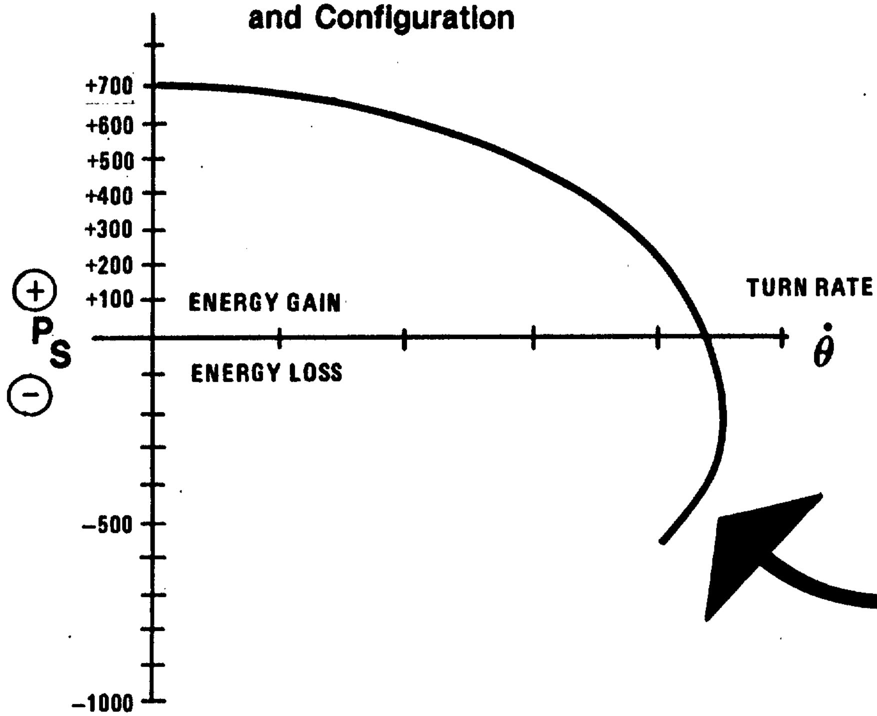
CONCLUSION: Each Aircraft Attempts to Fly and Fight in the Arena Where it Has the Most Going for it. If the opponent Leaves His Best Flying Arena to Attack then He Risks Arriving at a Point of Relative Disadvantage. There Are Overlapping Areas of Capabilities that Become "Meeting Points" of Advantage and Disadvantage.

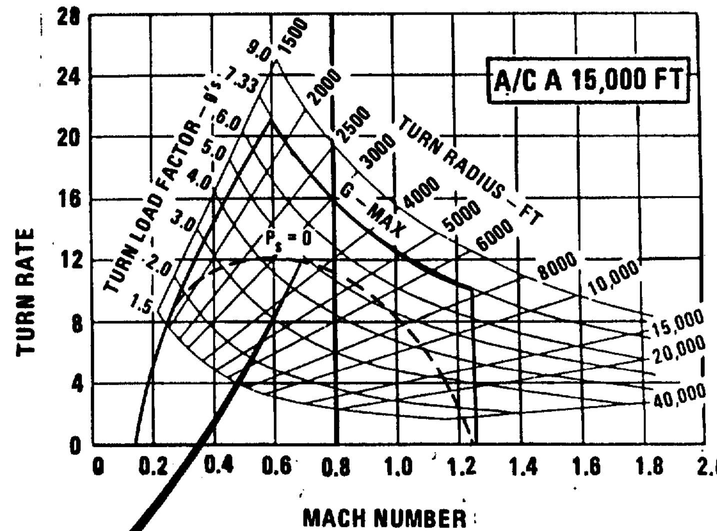
Having a Higher AOA Capability, Lower Speed Instantaneous Maximum Turn and Higher C_L Could Be Misused. The Pilot Must Be Aware of All the Inherent Weapon, Airframe, Airflow, and Performance Problems.

Fighter Performance (Cont'd)

C. The "Banana Chart" Comparison

- Specific Excess Power (P_S) and Turn Rate ($\dot{\theta}$) at Constant Altitude, Airspeed, Power Setting, and Configuration





A Vertical Slice Through a "Dog House" Turn Rate Diagram Will Produce the Relationship of P_S and $\dot{\theta}$ for a Fixed Altitude and Airspeed. This Allows for a More Detailed Comparison of Two Aircraft.

NOTE:

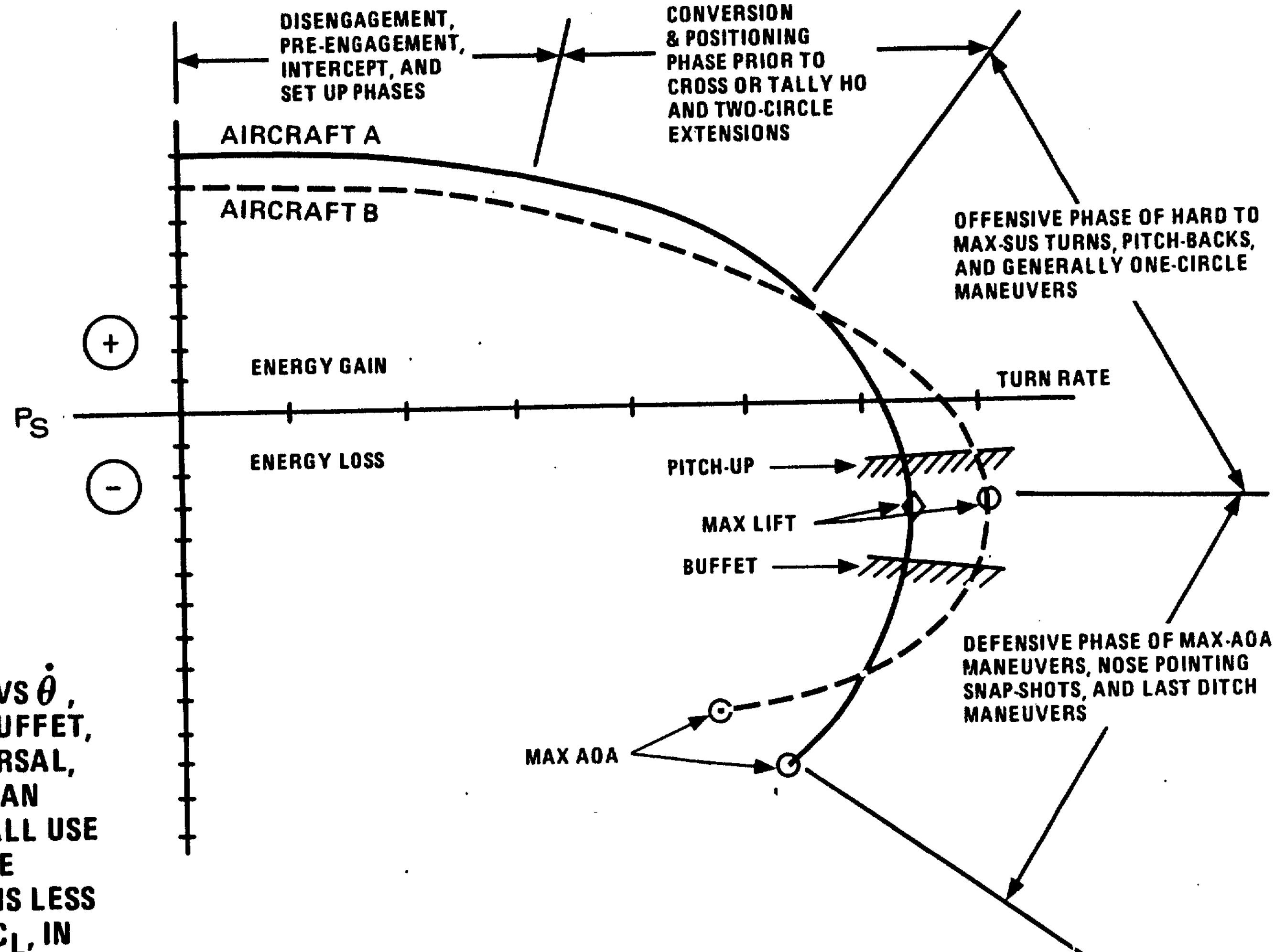
(1) P_S Can Be Scaled In Ft/Sec or KCAS/Sec as Demonstrated in the Charts on Pages FWS-159-161

(2) Turn Rate ($\dot{\theta}$) Can Also Be Expressed as Turn Load Factor (N_T):

$$N_T = \sqrt{\left(\frac{V\dot{\theta}}{g}\right)^2 + 1}$$

Fighter Performance (Cont'd)

• THE $P_S/\dot{\theta}$ DIAGRAM CAN QUANTIFY IN DETAIL THE PERFORMANCE BETWEEN TWO DISSIMILAR AIRCRAFT DURING THE PHASES OF A MANEUVERING ENGAGEMENT.



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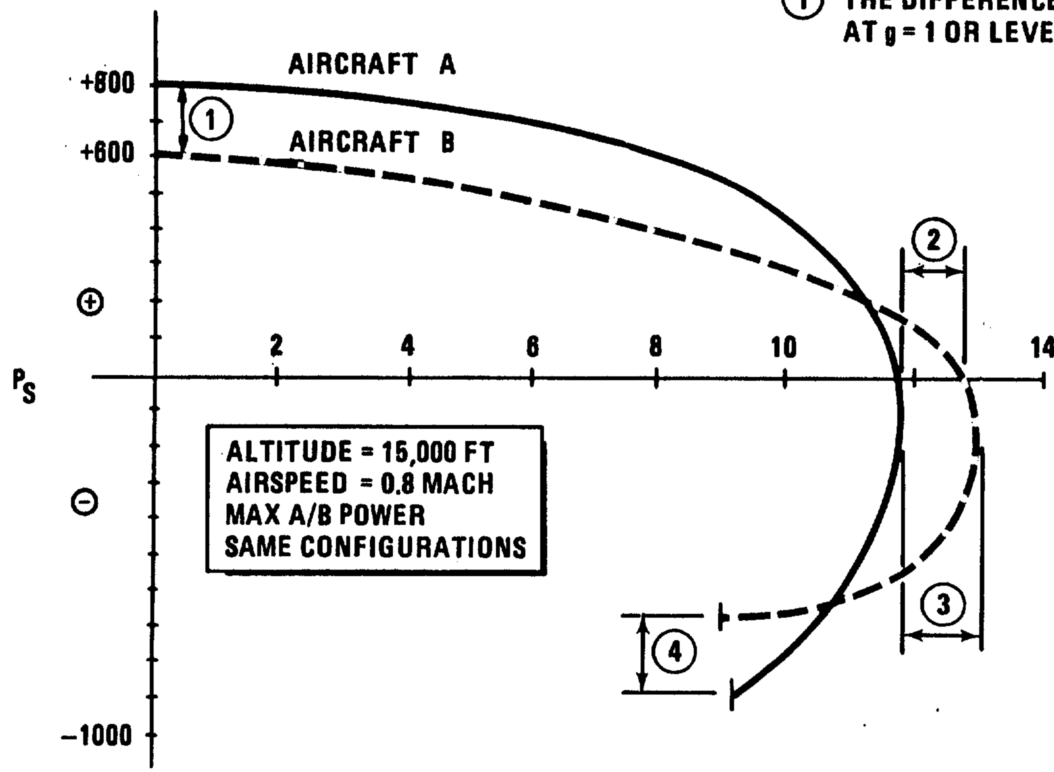
NOTE:

ON THE GRAPH OF P_S VS $\dot{\theta}$, SUCH QUALITIES AS BUFFET, PITCH-UP, ROLL REVERSAL, ADVERSE YAW, ETC. CAN RESTRICT THE OVERALL USE OF THE PERFORMANCE INDICATED IN REGIONS LESS THAN MAX AOA AND C_L, IN THE MANNER DEPICTED

Fighter Performance (Cont'd)

AN EXAMPLE OF $P_S/\dot{\theta}$ COMPARISONS:



① THE DIFFERENCE OF P_S AT NO TURN RATE ($\dot{\theta} = 0$), I.E. AT g = 1 OR LEVEL ACCELERATION

$\Delta P_S = 800\text{-}600 = 200$ FT/SEC
ADVANTAGE OF "A" OVER "B"

$\Delta P_S = 200\ (0.0194) = 3.88$ KCAS/SEC
LINEAR ACCELERATION
ADVANTAGE OF "A"

② THE DIFFERENCE IN SUSTAINED TURN RATE ($\dot{\theta}_{SUS}$) AT $P_S = 0$

$\Delta\dot{\theta}_{SUS} = 12.9 - 11.8$

$\Delta\dot{\theta}_{SUS} = 1.1$ DEG/SEC

ADVANTAGE FOR "B" OVER "A" IT EQUATES TO LESS THAN ½ g

③ THE DIFFERENCE IN INSTANTANEOUS TURN RATE AT MAX LIFT (C_L)

$\Delta\dot{\theta}_{INST} = 13.2 - 11.8 = 1.4$ DEG/SEC
ADVANTAGE OF "B" OVER "A"

④ MAXIMUM BLEED RATE IS AT

$\Delta P_{S_{MIN}}$ WHICH OCCURS AT

MAXIMUM ANGLE OF ATTACK (AOA)

$\Delta P_{S_{MIN}} = -(900 - 675) = -225$ FT/SEC

$\Delta P_{S_{MIN}} = (-225)(0.0194) = 4.37$ KCAS/SEC
DECELERATION

Fighter Performance (Cont'd)

- P_S Vs $\dot{\theta}$ Considerations:

1. ΔP_S at 1g Represents the Differential Energy Rate in Straight and Level. From the Example (Page 4-40) the Overall 200 Ft/Sec Advantage of "A" Over "B" Can Be Expressed Three Ways:

   - 200 Ft/Sec Differential Energy Advantage
   - 12000 Ft/Min Climb Rate Advantage
   - 3.88 Kts/Sec Linear Acceleration Advantage

   Escape Through Accelerating Out of an Attacker's Weapons Envelope Is Also a Consideration. Unloaded Acceleration Is Obviously the Best Method, but Conditions at One "g" Sets the Stage

Guns - Defense:	50-100 Ft/Sec ΔPS Required If You Start Right at the Outer Boundary (Greater than 1 Kt/Sec)
IR Missile Defense:	± 200 ΔPS, Situation Will Not Change
	± 400 ΔPS, Good Chance of Change

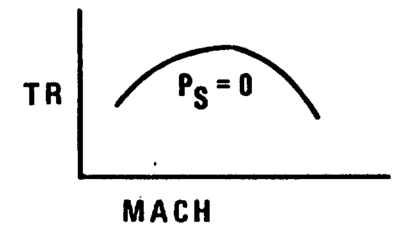
ΔP_S	
+200	Neutral
+400	Superior
>+400	Dominant

Greater than +400 ΔPS, the Aircraft with the Higher Energy Has the Advantage

Note: *With F-16/F-18/F-15/MiG-29/Su-27 Class Fighters Engaging One Another, the Capacity to Regain Energy Is Very High Near Sustained Corner Speeds. High P_S Advantages Must Be Weighed Carefully with Relative Conditions of Load and Angles.*

Fighter Performance (Cont'd)

2. $\Delta\dot{\theta}_{SUS}$ IS THE SUSTAINED TURN DIFFERENCES. THE BEST SOURCE OF JUST SUS-TURN IS THE TURN RATE DIAGRAM SINCE IT DOES VARY AND REACH A PEAK



√ TIME OF CONVERSION

HEAD-ON ENCOUNTER $\dfrac{180^0}{\Delta\dot{\theta}_{SUS}}$ = TIME IN SECONDS

$\Delta\dot{\theta}_{SUS}$ (Deg/Sec)
1 – 2 °/SEC (0 - ½ g) EQUAL RELATIVELY
2 – 4 °/SEC (½ - 1 g) SUPERIOR ADVANTAGE
>4 °/SEC (Over 2 g's) DOMINANT

Fighter Performance (Cont'd)

3. $\Delta P_{S_{MIN}}$ IS THE DIFFERENTIAL MINIMUM ENERGY RATE THAT OCCURS AT MAX AOA.

THESE PITCH AND TURN RATES ARE OFTEN STATED BUT RARELY USABLE OFFENSIVELY. THEY ARE MOST APPLICABLE IN 1v1 CONSIDERATIONS.

√ $\Delta P_{S_{MIN}}$ DEMONSTRATES THE CAPABILITY TO FORCE AN OVERSHOOT

$\Delta P_{S_{MIN}}$	
LESS THAN – 200 FT/SEC	EVEN MATCH
–200 TO –400 FT/SEC	ADVANTAGE
GREATER THAN –400 FT/SEC	SUPERIOR

Fighter Performance (Cont'd)

VIII. Maneuvering in the Horizontal Plane (Cont'd)

D. The "Agility Chart"

The Ability to Quickly Point Your Nose at the Enemy While Maintaining the Ability to Turn Rapidly

The Requirement Is Driven by

- Use of Forward Firing Ordnance
- Likelihood That Forces Will Merge
- Requirement for Multiple Kills
- Potential for Defenseive Situations

Classically, the "Ability to Maneuver" Have Been Derived and Defined by "Turn Rate Capability"

$\dot{\theta}$

HOWEVER!

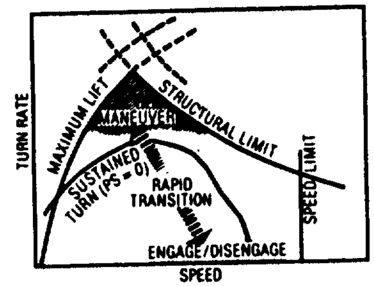
The Ability to "Maintain a Maneuver" Is Defined by Acceleration and Deceleration Capabilities

$\dot{V}_{CAL}$

Therefore, We Are Exploring the Relationship Between $\dot{\theta}$ and $\dot{V}_{CAL}$

Fighter Performance (Cont'd)

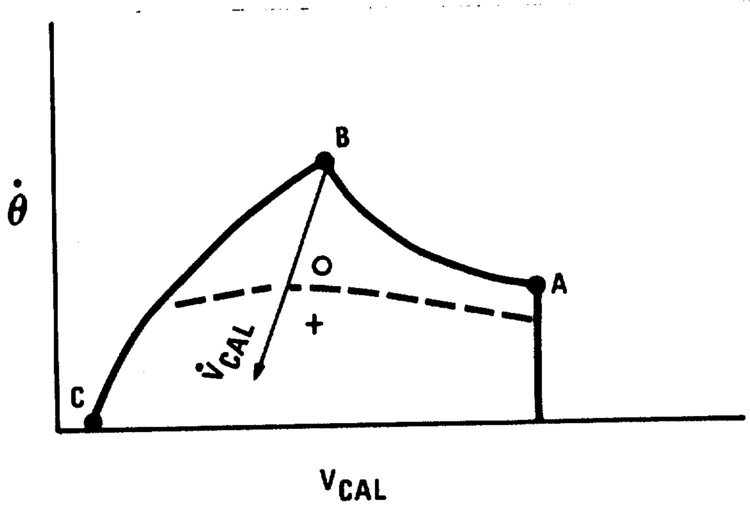
Agility Plots



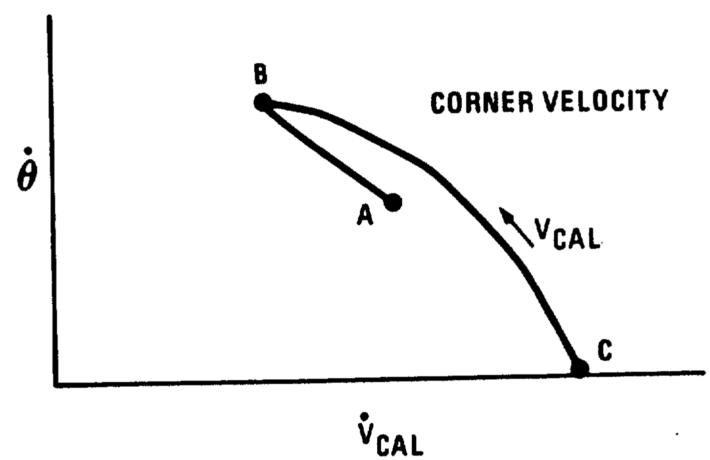
- AGILITY MUST BE ACCOMPANIED BY A CAPABILITY TO RECOVER LOST ENERGY DISSIPATED DURING A MAX–RATE TURN
- LIMITS OF AGILITY ARE DEFINED BY TURN RATE ($\dot{\theta}$) VARIATION WITH ACCELERATION (V_{CAL}) AT AIRCRAFT LIMITS:

  ✓ In other words, we must compare our turn-rate with our bleed-rate and set out to establish acceptable boundaries for the interchange

<u>DOGHOUSE CHART</u>



<u>AGILITY CHART</u>

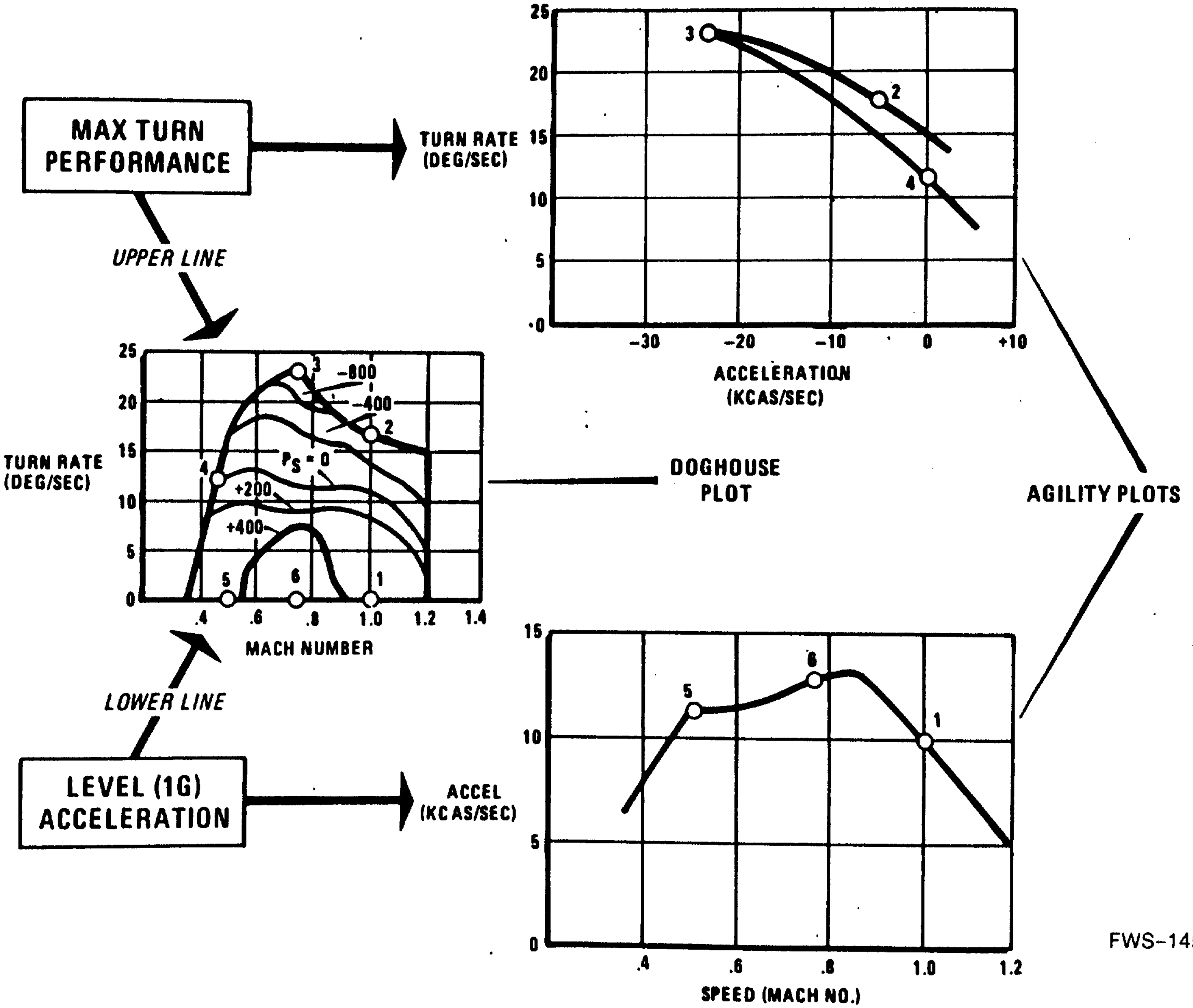


"AGILITY LIMITS" OCCUR AT BOUNDRY POINTS ON DOGHOUSE PLOTS

Point A: Max "Q"
Point B: Max Instantaneous Corner
Point C: Min Speed Flyable

Fighter Performance (Cont'd)

- AGILITY CHARTS ARE STRUCTURED FROM THE PERIPHERAL POINTS ON THE DOGHOUSE CHART



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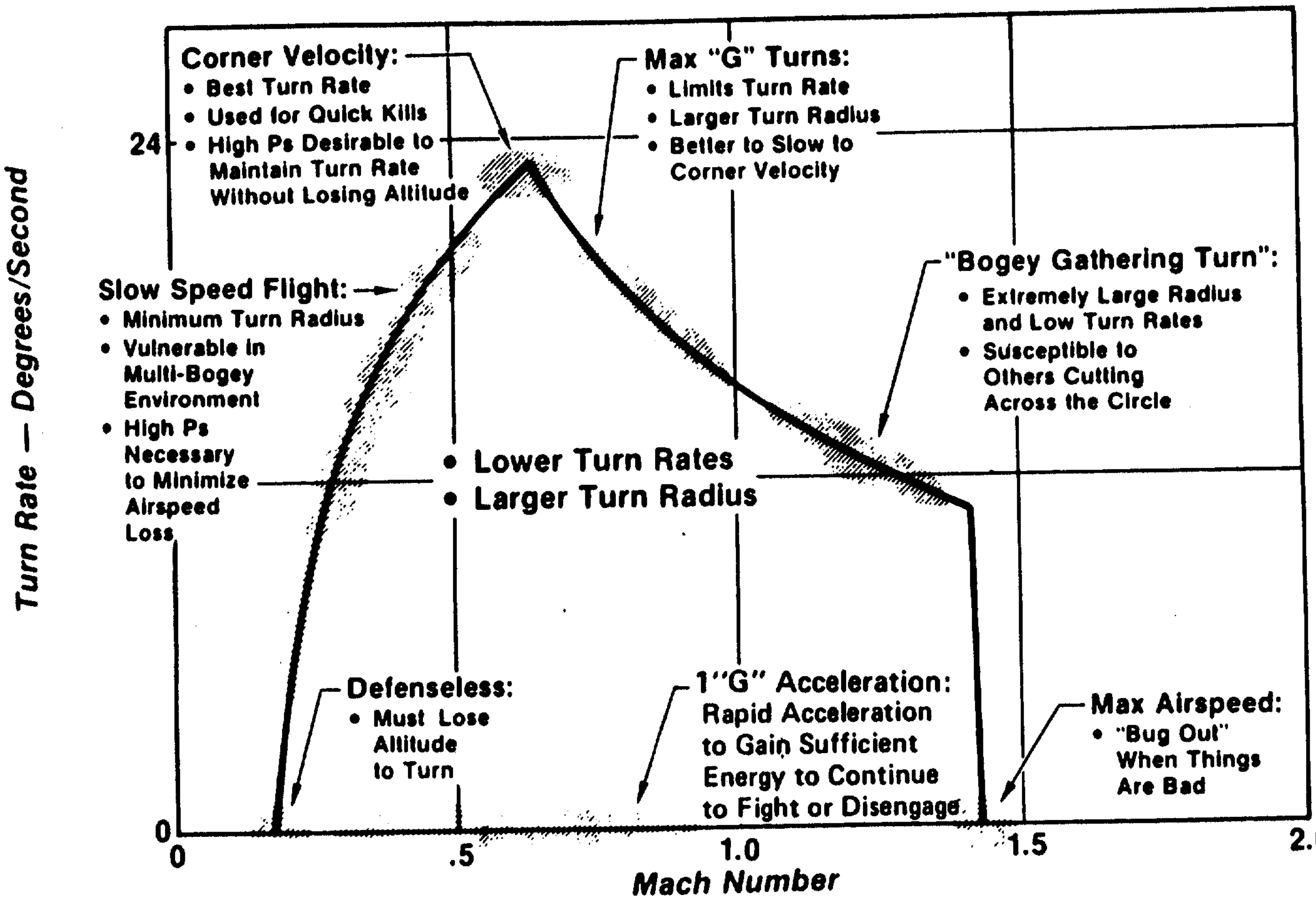
Fighter Performance (Cont'd)

Tactical Considerations with "Agility"

• IF AERIAL COMBAT WAS PERFORMED SEEKING THE LIMITS OF THE MANEUVER ENVELOPE



• DESIRE FOR QUICK KILLS PLACES A PREMIUM ON HIGH TURN RATES

• SUSCEPTIBILITY TO OTHER BOGEYS PROHIBITS UNACCEPTABLE AIRSPEED DECAY AT HIGH TURN RATES

• HIGH ACCELERATION RATES PERMIT RAPID REENTRY INTO THE FIGHT OR ABILITY TO DISENGAGE

Fighter Performance (Cont'd)

Agility Comparisons of F-5E and F-4E

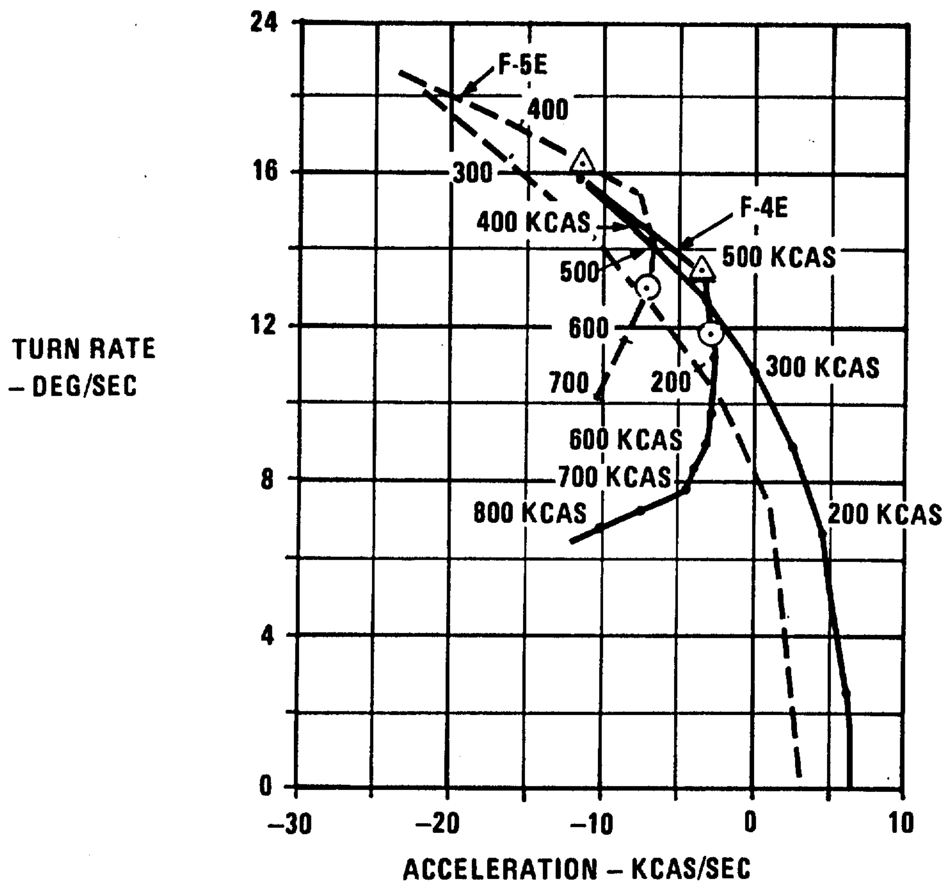
(2) Missiles + 50% Fuel; Max Pwr; 10,000 Ft

Agility of Two Aircraft Can Be Compared:

Directly to Define Relative Meeting Points of Advantage at Specific Speeds

OR

Indirectly to Define Conditions at a Specified Time Lapse from Any Initial Condition



= Begin 15 Second Deceleration from M = 0.95

= End of Deceleration

A/C	M	TURN
F-4E	0.89	189°
F-5E	0.76	218°

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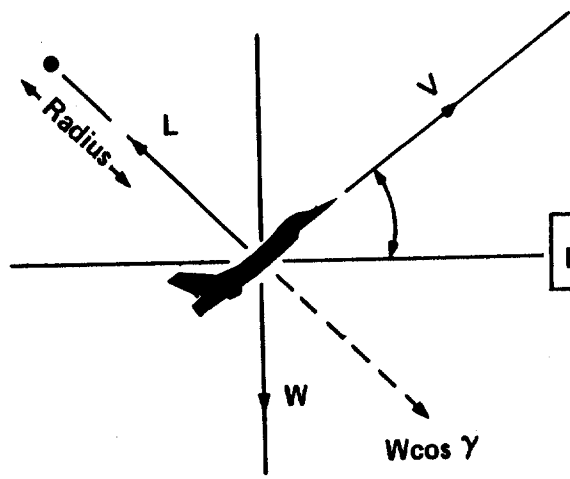
Fighter Performance (Cont'd)

IX. Maneuvering in the Vertical Plane

A. PITCH RATE CONSIDERATIONS



$$R = \frac{V^2}{a}$$

Throughout this section, equations for $\dot{\gamma}$, Θ are in radians/sec. To convert to deg/sec, multiply by 57.3.

