Professional Development Short Course On:

Tactical Missile Design - Integration

Instructor:

Eugene L. Fleeman

ATI Course Schedule: **http://www.ATIcourses.com/schedule.htm**

ATI's Tactical Missile Design: **http://www.aticourses.com/tactical_missile_design.htm**

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Tactical Missile Design

January 12-14, 2009
Laurel, Maryland

April 13-15, 2009
Beltsville, Maryland

$1590 (8:30am - 4:00pm)

"Register 3 or More & Receive 100^{00} each Off The Course Tuition."

Summary

This three-day short course covers the fundamentals of tactical missile design. The course provides a system-level, integrated method for missile aerodynamic configuration/propulsion design and analysis. It addresses the broad range of alternatives in meeting cost and performance requirements. The methods presented are generally simple closed-form analytical expressions that are physics-based, to provide insight into the primary driving parameters. Configuration sizing examples are presented for rocket-powered, ramjet-powered, and turbo-jet powered baseline missiles. Typical values of missile parameters and the characteristics of current operational missiles are discussed as well as the enabling subsystems and technologies for tactical missiles and the current/projected state-of-the-art. Videos illustrate missile development activities and missile performance. Finally, each attendee will design, build, and fly a small air powered rocket. Attendees will vote on the relative emphasis of the material to be presented. Attendees receive course notes as well as the textbook, *Tactical Missile Design, 2nd edition.*

Instructor

Eugene L. Fleeman has more than 40 years of government, industry, and academia experience in missile system and technology development. Formerly a manager of missile programs at Georgia Tech, Boeing, Rockwell International, and Air Force Research Laboratory, he is an internationally known lecturer on missiles and the author of over seventy publications including the *AIAA textbook Tactical Missile Design.*

What You Will Learn

- Key drivers in the missile design process.
- Critical tradeoffs, methods and technologies in subsystems, aerodynamic, propulsion, and structure sizing.
- Launch platform-missile integration.
- Robustness, lethality, accuracy, observables, survivability, reliability, and cost considerations.
- Missile sizing examples.
- Missile development process.

Who Should Attend

The course is oriented toward the needs of missile engineers, analysts, marketing personnel, program managers, university professors, and others working in the area of missile analysts, marketing personnel and technology development. Attendees will gain an understanding of missile design, missile technologies, launch platform integration, missile system measures of merit, and the missile system development process.

Course Outline

1. Introduction/Key Drivers in the Design Process. Overview of missile design process. Unique characteristics of tactical missiles. Key aerodynamic configuration sizing parameters. Missile conceptual design synthesis process. Projected capability in C4ISR.

2. Aerodynamic Considerations in Tactical Missile Design. Optimizing missile aerodynamics. Missile configuration layout (body, wing, tail) options. Selecting flight control alternatives. Wing and tail sizing. Predicting normal force, drag, pitching moment, and hinge moment.

3. Propulsion Considerations. Turbojet, ramjet, scramjet, ducted rocket, and rocket propulsion comparisons. Turbojet engine design considerations. Selecting ramjet engine, booster, and inlet alternatives. High density fuels. Effective thrust magnitude control. Reducing propellant and turbojet observables. Rocket motor prediction and sizing. Ramjet engine prediction and sizing. Motor case and nozzle materials.

4. Weight Considerations. Structural design criteria factor of safety. Structure concepts and manufacturing processes. Selecting airframe materials. Loads prediction. Weight prediction. Motor case design. Aerodynamic heating prediction and insulation trades. Dome material alternatives. Power supply and actuator alternatives.

5. Flight Trajectory Considerations. Aerodynamic sizing-equations of motion. Maximizing flight performance. Benefits of flight trajectory shaping. Flight performance prediction of boost, climb, cruise, coast, ballistic, maneuvering, and homing flight.

6. Measures of Merit and Launch Platform Integration. Achieving robustness in adverse weather. Seeker, data link, and sensor alternatives. Counter-countermeasures. Warhead alternatives and lethality prediction. Alternative guidance laws. Proportional guidance accuracy prediction. Time constant contributors and prediction. Maneuverability design criteria. Radar cross section and infrared signature prediction. Survivability considerations. Cost drivers of schedule, weight, learning curve, and parts count. Designing within launch platform constraints. Storage, carriage, launch, and separation environment. Internal vs. external carriage.

7. Sizing Examples and Sizing Tools. Trade-offs for extended range rocket. Sizing for enhanced maneuverability. Ramjet missile sizing for range robustness. Turbojet missile sizing for maximum range. Computer aided sizing tools for conceptual design. Soda straw rocket design, build, and fly. House of quality process. Design of experiment process.

8. Development Process. Design validation/technology development process. New missile follow-on projections. Examples of development facilities. New technologies for tactical missiles.

9. Summary and Lessons Learned.

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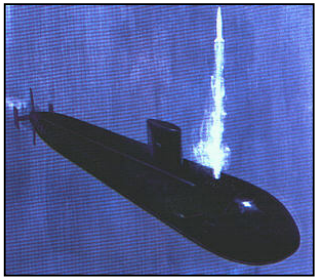
Outline

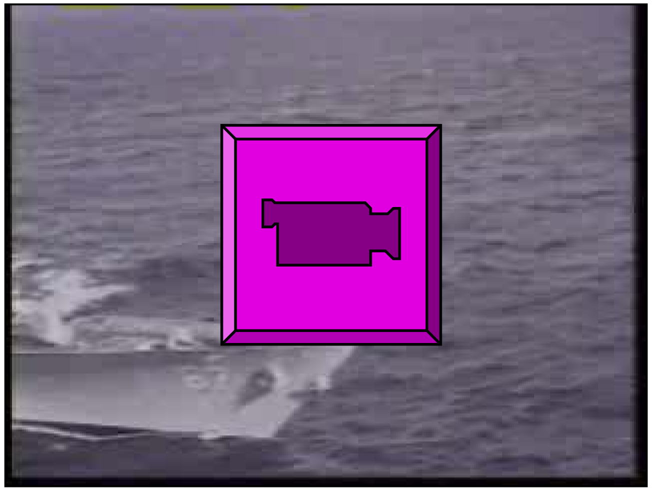
- Introduction / Key Drivers in the Missile Design - Integration Process
- Aerodynamic Considerations in Missile Design - Integration
- Propulsion Considerations in Missile Design - Integration
- Weight Considerations in Missile Design - Integration
- Flight Performance Considerations in Missile Design - Integration
- Measures of Merit and Launch Platform Integration
- Sizing Examples
- Missile Development Process
- Summary and Lessons Learned
- References and Communication
- Appendices (Homework Problems / Classroom Exercises, Example of Request for Proposal, Nomenclature, Acronyms, Conversion Factors, Syllabus)

Missile Design Should Be Conducted in a System-of-Systems Context

Example: Typical US Carrier Strike Group Complementary Missile Launch Platforms / Load-out

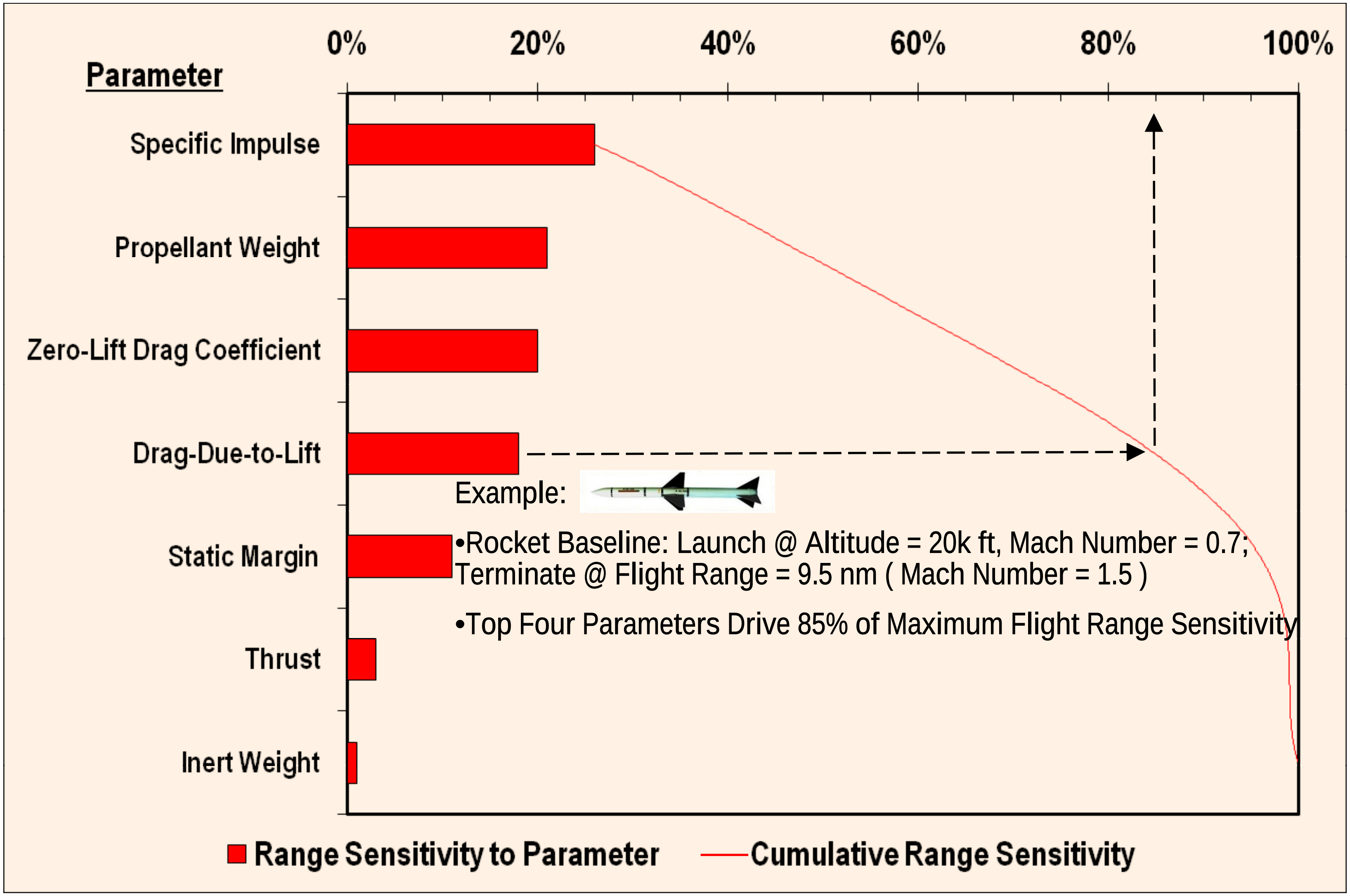
- Air-to-Surface: JASSM, SLAM, Harpoon, JSOW, JDAM, Maverick, HARM, GBU-10, GBU-5, Penguin, Hellfire
- Air-to-Air: AMRAAM, Sparrow, Sidewinder
- Surface-to-Air: SM-3, SM-2, Sea Sparrow, RAM
- Surface-to-Surface: Tomahawk, Harpoon



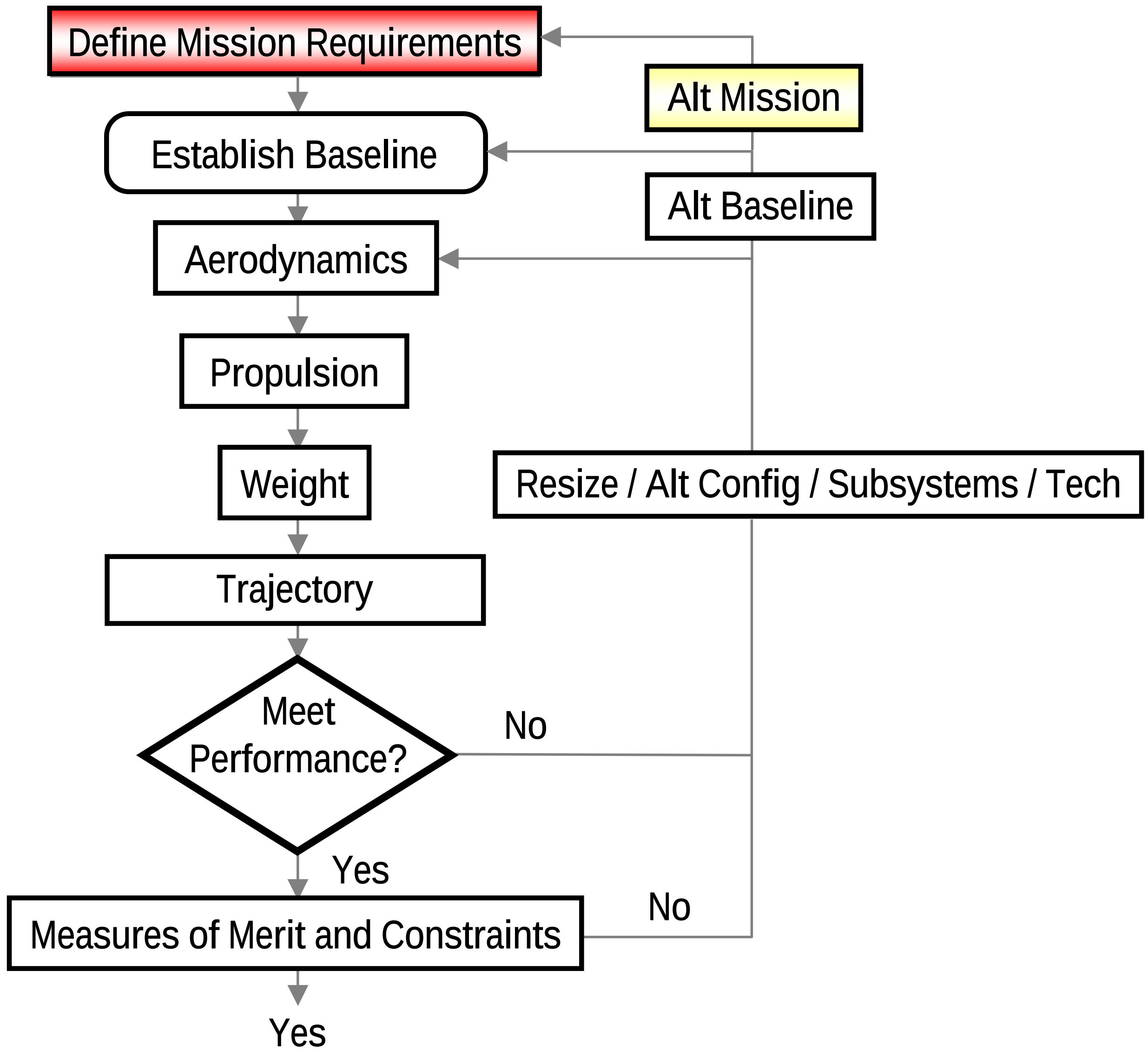


Pareto Effect: Only a Few Parameters Drive the Design

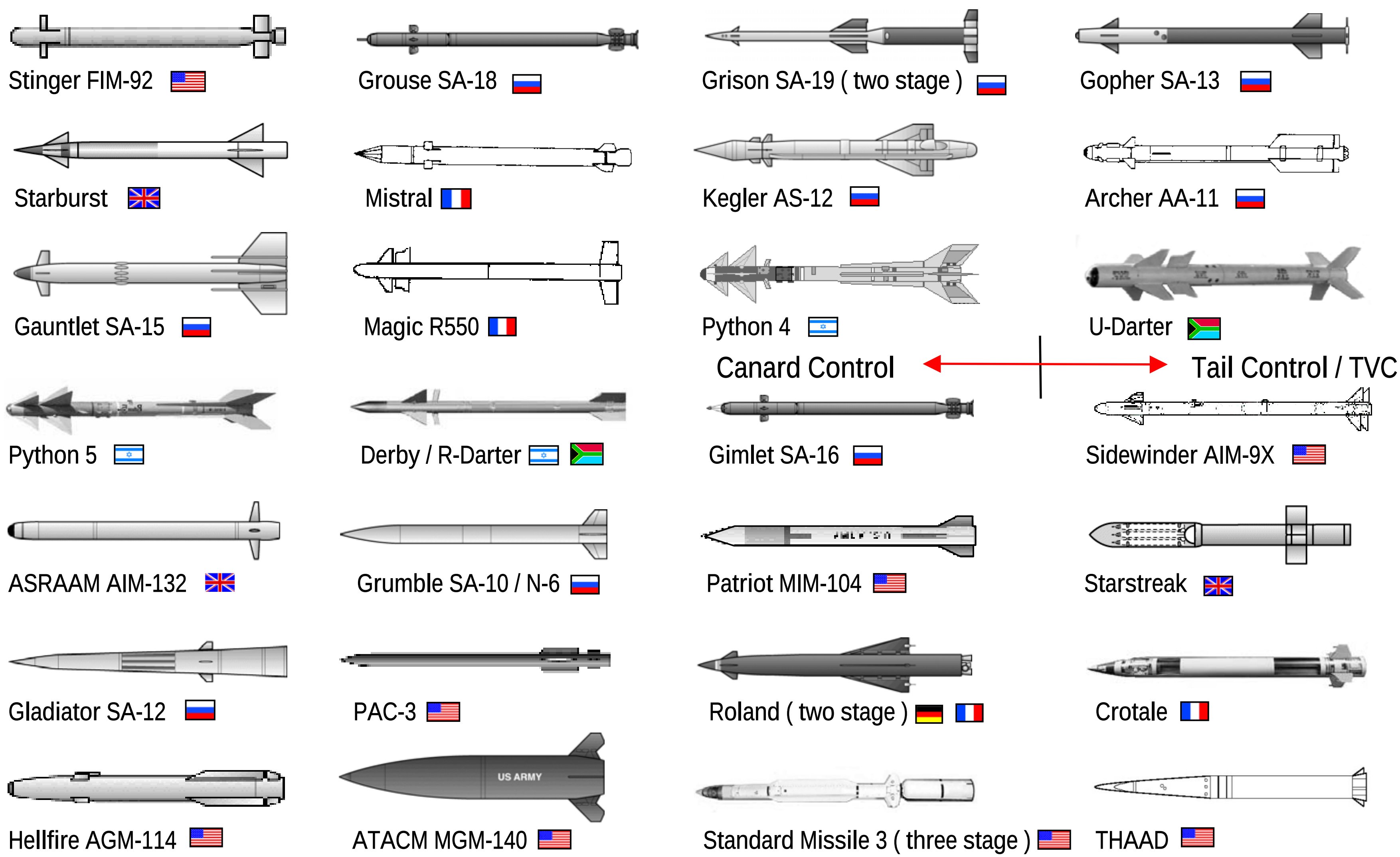
Example: Rocket Baseline Missile (Sparrow) Maximum Flight Range



