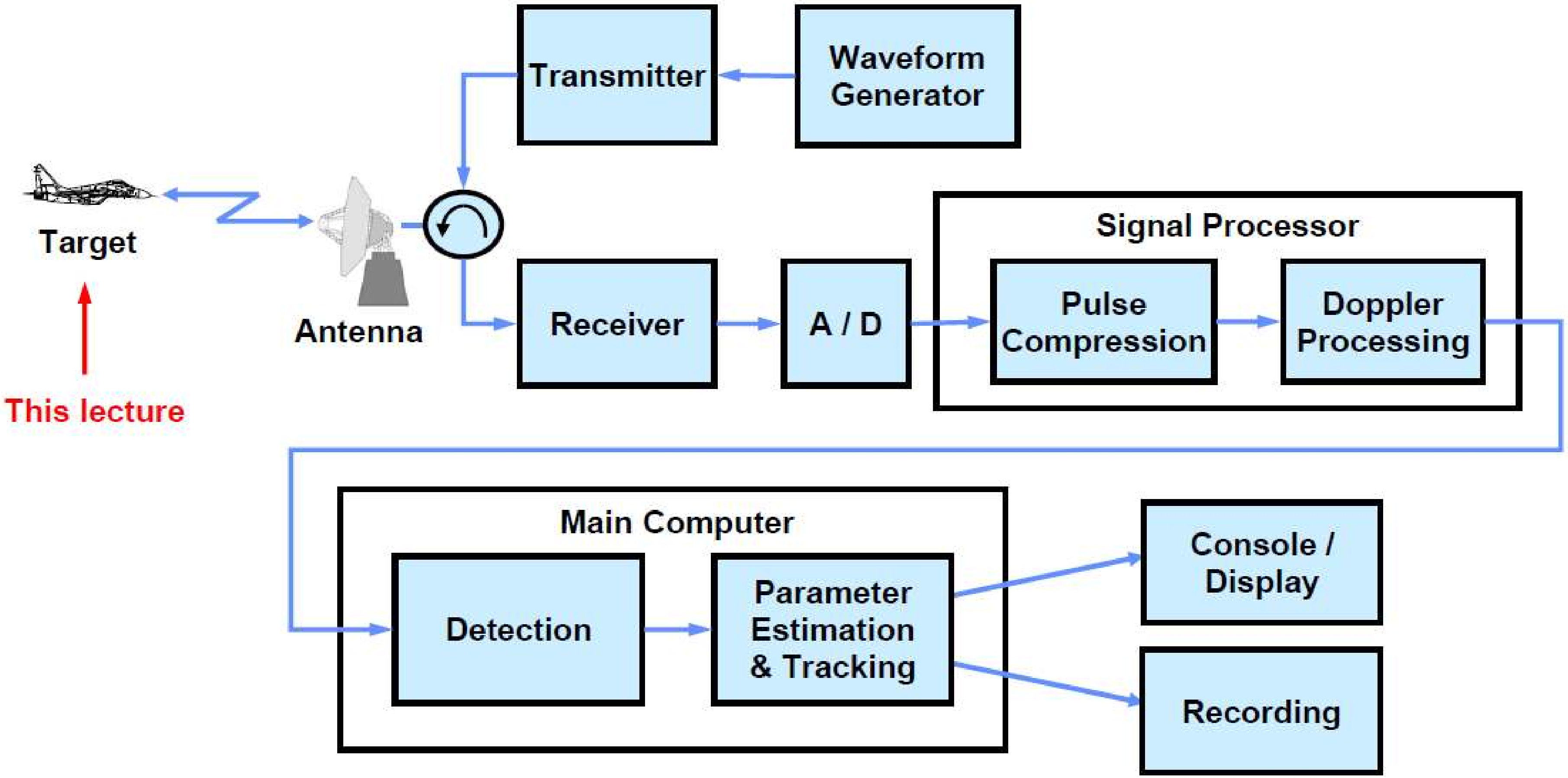
AJOU UNIVERSITY
1973

Radar Systems

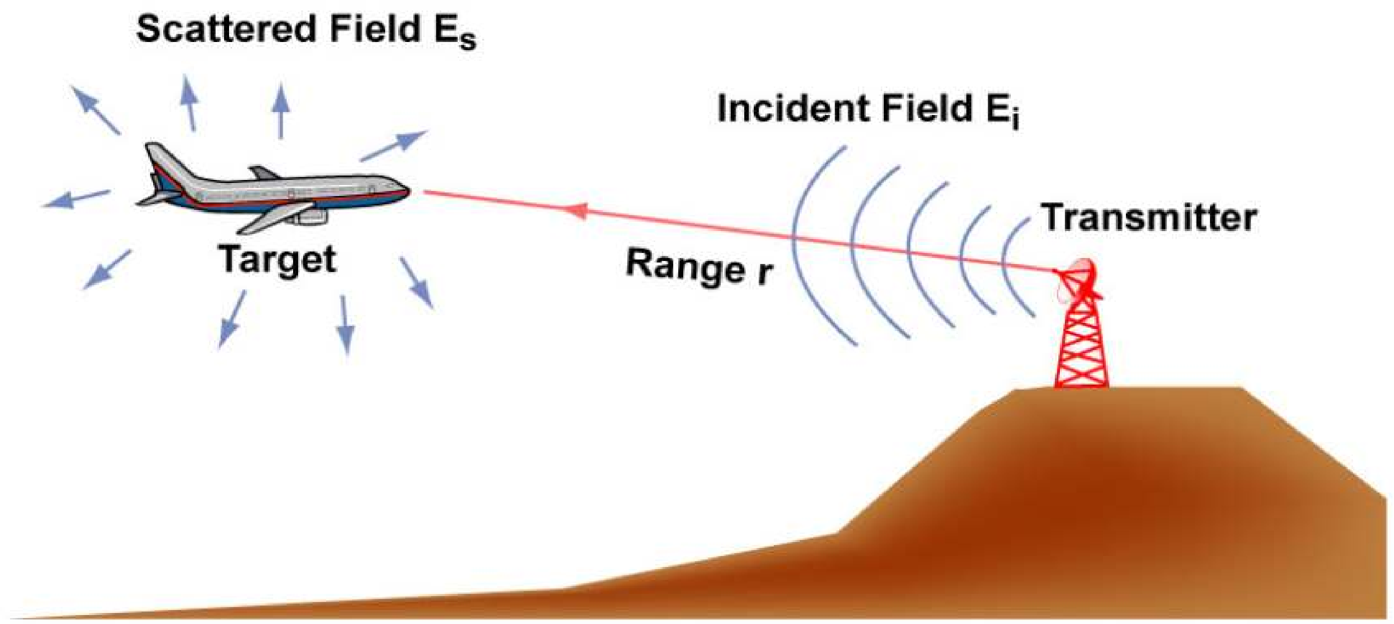
Lecture 4. Target Radar Cross Section

구 자 열

Generic Radar Block Diagram



Definition of Radar Cross Section (RCS or σ)

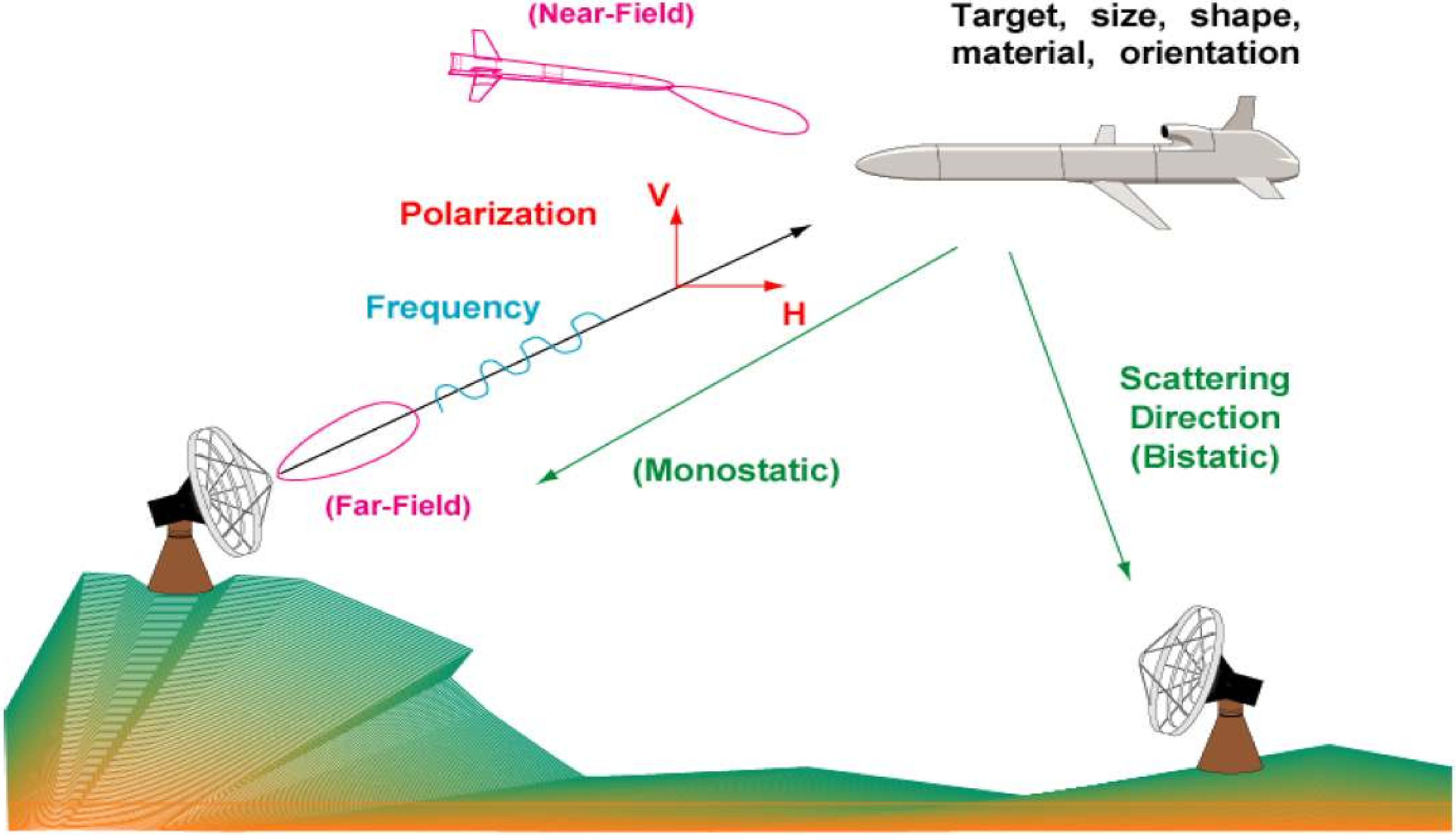


$$RCS = \lim_{r \to \infty} 4\pi r^2 \frac{|E_s|^2}{|E_i|^2} \quad \text{(Unit: Area)}$$

Figure by MIT OCW.

Radar Cross Section is the area intercepting that amount of power which, if radiated isotropically, produces the same received power in the radar.

Factors Determining RCS



Threat's View of the Radar Range Equation

What I can control

$$\text{Received Signal Energy} = \overset{\text{Transmit Power}}{[P_T]}\ \overset{\text{Transmit Gain}}{\left[\frac{4\pi A}{\lambda^2}\right]}\ \overset{\text{Spread Factor}}{\left[\frac{1}{4\pi R^2}\right]}\ \overset{\text{Losses}}{\left[\frac{1}{L}\right]}\ \overset{\text{Target RCS}}{[\sigma]}\ \overset{\text{Spread Factor}}{\left[\frac{1}{4\pi R^2}\right]}\ \overset{\text{Receive Aperture}}{[A]}\ \overset{\text{Dwell Time}}{[\tau]}$$

What I can not control

차　　례

• **What are typical levels of radar cross section?**
  - **On what do these depend?**

• **What contributes to radar cross section?**
  - **What are the scattering mechanisms?**
  - **What are typical signature contributors?**

• **How can target radar cross section be determined?**
  - **Measurement**
  - **Prediction**

Radar Cross Section of Sphere

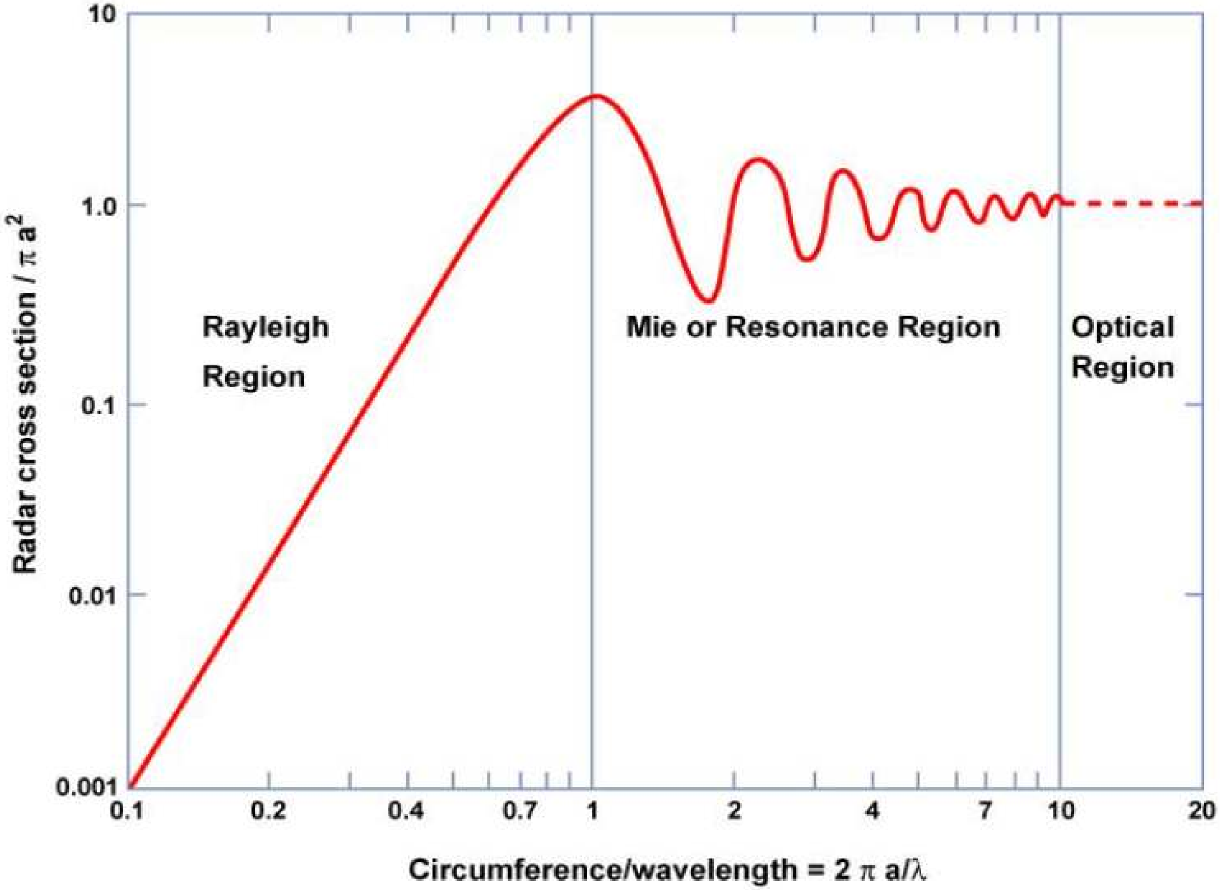


Figure by MIT OCW.

