TERMINAL HOMING STUDY

CONTRACT CD 2-82

STUDY PROGRESS REPORT

PRESENTED TO

DIRECTORATE OF COMBAT DEVELOPMENTS

FORT SILL, OKLAHOMA

OCTOBER 26, 1982

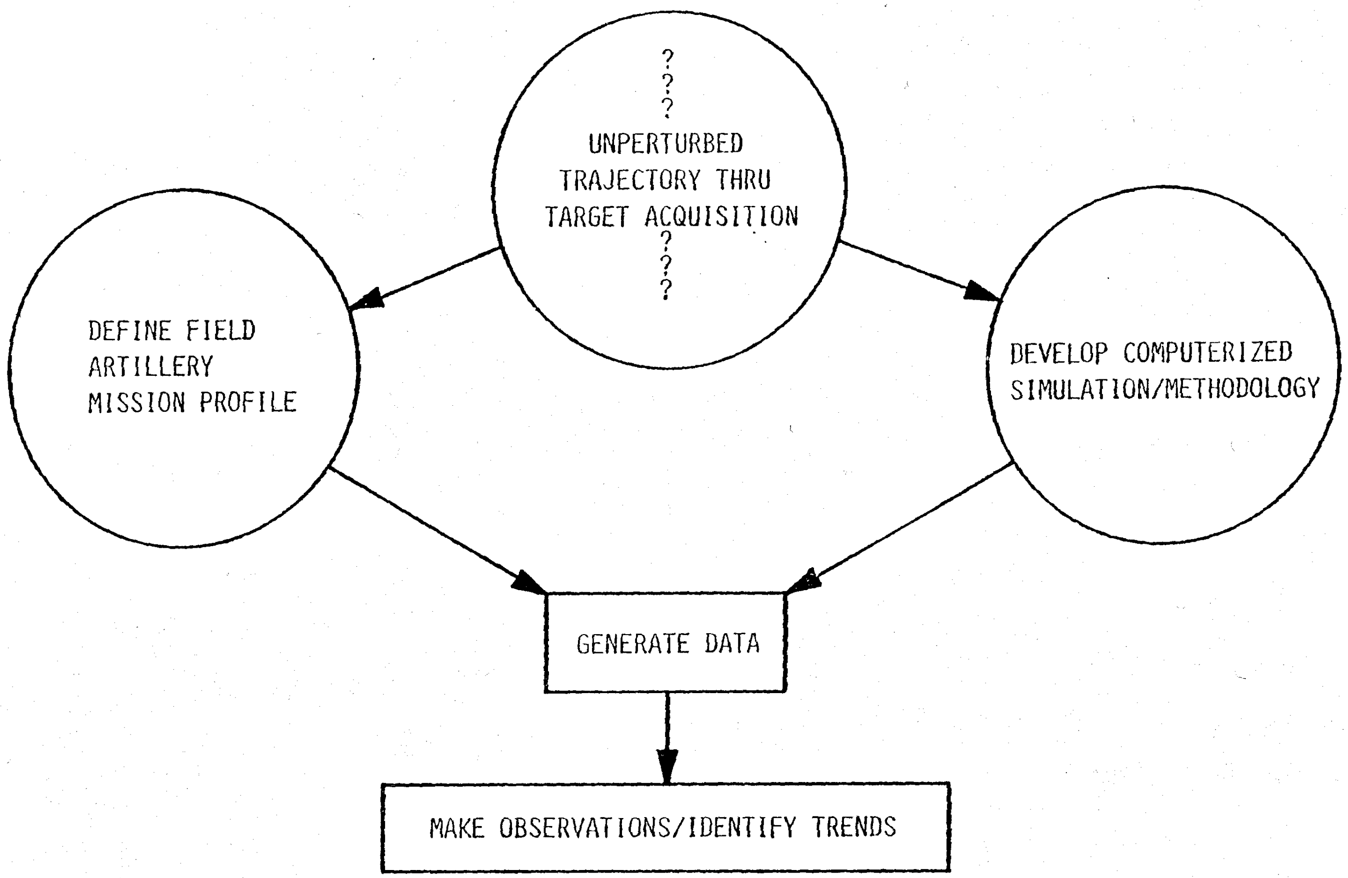
Bendix Guidance Systems Division

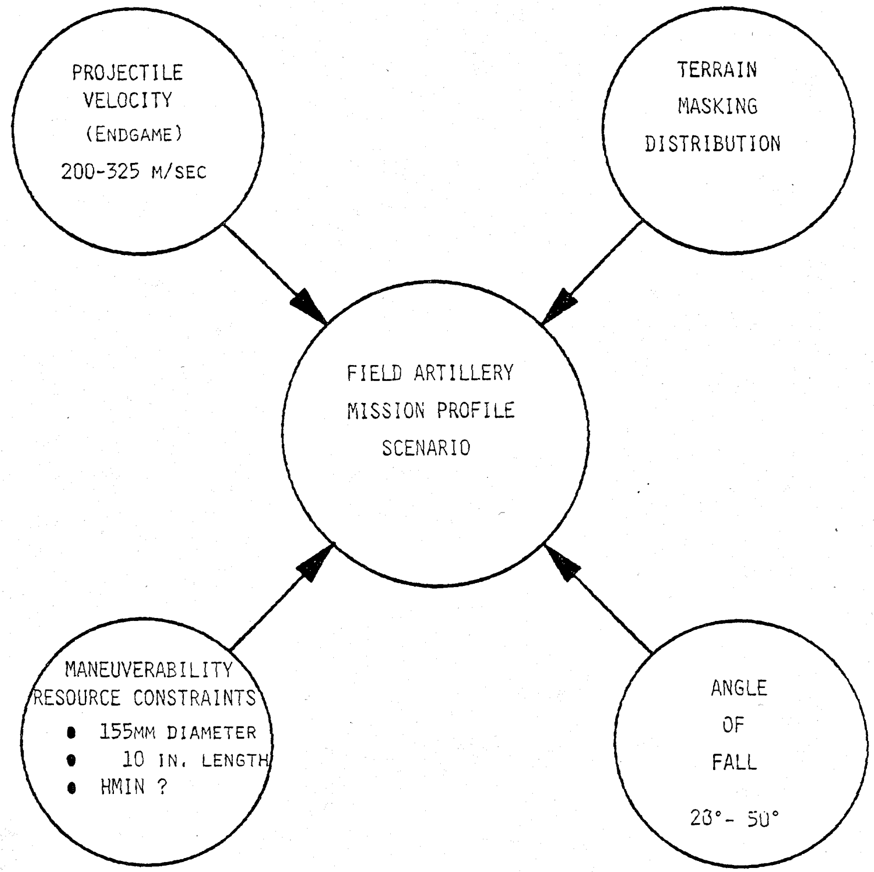
PRESENTATION OUTLINE

- REVIEW 1ST STUDY PROGRESS REPORT
- INTRODUCE SUBSEQUENT EFFORT
- METHODOLOGY DEVELOPMENT
  - TWO DIMENSIONAL RASTER SCAN
  - SIGNAL-TO-INTERFERENCE
  - PROBABILITY OF ACQUISITION
  - CONSTANT RADIUS MANEUVER
- DATA GENERATION
- OBSERVATIONS/TRENDS/CONCLUSIONS

