유무인 항공기의 추진시스템 저피탐 설계 연구 동향

Research Trends in Low-Observable Design of Propulsion Systems for Manned and Unmanned Aircraft

2023년 8월 7일 (15:00~17:00)
한화에어로스페이스 판교캠퍼스 영상회의실

명노신 교수

School of Mechanical and Aerospace Engineering
Gyeongsang National University
경상국립대학교
South Korea
http://acml.gnu.ac.kr; myong@gnu.ac.kr

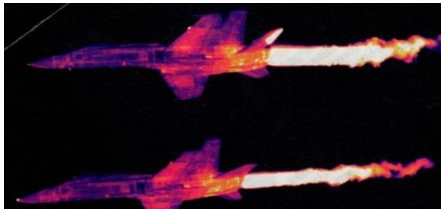
Definition of stealth

- **Definition of stealth**

The act of moving, proceeding, or acting in a ***covert*** way

The ability to ***blend*** in with the background

Reducing the aircraft signatures and observables, thus providing the aircraft with the capability of evading the enemy's air defence



- **Aircraft signatures**

  Active

  radar : airframe, engine inlet, weapons, radome, canopy

  Passive

  infrared : engine casing, airframe, exhaust plume, sun glint

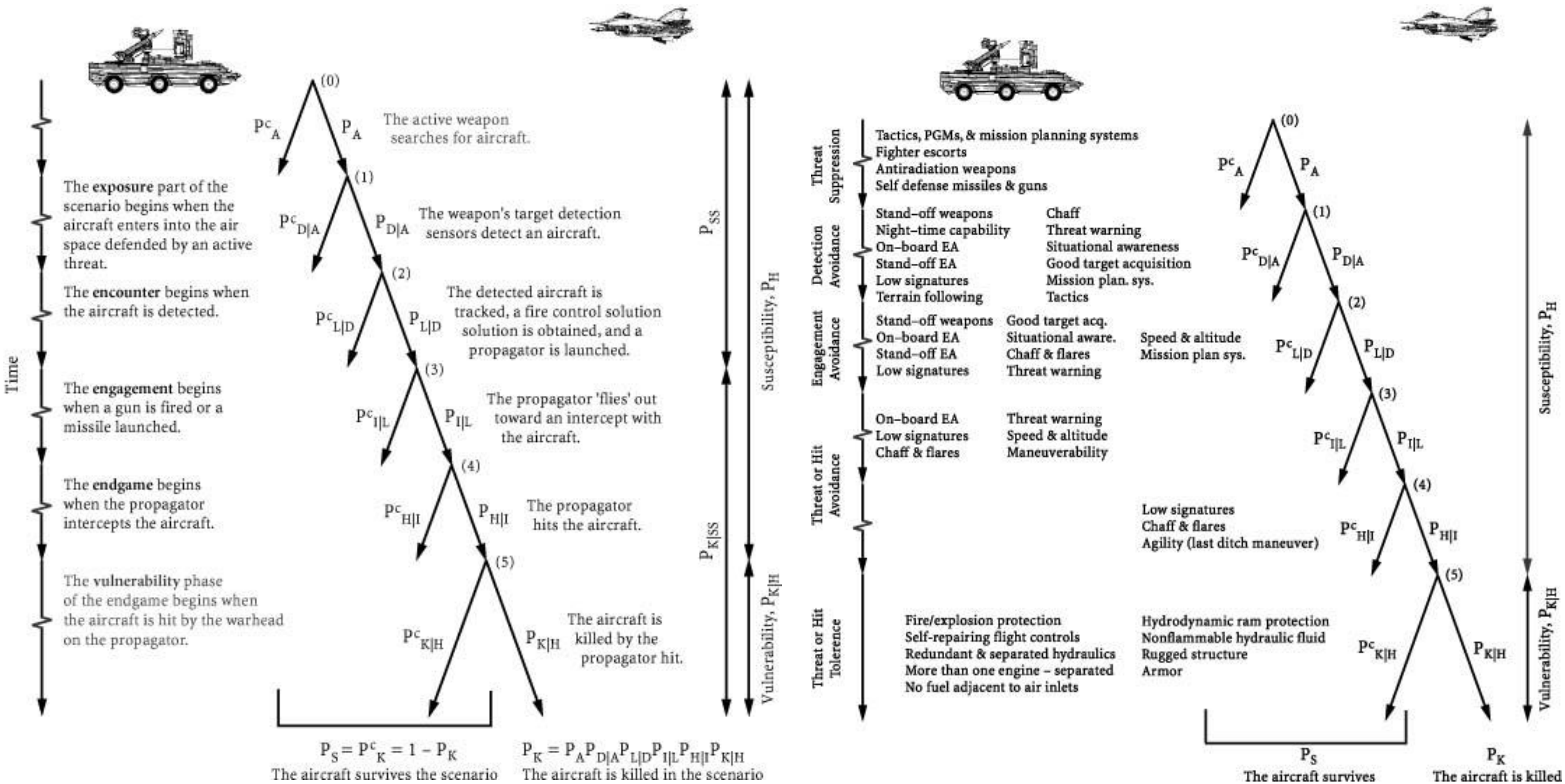
  acoustic : engine parts, engine exhaust, airframe

  visual : airframe, engine exhaust and glow, canopy glint

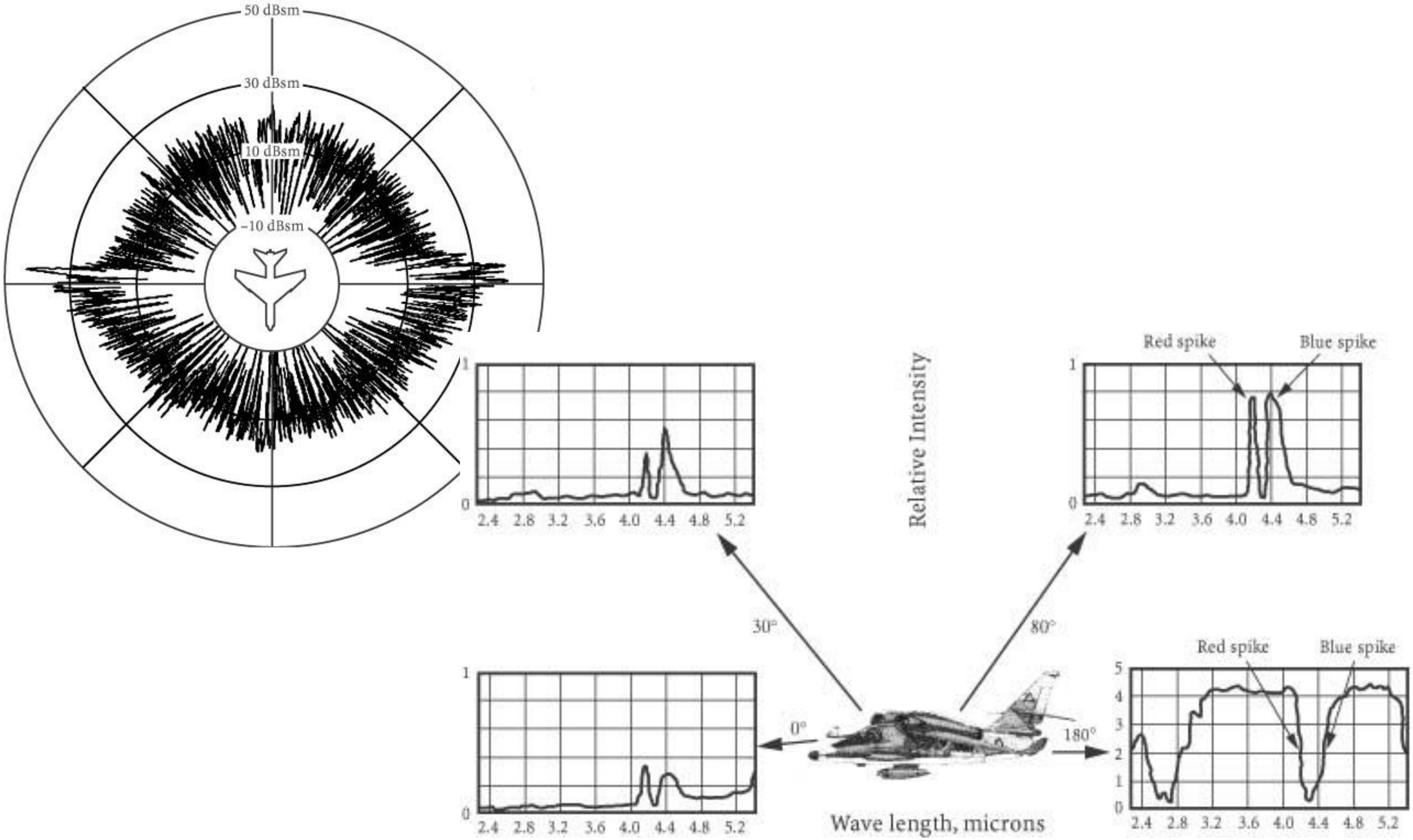
  misc. : navigation radar, communication, countermeasures

List of research projects (GNU-ACML)

Aircraft survivability (susceptibility and vulnerability)



RF & IR Signatures



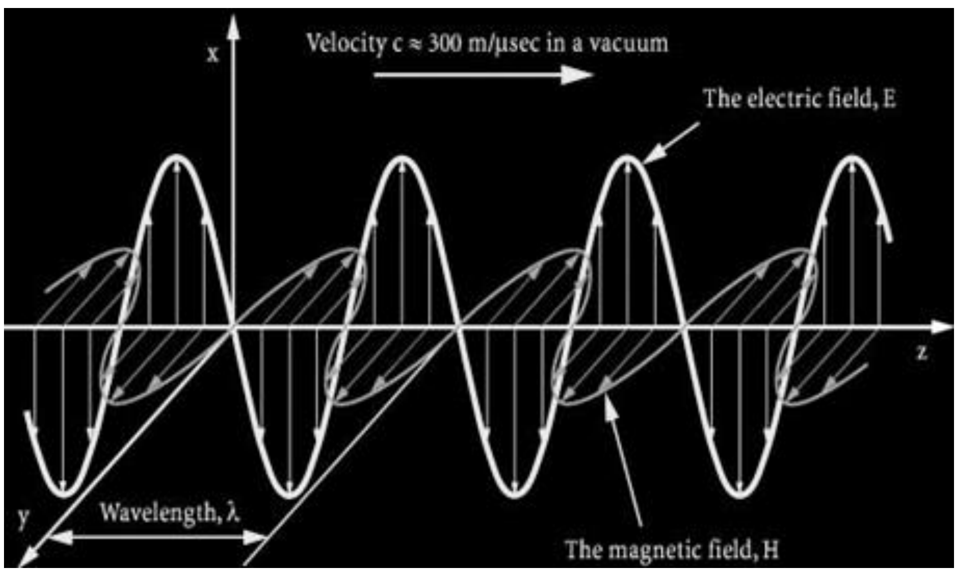
Correction: blue and red, not red and blue