R = Radius of Turn
V = Velocity
γ = Flight Path Angle
W = Weight $\boxed{W = mg}$
m = Mass
L = Total Lift = Aero Lift + Thrust Lift
a = Acceleration $\boxed{F = ma}$
N_T = Turn Load Factor $\boxed{N_T = L/W}$
F = mg = L − W cosγ

$$a = \frac{F}{m} = \frac{L - W\cos\gamma}{W/g} = (g/W)\,(L - W\cos\gamma)$$

$$a = g\left(\frac{L}{W} - \cos\gamma\right)$$

$$\boxed{a = g(N_T - \cos\gamma)}$$

$$\boxed{R = \frac{V^2}{a} = \frac{V^2}{g}\left(\frac{1}{N_T - \cos\gamma}\right)}$$

$$\frac{d\gamma}{dt} = \dot{\gamma} = \frac{V}{R} = \left(\frac{V}{V^2}\right) g \left(\frac{N_T - \cos\gamma}{1}\right)$$

$$\dot{\gamma} = (g/V)\,(N_T - \cos\gamma)$$

$$\boxed{\dot{\gamma} = a/v}$$

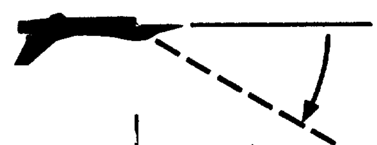
Fighter Performance (Cont'd)

PITCH RATE SITUATIONS:

- Case 1: PULL-UP FROM LEVEL FLIGHT (R_{PU} & $\dot{\gamma}_{PU}$)
  at t = 0, then $\gamma = 0^o$

$$R_{PU} = \frac{V^2}{g}\left(\frac{1}{N_T - 1}\right), \quad \dot{\gamma}_{PU} = \frac{g}{V}\,(N_T - 1)$$

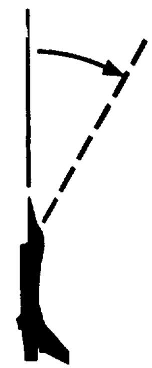
Case 2: PULL-THROUGH FROM INVERTED FLIGHT (R_{PT} & $\dot{\gamma}_{PT}$)
at t = 0, then $\gamma = 180^o$



$$R_{PT} = \frac{V^2}{g}\left(\frac{1}{N_T + 1}\right)$$ (utilizes the added value of radial "g")

$$\dot{\gamma}_{PT} = \frac{g}{V}\,(N_T + 1)$$

Case 3: PULL-IN-VERTICAL MANEUVER (R_{VM}, $\dot{\gamma}_{VM}$)
at t = 0, then $\gamma = \pm 90^o$



$$R_{VM} = \frac{V^2}{g}\left(\frac{1}{N_T - 0}\right) = \frac{V^2}{g\,N_T}$$

$$\dot{\gamma}_{VM} = \frac{g}{V}(N_T - 0) = \frac{g\,N_T}{V}$$

TURN RATE IN THE VERTICAL PLANE	$= K_{\dot{\theta}}$	(Turn Rate in the Horzontal Plane)

TURN RADIUS IN THE VERTICAL PLANE	$= K_R$	(Turn Radius in the Horizontal Plane)

Fighter Performance (Cont'd)

VERTICAL PLANE TURN RATE IS RELATED TO HORIZONTAL PLANE TURN RATE

HORIZONTAL PLANE	VERTICAL PLANE	TURN RATE RATIOS ~VERTICAL TO HORIZONTAL
	$\dot{\gamma}_{PULLUP} = \frac{g}{V}(N_T - 1)$	$\frac{\dot{\gamma}_{PULLUP}}{\dot{\theta}_{HORIZ}} = \frac{(N_T - 1)}{\sqrt{N_T^2 - 1}}$
$\dot{\theta}_{HORIZ} = \frac{g}{V}\sqrt{N_T^2 - 1}$	$\dot{\gamma}_{PULL\ THROUGH} = \frac{g}{V}(N_T + 1)$	$\frac{\dot{\gamma}_{PULL\ THROUGH}}{\dot{\theta}_{HORIZ}} = \frac{(N_T + 1)}{\sqrt{N_T^2 - 1}}$
	$\dot{\gamma}_{VERT\ MAN} = \frac{g N_T}{V}$	$\frac{\dot{\gamma}_{VERT\ MAN}}{\dot{\theta}_{HORIZ}} = \frac{N_T}{\sqrt{N_T^2 - 1}}$

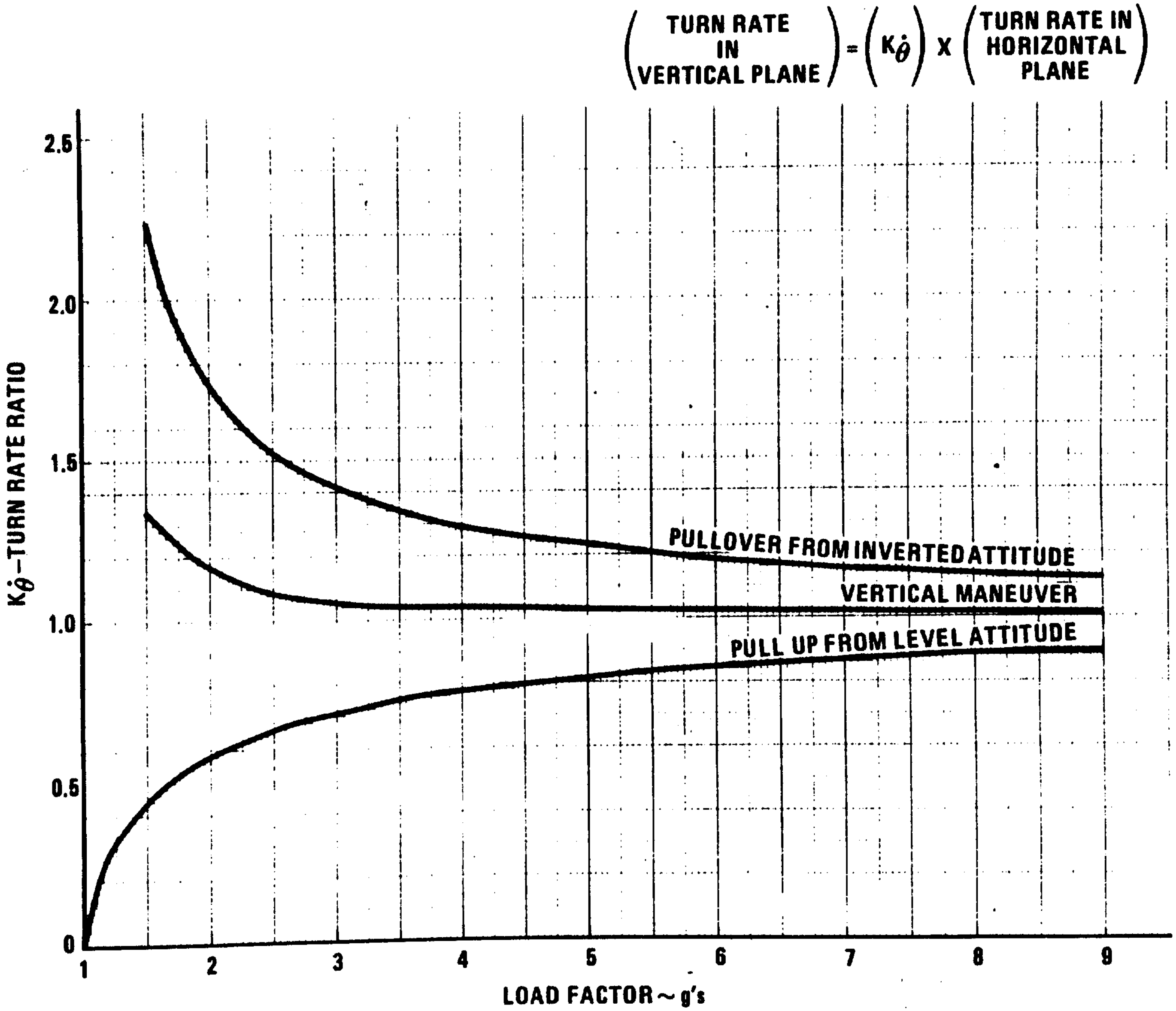
① THE RATIOS CAN BE PLOTTED VERSUS LOAD FACTOR (η)

② $\dot{\theta}_{HOR}$ CAN BE OBTAINED FROM DOG HOUSE PLOTS

③ $\dot{\gamma}_{PULLUP}$, $\dot{\gamma}_{PULLOVER}$, AND $\dot{\gamma}_{VERT\ MAN}$ CAN THEN BE OBTAINED BY MULTIPLYING ① X ②

Fighter Performance (Cont'd)

Vertical Plane Turn Rates



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Fighter Performance (Cont'd)

B. Turn Radius Considerations

VERTICAL PLANE TURN RADIUS IS RELATED TO HORIZONTAL PLANE TURN RADIUS

HORIZONTAL PLANE

$$R_{HORIZ} = \frac{V^2}{g\sqrt{N_T^2 - 1}}$$

VERTICAL PLANE

R_{PULLUP} FROM LEVEL ATTITUDE:

$$R_{PULLUP} = \frac{V^2}{g(N_T - 1)}$$

$R_{PULLOVER}$ FROM INVERTED ATTITUDE:

$$R_{PULLOVER} = \frac{V^2}{g(N_T + 1)}$$

$R_{VERT\ MAN}$:

$$R_{VERT\ MAN} = \frac{V^2}{g N_T}$$

TURN RADIUS RATIOS ~ VERTICAL TO HORIZONTAL

$$\frac{R_{PULLUP}}{R_{HORIZ}} = \frac{\sqrt{N_T^2 - 1}}{(N_T - 1)}$$

$$\frac{R_{PULLOVER}}{R_{HORIZ}} = \frac{\sqrt{N_T^2 - 1}}{(N_T + 1)}$$

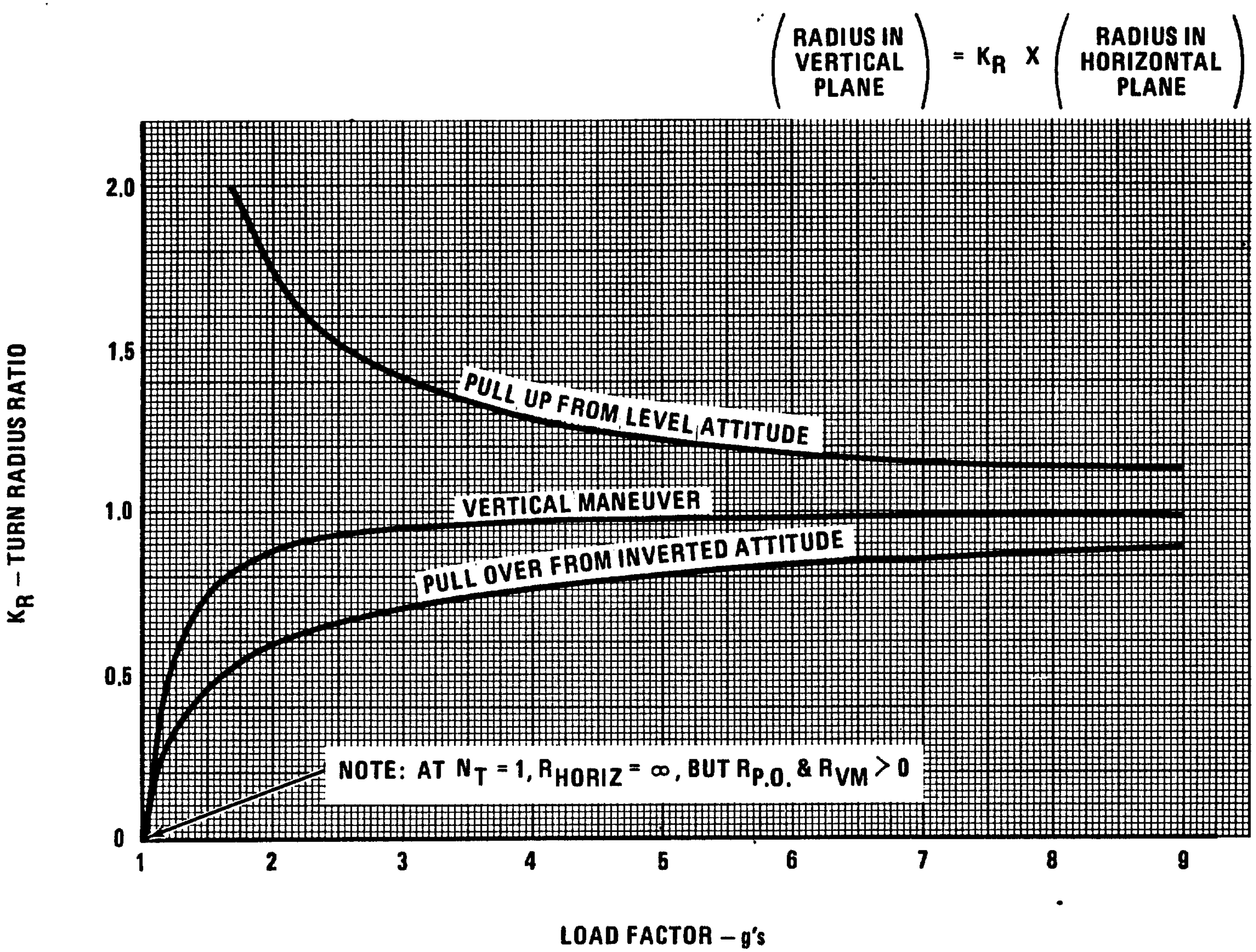
$$\frac{R_{VERT\ MAN}}{R_{HORIZ}} = \frac{\sqrt{N_T^2 - 1}}{N_T}$$

(1) THE RATIOS CAN BE PLOTTED VERSUS LOAD FACTOR (N_T)

(2) R_{HORIZ} CAN BE OBTAINED FROM DOG HOUSE PLOTS

(3) R_{PULLUP}, $R_{PULLOVER}$, AND $R_{VERT\ MAN}$ CAN THEN BE OBTAINED BY MULTIPLING (1) X (2)

Fighter Performance (Cont'd)
Vertical Plane Turn Radius



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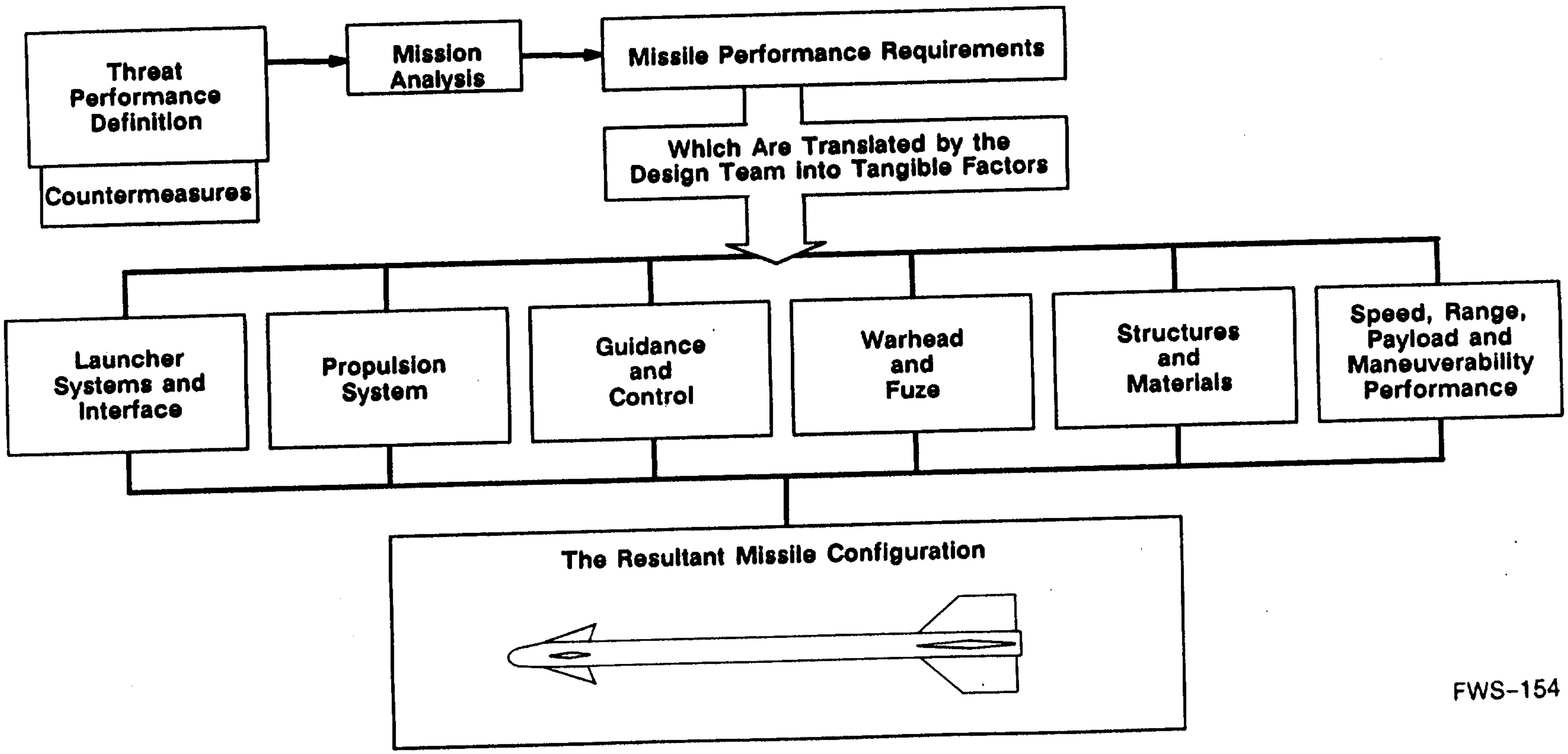
X. Missile Aerodynamics

Reference: Lester L. Cronvich's Article on "Missile Aerodynamics" and Frederick S. Billig's Article "Tactical Missile Design Concepts," Both in the Lockheed Horizons Magazine, Volume 4, 03 November 1983

- **A Missile Represents the Final Product of a Team Design Approach of which "Performance" Is Merely One of the Overall Factors**
  - **We Think that Performance Drives Most Aerodynamics Platforms, However, In Tactical Missiles Other Factors Play Important Roles Which Both Benefit and Hinder Better Performance**
  - **The Final Aerodynamic Configuration Must Consider what the Missile Is Supposed to Do, on what and How It Is Being Transported, and Under what Conditions Will It Be Launched.**

- **Each Missile Is Designed to Very Specific Requirements that Both Become Its Strong and Weak Points**



Missile Aerodynamics (Cont'd)

- **Factors that Influence Missile Design and Overall Performance**

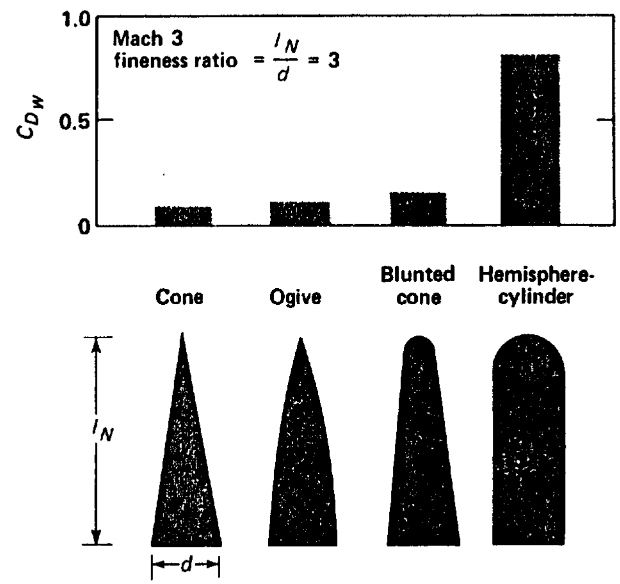
  - **Propulsion:** Types (1) Turbojet (3) Ramjet (2) Rocket (4) Combinations

    ... The "Shape" of a Missile Is Greatly Dependent Upon the Type of Propulsion System (Motor). Inlets, Nozzles, Pumps, Etc All Effect Drag, Weight, and Center of Mass

    ... Fuel Consumption Makes the Greatest Impact on Controllability Due to the Changing Center of Gravity

  - **Guidance:** The Choice of Technique, Lifting/Control Surfaces, Sensor Dome or Nose Style, and Peripheral Antennas, Etc All Effect Both the Magnitudes of Performance (Range/Payload) and the Rate of Performance (Accel/Turn)

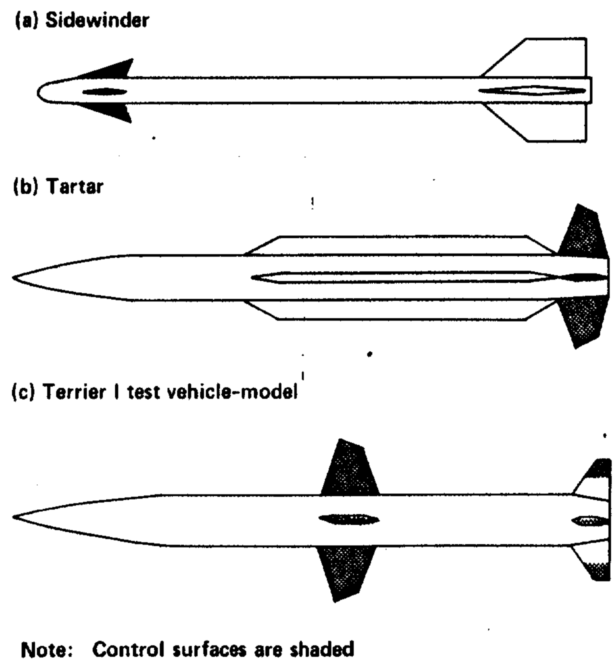
  - **Warhead:** The Warhead Generally Is the Payload, and Its Placement Effects the Aerodynamic Balance of the Missile.



The effect of sensor dome bluntness on the wave drag coefficient, C_{D_W}.

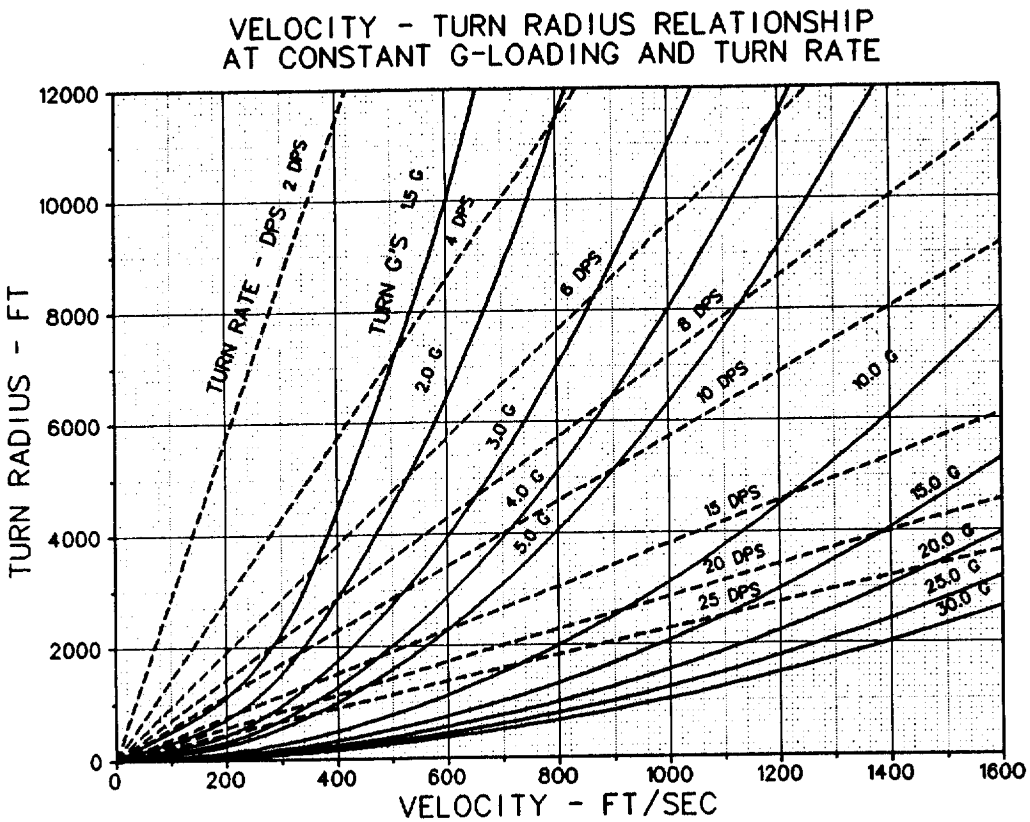
Missile Aerodynamics (Cont'd)

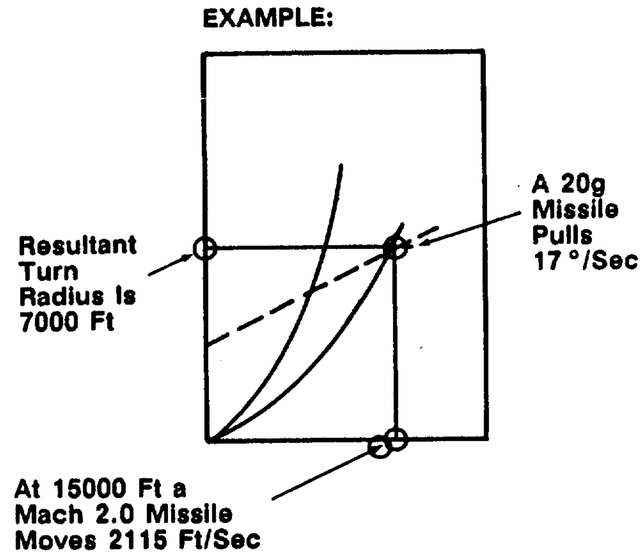
- **Missile Flight Control System**
  - **Classical Missile Design Utilizes Moving Control Surfaces that Are Placed in Three General Areas:**
    - **. . . Canard Surfaces Well Forward**
    - **. . . Tail Surfaces Well Aft**
    - **. . . Wing Surfaces Near the Midbody**
  - **More Modern Designs Utilize Variable Nozzle and Jet Vanes Either Alone or in Combination Surfaces**
    - **. . . Surfaces Are Also Becoming More Complex and Optimized for the Mission of the Missile**
    - **. . . Relighting Motors Also Add a Feature to New Missiles that Allow Longer Sustained Maneuvering**



Types of aerodynamic control.

Treating an Airborne Missile as an Aerodynamic Vehicle





You Must Convert Mach Number to Ft/Sec at the Desired Altitude. Use Table on Page 70

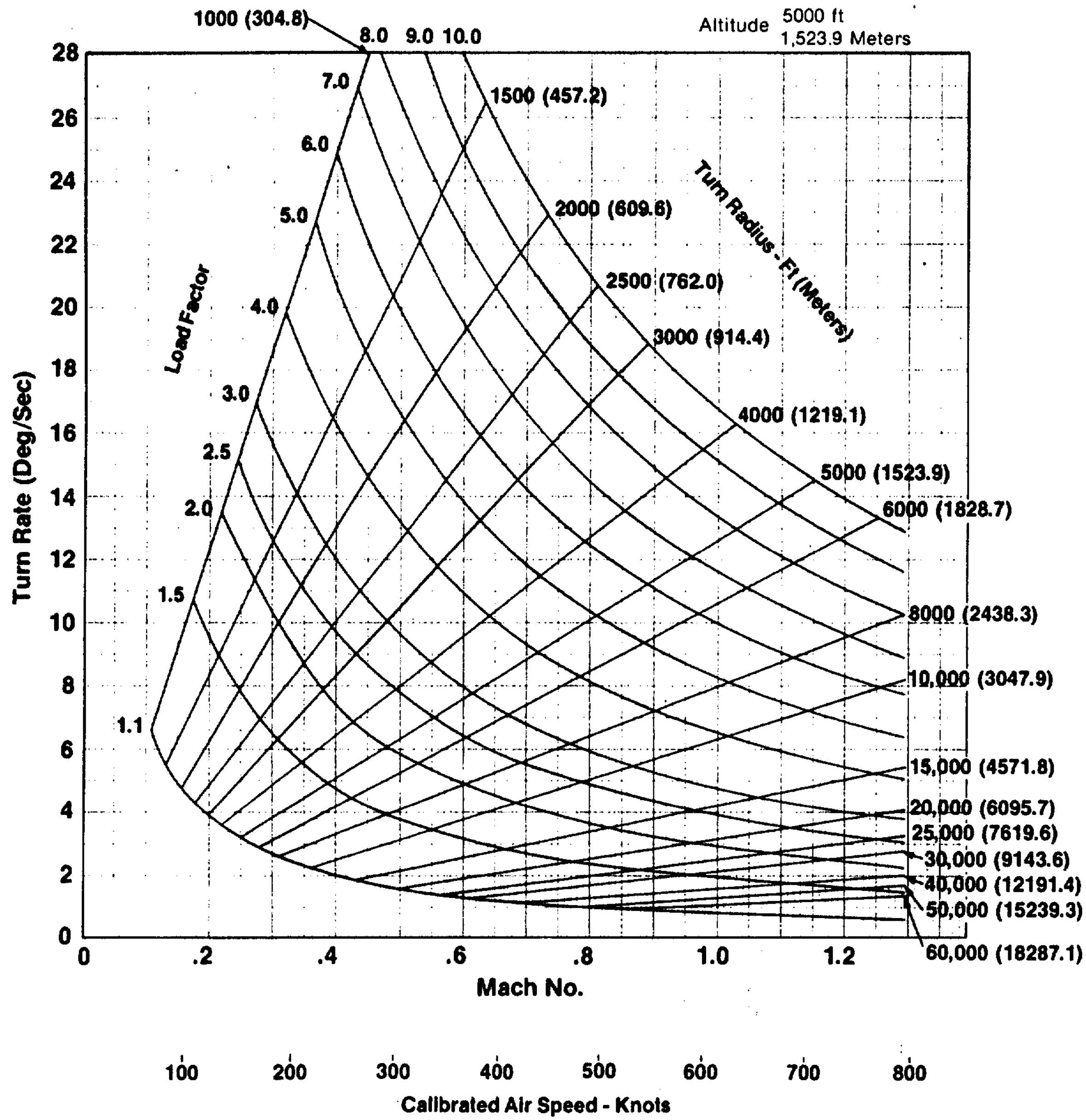
MACH	ALT	FT/SEC
1	5 Kft	1097
2	15 Kft	2115
3	20 Kft	3110

XI. Fighter Performance Examples

- **Doghouse Comparisons of Aircraft**
  - F-51 Mustang
  - F-86 Sabre
  - MiG-15 UTI (Magot)
  - F-5A Freedom Fighter
  - F-5E Tiger
  - F-4E Phantom II
  - F-16A Fighting Falcon
  - F-106 Delta Dart
  - KFIR C-7
  - T-2C Buckeye