Rayleigh Region

$\lambda >> a$

$\sigma = k / \lambda^4$

Resonance or Mie Region

Oscillations

Backscattered wave interferes with creeping wave

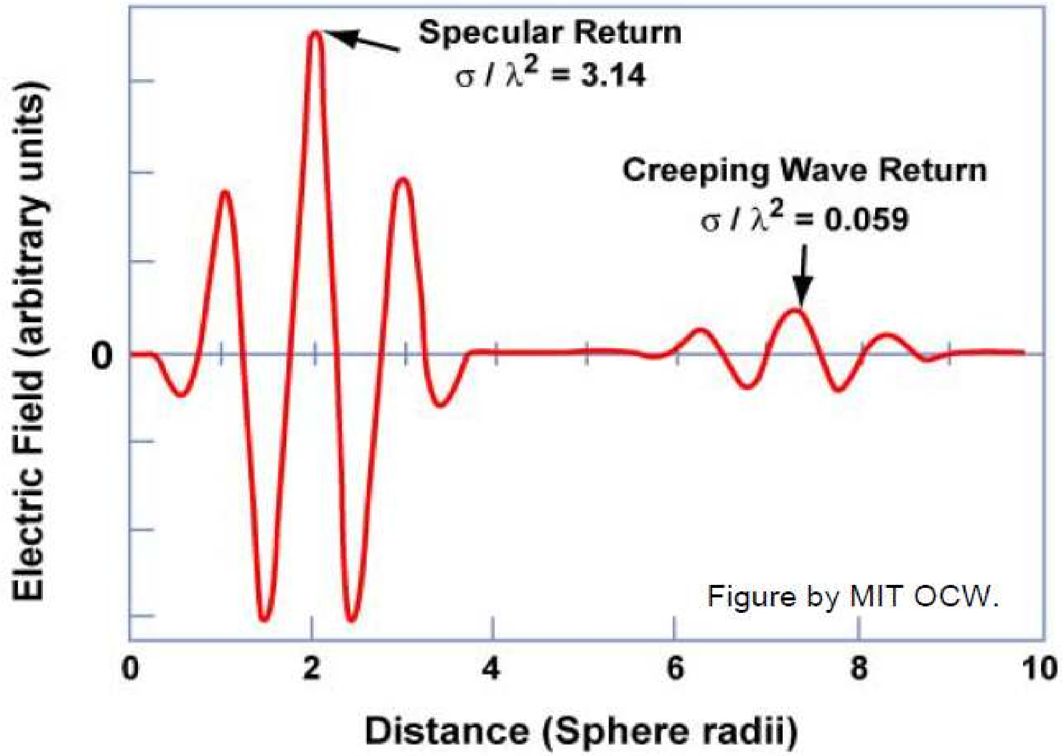
Optical Region

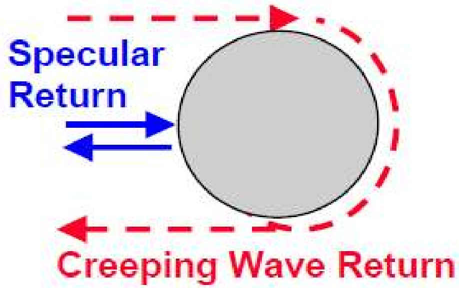
$\lambda << a$

$\sigma = \pi a^2$

Surface and edge scattering occur

Backscatter of Short Pulse from Sphere





Radius of sphere is equal to the radar wavelength

Radar Cross Section of Typical RV

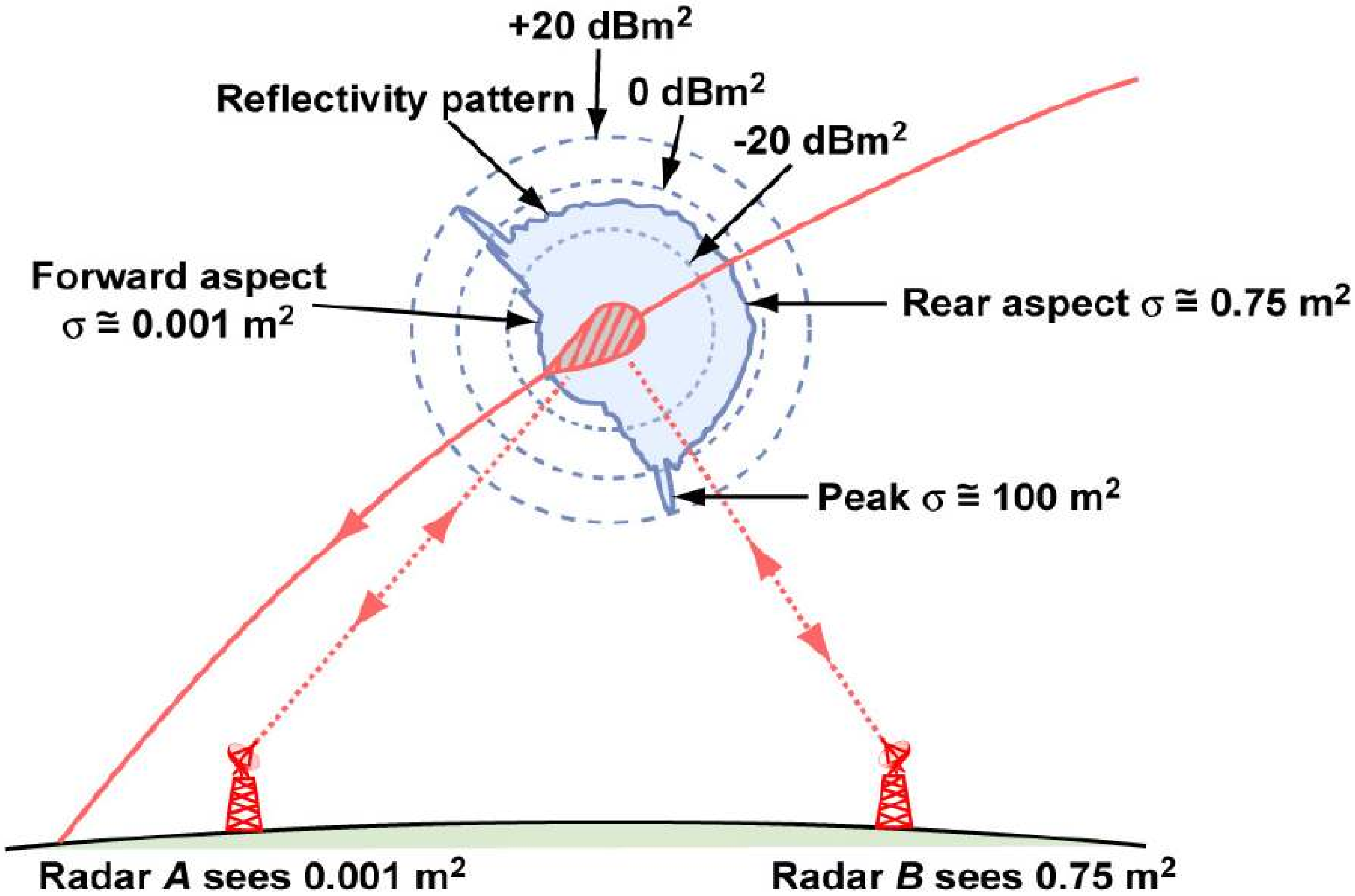
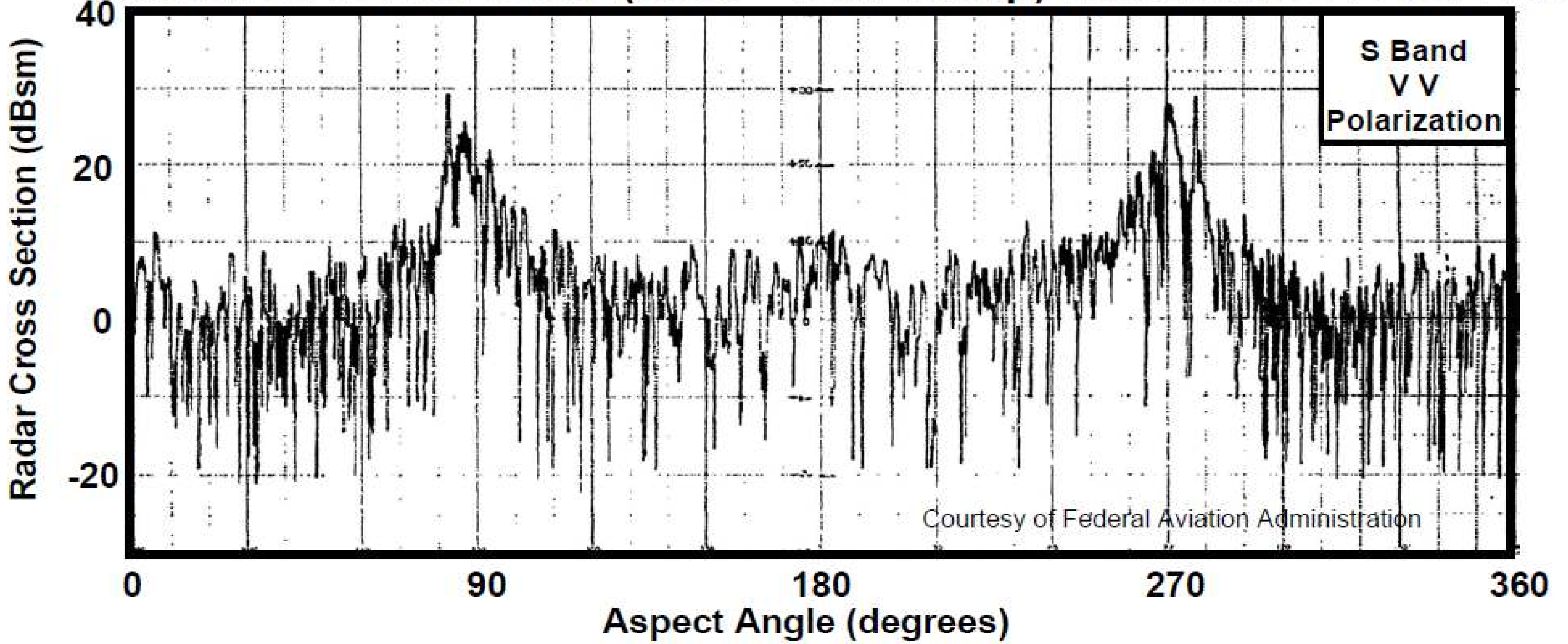


Figure by MIT OCW.

Radar Cross Section of Cessna 150L

Measured at RATSCAT (6585th Test Group) Holloman AFB for FAA



Cessna 150L (in takeoff)

Cessna 150L (in flight)

Examples of Radar Cross Sections

	Square meters
Small, single engine aircraft	1
Four passenger jet	2
Large fighter	6
Medium jet airliner	40
Jumbo jet	100
Helicopter	3
Small open boat	0.02
Small pleasure boat (20-30 ft)	2
Cabin cruiser (40-50 ft)	10
Ship(5,000 tons displacement, L Band)	10,000
Automobile / Small truck	100 - 200
Bicycle	2
Man	1
Birds	10^{-2} - 10^{-3}
Insects	10^{-4} - 10^{-5}

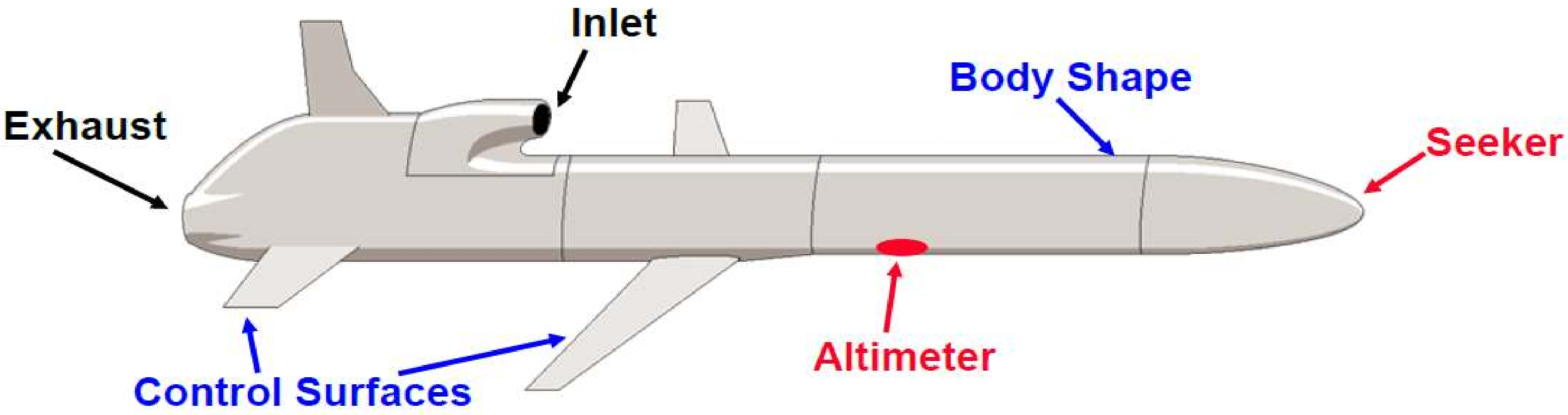
차　　례

• What are typical levels of radar cross section?
  - On what do these depend?

• What contributes to radar cross section? ⟸
  - What are the scattering mechanisms?
  - What are typical signature contributors?