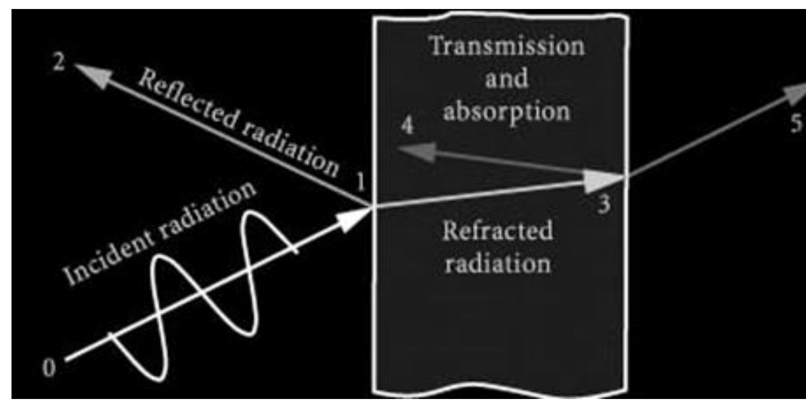
Radar fundamentals

Electromagnetic radiation

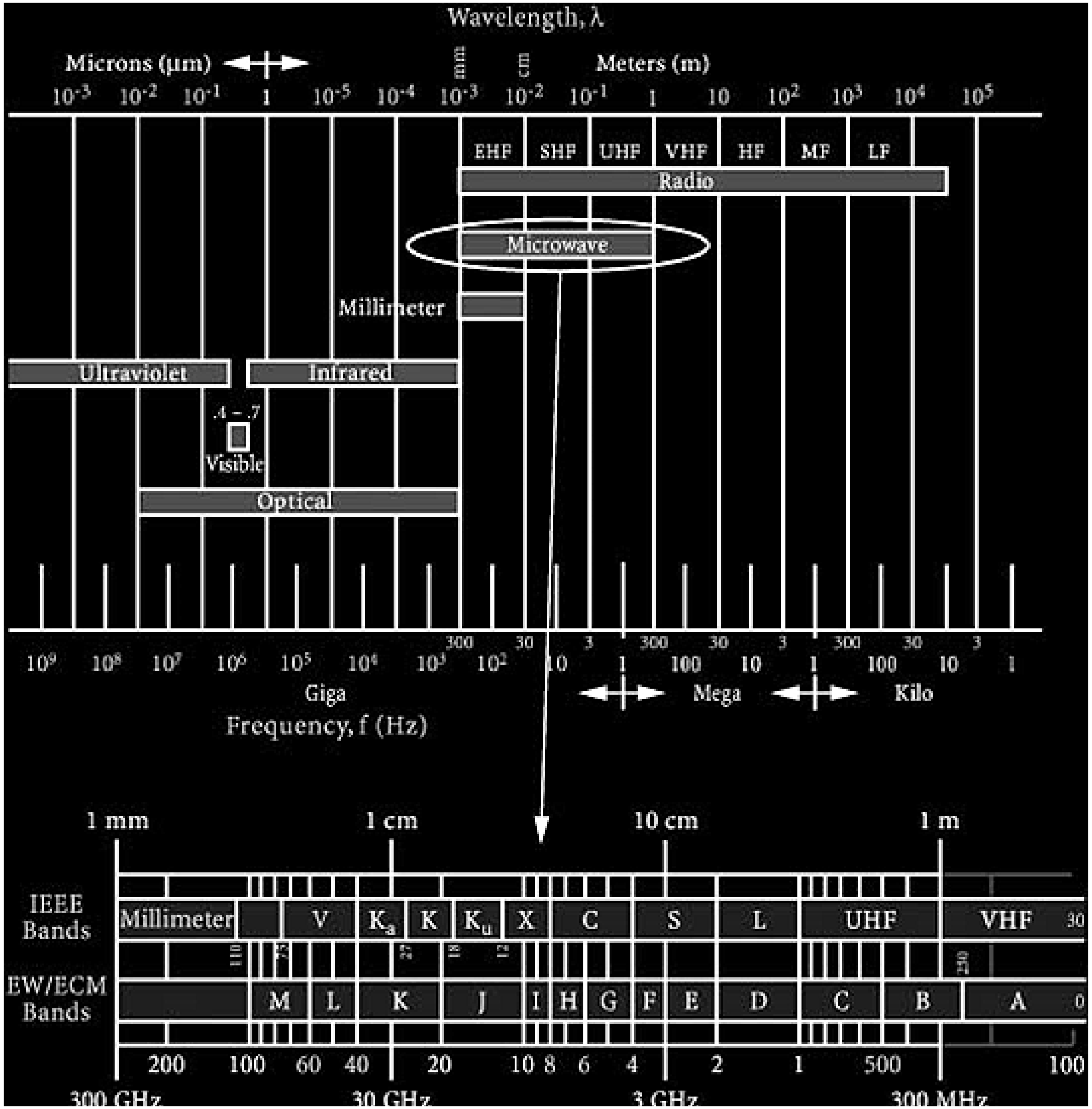
Radar, infrared, and visual detection, tracking, and guidance systems are designed to sense electromagnetic (EM) radiation that is either reflected or emitted by an aircraft.

Electromagnetic radiation is emitted by accelerating or decelerating charged particles, such as harmonically oscillating electrons.





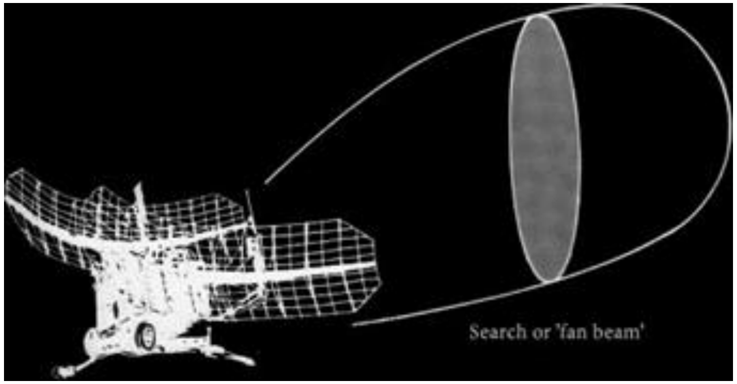
Radar fundamentals

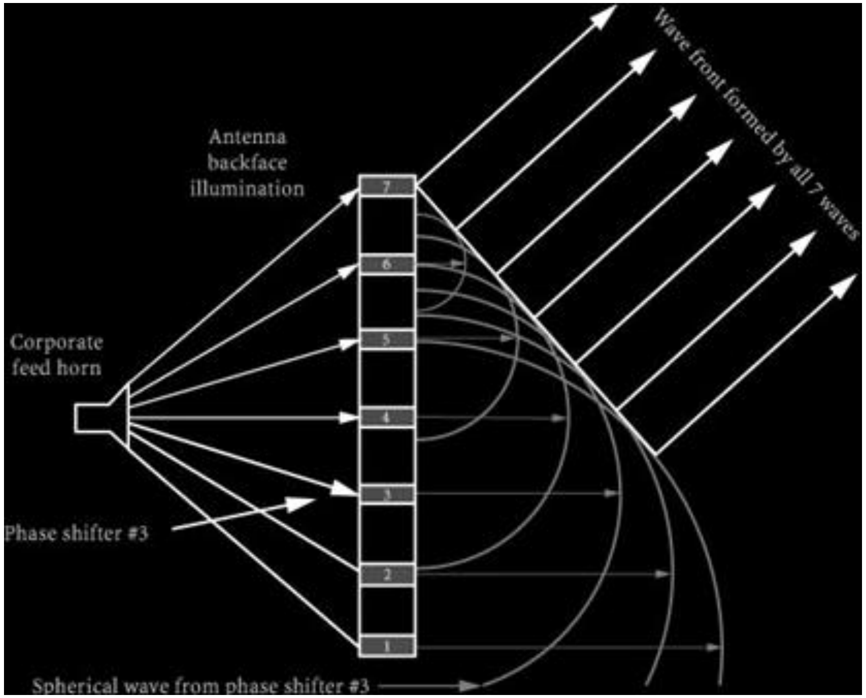


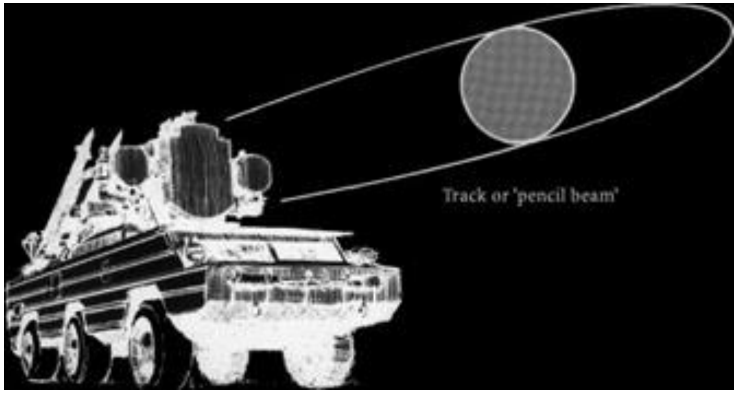
Radar fundamentals

Radar types

Surveillance radar antennas (VHF, UHF, L and S bands; 1–10 deg. Beamwidth)
Weapon control radars (S, C, X,K u , K bands; less than 1 to 2 deg. Beamwidth)
Phased-array antennas (AESA; active electronically scanned array)







Bi-static radar

Mono-static radar

Radar horizon

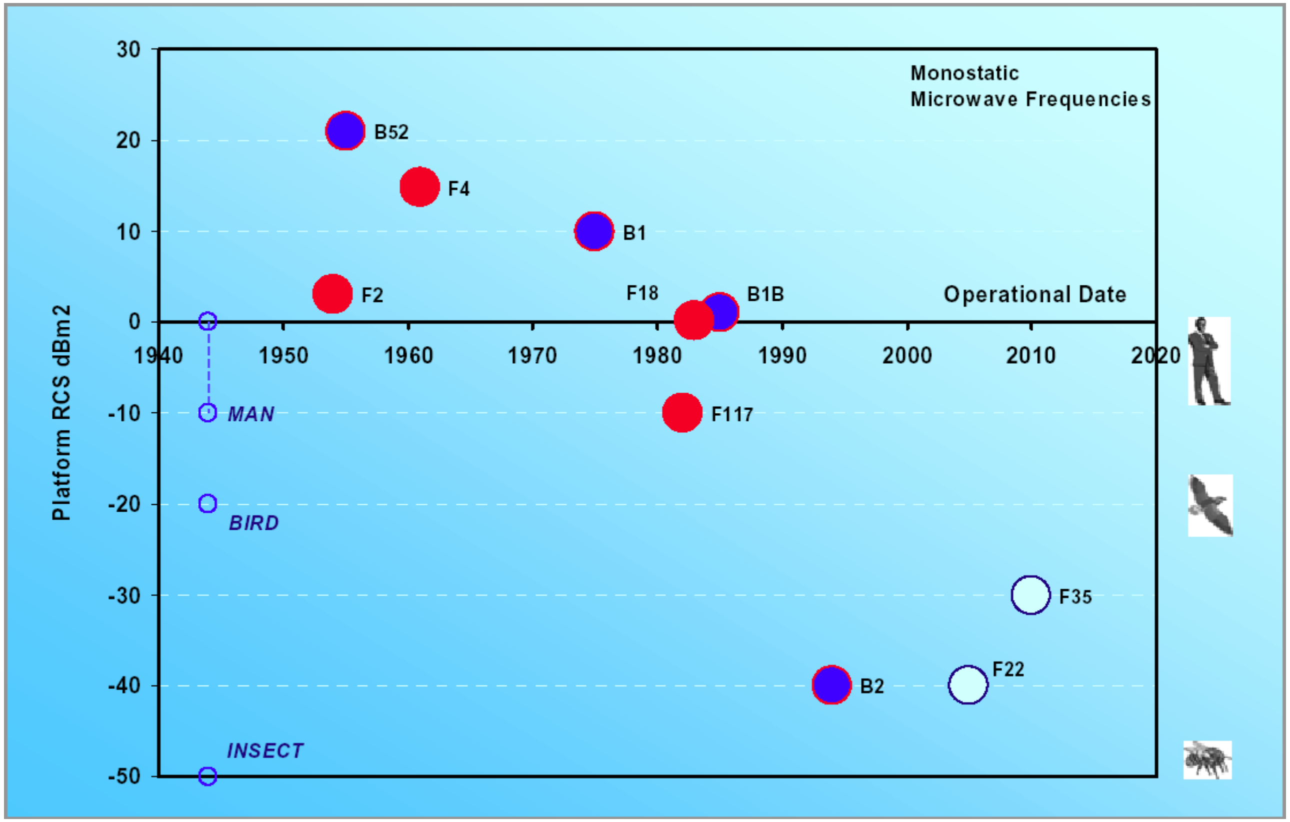
Radar fundamentals

- **Definition of radar cross section (RCS)**

  σ=Power reflected to receiver per unit solid angle * 4 π /Incident power density

  σ in dBsm = 10 $\log_{10}$ (σ,m^2)

$$\sigma = \lim_{R\to\infty} 4\pi R^2 \frac{\left|E_{scattering}\right|^2}{\left|E_{incident}\right|^2} \quad (\text{dBsm})$$