5000 Ft
15000 Ft
25000 Ft
(Work Sheets Enclosed)

5000 Ft Turn Rate Worksheet



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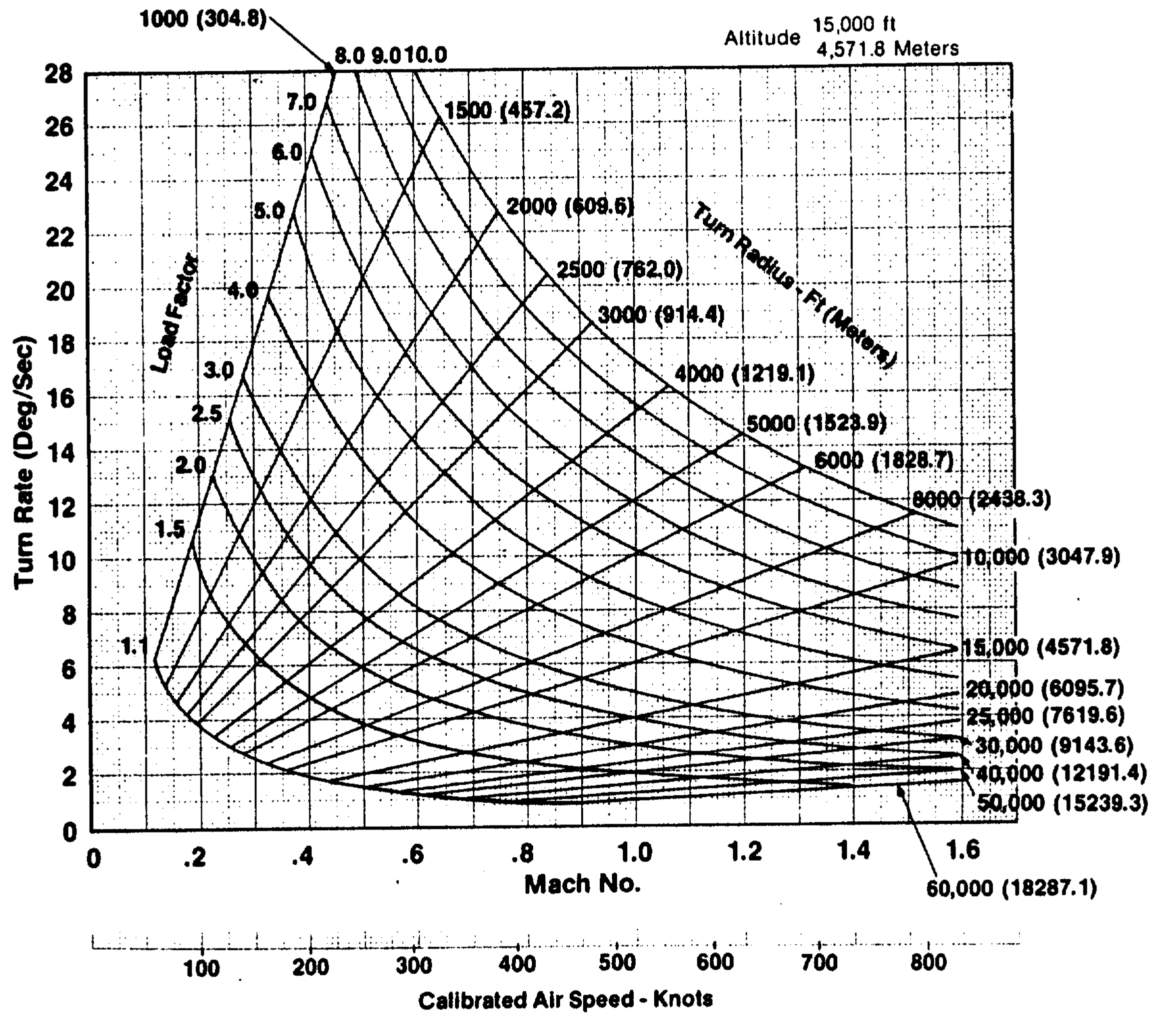
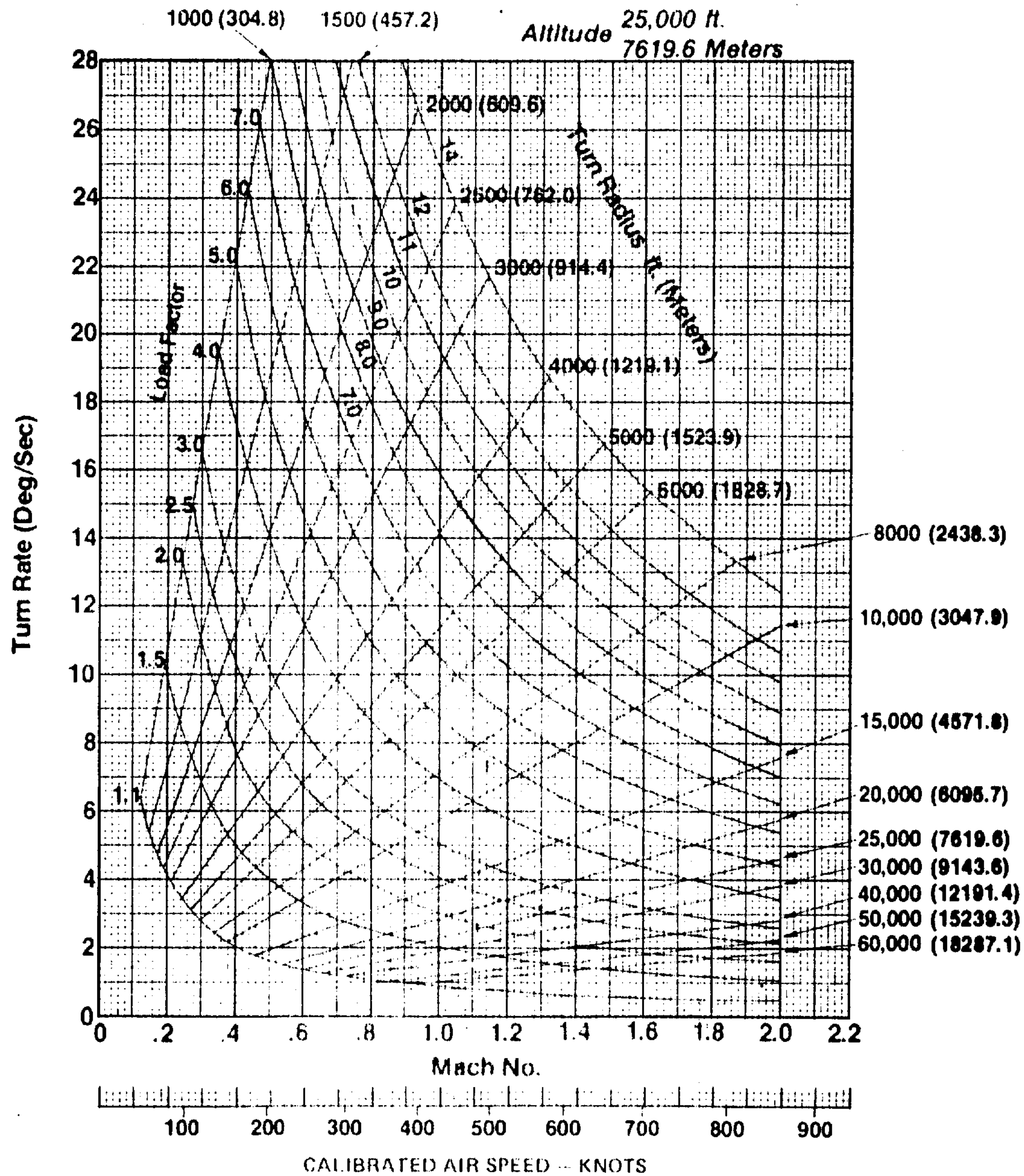
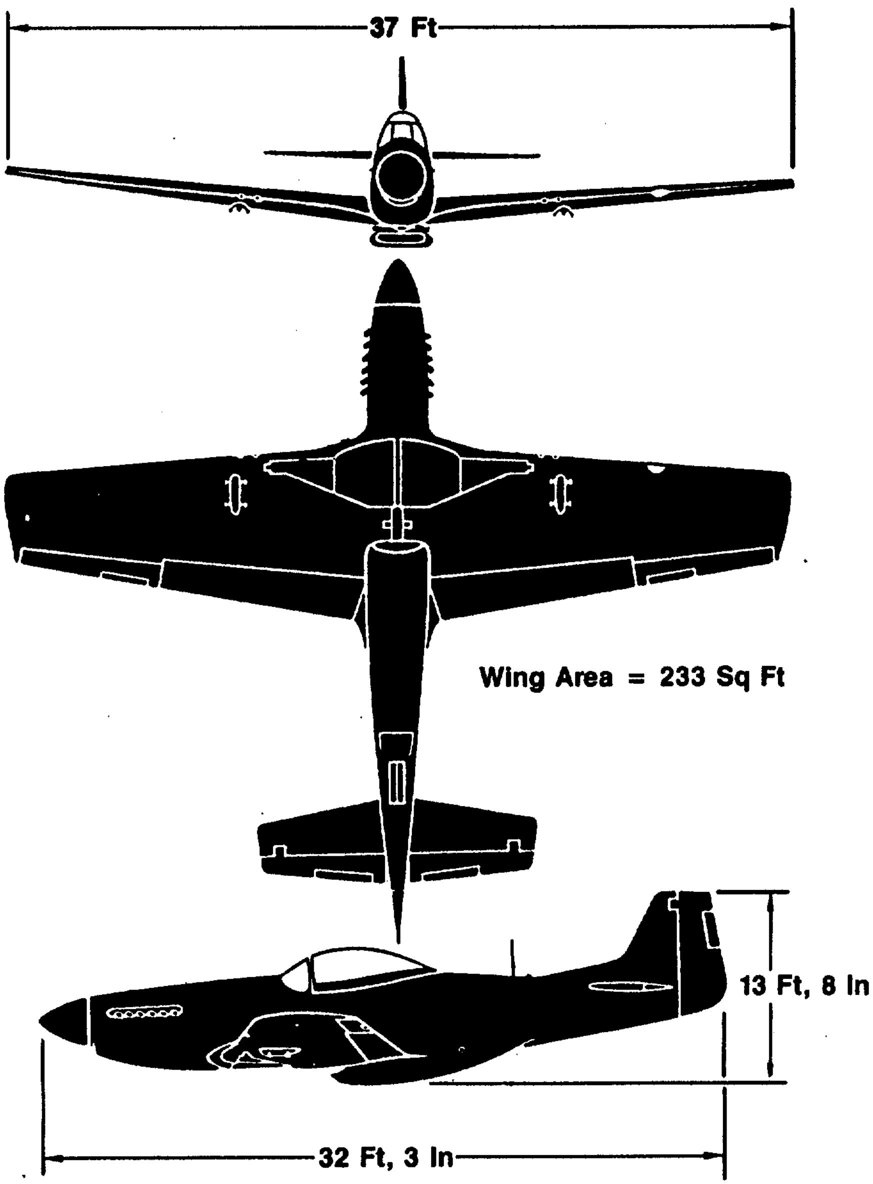
15,000 Ft Turn Rate Worksheet



25,000 Ft Turn Rate Worksheet



North American F-51D

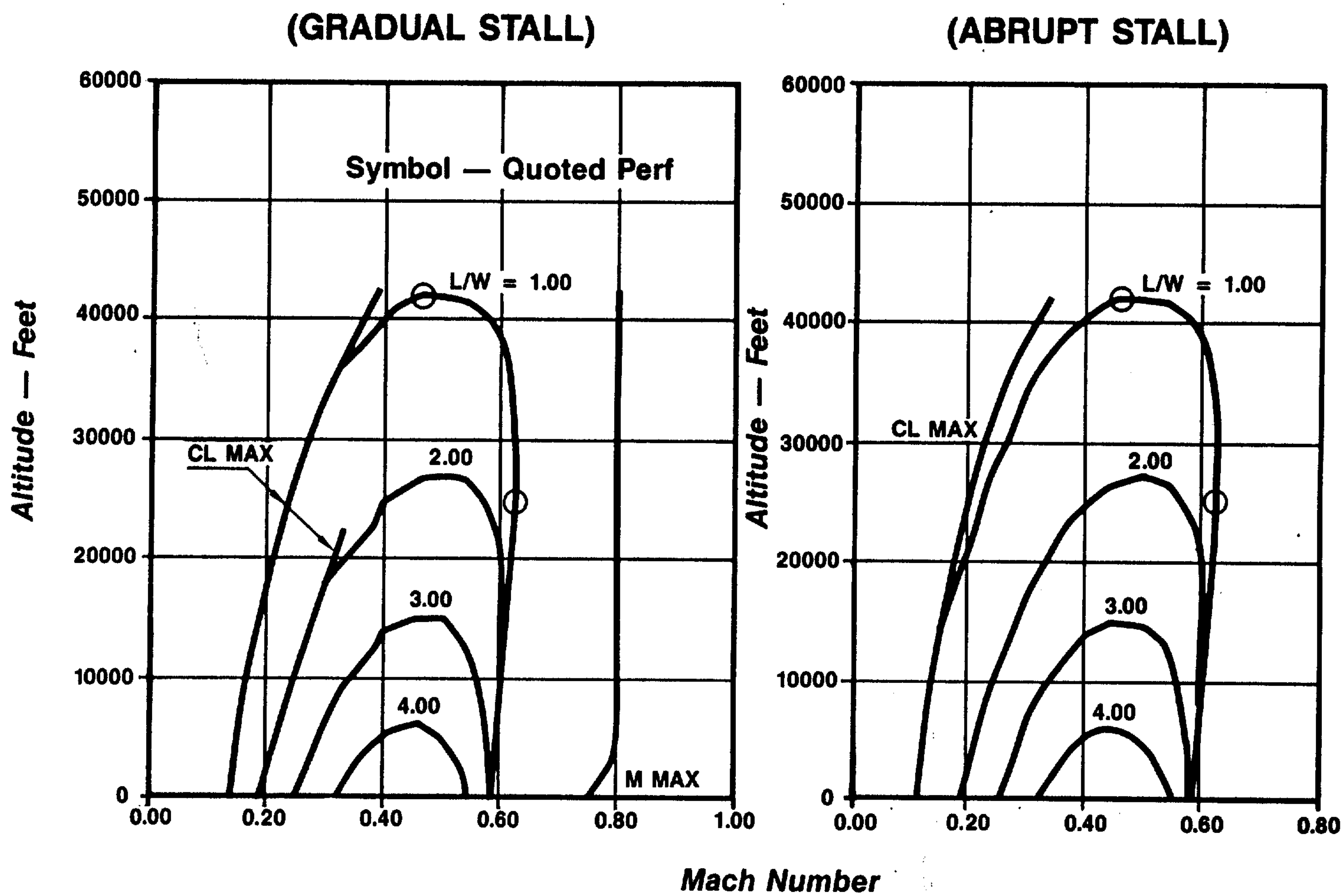


PHYSICAL DESCRIPTION
and
QUOTED PERFORMANCE

- Engine - Packard V-12, 1,720 HP
- Top Speed - 437 MPH (0.63M) (25K Ft Alt)
- Ceiling - 41,900 Ft
- Range - 2,300 Miles
- Empty Weight - 7,125 Lb
- Gross Wt - 11,600 Lb
- 50% Fuel Wt - 9,362 Lb

F-51D Sustained Envelope – 50% Fuel

Correlation with Quoted Performance

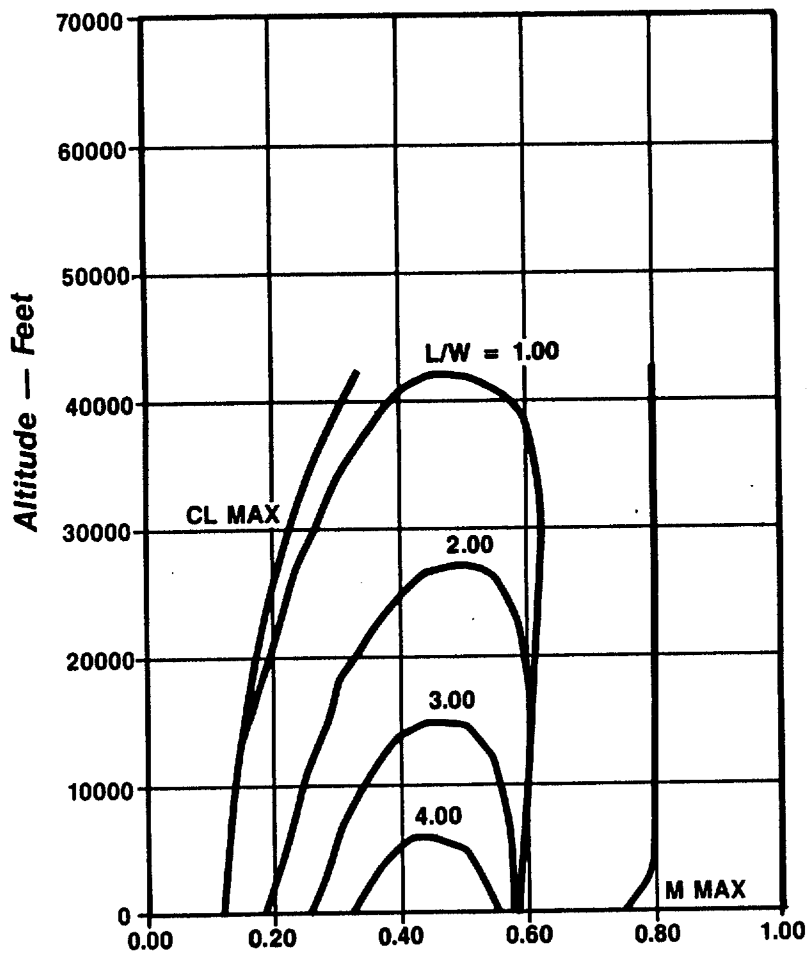


F-51D Sustained Envelope – 50% Fuel

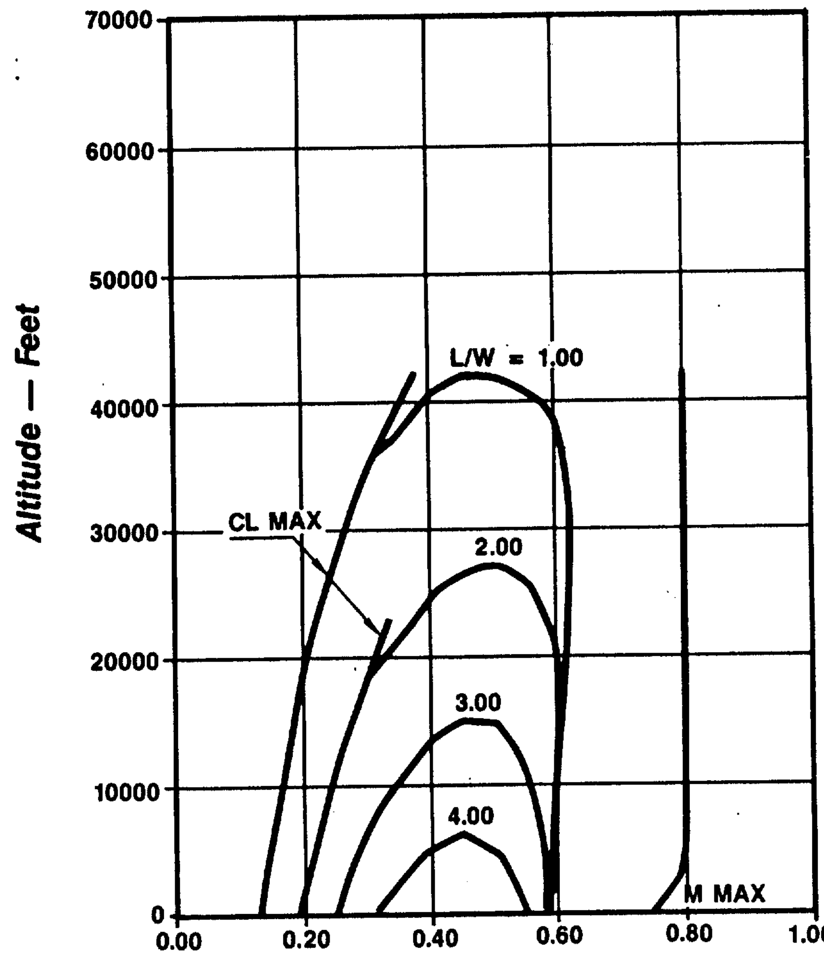
C_L Max, Max Power

Weight = 9362 Lb
Packard V-12 Engine
(6) 50 Cal Machine Guns

(ABRUPT STALL)



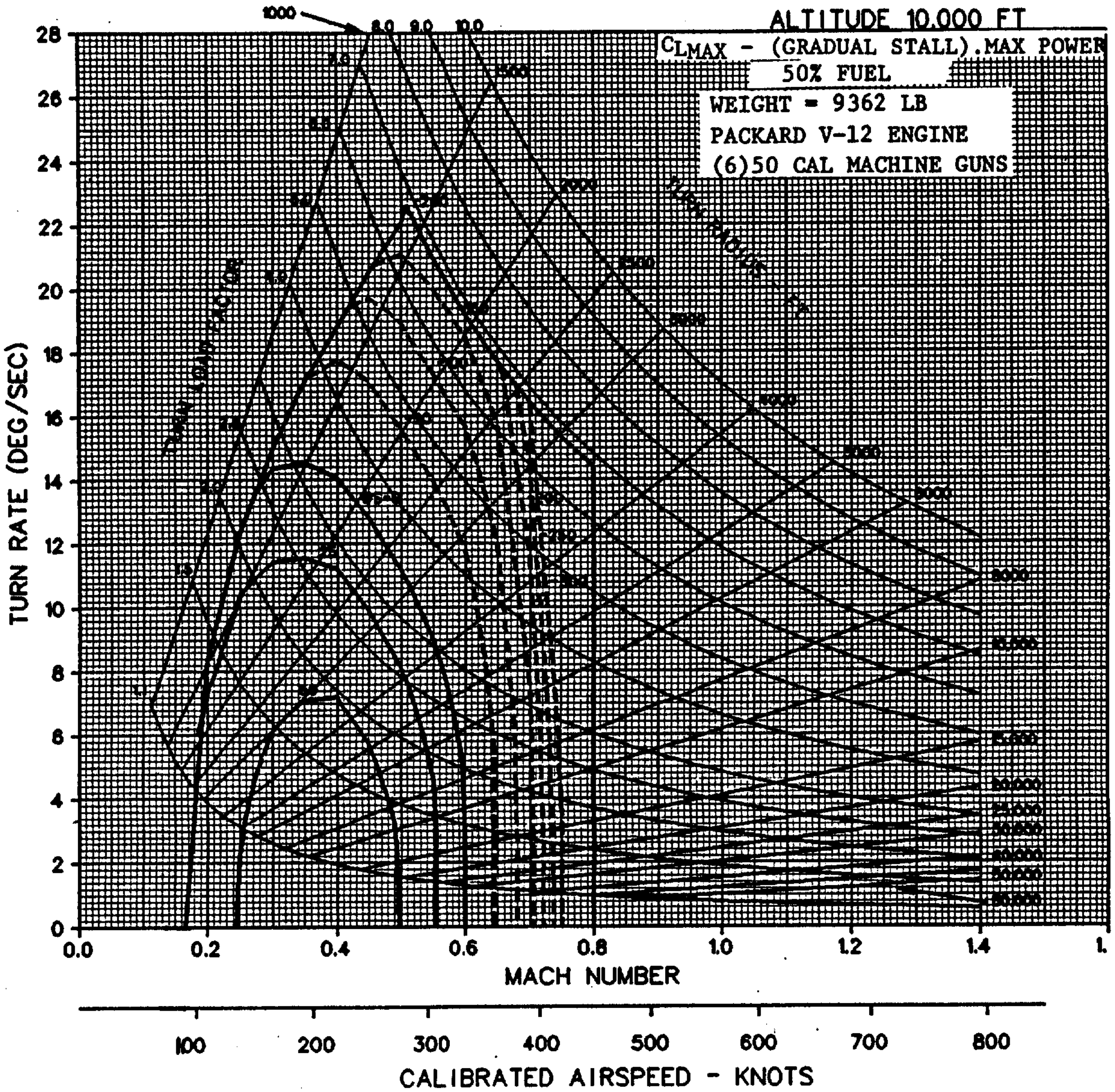
(GRADUAL STALL)



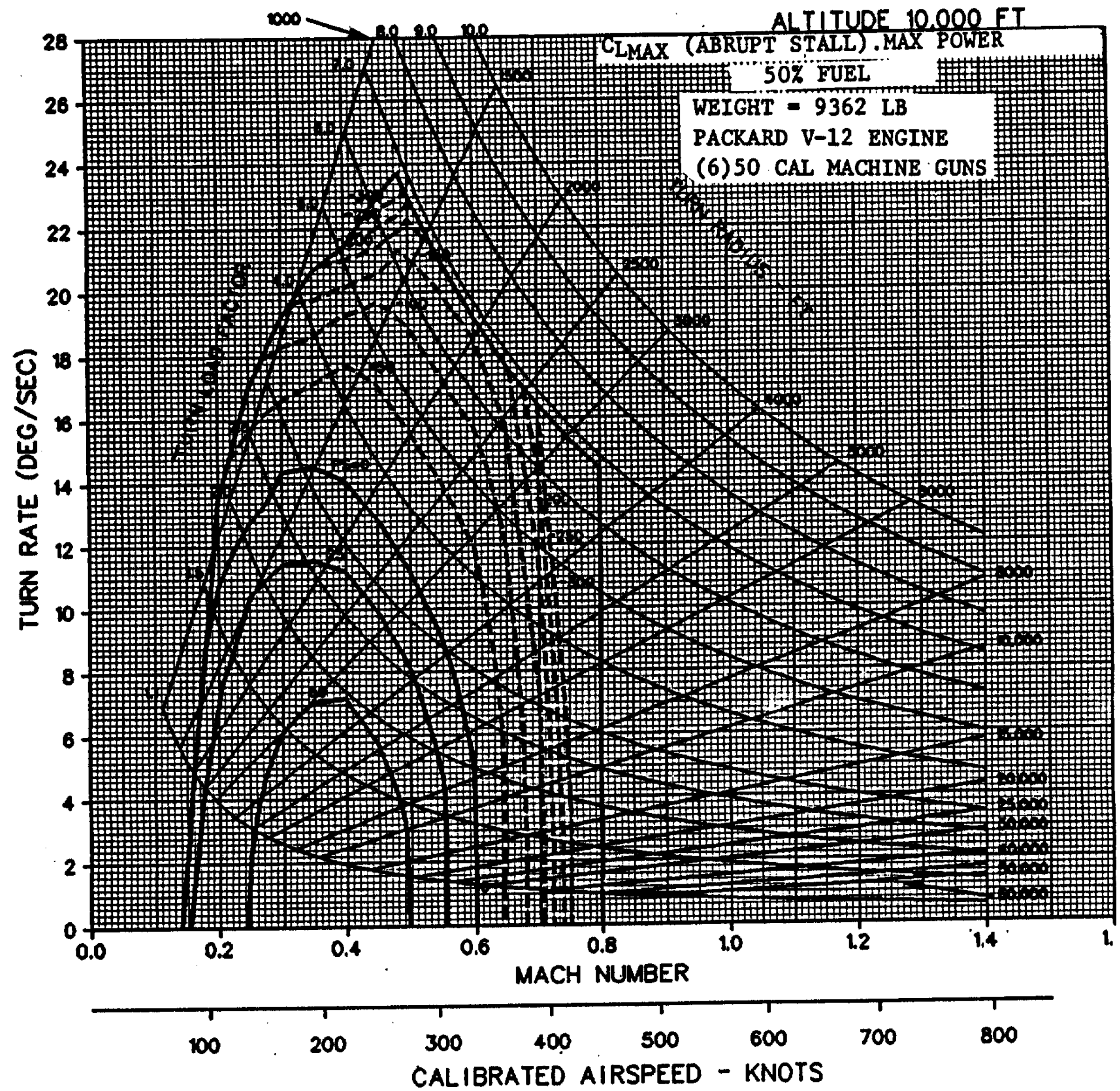
Mach Number

FWS-164

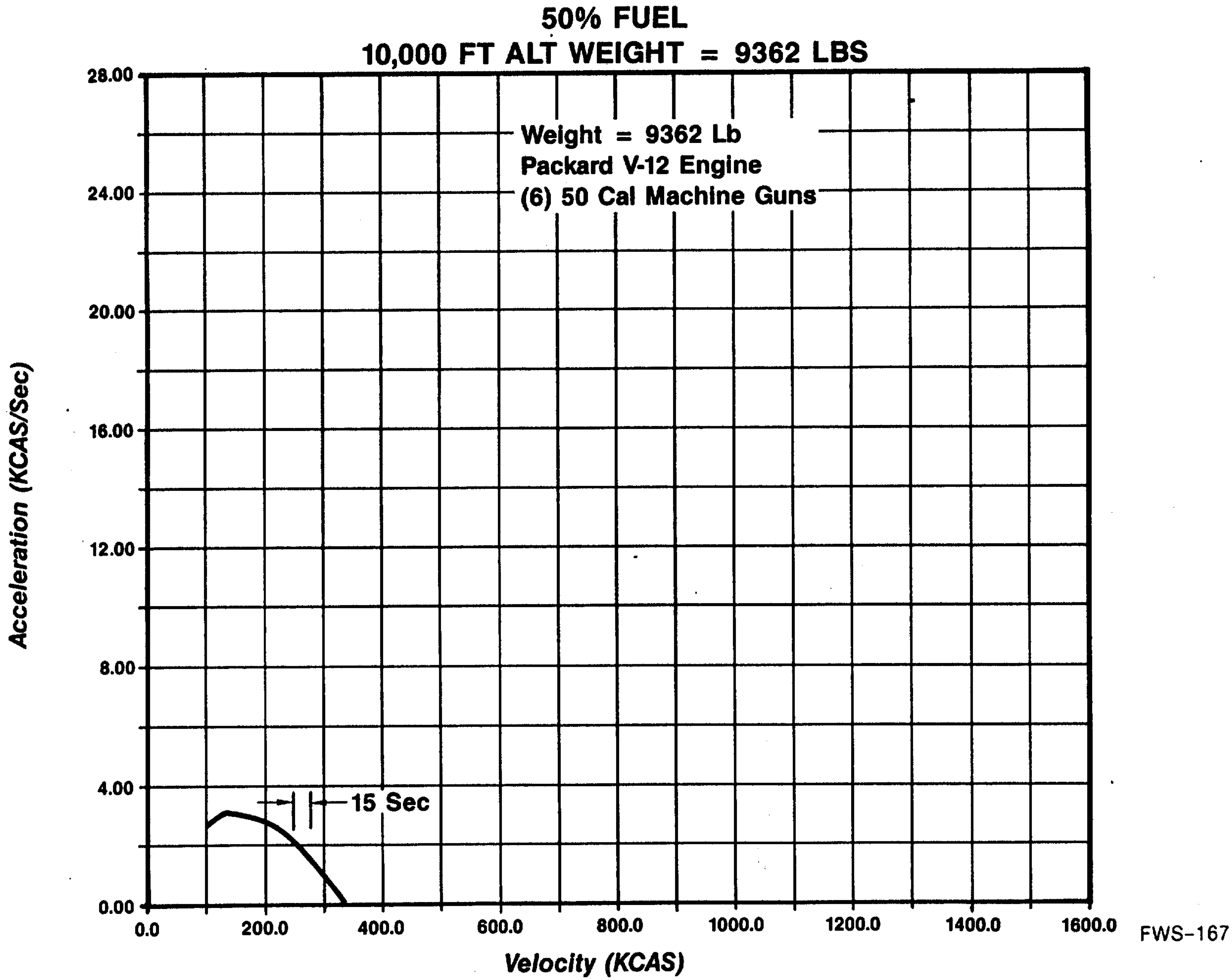
F-51D Turn Rate Diagram



F-51D Turn Rate Diagram

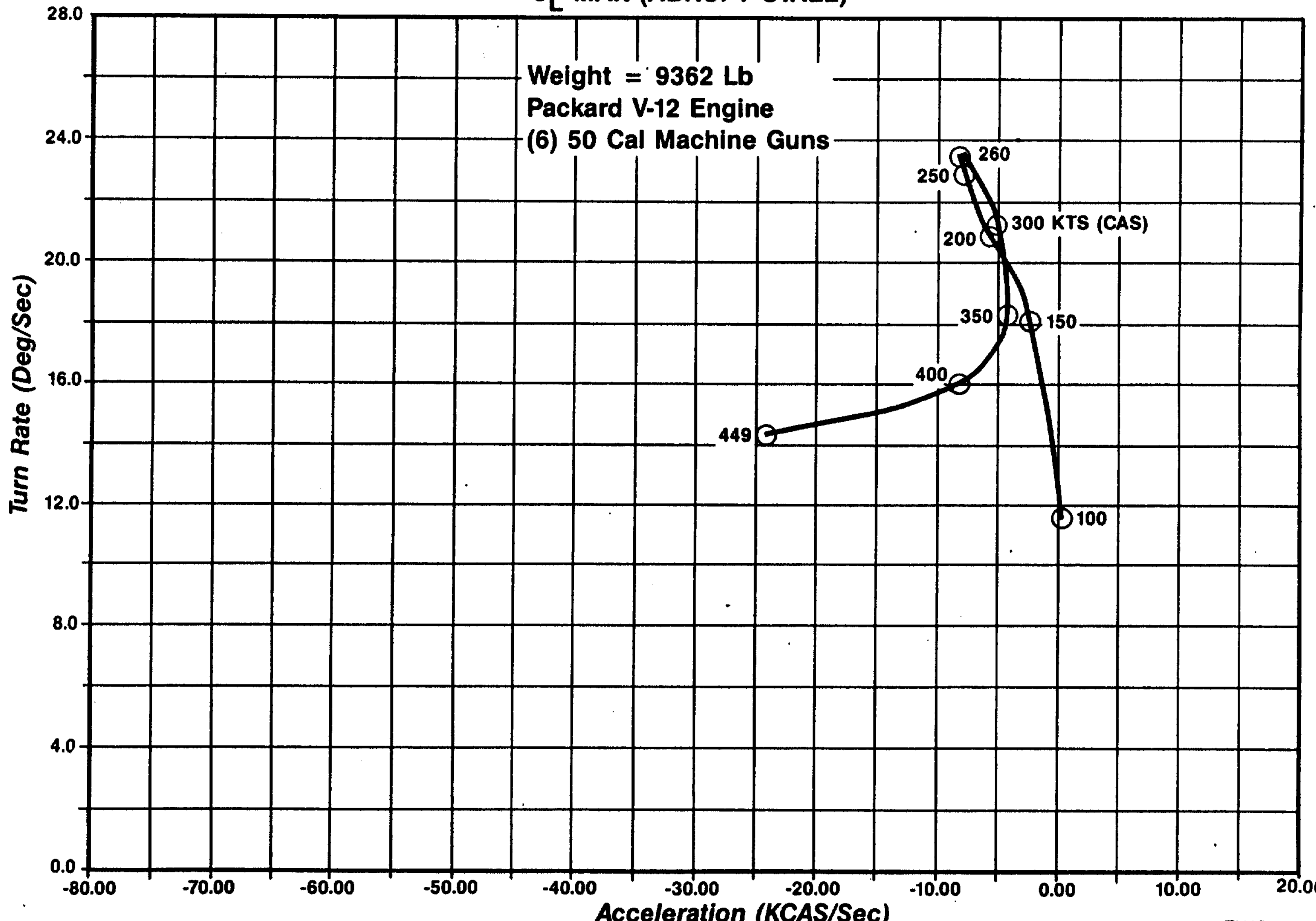


F-51D Max Power 1 G Acceleration



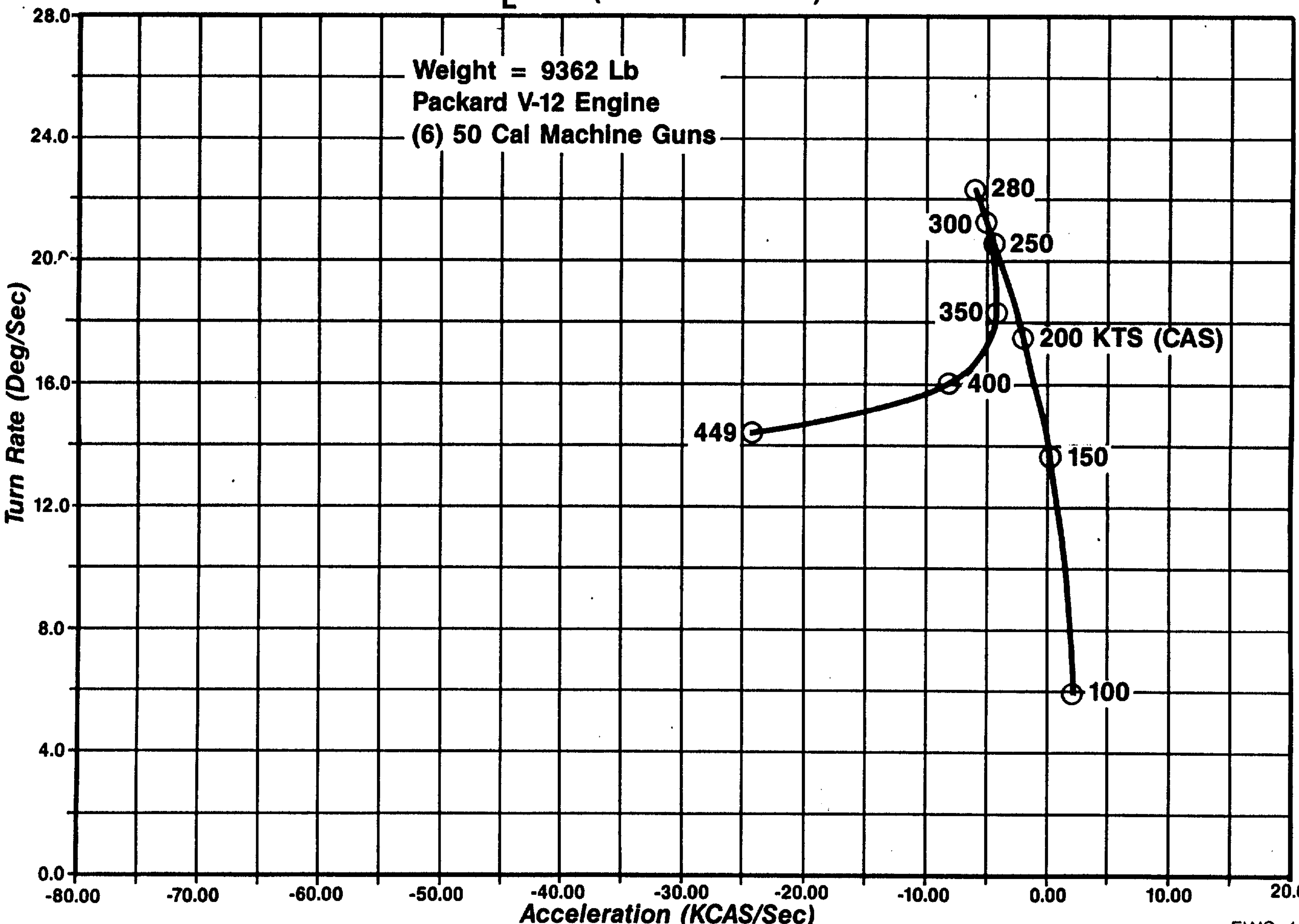
F-51D Max Power Dynamic Speed Turn

50% FUEL
10,000 FT ALT WEIGHT = 9362 LBS
C_L MAX (ABRUPT STALL)