DESIRED TECHNOLOGY CHARACTERISTICS

- ALL WEATHER CAPABILITY
- DAY/NIGHT CAPABILITY
- AUTONOMOUS
- INHERENTLY LOAL
- HIGH OBSCURANT PENETRABILITY
- SUFFICIENTLY MATURE FOR 1990 IOC
- AFFORDABLE

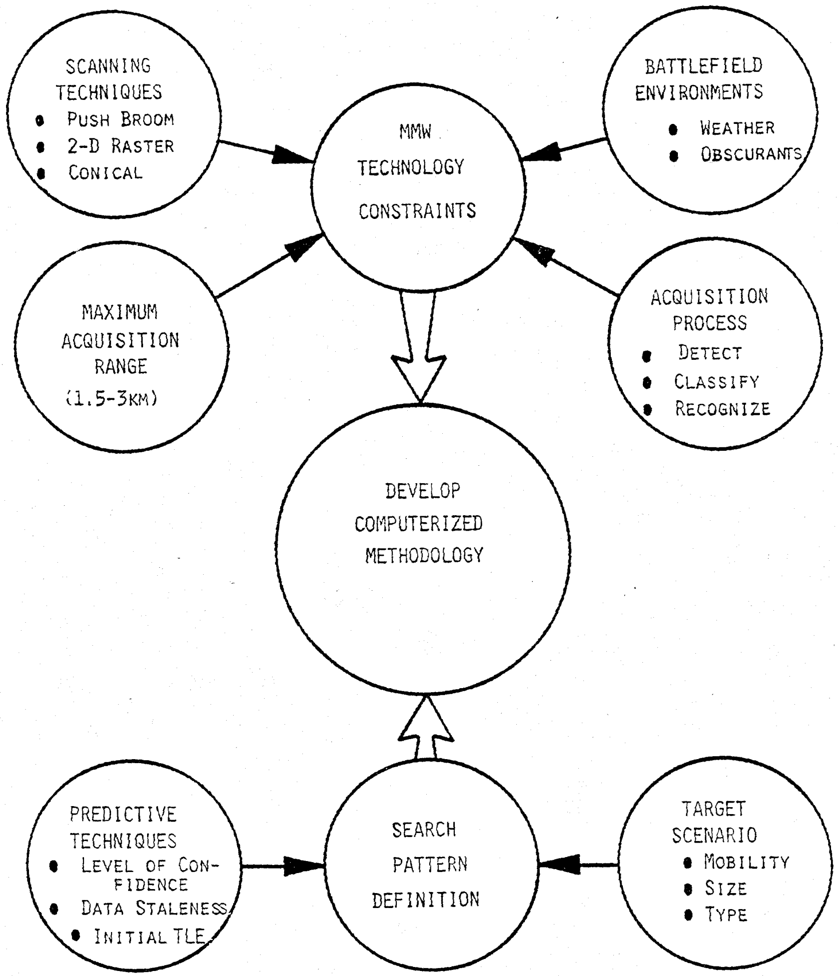

???
UNPERTURBED TRAJECTORY THRU TARGET ACQUISITION
???
DEFINE FIELD ARTILLERY MISSION PROFILE
DEVELOP COMPUTERIZED SIMULATION/METHODOLOGY
GENERATE DATA
MAKE OBSERVATIONS/IDENTIFY TRENDS



PROJECTILE
VELOCITY
(ENDGAME)
200-325 M/SEC
TERRAIN
MASKING
DISTRIBUTION
FIELD ARTILLERY
MISSION PROFILE
SCENARIO
MANEUVERABILITY
RESOURCE CONSTRAINTS
• 155MM DIAMETER
• 10 IN. LENGTH
• HMIN ?
ANGLE
OF
FALL
20°- 50°

FA MISSION PROFILE INPUTS

- MASKING DISTRIBUTION (SHARPLY ROLLING TERRAIN)
- 20°, 30°, 40°, 50° ANGLES OF FALL
- 200 M/SEC, 270 M/SEC, 325 M/SEC PROJECTILE VELOCITIES
- 500 - 1500 METER MINIMUM SCAN ALTITUDE



SCANNING TECHNIQUES
• PUSH BROOM
• 2-D RASTER
• CONICAL
MMW TECHNOLOGY CONSTRAINTS
BATTLEFIELD ENVIRONMENTS
• WEATHER
• OBSCURANTS
MAXIMUM ACQUISITION RANGE (1.5-3KM)
ACQUISITION PROCESS
• DETECT
• CLASSIFY
• RECOGNIZE
DEVELOP COMPUTERIZED METHODOLOGY
PREDICTIVE TECHNIQUES
• LEVEL OF CONFIDENCE
• DATA STALENESS
• INITIAL TLE
SEARCH PATTERN DEFINITION
TARGET SCENARIO
• MOBILITY
• SIZE
• TYPE

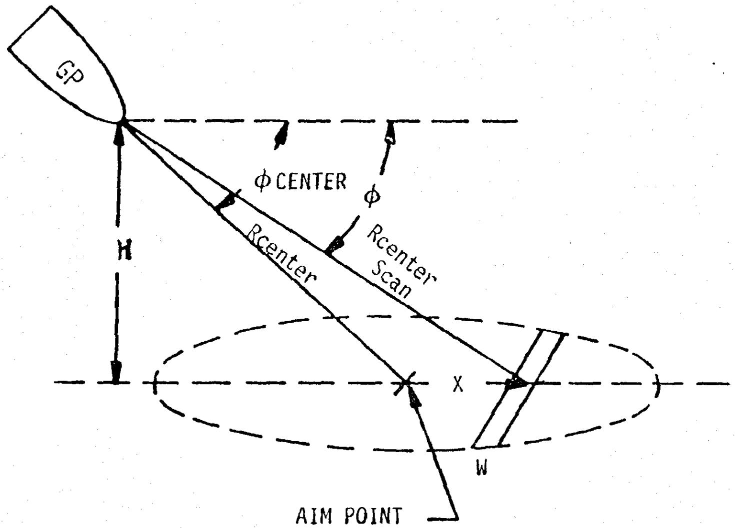
METHODOLOGY INPUTS

- RASTER SCAN
- SIGNAL-TO-INTERFERENCE RATIO
- 700 METER RADIUS SEARCH AREA
  - MOVING COMPANY SIZE TARGET (30KM/HR)
  - 2σ LEVEL OF CONFIDENCE
  - 5 MINUTE DATA STALENESS
  - 100 METERS INITIAL TLE
- ASSUMED CONSTANT VELOCITY AND ANGLE OF FALL IN THE ENDGAME

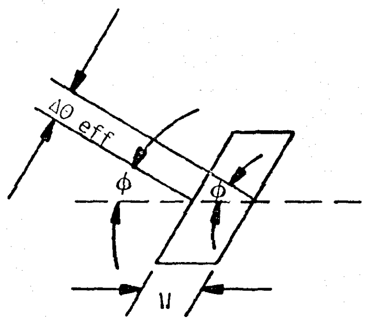
GP RASTER SCAN ANALYSIS

- GP APPROACHES GROUND AIMPOINT AT (ASSUMED) CONSTANT SPEED V_P AND ANGLE ϕ_{CENTER} $(= \gamma_f)$
- RASTER SCAN TECHNIQUE USED BECAUSE IT FINDS THE CLOSEST TARGET FIRST
- SCAN OF CIRCULAR SEARCH AREA STARTS AT BOUNDARY POINT CLOSEST TO GP
- AZIMUTH AND ELEVATION SCAN ANGLE HISTORIES TAILORED TO COVER SEARCH AREA AT CONSTANT AZIMUTH SCAN RATE.