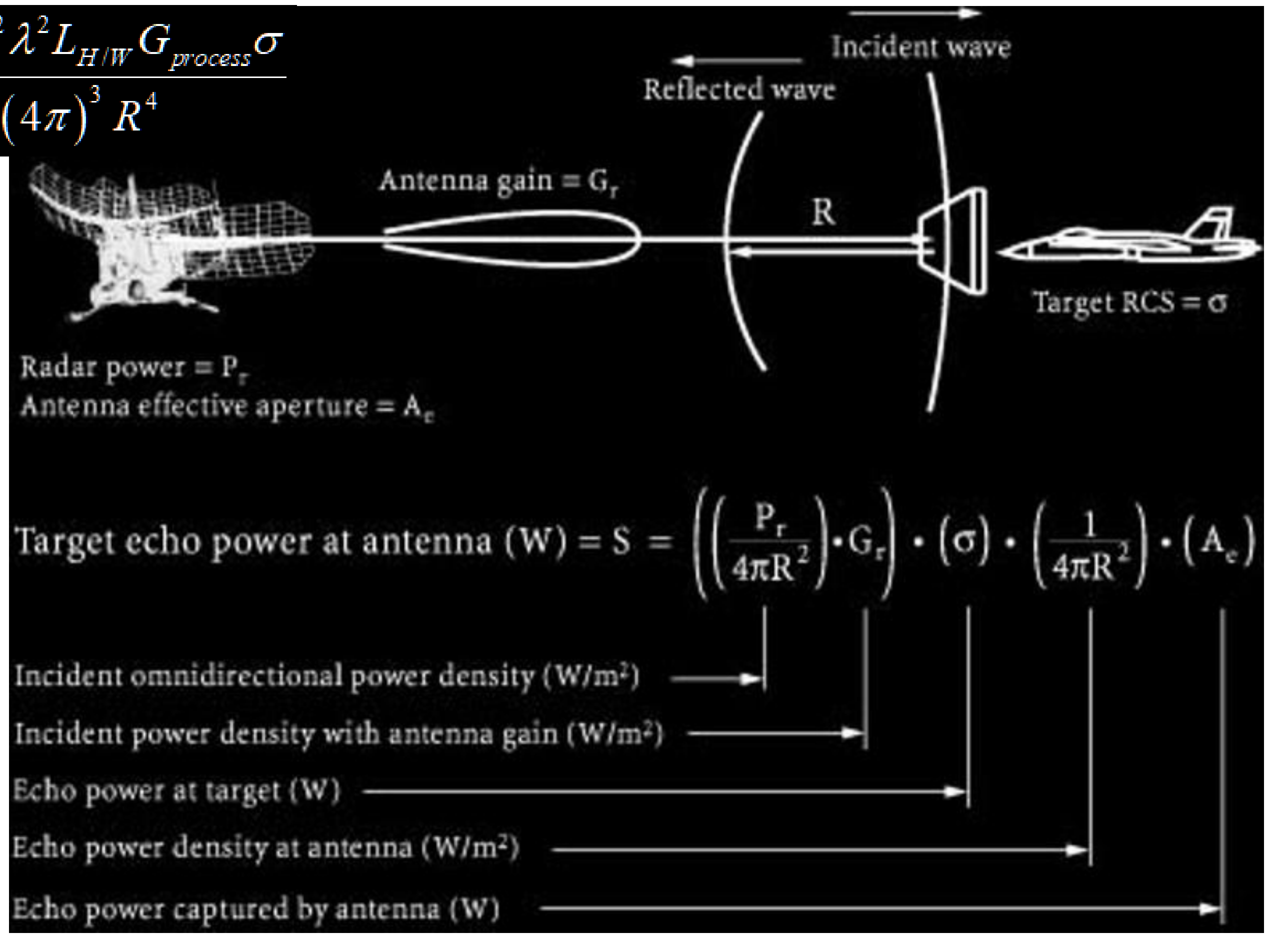
Pollard, R., Detection of low RCS air targets, Stealth Conference 2004, U.K.

Radar range equations

- **Receiving power**

  The radar range equation defines the maximum range at which a given radar can detect a given target in free space.

$$P_{receive} = \frac{P_{trans} G^2 \lambda^2 L_{H/W} G_{process} \sigma}{(4\pi)^3 R^4}$$



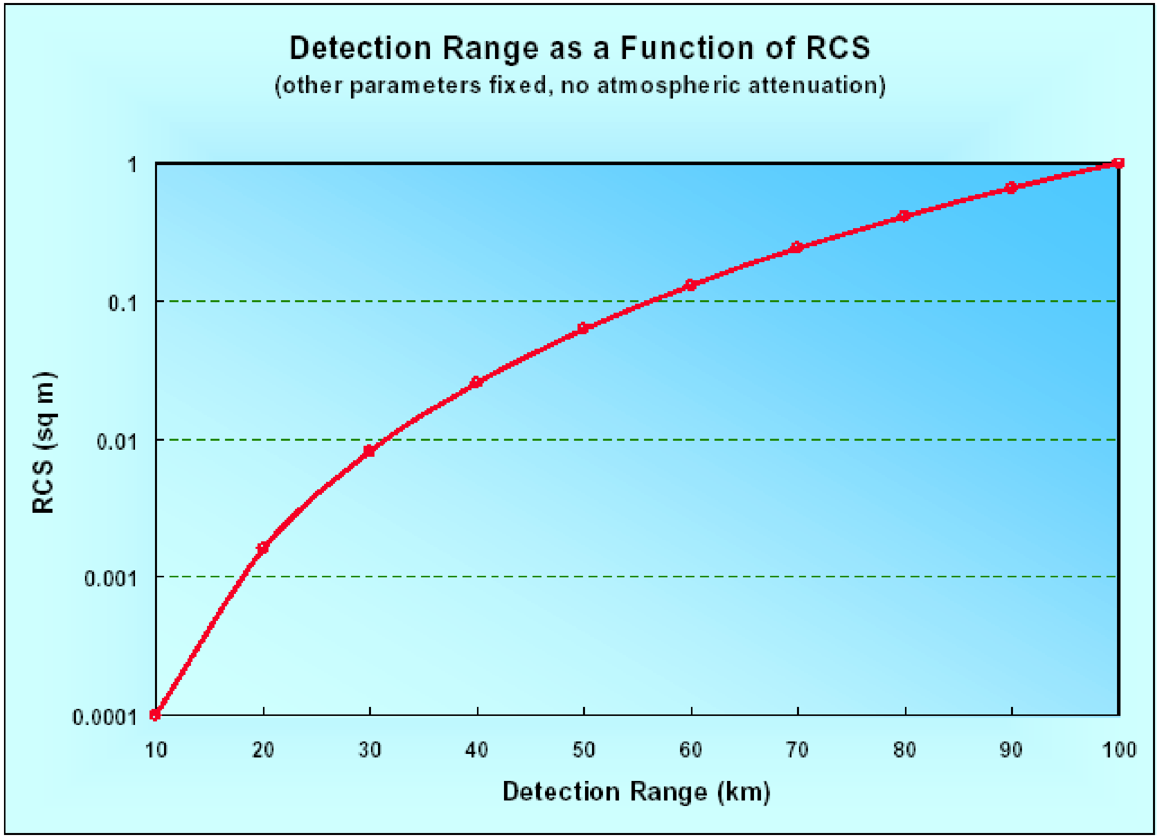
Radar range equations

- **Detection range equation**
  12 dB reduction to halve the range

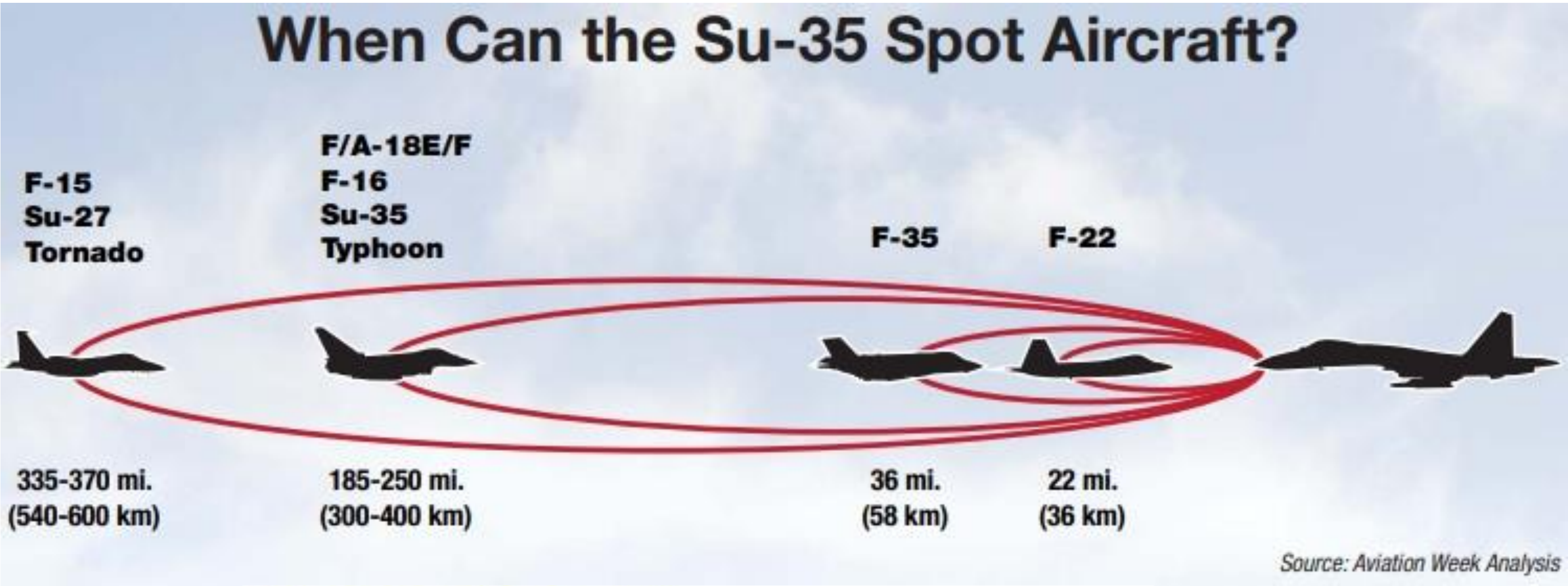
$$Range = \left[\frac{P_{trans} G^2 \lambda^2 L_{H/W} G_{process} \sigma}{(4\pi)^3 k_B T_{eff} W_{bandwidth} SNR_{min}} \right]^{1/4}$$

$$P_{receive} = \frac{P_{trans} G^2 \lambda^2 L_{H/W} G_{process} \sigma}{(4\pi)^3 R^4}$$