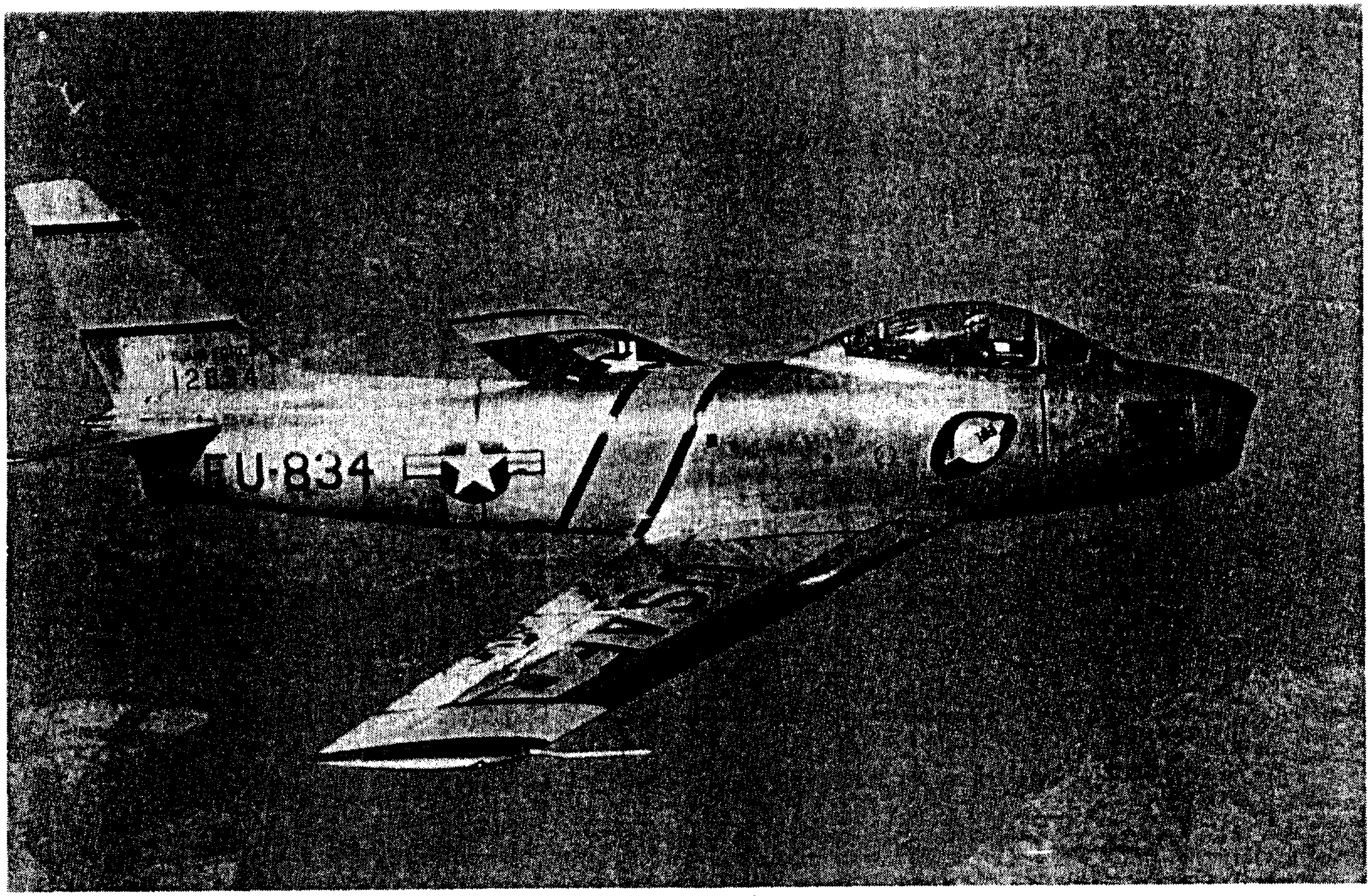
F–51D Max Power Dynamic Speed Turn

50% FUEL
ALTITUDE = 10,000 FT ALT WEIGHT = 9362 LBS
C_L MAX (GRADUAL STALL)

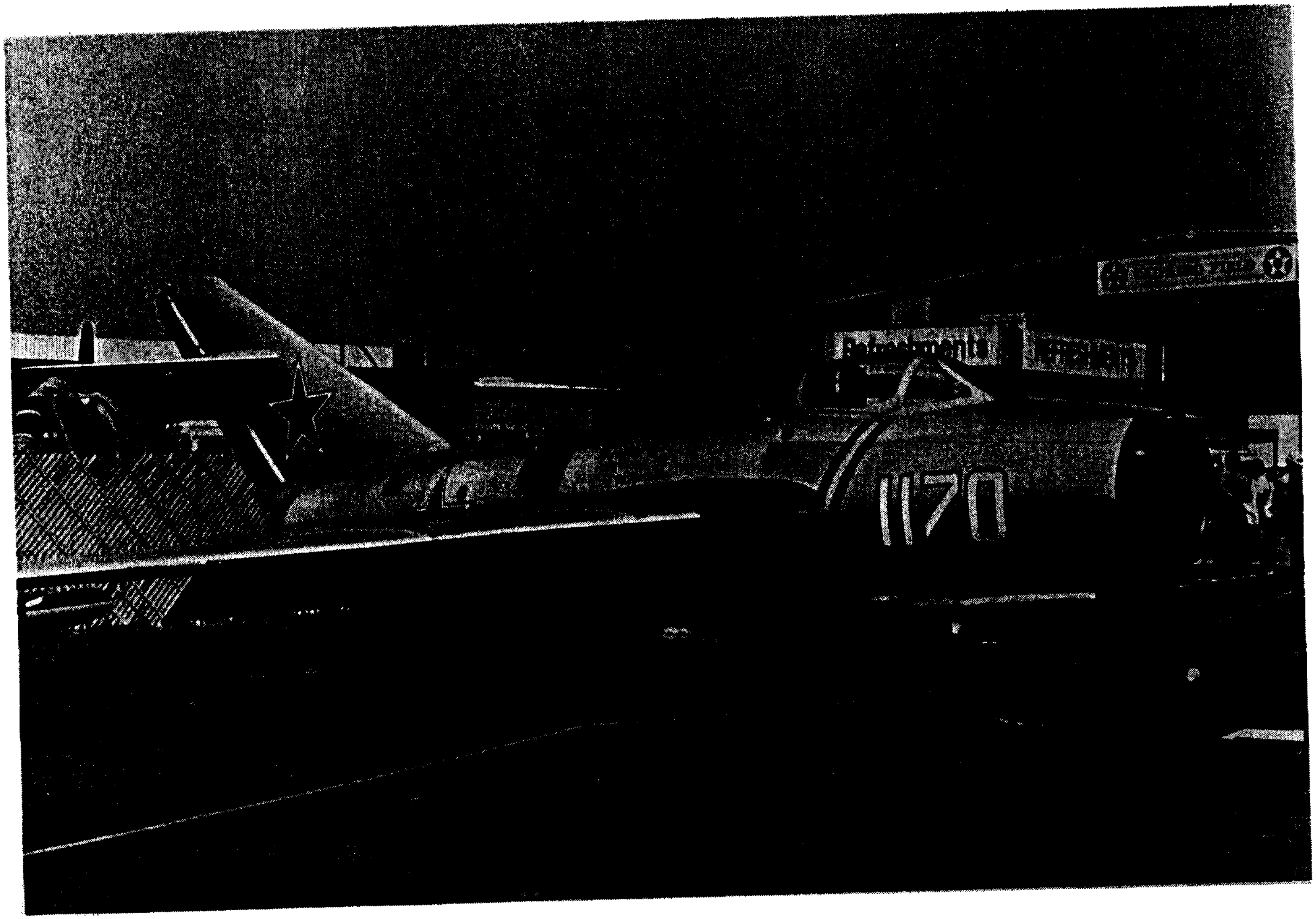


FWS–169

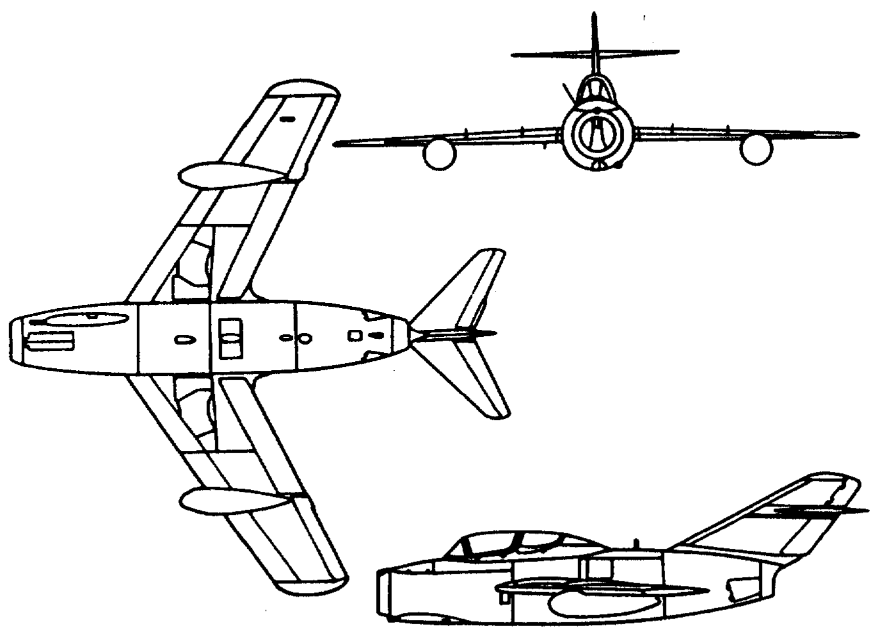
F-86



MiG-15

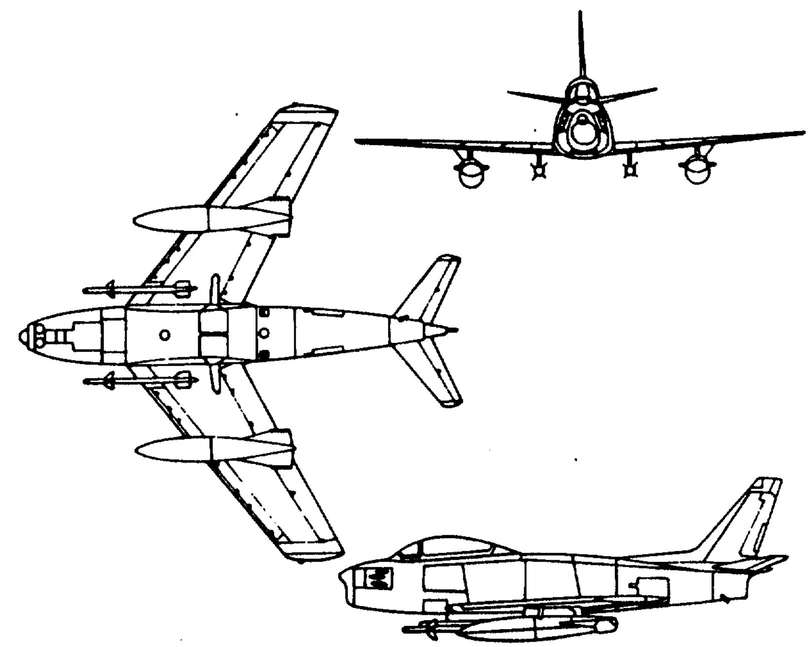


MiG-15 UTI Magot



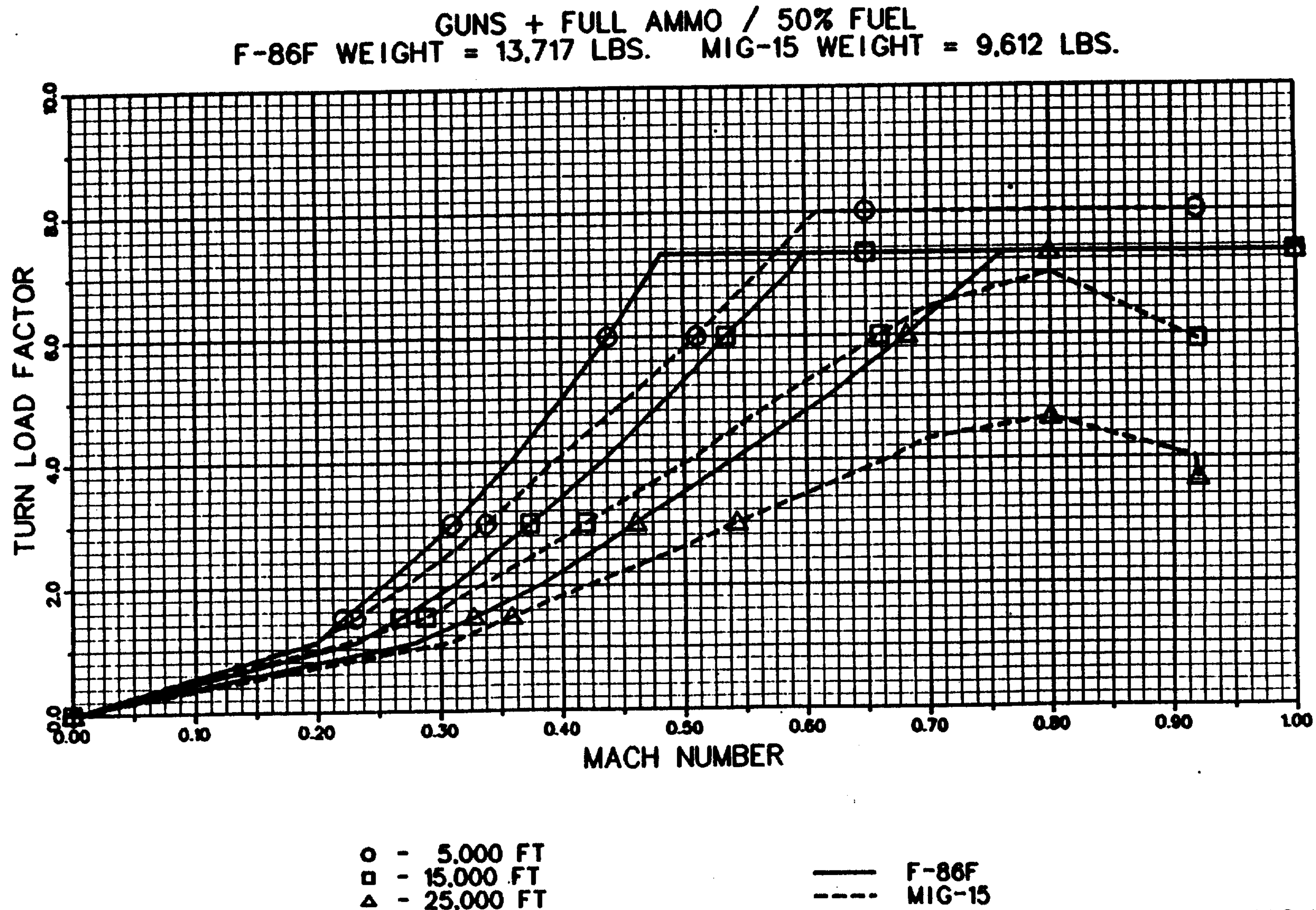
Wing Area	222 Ft^2	(21 m^2)
Empty Weight	8,320 Lbs	(3,774 Kg)
Internal Fuel	305 U.S. Gal	(1,154 Liter)
	1,984 Lbs	(900 Kg)
Max External Fuel	129 U.S. Gal	(488 Liter)
	839 Lbs	(380 Kg)
Combat Weight	9,612 Lbs	(4,359 Kg)
VK-1 TurboJet		
Max Mil-Pwr (Dry) Thrust at SL	5,955 Lbs	(2,700 Kg)
Combat Thrust/Weight Ratio	62	
Combat Wing Loading	43 Lbs/Ft^2	(211 Kg/m^2)
Max TOGW	11,085 Lbs	(5,028 Kg)
Max Subsonic Design Load Factor	8 g's	

F-86F Sabre Jet

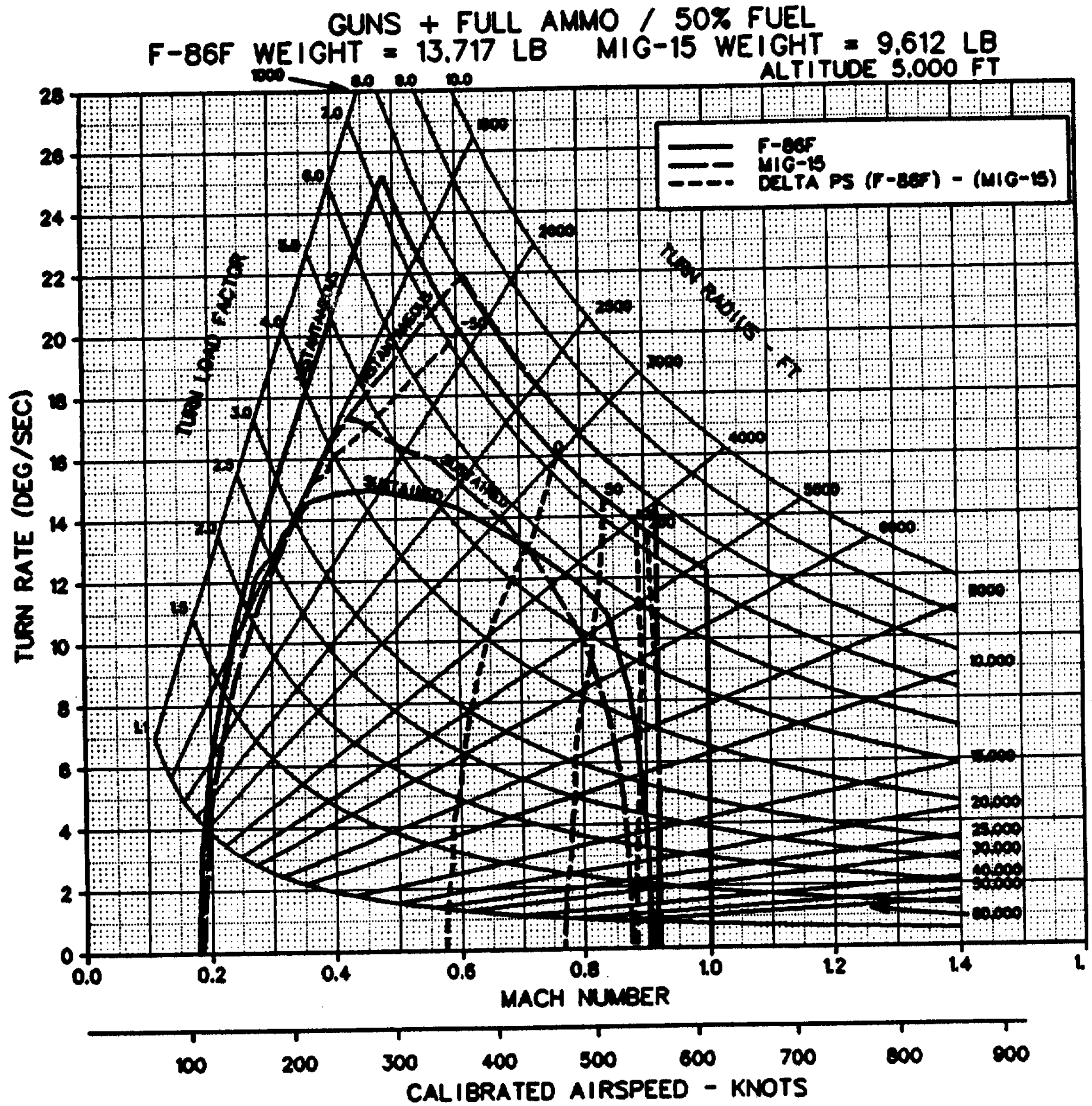


Wing Area	288 Ft^2	(27 m^2)
Empty Weight	10,950 Lbs	(4,967 Kb)
Internal Fuel	435 U.S. Gal	(1,946 Liter)
	2,827 Lbs	(1,282 Kg)
Max External Fuel	307 U.S. Gal	(1,162 Liter)
	2,000 Lbs	(907 Kg)
Combat Weight	13,717 Lbs	(6,221 Kg)
J47-GE-27 TurboJet		
Max Mil-Pwr (Dry) Thrust at SL	5,970 Lbs	(2,708 Kg)
Combat Thrust/Weight Ratio	44	
Combat Wing Loading	48 Lbs/Ft^2	(230 Kg/m^2)
Max TOGW	16,860 Lbs	(7,647 Kg)
Max Subsonic Design Load Factor	7.33 g's	

F-86F and MiG-15 V-N Diagram



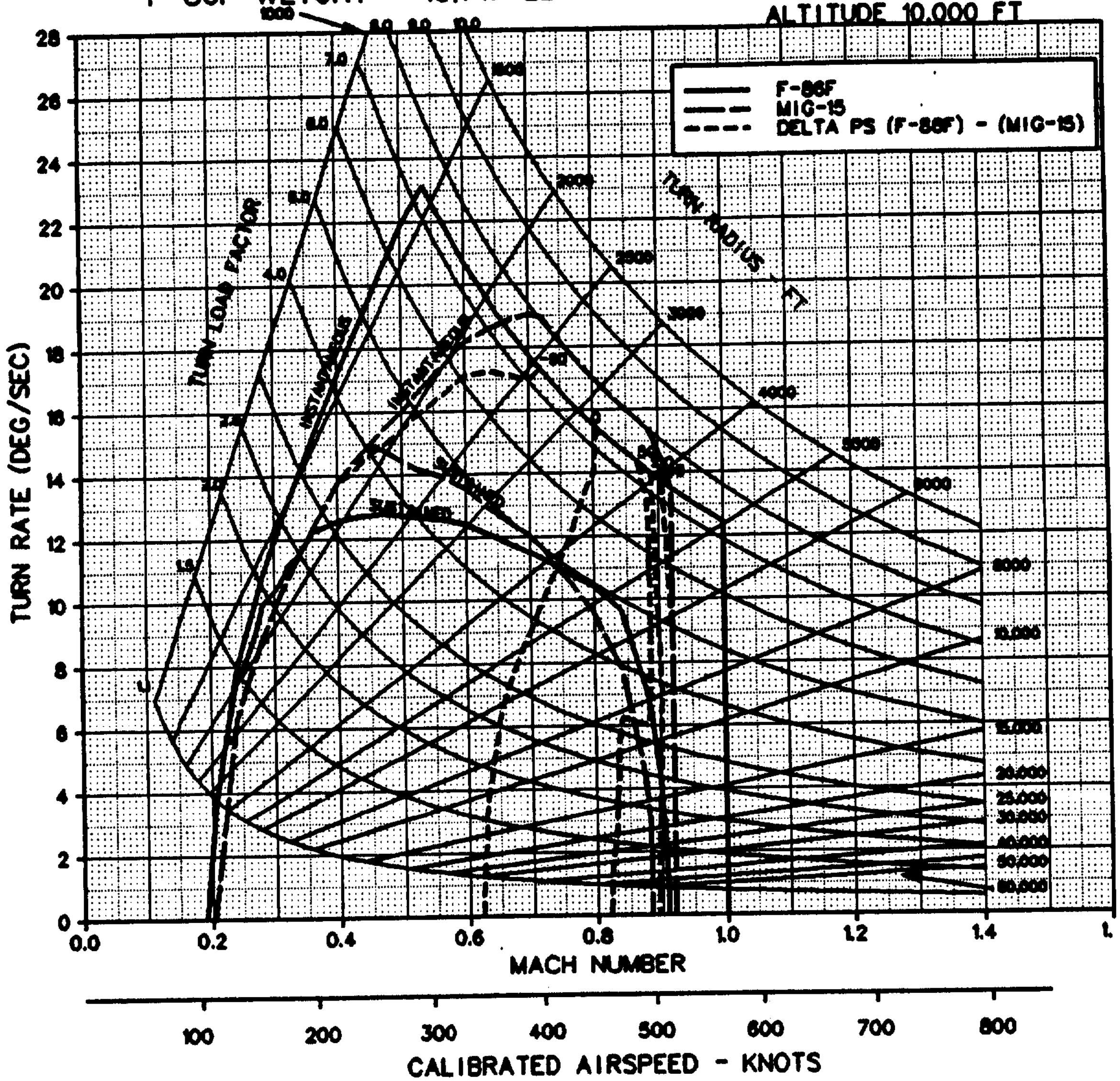
F-86 / MiG-15 Turn Rate Comparison



FWS-174

F-86 / MiG-15 Turn Rate Comparison

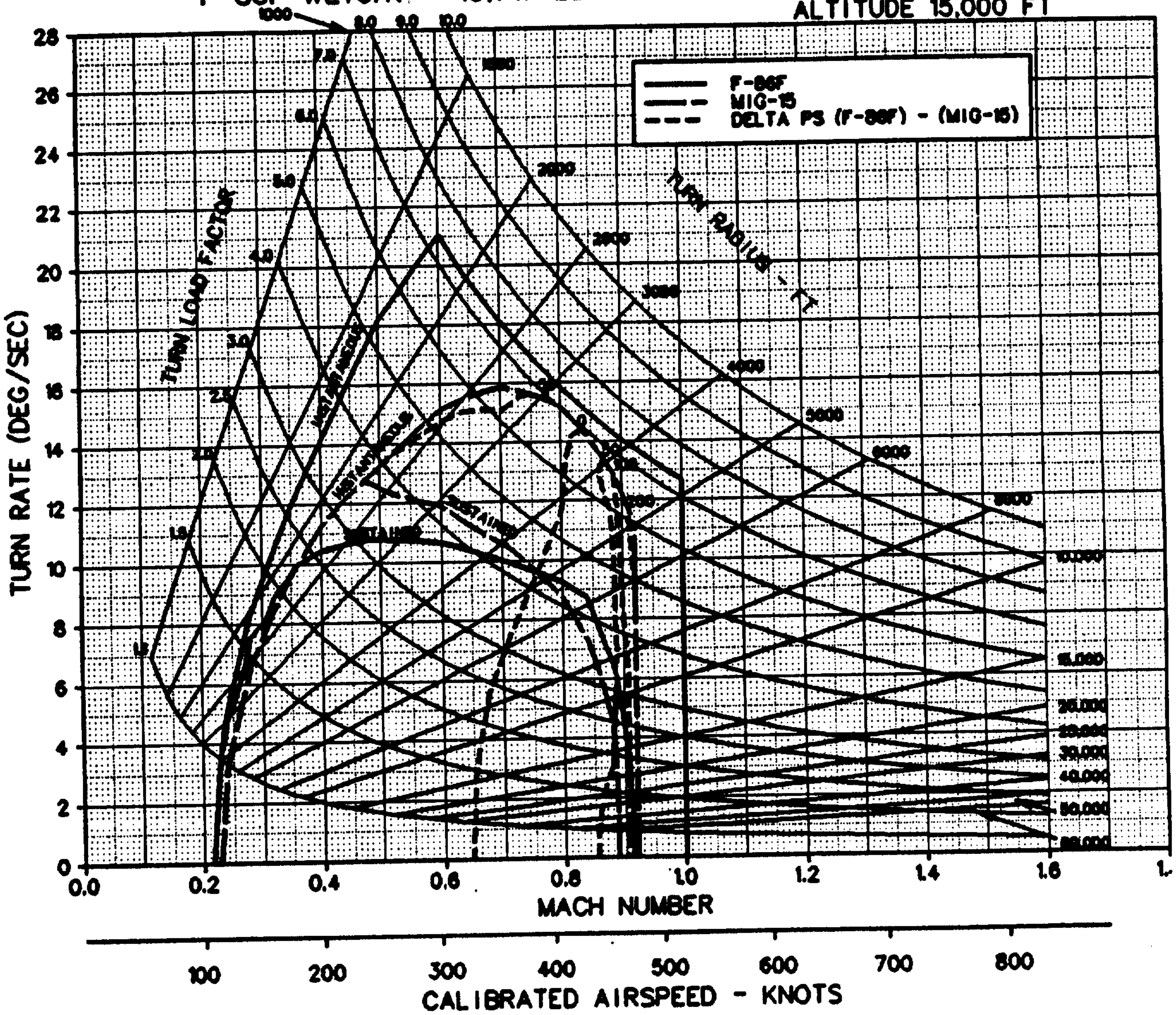
GUNS + FULL AMMO / 50% FUEL
F-86F WEIGHT = 13,717 LB   MIG-15 WEIGHT = 9,612 LB
ALTITUDE 10,000 FT



