AD-A219 432

# ANNUAL REPORT
# THEATER MISSILE DEFENSE
# CONTRACT NO.: DASG60-89-C-0019
# 10 FEB 1989 TO 9 MARCH 1990

The objective of this effort is to support the USASDC TMD Applications Project Office (TMDAPO) in the analysis of Optical Concepts that are being proposed or developed for application to Theater Missile Defense (TMD). The effort consists of responding to specific requests for analysis of systems involving optical sensors. These analyses may include the identification of performance requirements, definition of relevant issues and/or recommended procedures for resolving the issues. This annual report, will be divided into two major parts. This first part, will present an overview of the major tasks undertaken; and the second part, will consist of appendices containing the narrative response or the presentation material developed in support of each of these tasks.

## PART 1 - OVERVIEW

### 1.1 Review of " A Theater Application of LWIR Technology For The Defense Against ICBM's/SLBM's".

The first task undertaken during this reporting period, was to review an airborne optical concept submitted by Boeing Aerospace for presentation to the Theater Missile Defense Conference in London. The paper titled "A Theater Application of LWIR Technology For The Defense Against ICBM's/SLBM's" was subsequently withdrawn due to several key technical errors identified by this NRC review. The request for review came from the AOA Project Office Manager. A summary of NRC major concerns and issues with this paper are included in Appendix A.

### 1.2 Review of MBB AIRS Concept

At the Governments request NRC attended presentations of the AIRS Concept by MBB and prepared a review for TMDAPO. The review concluded that the study offered useful and correct results and that the AIRS Concept was the most effective solution for the MBB Option V threat. Major areas of concern noted were related to a combination of unrealistic requirements and assumptions which led to significant cost for AIRS. This review resulted in recommendations for several additional efforts on the part of NRC to resolve the major issues remaining. Subsequent tasks were considered in a more general context rather than tied to the AIRS concept and this process eventually led to the Task of defining the locator concept, discussed in one of the following paragraphs. A more detailed description of the conclusions of this review are presented in Appendix B.

## 1.3 Evaluation of British Aerospace Corporation (BAC) Signature Results

NRC was asked to evaluate radiometric signatures presented by BAC. The review of these signatures suggested two possible explanations for inconsistently high values including: 1) that ICBM temperatures were used for the calculation or 2) that the scale on one of the Figures was in error by an order of magnitude. These possibilities, the analysis leading to them and assessment of their relative likelihood are summarized in the memo presented in Appendix C.

## 1.4 Review of Boost Phase Radiometric Signatures

NRC was requested to review the available sources of Boost Phase Signatures. This review concluded that those presented in NRC-TL-86-088 represented the best signatures currently available. The process used to derive these signatures as well as typical signatures obtained by integrating the results presented in this report are summarized in the presentation included as Appendix D to this report.

## 1.5 Low Cost Airborne Tactical Optical Reconnaissance (Locator) System

As a result of the discussions following the review of the MBB AIRS Concept, it became apparent that there was a need to establish a good reference point for defining the capabilities and cost of a "Low Cost" Tactical Airborne Optical Sensor System. In order to establish this reference point, NRC undertook the task of defining and analyzing a low cost optical system which would take advantage of large signatures and stereo viewing and would be limited to the existing state-of-the-art. This study defined a reference performance for such a system and developed the tools required for comparing cost performance trade-offs. The results of this analysis are included in the presentation material presented in Appendix E of this report.

# PART II - APPENDIXES

The Appendixes which follow include the written material and presentations described above. The written material is reproduced exactly as it was delivered to TMDAPO. The presentations include the original presentation charts used to present the information to TMDAPO with brief facing page text indicating the major points made by each chart.

# APPENDIX A

## APPENDIX A

Summary of Critical ISSUES CONCERNING BOEING AEROSPACE PAPER TITLED "A Theater Application of LWIR Technology for Defense Against ICBM's/SLBM's", December 19, 1989 by Darrel L. Choate and Timothy E. Peters.

1. The basic premise of this paper is to add an AOS element to SNIA's TMDAS architecture to enhance defense against ICBM's and SLBM's. However, defense against these threats is not the recognized mission of Theater Missile Defense. If it is assumed that the nuclear warheads on these threats have been replaced with conventional munitions, then their effectiveness is questionable, considering the CEP's quoted in table III-2 and the target set to be defended. Thus this paper is based on a set of unrealistic assumptions.

2. The SS-12 and SS-23 are being eliminated by the INF Treaty, hence these threats should not be included in table II-3.

3. The fields of regard of the AOS platforms do not provide stereo viewing over the coverage area as stated in the text and furthermore, the easterly orientation does not account for the solar exclusion issue.

4. The LWIR sensor specifications are a gross over design for the TMD threats. The paper does not justify acquisition range, hard earth angle requirement, angular resolution and measurement accuracy requirements. This sensor, as designed would require very many detectors per platform which is major production issue at this time. It should be further noted that these specifications are more stressing than the current AOA sensor, and hence it is questionable whether this design could be fielded in the time stated or that it represents pre-1985 technology as stated in the paper on page 9.

5. If an SLBM threat is postulated, the attack corridors would certainly be arranged to outflank the defensive deployment orientated toward the east, as presented in the paper.

6. The statement that increased battle time inherently decreases the interceptor's difficulty and therefore cost is not necessarily true. To achieve increased battle

space requires increased interceptor velocity and improved cross range maneuver capability. It also requires longer seeker acquisition range, since closing velocities are higher.