$$SNR_{min} = \frac{P_{receive_{min}}}{k_B T_{eff} W_{bandwidth}}$$



Impact of low RF signal

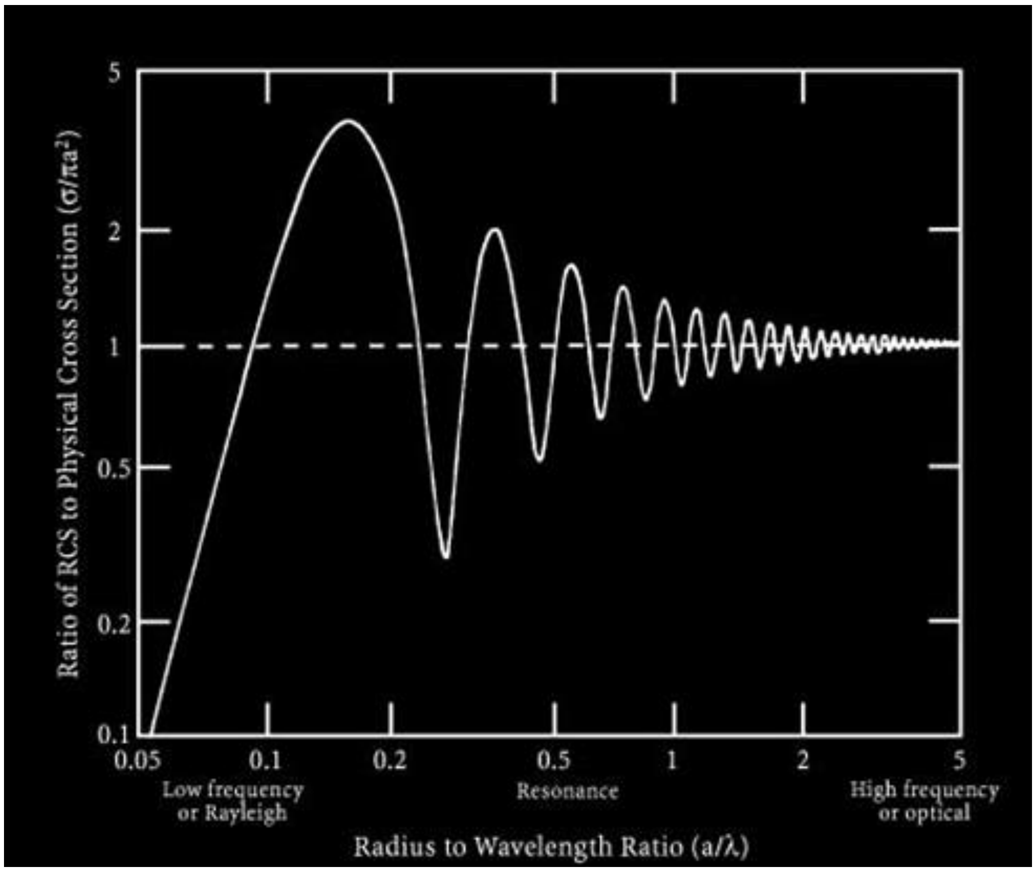


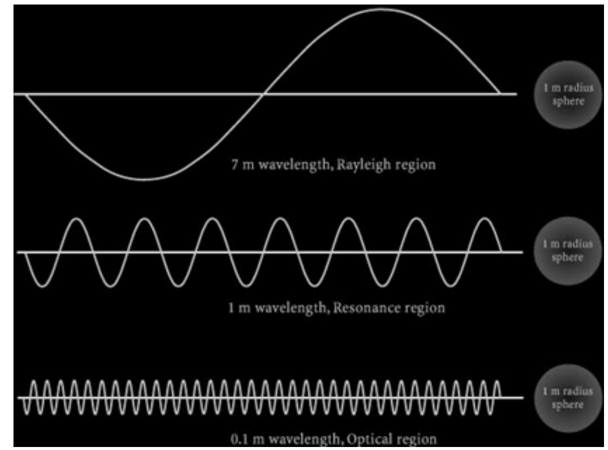
- To halve the detection range:-
  - *Radar*
    - 12dB RCS reduction.
  - *Acoustic*
    - 6dB noise reduction.
  - *Infrared*
    - 25% temperature reduction.
  - *Visual*
    - Dependant on background (Paints and or Camouflage netting).

RCS characteristics

σ=function of frequency, polarization, angles (azimuth & elevation)

Rayleigh (low freq.), resonance (Mie intermediate freq.), optical (high freq.) regimes





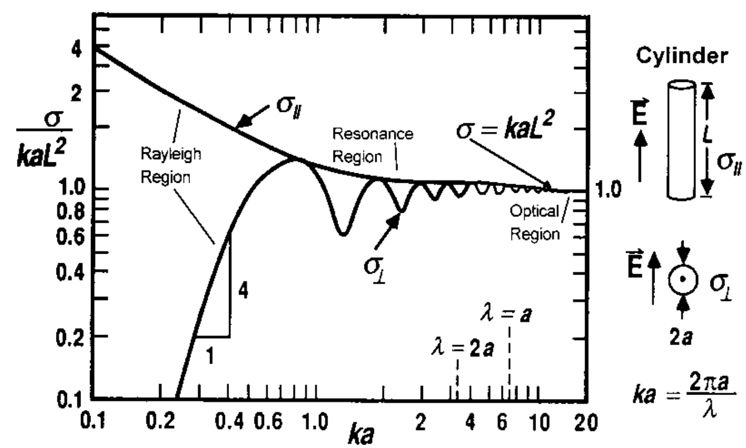
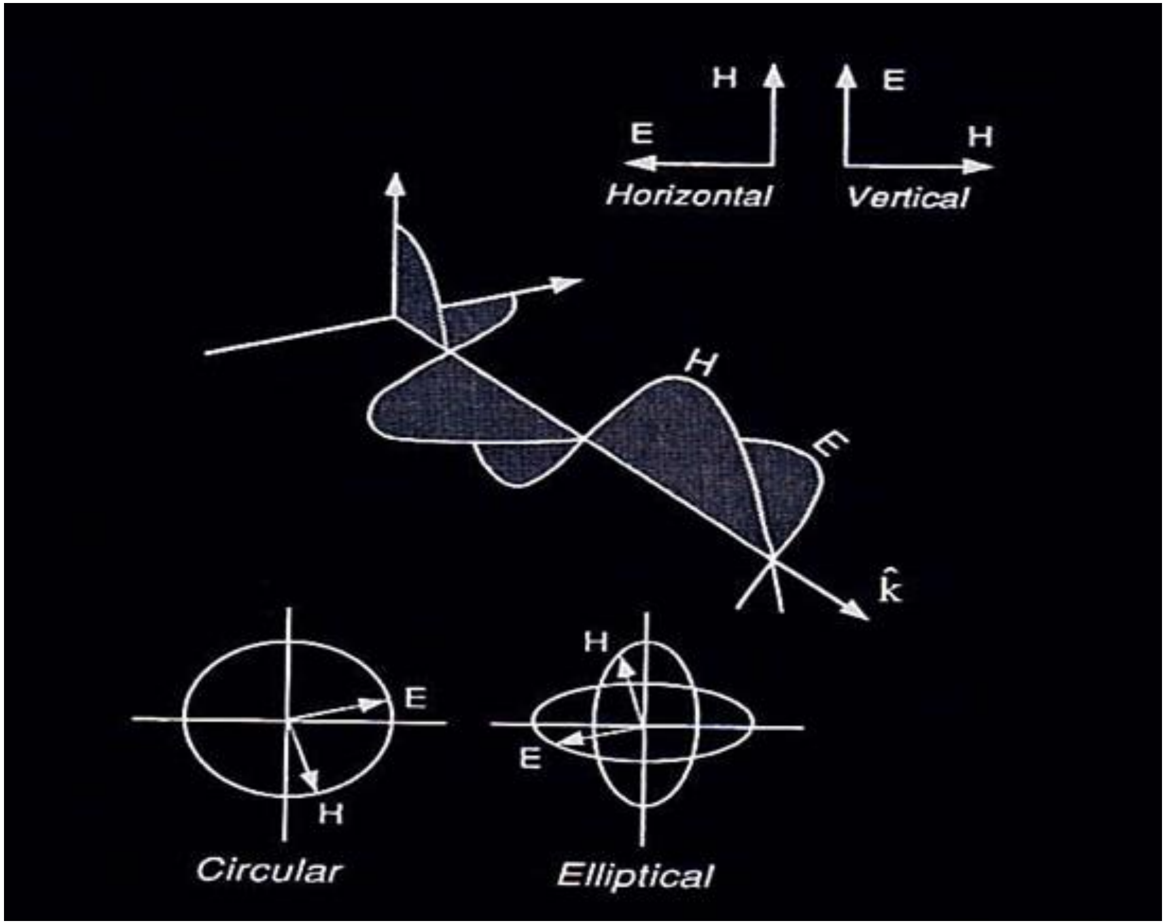
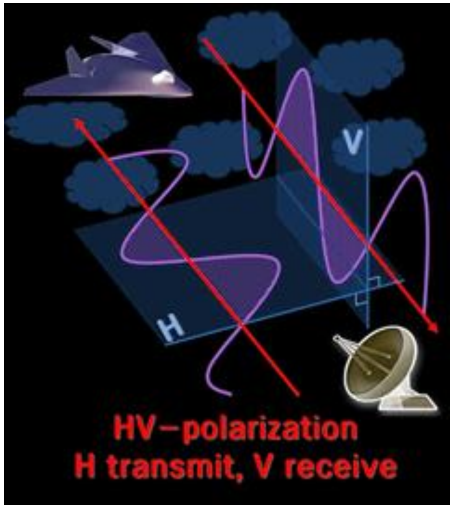
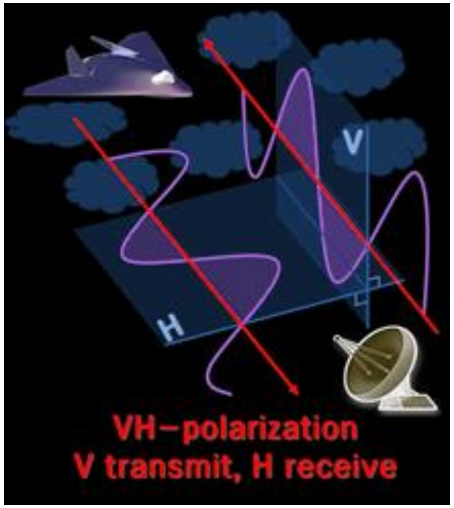