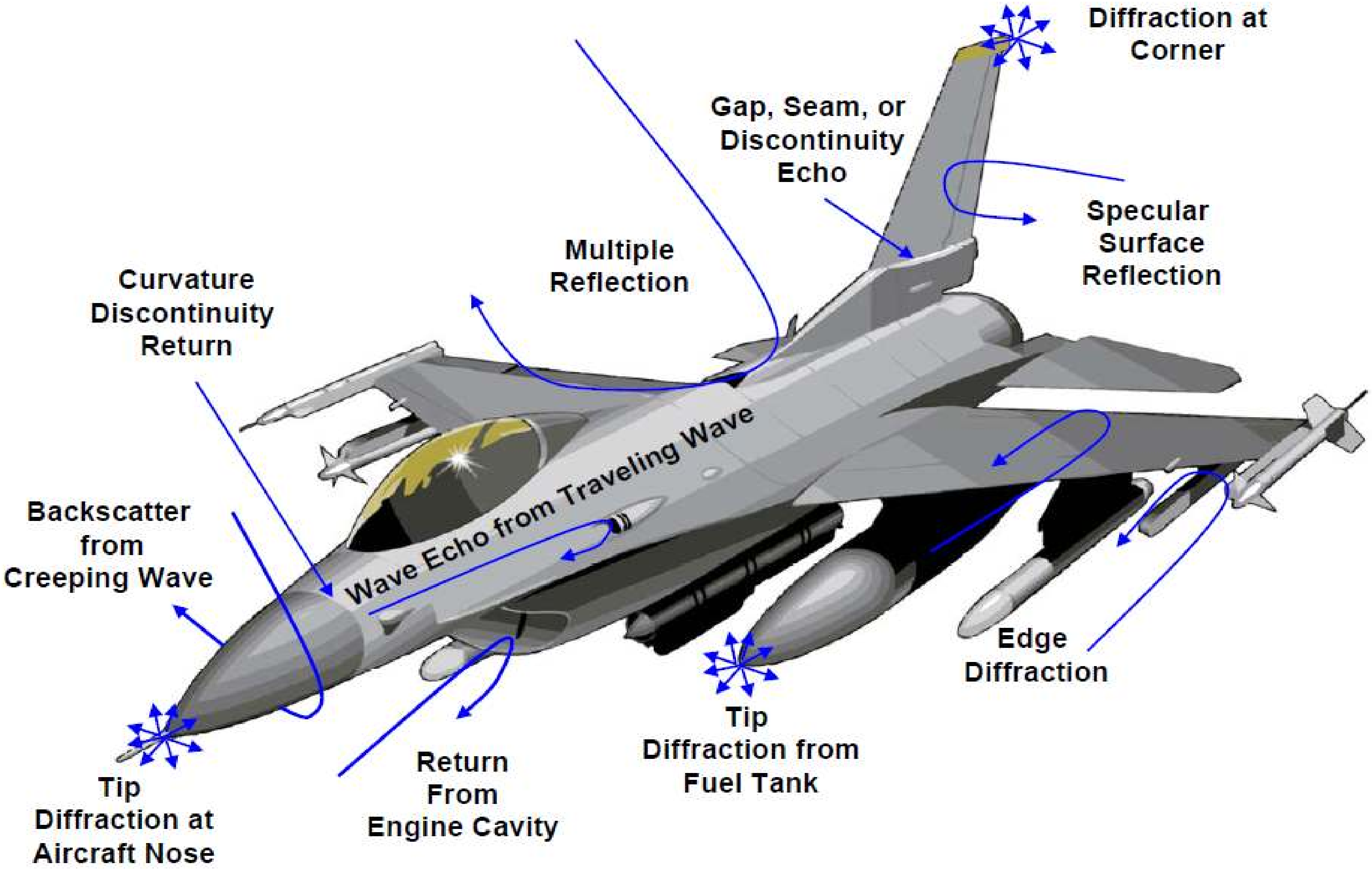
• How can target radar cross section be determined?
  - Measurement
  - Prediction

RCS Target Contributors



- Types of RCS Contributors
  - Structural (Body shape, Control surfaces, etc.)
  - Avionics (Altimeter, Seeker, GPS, etc.)
  - Propulsion (Engine inlets and exhausts, etc.)

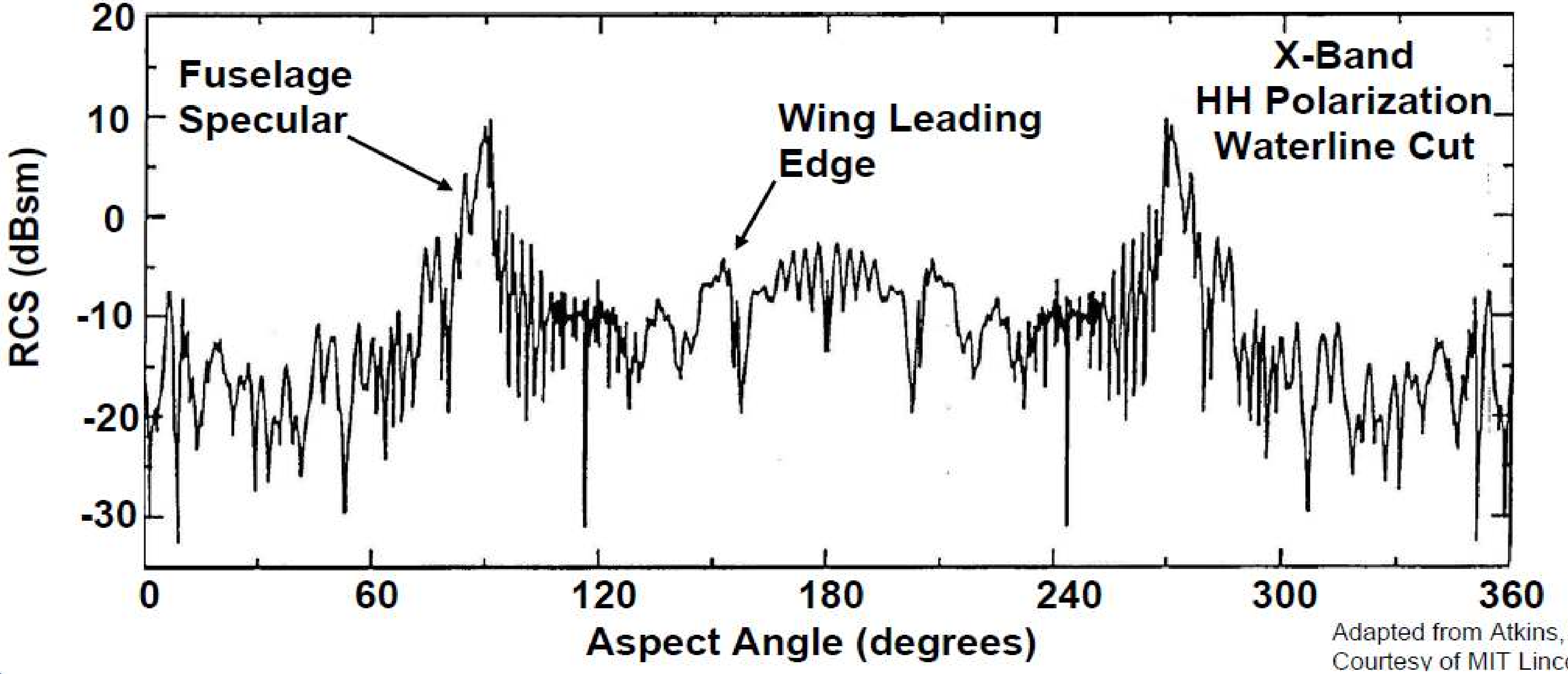
Scattering Mechanisms for an Arbitrary Target



Measured RCS of C-29 Aircraft Model

1/12 Scale Model Measurement

Full Scale C-29
BAE Hawker 125-800

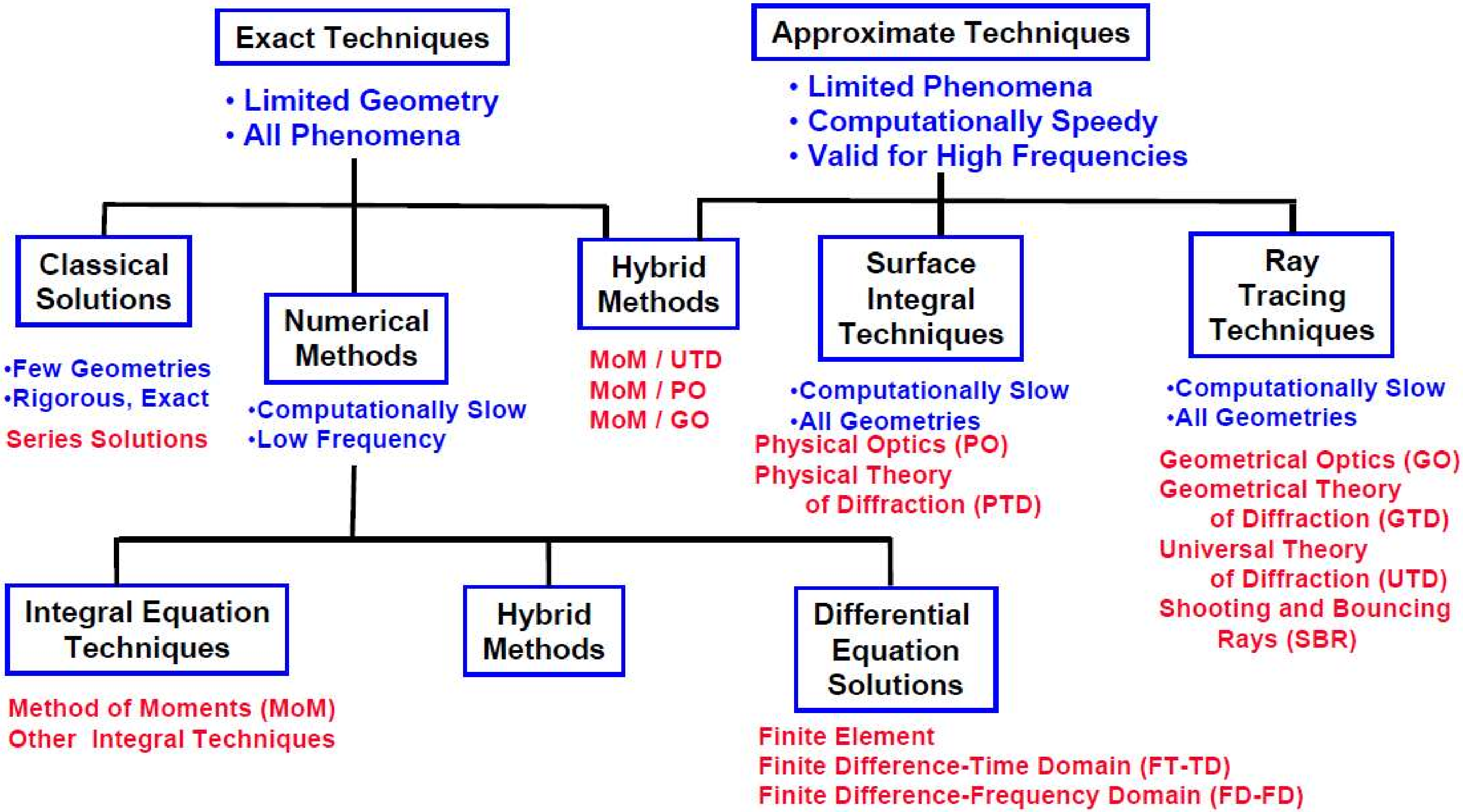


Adapted from Atkins, Reference 5
Courtesy of MIT Lincoln Laboratory

Methods of Radar Cross Section Calculation

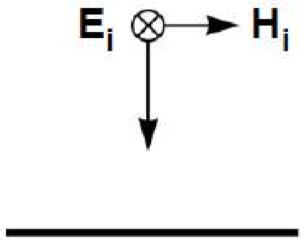
RCS Method	Approach to Determine Surface Currents
Finite Difference-Time Domain (FD-TD)	Solve Differential Form of Maxwell's Equation's for Exact Fields
Method of Moments (MoM)	Solve Integral Form of Maxwell's Equation's for Exact Currents
Geometrical Optics (GO)	Current Contribution Assumed to Vanish Except at Isolated Specular Points
Physical Optics (PO)	Currents Approximated by Tangent Plane Method
Geometrical Theory of Diffraction (GTD)	Geometrical Optics with Added Edge Current Contribution
Physical Theory of Diffraction (PTD)	Physical Optics with Added Edge Current Contribution