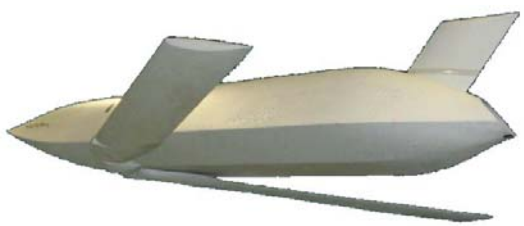
Missile Synthesis Is a Creative Process That Requires Evaluation of Alternatives and Iteration



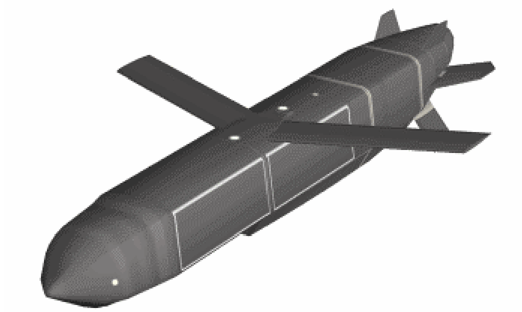
Most Supersonic Missiles Are Wingless



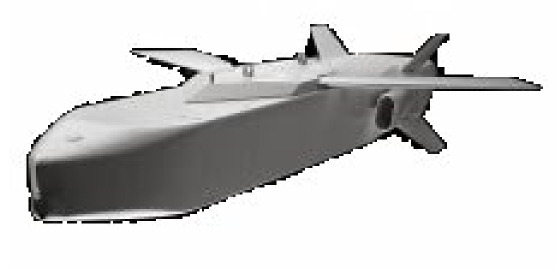
Subsonic Cruise Missiles Have Relatively Large Wings



JASSM



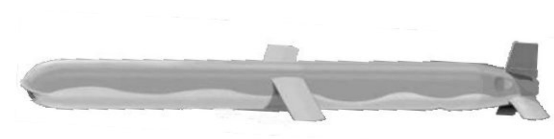
Apache



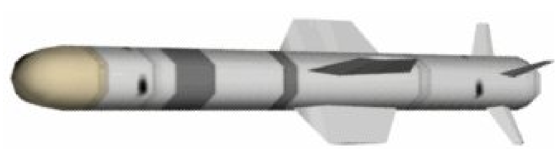
Taurus

CALCM

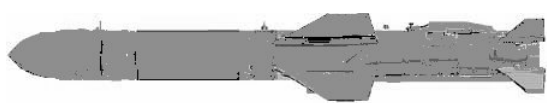
Naval Strike Missile



Tomahawk



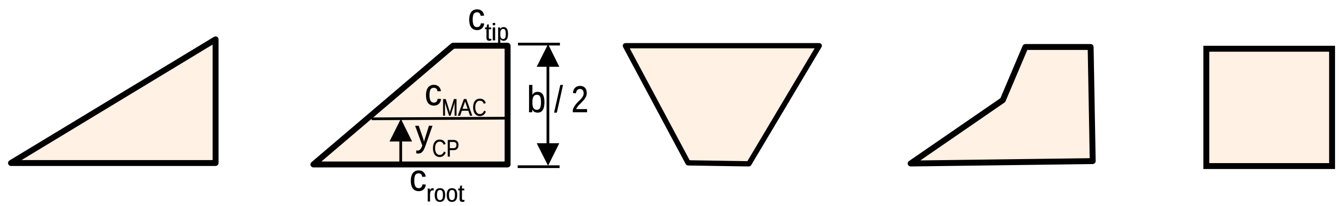
Harpoon



ANAM / Gabriel 5

Permission of Missile Index.

Wing, Tail, and Canard Panel Geometry Trade-off



Parameter	Triangle (Delta)	Aft Swept LE Trapezoid	Bow Tie	Double Swept LE	Rectangle
Variation x_{AC}	–	○	○	●	◒
y_{CP} (Bending / Friction)	●	◒	–	○	–
Supersonic Drag	●	◒	◒	○	–
RCS	◒	◒	●	○	–
Span Constraint	–	◒	◒	◒	●
Stability & Control	○	●	◒	●	○
Aeroelastic Stab.	●	◒	–	◒	○

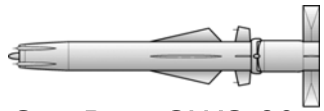
λ = Taper ratio = c_{tip} / c_{root}
A = Aspect ratio = $b^2 / S = 2\, b / [(1 + \lambda)\, c_{root}]$
y_{CP} = Outboard center-of-pressure = $(b / 6) (1 + 2 \lambda) / (1 + \lambda)$
c_{MAC} = Mean aerodynamic chord = $(2 / 3)\, c_{root} (1 + \lambda + \lambda^2) / (1 + \lambda)$

Note: Superior ● Good ◒ Average ○ Poor –

Based on equal surface area and equal span.
Surface area often has more impact than geometry.

Examples of Inlets for Current Supersonic Air-Breathing Missiles

- United Kingdom

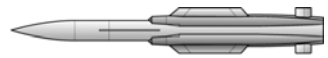


Sea Dart GWS-30

Meteor

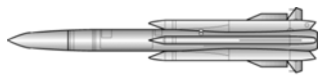
- France

ASMP

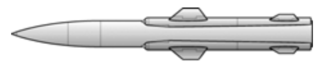


ANS

- Russia

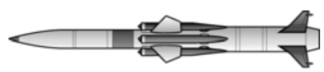


AS-17 / Kh-31



Kh-41

SS-N-22 / 3M80

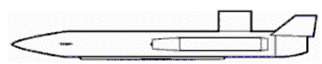


SA-6

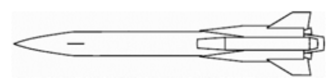
SS-N-19

SS-N-26

- China

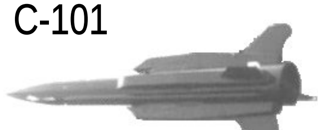


C-101



C-301

- Taiwan



Hsiung Feng III

- India

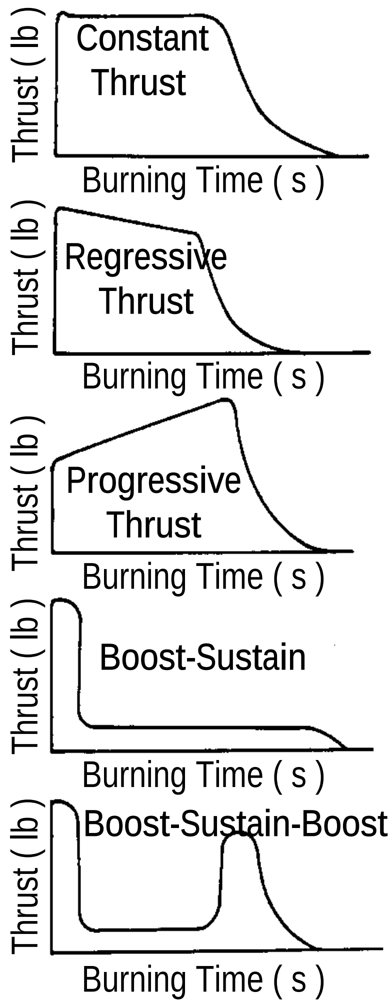
BrahMos

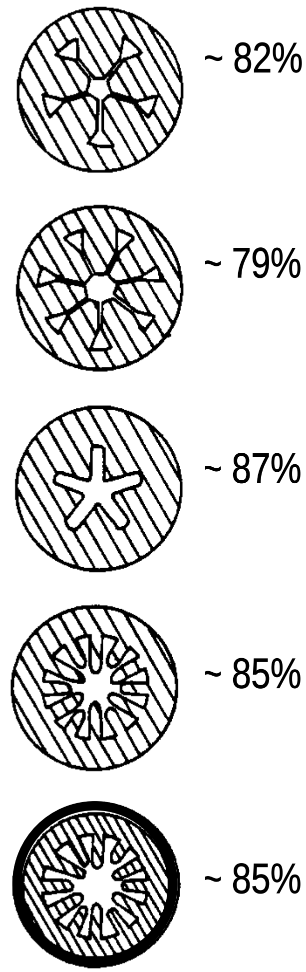
- Aft inlets have lower inlet volume and do not degrade lethality of forward located warhead.
- Nose Inlet may have higher flow capture, pressure recovery, smaller carriage envelope, and lower drag.

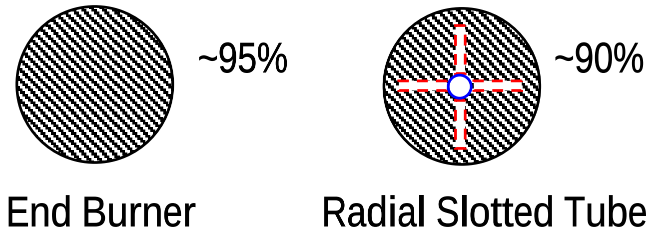
Conventional Solid Rocket Thrust-Time Design Alternatives - Propellant Cross Section Geometry

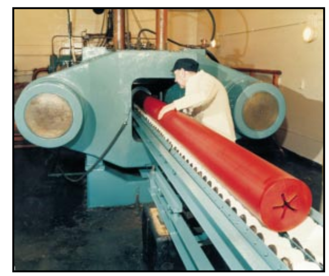
Example Mission | **Thrust Profile** | **Example Web Cross Section Geometry / Volumetric Loading**

- ≈ Cruise
- Dive at ≈ constant dynamic pressure
- Climb at ≈ constant dynamic pressure
- Fast launch – ≈ cruise
- Fast launch – ≈ cruise – high speed terminal







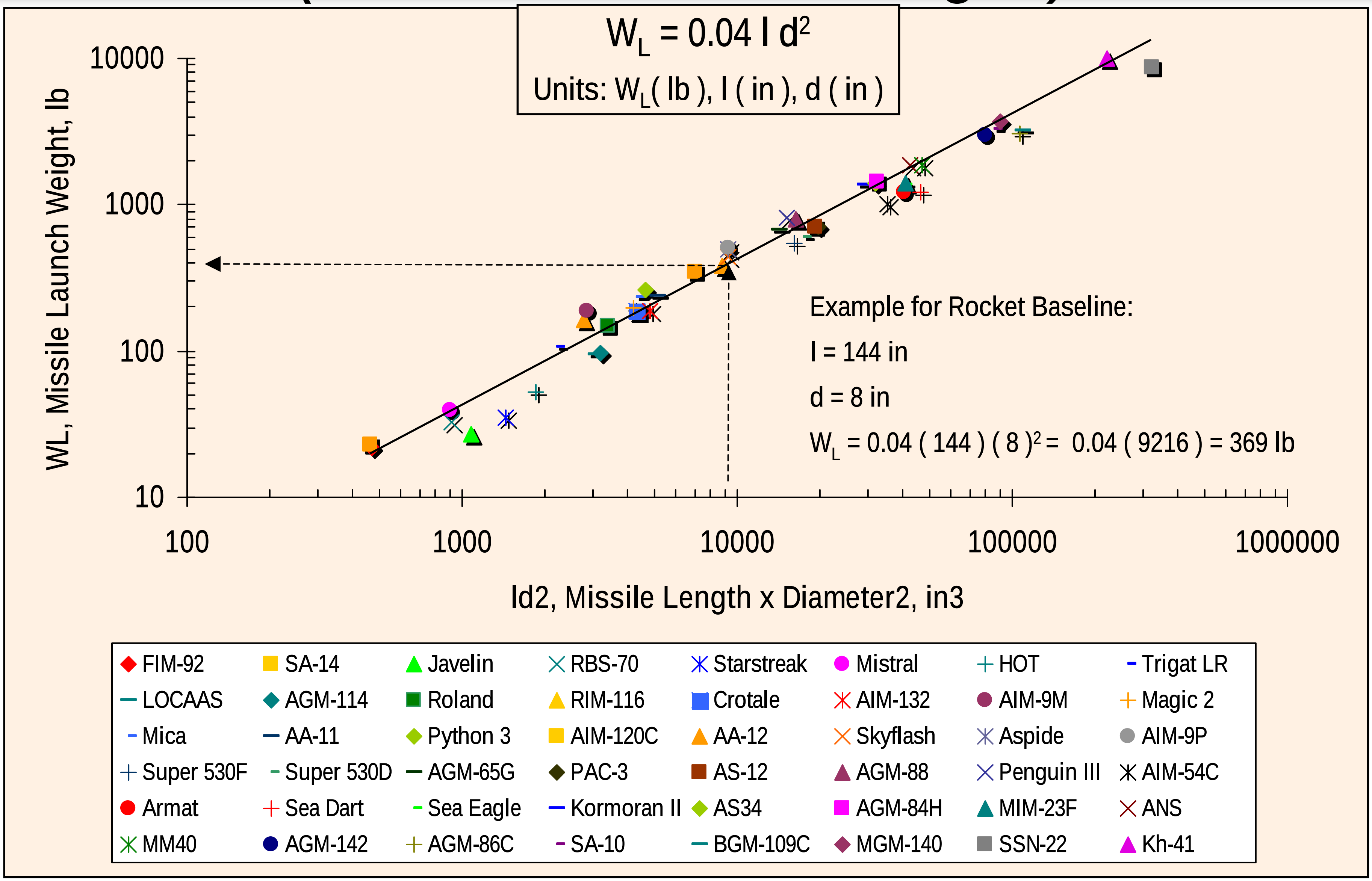

Extrusion Production of Star Web Propellant. Photo Courtesy of BAE.