FWS-175

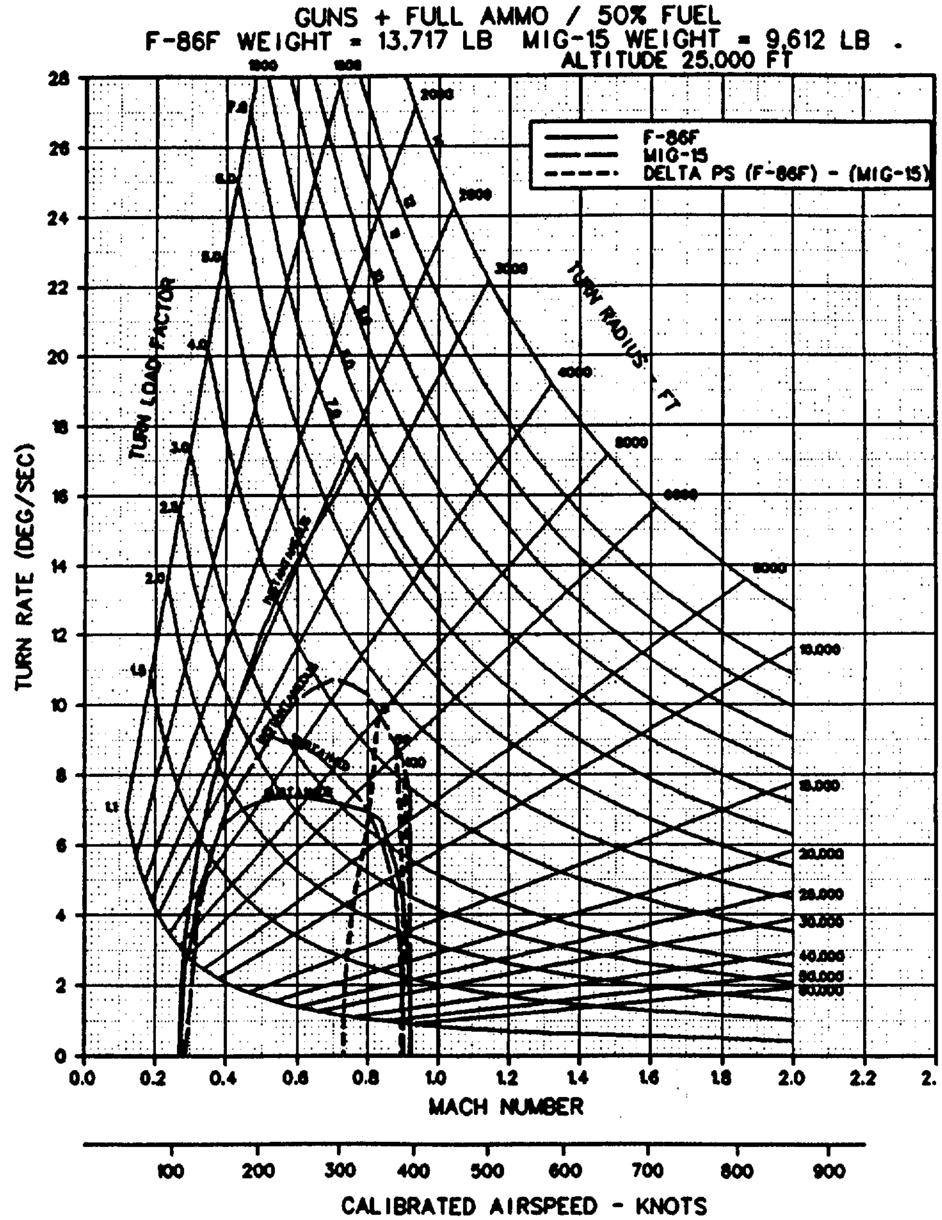
F-86 / MiG-15 Turn Rate Comparison

GUNS + FULL AMMO / 50% FUEL
F-86F WEIGHT = 13,717 LB   MIG-15 WEIGHT = 9,612 LB
ALTITUDE 15,000 FT



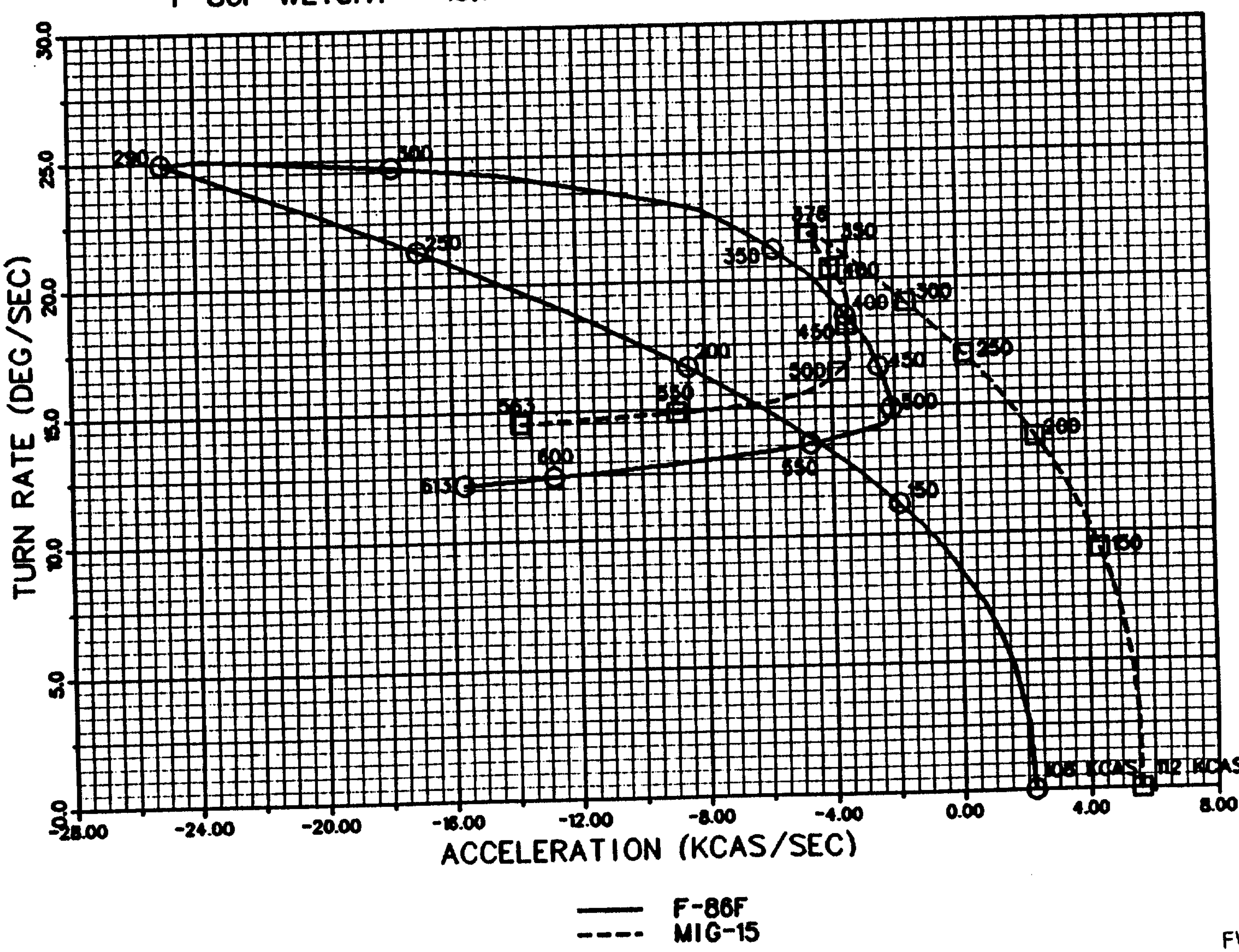
FWS-176

F-86 / MiG-15 Turn Rate Comparison



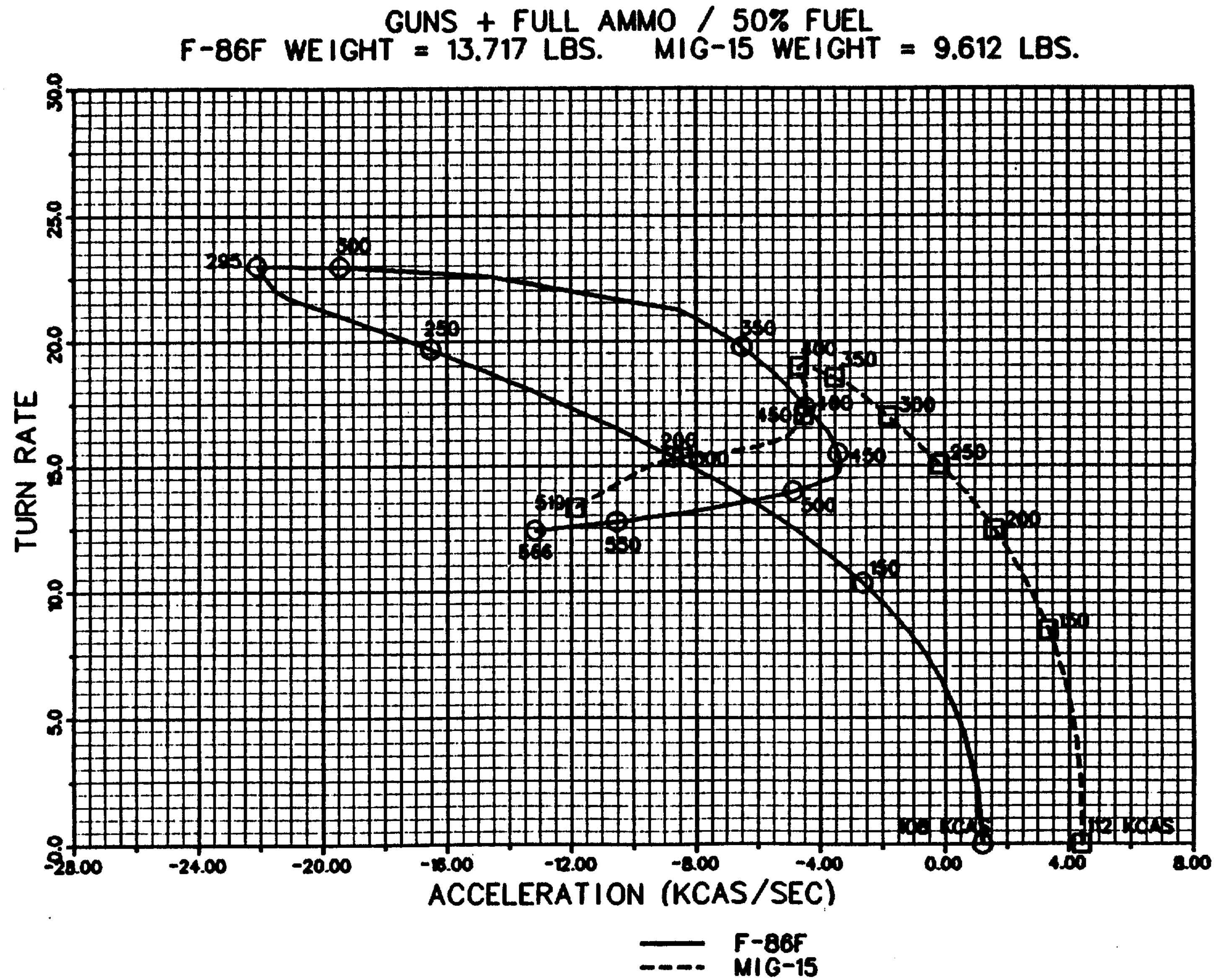
F-86 & MiG-15 Dynamic Speed Turns at 5,000 Ft

GUNS + FULL AMMO / 50% FUEL
F-86F WEIGHT = 13.717 LBS.   MIG-15 WEIGHT = 9.612 LBS.



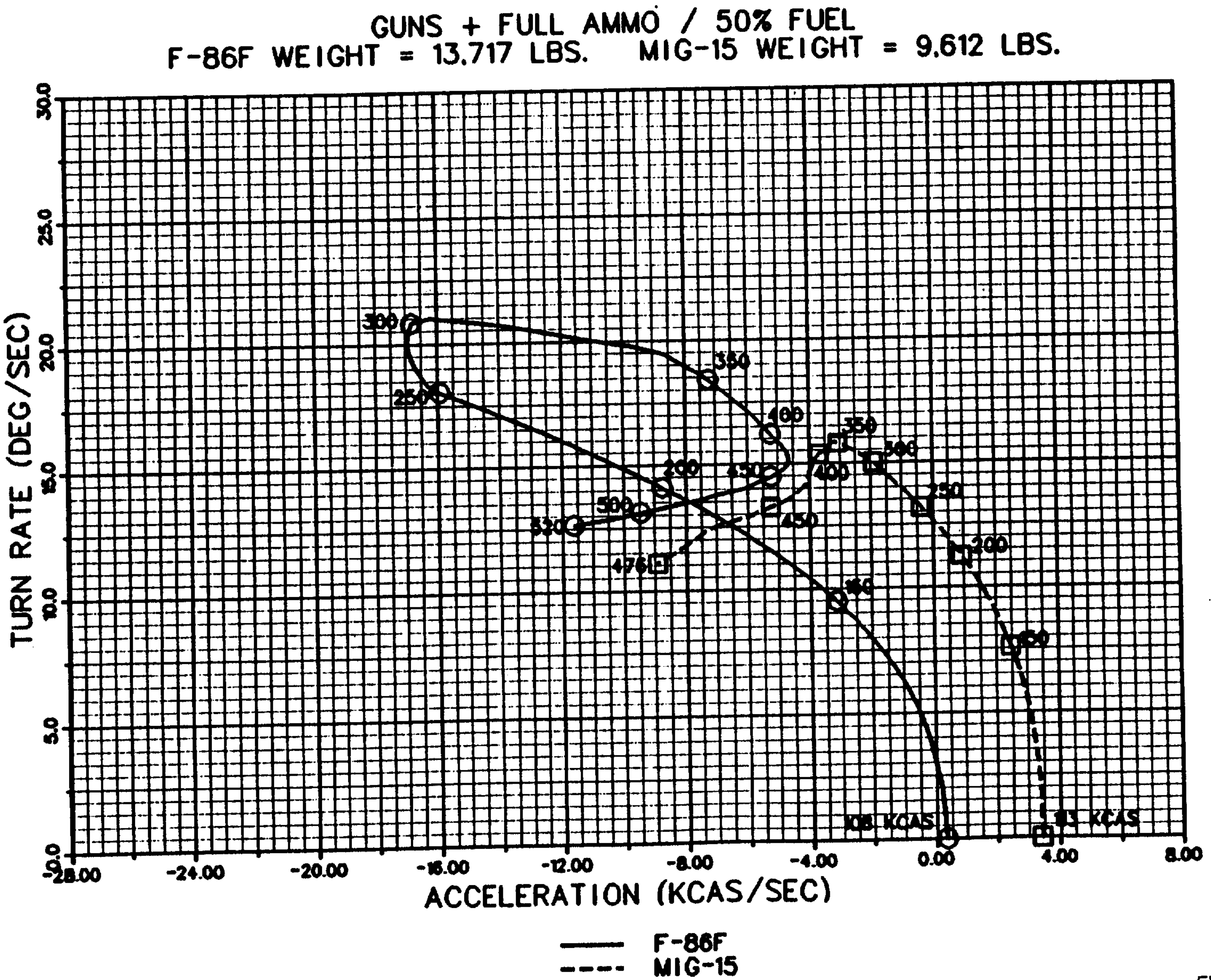
FWS-178

F-86 & MiG-15 Dynamic Speed Turns at 10,000 Ft



FWS-179

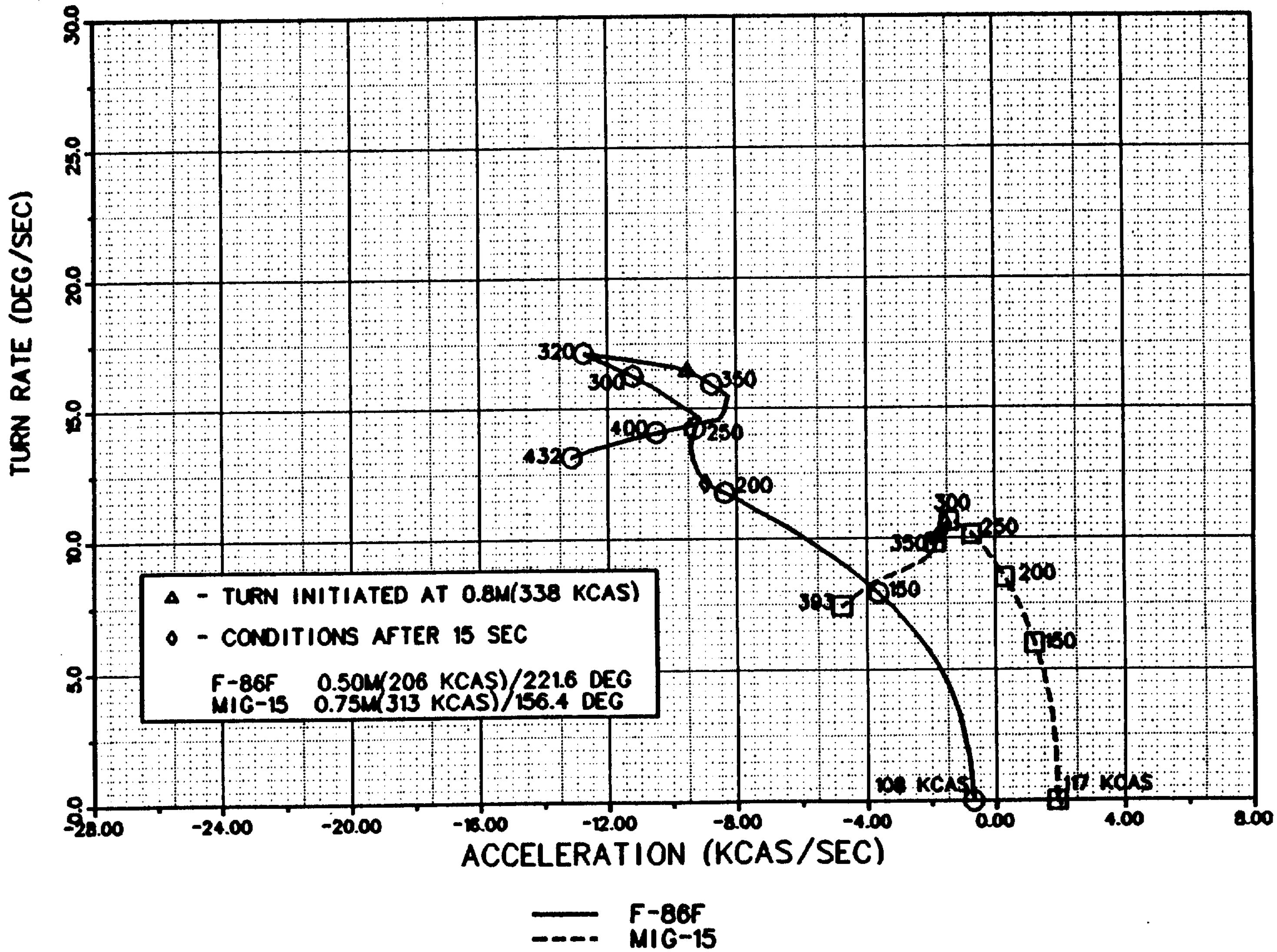
F-86 & MiG-15 Dynamic Speed Turns at 15,000 Ft



FWS-180

F-86 & MiG-15 Dynamic Speed Turns at 25,000 Ft

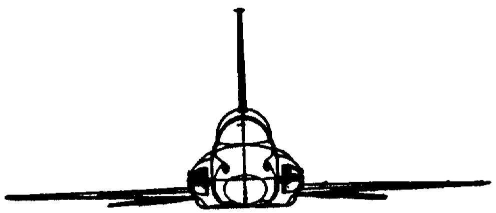
GUNS AND FULL AMMO / 50% FUEL
F-86F WEIGHT = 13.717 LB   MIG-15 WEIGHT = 9.612 LB



FWS-181

F-5A

"Freedom Fighter" by Northrop

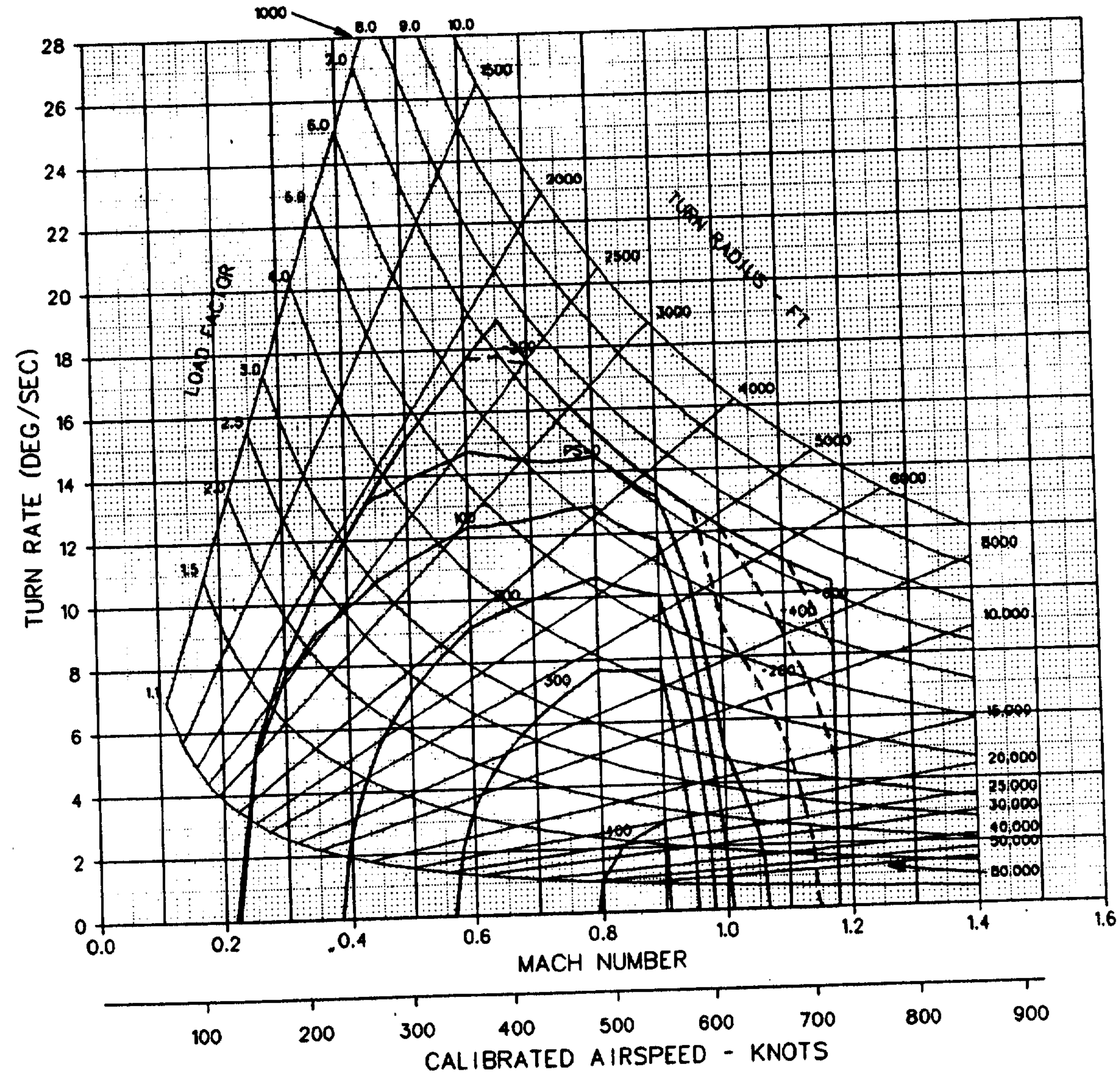


(2) GUNS w / full ammo
560 rds of 20 mm
50% internal Fuel = 1895 lbs (859 kg)
Combat Weight = 11410 lbs (5175 kg)

WING AREA	170 Sq Ft	(15.9 Sq M)
EMPTY WEIGHT	9120 Lbs	(4136 Kg)
INTERNAL FUEL	583 US Gal	(2207 Liter)
	3790 Lbs	(1719Kg)
TAKEOFF WEIGHT WITH (2) GUNS	13305 Lbs	(6034 Kg)
MAX EXTERNAL FUEL	546 US Gal	(2067 Liter)
	3549 Lbs	(1610 Kg)
COMBAT WEIGHT	11410 Lbs	(5175 Kg)
MAX A/B THRUST AT SEA LEVEL ((2) J85-GE-13)	8160 Lbs	(3700 Kg) 36.3 KN
MAX MIL PWR THRUST AT SEA LEVEL	5440 Lbs	(2467 Kg) 24.2 KN
COMBAT T/W RATIO	0.715	
COMBAT WING LOADING	67 Lb/Sq Ft	(327 Kg/Sq M)
MAX TOGW	20570 Lbs	(9331 Kg)
MAX SUBSONIC DSGN. LOAD FACTOR	7.33 g's	

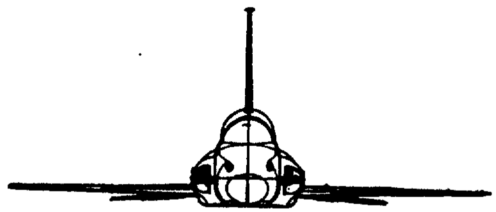
Turn Performance at 5,000 Ft (1524m)

Utilizing Maximum Afterburner (Wet) Power



F-5A

"Freedom Fighter" by Northrop

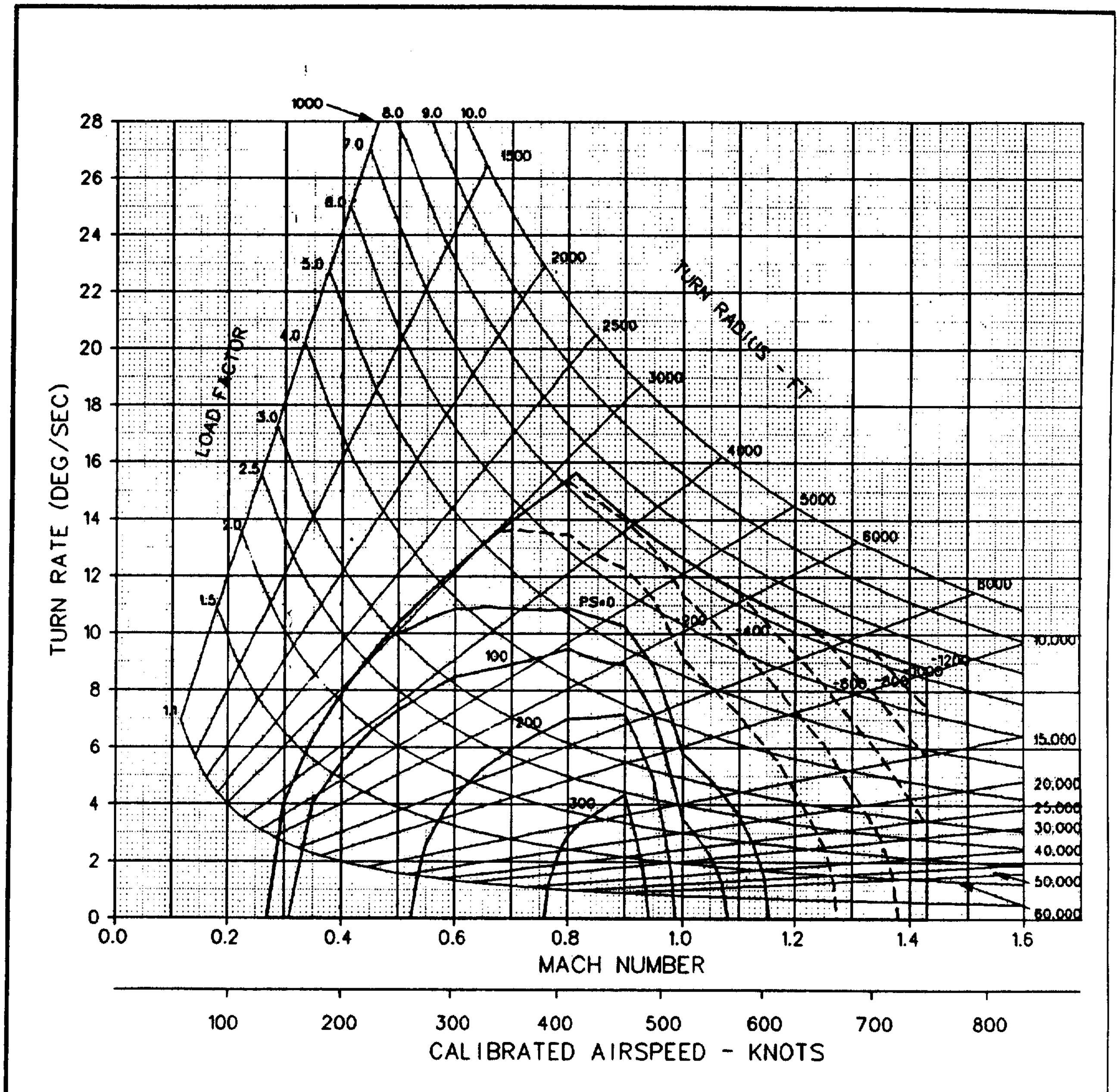


(2) GUNS w / full ammo
560 rds of 20 mm
50% Internal Fuel = 1895 lbs (859 kg)
Combat Weight = 11410 lbs (5175 kg)

WING AREA	170 Sq Ft	(15.9 Sq M)
EMPTY WEIGHT.............	9120 Lbs	(4136 Kg)
INTERNAL FUEL	583 US Gal	(2207 Liter)
	3790 Lbs	(1719Kg)
TAKEOFF WEIGHT		
WITH (2) GUNS............	13305 Lbs	(6034 Kg)
MAX EXTERNAL FUEL	546 US Gal	(2067 Liter)
	3549 Lbs	(1610 Kg)
COMBAT WEIGHT	11410 Lbs	(5175 Kg)
MAX A/B THRUST		
AT SEA LEVEL	8160 Lbs	(3700 Kg)
((2) J85-GE-13)		36.3 KN
MAX MIL PWR THRUST		
AT SEA LEVEL	5440 Lbs	(2467 Kg)
		24.2 KN
COMBAT T/W		
RATIO	0.715	
COMBAT WING		
LOADING	67 Lb/Sq Ft	(327 Kg/Sq M)
MAX TOGW	20570 Lbs	(9331 Kg)
MAX SUBSONIC DSGN.		
LOAD FACTOR..............	7.33 g's	

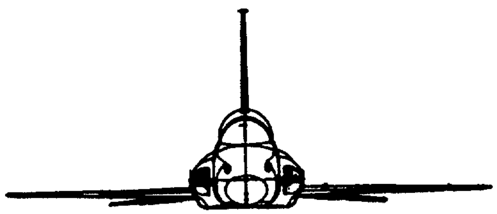
Turn Performance at 15,000 Ft (4752m)

Utilizing Maximum Afterburner (Wet) Power



F-5A

"Freedom Fighter" by Northrop

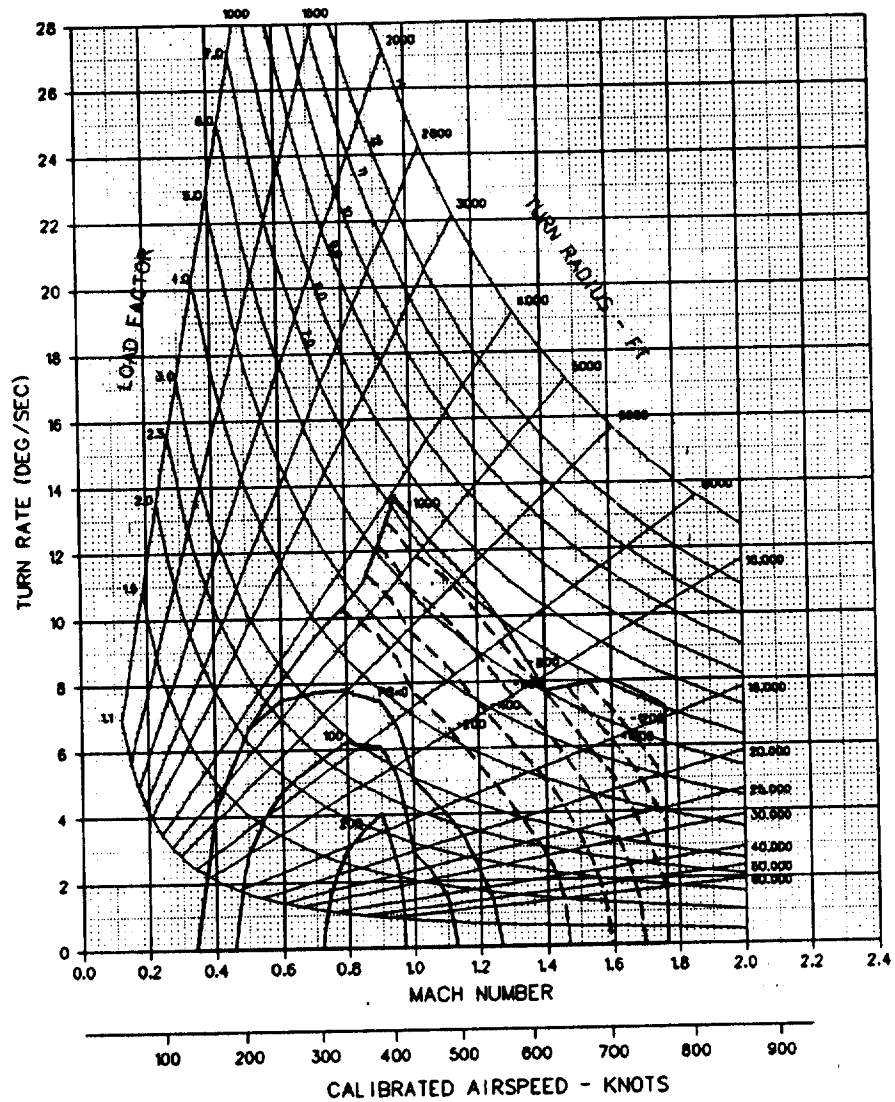


(2) GUNS w / full ammo
560 rds of 20 mm
50% Internal Fuel = 1895 lbs (859 kg)
Combat Weight = 11410 lbs (5175 kg)