RCS Prediction Techniques Family Tree

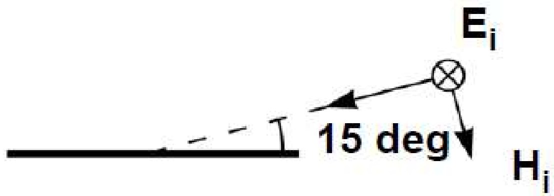


Description of Sample Cases on Video

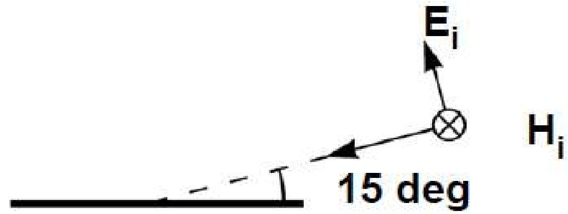
- Case 1



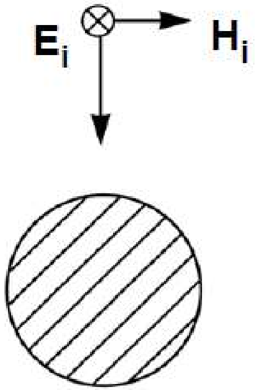
- Case 2



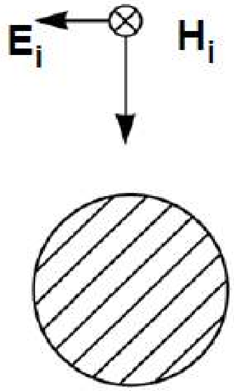
- Case 3



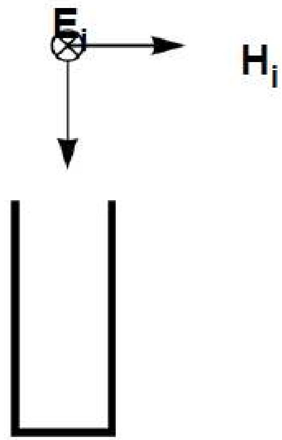
- Case 4



- Case 5

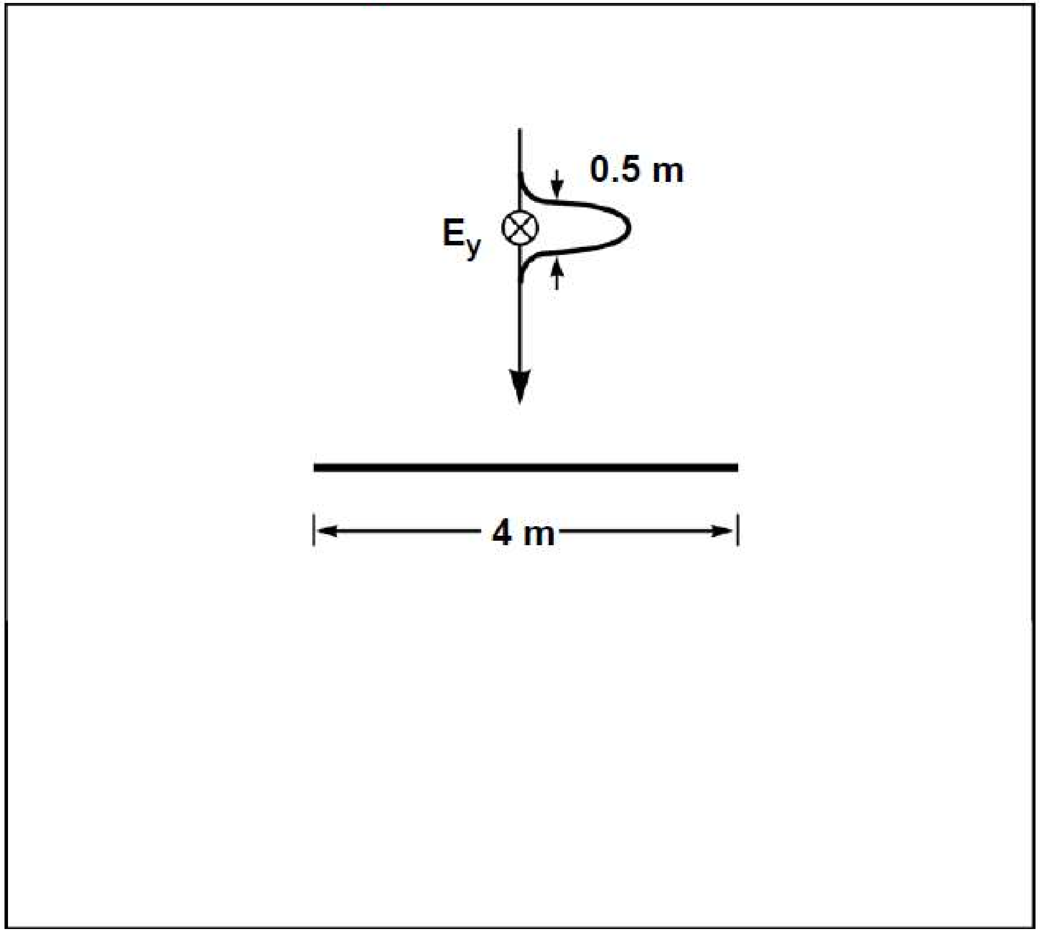


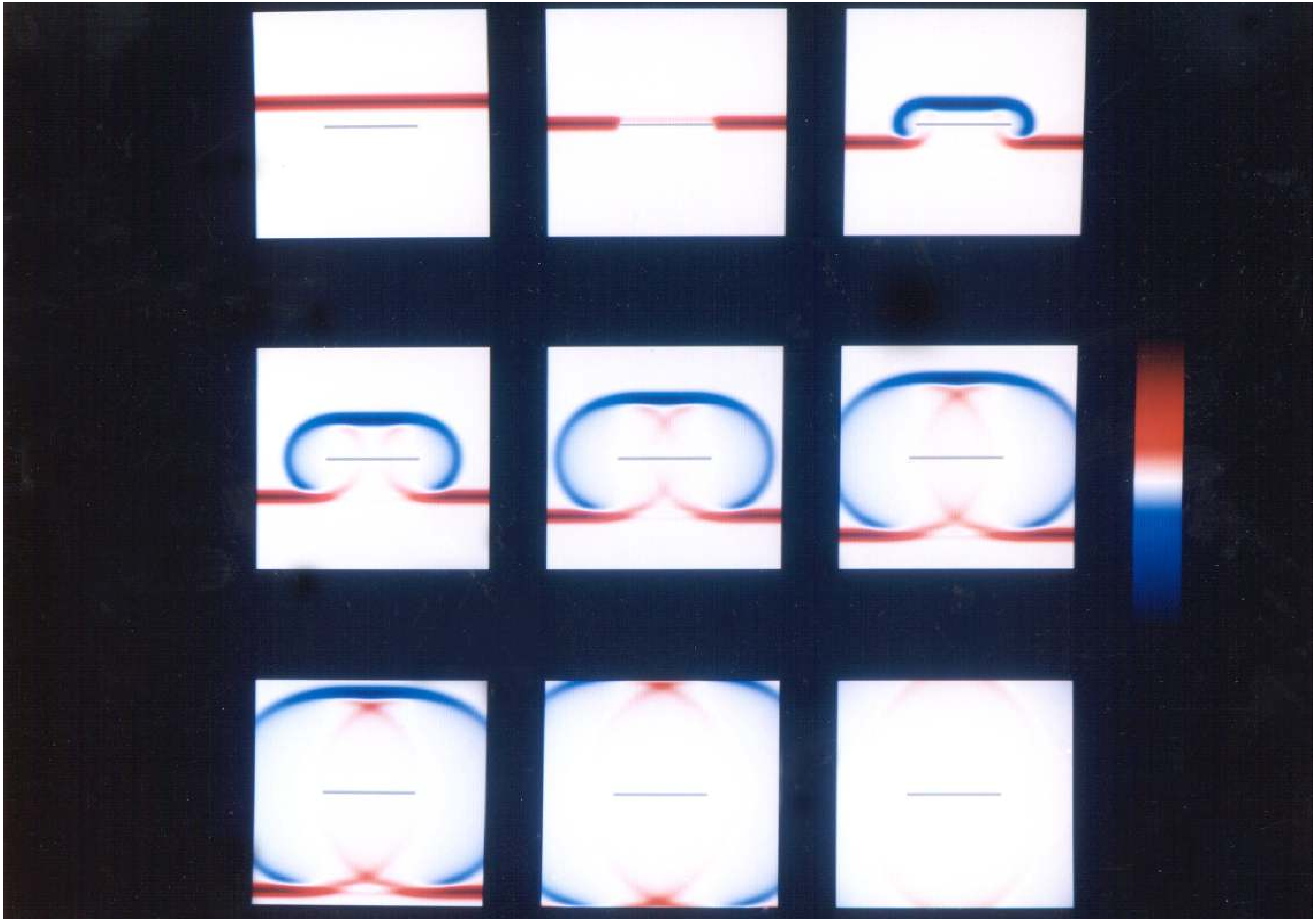
- Case 6



FD-TD Simulation of Scattering by Strip

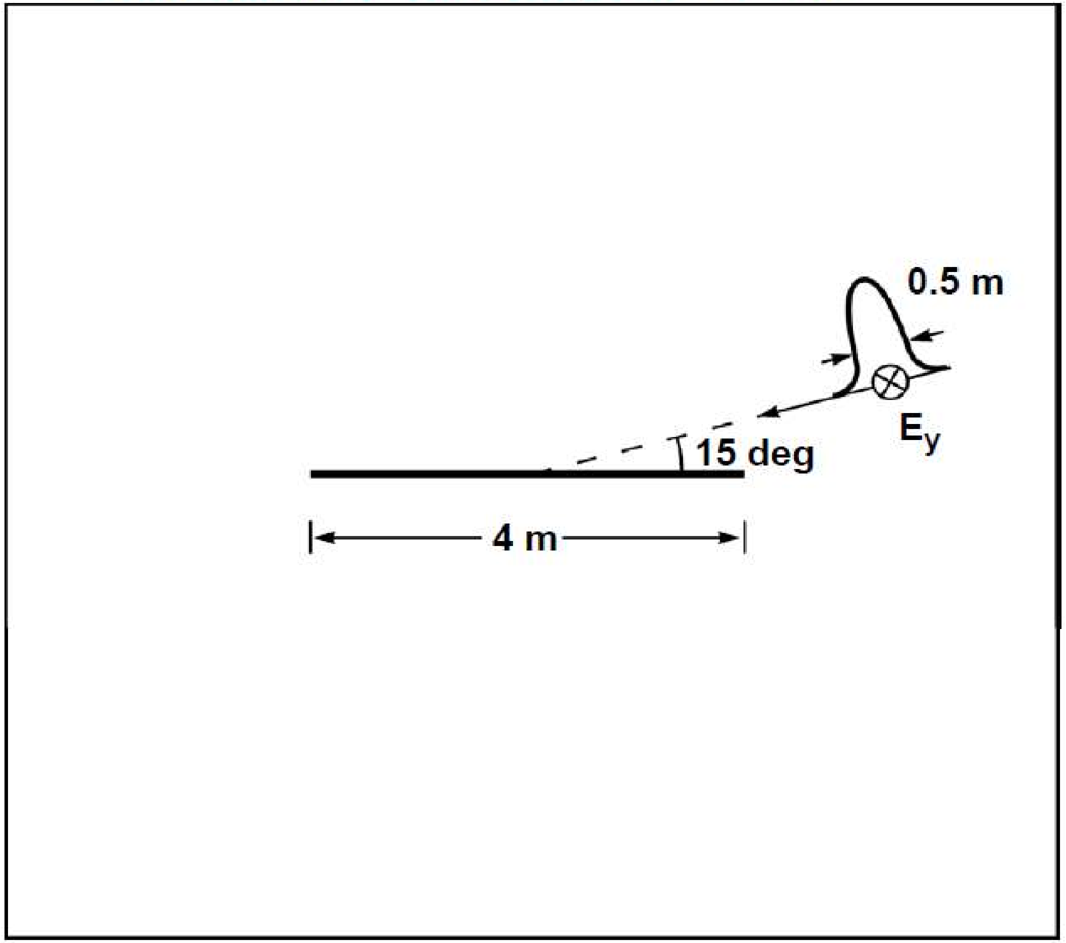
- Gaussian pulse plane wave incidence
- E-field polarization (E_y plotted)
- Phenomena: specular reflection

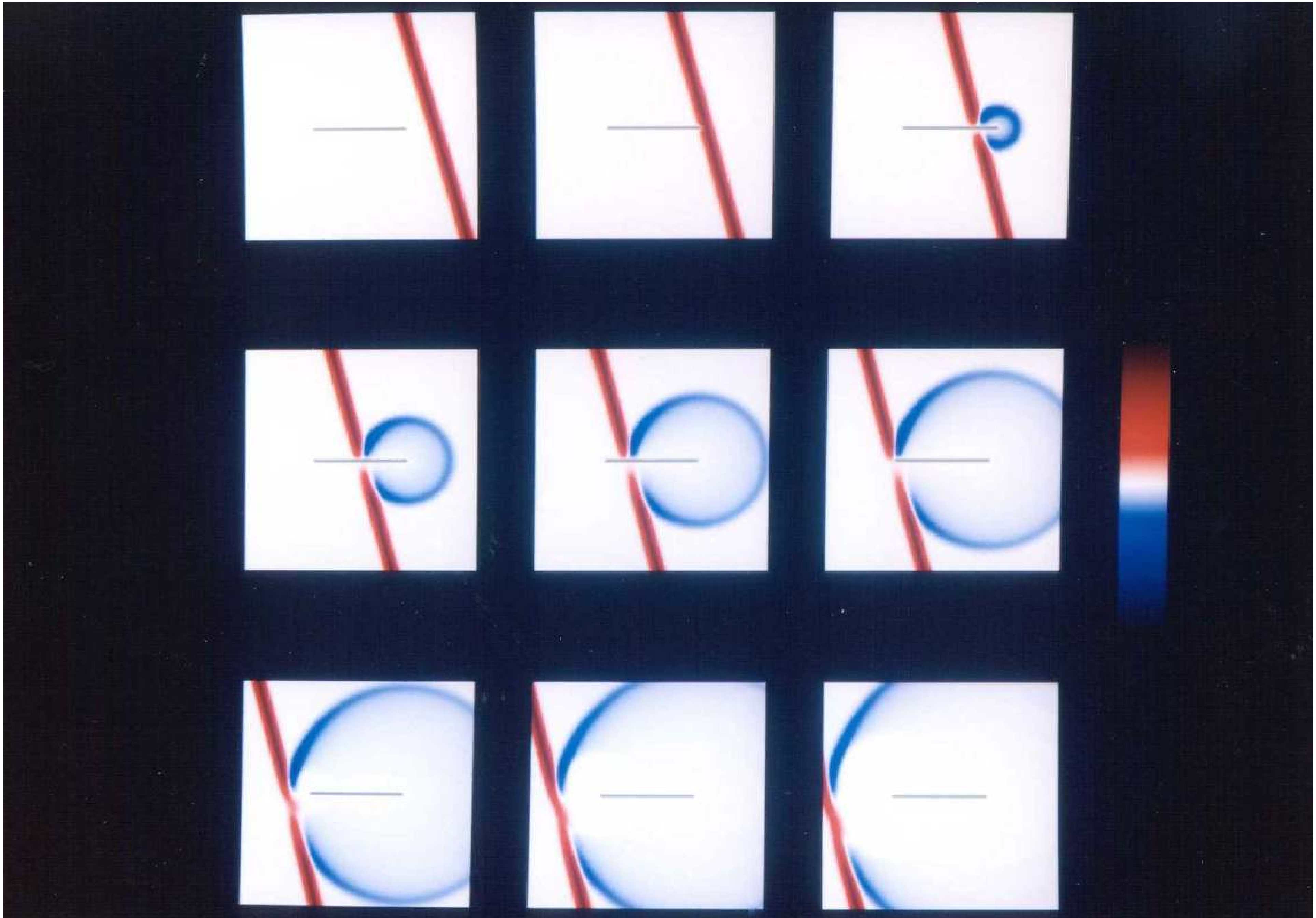




FD-TD Simulation of Scattering by Strip

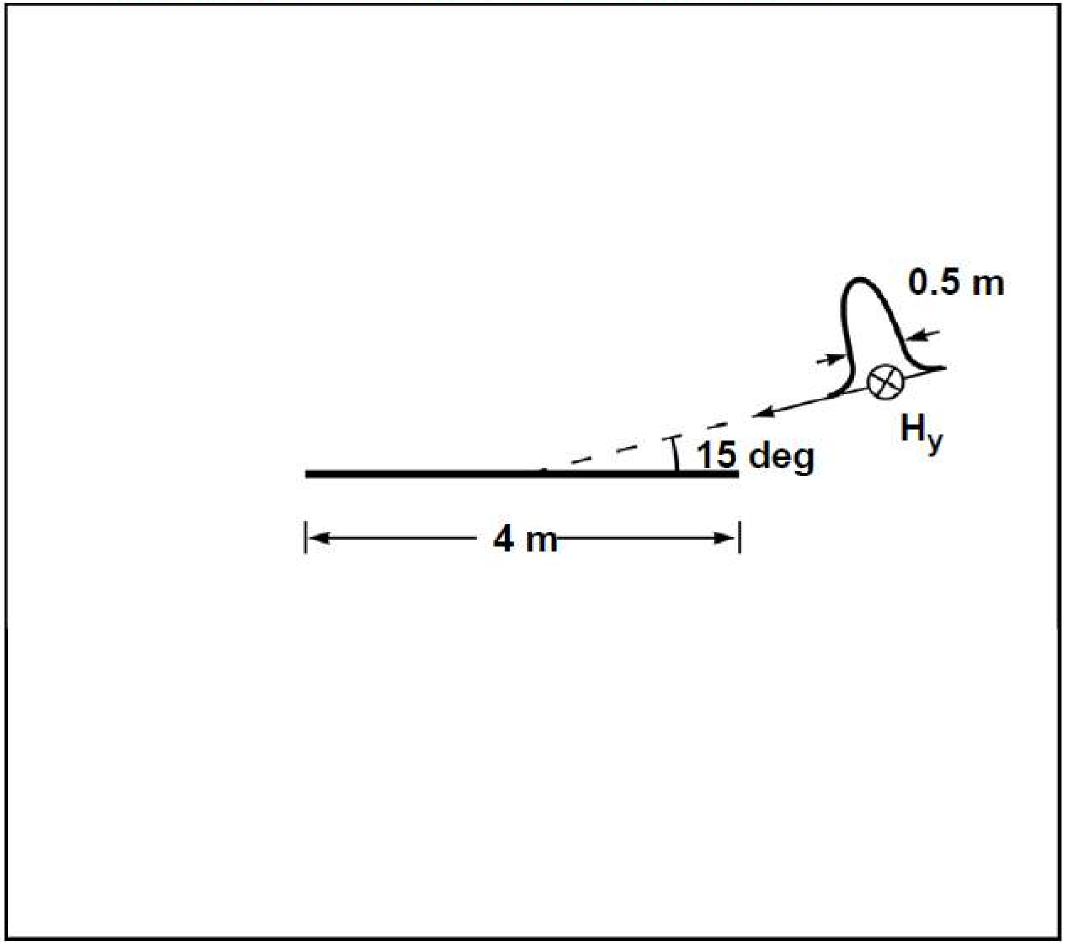
- Gaussian pulse plane wave incidence
- E-field polarization (E_y plotted)
- Phenomena: leading edge diffraction