Medium Burn Rate Propellant

High Burn Rate Propellant

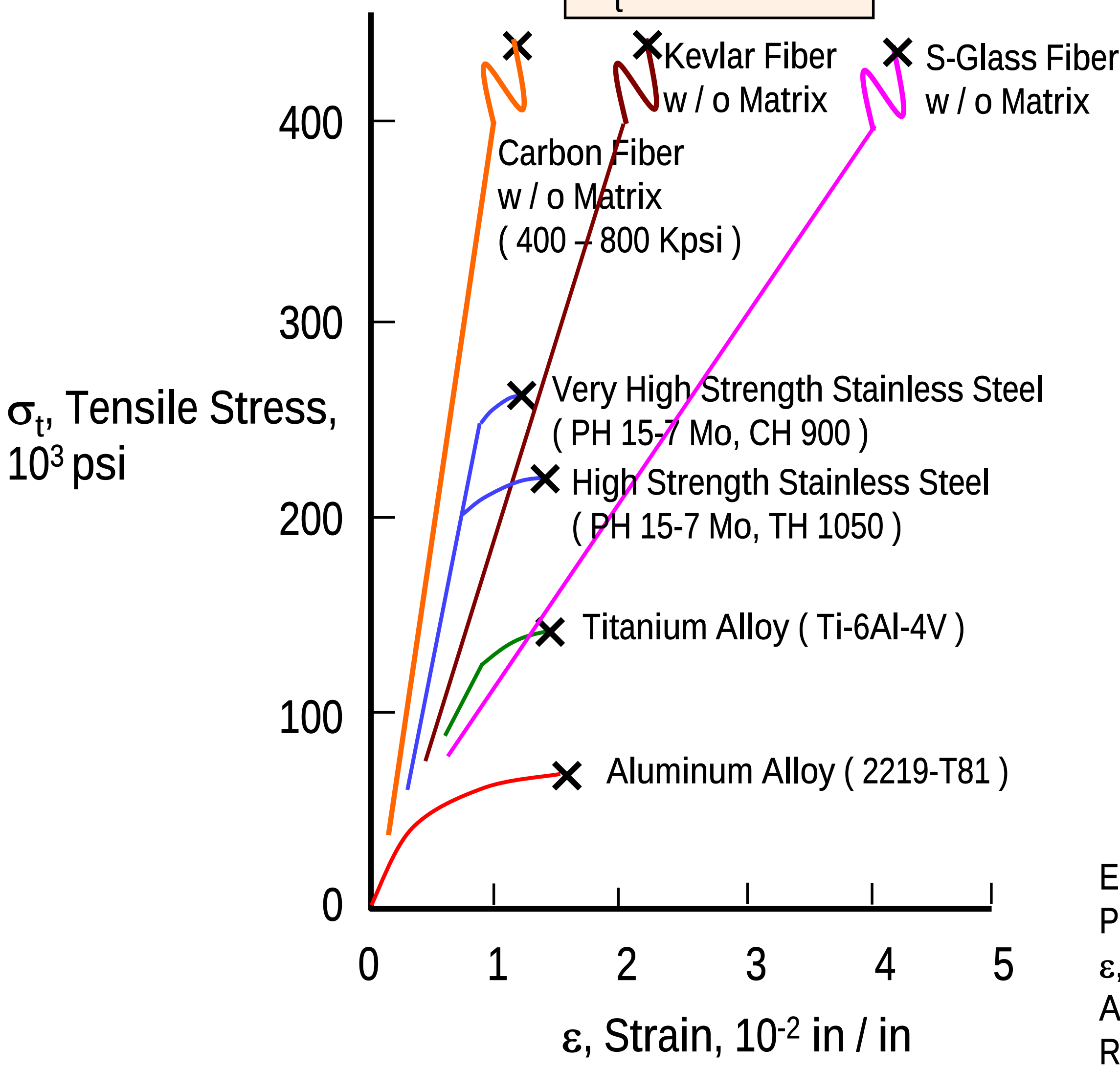
Note: High thrust and chamber pressure require large surface burn area.

Missile Weight Is Driven by Body Volume (i.e., Diameter and Length)



Strength – Elasticity of Airframe Material Alternatives

$\sigma_t = P / A = E\,\varepsilon$

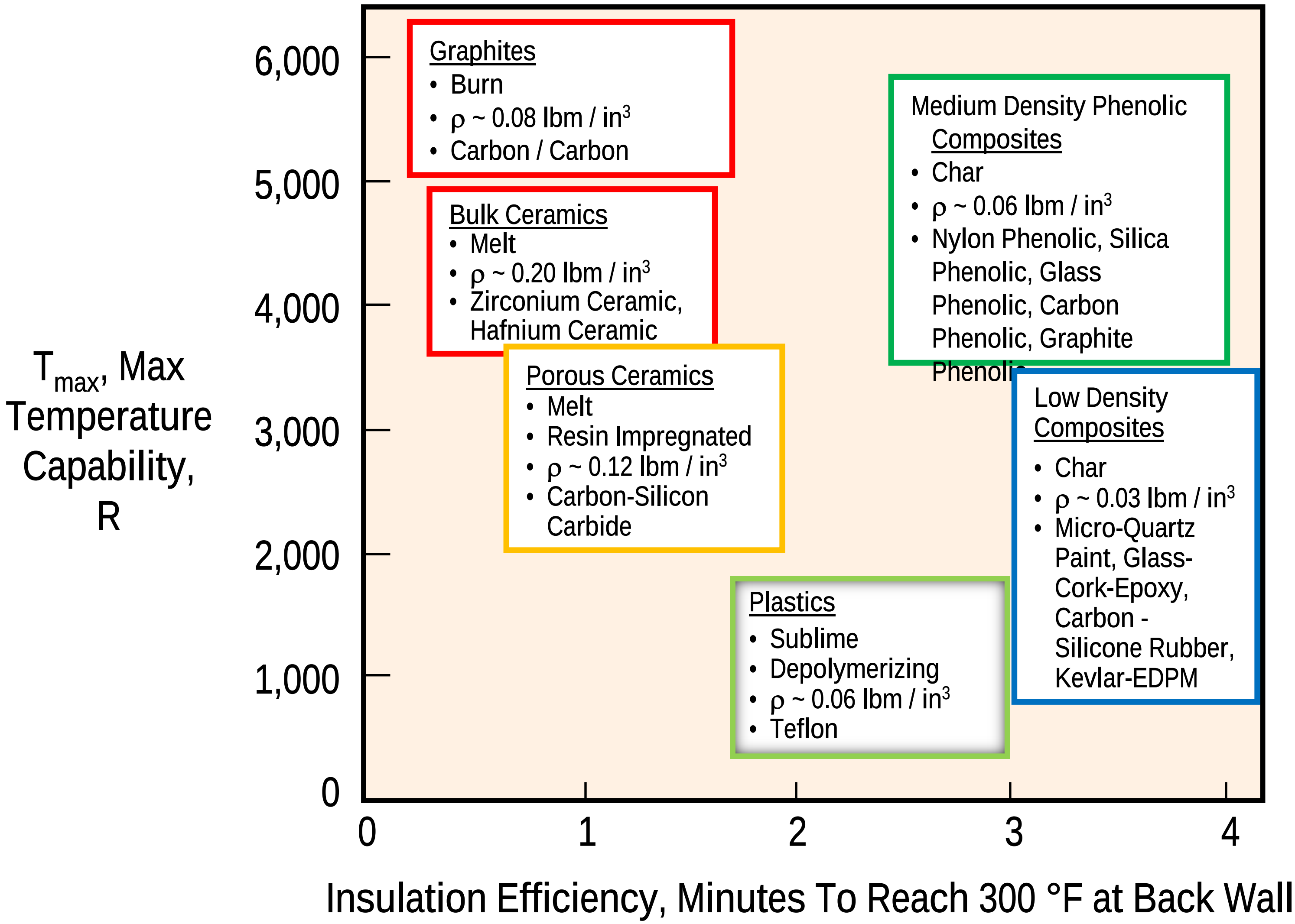


Note:

- High strength fibers are:
  - Very small diameter
  - Unidirectional
  - High modulus of elasticity
  - Very elastic
  - No yield before failure
  - Non forgiving failure
- Metals:
  - More ductile, yield s before failure
  - Allow adjacent structure to absorb load
  - Resist crack formation
  - Resist impact loads
  - More forgiving failure

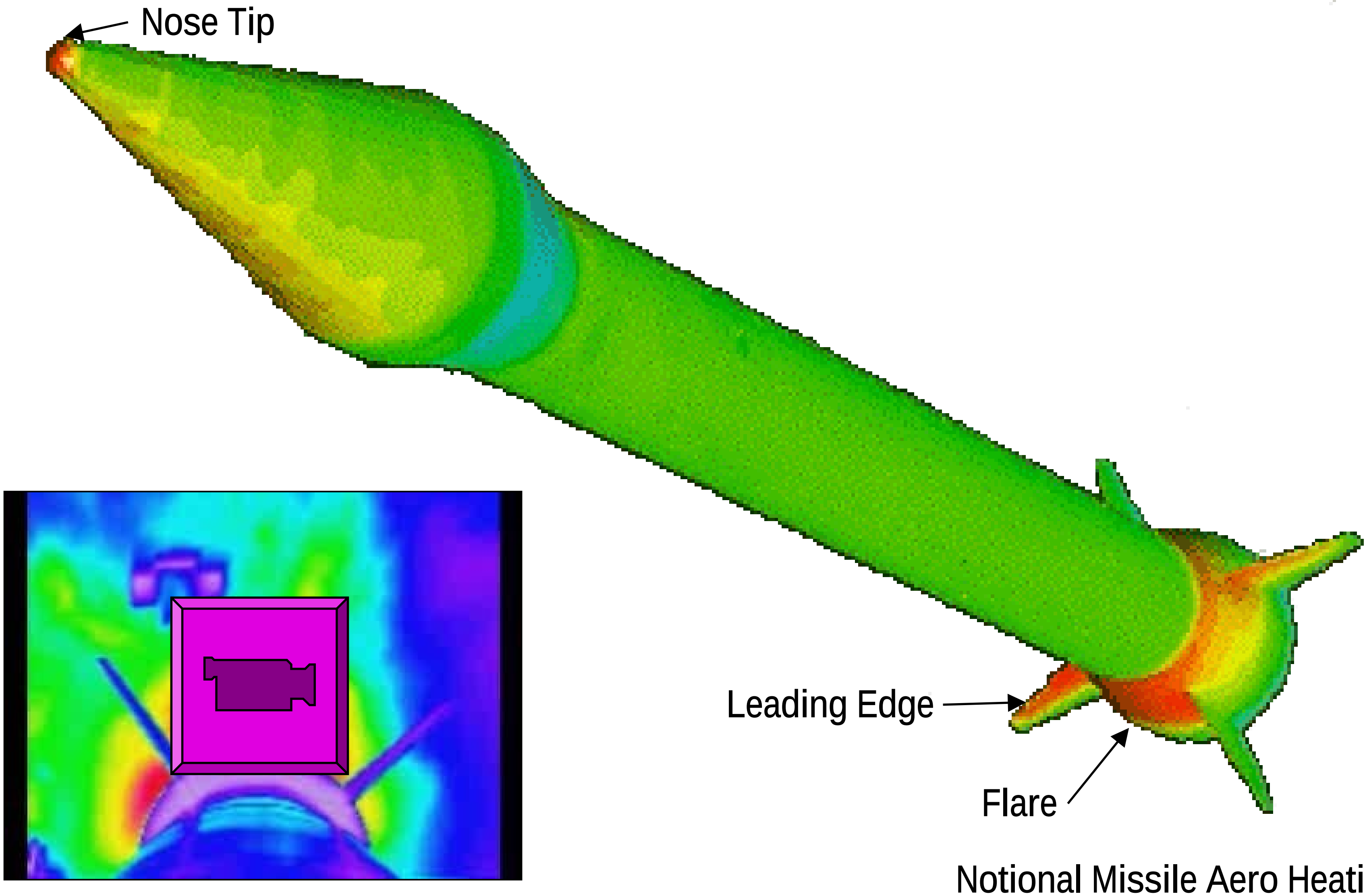
E, Young's modulus of elasticity, psi
P, Load, lb
ε, Strain, in / in
A, Area, in^2
Room temperature

Composites Are Good Insulators for High Temperature Structure and Propulsion (cont)



Note: Assumed Weight Per Unit Area of Insulator / Ablator = 1 lb / ft^2

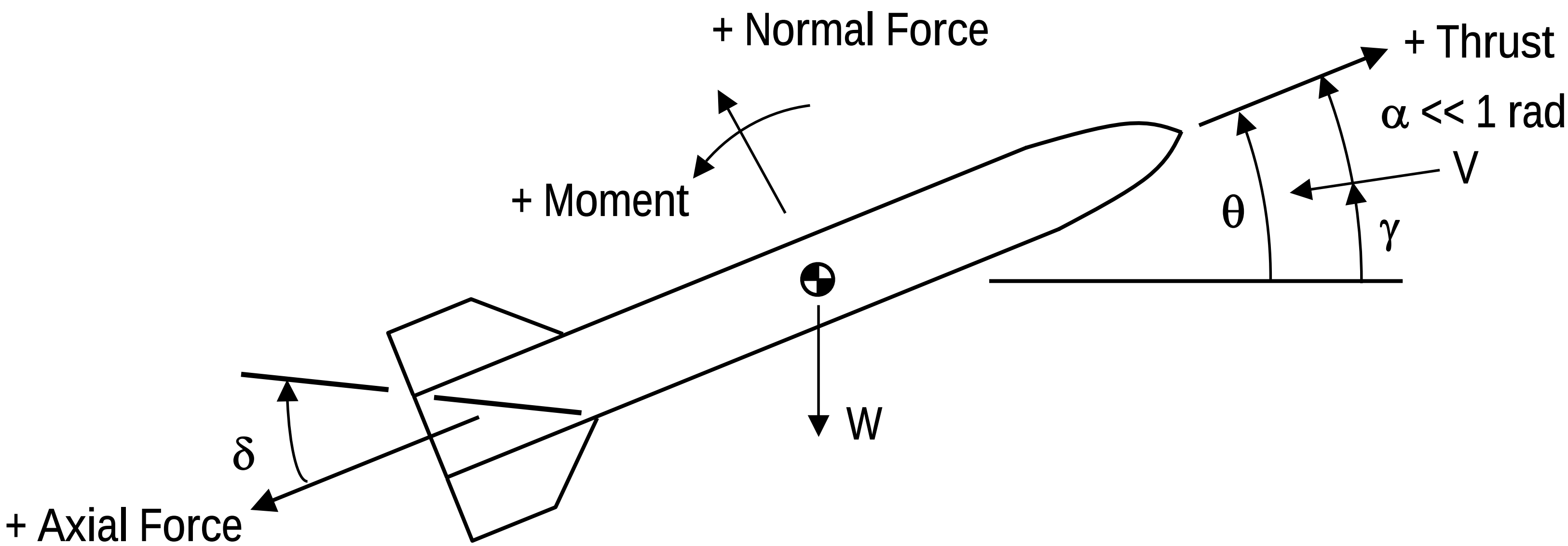
Examples of Aerodynamic Hot Spots



Notional Missile Aero Heating

Video of Radiometric Imagery – SM-3 Flight

3-DOF Simplified Equations of Motion Show Drivers for Configuration Sizing



$I_y \ddot{\theta} \approx I_y \ddot{\alpha} \approx q\, S_{Ref}\, d\, C_{m_\alpha}\, \alpha + q\, S_{Ref}\, d\, C_{m_\delta}\, \delta$

$(W / g_c)\, \dot{\gamma} \approx S_{Ref}\, \rho\, V\, C_{N_\alpha}\, \alpha / 2 + S_{Ref}\, \rho\, V\, C_{N_\delta}\, \delta / 2 + (T \sin \alpha) / V - (W / V) \cos \gamma$

$(W / g_c)\, \dot{V} \approx T - C_A\, S_{Ref}\, q - C_{N_\alpha}\, \alpha^2\, S_{Ref}\, q - W \sin \gamma$