Figure RCS of a cylinder relative to wavelength

RCS characteristics





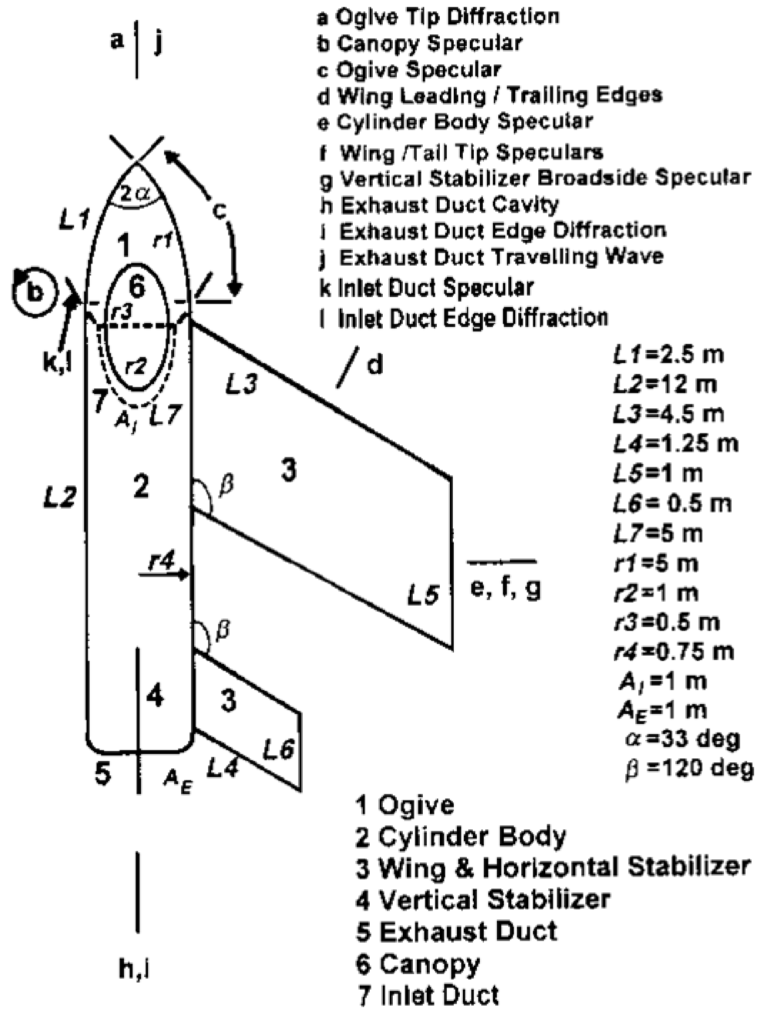


RCS calculations

A hypothetical aircraft with dimensions comparable to an F-16 (wavelength 6 cm of SAM threats): Accurate within 3 dB

$$\sigma = \sum_{m=1}^{M} \sigma_m$$

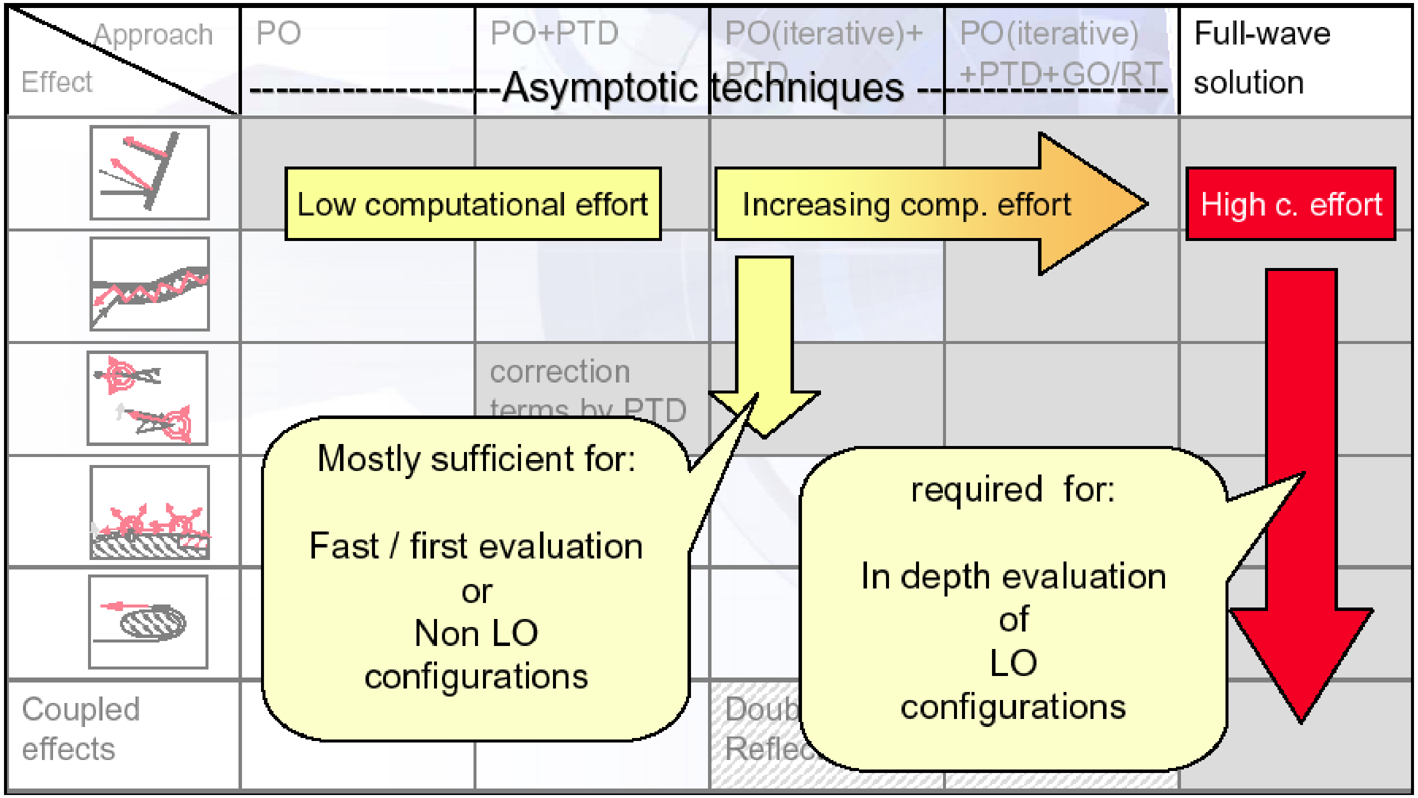
Figure feature	Equation	RCS @ 0° (dBsm)	RCS @ 10° (dBsm)	RCS @ 20° (dBsm)	RCS @ 30° (dBsm)	RC @ 4 (dB
a	$\lambda^2 \tan^4 \alpha/(16\pi)$	−40	−40	−40	−40	−4
b	$\pi r_3 r_2^*$	−7	−5	−2	1	2
c	$\pi r_1^2(1 - \cos \alpha/\sin \theta)$	−60	−60	−60	−60	−6
d	$2(L3^2 + L4^2)/\pi$	−60	−60	−60		−6
e	$2\pi r4 \cdot L2^2/\lambda$	−60	−60	−60	−60	−6
f	$(L5^2 + L6^2)/\pi$	−60	−60	−60	−60	−6
g	$4\pi(L4 \cdot L6 \sin \beta)^2/\lambda$	−60	−60	−60	−60	−6
h	$2A_E$	−60	−60	−60	−60	−6
i	$(2\lambda)^2/\pi$	−23	−23	−23	−23	−2
j	$\pi\lambda(r4)^2/(L1 + L2)$	−21	−60	−60	−60	−6
k	$2A_I \cos^2\theta$	3			1.8	−0.
l	$(L7)^2/\pi^{**}$, $(2\lambda)^2/\pi$	9	−23	−23	−23	−2
Total	Noncoherent Sum	10				3.



Example first-order RCS estimate from specular segments.

RCS calculations

Component buildup method, high-frequency asymptotic methods, full wave methods



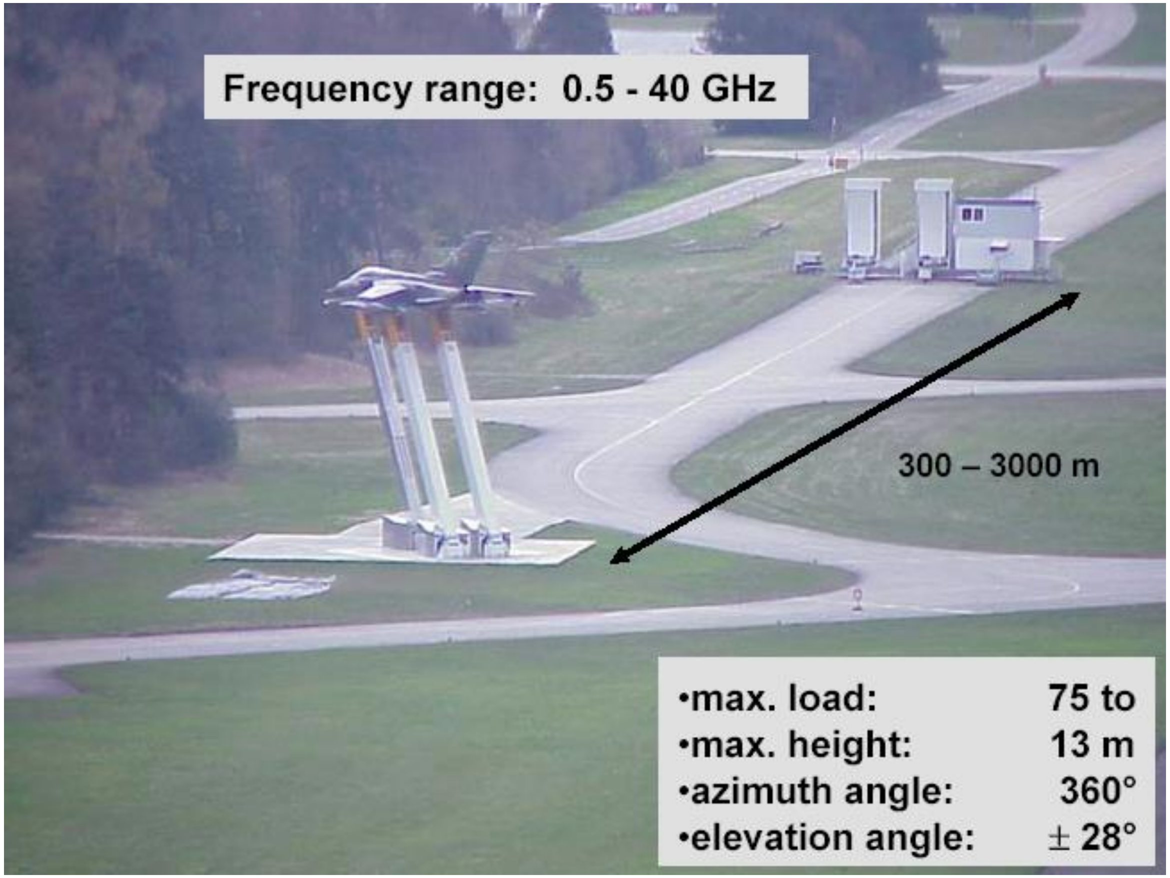
PO (physical optics)

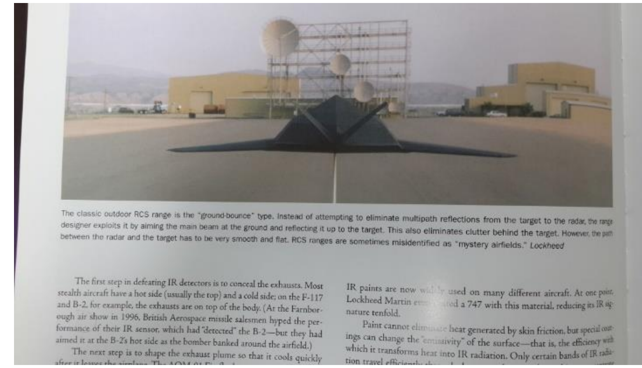
PTD (physical theory of diffraction)

GO/RT (geometrical optics / ray tracing)

Ritter, J., The Role of CEM in the Realization of RCS Reduction of Aircraft, Stealth Conference 2005, U.K.

Outdoor RCS measurement





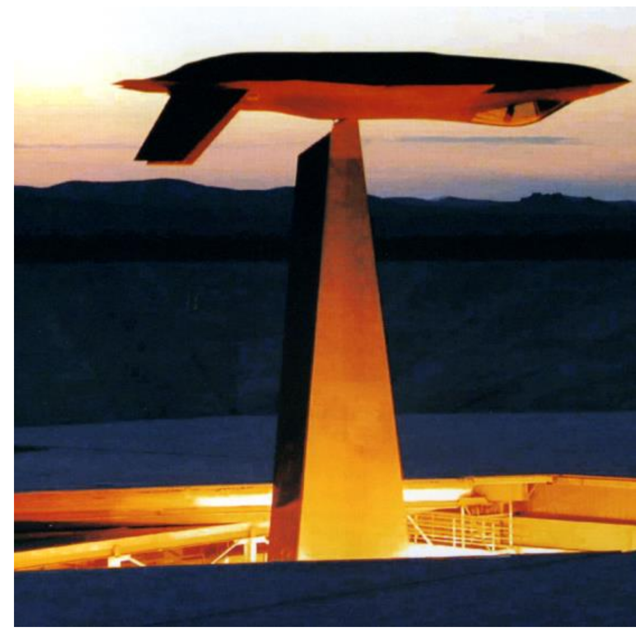
The classic outdoor RCS range is the "ground-bounce" type. Instead of attempting to eliminate multipath reflections from the target to the radar, the range designer exploits it by aiming the main beam at the ground and reflecting it up to the target. This also eliminates clutter behind the target. However, the path between the radar and the target has to be very smooth and flat. RCS ranges are sometimes misidentified as "mystery airfields." *Lockheed*

The first step in defeating IR detectors is to conceal the exhausts. Most stealth aircraft have a hot side (usually the top) and a cold side; on the F-117 and B-2, for example, the exhausts are on top of the body. (At the Farnborough air show in 1996, British Aerospace missile salesmen hyped the performance of their IR sensor, which had "detected" the B-2—but they had aimed it at the B-2's hot side as the bomber banked around the airfield.)