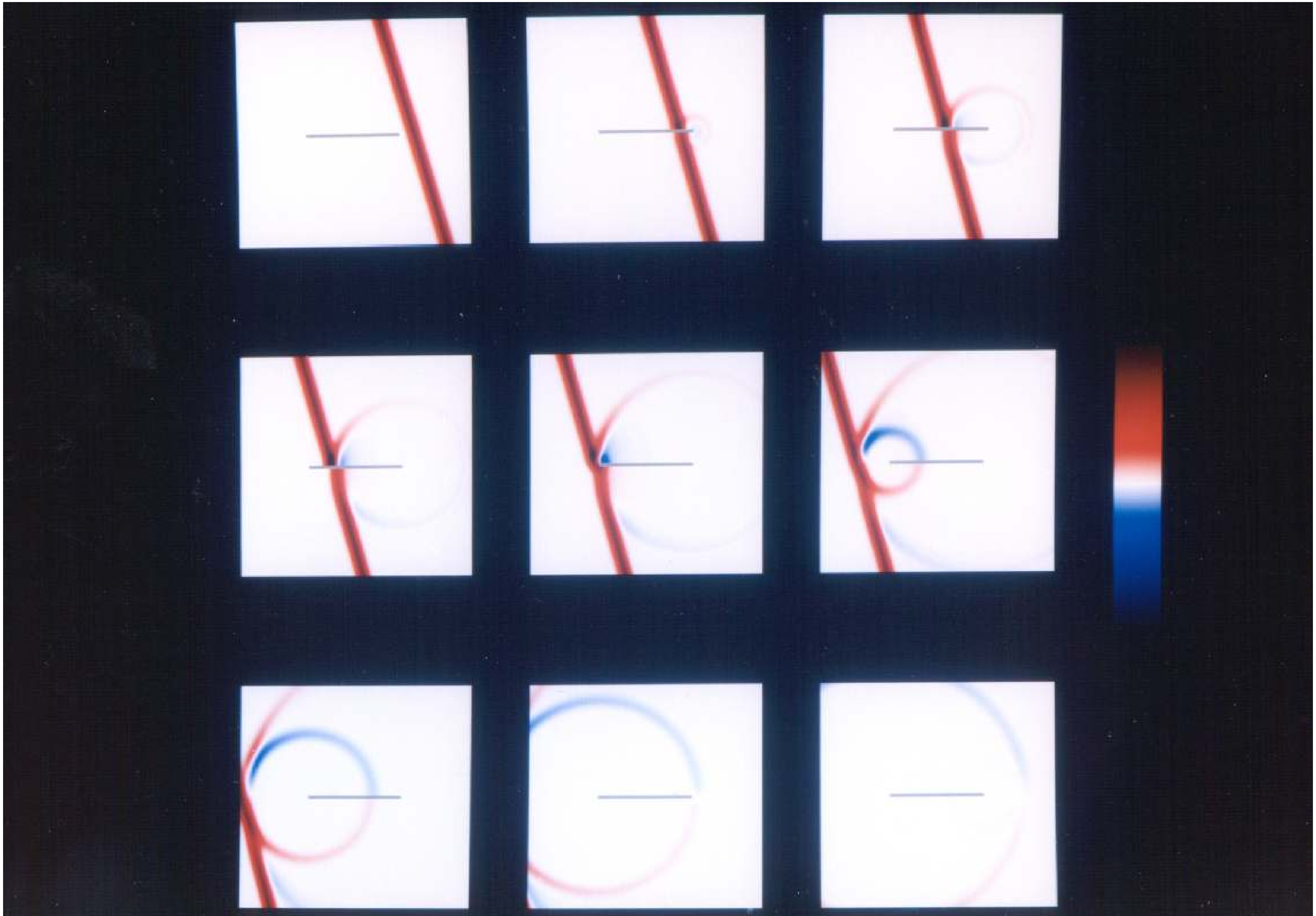




FD-TD Simulation of Scattering by Strip

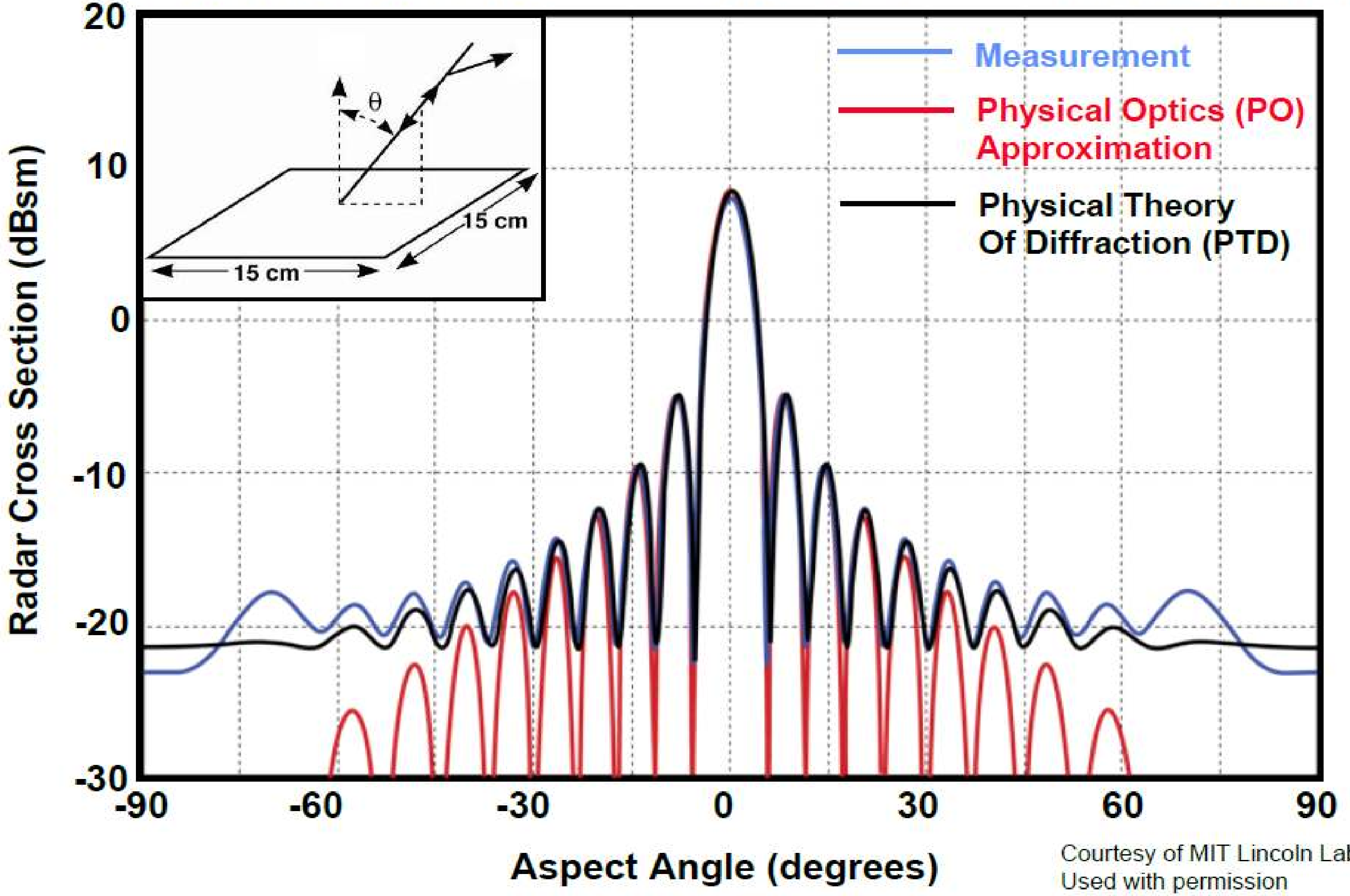
- Gaussian pulse plane wave incidence
- H-field polarization (H_y plotted)
- Phenomena: trailing edge diffraction





Monostatic RCS of a Square Plate

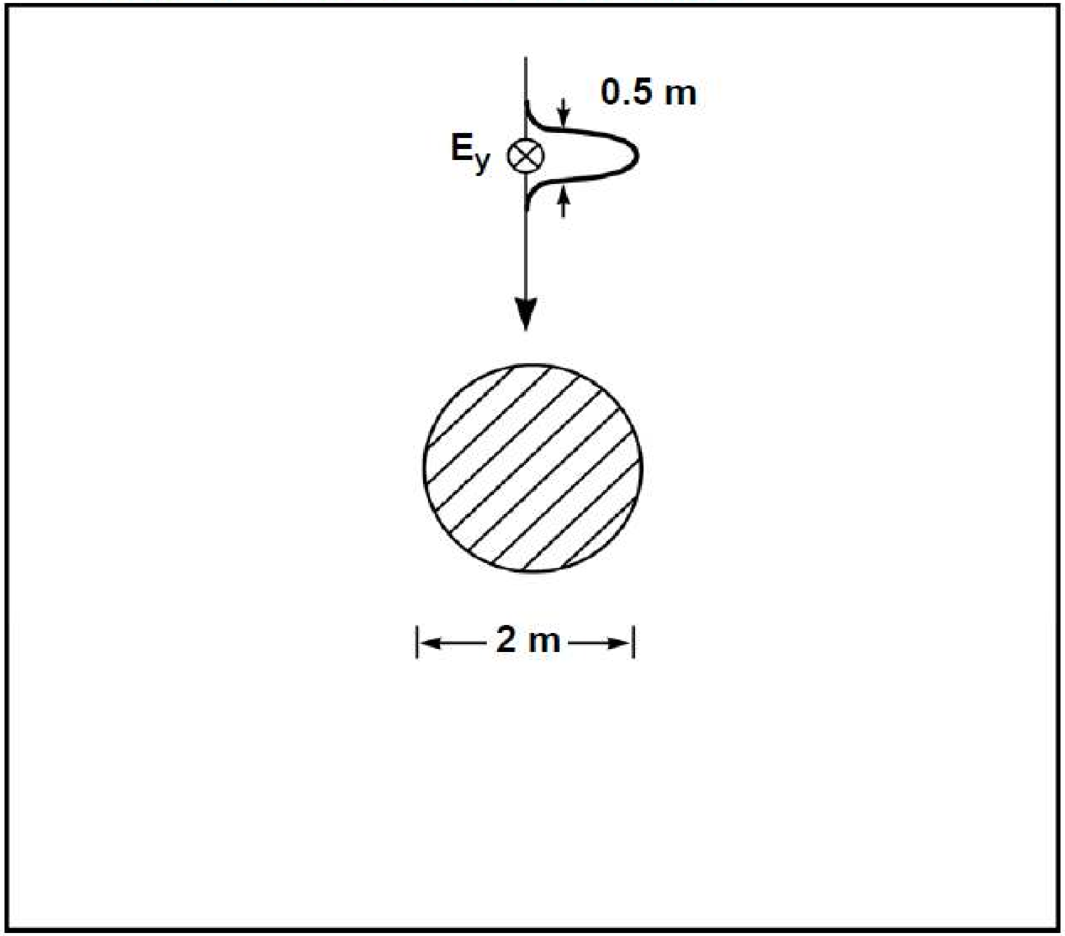
- 15 cm x 15 cm Plate   10.0 GHz   HH Polarization