GP RASTER SCAN ANALYSIS (CONTINUED)



BEAM-GROUND INTERSECTION



$$X = \frac{H}{\text{TAN}\,\phi} - \frac{H}{\text{TAN}\,\phi\ \text{CENTER}}$$

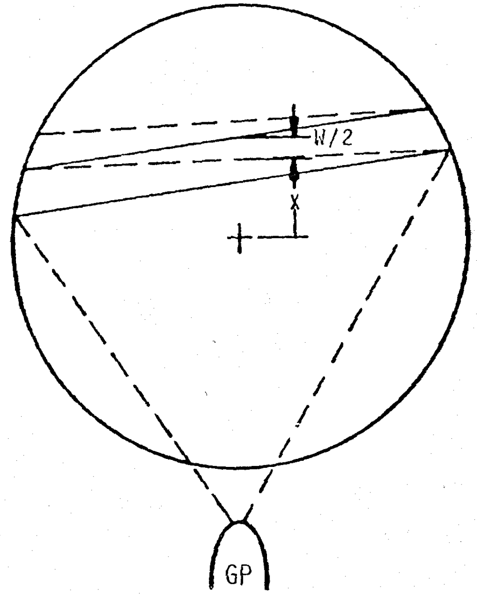
$$\Downarrow$$

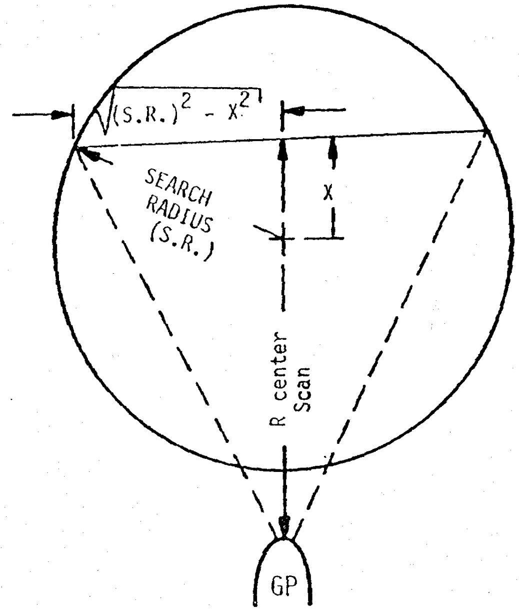
$$\text{SIN}\,\phi = \frac{1}{\sqrt{\left(\frac{X}{H}\right)^2 + \frac{2}{\text{TAN}\,\phi\ \text{CENTER}}\,\frac{X}{H} + 1 + \frac{1}{\text{TAN}^2\,\phi\ \text{CENTER}}}}$$

$$W = \Delta O\,\text{EFF}\ R_{\text{CENTER SCAN}}\ \frac{1}{\text{SIN}\,\phi}$$

$$\left(\text{ALSO,}\quad R_{\text{CENTER SCAN}} = \frac{H}{\text{SIN}\,\phi}\right)$$

GP RASTER SCAN ANALYSIS (CONTINUED)





$$\left(\frac{W}{2}\right)\left(\frac{1}{\dot{X}}\right) = \frac{\Delta\,\theta_{EFF}\, R_{\substack{CENTER\\SCAN}}}{2\,(\sin\phi)\,\dot{X}} = \text{TIME FOR ONE-WAY SCAN} = 2\left(\frac{1}{\dot{\beta}_{MAX}}\right)\tan^{-1}\left[\frac{\sqrt{S.R.^2 - x^2}}{R_{\substack{CENTER\\SCAN}}}\right]$$

- SINCE $R_{\substack{CENTER \\ SCAN}} = \frac{H}{\sin\phi}$, THE ABOVE REDUCES TO:

$$\dot{X} = \left(\frac{\Delta\Theta_{EFF}\ \dot{\beta}_{MAX}}{4}\right) H \frac{\left[\left(\frac{X}{H}\right)^2 + \frac{2}{\tan\phi_{CENTER}}\left(\frac{X}{H}\right) + 1 + \frac{1}{\tan^2\phi_{CENTER}}\right]}{\tan^{-1}\left(\frac{\sqrt{\left(\frac{S.R.}{H}\right)^2 - \left(\frac{X}{H}\right)^2}}{\sqrt{\left(\frac{X}{H}\right)^2 + \frac{2}{\tan\phi_{CENTER}}\left(\frac{X}{H}\right) + 1 + \frac{1}{\tan^2\phi_{CENTER}}}}\right)}$$

- THE ABOVE HAS AN UNSTABLE INTEGRATION. DIVIDE IT BY $\dot{H} = -V_P \sin\phi_{CENTER}$ AND INTEGRATE THE FOLLOWING:

$$\frac{DX}{DH} = -\left(\frac{\Delta\Theta_{EFF}\ \dot{\beta}_{MAX}}{4\ V_P \sin\phi_{CENTER}}\right) H \frac{\left(\frac{X}{H}\right)^2 + \frac{2}{\tan\phi_{CENTER}}\left(\frac{X}{H}\right) + 1 + \frac{1}{\tan^2\phi_{CENTER}}}{\tan^{-1}\left(\frac{\sqrt{\left(\frac{S.R.}{H}\right)^2 - \left(\frac{X}{H}\right)^2}}{\sqrt{\left(\frac{X}{H}\right)^2 + \frac{2}{\tan\phi_{CENTER}}\left(\frac{X}{H}\right) + 1 + \frac{1}{\tan^2\phi_{CENTER}}}}\right)}$$

THIS MUST BE INTEGRATED WITH H INCREASING.

DETECTION PROBABILITY DETERMINED BY SIGNAL-TO-INTERFERENCE RATIO

- KEY FACTORS ARE TARGET BRIGHTNESS, CLUTTER BRIGHTNESS (COMPETES WITH TARGET) AND RECEIVER NOISE
- SIGNAL-TO-INTERFERENCE RATIO QUANTITIES "DETECTABILITY" OF TARGET IN PRESENCE OF THE OTHER FACTORS

OUTPUT SIGNAL-TO-INTERFERENCE RATIO, $(S/I)_O$

$$(S/I)_O = \frac{\text{OUTPUT SIGNAL}}{\text{OUTPUT INTERFERENCE}}$$

$$= \frac{(G_C)(S_C)_I}{N_I + (S_U)_I + (C_U)_I + (G_C)\ (C_C)_I}$$

$$= \frac{(G_C)\ (S_C/N)_I}{1 + (S_C/N)_I + (C_U/N)_I + (G_C)\ (C_C/N)_I}$$

WHERE
G_C = SYSTEM GAIN
S_C = CORRELATED TARGET SIGNAL
S_U = UNCORRELATED TARGET SIGNAL
C_C = CORRELATED CLUTTER SIGNAL
C_C = UNCORRELATED CLUTTER SIGNAL
N = SYSTEM NOISE

- WITH LESS THAN 1% ERROR:

$$\left(\frac{S}{I}\right)_O \cong \frac{G_C \left(\frac{S_C}{N}\right)_I}{1 + G_C \left(\frac{C_C}{N}\right)_I}$$