WING AREA	170 Sq Ft	(15.9 Sq M)
EMPTY WEIGHT	9120 Lbs	(4136 Kg)
INTERNAL FUEL	583 US Gal	(2207 Liter)
	3790 Lbs	(1719Kg)
TAKEOFF WEIGHT WITH (2) GUNS	13305 Lbs	(6034 Kg)
MAX EXTERNAL FUEL	546 US Gal	(2067 Liter)
	3549 Lbs	(1610 Kg)
COMBAT WEIGHT	11410 Lbs	(5175 Kg)
MAX A/B THRUST AT SEA LEVEL ((2)J85-GE-13)	8160 Lbs	(3700 Kg) 36.3 KN
MAX MIL PWR THRUST AT SEA LEVEL	5440 Lbs	(2467 Kg) 24.2 KN
COMBAT T/W RATIO	0.715	
COMBAT WING LOADING	67 Lb/Sq Ft	(327 Kg/Sq M)
MAX TOGW	20570 Lbs	(9931 Kg)
MAX SUBSONIC DSGN. LOAD FACTOR	7.33 g's	

Turn Performance at 25,000 Ft (7620m)

Utilizing Maximum Afterburner (Wet) Power

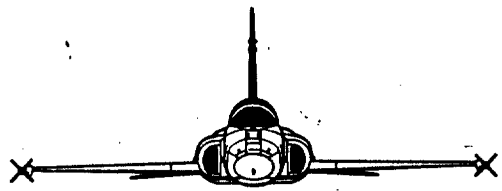


Turn Performance at 5,000 Ft (1524m)

Utilizing Maximum Afterburner (Wet) Power

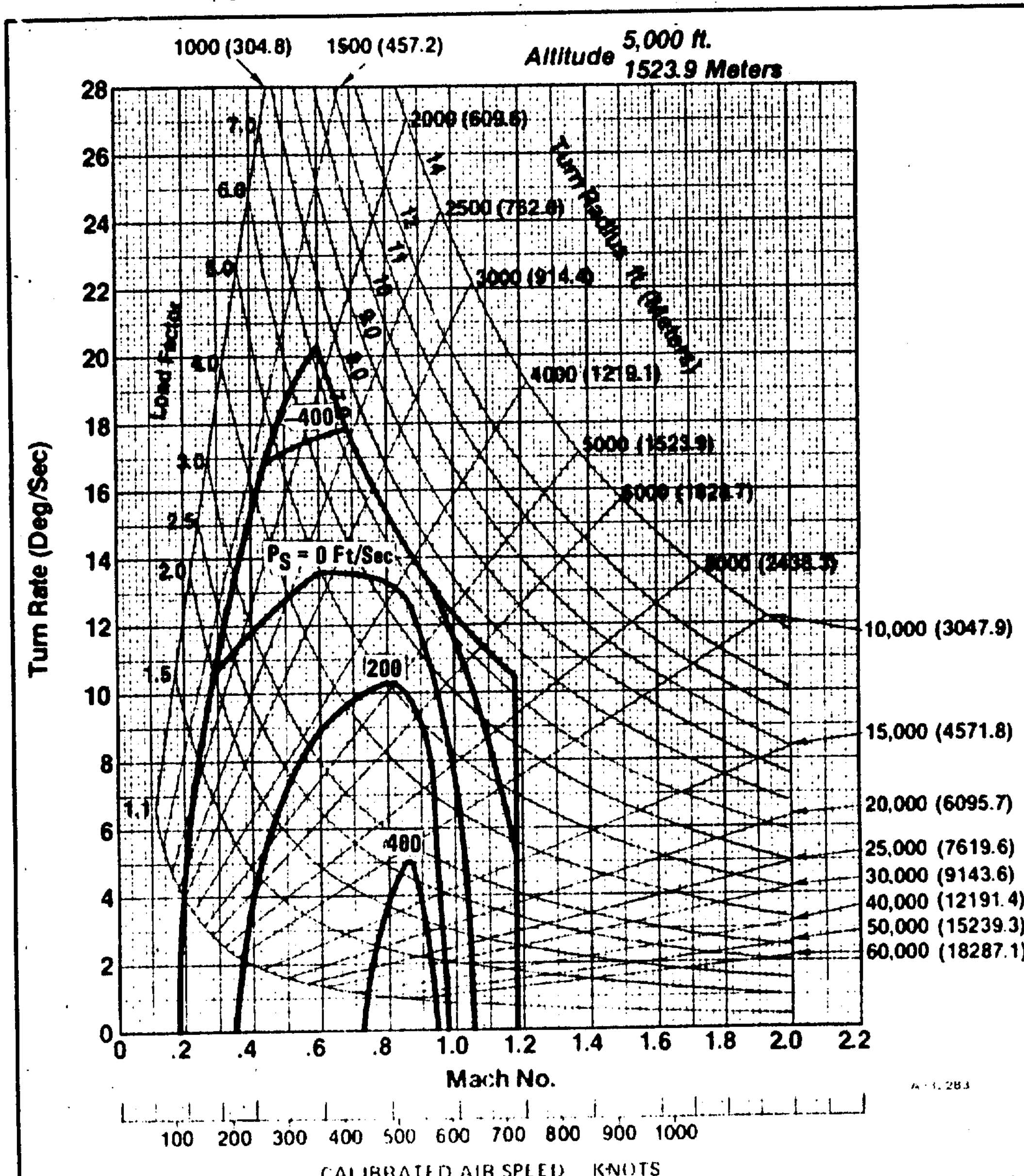
F-5E

"Tiger II" by Northrop



- (2) AIM-9 IR Missiles
- (560) rds 20mm
- 50% Internal Fuel = 2200 Lbs (998 Kg)
- Combat Weight = 13584 Lbs (6162 Kg)

WING AREA	186 FT^2	(17.3 m^2)
EMPTY WEIGHT	9683 LBS	(4392 Kg)
INTERNAL FUEL	677 U.S.GAL	(2562 Liter)
	4400 LBS	(1996 Kg)
TAKEOFF WEIGHT WITH (2) IR MISSILES + GUN	15784 LBS	(7160 Kg)
MAX EXTERNAL FUEL	825 U.S.GAL	(3123 Liter)
	5360 LBS	(2431 Kg)
COMBAT WEIGHT	13584 LBS	(6162 Kg)
MAX A/B (Wet) THRUST AT SL ([2] J-85-GE-21)	10000 LBS	(4535 Kg) (44.5 KN)
MAX MIL-PWR (Dry) THRUST AT SL	7000 LBS	(3175 Kg) (31.1 KN)
COMBAT THRUST/WEIGHT RATIO	0.74	
COMBAT WING LOADING	73 LBS/FT^2	(356 Kg/m^2)
MAX TOGW	24664 LBS	(11187 Kg)
MAX SUBSONIC DESIGN LOAD FACTOR	7.33 g's	

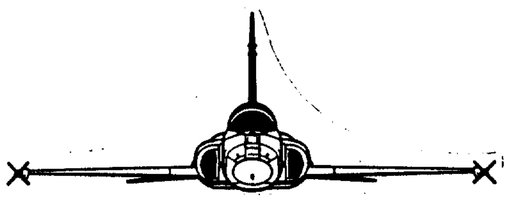


Turn Performance at 15,000 Ft (4572m)

Utilizing Maximum Afterburner (Wet) Power

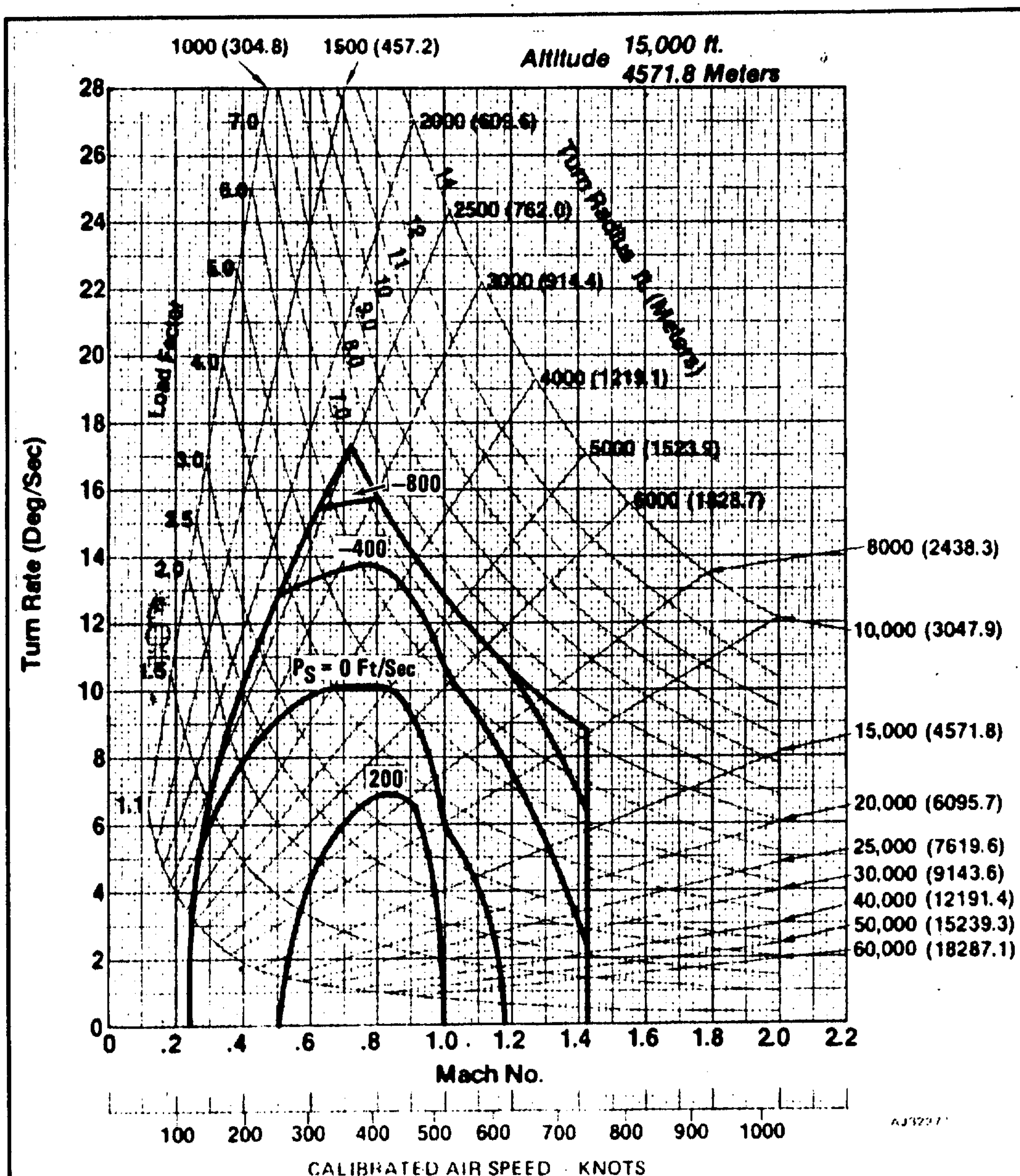
F-5E

"Tiger II" by Northrop



- (2) AIM-9 IR Missiles
- (560) rds 20mm
- 50% Internal Fuel = 2200 Lbs (998 Kg)
- Combat Weight = 13584 Lbs (6162 Kg)

WING AREA	186 FT^2	(17.3 m^2)
EMPTY WEIGHT	9683 LBS	(4392 Kg)
INTERNAL FUEL	677 U.S.GAL	(2562 Liter)
	4400 LBS	(1996 Kg)
TAKEOFF WEIGHT WITH		
(2) IR MISSILES + GUN	15784 LBS	(7160 Kg)
MAX EXTERNAL FUEL	825 U.S.GAL	(3123 Liter)
	5360 LBS	(2431 Kg)
COMBAT WEIGHT	13584 LBS	(6162 Kg)
MAX A/B (Wet) THRUST AT SL	10000 LBS	(4535 Kg)
([2] J-85-GE-21)		(44.5 KN)
MAX MIL-PWR (Dry) THRUST AT SL .	7000 LBS	(3175 Kg)
		(31.1 KN)
COMBAT THRUST/WEIGHT RATIO . .	0.74	
COMBAT WING LOADING	73 LBS/FT^2	(356 Kg/m^2)
MAX TOGW	24664 LBS	(11187 Kg)
MAX SUBSONIC DESIGN		
LOAD FACTOR	7.33 g's	

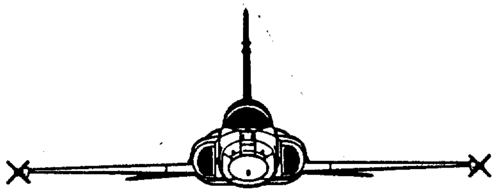


Turn Performance at 25,000 Ft (7620m)

Utilizing Maximum Afterburner (Wet) Power

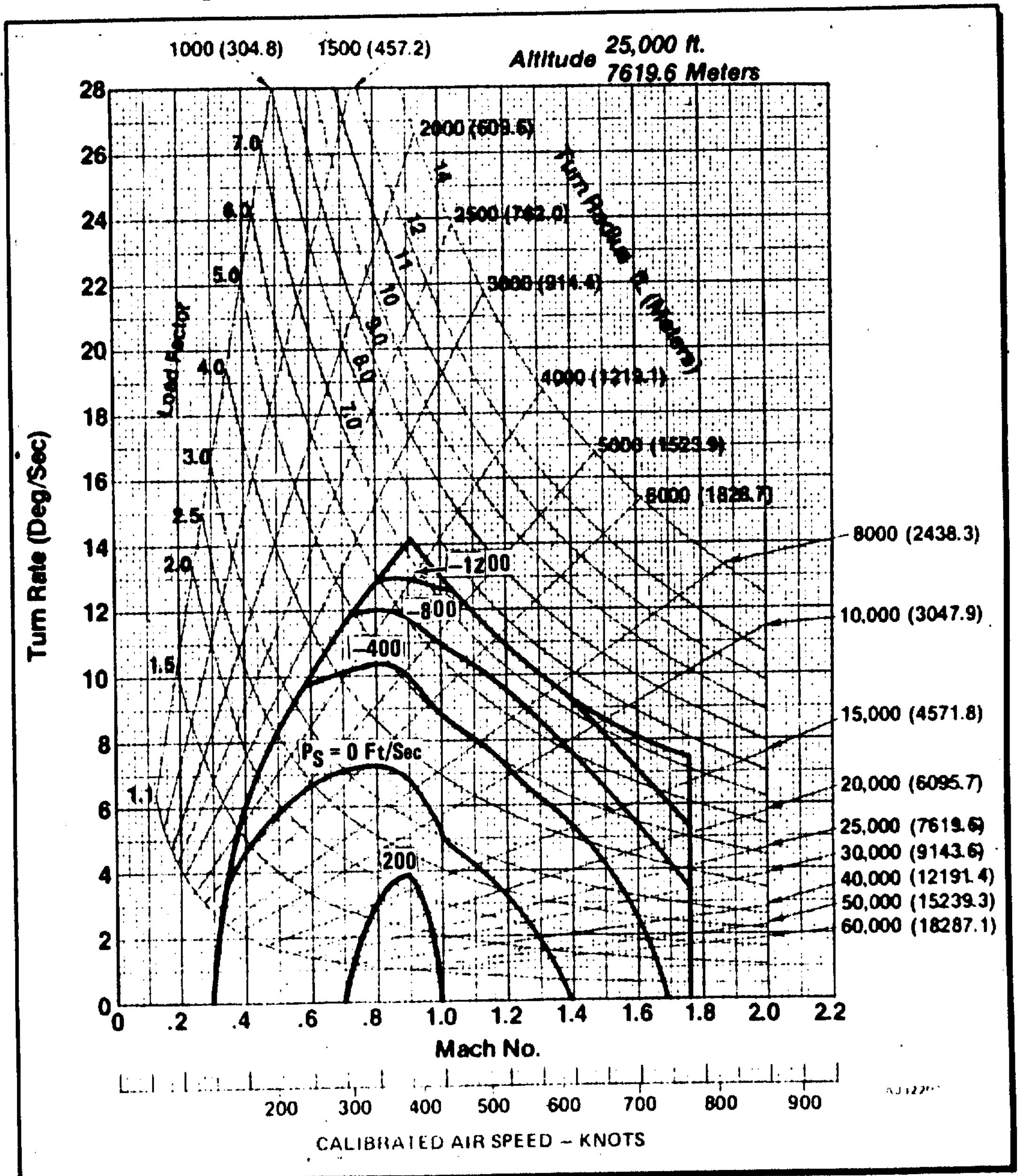
F-5E

"Tiger II" by Northrop



- (2) AIM-9 IR Missiles
- (560) rds 20mm
- 50% Internal Fuel = 2200 Lbs (998 Kg)
- Combat Weight = 13584 Lbs (6162 Kg)

WING AREA	186 FT^2	(17.3 m^2)
EMPTY WEIGHT	9683 LBS	(4392 Kg)
INTERNAL FUEL	677 U.S.GAL	(2562 Liter)
	4400 LBS	(1996 Kg)
TAKEOFF WEIGHT WITH (2) IR MISSILES + GUN	15784 LBS	(7160 Kg)
MAX EXTERNAL FUEL	825 U.S.GAL	(3123 Liter)
	5360 LBS	(2431 Kg)
COMBAT WEIGHT	13584 LBS	(6162 Kg)
MAX A/B (Wet) THRUST AT SL ([2] J-85-GE-21)	10000 LBS (44.5 KN)	(4535 Kg)
MAX MIL-PWR (Dry) THRUST AT SL	7000 LBS (31.1 KN)	(3175 Kg)
COMBAT THRUST/WEIGHT RATIO	0.74	
COMBAT WING LOADING	73 LBS/FT^2	(356 Kg/m^2)
MAX TOGW	24664 LBS	(11187 Kg)
MAX SUBSONIC DESIGN LOAD FACTOR	7.33 g's	

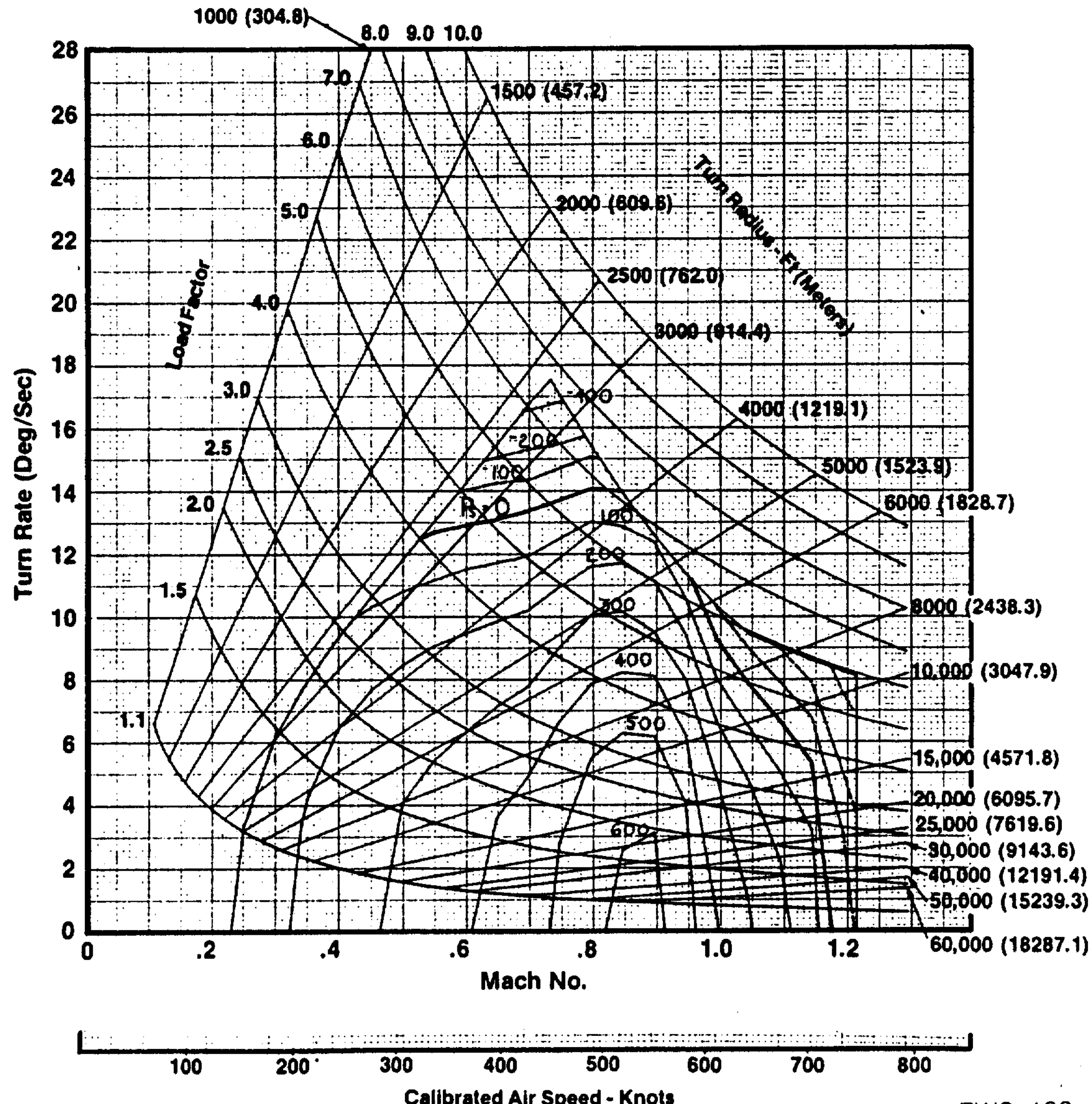


Turn Performance at 5000 ft (1524m) Utilizing Maximum Performance (WET) Power

F-4E

"Phantom II"
by McDonnell Douglas

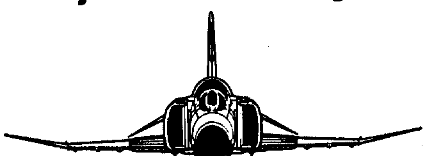
(2) AIM-7F
(2) AIM-9P
625 rds of 20mm
50% Internal Fuel= 6030 lbs
Combat Weight = 41547 lbs



Wing Area..................530 ft² (49 m²)
Empty Weight.............33100 lbs (15014 Kg)
Internal Fuel.............12060 lbs (5470 Kg)
1855 U.S. Gal (7023 Liter)
Takeoff Weight with (2) IR Missiles
+ (2) AIM-7.............47577 lbs (21581 Kg)
Max External Fuel..........8710 lbs (3951 Kg)
1340 U.S. Gal (5072 Liter)
Combat Weight............41547 lbs (18846 Kg)
Max A/B Engine Thrust....35640 lbs (16166 Kg)
AT S_L ([2] J-79's)
Combat Thrust/Weight...... 0.86
Combat Wing Loading...... 78 lbs/ft² (381 Kg/m²)
Max TOGW..............58,000 lbs (26308 Kg)
Max Design Load Factor .. 7.5 g's

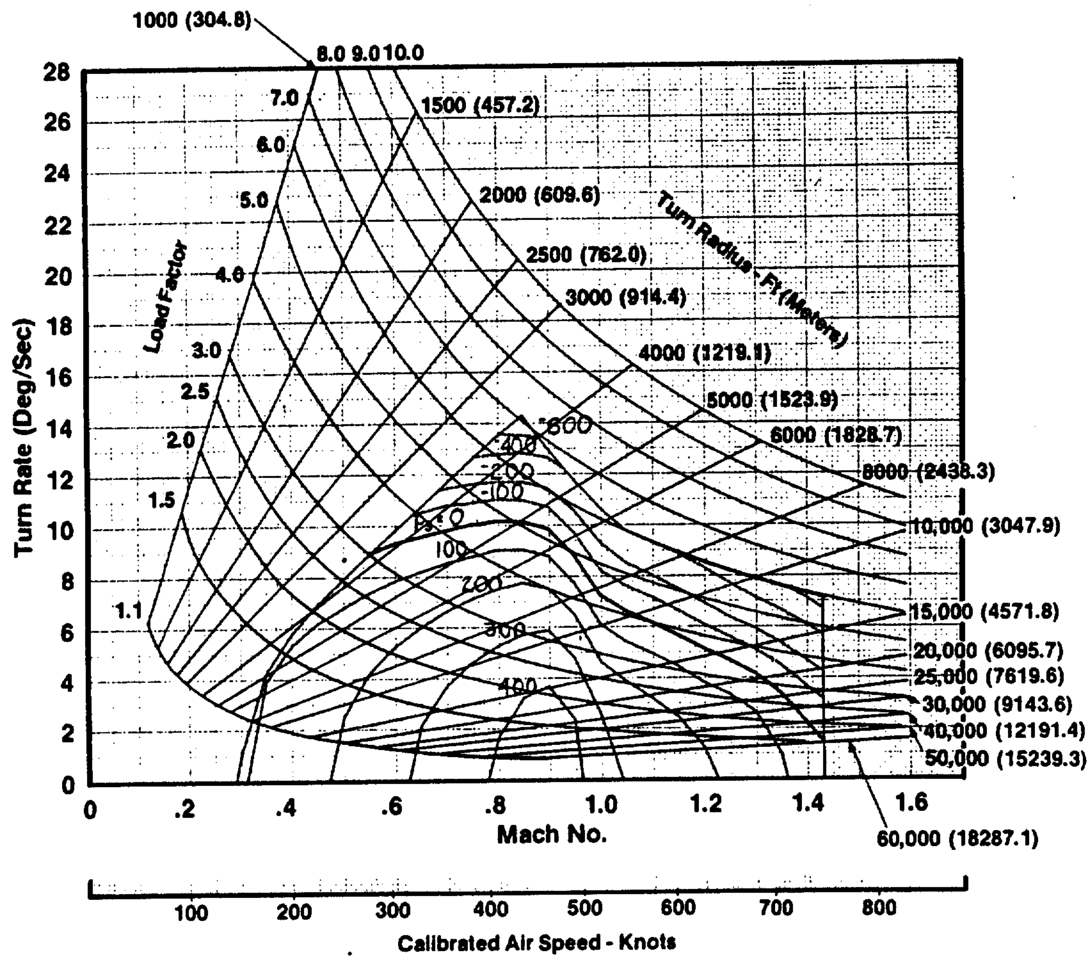
Turn Performance at 15,000 Ft (4572m)
Utilizing Maximum Afterburner (WET) Power

F-4E
"Phantom II"
by McDonnell Douglas



(2) AIM-7F
(2) AIM-9P
625 rds of 20mm
50% Internal Fuel= 6030 lbs
Combat Weight = 41547 lbs

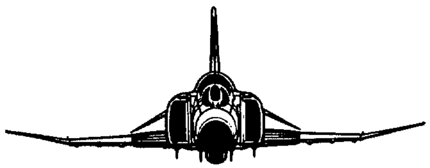
Wing Area	530 ft²	(49 m²)
Empty Weight	33100 lbs	(15014 Kg)
Internal Fuel	12060 lbs	(5470 Kg)
	1855 U.S. Gal	(7023 Liter)
Takeoff Weight with (2) IR Missiles + (2) AIM-7	47577 lbs	(21581 Kg)
Max External Fuel	8710 lbs	(3951 Kg)
	1340 U.S. Gal	(5072 Liter)
Combat Weight	41547 lbs	(18846 Kg)
Max A/B Engine Thrust AT S_L ([2] J-79's)	35640 lbs	(16166 Kg)
Combat Thrust/Weight	0.86	
Combat Wing Loading	78 lbs/ft²	(381 Kg/m²)
Max TOGW	58,000 lbs	(26308 Kg)
Max Design Load Factor	7.5 g's	



Turn Performance at 25,000 Ft (7620m)

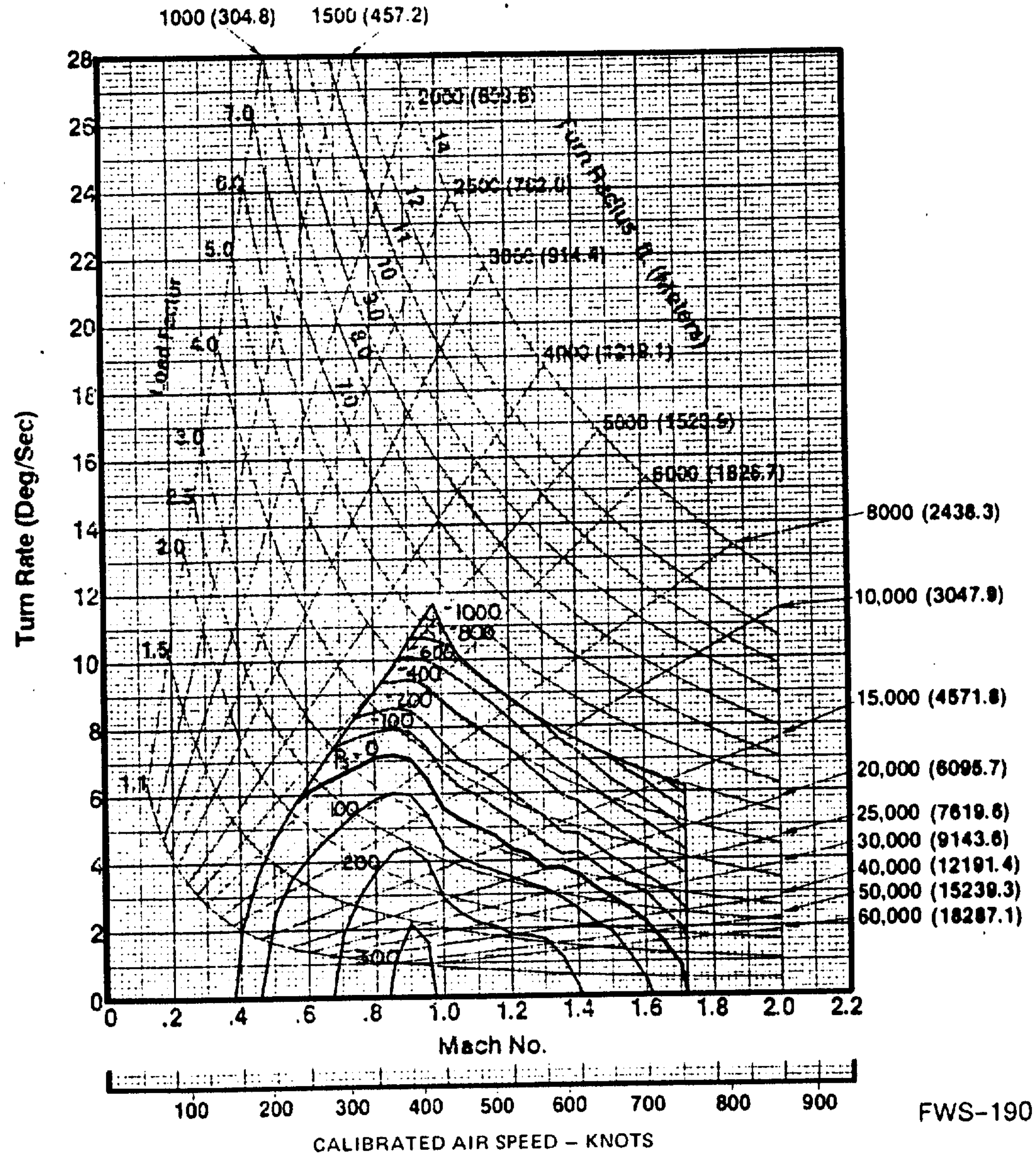
Utilizing Maximum Afterburner (Wet) Power

F-4E
"Phantom II"
by McDonnell Douglas



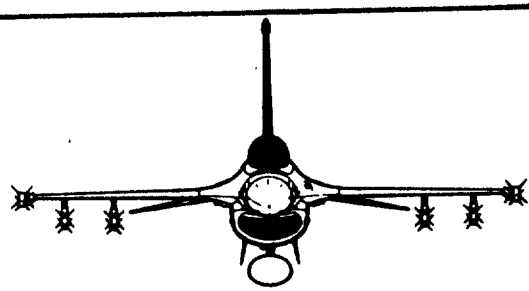
(2) AIM-7F
(2) AIM-9P
625 rds of 20mm
50% Internal Fuel= 6030 lbs
Combat Weight = 41547 lbs