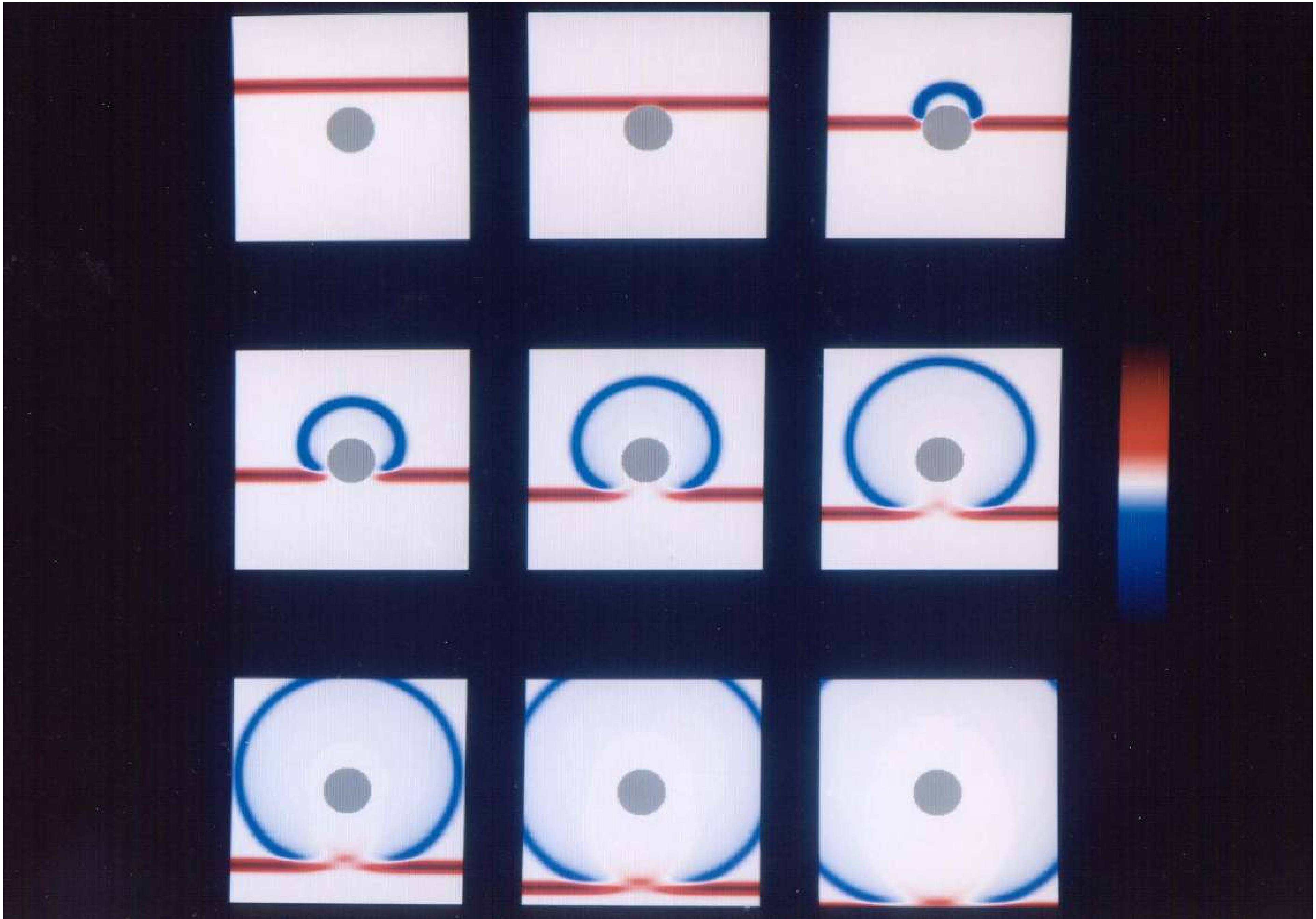


Courtesy of MIT Lincoln Laboratory
Used with permission

FD-TD Simulation of Scattering by Cylinder

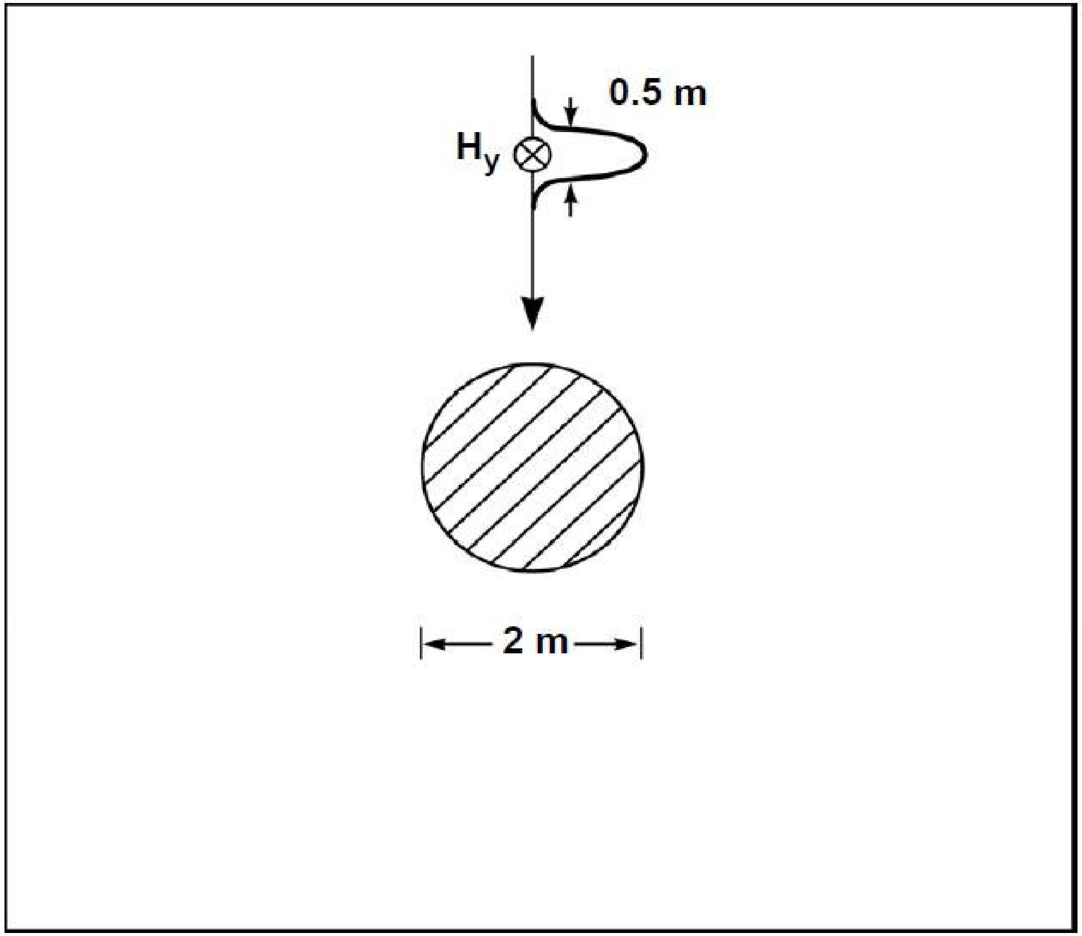
- Gaussian pulse plane wave incidence
- E-field polarization (E_y plotted)
- Phenomena: specular reflection

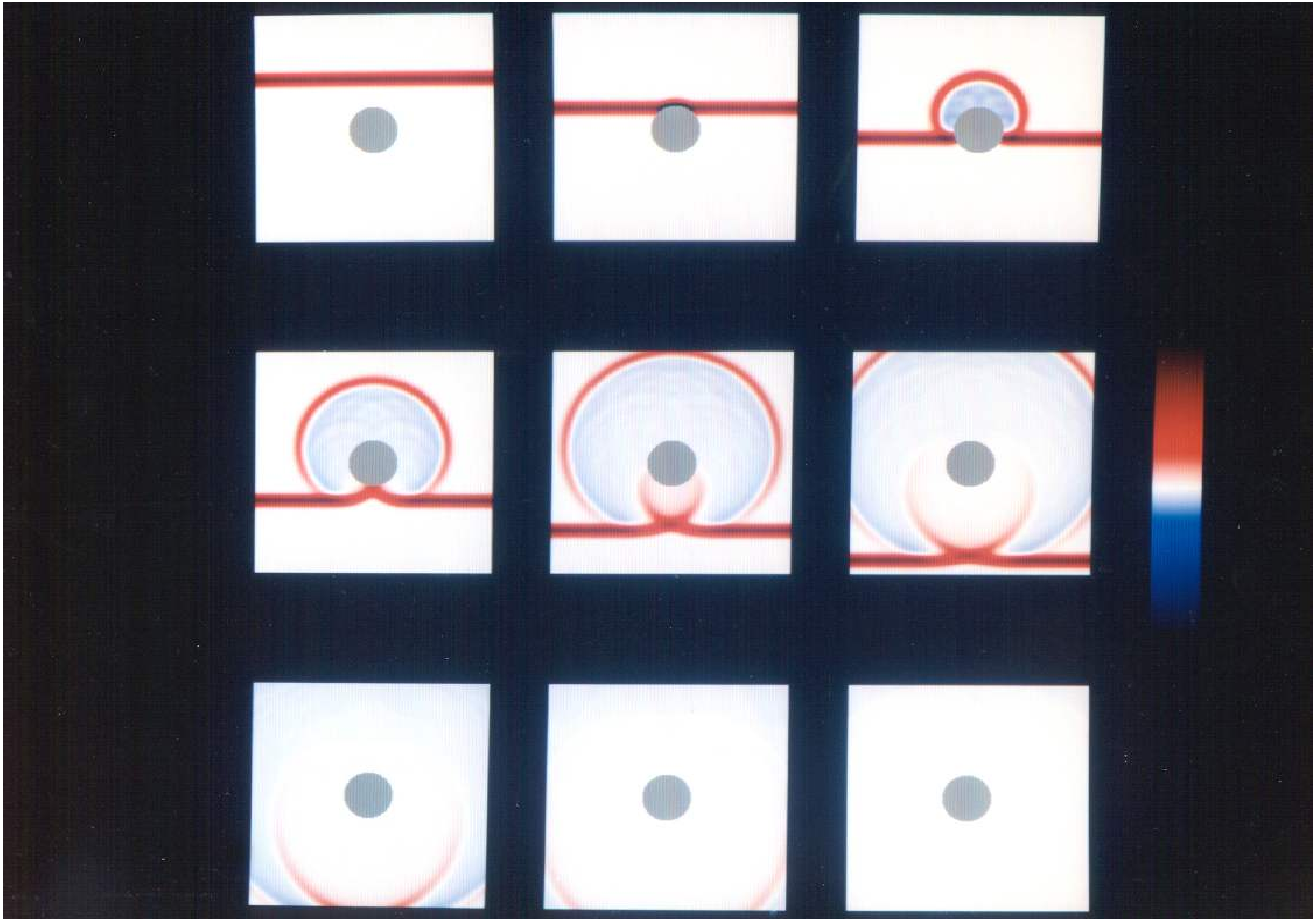




FD-TD Simulation of Scattering by Cylinder

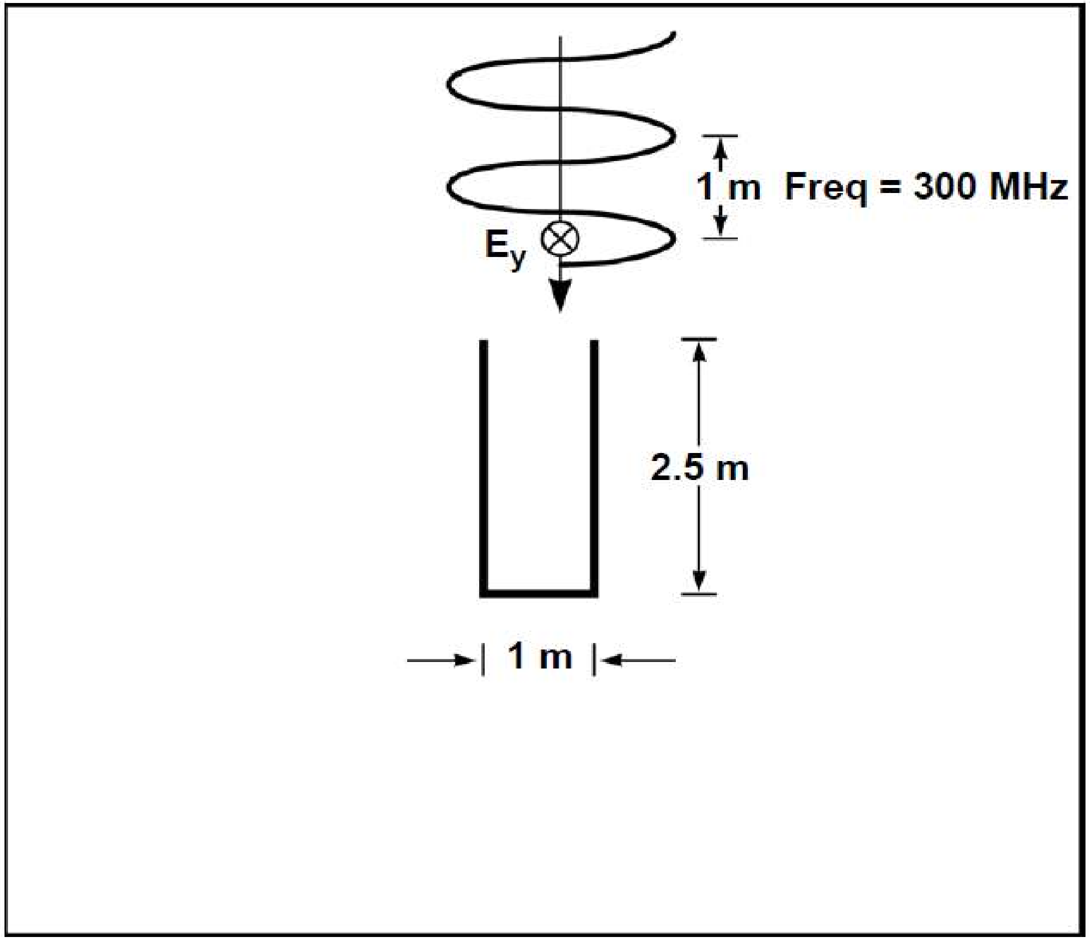
- Gaussian pulse plane wave incidence
- H-field polarization (H_y plotted)
- Phenomena: creeping wave

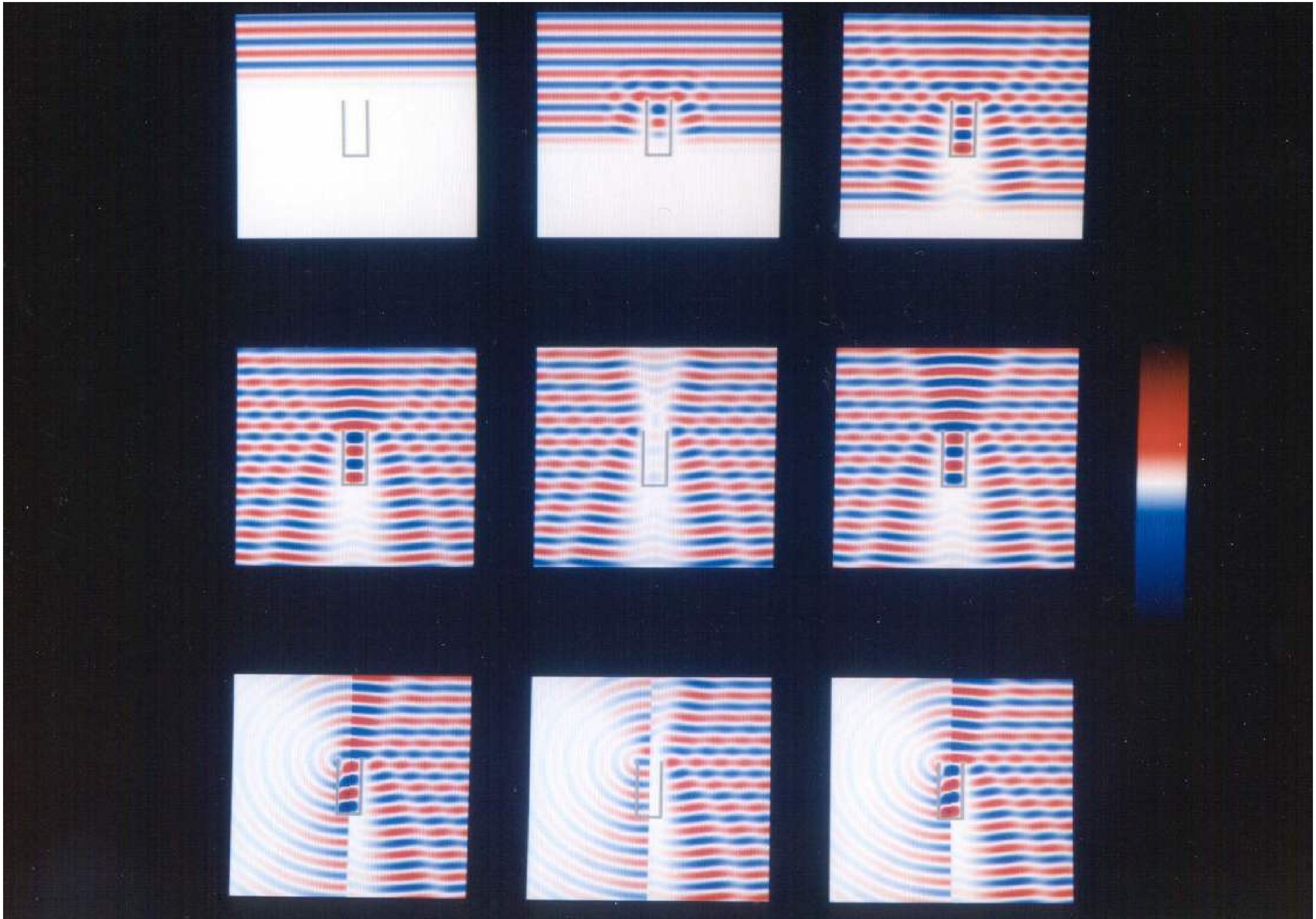




FD-TD Simulation of Scattering by Cavity

- Sinusoidal plane wave incidence
- E-field polarization (E_y plotted)
- Phenomena: standing wave





차　　례

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  - On what do these depend?