The next step is to shape the exhaust plume so that it cools quickly

IR paints are now [illegible] used on many different aircraft. At one point, Lockheed Martin [illegible] a 747 with this material, reducing its IR signature tenfold.

Paint cannot [illegible] heat generated by skin friction, but special coatings can change the "[illegible]" of the surface—that is, the efficiency with which it transforms heat into IR radiation. Only certain bands of IR radiation travel efficiently



Kruse, J., Applying Stealth Technology to Non-Stealthy Platforms, Stealth Conference 2005, U.K.

Indoor RCS measurement and scaling laws

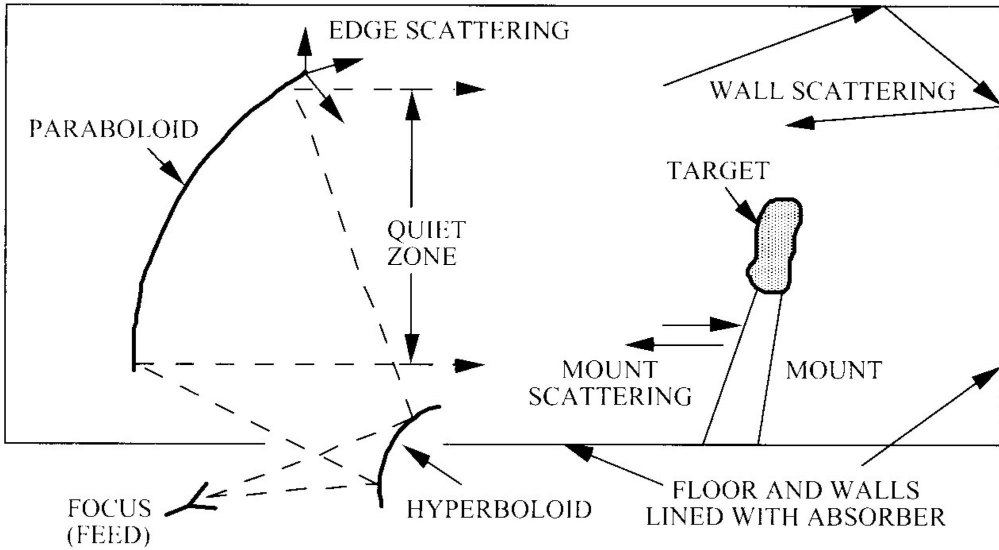


Fig. 8.7 Some sources of RCS measurement error.

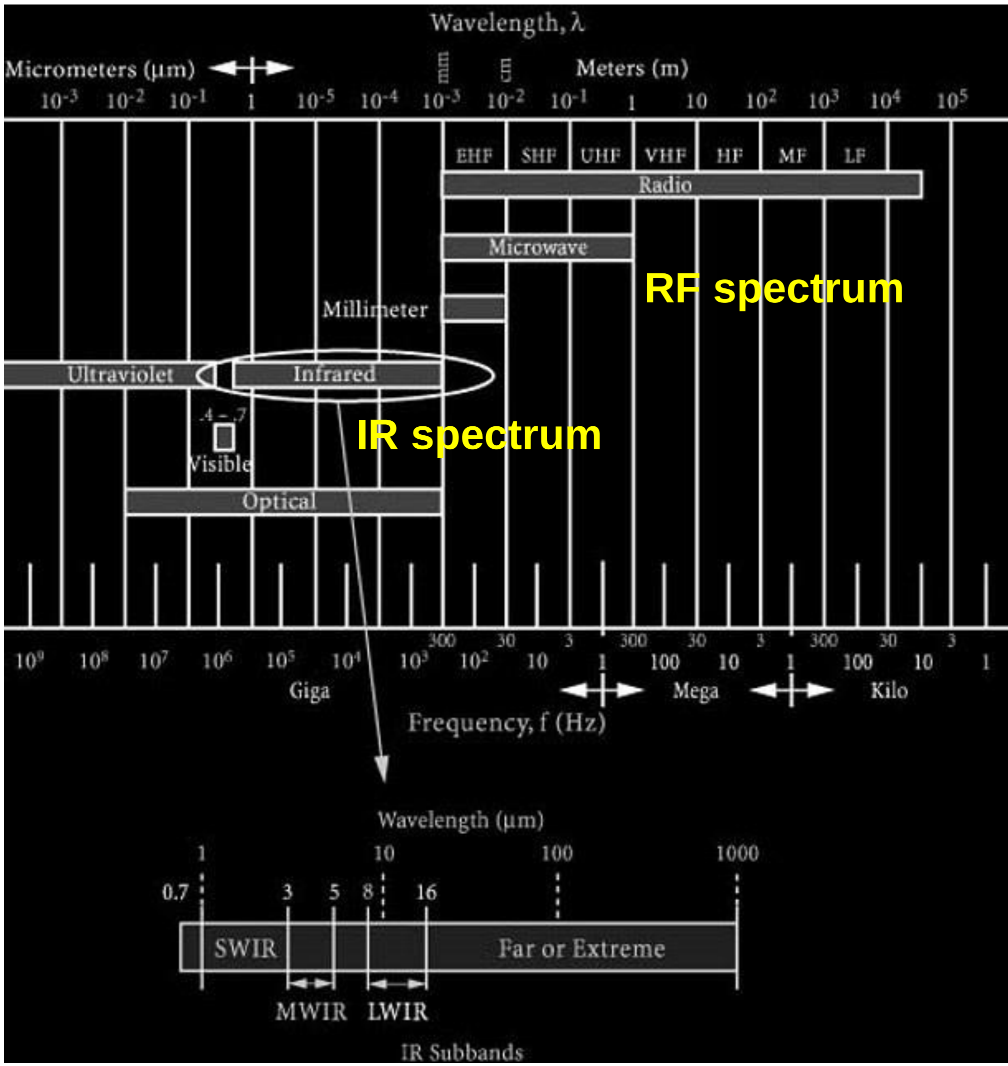
This small scale model of Have Blue is undergoing RCS tests in Lockheed's anechoic chamber at Rye Canyon. *Lockheed Martin*

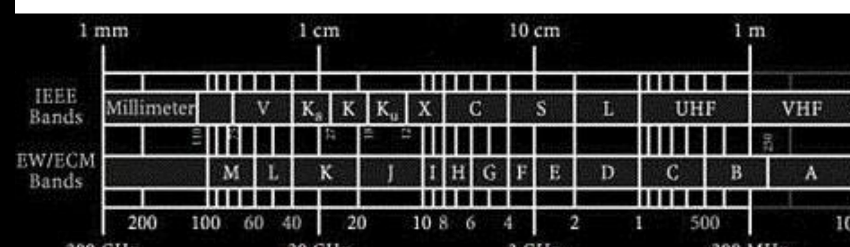
Figure of merit of an RCS chamber: The quiet zone and the operating frequency range

Scaling laws for scale-model testing:

- For p scaling factor, $f_m = pf\,,\ \sigma_m = p\sigma$
- The complex index of refraction and impedances should be duplicated.