7. The functional techniques and performance is somewhat ambiguous and questionable. Track on multiple objects in a threat cloud is to be represented by a single track file (implying limited resolution of each threat object). However, detailed independent angle and radiometric data is necessary on each object to perform exoatmospheric LWIR discrimination. In another part of the paper, discrimination is said to use atmospheric deceleration of different weight objects. Not only does this disagree with previous statements, but for the engagements presented to occur, exoatmospheric discrimination is necessary to launch the interceptors.

# APPENDIX B

## NRC REVIEW OF MBB AIRS CONCEPT

## Areas of Agreement AIRS Concept

NRC believed this to be a high quality study and is in agreement with a great many of the conclusions incorporated in the study. For example: we agree that the AIRS Concept or something very close to the AIRS Concept is the only reasonable surveillance solution for Option V. We agree with their conclusions and modeling of the cloud-free line-of-sight data. We agree that the boost phase intensities are very large and provide an easy target for the optical system. The two segment sensor is a good approach although even more advantage could be taken of this concept by allowing growth into the second segment thus providing a lower cost initial capability. The suggested use of AIRS Plus AIM as a mobile concept possibly to support defense against third country threats appears to be a interesting and useful idea.

# AREAS OF AGREEMENT AIRS CONCEPT (U)



"GOOD STUDY"

- AIRS ONLY REASONABLE SURVEILLANCE SOLUTION FOR OPTION-5
- CFLOS DATA

  1) NO PROBLEM > 10 - 12KM
  2) MODEL AS STEP FUNCTION

- BOOST INTENSITIES (VERY LARGE)
- 2 - SEGMENT SENSOR
- AIRS + AIM => 3RD COUNTRY-"MOBILE" OPTION (?US-RESERVE)

## Potential Areas of Disagreement

Although NRC agreed with most of the results of this study, there were several areas in which NRC felt that there were notable problems. The major problem area is that of cost. NRC believes that the significant portion of the AIRS capability could be achieved with significantly lower cost than suggested by MBB. This would negate their conclusion that AIRS would not have any role for options 1 through 4. Some suggestions for areas and considerations which would further reduce the cost are included as sub-headings under the cost rules out AIRS for options 1 through 4 heading of this chart. Other areas of concern were, that the stereo tracking results needed additional analysis, the area of frame-time trade-offs, band selection and the trade-off studies suggested in the last bullet on this chart.

NRC

# POTENTIAL AREAS OF DISAGREEMENT

## AIRS CONCEPT (U)



- COST RULES OUT AIRS FOR OPTIONS 1 - 4
  - ONLY USE LOWER SEGMENT
  - REDUCE SENSOR COST
    - SIGNATURE REQUIREMENTS TO SEVERE (W/O SS-XX ASCENT HEAT & BOOSTER)
    - IF SEPARATES CUE FROM BOOSTER TRAJECTORY
    - FAST BURN INCREASES ASCENT HEATING
    - SCAN RATE - TRACK PERFORMANCE TRADE-OFFS - ESPECIALLY BOOST PHASE
  - 2 A/C TRIANGULATION WITH GROWTH TO 3 A/C
  - DESIGN FOR BOOST TRACK (~ BOSS)
  - LOWER COST RPV WITH GROWTH TO 20KM (AIRS:-1-2B$; PIONEER~400K$/RPV)
- STEREO TRACKING OF ACCELERATING TARGETS (STILL LEARNING RAPIDLY)
- FRAME TIME TRADE-OFFS
- BAND SELECTION
- OPERATING ALTITUDE(IE RPV-$)-RANGE-VULNERABILITY & SENSOR REQUIREMENTS(IE SENSOR $) TRADES

## Recommended NRC Tasks

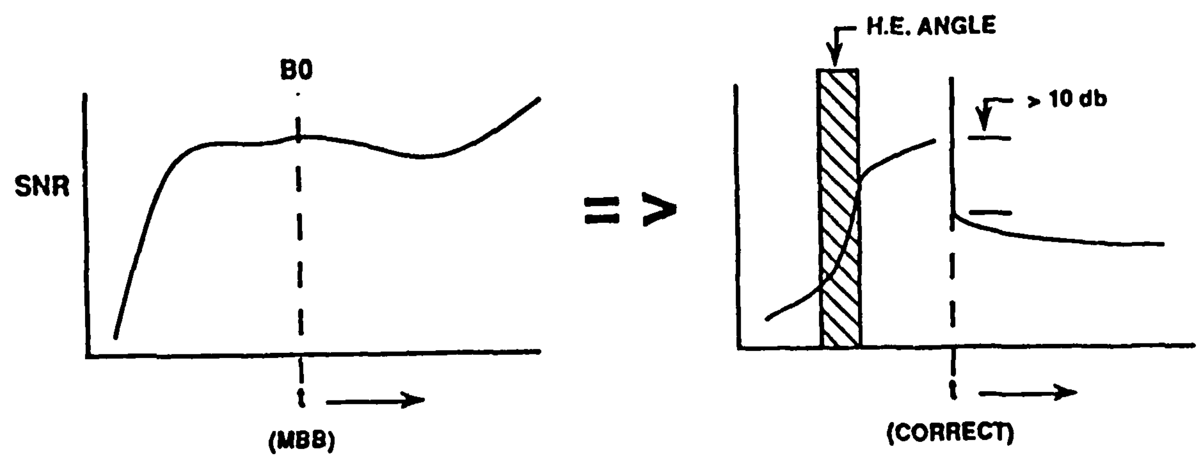
These charts recommend six areas for additional analysis which would enhance the MBB AIRS analysis.