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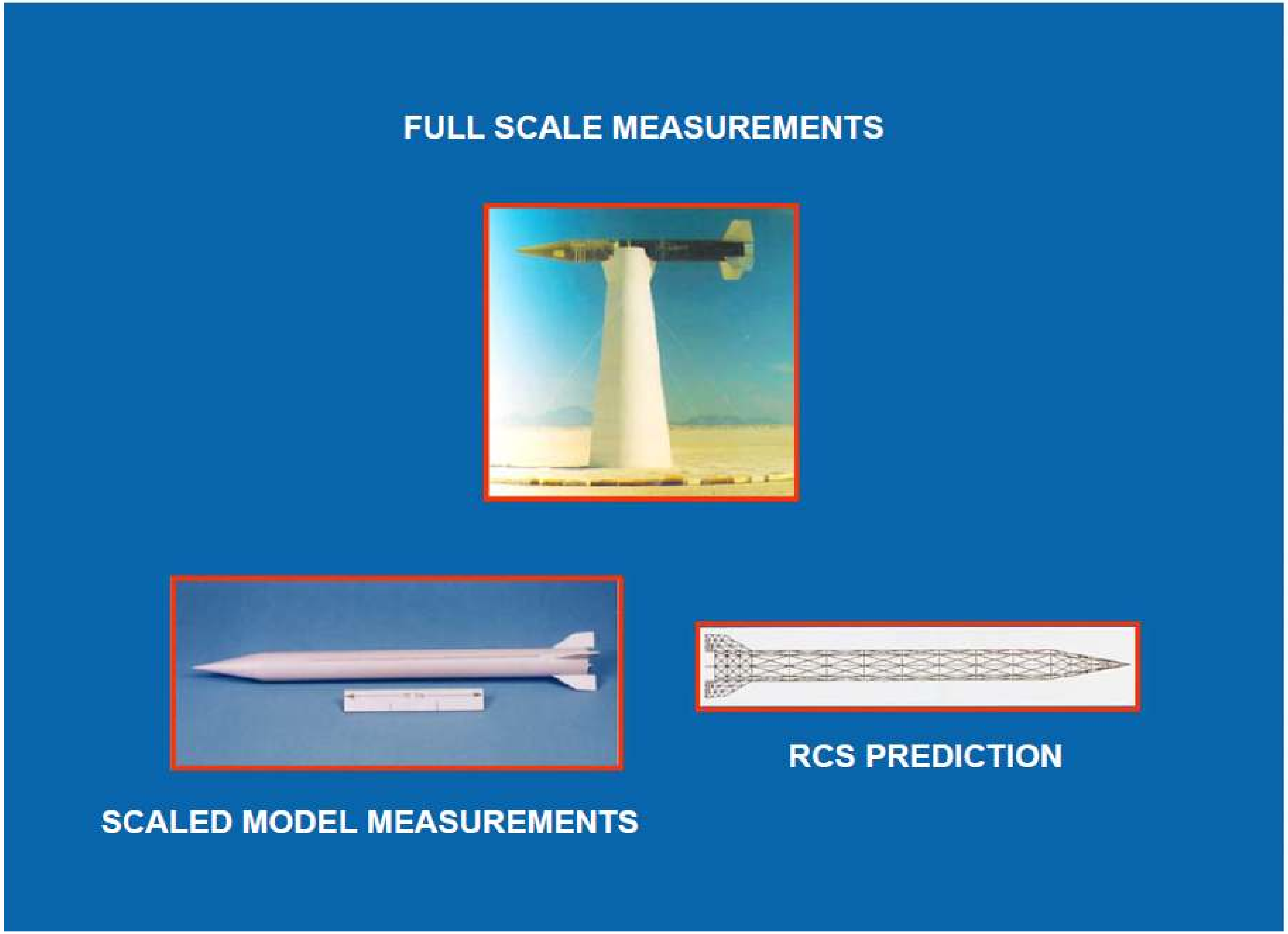
• **How can target radar cross section be determined?**
  - Measurement
  - Prediction

Techniques for RCS Analysis



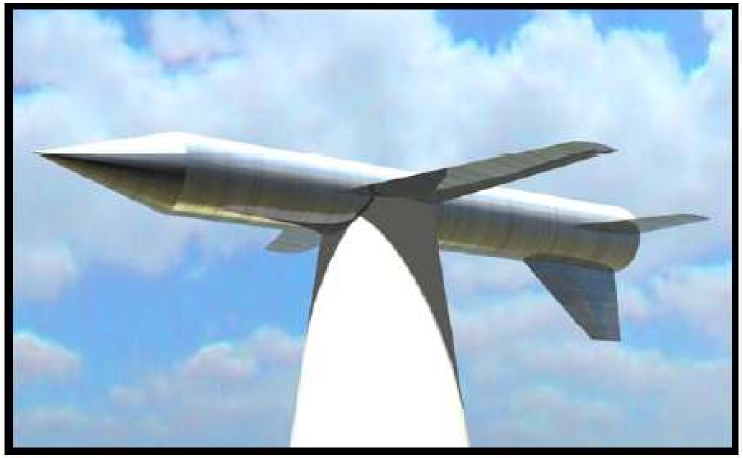
Full Scale Measurements

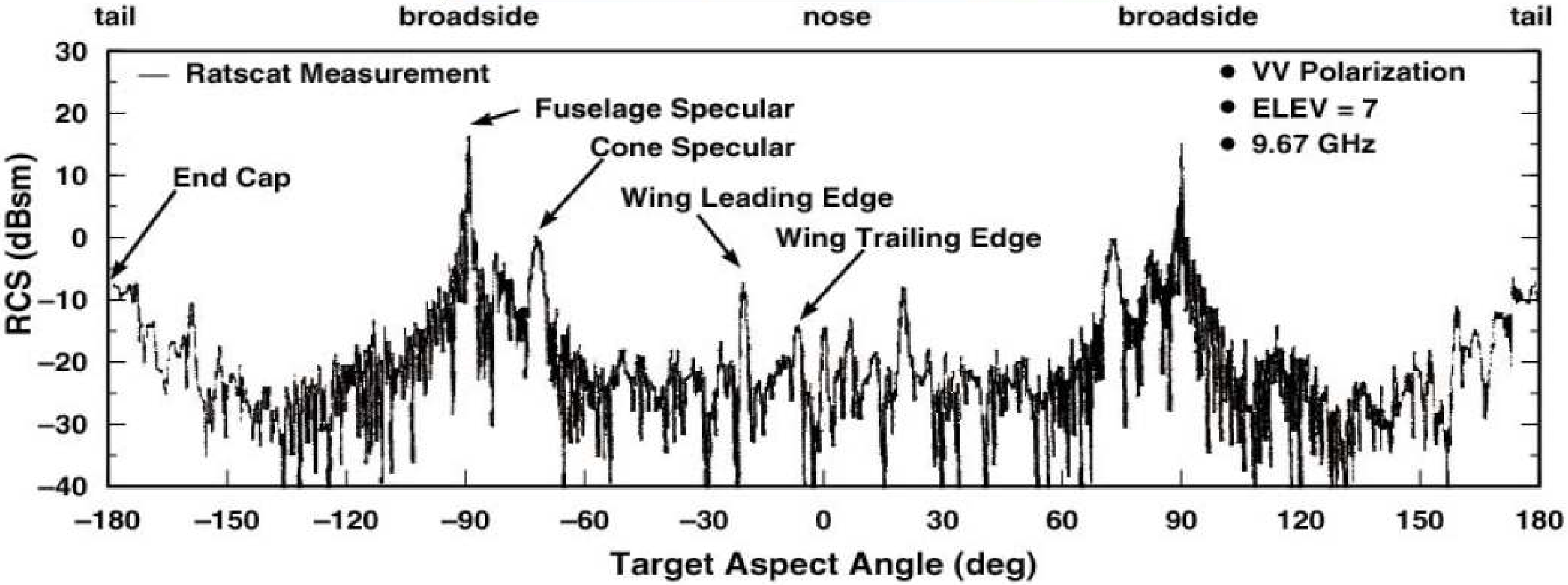
Target on support

- **Foam column mounting**
  - **Dielectric properties of styrofoam close to those of free space**
- **Metal pylon mounting**
  - **Metal pylon shaped to reduce radar reflections**
  - **Background subtraction can be used**

Derived from: http://www.af.mil/shared/media/photodb/photos/050805-F-0000S-003.jpg

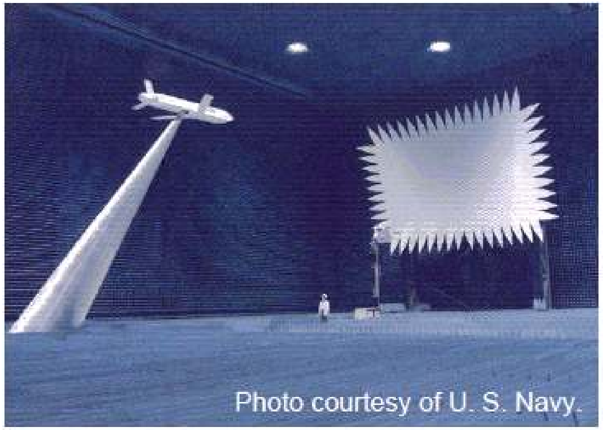
Johnson Generic Aircraft Model (JGAM)

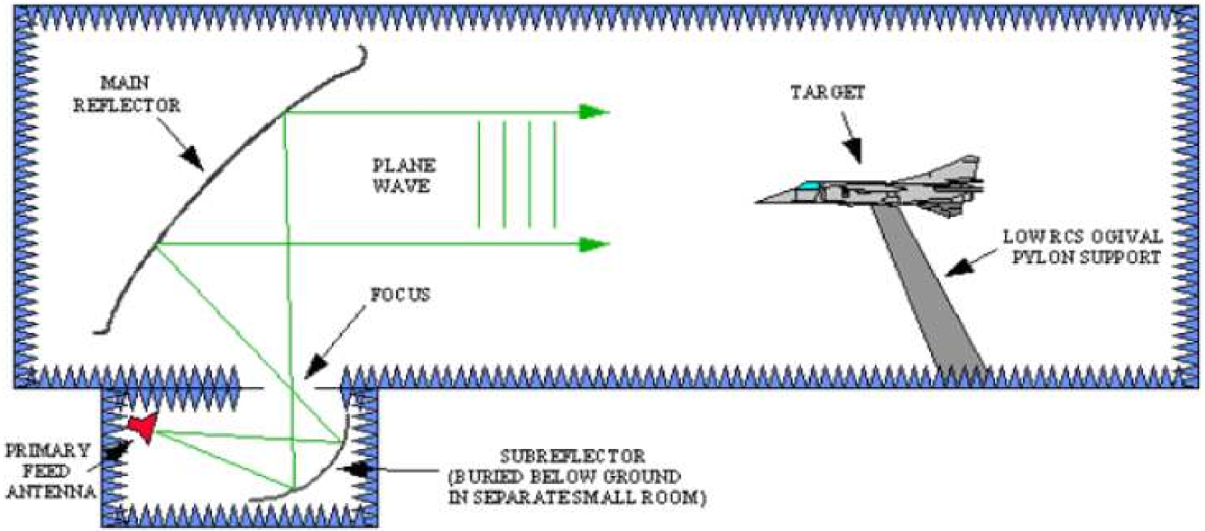




Compact Range RCS Measurement

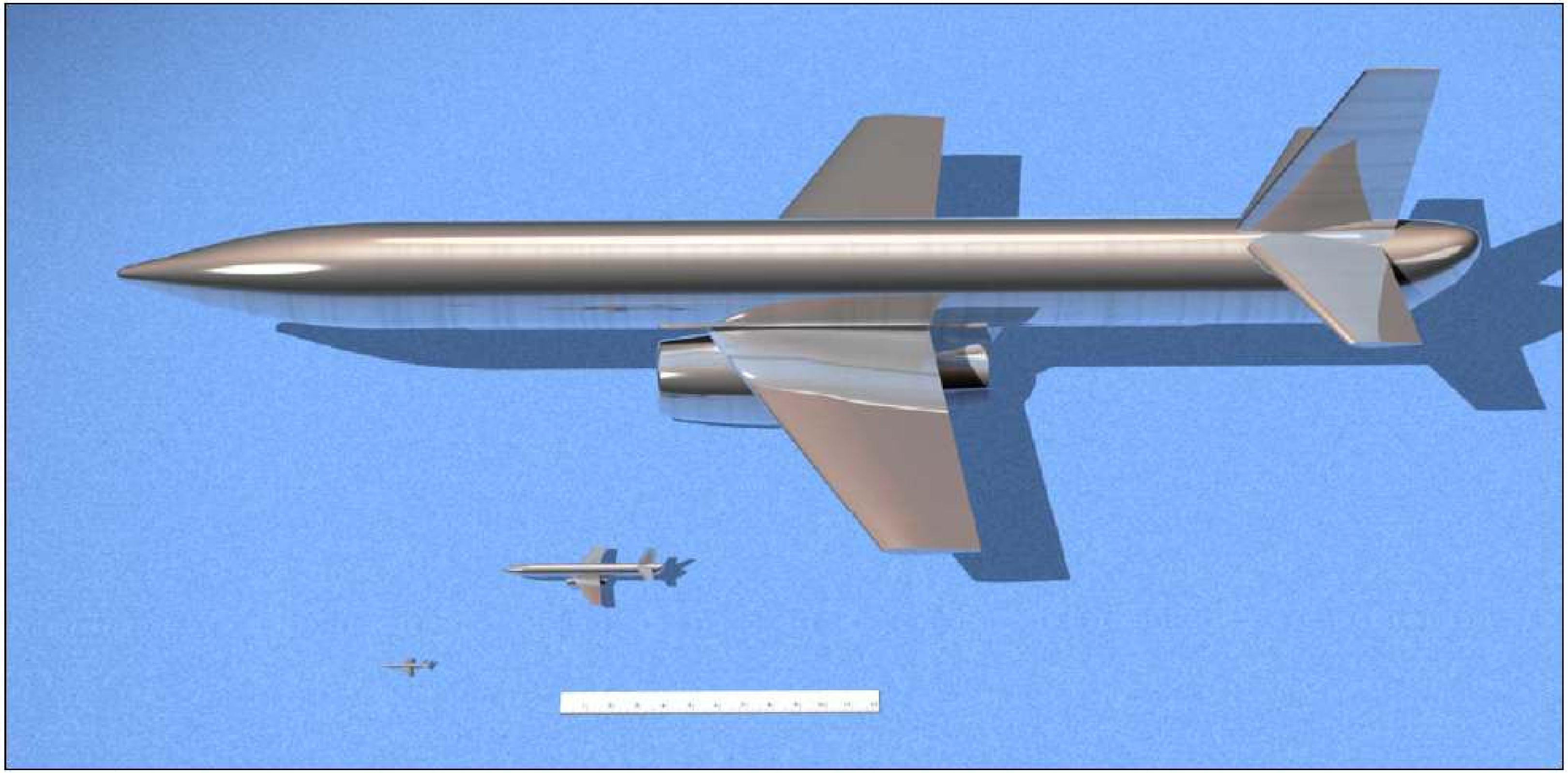
Radar Reflectivity Laboratory (Pt. Mugu) / AFRL Compact Range (WPAFB)