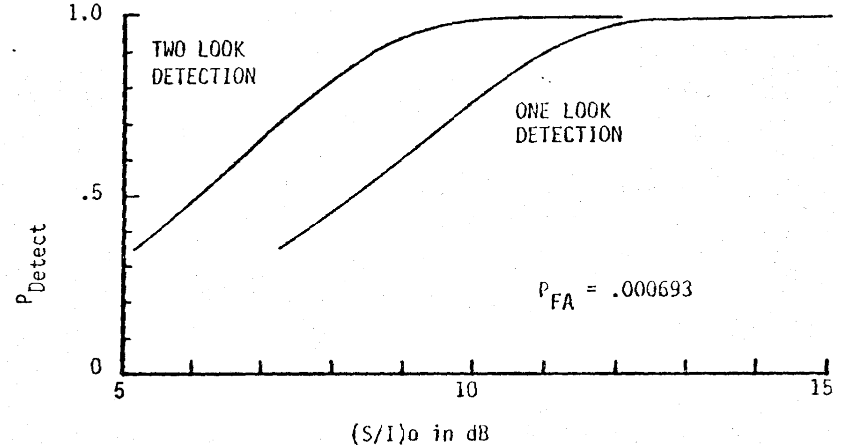
- CLUTTER-LIMITED CASE, $\left(\frac{S}{I}\right)_O \cong \left(\frac{S_C}{C_C}\right)_I$,

  OCCURS FOR CLOSER RANGES AND LOW ATMOSPHERIC LOSSES.

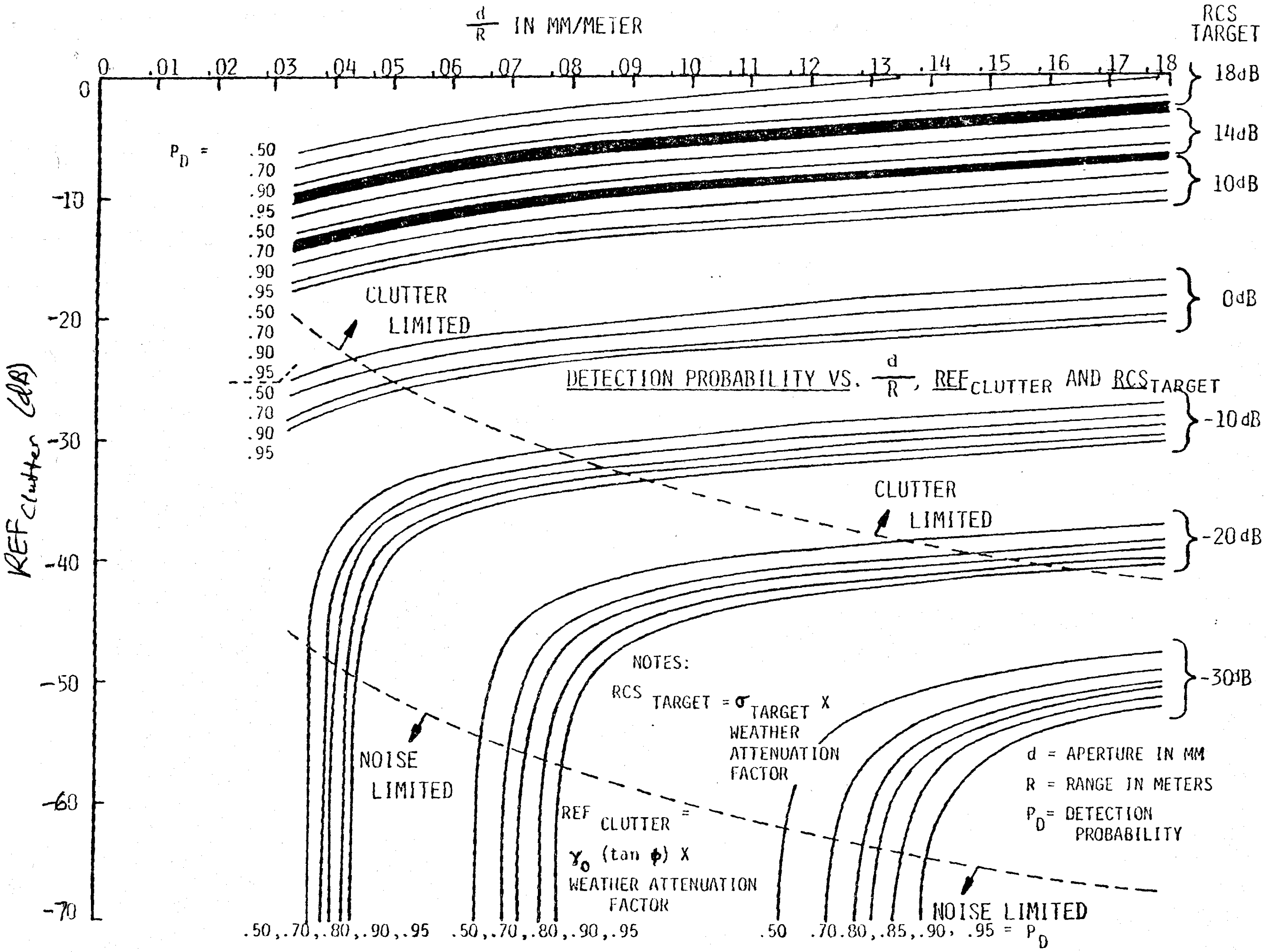
- NOISE-LIMITED CASE, $\left(\frac{S}{I}\right)_O \cong G_C \left(\frac{S_C}{N}\right)_I$,

  OCCURS FOR LONGER RANGES AND/OR HIGH ATMOSPHERIC LOSSES.

PROBABILITY OF DETECTION vs (S/I)o



- Target is nonfluctuating (Marcum/Swerling)
- Integrating return for two looks offers substantially better performance for a given (S/I)o.