<u>Configuration Sizing Implication</u>

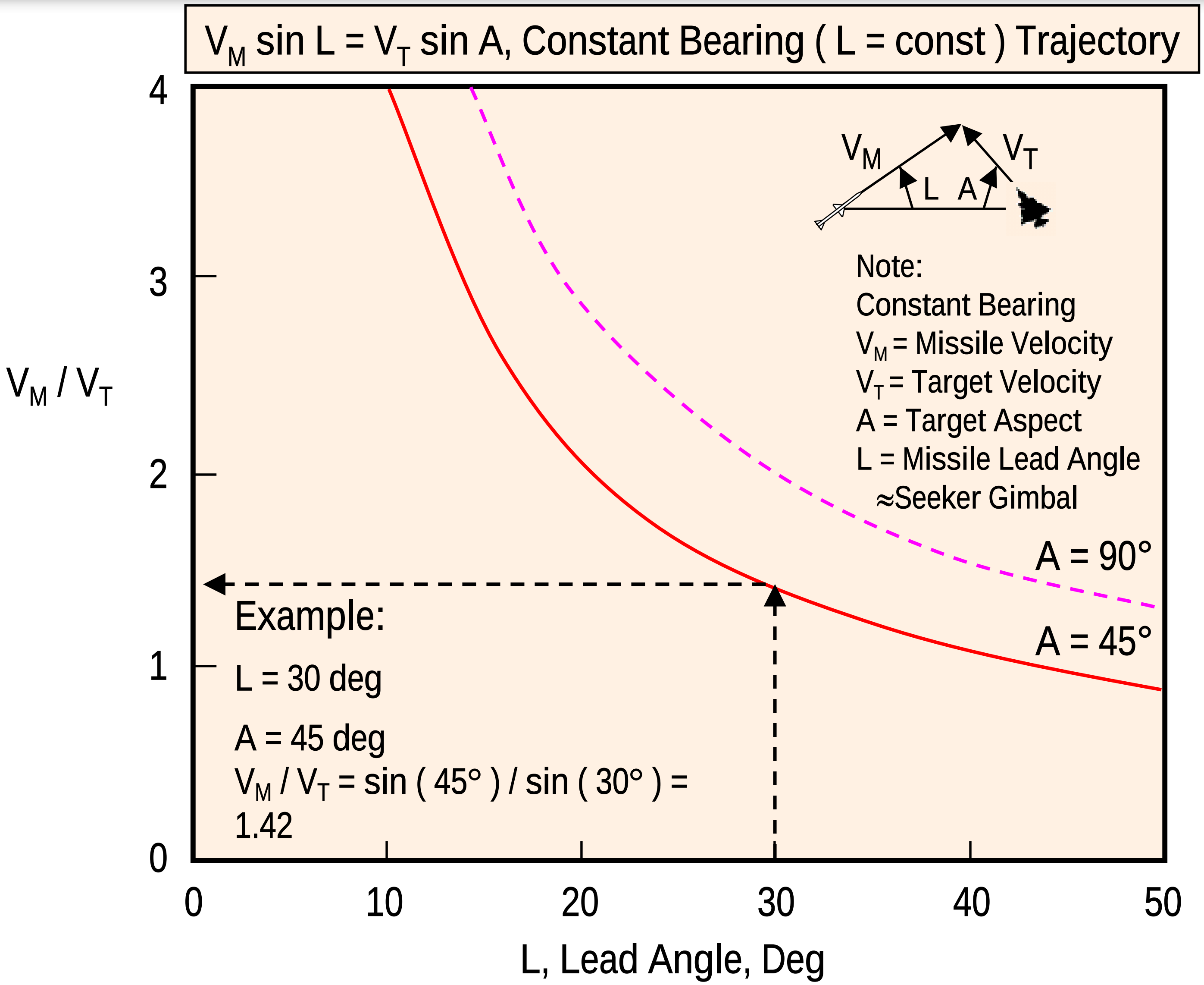
High Control Effectiveness ⇒ $C_{m_\delta} > C_{m_\alpha}$, I_y small (W small), q large

Large / Fast Heading Change ⇒ C_N large, W small, ρ large (low alt), V large, T / V large

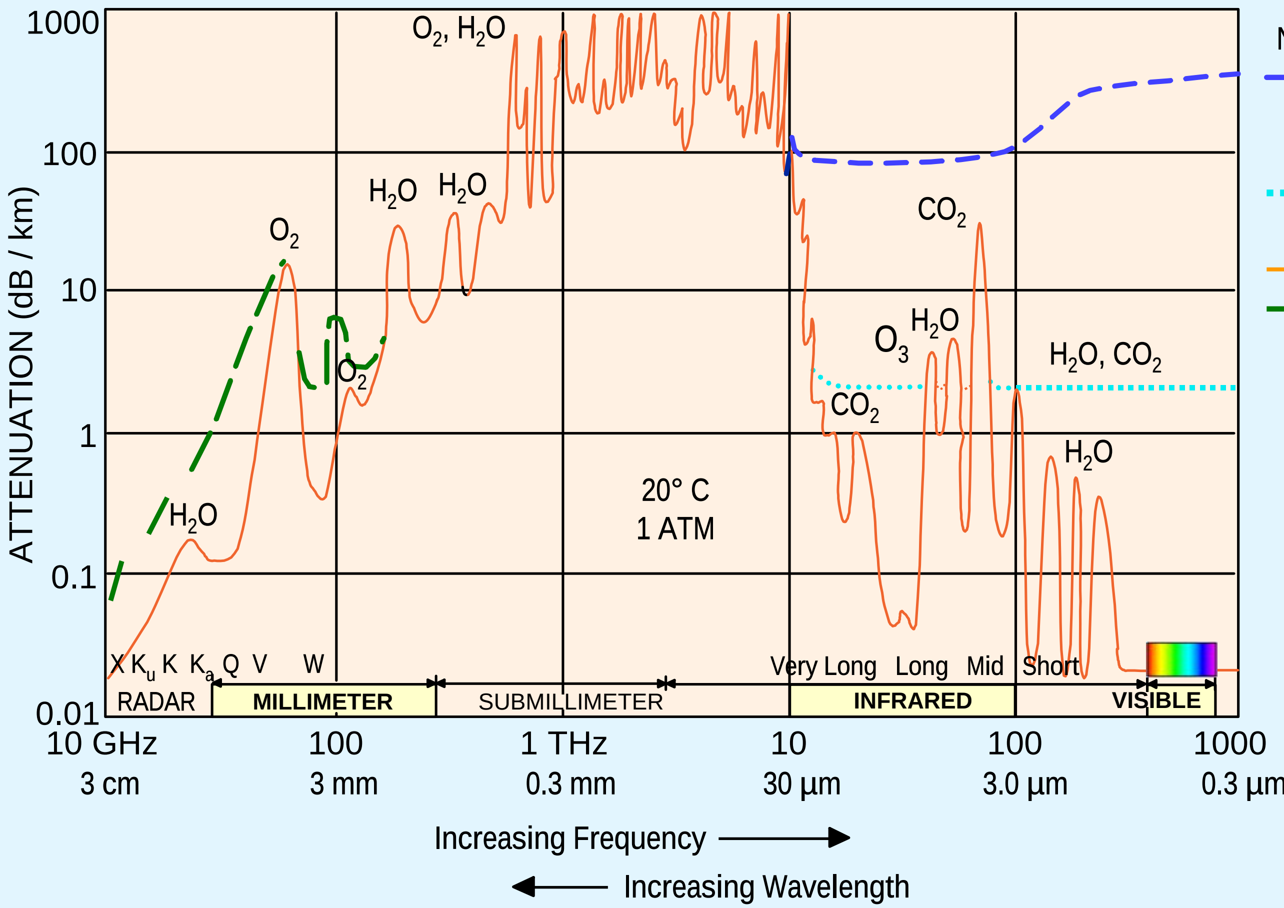
High Speed / Long Range ⇒ Total Impulse large, C_A small, q small

Note: Based on aerodynamic control

High Missile Velocity and Target Lead Required to Intercept High Speed Crossing Target



A Radar Seeker / Sensor Is More Robust in Adverse Weather



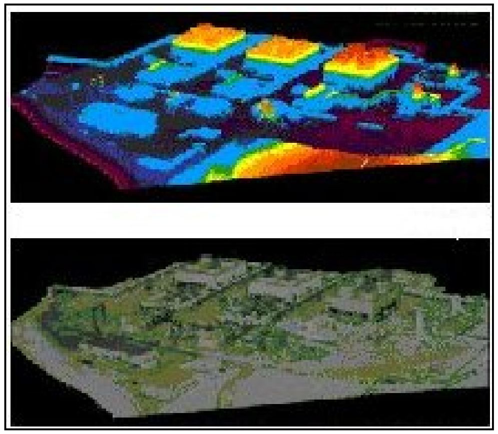
Note:
- EO attenuation through cloud @ 0.1 g / m^3 and 100 m visibility
- EO attenuation through rain @ 4 mm / h
- Humidity @ 7.5 g / m^3
- Millimeter wave and microwave attenuation through cloud @ 0.1 gm / m^3 or rain @ 4 mm / h

- Attenuation by absorption, scattering, and reflection
- EO sensors are ineffective through cloud cover
- Clouds have greater effect on attenuation than “greenhouse gases”, such as H_2O and CO_2
- Radar sensors have good to superior performance through cloud cover and rain

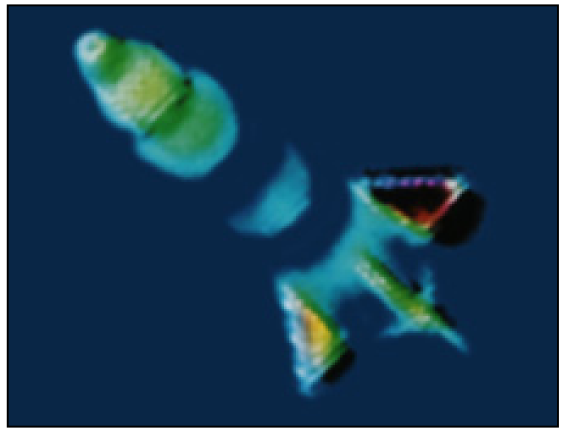
Source: Klein, L.A., Millimeter-Wave and Infrared Multisensor Design and Signal Processing, Artech House, Boston, 1997

An Imaging Sensor Enhances Target Acquisition / Discrimination

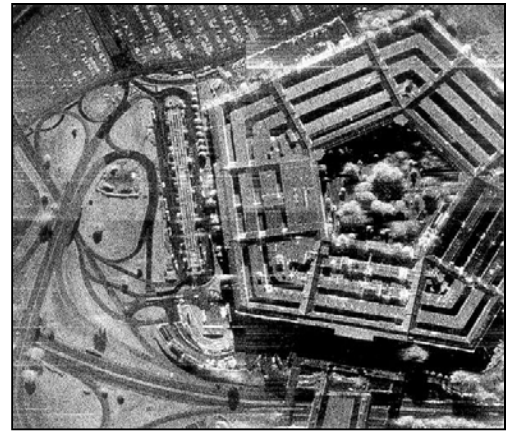
Imaging LADAR



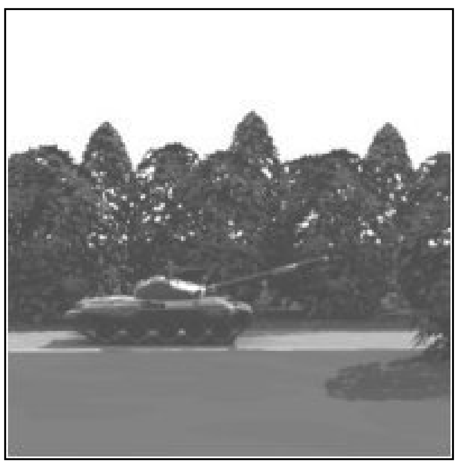
Imaging Infrared



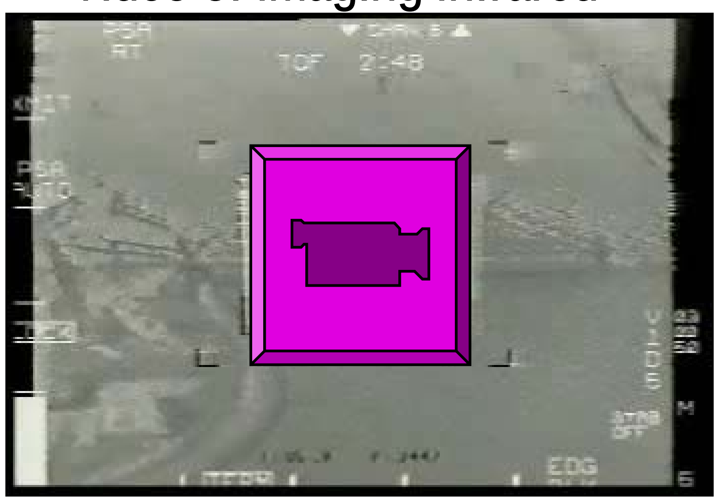
SAR



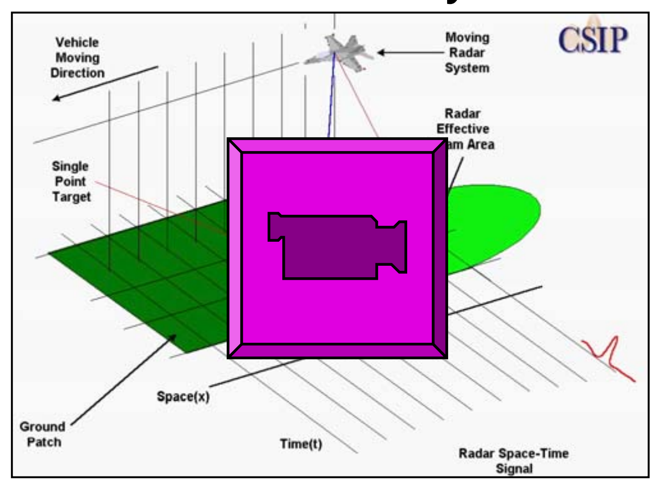
Passive Imaging mmW



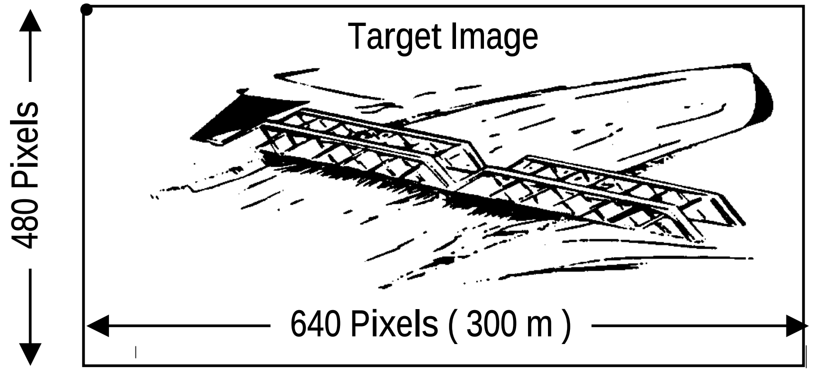
Video of Imaging Infrared

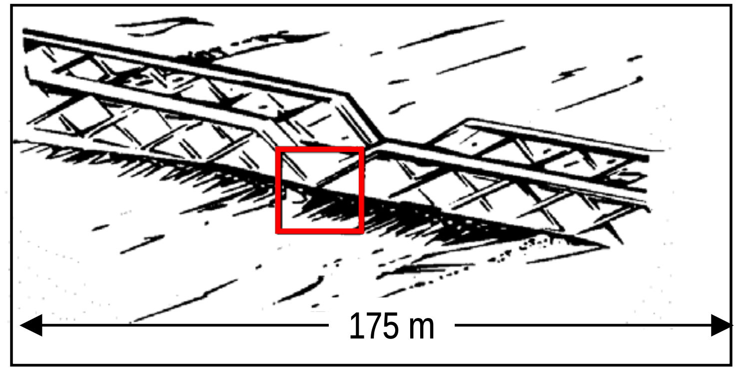


Video of SAR Physics



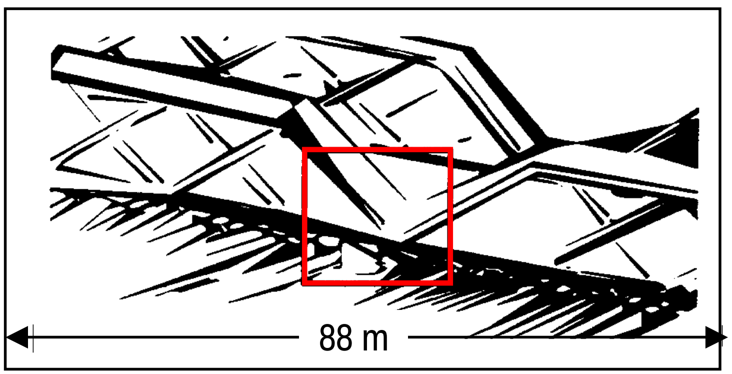
GPS / INS Allows Robust Seeker Lock-on in Adverse Weather and Clutter

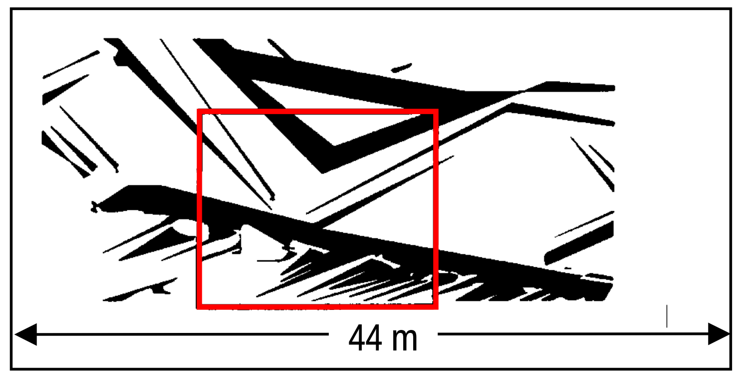




Seeker Lock-on @ 850 m to go (1 pixel = 0.47 m)
3 m GPS / INS error $\Rightarrow$ $n_{M_{req}}$ = 0.15 g, σ < 0.1 m