# RECOMMENDED NRC TASKS (U)

1) REVIEW GEOMETRIES & BOOST TRAJECTORIES FOR TYPICAL/LIMIT CASES
=> BOOST TRACK TIME REASONABLE BOOST ARCHITECT/SCENARIOS AS FUNCTION OF SENSOR TECHNOLOGY (PRESENT, PRESENT-EXOTIC, ADVANCED; AIRS)

- SENSOR ALT: 12, 15, 20KM
- RANGE: 50, 100, 150, 250, 400KM
- CLOUD 0, 8 & 12KM

2) REVIEW SIGNATURES (EXPLAIN OR RECOMMEND MODIFICATIONS)



# RECOMMENDED TASKS (CONT'D) (U)



3) INVESTIGATE TRACK PERFORMANCE IN BOOST PHASE (BASE ON EXISTING & NEW RUNS)

- FRAME TIME, SENSOR "COST", RANGE (DIST FROM FLOT)
- NO. OF PLATFORMS
- STEREO / ACCELERATING - TARGET

4) INVESTIGATE LOW COST AIRS THAT CAN GROW TO FULL AIRS AS THREAT GROWS FROM 1 -> 5

- INITIALLY DESIGN FOR BOOST DETECTION ONLY
- INITIALLY "LOW-SEGMENT" ONLY
- MODERATE COST INITIAL PLATFORM (>12KM, ? ENDURANCE,....) WITH GROWTH TO OPTION - 5

5) REVIEW TESTING PLAN TO INTEGRATE INTO EXISTING TESTS AND VERIFY TECHNOLOGY

6) SUMMARIZE IMPACT BY ESTIMATING COST SAVINGS FOR:

a) REDUCED REQUIREMENTS
b) REDUCED REQUIREMENTS & CAPABILITIES

# APPENDIX C

# NRC EVALUATION OF BAC SIGNATURE

## APPENDIX C - NRC EVALUATION OF BAC SIGNATURE

TO: Ron Patrick

FROM: Herb Hunter

SUBJECT: BAC Signature Evaluation

Reference: Excerps from Wolverene Briefing, 30 May 1989 by British Aerospace Limited

DATE: 17 July 1989

This memo summarizes a "sanity check" which has been performed to understand the apparently high values of the signatures shown on the right hand side of Figure 89-0198-212 on page 36 of the Reference Document. The analysis shows 2 possible explanations: 1) That ICBM temperatures were used for the calculation, or 2) That the scale is in error by an order of magnitude. It is felt that the first of these is the most likely explanation.

From the dimensions of the objects, we may infer that the nose-on area is approximately 0.32 to 0.4 square meters. It also may be assumed, that the emissivity lies between 0.7 and 0.95, thus, it is reasonable to assume a nose-on emissivity area of approximately 0.3 square meters. If we also assume a black body, we can infer the temperature from the radiometric intensities presented in the Figure. If we assume the intensity is a constant for the lower band in the left hand signature, as shown in the overlays in Figure 1, we obtain a constant temperature of 409 degrees. The upper curve on the overlay corresponds to the high-band signature under the same assumptions used to derive this temperature. Since they are in reasonably good agreement with the solid lines on the reference Figure, we conclude that the Figure on the left hand side is consistent with the temperature of 409 degrees. Figure 2, is a typical temperature history for a conical object without an ascent shroud. It shows that 400 degrees is a reasonable temperature for this object. Note, that Figure 2 presents both the average temperature and the temperature of a number of stations on the vehicle. The symbol "Y" represents the T**4 average temperature, "T1" is the stagnation point temperature, "T2" and "T3" are temperatures at 2 conical stations and "T4" is the base temperature. Note also, that T1 will be considerably higher than the other temperatures, but it occurs on a very small area and therefore has very little effect on the signature. The most appropriate temperature for our present comparison is the average temperature. This will remain true for all the plots of the temperatures in this memo.

Following the same procedure with the plots on the right hand side of Figure 89-0198-212, we approximate the nose-on intensity with the 3 straight lines shown on the right hand side of the overlay in Figure 1. This yields temperatures ranging from 1100 to 1720 degrees which produce high-band signatures indicated by the lower curve on this overlay. Again, the agreement between the approximate model and the temperature shown in the Figure is reasonably good. However, the temperatures are considerably higher than expected for the velocities encountered by this vehicle. This can be seen from Figures 3 and 4 which show typical temperature histories for conical vehicles with and without ascent shrouds at ranges of 500 and 900 kilometers. In these figures, the average temperature indicated by the Y's is considerably smaller than 1700 degrees. Figure 5 presents typical temperature histories for a similar vehicle on an ICBM trajectory. Examination of this Figure shows that the 1700 degree temperature is much more compatible with this range than with the typical tactical ranges shown in Figures 3 and 4. Thus, one reasonable explanation for the apparently high values of the signature, is that they were calculated for ICBM velocity instead of tactical velocities.

Another possibility investigated was that the scale was in error by an order of magnitude. Again, the lower band signature was approximated by the solid line shown in Figure 1, but the intensity value was reduced by an order of magnitude. This resulted in a temperature ranging between 631 and 815 degrees K and produced the high-band signature shown on the overlay presented in Figure 6. Examination of Figures 3 and 4 shows that these temperatures (indicated by the arrow labeled scale *0.1) are in considerable better agreement with tactical missile ranges than the temperatures calculated using the temperature scale shown on the original Figure. Figure 6 shows reasonable agreement between the approximate IR signature. However, comparison of Figure 1 and Figure 6 suggests that the most likely explanation is that ICBM temperatures were used to make the calculations on the right hand side of the Figure in the Reference document.