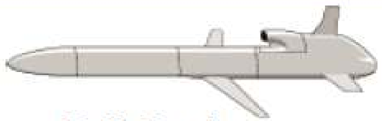




Scale Model Measurement

MQM-107 Drone in 0.29, 0.034, and 0.01 scaled sizes





Full Scale → **Scale Factor** → **Subscale**

Full Scale: Measure at frequency f

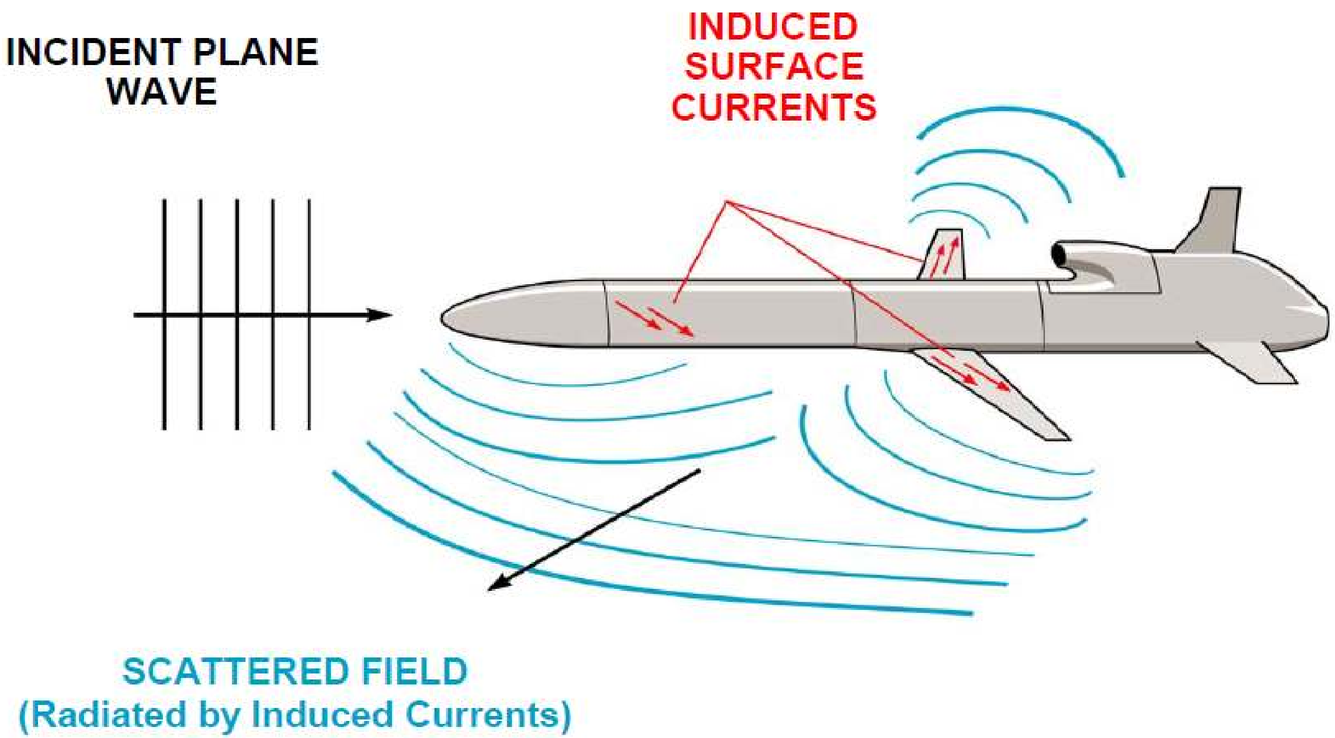
Scale Factor: S (Reduced Size)

Subscale: Measure at frequency S x F

Scaling of Targets for RCS Measurements

QUANTITY	FULL-SCALE	SUBSCALE
LENGTH	L	$L' = L/S$
TIME	t	$t' = t/S$
FREQUENCY	f	$f' = Sf$
WAVELENGTH	λ	$\lambda' = \lambda/S$
CONDUCTIVITY	g	$g' = Sg$
PERMITTIVITY	ε	$\varepsilon' = \varepsilon$
PERMEABILITY	μ	$\mu' = \mu$
RCS	σ	$\sigma' = \sigma/S^2$

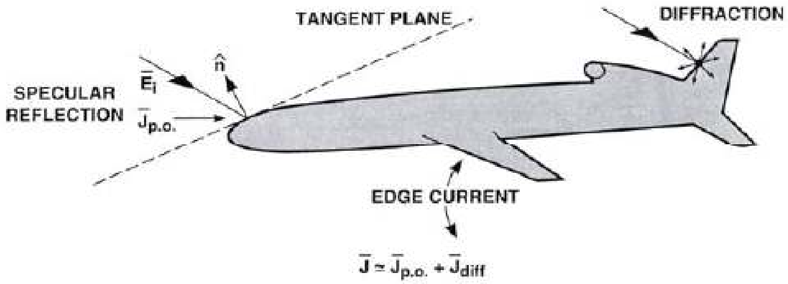
Electromagnetic Scattering



- TWO STEP PROCESS TO DETERMINE SCATTERED FIELD
  - DETERMINE INDUCED SURFACE CURRENTS
  - CALCULATE FIELD RADIATED BY CURRENTS

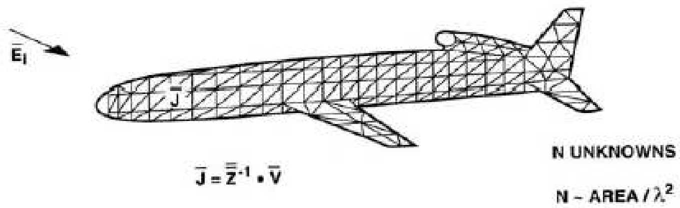
RCS Prediction Approaches

- **High frequency approximations**
  - Physical theory of diffraction



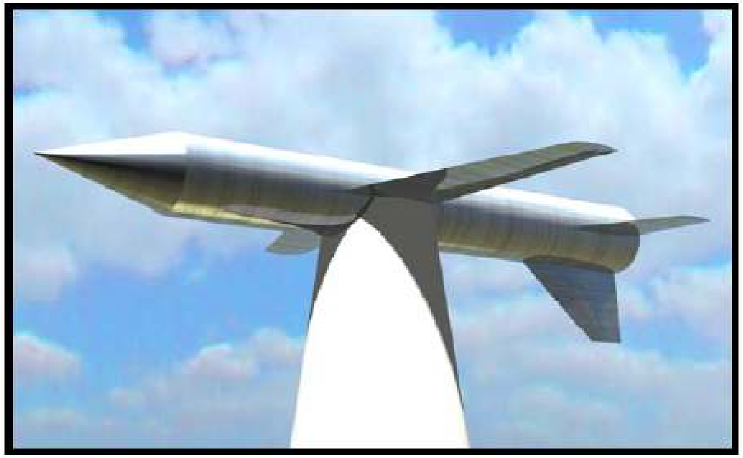
- Advantages
  - Reduced computational requirements
  - Arbitrary, complex geometries
- Disadvantages
  - Neglects some scattering
  - Applicable only to large, smooth geometries
- Codes
  - Xpatch

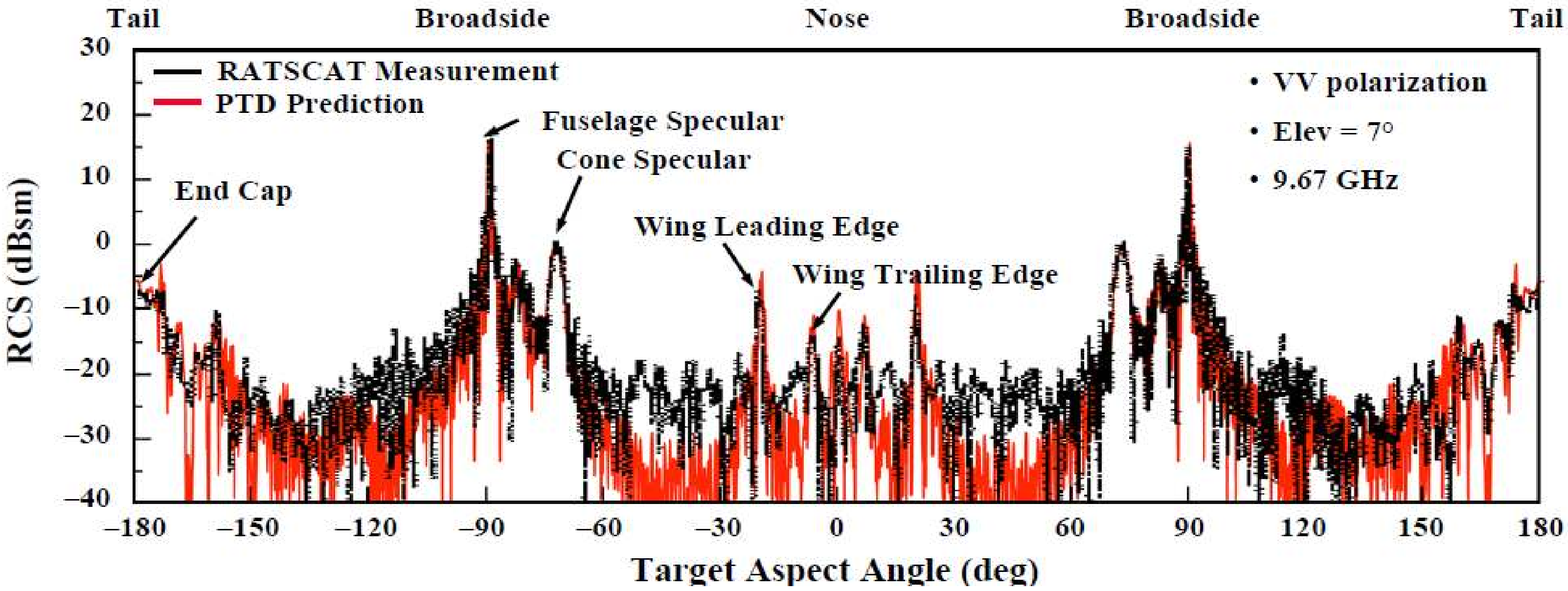
- **Exact numerical approaches**
  - Method of Moments



- Advantages
  - Exact formulation
- Disadvantages
  - Computationally intensive
- Codes
  - CARLOS
  - CICERO (Body of revolution)
  - FISC
  - FERM

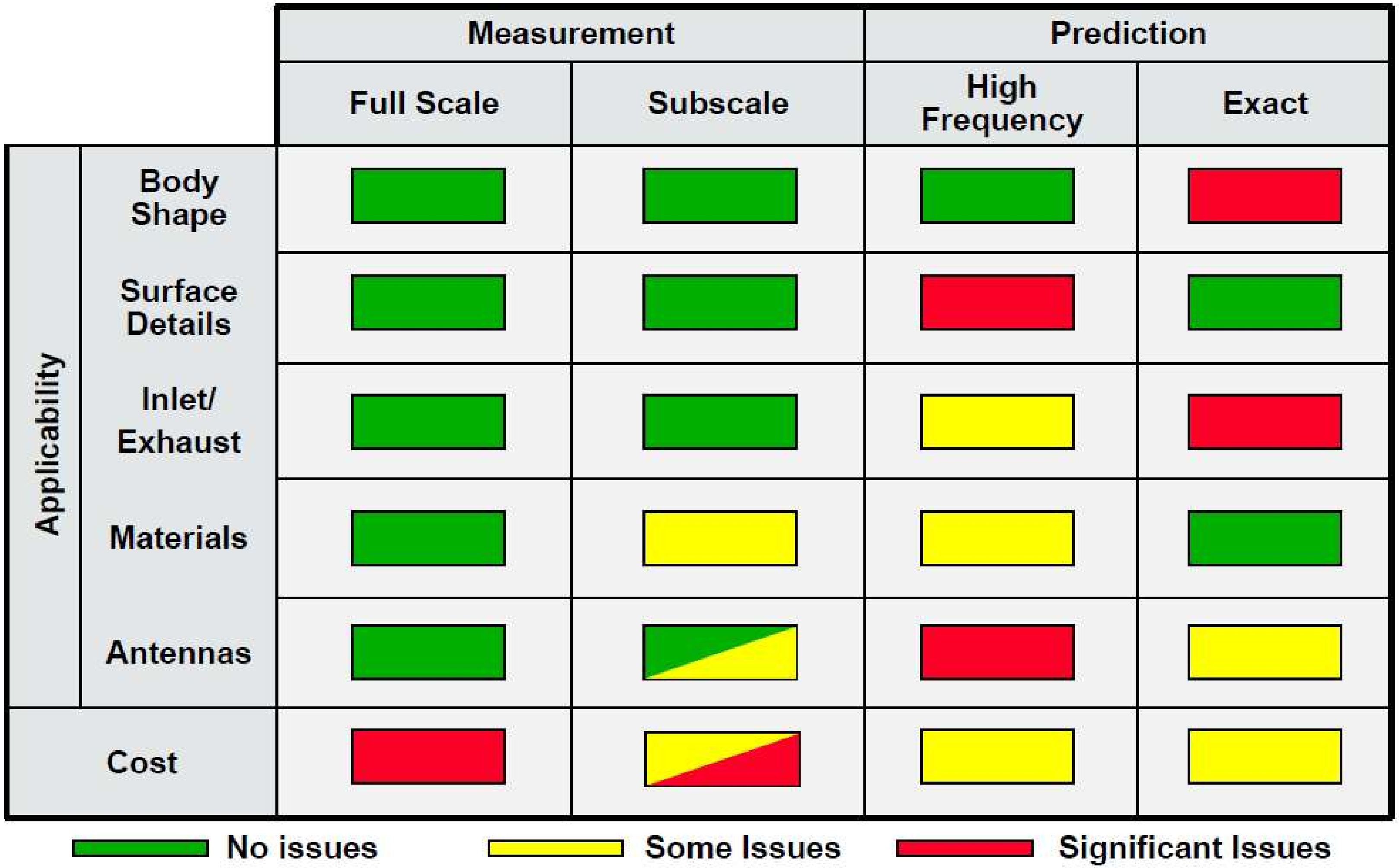
Measured and Calculated RCS of JGAM





Signature Analysis Approaches

X-band air vehicle targets



Q & A