Seeker Lock-on @ 500 m to go (1 pixel = 0.27 m)
3 m GPS / INS error $\Rightarrow$ $n_{M_{req}}$ = 0.44 g, σ < 0.1 m



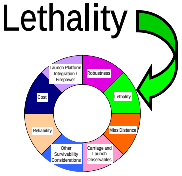


Seeker Lock-on @ 250 m to go (1 pixel = 0.14 m)
3 m GPS / INS error $\Rightarrow$ $n_{M_{req}}$ = 1.76 g, σ < 0.1 m

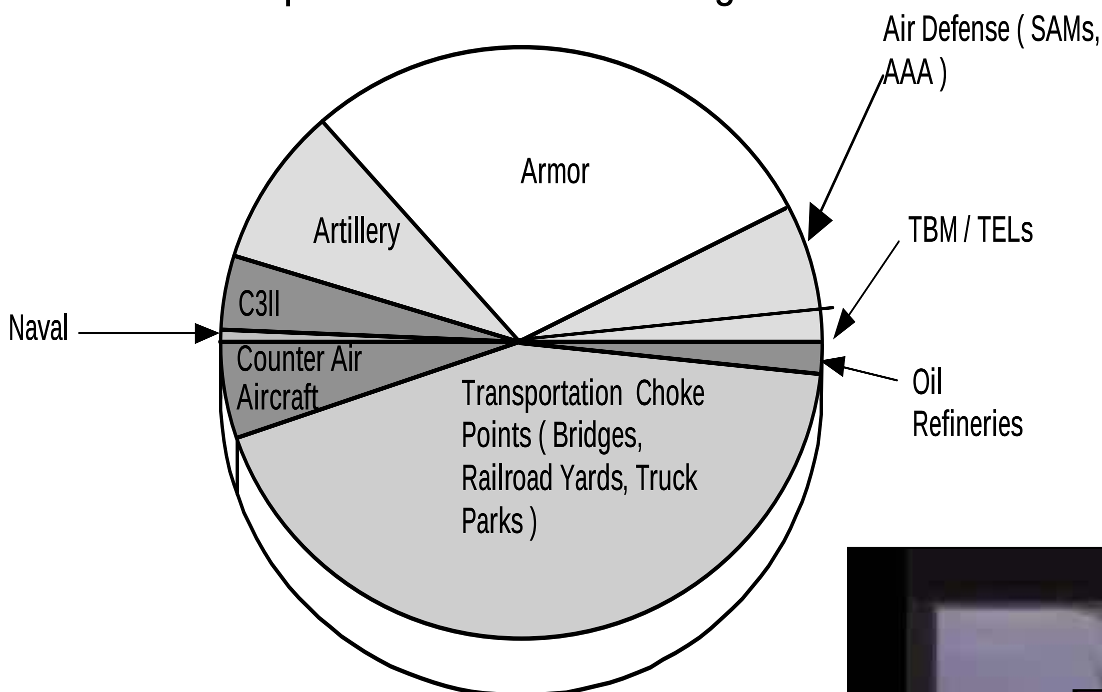
Seeker Lock-on @ 125 m to go (1 pixel = 0.07 m)
3 m GPS / INS error $\Rightarrow$ $n_{M_{req}}$ = 7.04 g, σ = 0.2 m

Note: $\square$ = Target Aim Point and Seeker Tracking Gate, GPS / INS Accuracy = 3 m, Seeker 640 x 480 Image, Seeker FOV = 20 deg, Proportional Guidance Navigation Ratio = 4, Velocity = 300 m / s, G&C Time Constant = 0.2 s.

A Target Set Varies in Size and Hardness



Example of Precision Strike Target Set

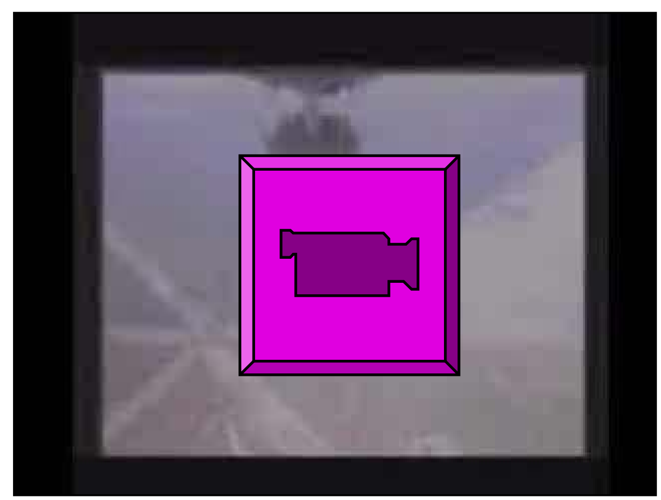


Examples of Targets where Size and Hardness Drive Warhead Design / Technology

•Small Size, Hard Target: Tank $\Rightarrow$ Small Shaped Charge, EFP, or KE Warhead

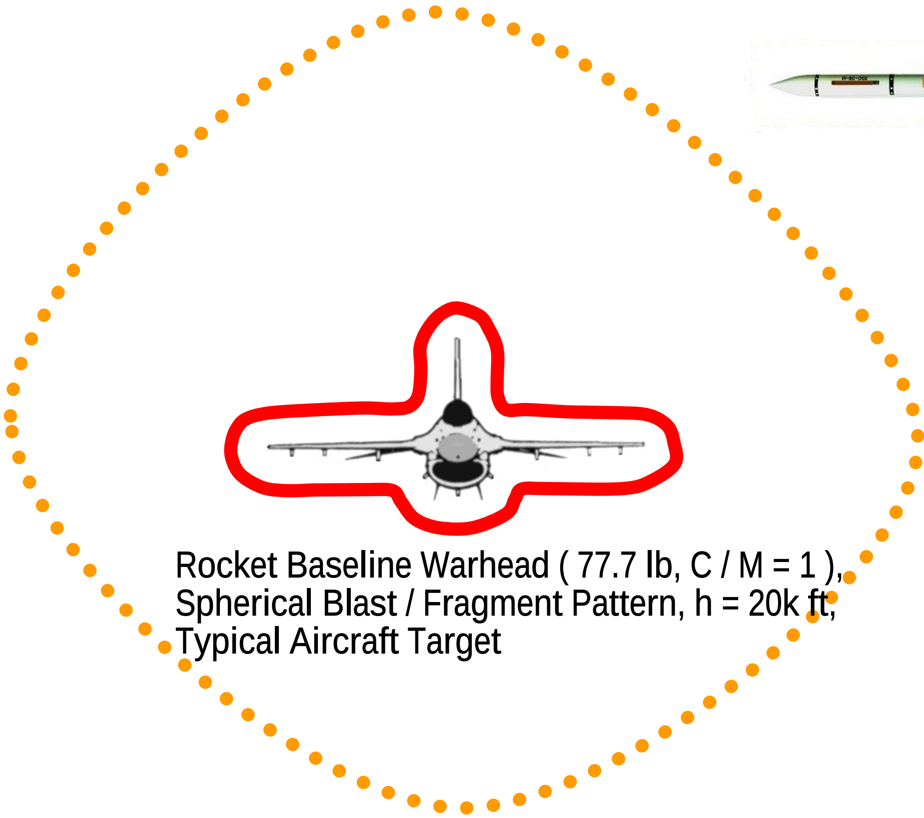
•Deeply Buried Hard Target: Bunker $\Rightarrow$ Long KE / Blast Frag Warhead

•Large Size Target: Building $\Rightarrow$ Large Blast Frag Warhead



Video Examples of Precision Strike Targets / Missiles

Accurate Guidance Enhances Lethality

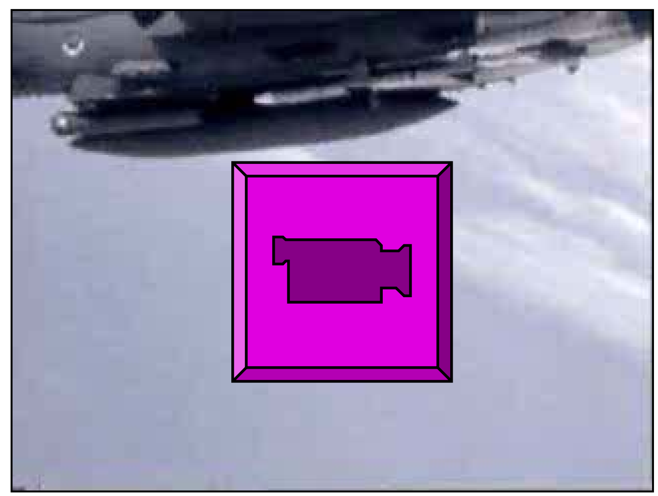


AIM-7 Sparrow 77.7 lb blast / frag warhead

Typical Aircraft Target Vulnerability

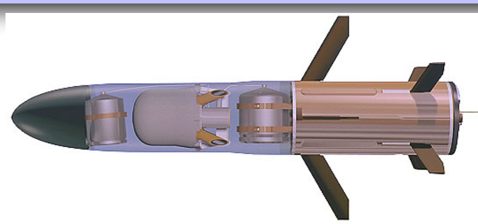
$P_K > 0.5$ if $\sigma < 5$ ft (Δ p > 330 psi, fragments impact energy > 130k ft-lb / ft^2)

$P_K > 0.1$ if $\sigma < 25$ ft (Δp > 24 psi, fragments impact energy > 5k ft-lb / ft^2)



Video of AIM-7 Sparrow Warhead (Aircraft Targets)

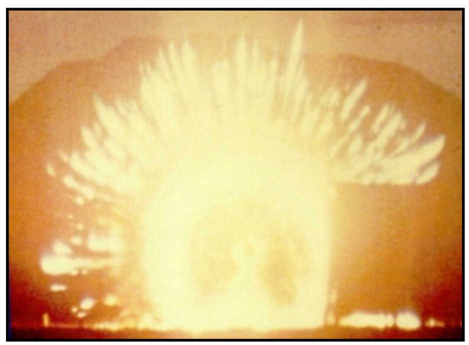
Accurate Guidance Enhances Lethality (cont)



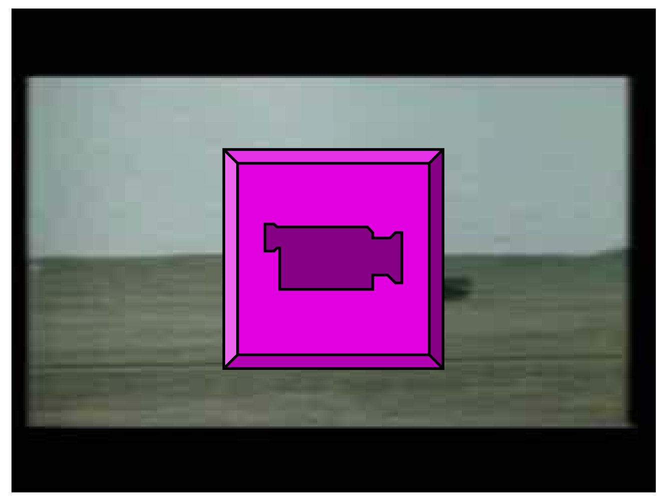
BILL- Two 1.5 kg EFP warheads ....

Roland 9 kg warhead: multi-projectiles from preformed case……………..

Hellfire 24 lb shaped charge
warhead …………………………..



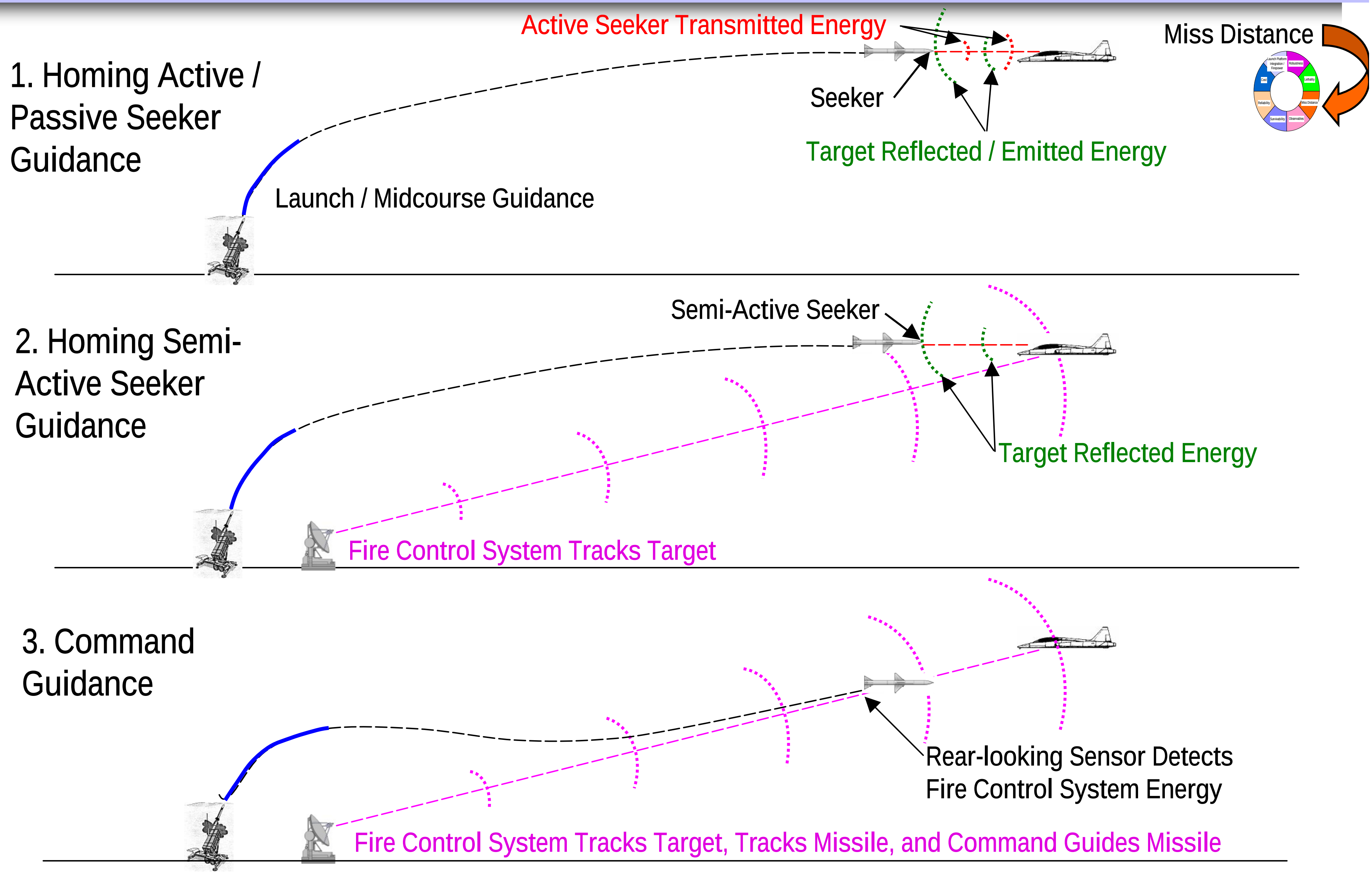
2.4 m
witness
plate



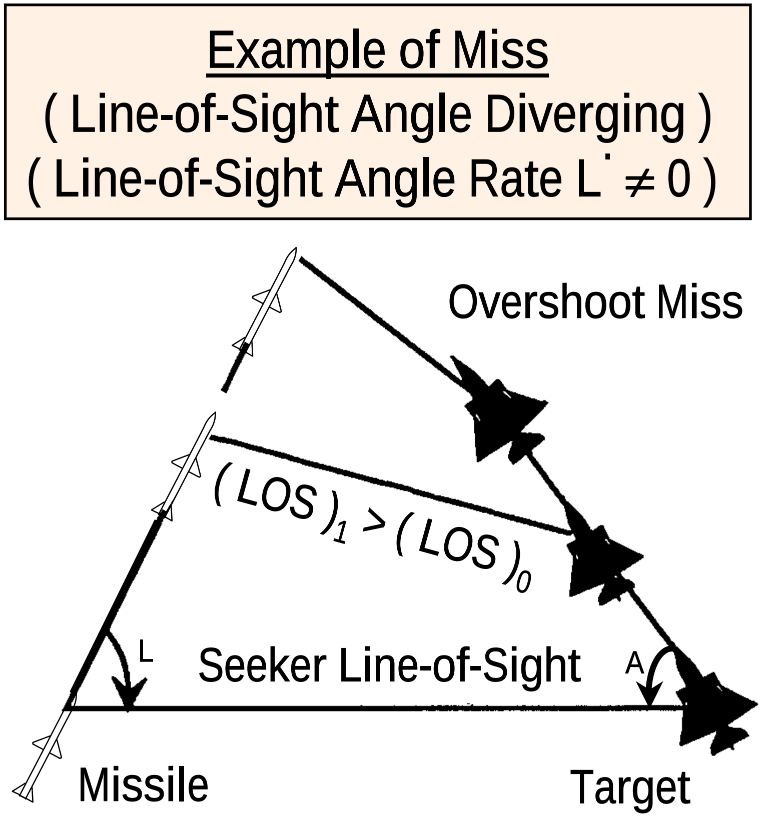
Video: BILL, Roland, Hellfire, and Guided MLRS warheads