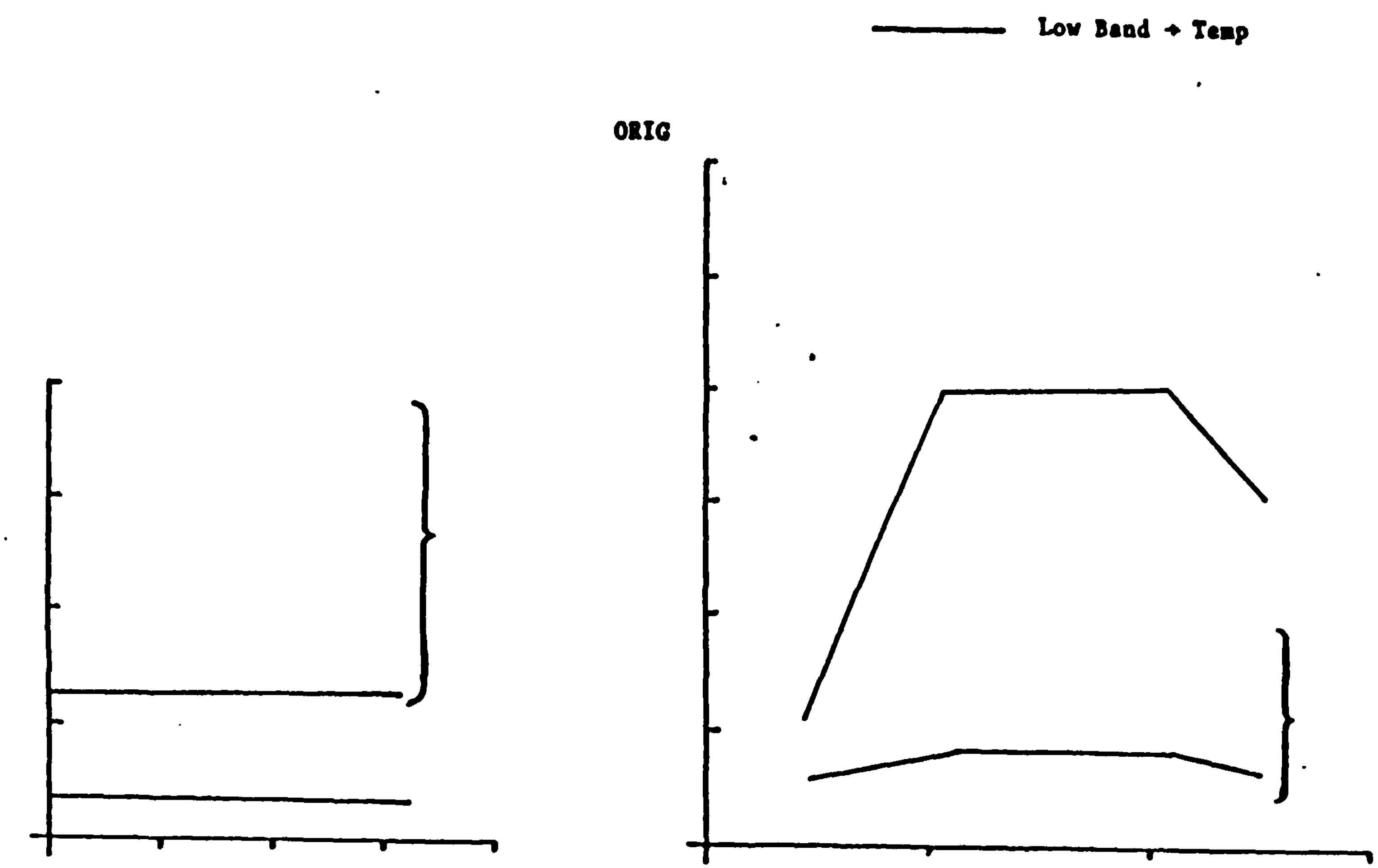



Figure 1. Overlay For Reference Figure 87/0198-212 Assuming ICBM Temperature Used