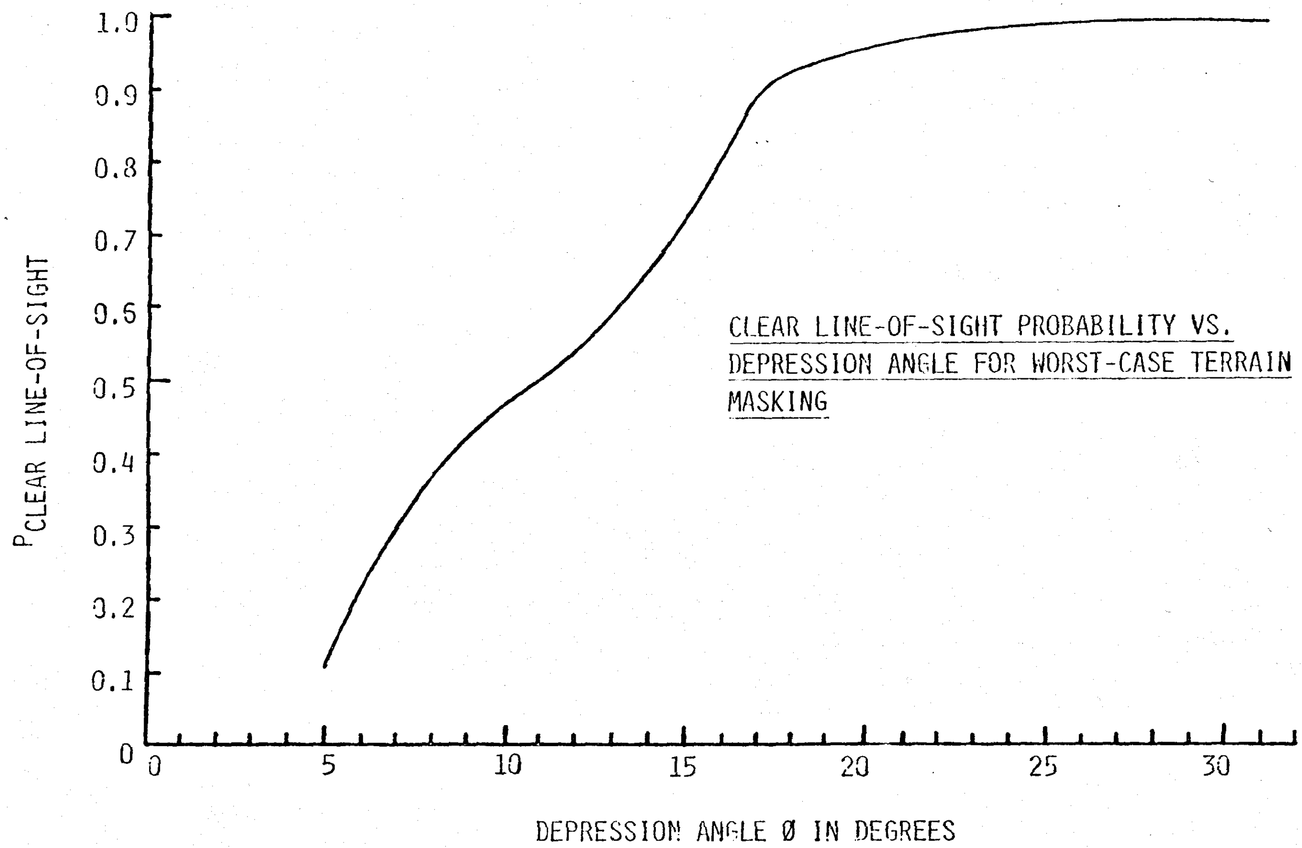


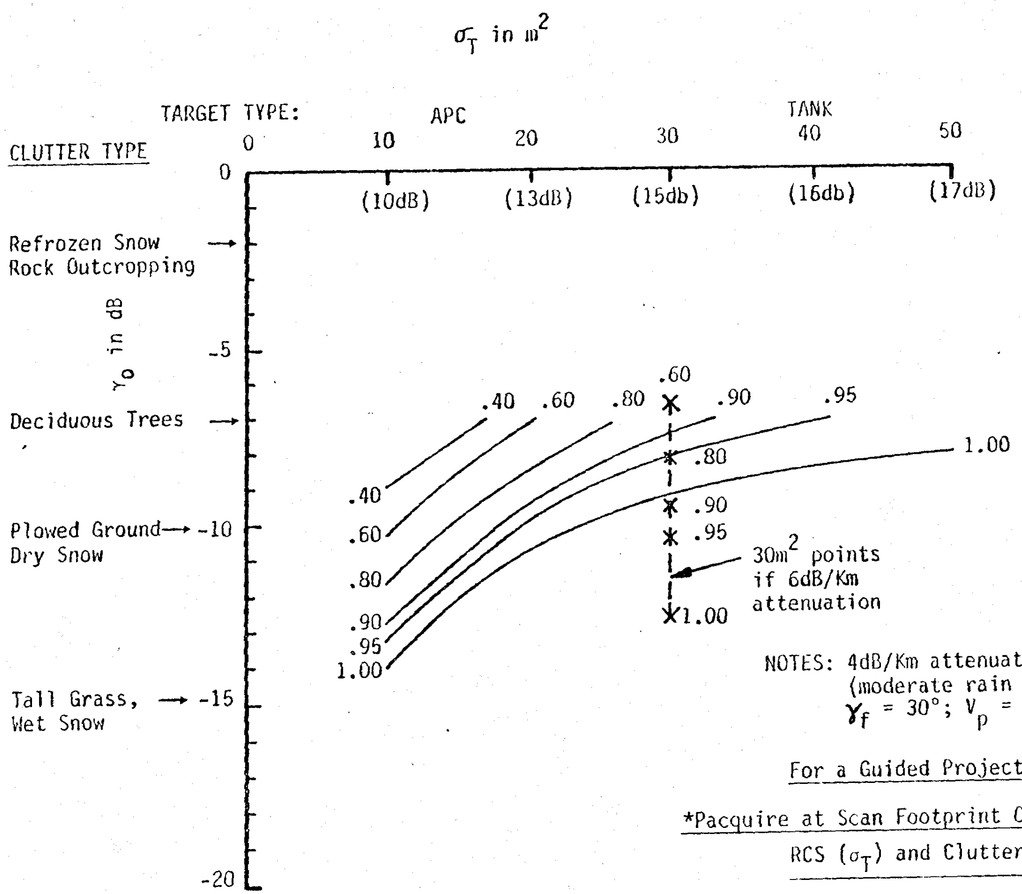
d/R IN MM/METER
RCS TARGET
0 .01 .02 .03 .04 .05 .06 .07 .08 .09 .10 .11 .12 .13 .14 .15 .16 .17 .18
0 -10 -20 -30 -40 -50 -60 -70
REF clutter (dB)
18dB
14dB
10dB
0dB
-10 dB
-20 dB
-30dB
P D = .50 .70 .90 .95 .50 .70 .90 .95 .50 .70 .90 .95 .50 .70 .90 .95
CLUTTER LIMITED
DETECTION PROBABILITY VS. d/R, REF CLUTTER AND RCS TARGET
CLUTTER LIMITED
NOISE LIMITED
NOTES:
RCS TARGET = σ TARGET X WEATHER ATTENUATION FACTOR
REF CLUTTER = γ0 (tan φ) X WEATHER ATTENUATION FACTOR
d = APERTURE IN MM
R = RANGE IN METERS
P D = DETECTION PROBABILITY
NOISE LIMITED
.50,.70,.80,.90,.95 .50,.70,.80,.90,.95 .50 .70.80,.85,.90, .95 = P D

ACQUISITION PROBABILITY DEFINITION

$$P_{ACQUIRE} = P_{DETECT} \times P_{CLEAR\ LINE\text{-}OF\text{-}SIGHT}$$

- $P_{CLEAR\ LINE\text{-}OF\text{-}SIGHT}$ DEPENDS ON TERRAIN MASK EFFECTS AND DEPRESSION ANGLE.
- AS SEEN BEFORE, P_{DETECT} ALSO DEPENDS ON DEPRESSION ANGLE.