IR fundamentals





- **IR radiation**

  EM radiation caused by the accelerations and decelerations of electrons

IR fundamentals

- **IR radiation (solid)**

  EM radiation caused by the accelerations and decelerations of electrons

  Continuum (solid) radiation governed by Planck's law

$$M_e = \varepsilon \sigma T^4 \ (\mathrm{W/cm^2})$$

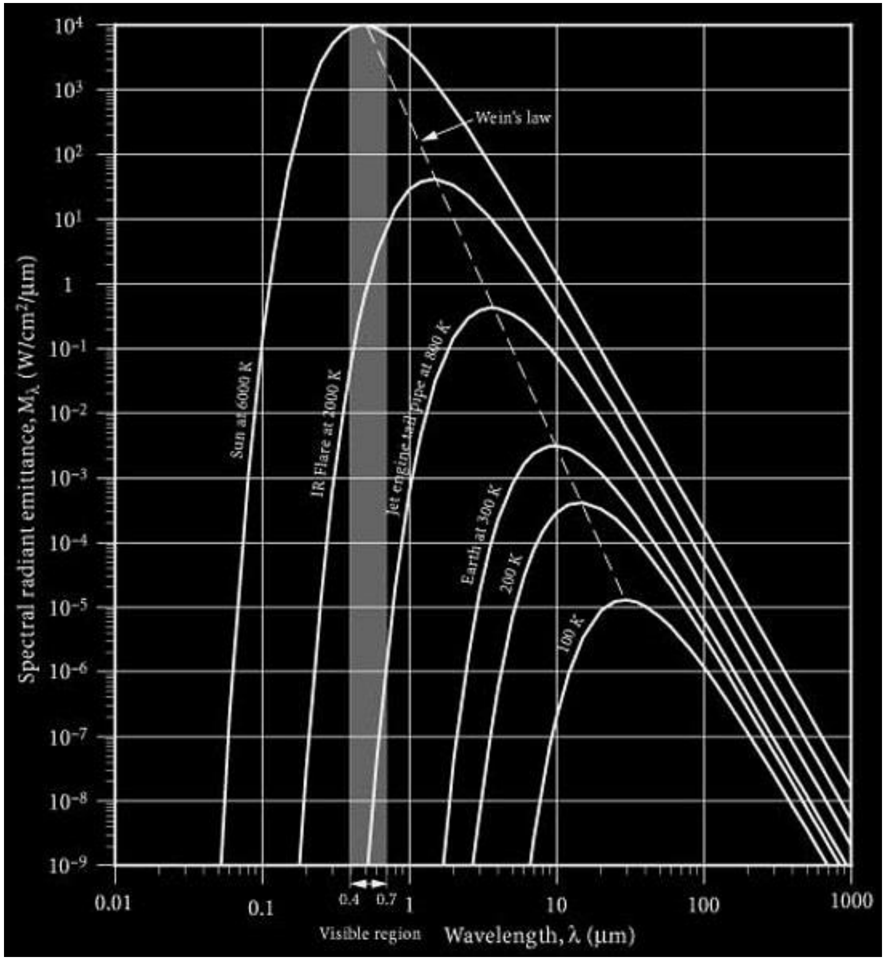
Wavelength: 0.7 ~ 1000 micron

continuum radiator (solid; grey bodies

Wein's law of the wavelength associated with the peak spectral radiant exitance

$$\lambda = \frac{3000}{T} \ (\mu m)$$

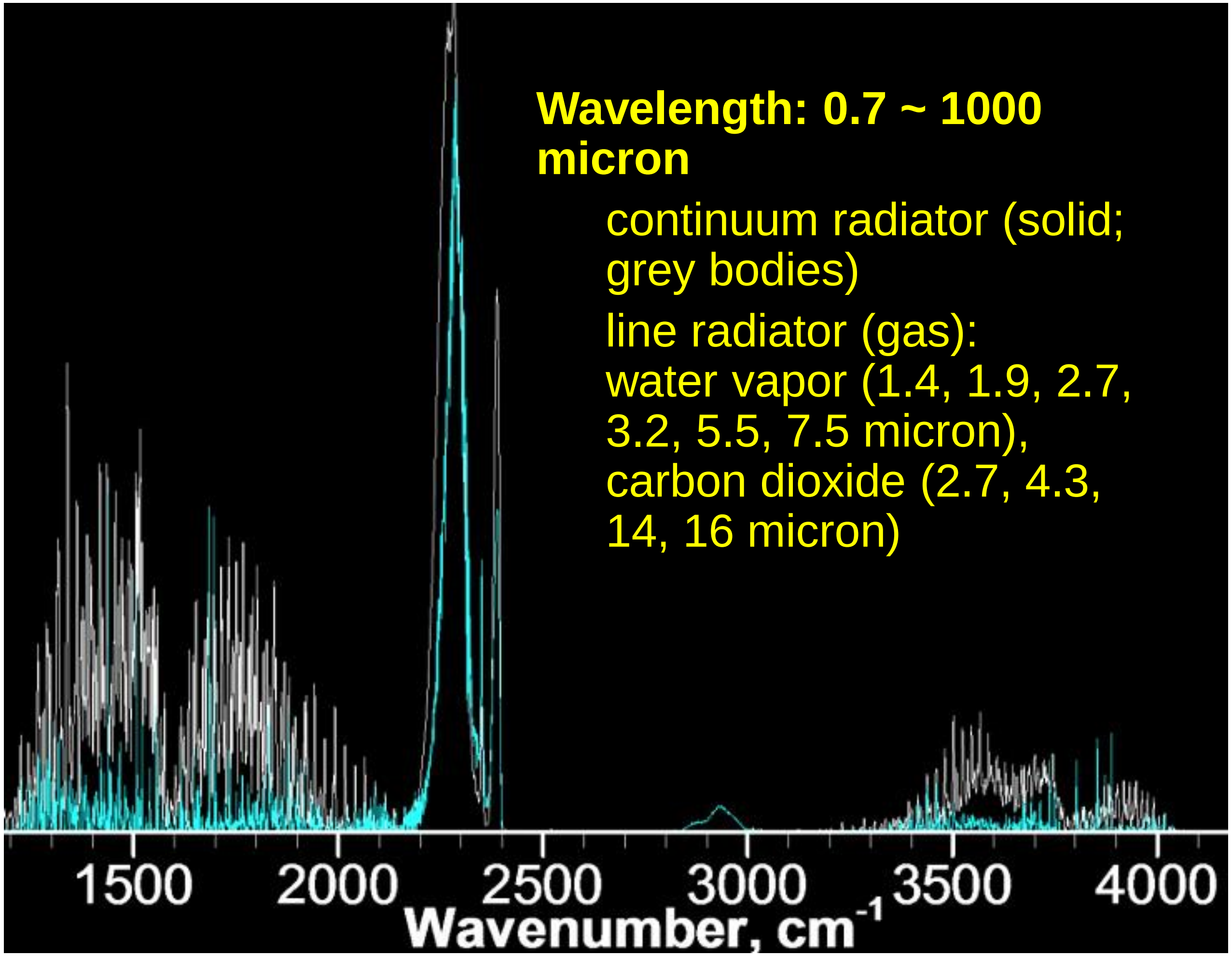
Intensity (W/sr): angular density of the power emitted from a source
Radiance (W/cm^2/sr): angular power density per unit area of the source



IR fundamentals

- **IR radiation (gas)**

Discrete (line) gaseous radiation: emitted and absorbed only at discrete wavelengths associated with specific rotation and vibration frequencies CO_2 at 2.7 and 4.3 μm; H_2O at 2.7 μm.

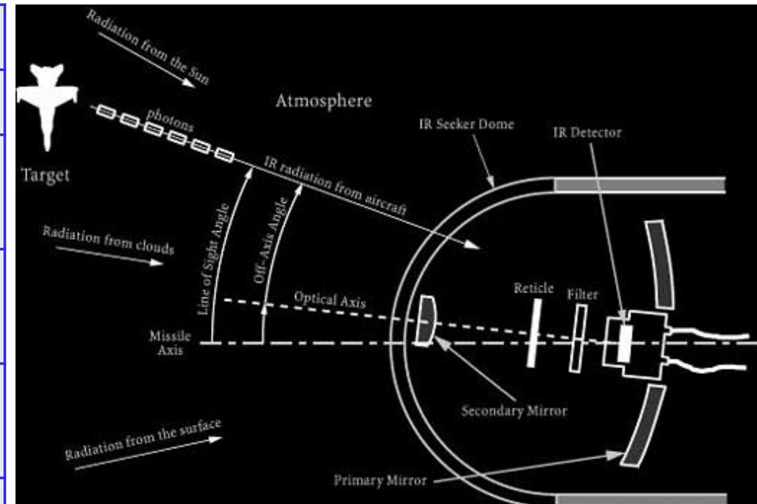


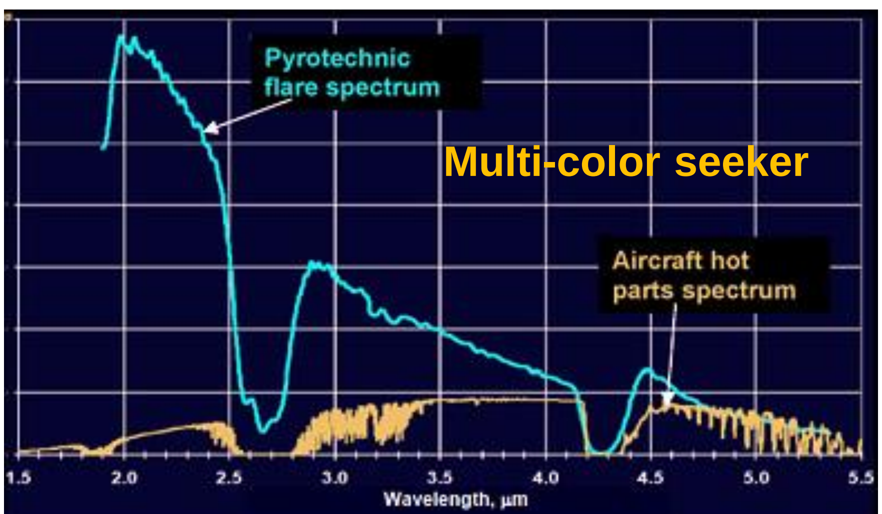
Proliferation of IR seeker missiles

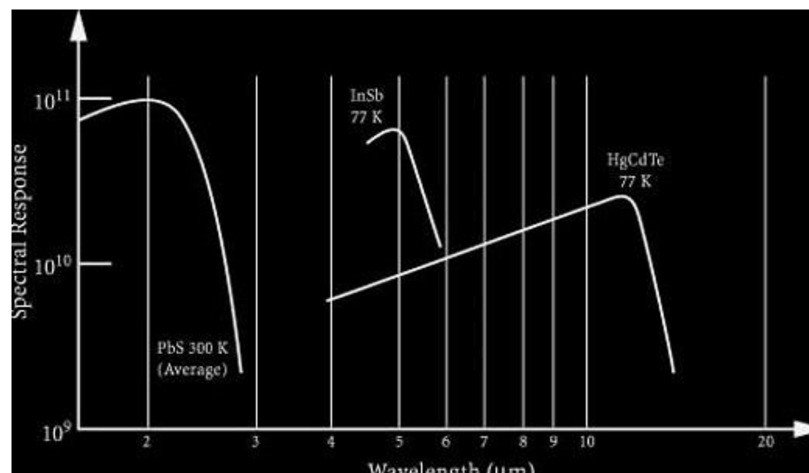
IR detector MANPADS

	Mistral 1	Strela-2M	Igla	FIM-92B/C
Country	Europe	Russia	Russia	USA
Range	300-6,000m	800-4,200m	500-5,200m	200-4,800m
Altitude	5-3,000m	15-2,300m	10-3,000m	0-3,800m
Band μm	2-4/ 3.5-5	1.7-2.8	1.5-2.5/ 3-5	0.3-0.4/ 3.5
Mach	Max 2.5	Max 1.3	> 2.0	Max 2.2