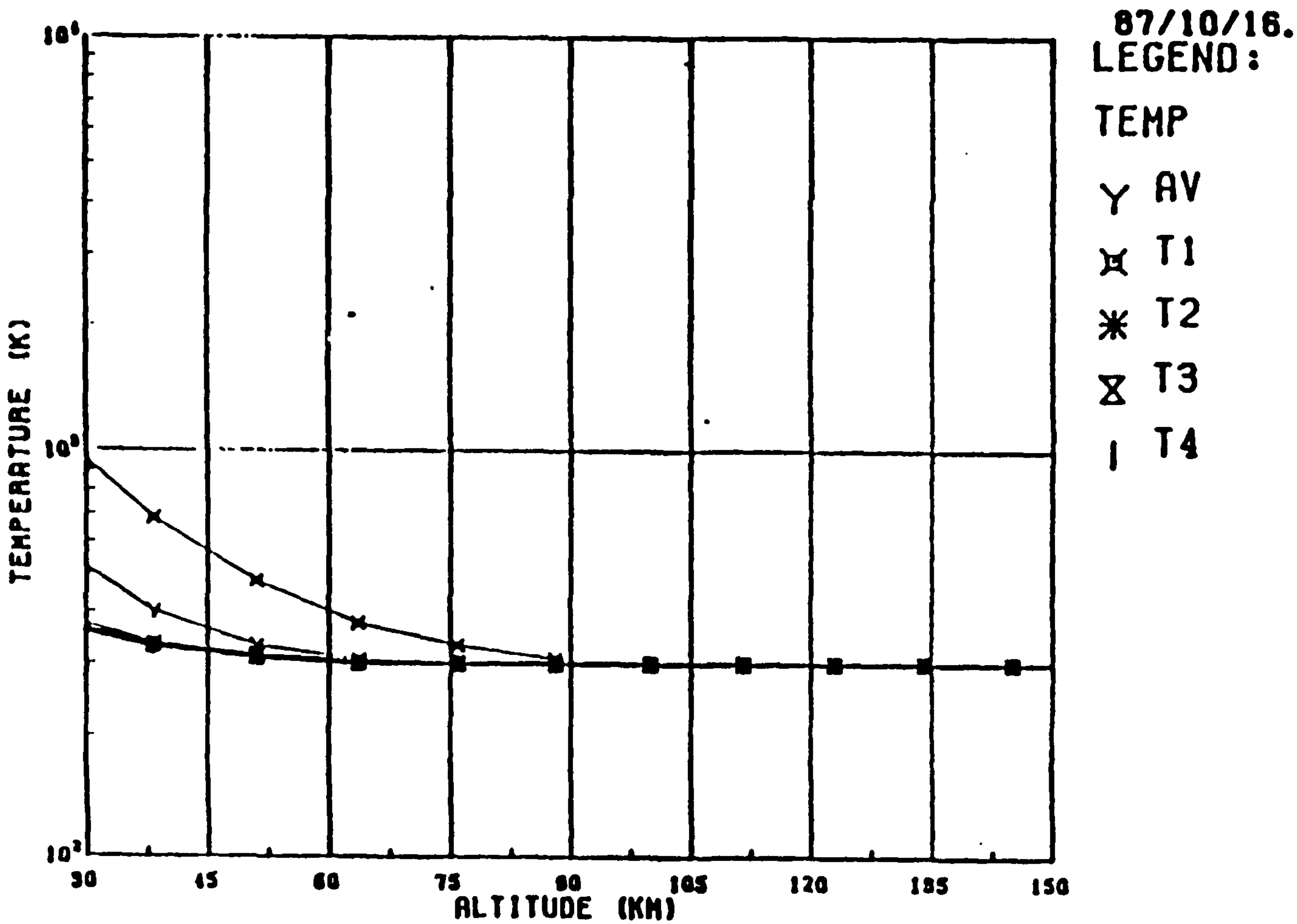



**Figure 2. Typical Temperature History - Range = 250KM w/o Ascent Shroud**

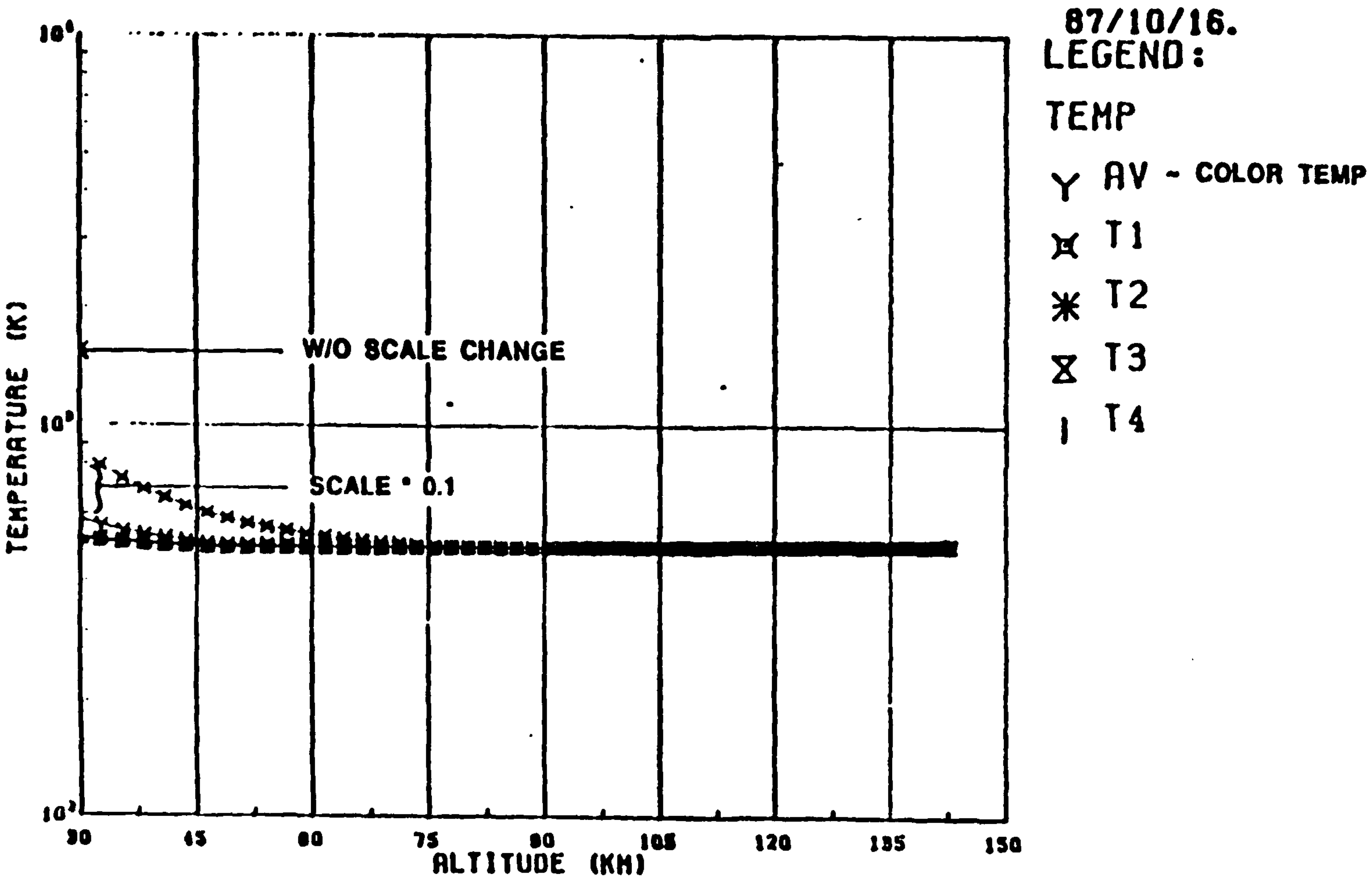