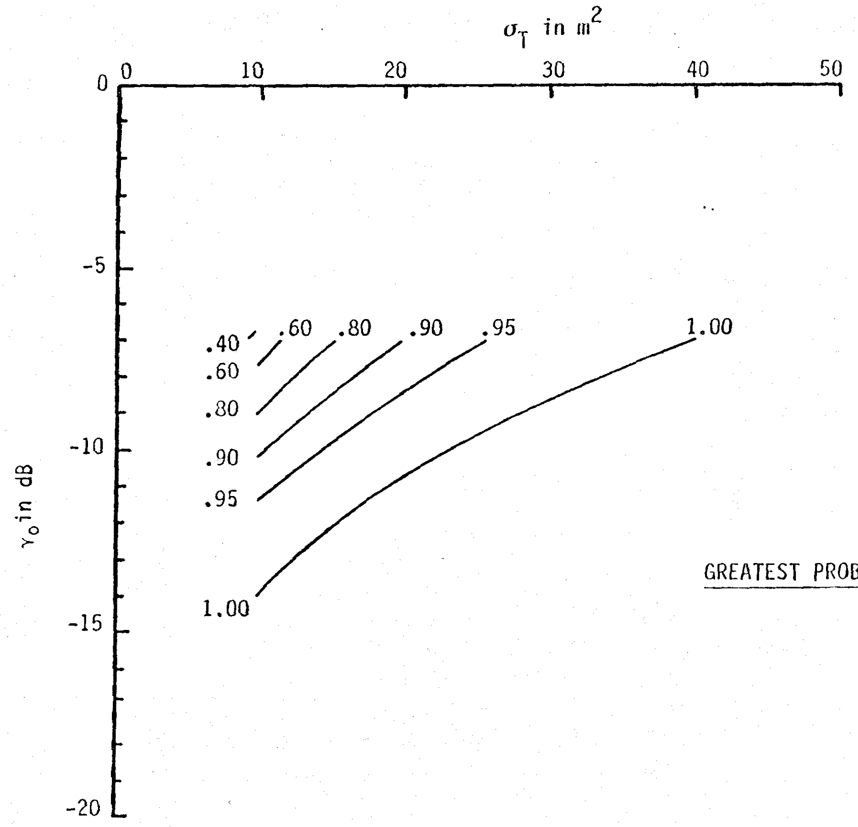

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
$P_{CLEAR\ LINE-OF-SIGHT}$
0
5
10
15
20
25
30
DEPRESSION ANGLE Ø IN DEGREES
CLEAR LINE-OF-SIGHT PROBABILITY VS. DEPRESSION ANGLE FOR WORST-CASE TERRAIN MASKING



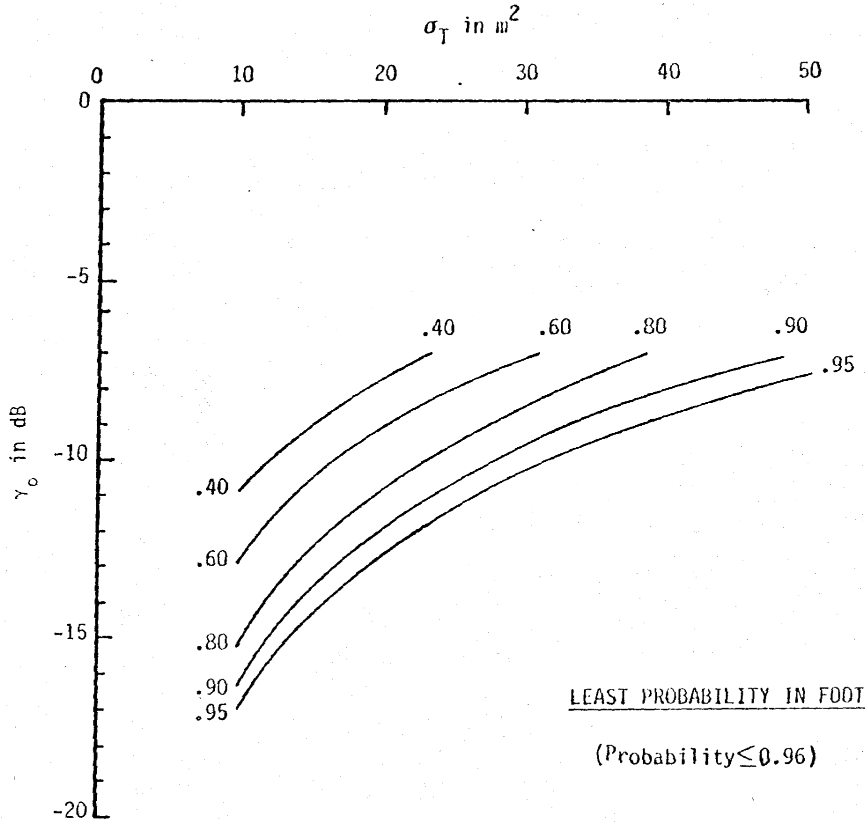
For a Guided Projectile,

*Pacquire at Scan Footprint Center vs. Target RCS (σ_T) and Clutter Density (γo)

*Single look detection.



GREATEST PROBABILITY IN FOOTPRINT



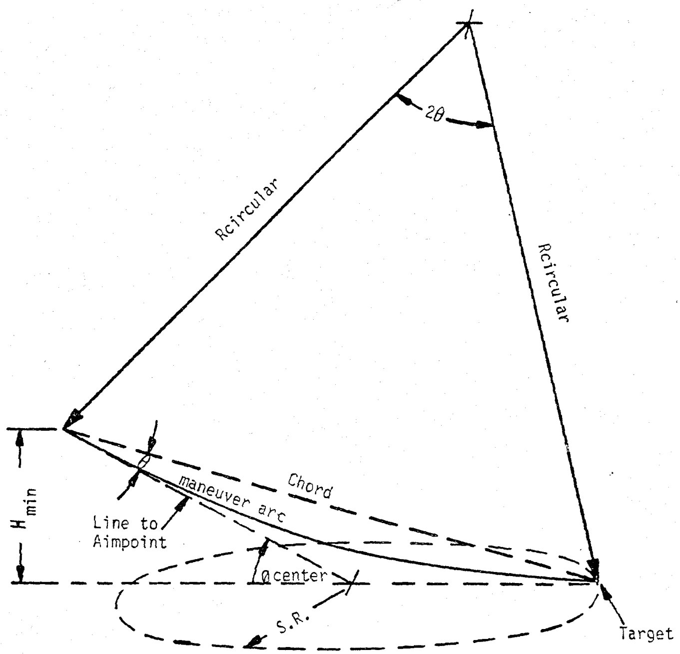
LEAST PROBABILITY IN FOOTPRINT

(Probability$\leq$0.96)

GP MANEUVERABILITY CONSTRAINTS FORCE SEEKER/AIRFRAME TRADES

- BALANCE ACQUISITION PROBABILITY NEEDS vs. MANEUVER CAPABILITY LIMITS TO ACQUIRE AND HIT ANY TARGET IN THE AREA SEARCHED
- KEY MANEUVERABILITY ISSUES ARE SEARCH AREA RADI VS. GP VELOCITY AND ALTITUDE AT TARGET ACQUISITION
- WORST-CASE ASSUMPTION IS THAT TARGET IS FOUND AT END OF SEARCH AND FLAIR MANEUVER FROM H_{MIN} IS REQUIRED

GP TERMINAL MANEUVER ANALYSIS



- Assume constant-speed, circular arc maneuver
- Realistic worst-case shown in flair to target at last point scanned

GP TERMINAL MANEUVER ANALYSIS (CONTINUED)