Wing. Area	530 ft²	(49 m²)
Empty Weight	33100 lbs	(15014 Kg)
Internal Fuel	12060 lbs	(5470 Kg)
	1855 U.S. Gal	(7023 Liter)
Takeoff Weight with (2) IR Missiles + (2) AIM-7	47577 lbs	(21581 Kg)
Max External Fuel	8710 lbs	(3951 Kg)
	1340 U.S. Gal	(5072 Liter)
Combat Weight	41547 lbs	(18846 Kg)
Max A/B Engine Thrust AT S_L ([2] J-79's)	35640 lbs	(16166 Kg)
Combat Thrust/Weight	0.86	
Combat Wing Loading	78 lbs/ft²	(381 Kg/m²)
Max TOGW	58,000 lbs	(26308 Kg)
Max Design Load Factor	7.5 g's	

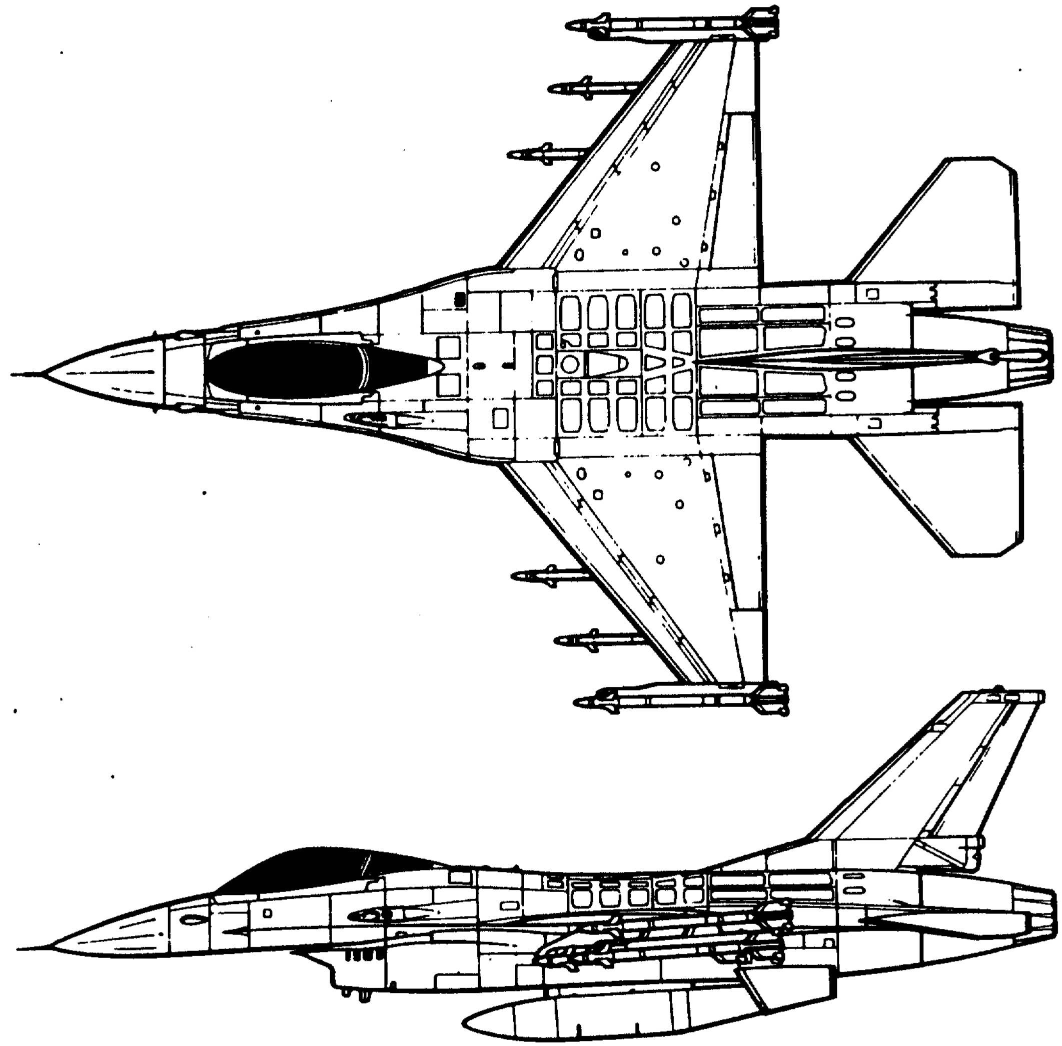


FWS-190

F-16A



WING AREA	300 Sq Ft	(28 Sq M)
EMPTY WEIGHT............	16131 Lbs	(7317 Kg)
INTERNAL FUEL	1073 US Gal	(4060 Liter)
	6972 Lbs	(3162 Kg)
TAKEOFF WEIGHT WITH (2) IR + GUN.........	24361 Lbs	(11065 Kg)
MAX EXTERNAL FUEL	1465 US Gal	(5545 Liter)
	9522 Lbs	(4318 Kg)
COMBAT WEIGHT	20875 Lbs	(9469 Kg)
MAX A/B THRUST AT SEA LEVEL .... (F100-PW-220NSI)	23744 Lbs	(10770 Kg) 106 KN
MAX MIL PWR THRUST AT SEA LEVEL	14601 Lbs	(6623 Kg) 65 KN
COMBAT T/W RATIO	1.14	
COMBAT WING LOADING	70 Lb/Sq Ft	(340 Kg/Sq M)
MAX TOGW	37500 Lbs	(17010 Kg)
MAX SUBSONIC DSGN. LOAD FACTOR..............	9.3 g's	

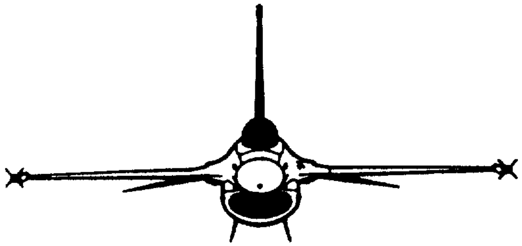


FWS-191

Turn Performance at 5,000 Ft (1524m)

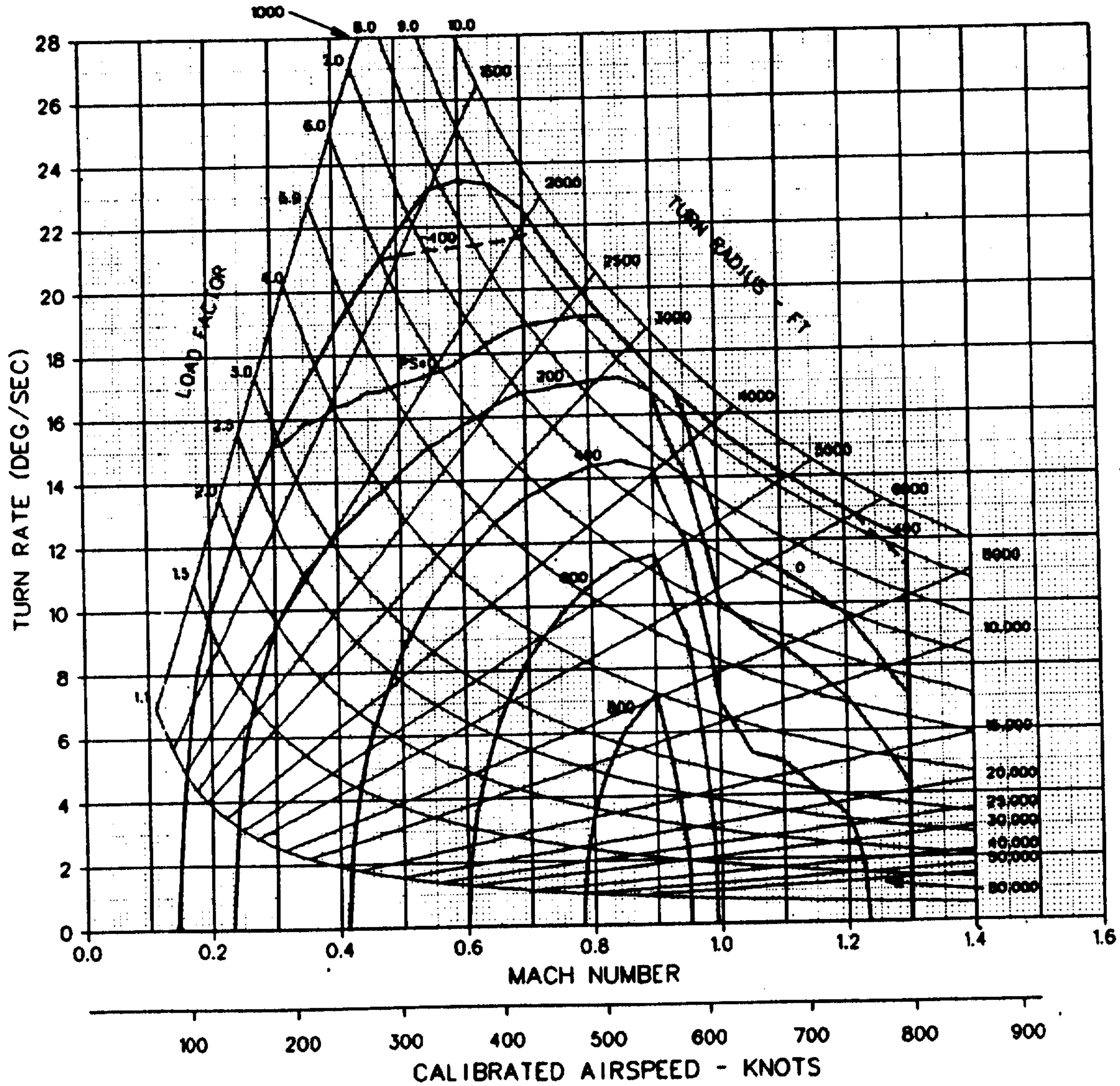
Utilizing Maximum Afterburner (Wet) Power

F-16A
"Fighting Falcon"
by General Dynamics



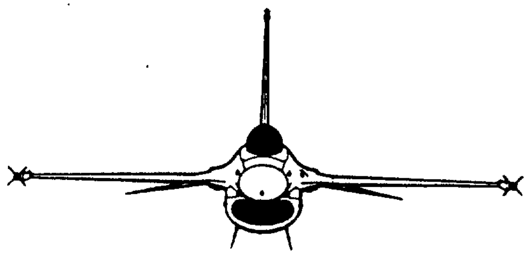
(2) AIM-9P3 IR Missiles
512 rds of 20 mm
50% internal Fuel = 3486 lbs (1581 kg)
Combat Weight = 20,875 lbs (9469 kg)

WING AREA	300 Sq Ft	(28 Sq M)
EMPTY WEIGHT	16131 Lbs	(7317 Kg)
INTERNAL FUEL	1073 US Gal	(4060 Liter)
	6972 Lbs	(3162 Kg)
TAKEOFF WEIGHT WITH (2) IR + GUN	24361 Lbs	(11065 Kg)
MAX EXTERNAL FUEL	1465 US Gal	(5545 Liter)
	9522 Lbs	(4318 Kg)
COMBAT WEIGHT	20875 Lbs	(9469 Kg)
MAX A/B THRUST AT SEA LEVEL (F100-PW-220NSI)	23744 Lbs	(10770 Kg) 106 KN
MAX MIL PWR THRUST AT SEA LEVEL	14601 Lbs	(6623 Kg) 65 KN
COMBAT T/W RATIO	1.14	
COMBAT WING LOADING	70 Lb/Sq Ft	(340 Kg/Sq M)
MAX TOGW	37500 Lbs	(17010 Kg)
MAX SUBSONIC DSGN. LOAD FACTOR	9.3 g's	



F-16A

"Fighting Falcon"
by General Dynamics



(2) AIM-9P3 IR Missiles
512 rds of 20 mm
50% internal Fuel = 3486 lbs (1581 kg)
Combat Weight = 20,875 lbs (9469 kg)

WING AREA	300 Sq Ft	(28 Sq M)
EMPTY WEIGHT	16131 Lbs	(7317 Kg)
INTERNAL FUEL	1073 US Gal	(4060 Liter)
	6972 Lbs	(3162 Kg)
TAKEOFF WEIGHT WITH (2) IR + GUN	24361 Lbs	(11065 Kg)
MAX EXTERNAL FUEL	1465 US Gal	(5545 Liter)
	9522 Lbs	(4318 Kg)
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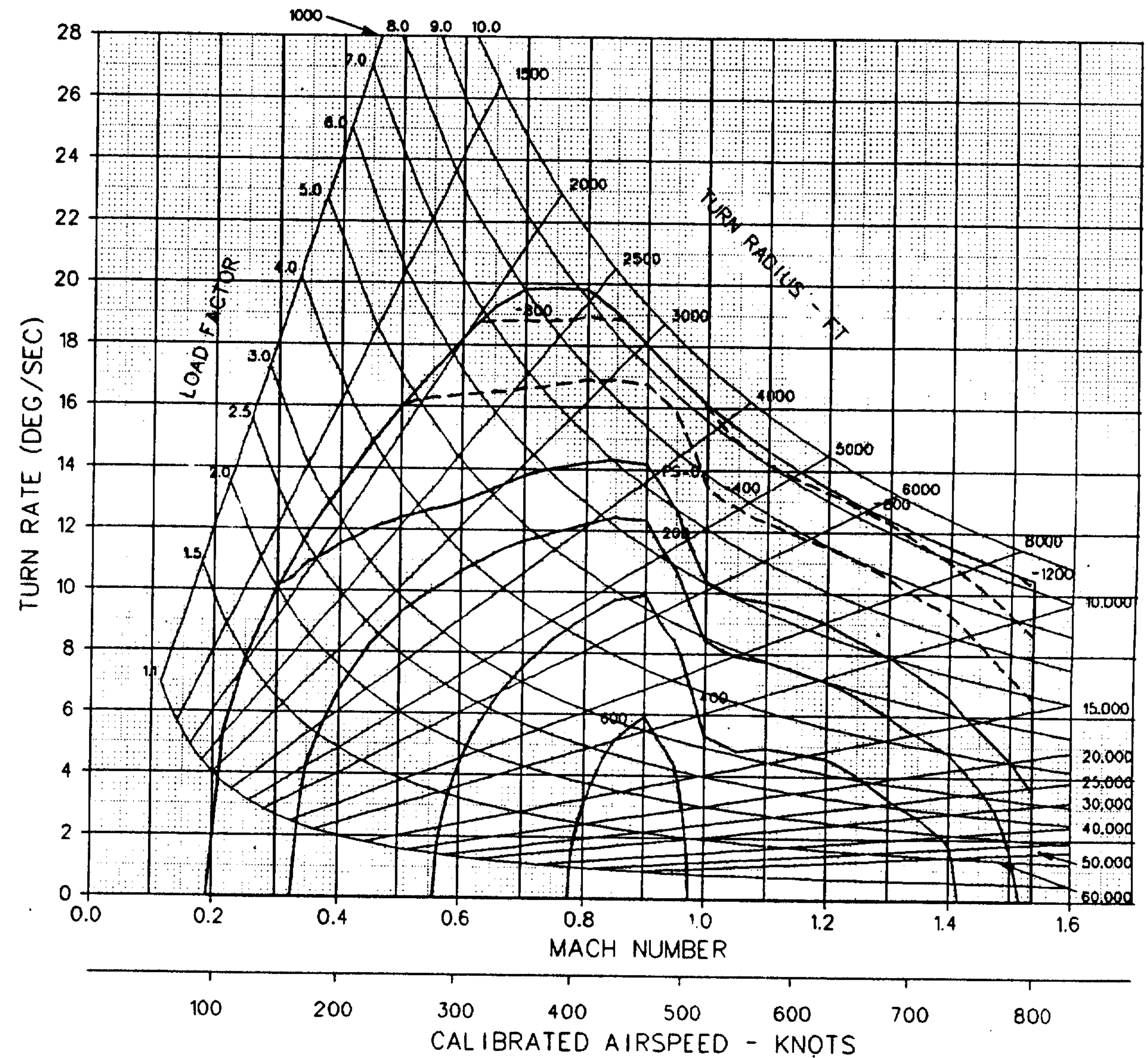
MAX A/B THRUST AT SEA LEVEL (F100-PW-220NSI)	23744 Lbs	(10770 Kg) 106 KN
MAX MIL PWR THRUST AT SEA LEVEL	14601 Lbs	(6623 Kg) 65 KN
COMBAT T/W RATIO	1.14	
COMBAT WING LOADING	70 Lb/Sq Ft	(340 Kg/Sq M)
MAX TOGW	37500 Lbs	(17010 Kg)
MAX SUBSONIC DSGN. LOAD FACTOR	9.3 g's	

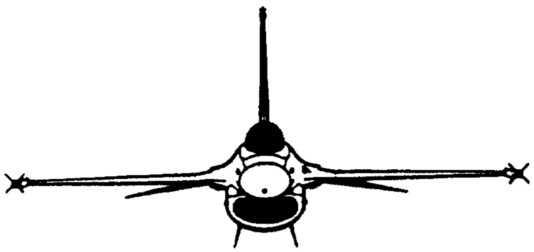
Turn Performance at 15,000 Ft (4572m)

Utilizing Maximum Afterburner (Wet) Power



F-16A

"Fighting Falcon" by General Dynamics

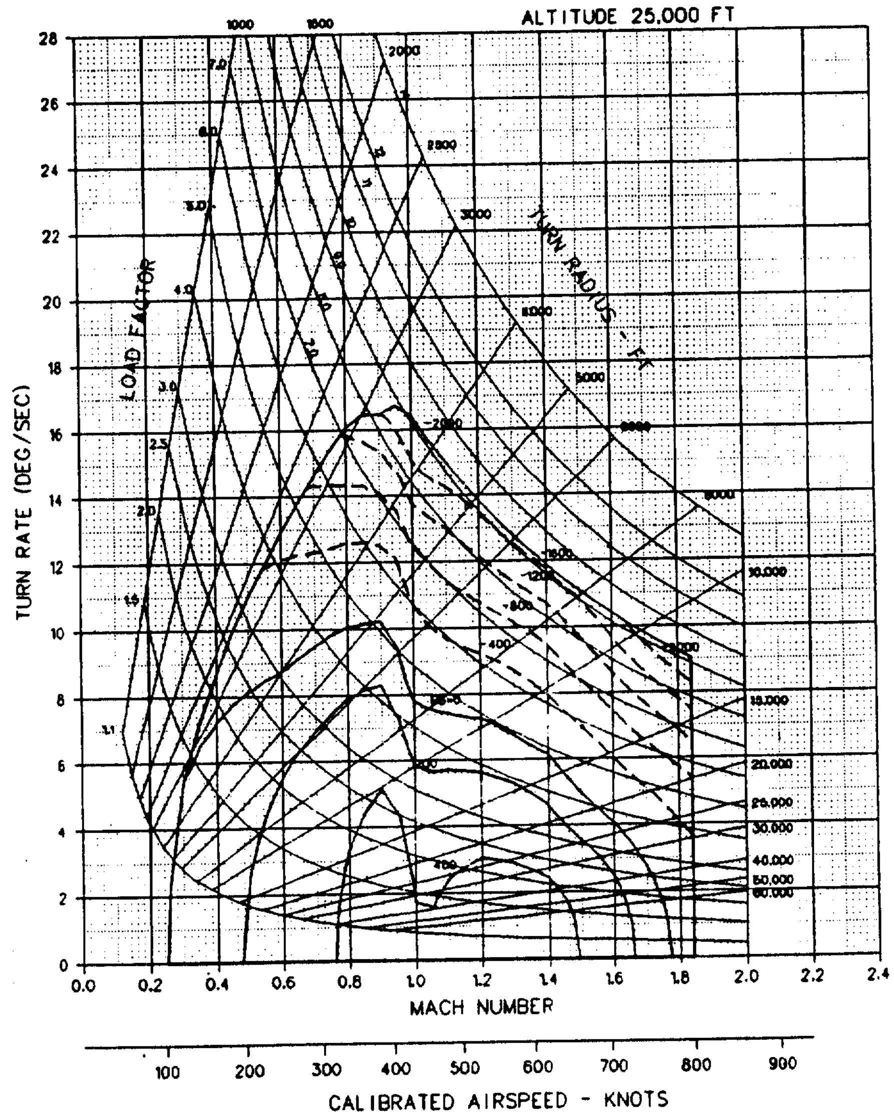


(2) AIM-9P3 IR Missiles
512 rds of 20 mm
50% Internal Fuel = 3486 lb (1581 kg)
Combat Weight = 20,875 lb (9469 kg)

Wing area	300 sq ft	(28 sq m)
Empty weight	16131 lb	(7317 kg)
Internal fuel	1073 US gal	(4060 liter)
	6972 lbs	(3162 kg)
Takeoff weight with (2) IR + gun	24361 lb	(11065 kg)
Max external fuel	1465 US gal	(5545 liter)
	9522 lb	(4318 kg)
Combat weight	20875 lb	(9469 kg)
Propulsion	(1) F100-PW-220NSI	
Max A/B thrust sls, uninstalled	23744 lb	(106 kN)
Mil pwr thrust sls, uninstalled	14601 lb	(65 kN)
Combat T / W ratio	1.14	
Combat wing loading	70 lb/sq ft	(340 kg/sq m)
Max TOGW	37500 lb	(17010 kg)
Max subsonic design load factor	9.3 g	

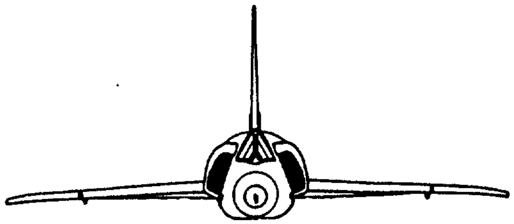
Turn Performance at 25,000 Ft (7620m)

Utilizing Maximum Afterburner (Wet) Power



F-106A

"Delta Dart" by Convair

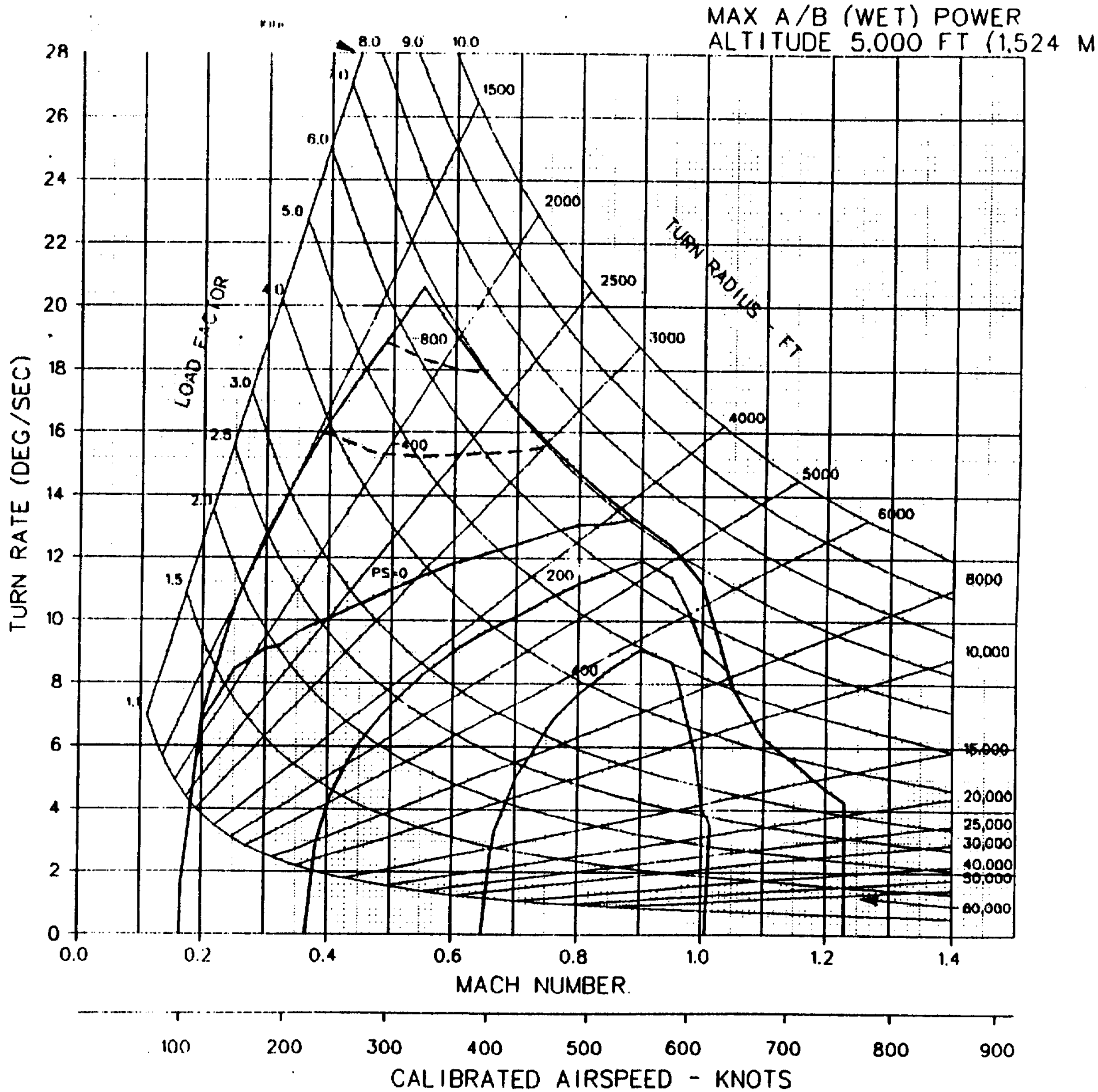


(2) AIM-4G + (2) AIM-4F Missles
50% Internal Fuel = 4921 lbs (2232 kg)
Combat Weight = 32,426 lbs (14708 kg)

Wing area	695 sq ft	(64.6 sq m)
Empty weight...............	25277 lb	(11466 kg)
Internal fuel	1514 US gal	(5730 liter)
	9841 lbs	(4464 kg)
Takeoff weight with		
(2) IR + (2) SAR	37347 lb	(16941 kg)
Max external fuel	716 US gal	(2710 liter)
	4654 lb	(2111 kg)
Combat weight	32426 lb	(14708 kg)
Propulsion	(1) J75-P-17	
Max A/B thrust		
sls, uninstalled	24500 lb	(109 kN)
Mil pwr thrust		
sls, uninstalled	16100 lb	(71.6 kN)
Combat T / W ratio	0.76	
Combat wing loading.....	47 lb/sq ft	(228 kg/sq m)
Max TOGW	42500 lb	(19278 kg)
Max subsonic design		
load factor	7.0 g	

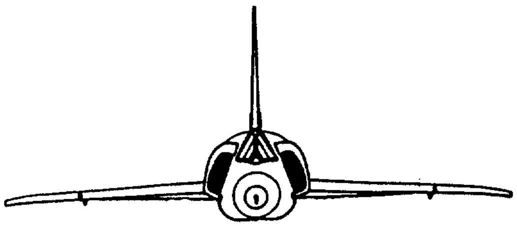
Turn Performance at 5,000 Ft (1524m)

Utilizing Maximum Afterburner (Wet) Power



F-106A

"Delta Dart" by Convair

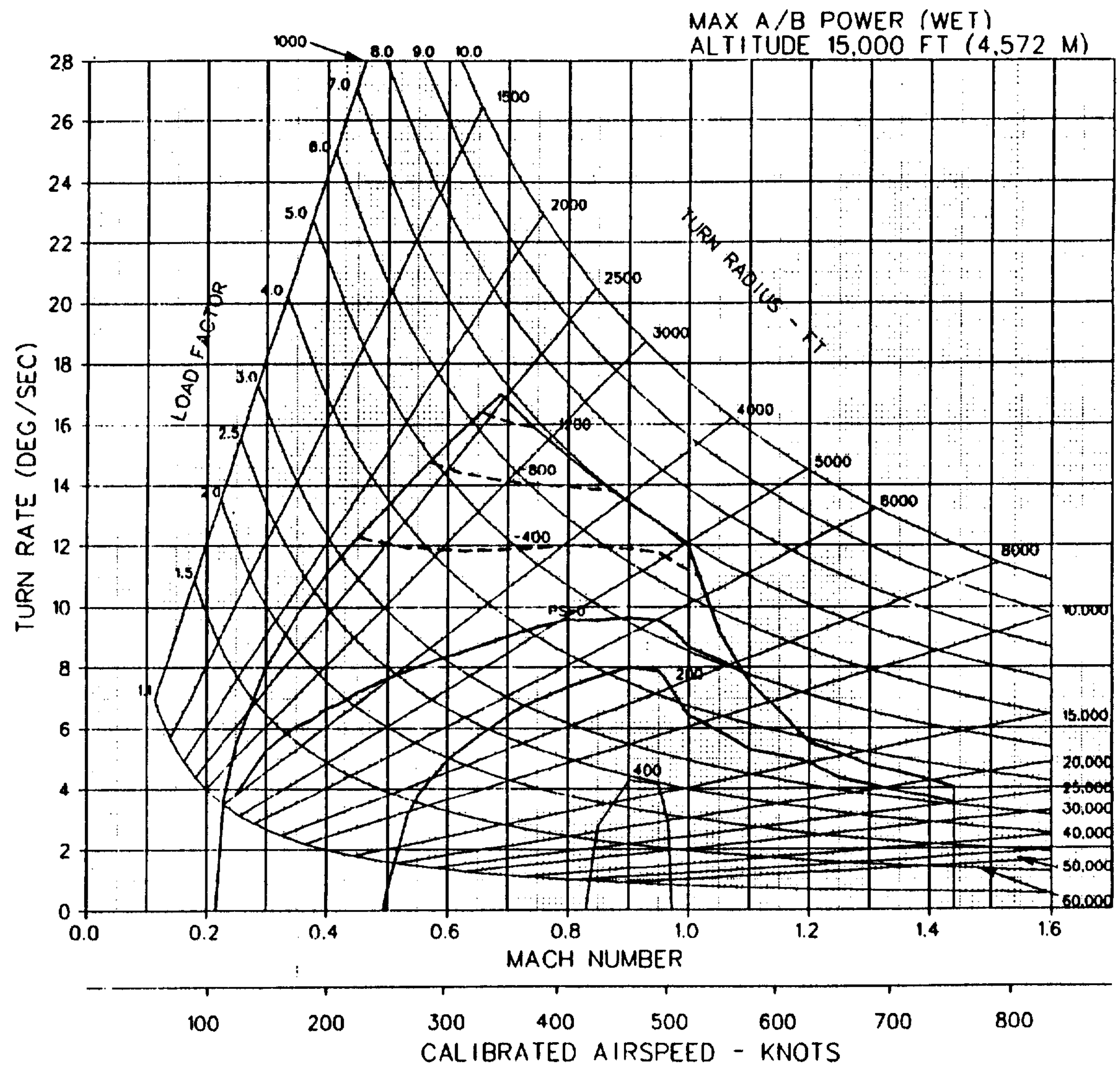


(2) AIM-4G + (2) AIM-4F Missles
50% Internal Fuel = 4921 lbs (2232 kg)
Combat Weight = 32,426 lbs (14708 kg)

Wing area	695 sq ft	(64.6 sq m)
Empty weight	25277 lb	(11466 kg)
Internal fuel	1514 US gal	(5730 liter)
	9841 lbs	(4464 kg)
Takeoff weight with (2) IR + (2) SAR	37347 lb	(16941 kg)
Max external fuel	716 US gal	(2710 liter)
	4654 lb	(2111 kg)
Combat weight	32426 lb	(14708 kg)
Propulsion	(1) J75-P-17	
Max A/B thrust sls, uninstalled	24500 lb	(109 kN)
Mil pwr thrust sls, uninstalled	16100 lb	(71.6 kN)
Combat T / W ratio	0.76	
Combat wing loading	47 lb/sq ft	(228 kg/sq m)
Max TOGW	42500 lb	(19278 kg)
Max subsonic design load factor	7.0 g	

Turn Performance at 15,000 Ft (4572m)

Utilizing Maximum Afterburner (Wet) Power

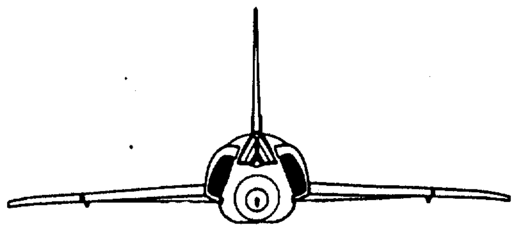


Turn Performance at 25,000 Ft (7620m)