Figure 3. Typical Temperature History - Range = 500KM w/o Ascent Shroud

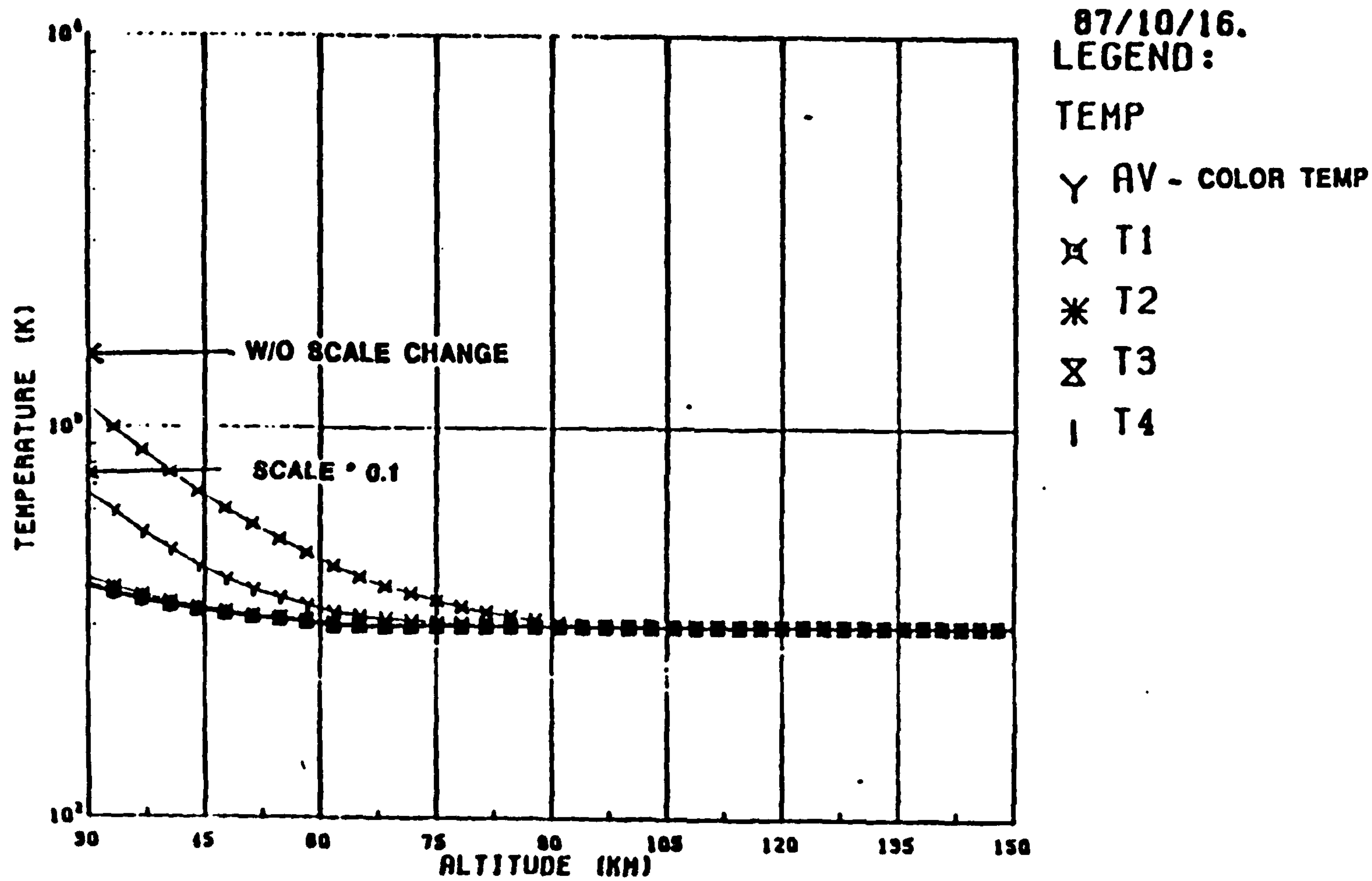