- H_{MIN} IS THE ALTITUDE FROM WHICH THE LAST GROUND POINT IS SCANNED.
- FROM THE PREVIOUS FIGURE,

$$R_{CIRCULAR} = \frac{H^2_{MIN} + \left(\frac{H_{MIN}}{TAN\ \phi_{CENTER}} + SEARCH\ RADIUS\right)^2}{2\ (SEARCH\ RADIUS)\ SIN\ \phi_{CENTER}}$$

$$T_{GO} = \frac{2\theta\ R_{CIRCULAR}}{V_P}$$

WHERE

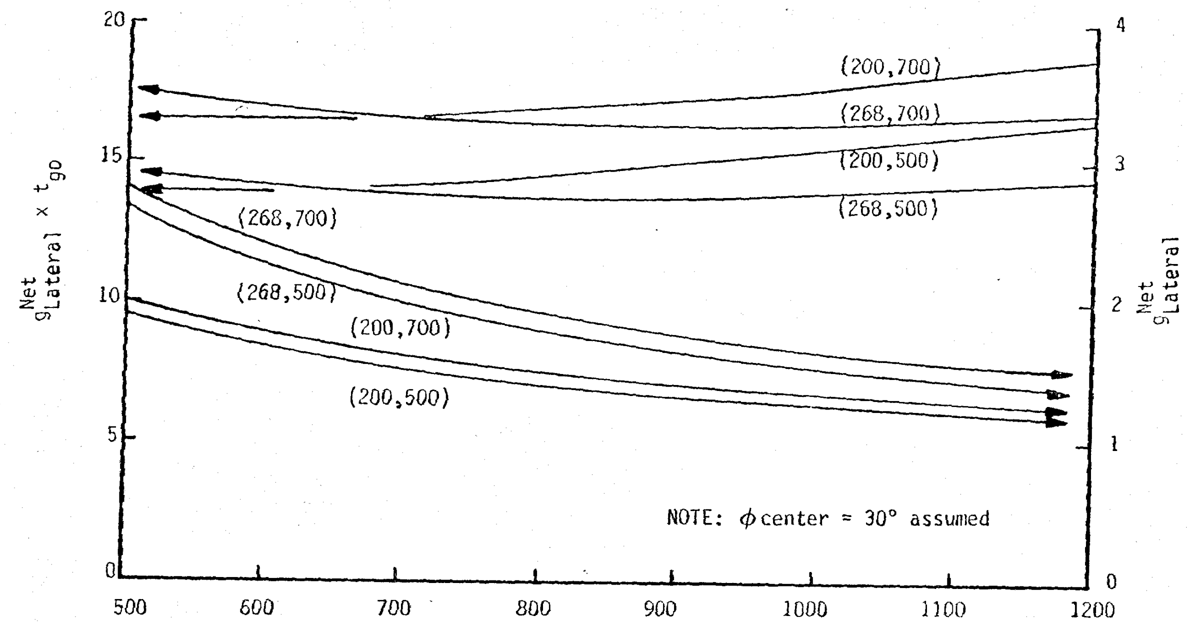
$$\theta = SIN^{-1}\left[\frac{\sqrt{H^2_{MIN} + \left(\frac{H_{MIN}}{TAN\ \phi\ CENTER} + SEARCH\ RADIUS\right)^2}}{2\ R_{CIRCULAR}}\right]$$

GP TERMINAL MANEUVER ANALYSIS (CONTINUED)

- NET LATERAL G's REQUIRED MUST ALSO INCLUDE A QUANTITY TO OVERCOME GRAVITATION FORCE
- ASSUMING THIS ACCELERATION TO BE EQUAL TO THE AMOUNT SEEN ALONG THE MANEUVER CHORD,

$$G^{NET}_{LATERAL} = \frac{V_\rho^2}{9.81\ R_{CIRCULAR}} + \cos\left(\phi_{CENTER} - \theta\right)$$

- QUANTITIES OF INTEREST ARE $G^{NET}_{LATERAL}$ AND $G^{NET}_{LATERAL} \times T_{GO}$.



H_{min} in meters

$g^{Net}_{Lateral}$ and $g^{Net}_{Lateral} \times t_{go}$ Flair Maneuver Requirements vs. H_{min} for Various Values of (V_p, Search Radius)

GP TERMINAL MANEUVER ANALYSIS (CONTINUED)

- LOWERING THE SEARCH RADIUS TO 500 M CUTS THE G AND G-SEC. REQUIREMENTS. LOWER H_{MIN} VALUES ARE POSSIBLE, YIELDING HIGHER $P_{ACQUIRE}$, ULTIMATELY.

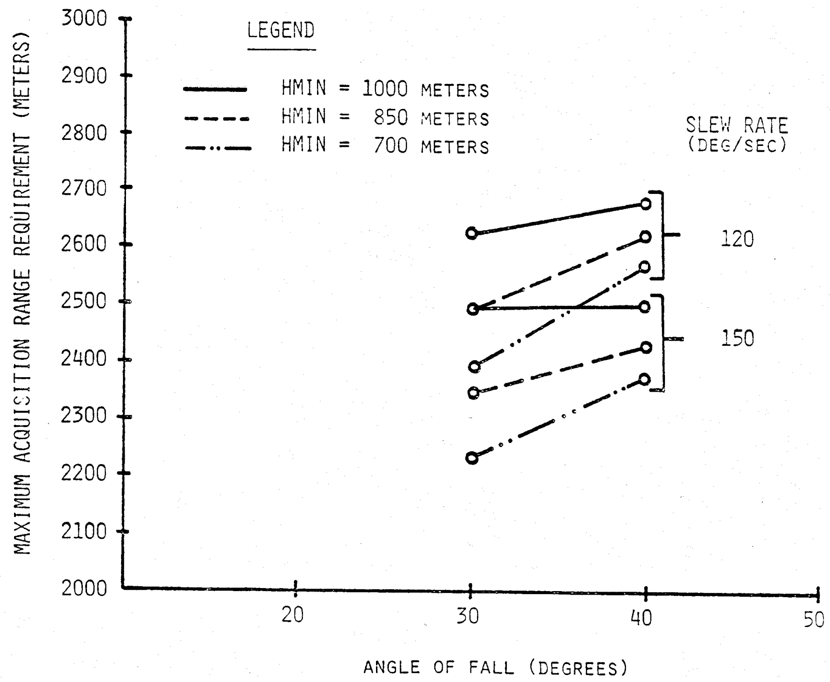
- HIGHER V_P VALUE RAISES G REQUIREMENT. THE G-SEC. REQUIREMENT IS ALSO HIGHER FOR LOWER ALTITUDES.

WHAT DOES ALL THIS MEAN?