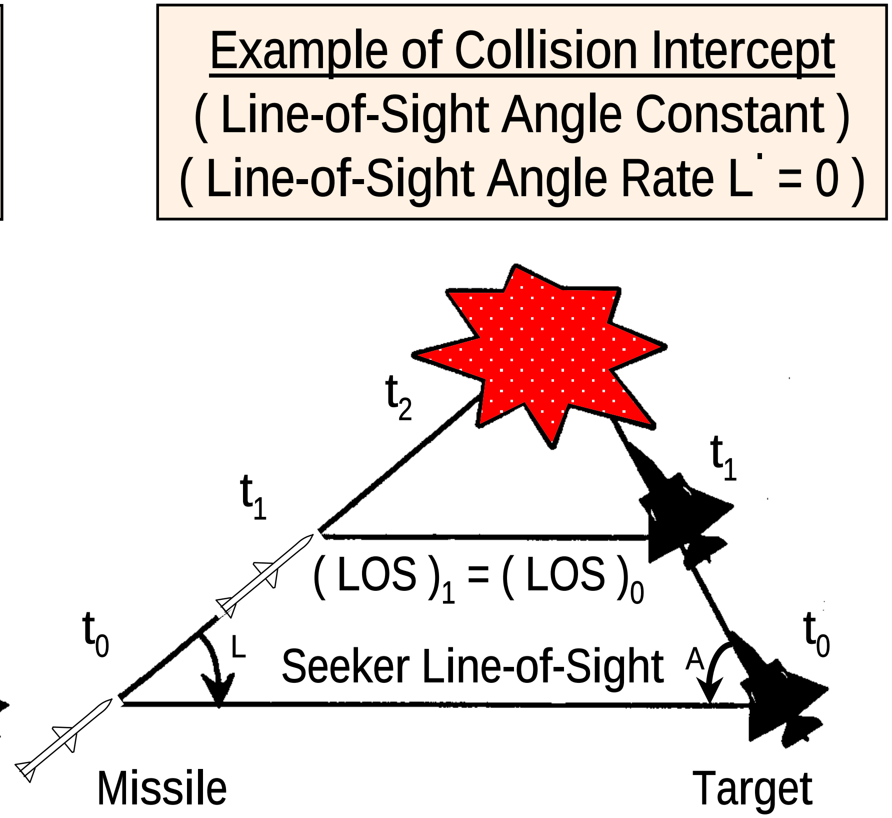
Guided MLRS 180 lb blast
fragmentation warhead

Examples of Terminal Guidance Laws



A Collision Intercept Has Constant Bearing for a Constant Velocity, Non-maneuvering Target





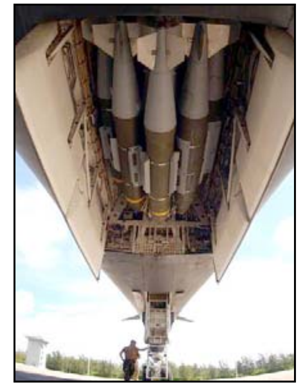
Note: L = Missile Lead
A = Target Aspect

Examples of Weapon Bay Internal Carriage and Load-out

Center Weapon Bay Best for Ejection Launchers

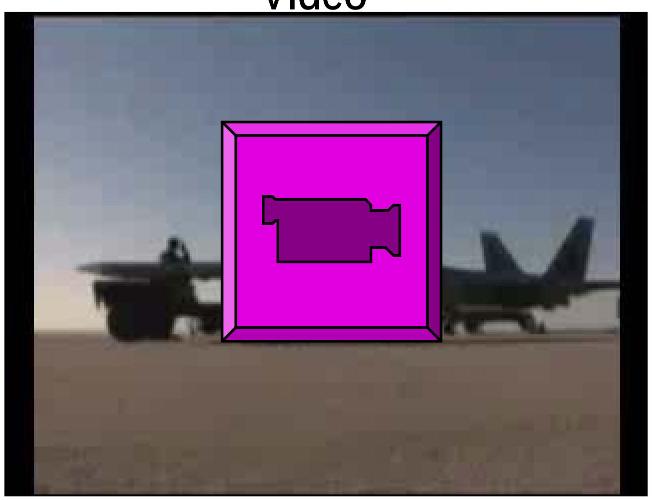
F-22 Semi-Bay Load-out: 2 SDB, 1 AIM-120C

F-117 Bay Load-out: 1 GBU-27, 1 GBU-10



B-1 Single Bay Load-out: 8 GBU-31

Video



F-22 Carriage (AMRAAM / JDAM / AIM-9)

Side Weapon Bay Best for Rail Launchers

F-22 Side Bay: 1 AIM-9 in Each Side Bay

RAH-66 Side Bay: 1 AGM-114, 2 FIM-92, 4 Hydra 70 in Each Side Bay

Minimum Smoke Propellant Has Low Launch Plume Observables

High Smoke Example: AIM-7

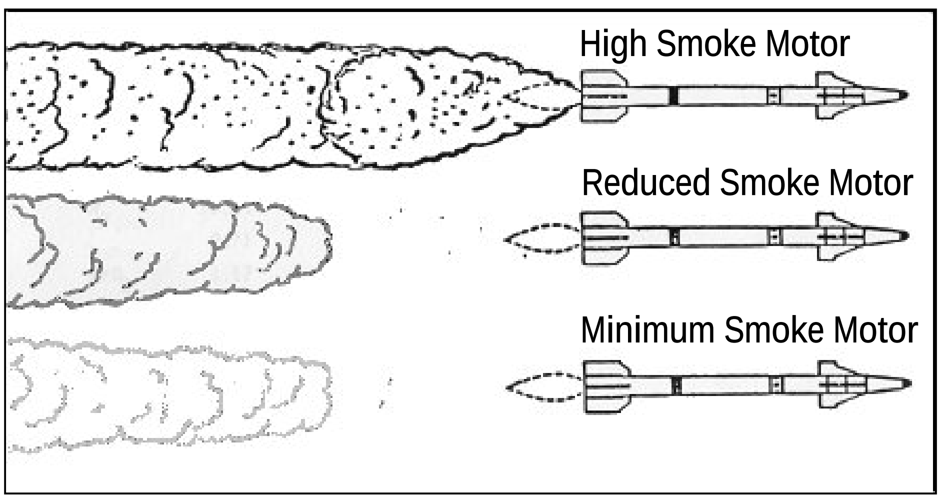
Particles (e.g., metal fuel oxide) at all atmosphere temperature.

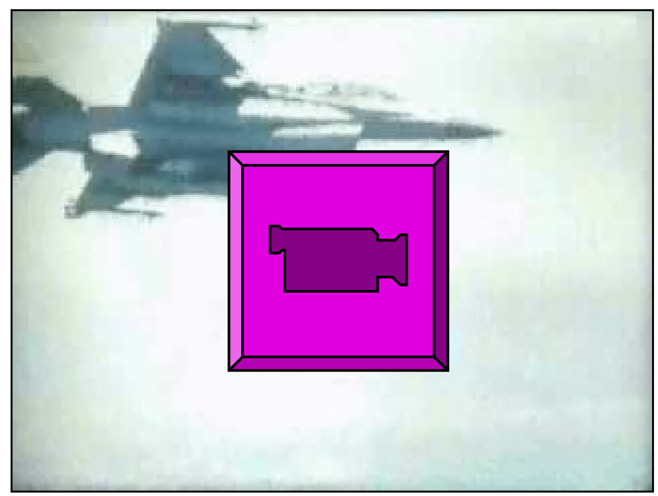
Reduced Smoke Example: AIM-120

Contrail (HCl from AP oxidizer) at T < -10° F atmospheric temperature.

Minimum Smoke Example: Javelin

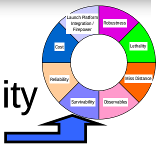
Contrail (H_2O) at T < -35º F atmospheric temperature.





Examples of Alternative Approaches for Precision Strike Missile Survivability

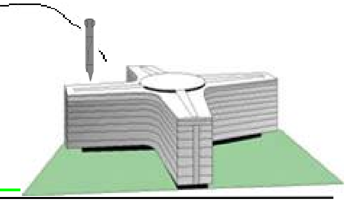
Other Survivability Considerations



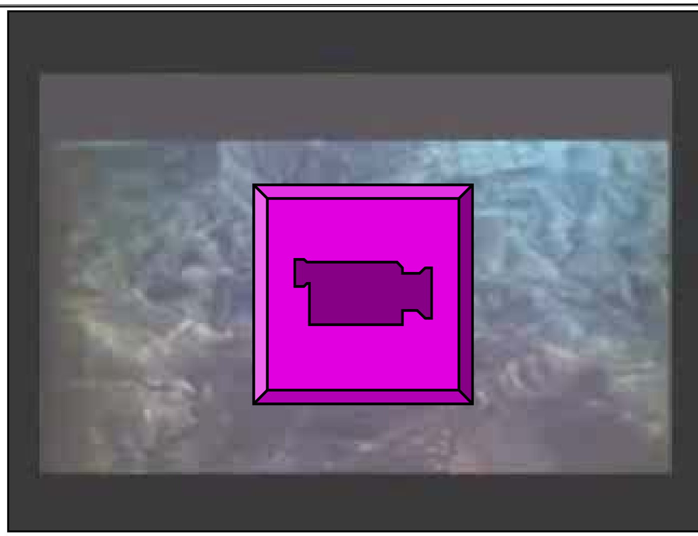
1. Low Observables, High Altitude Cruise, High Speed

2. Mission Planning / Threat Avoidance / Lateral Offset Flight

4. High g Terminal Maneuvering



3. Low Altitude Terrain Masking / Clutter



Video of Tomahawk Using Terrain Following

Examples of Survivability Configured Missiles

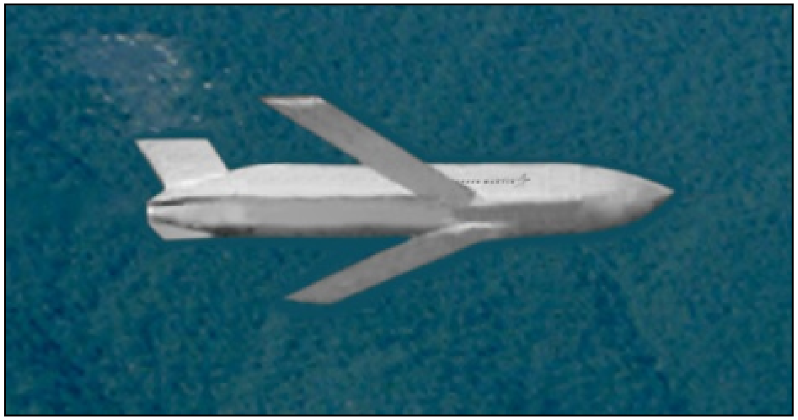
High Speed

SS-N-22 Sunburn (Ramjet Propulsion)

SS-N-27 Sizzler (Supersonic Rocket Penetrator after Subsonic Turbojet Flyout)

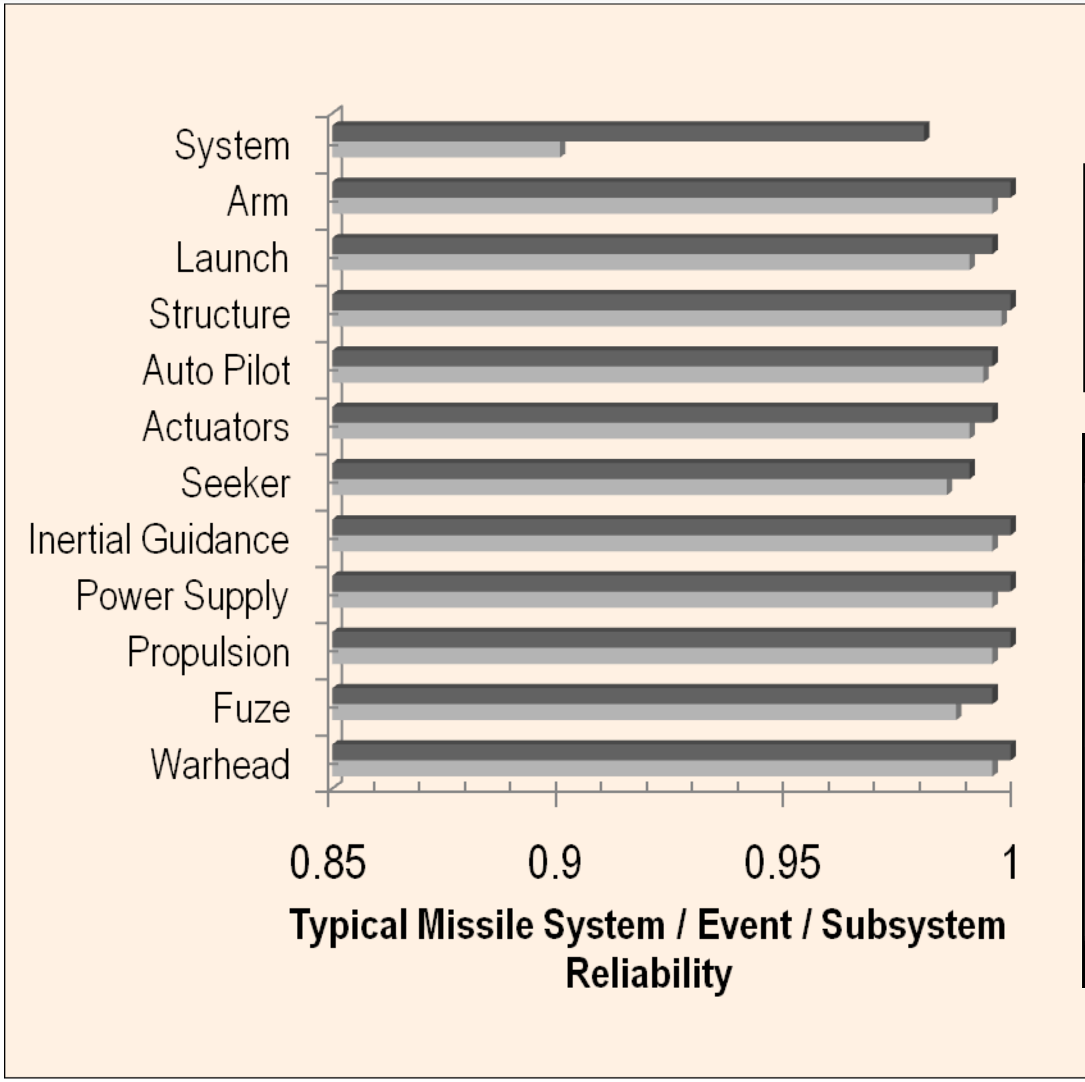
Low RCS

NSM (Faceted Dome, Roll Dome with Inlet Top or Bottom, Swept Surfaces, Body Chines, Composite Structure)

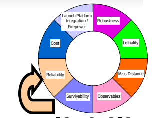


JASSM (Flush Inlet, Window Dome, Swept Surfaces, Trapezoidal Body, Composite Structure)

High System Reliability Provided by Few Events, High Subsystem Reliability and Low Parts Count