Utilizing Maximum Afterburner (Wet) Power

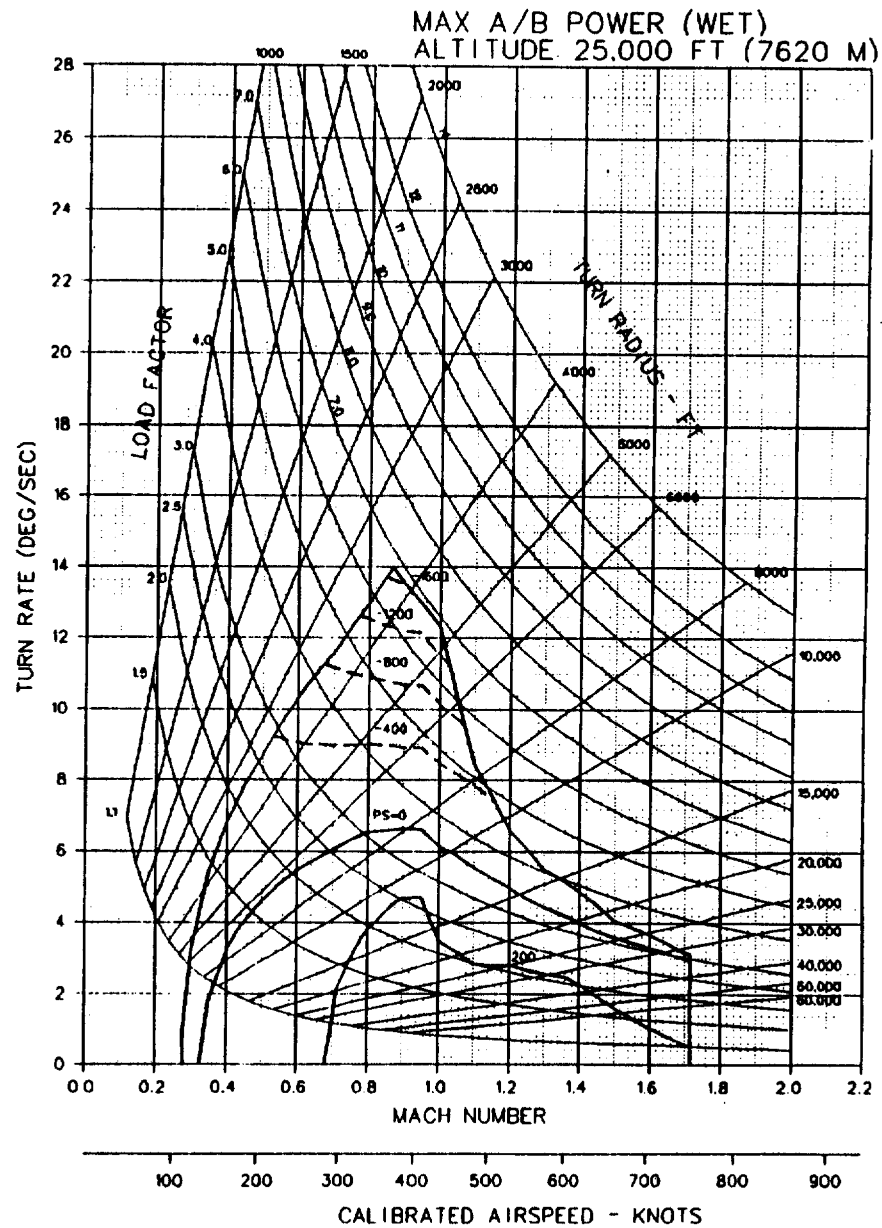
F-106A

"Delta Dart" by Convair



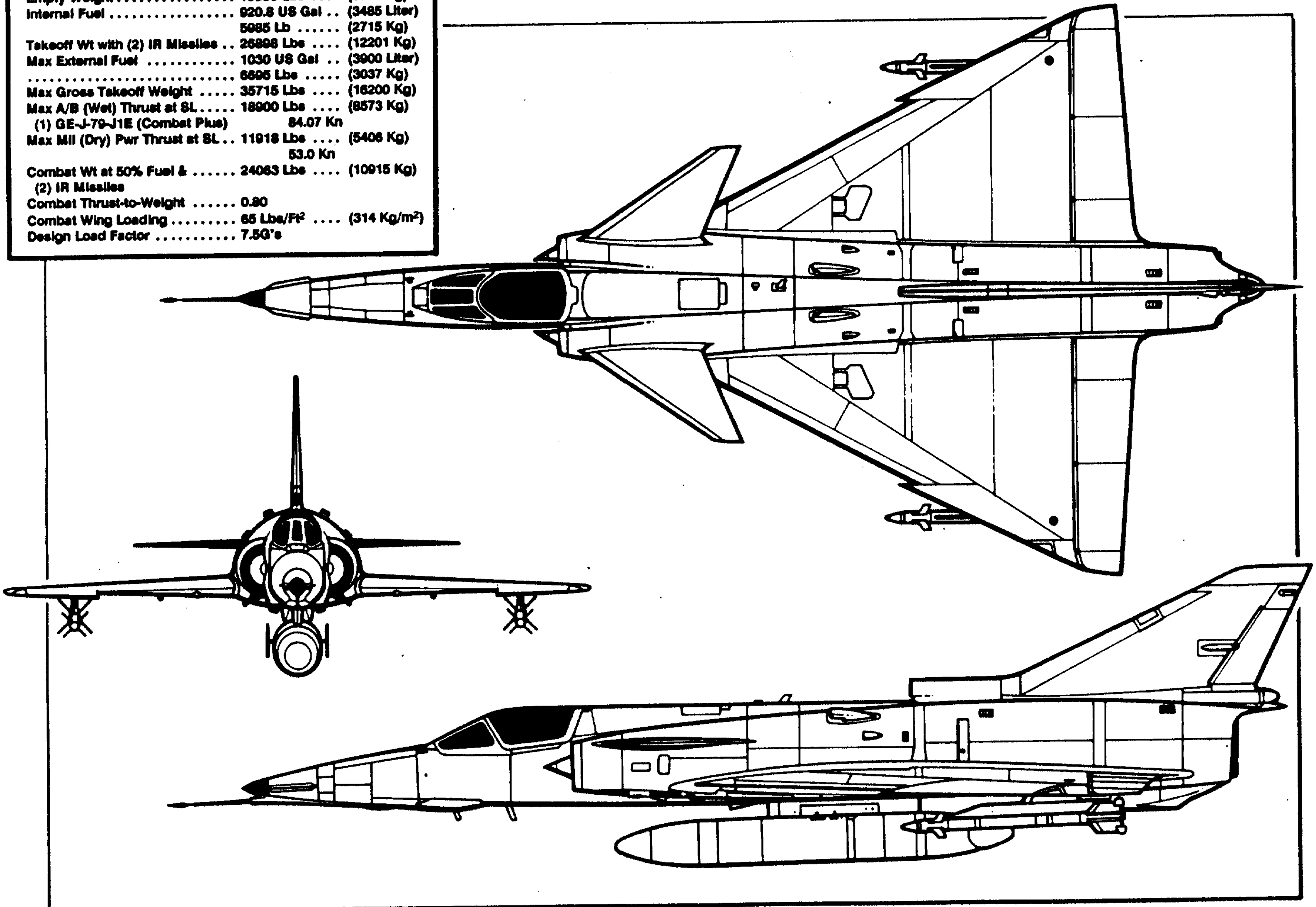
(2) AIM-4G + (2) AIM-4F Missles
50% Internal Fuel = 4921 lbs (2232 kg)
Combat Weight = 32,426 lbs (14708 kg)

Wing area	695 sq ft	(64.6 sq m)
Empty weight................	25277 lb	(11466 kg)
Internal fuel	1514 US gal	(5730 liter)
	9841 lbs	(4464 kg)
Takeoff weight with		
(2) IR + (2) SAR	37347 lb	(16941 kg)
Max external fuel	716 US gal	(2710 liter)
	4654 lb	(2111 kg)
Combat weight	32426 lb	(14708 kg)
Propulsion	(1) J75-P-17	
Max A/B thrust		
sls, uninstalled	24500 lb	(109 kN)
Mil pwr thrust		
sls, uninstalled	16100 lb	(71.6 kN)
Combat T / W ratio	0.76	
Combat wing loading......	47 lb/sq ft	(228 kg/sq m)
Max TOGW	42500 lb	(19278 kg)
Max subsonic design		
load factor	7.0 g	



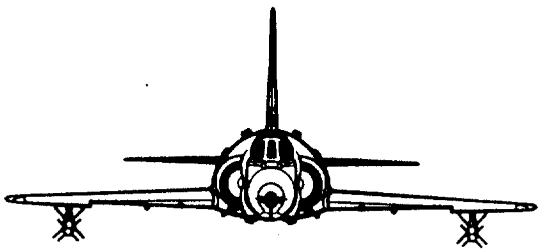
Wing Span	26.97 Ft	(8.22m)
Wing Area	374.6 Ft^2	(34.8m^2)
Canard Area	17.9 Ft^2	(1.7m^2)
Overall Length	51.35 Ft	(15.65m)
Empty Weight	19550 Lbs	(8868 Kg)
Internal Fuel	920.8 US Gal	(3485 Liter)
	5985 Lb	(2715 Kg)
Takeoff Wt with (2) IR Missiles	26898 Lbs	(12201 Kg)
Max External Fuel	1030 US Gal	(3900 Liter)
	6695 Lbs	(3037 Kg)
Max Gross Takeoff Weight	35715 Lbs	(16200 Kg)
Max A/B (Wet) Thrust at SL	18900 Lbs	(8573 Kg)
(1) GE-J-79-J1E (Combat Plus)	84.07 Kn	
Max Mil (Dry) Pwr Thrust at SL	11918 Lbs	(5406 Kg)
	53.0 Kn	
Combat Wt at 50% Fuel & (2) IR Missiles	24063 Lbs	(10915 Kg)
Combat Thrust-to-Weight	0.80	
Combat Wing Loading	65 Lbs/Ft^2	(314 Kg/m^2)
Design Load Factor	7.5G's	

KFIR C-7



KFIR C-7

(Israeli Aircraft Industries)

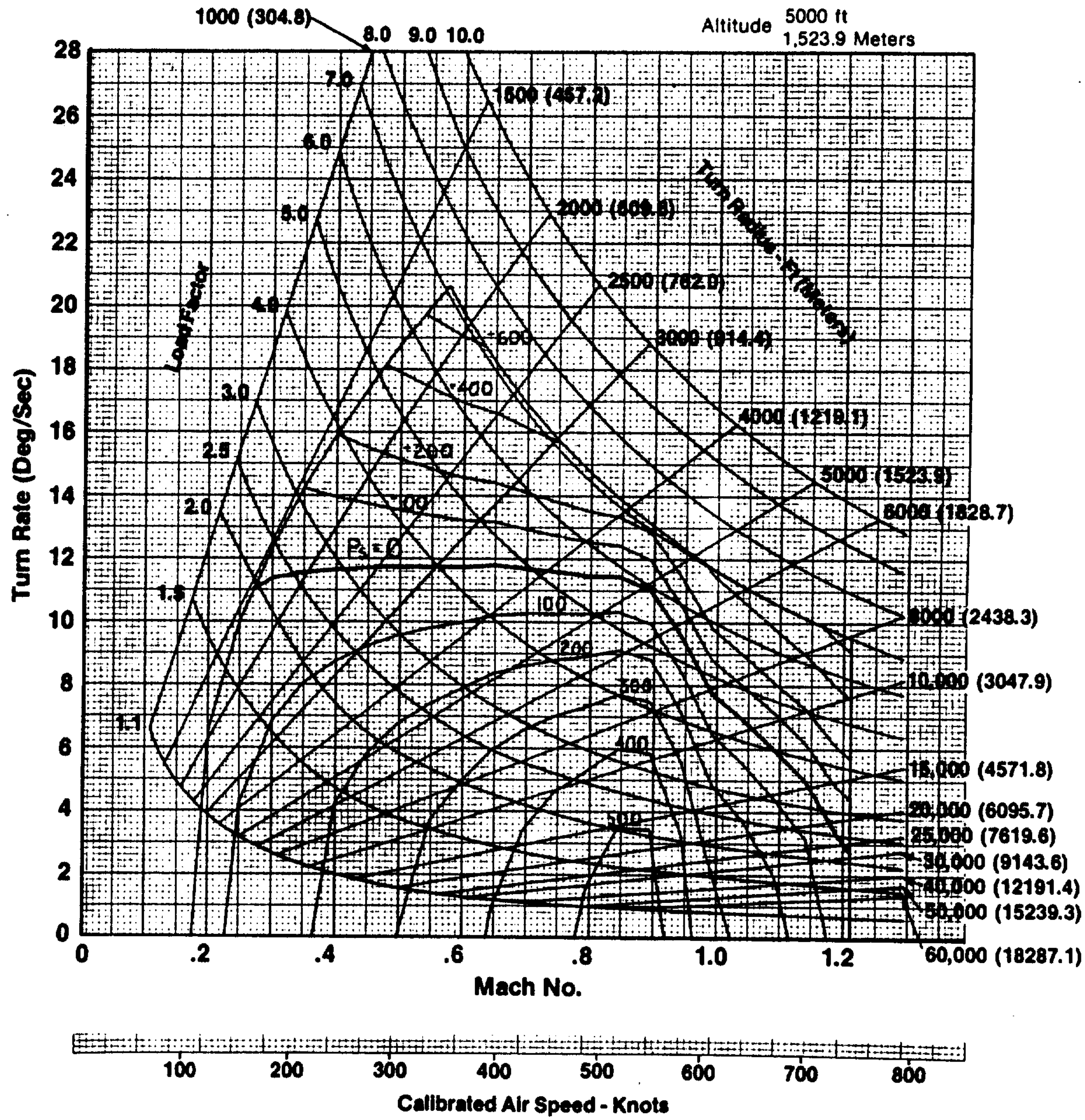


(2) Python IR Missiles
280 rds of 30 mm
50% Internal Fuel = 2835 lbs (1286 kg)
Combat Weight = 24,063 lbs (10915 kg)

Wing Span	26.97 Ft	(8.22m)
Wing Area	374.6 Ft²	(34.8m²)
Canard Area	17.9 Ft²	(1.7m²)
Overall Length	51.35 Ft	(15.65m)
Empty Weight	19550 Lbs	(8868 Kg)
Internal Fuel	920.8 US Gal	(3485 Liter)
	5985 Lb	(2715 Kg)
Takeoff Wt with (2) IR Missiles	26898 Lbs	(12201 Kg)
Max External Fuel	1030 US Gal	(3900 Liter)
	6695 Lbs	(3037 Kg)
Max Gross Takeoff Weight	35715 Lbs	(16200 Kg)
Max A/B (Wet) Thrust at SL	18900 Lbs	(8573 Kg)
(1) GE-J-79-J1E (Combat Plus)	84.07 Kn	
Max Mil (Dry) Pwr Thrust at SL	11918 Lbs	(5406 Kg)
	53.0 Kn	
Combat Wt at 50% Fuel & (2) IR Missiles	24063 Lbs	(10915 Kg)
Combat Thrust-to-Weight	0.80	
Combat Wing Loading	65 Lbs/Ft²	(314 Kg/m²)
Design Load Factor	7.5G's	

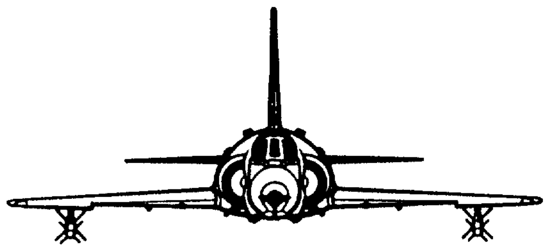
Turn Performance at 5,000 Ft (1524m)

Utilizing Maximum Afterburner (Wet) Power



KFIR C-7

(Israeli Aircraft Industries)

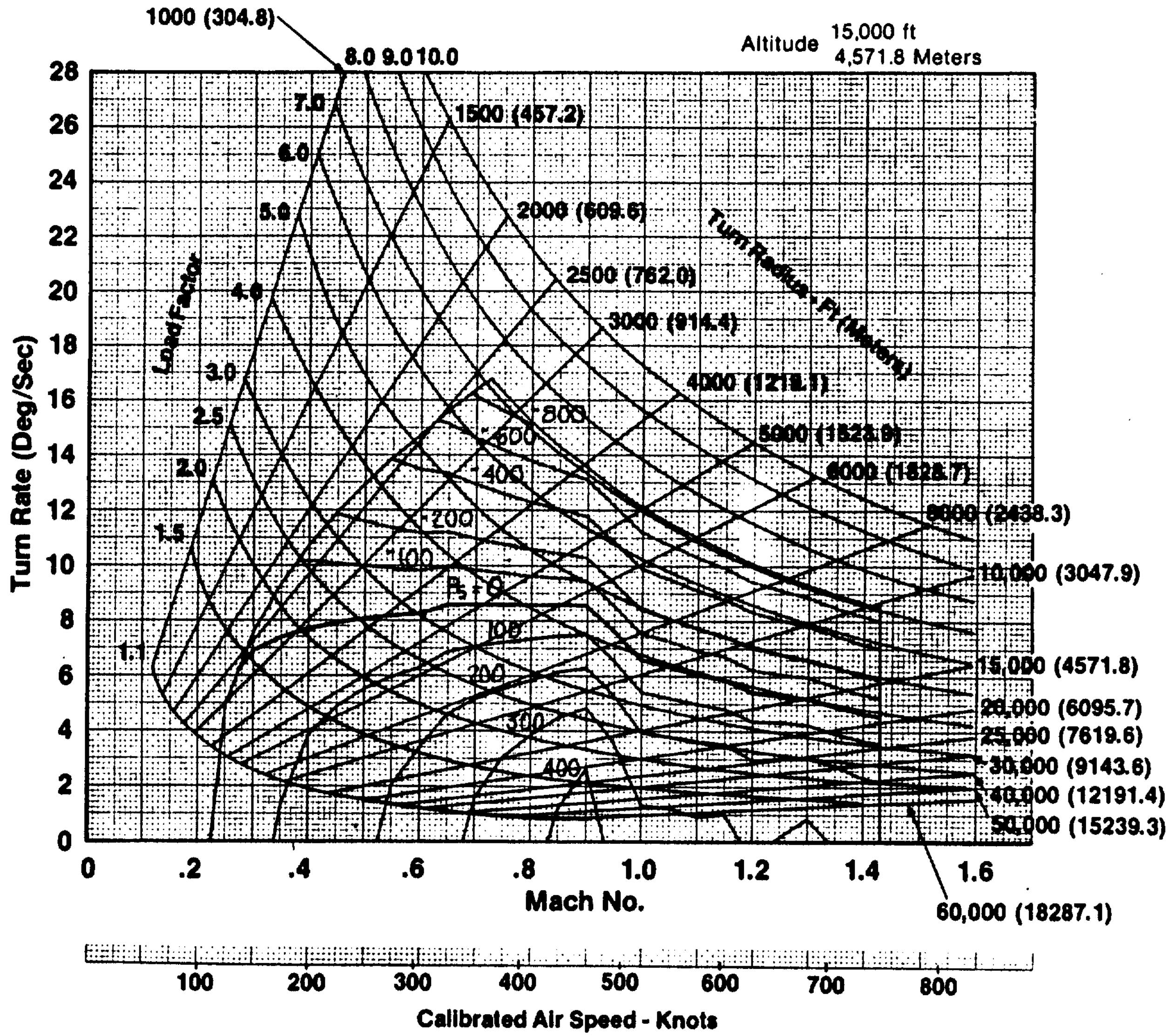


(2) Python IR Missiles
280 rds of 30 mm
50% Internal Fuel = 2835 lbs (1286 kg)
Combat Weight = 24,063 lbs (10915 kg)

Wing Span	26.97 Ft	(8.22m)
Wing Area	374.6 Ft²	(34.8m²)
Canard Area	17.9 Ft²	(1.7m²)
Overall Length	51.35 Ft	(15.65m)
Empty Weight	19550 Lbs	(8868 Kg)
Internal Fuel	920.8 US Gal	(3485 Liter)
	5985 Lb	(2715 Kg)
Takeoff Wt with (2) IR Missiles	26898 Lbs	(12201 Kg)
Max External Fuel	1030 US Gal	(3900 Liter)
	6695 Lbs	(3037 Kg)
Max Gross Takeoff Weight	35715 Lbs	(16200 Kg)
Max A/B (Wet) Thrust at SL	18900 Lbs	(8573 Kg)
(1) GE-J-79-J1E (Combat Plus)	84.07 Kn	
Max Mil (Dry) Pwr Thrust at SL	11918 Lbs	(5406 Kg)
	53.0 Kn	
Combat Wt at 50% Fuel & (2) IR Missiles	24063 Lbs	(10915 Kg)
Combat Thrust-to-Weight	0.80	
Combat Wing Loading	65 Lbs/Ft²	(314 Kg/m²)
Design Load Factor	7.5G's	

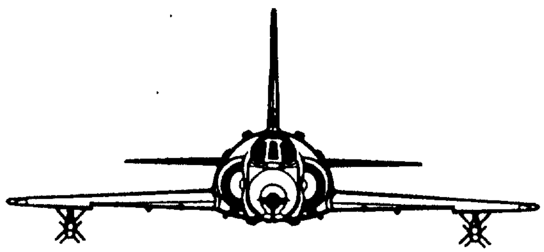
Turn Performance at 15,000 Ft (4752m)

Utilizing Maximum Afterburner (Wet) Power



KFIR C-7

(Israeli Aircraft Industries)

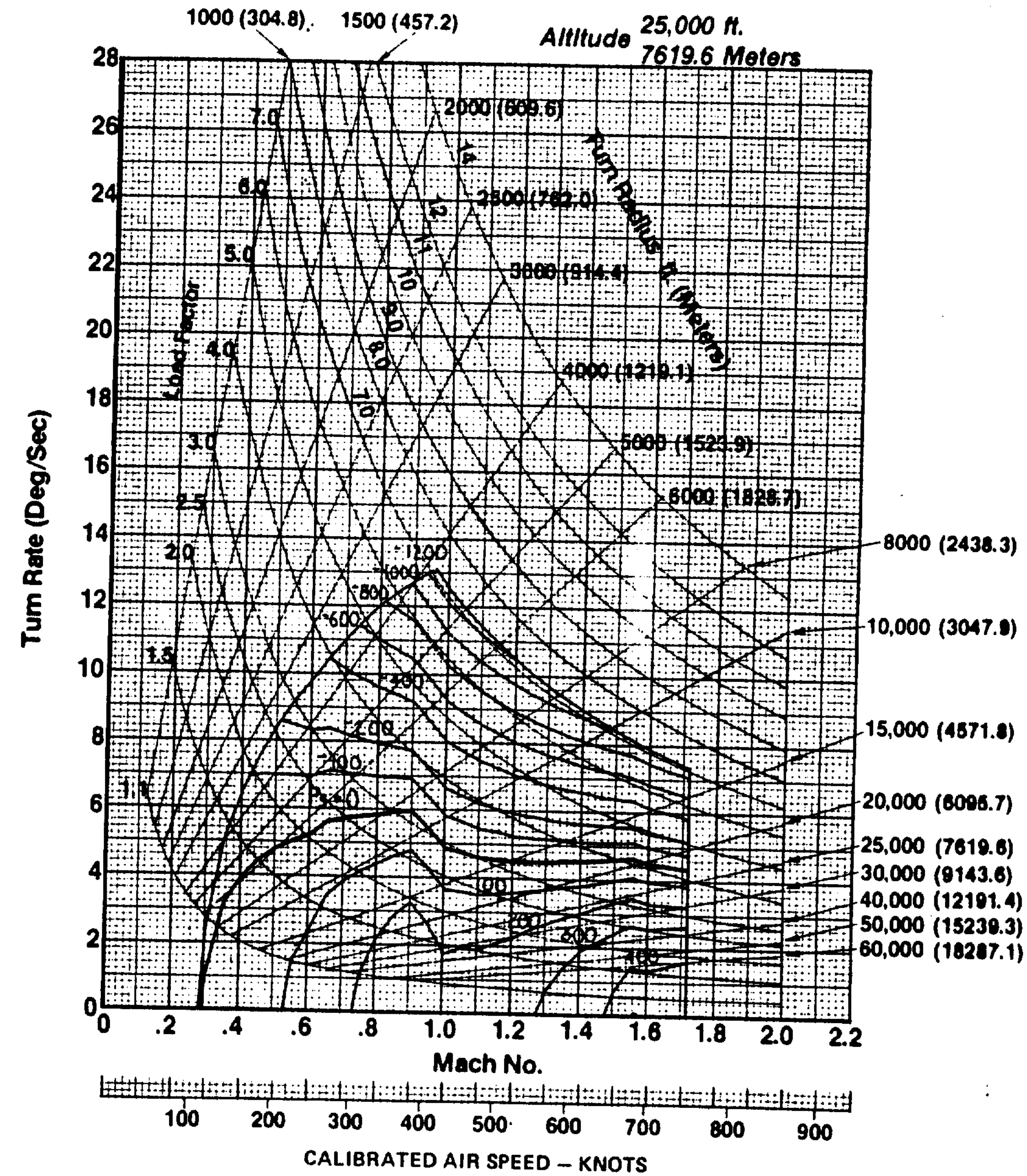


(2) Python IR Missiles
280 rds of 30 mm
50% Internal Fuel = 2835 lbs (1286 kg)
Combat Weight = 24,063 lbs (10915 kg)

Wing Span	26.97 Ft	(8.22m)
Wing Area	374.6 Ft^2	($34.8m^2$)
Canard Area	17.9 Ft^2	($1.7m^2$)
Overall Length	51.35 Ft	(15.65m)
Empty Weight	19550 Lbs	(8868 Kg)
Internal Fuel	920.8 US Gal	(3485 Liter)
	5985 Lb	(2715 Kg)
Takeoff Wt with (2) IR Missiles	26898 Lbs	(12201 Kg)
Max External Fuel	1030 US Gal	(3900 Liter)
	6695 Lbs	(3037 Kg)
Max Gross Takeoff Weight	35715 Lbs	(16200 Kg)
Max A/B (Wet) Thrust at SL	18900 Lbs	(8573 Kg)
(1) GE-J-79-J1E (Combat Plus)	84.07 Kn	
Max Mil (Dry) Pwr Thrust at SL	11918 Lbs	(5406 Kg)
	53.0 Kn	
Combat Wt at 50% Fuel & (2) IR Missiles	24063 Lbs	(10915 Kg)
Combat Thrust-to-Weight	0.80	
Combat Wing Loading	65 Lbs/Ft^2	(314 Kg/m^2)
Design Load Factor	7.5G's	

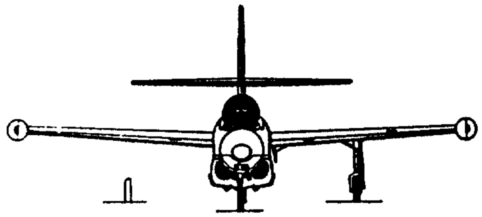
Turn Performance at 25,000 Ft (7620m)

Utilizing Maximum Afterburner (Wet) Power



T-2D

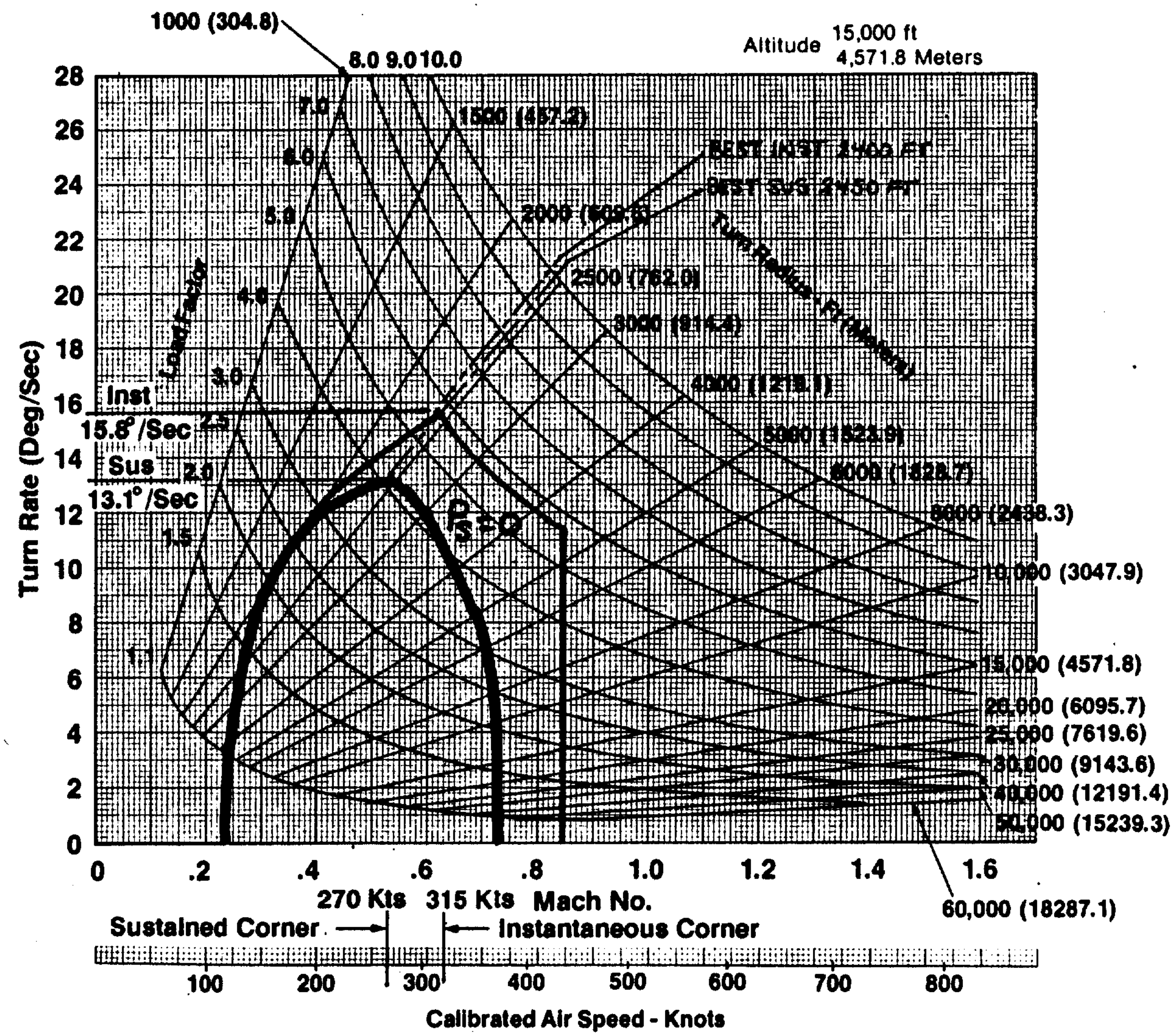
"Buckeye" by Rockwell



Wing Span	255 Ft	(23.7m)
Empty Weight	8115 Lbs	(3681 Kg)
Internal Fuel	4492 Lb	(2038 Kg)
(Fus + Wing + Tip)	691 US Gal	(3141 Liter)
Takeoff Weight	12815 Lbs	(5813 Kg)
Max Takeoff Weight	13191 Lbs	(5983 Kg)
Max Mil-Pwr (Dry) at SL	5900 Lbs	(2676 Kg)
(2) J85-GE-4	26.2 Kn	
Combat Wt at 50% Fuel	10569 Lbs	(4794 Kg)
Combat Thrust-to-Weight	0.56	
Combat Wing Loading	41.4 Lbs/Ft²	(202.3 Kg/m²)
Design Load Factor	7.5G's	

Turn Performance at 15,000 Ft (4752m)

Utilizing Maximum Mil-Pwr (Dry) Power



Fighter Comparisons Summary

- AIRCRAFT DIMENSIONS & WEIGHTS
  - ✔VID Range
  - ✔Configuration Cues on Performance
- POWER PLANT CHARACTERISTICS
  - ✔Smoke & Burner Plume/Puff
  - ✔Performance Installed
  - ✔Response
- AERODYNAMIC CHARACTERISTICS
  - ✔Wing Loading
  - ✔Control & Maneuvering Surfaces
  - ✔Wing Sweep
  - ✔Adverse Handling Qualities
  - ✔Design & Structural Limits
  - ✔Deceleration Devices
  - ✔Flight Control Response
- FIRE CONTROL AND ELECTRONICS
  - ✔Radar
  - ✔Gun Sight/HUD
  - ✔Modes
  - ✔Weapon Interface
  - ✔Heads-In vs Heads-Out

Fighter Comparisons Summary (Cont'd)

- ARMAMENT
  - ✔ Types
  - ✔ Number
  - ✔ Envelopes
  - ✔ Limitations
  - ✔ Kill Quality
- VULNERABILITY/SURVIVABILITY
  - ✔ Hardness
  - ✔ Offensive Capability
  - ✔ Stealth
  - ✔ Sorties
  - ✔ Degraded Mode Operation
- ENERGY MANEUVARABILITY FACTORS
  - ✔ Climb and Acceleration/Deceleration
  - ✔ Speed Regimes (Max Mach, Q, Stall, Etc.)
  - ✔ Turn Rate and Radius (Inst. & Sus)
  - ✔ Altitude Ceilings and Optimizations
  - ✔ G and Energy (Values and Rates)
  - ✔ Specific Maneuvers and Heading Reversals

Fighter Performance (Cont'd)

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