- WE HAVE DEMONSTRATED THAT TRADES EXIST BETWEEN GP AIRFRAME AND SEEKER DESIGNS
- WE HAVE DEVELOPED THE TOOLS FOR CONDUCTING THESE TRADES
- NOW, WE SHOW TRADE STUDY RESULTS

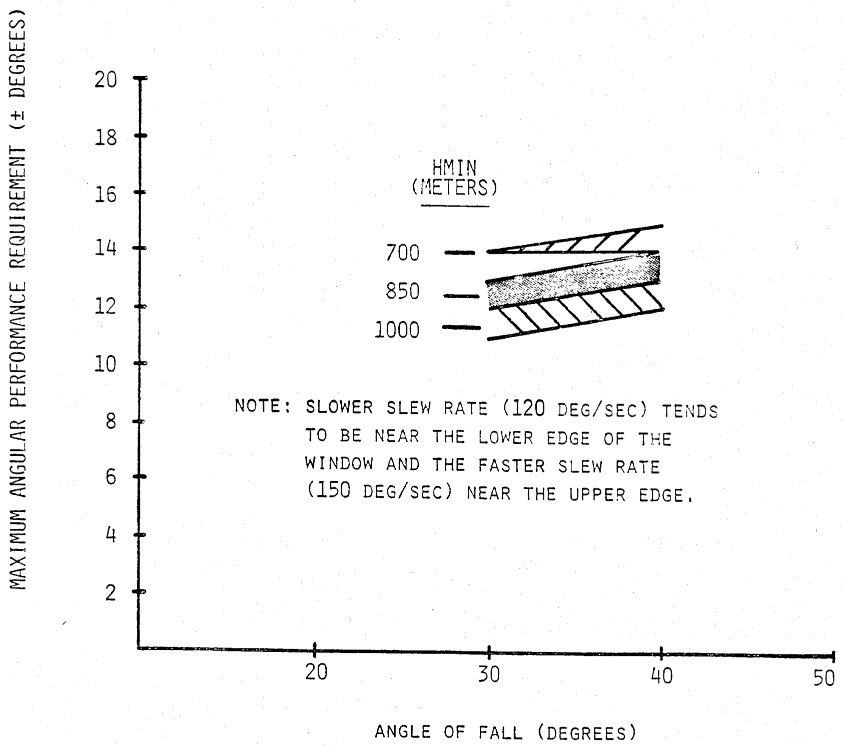
MAXIMUM ACQUISITION RANGE REQUIREMENT

- RASTER SCAN
- 500 METER RADIUS SEARCH AREA
  - (2σ; 3 MIN)
  - (1σ; 5 MIN)
- 270 M/SEC
- EXCLUDING P_{ACQ}



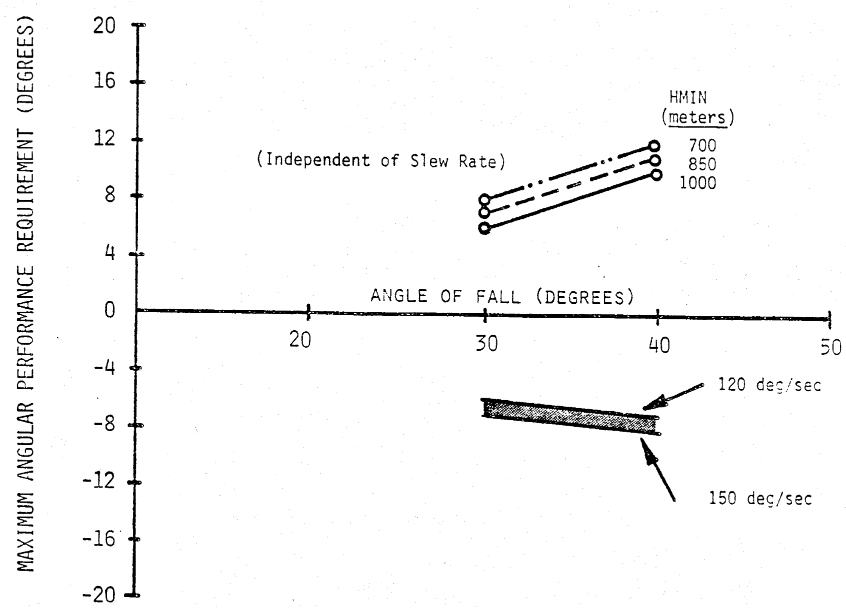
MAXIMUM AZIMUTHAL SCAN REQUIREMENT

- RASTER SCAN
- 500 METER RADIUS SEARCH AREA
  - (2σ; 3 MIN)
  - (1σ; 5 MIN)
- 270 M/SEC



MAXIMUM ELEVATION SCAN REQUIREMENT

- RASTER SCAN
- 500 METER RADIUS SEARCH AREA
  (2σ; 3 MIN)
  (1σ; 5 MIN)
- 270 M/SEC



MMW SEEKER PERFORMANCE WINDOWS

- 500 METER RADIUS SEARCH AREA

  (2σ, 3 MIN OR 1σ, 5 MIN)

GIVEN: ATTN = 4.0 dB/KM (4 MM/HR RAIN)

GAZ = -7.0 dB (DECIDUOUS TREES)

TRCS = 30 M^2 (LARGER THAN APC, SMALLER THAN TANK)

PACQ $\geq$ 0.96

P_{HIT} $\geq$ 0.72 (3 MIN. DATA STALENESS)

P_{HIT} $\geq$ 0.52 (5 MIN. DATA STALENESS)

REQT:

GAF = 30^0

MANEUVERABILITY = 14 - 16 G-SEC

HMIN = 500 - 1000 METERS

VP = 200 - 270 M/SEC

ACQ. RG. = 2072 - 2629 METERS

SI = $\pm 11^0$ - $\pm 16^0$

FI = $\pm 6^0$ - -7^0, $+10^0$

BEDMX = 120 DEG/SEC

DESIGN GOALS

- 500 METER RADIUS SEARCH AREA (2σ, 3 MIN OR 1σ, 5 MIN)

OPTION #1: (nominal 1.3 g's for 12.5 sec)

HMIN = 1000 meters
VP = 200 m/sec
ACQ. RG. = 2460 meters
SI = ±12°
FI = ±6°
BEDMX = 120 deg/sec

OPTION #2: (nominal 1.5 g's for 9.5 sec)

HMIN = 700 meters
VP = 200 m/sec
ACQ. RG. = 2184 meters
SI = ±14°
FI = -7°, +8°
BEDMX = 120 deg/sec

OPTION #3: (nominal 1.7 g's for 8.5 sec)

HMIN = 600 meters
VP = 200 m/sec
ACQ. RG. = 2121 meters
SI = ±15°
FI = -7°, +9°
BEDMX = 120 deg/sec

OPTION #4: (nominal 1.9 g's for 7.5 sec)

HMIN = 500 meters
VP = 200 m/sec
ACQ. RG. = 2072 meters
SI = ±16°
FI = -7°, +10°
BEDMX = 120 deg/sec

OPTION #5: (nonminal 1.7 g's for 8.5 sec)

HMIN = 850 meters
VP = 270 m/sec
ACQ. RG. = 2498 meters
SI = ±12°
FI = -6°, +7°
BEDMX = 120 deg/sec

OPTION #6: (nominal 1.5 g's for 9.5 sec)

HMIN = 1000 meters
VP = 270 m/sec
ACQ. RG. = 2629 meters
SI = ±11°
FI = ±6°
BEDMX = 120 deg/sec

OPTION #7: (nominal 2.0 g's for 7 sec)

HMIN = 700 meters
VP = 270 m/sec
ACQ. RG. = 2395 meters
SI = ±14°
FI = -6°, +8°
BEDMX = 120 deg/sec

SUMMARY

- ANALYTICAL SIMULATION STUDY TOOLS DEVELOPED; INITIAL TRADES COMPLETED.

- WITHIN CONSTRAINTS OF EXPECTED HARDWARE CAPABILITIES AND MINIMAL TRAJECTORY SHAPING, 94GHz MMW SEEKER SYSTEM ADAPTABLE TO FA MISSION PROFILE.