Figure 4. Typical Temperature History - Range ~ 900KM With Ascent Shroud

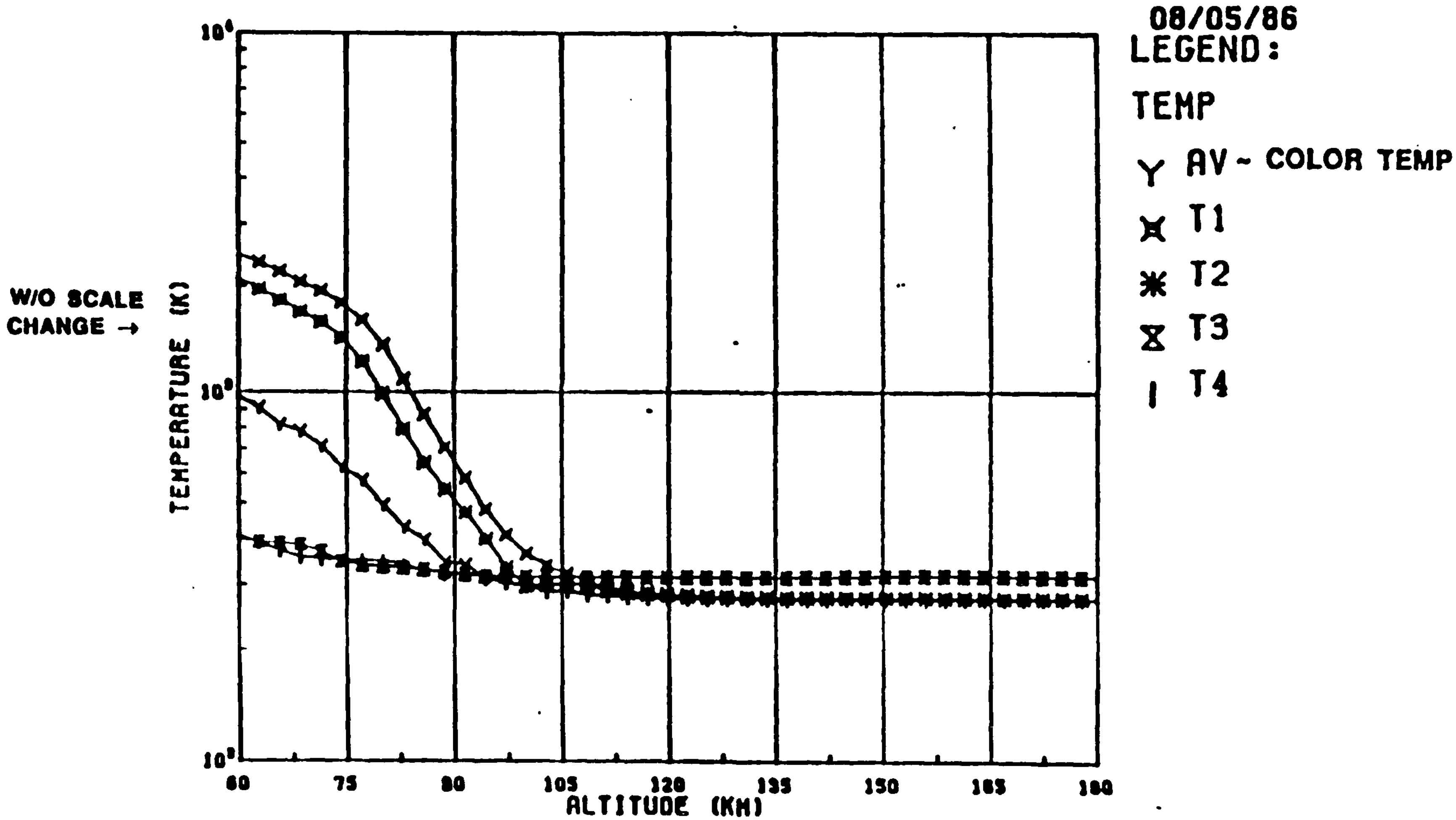



Figure 5. Typical Temperature - ICBM (Range ~ 7000KM)