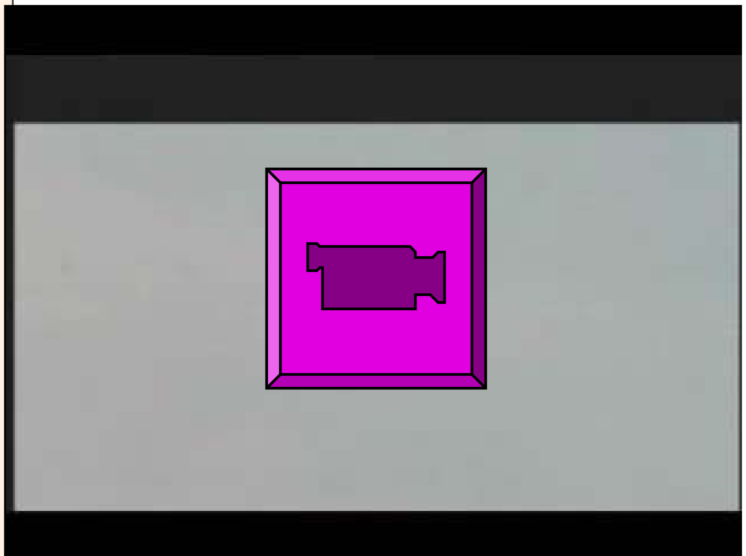


Note: Typical max reliability
Typical min reliability



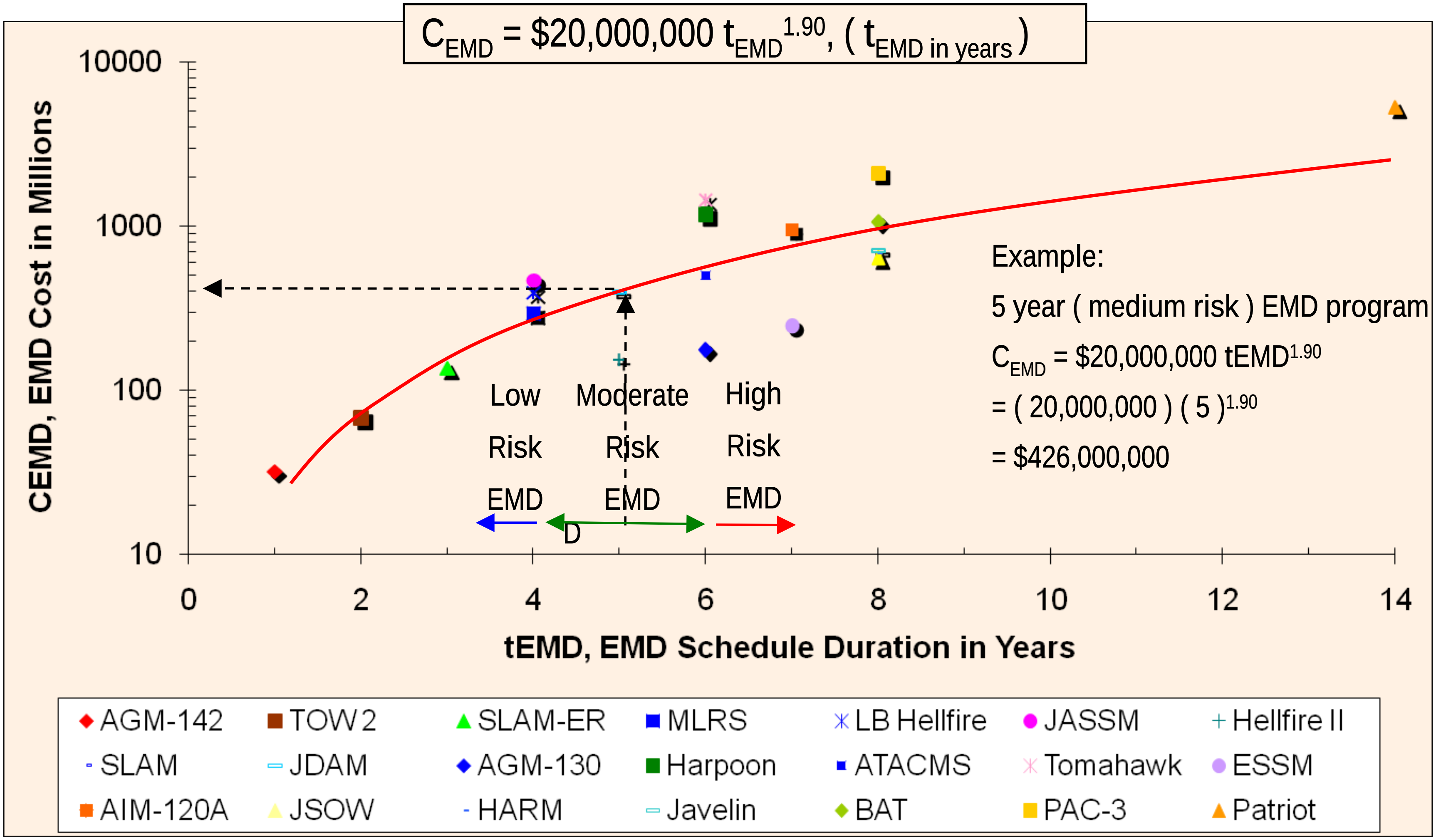
Reliability

$R_{system} \approx .R_{Subsystem1} \times R_{Subsystem2} \times \ldots$
Example: $R_{system} \approx R_{Arm} \times R_{Launch} \times R_{Struct} \times R_{Auto} \times R_{Act} \times R_{Seeker} \times R_{In\ Guid} \times R_{PS} \times R_{Prop} \times R_{Fuze} \times R_{W/H} \approx 0.94$



Example Video of Weapon System with Many Events: Sensor Fuzed Weapon (SFW)

EMD Cost Is Driven by Schedule Duration and Risk



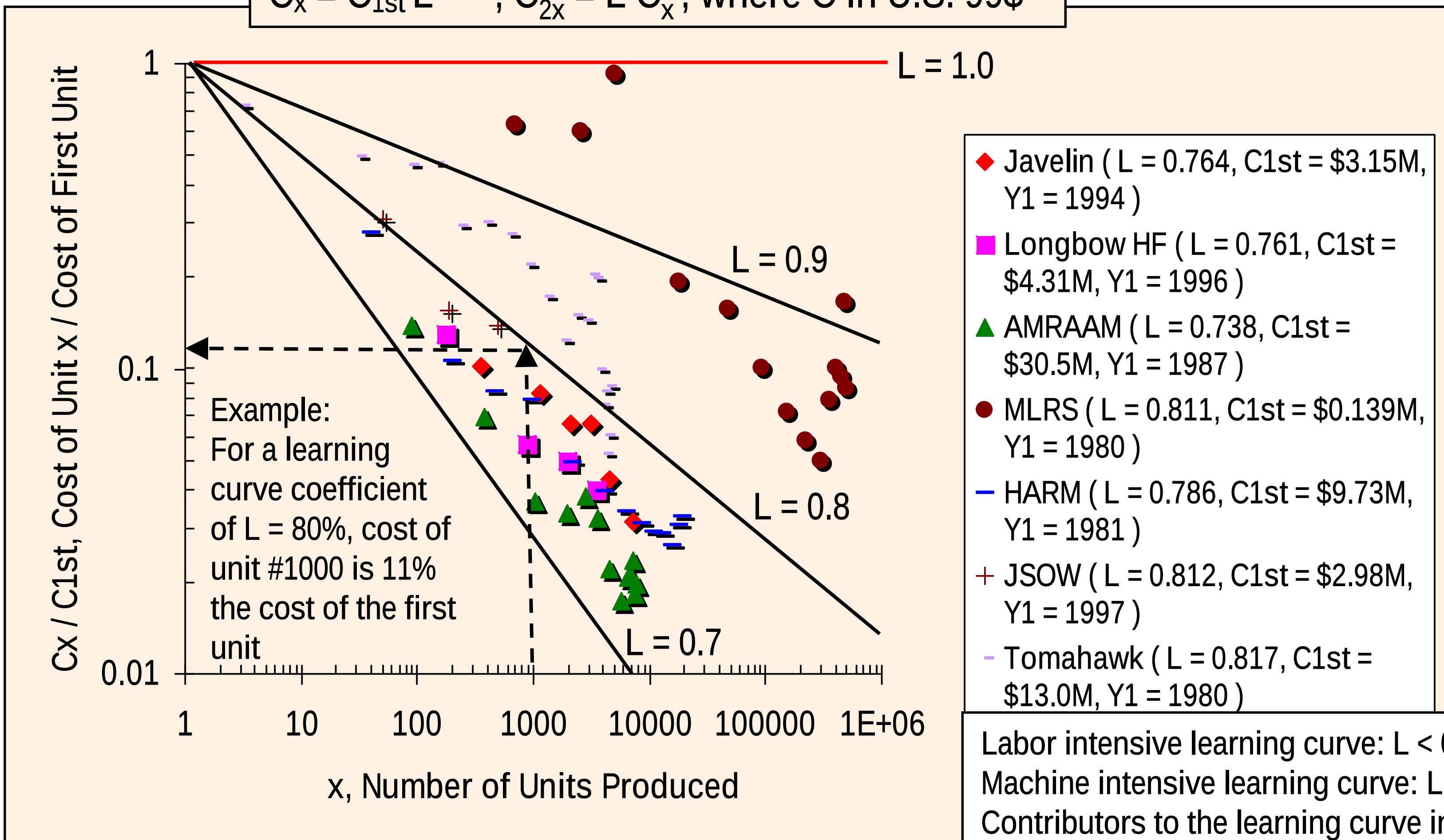
Note: EMD required schedule duration depends upon risk. Should not ignore risk in shorter schedule.

-- Source of data: Nicholas, T. and Rossi, R., "U.S. Missile Data Book, 1999," Data Search Associates, 1999

– EMD cost based on 1999 US$

Learning Curve and Large Production Reduce Unit Production Cost

$C_x = C_{1st} L^{\log_2 x}$, $C_{2x} = L\, C_x$, where C in U.S. 99$



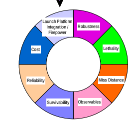
Labor intensive learning curve: L < 0.8
Machine intensive learning curve: L > 0.8)
Contributors to the learning curve include:

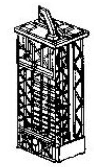
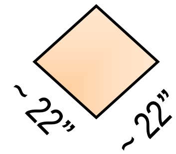
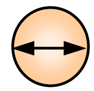
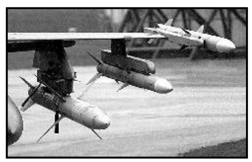
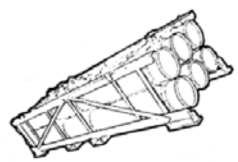
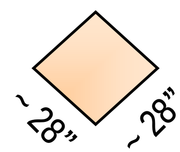
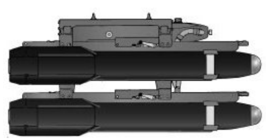
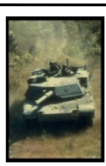
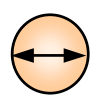
- More efficient labor
- Reduced scrap
- Improved processes
- New missile components fraction

Source of data: Nicholas, T. and Rossi, R., "U.S. Missile Data Book, 1999," Data Search Associates, 1999

Missile Carriage Size, Shape, and Weight Limits May Be Driven by Launch Platform Compatibility

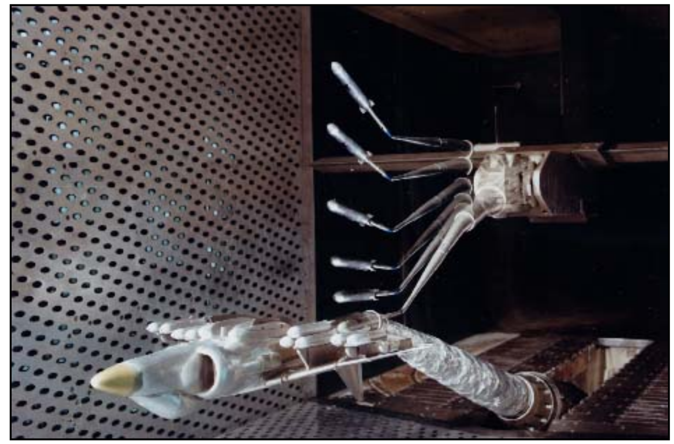
Launch Platform Integration / Firepower



US Launch Platform	Launcher	Carriage Span / Shape	Length	Weight
 Surface Ships	 VLS		263”	3400 lb
 Submarines	 CLS	 22 “	263”	3400 lb
 Fighters / Bombers / Large UCAVs	 Rail / Ejection	~24” x ~24”	~168”	~500 lb to ~3000 lb
 Ground Vehicles	 Launch Pods		158”	3700 lb
 Helos / Small UCAVs	 Helo Rail, UCAV Rail / Ejection	~13” x ~13”	~ 70”	~ 120 lb
 Tanks	 Gun Barrel	 120 mm	~ 40”	~ 60 lb

Store Compatibility Wind Tunnel Tests Are Required for Aircraft Launch Platforms

F-18 Store Compatibility Test in AEDC 16T



AV-8 Store Compatibility Test in AEDC 4T

Types of Wind Tunnel Testing for Store Compatibility

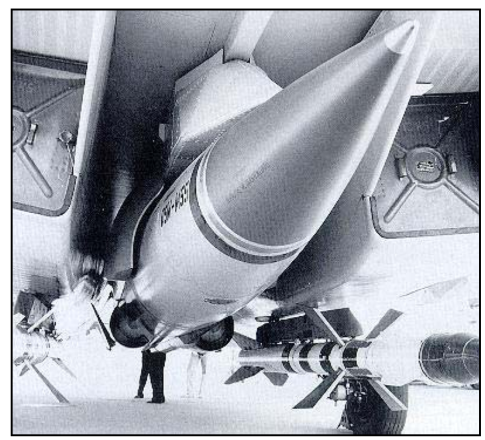
- Flow field mapping with probe

- Flow field mapping with store

- Captive trajectory simulation

- Drop testing

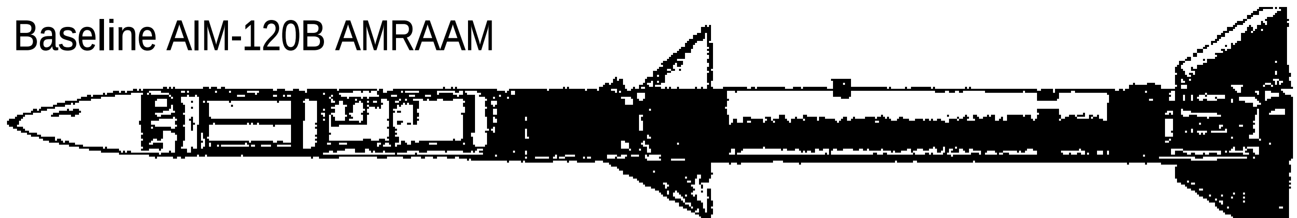
- Carriage Loads



Example Stores with Flow Field Interaction: Kh-41 + AA-10

Compressed Carriage Missiles Provide Higher Firepower

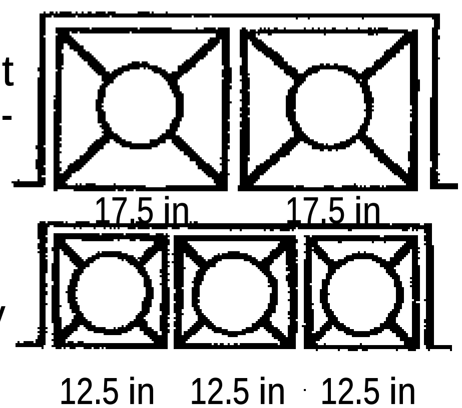
Baseline AIM-120B AMRAAM

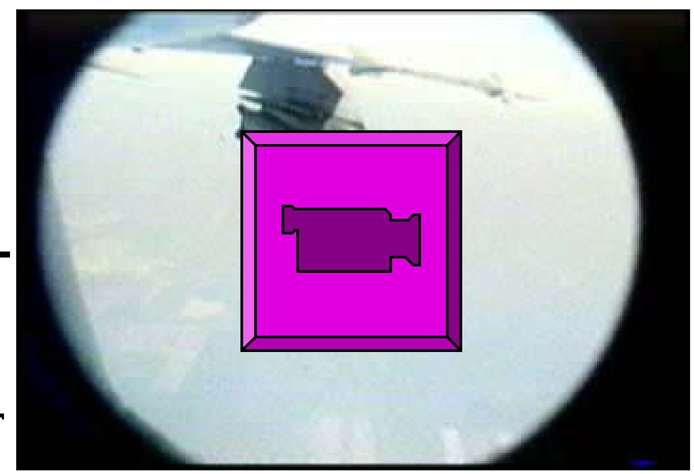


Compressed Carriage AIM-120C AMRAAM (Reduced Span Wing / Tail)

Baseline AMRAAM: Load-out of 2 AIM-120B per F-22 Semi-Bay

Compressed Carriage AMRAAM: Load-out of 3 AIM-120C per F-22 Semi-Bay





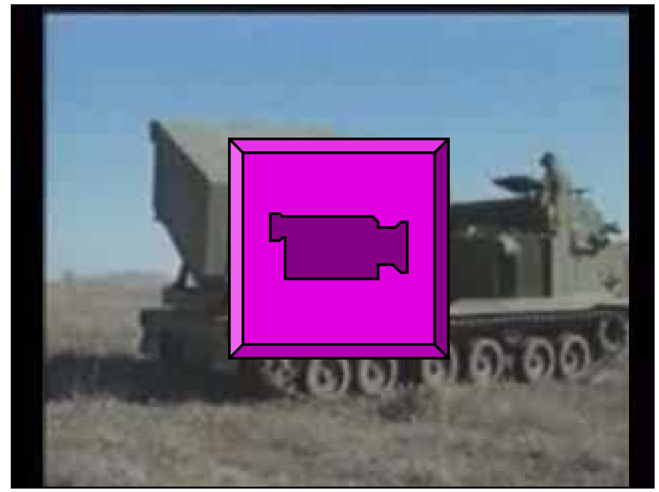
Video of Longshot Kit on CBU-87 / CEB

Note: Alternative approaches to compressed carriage include surfaces with small span, folded surfaces, wrap around surfaces, and planar surfaces that extend (e.g., switch blade, Diamond Back, Longshot).