IR missile seeker

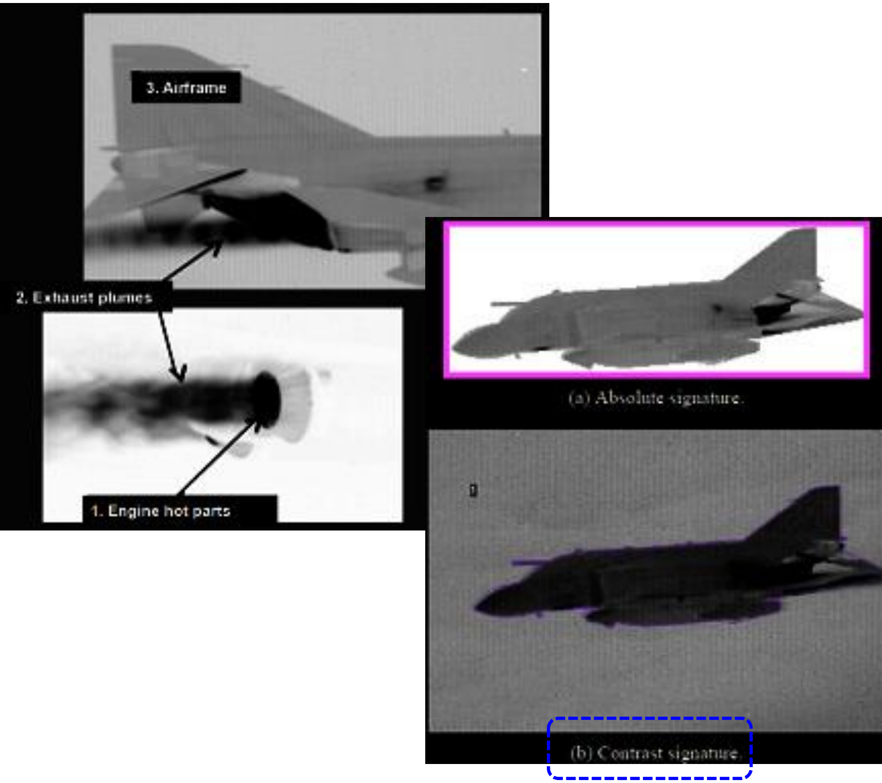


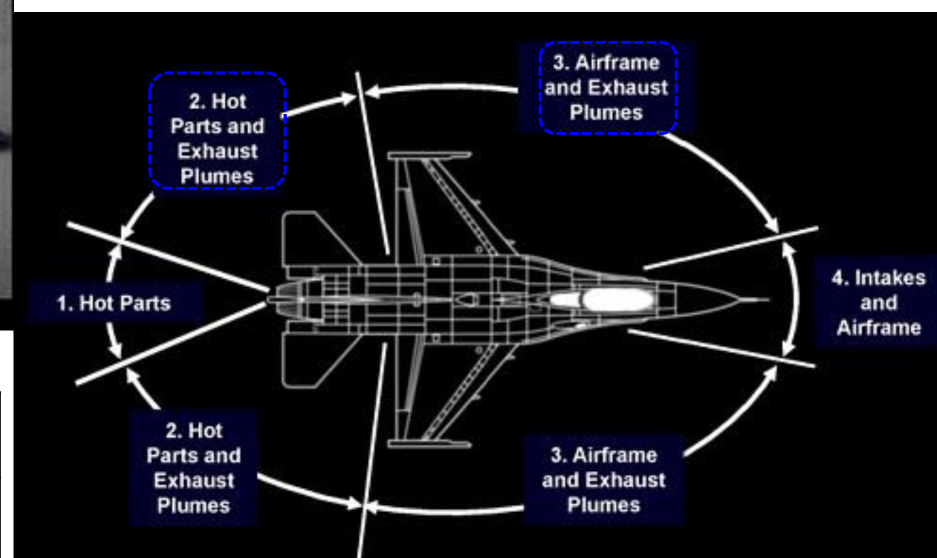




IR sources in aircraft

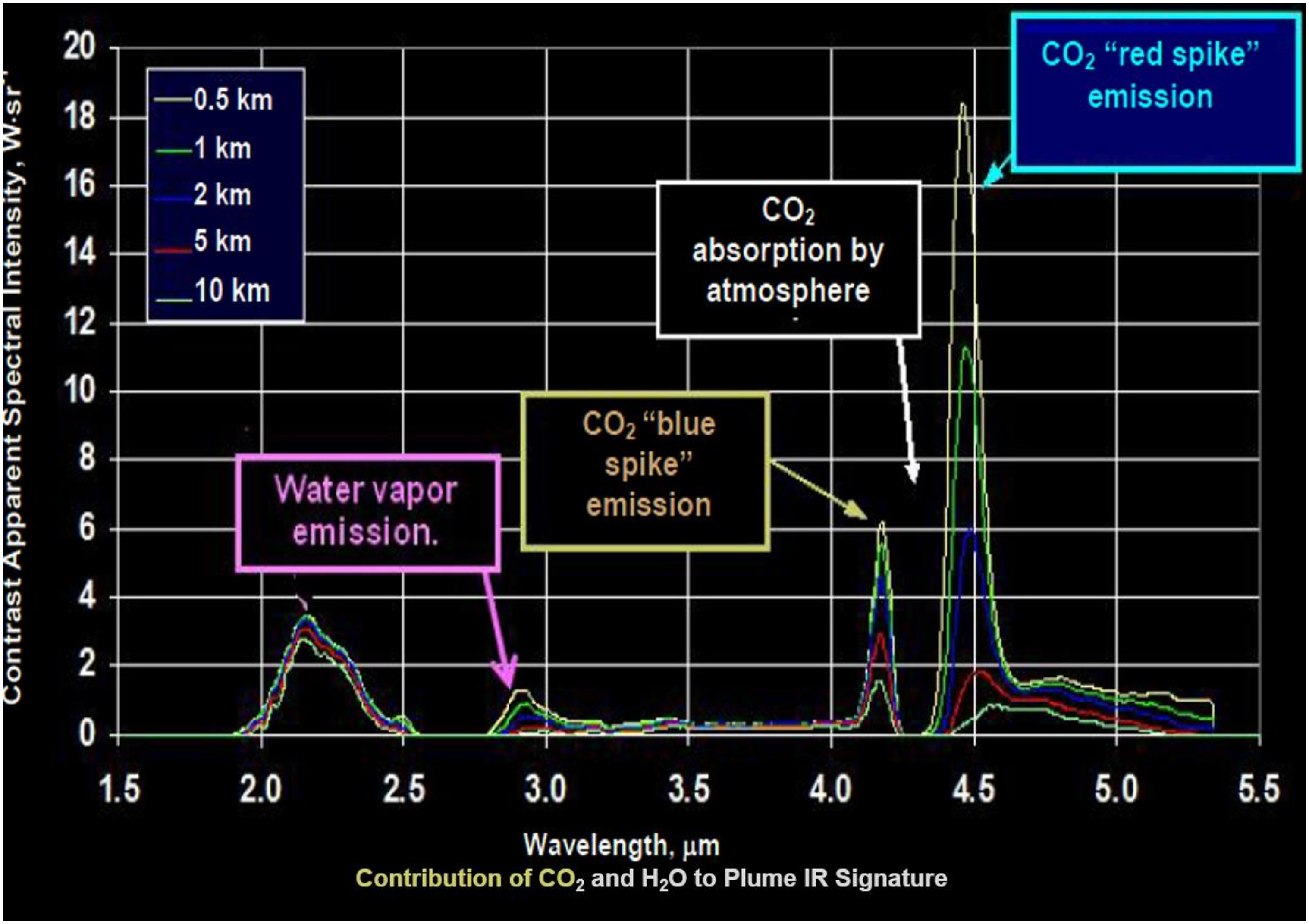
Sources of IR in aircraft (passive)



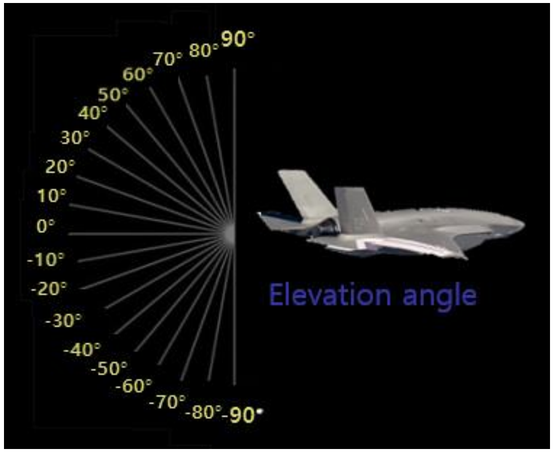


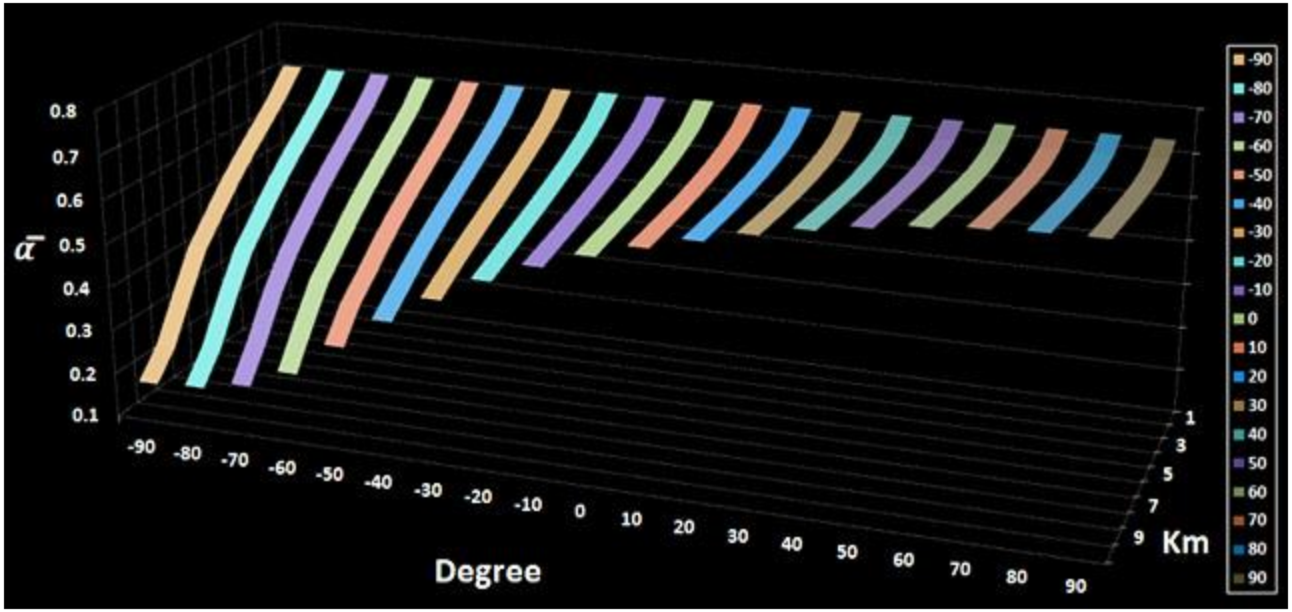
Band (μm)	2~3	4~5
IR level (W/sr) (Jet fighter)	O(5~100)	O(100~1000)

IR fundamentals: atmospheric effect



IR fundamentals: atmospheric transmission



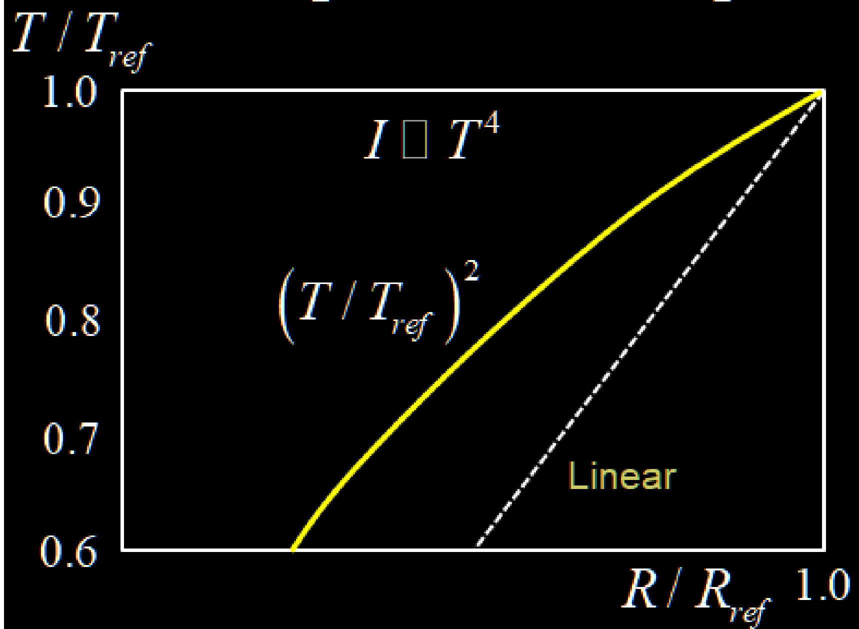


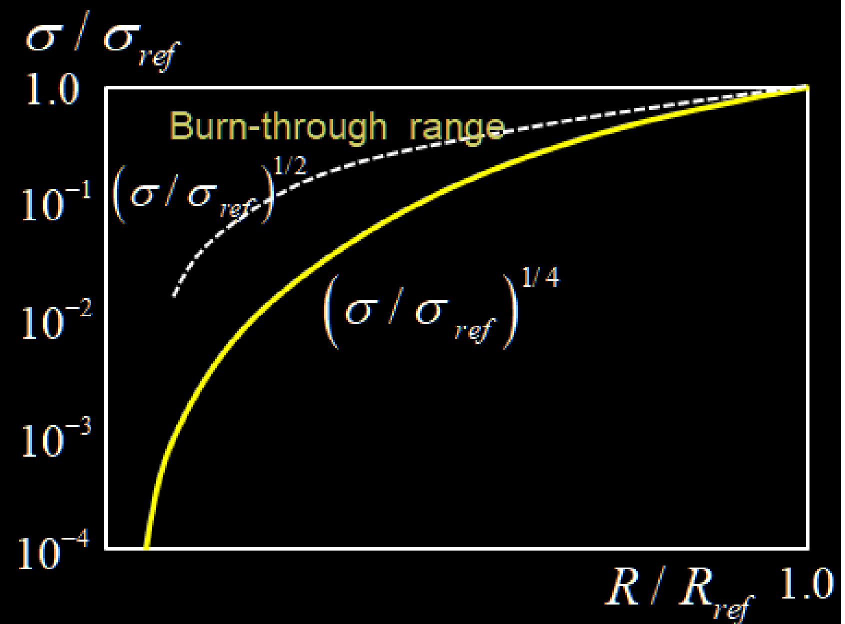
Atmospheric transmission vs elevation angle (deg) and distance (km)

Detection range relations:
IR (passive) vs RF (active)

$$R_{IR\ Lock-on} = \left[\frac{I_{contranst}\,\eta_{atmos}}{I_{noise\ equiv\ irrad}\cdot SNR_{\min}}\right]^{1/2}$$

$$R_{RF} = \left[\frac{\sigma P_{trans} G^2 \lambda^2 L_{H/W} G_{process}}{(4\pi)^3 k_B T_{eff} W_{bandwidth} SNR_{\min}}\right]^{1/4}$$





Spectrum, view angles
Contrast, atmospheric effect
Surface condition

Frequency, angles, polarization
Monostatic vs bistatic radar
RAM, RAS

RCS & IR reduction in PW F135 engine