Robustness Is Required for Storage, Shipping, and Launch Platform Carriage Environment

Environmental Parameter	Typical Requirement
♦Surface Temperature	-60° F* to 160° F
♦Surface Humidity	5% to 100%
♦Rain Rate	120 mm / h**
♦Surface Wind	100 km / h steady***
	150 km / h gusts****
♦Salt fog	3 g / mm^2 deposited per year
♦Vibration	10 g rms at 1,000 Hz: MIL STD 810, 648, 1670A
♦Shock	Drop height 0.5 m, half sine wave 100 g / 10 ms: MIL STD 810, 1670A
♦Acoustic	160 dB

Video: Ground / Sea Environment



Note: MIL-HDBK-310 and earlier MIL-STD-210B suggest 1% world-wide climatic extreme typical requirement.

* Lowest recorded temperature = -90° F. 20% probability temperature lower than -60° F during worst month / location.

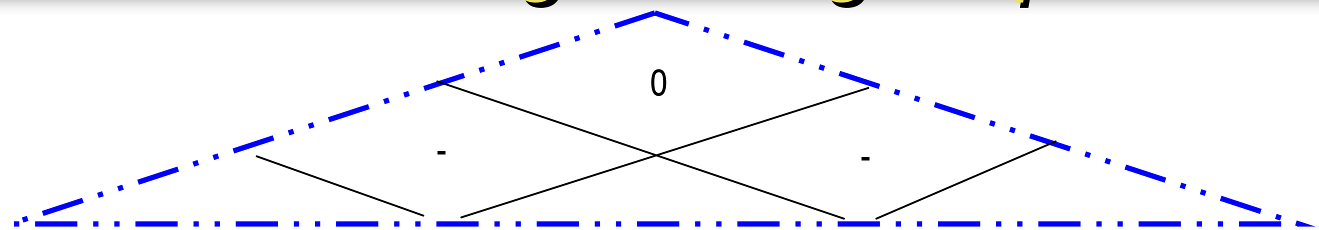
** Highest recorded rain rate = 436 mm / h. 0.5% probability greater than 120 mm / h during worst month / location.

*** Highest recorded steady wind = 342 km / h. 1% probability greater than 100 km / h during worst month / location.

**** Highest recorded gust = 378 km / h. 1% probability greater than 150 km / h during worst month of worst location.

Typical external air carriage maximum hours less for aircraft (~ 100 h) than for helicopter (~ 1000 h)

House of Quality Translates Customer Requirements into Engineering Emphasis



		Body (Material, Chamber Length)	Tail (Material, Number, Area, Geometry)	Nose Plug (Material, Length)
Flight Range	5	7	2	1
Weight	2	4	1	5
Cost	3	1	2	7
		46 = 5 x 7 + 2 x 4 + 3 x 1	18 = 5 x 2 + 2 x 1 + 3 x 2	36 = 5 x 1 + 2 x 5 + 3 x 7
		1	3	2

Note: Based on House of Quality, inside chamber length most important design parameter.

Note on Design Characteristics Sensitivity Matrix: (Room 5):

++ Strong Synergy

+ Synergy

0 Near Neutral Synergy

- Anti-Synergy

- - Strong Anti-Synergy

1 - Customer Requirements

2 – Customer Importance Rating (Total = 10)

3 – Design Characteristics

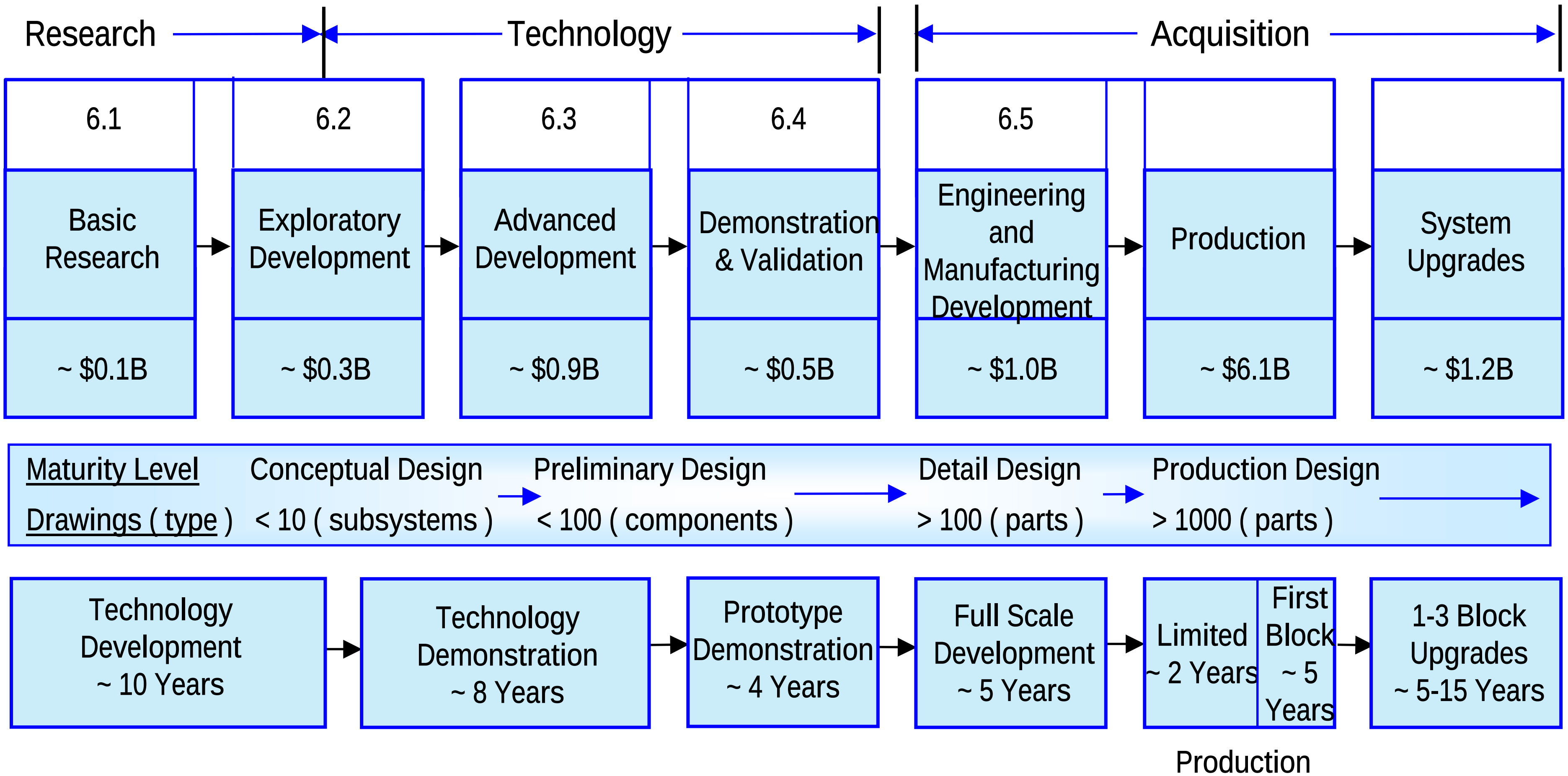
4 – Design Characteristics Importance Rating (Total = 10)

5 – Design Characteristics Sensitivity Matrix

6 – Design Characteristics Weighted Importance

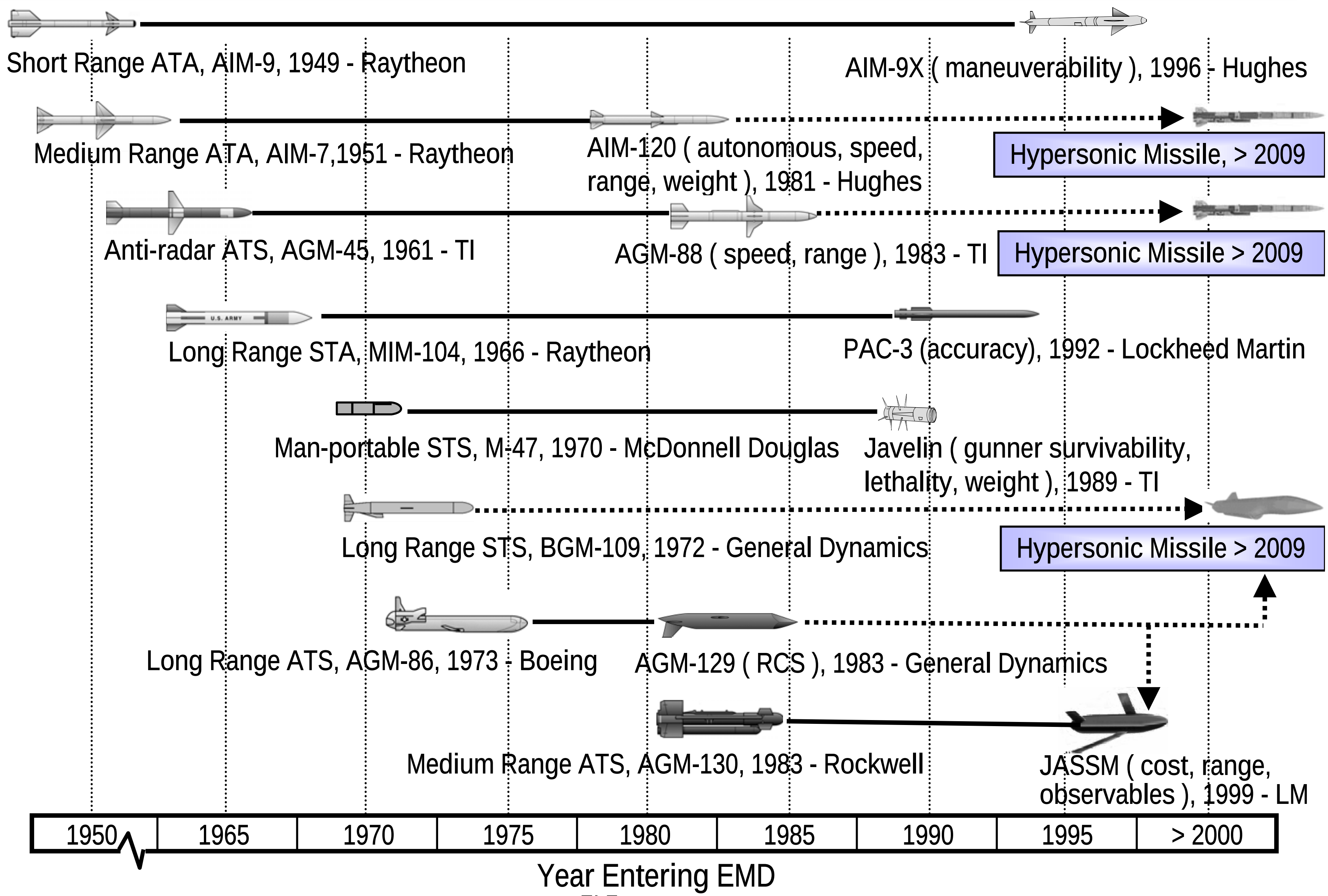
7 – Design Characteristics Relative Importance

Relationship of Design Maturity to the US Research, Technology, and Acquisition Process

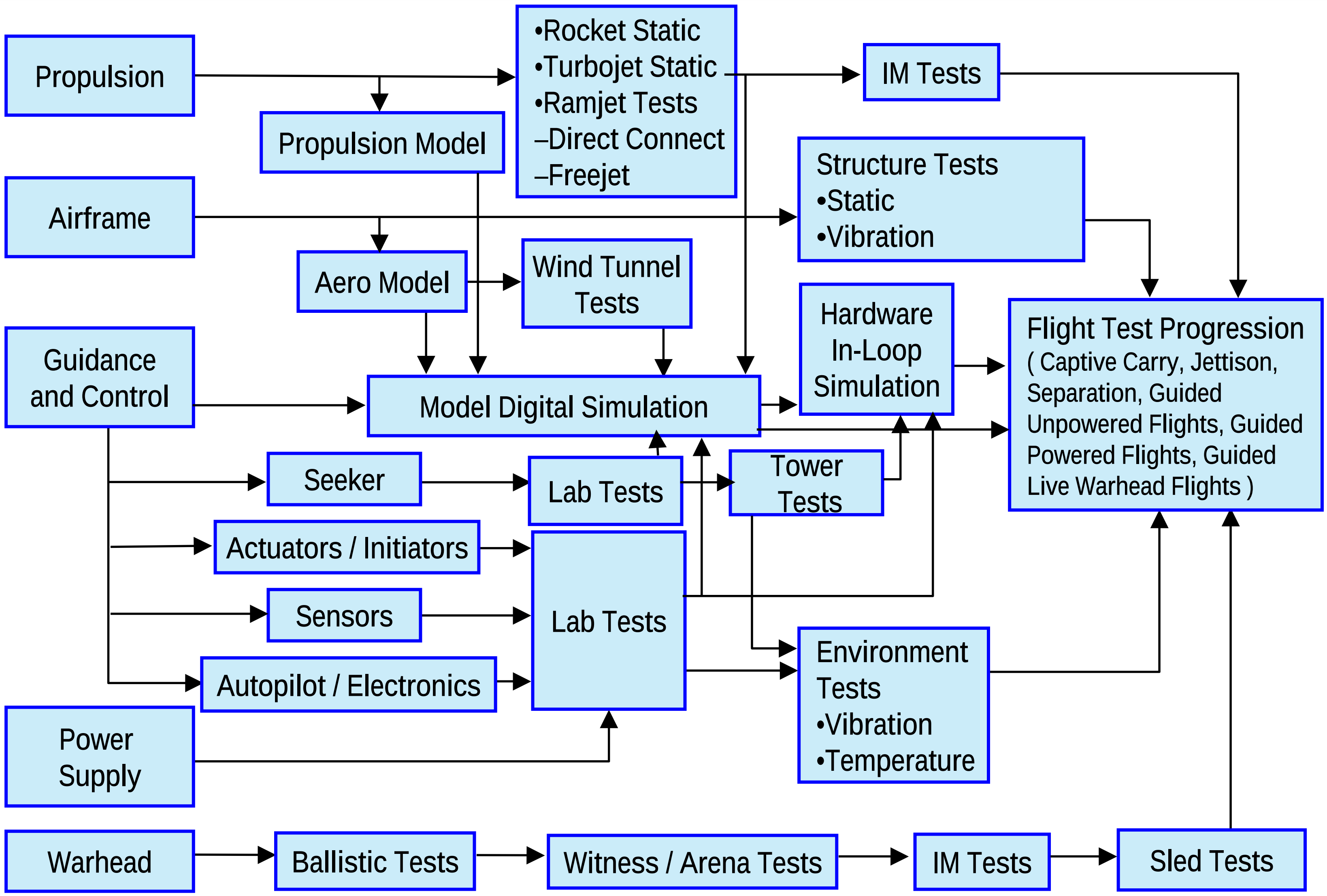


Note:
Total US DoD Research and Technology for Tactical Missiles ≈ $1.8 Billion per year
Total US DoD Acquisition (EMD + Production + Upgrades) for Tactical Missiles ≈ $8.3 Billion per year
Tactical Missiles ≈ 11% of U.S. DoD RT&A budget
US Industry IR&D typically similar to US DoD 6.2 and 6.3A

US Tactical Missile Follow-On Programs Occur about Every 24 Years



Missile Design Validation / Technology Development Is an Integrated Process



Conduct Balanced, Unbiased Trade-offs