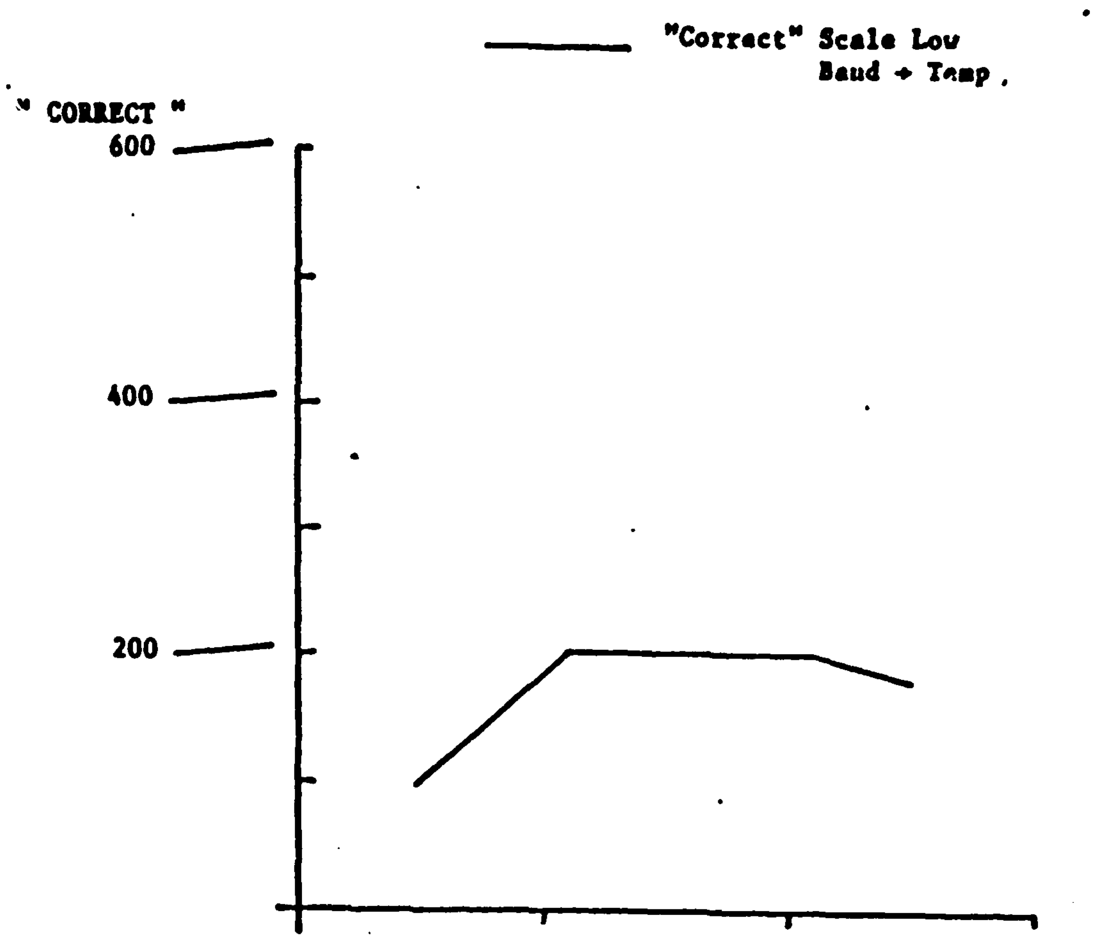



Figure 6. Overlay For Reference Figure 89/0198-212 Assuming Scale Error

# APPENDIX D

# RECOMMENDATIONS FOR BOOST PHASE RADIOMETRIC SIGNATURES

## Boost Signature Recommendations

This chart shows the methodology that was used to calculate the booster signature from which the reommended signatures were derived. Notice that several industry standard models are first used to calculate the exhause properties, the plume flowfield properties and then the radiometric signature. This signature was then compared to available experimental measurements and the process iterated until input options were selected which would result in signatures that compared to the available experimental data. These models where then used to calculate the signatures for the desired vehicles.

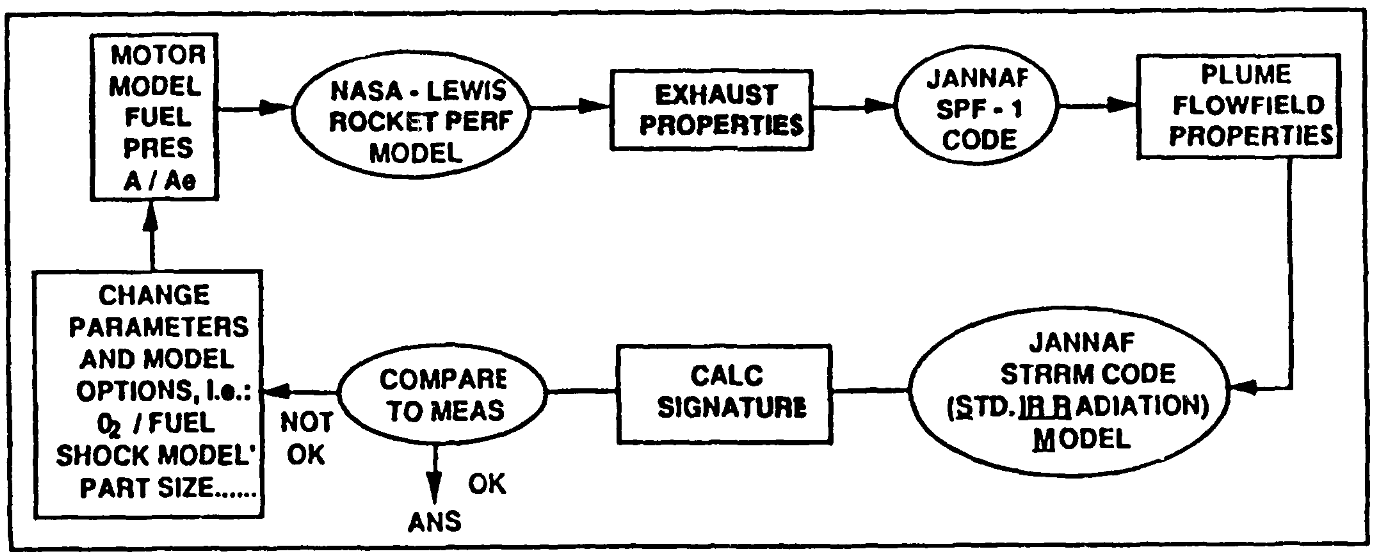
# BOOST SIGNATURE RECOMMENDATIONS

- BEST @ NRC SUMMARIZED IN NRC-TL-86-088

  DELIVERED TO ARMY: DASD-H-SST (G. LENNING) SEPT 1986
  UNDER CONTRACT DASG60-85-C-0053; CDRL A002

  DERIVATIVE CURVES IN MIKE HOLBERT'S 3/89 SUMMARY BRIEF

- METHODOLOGY



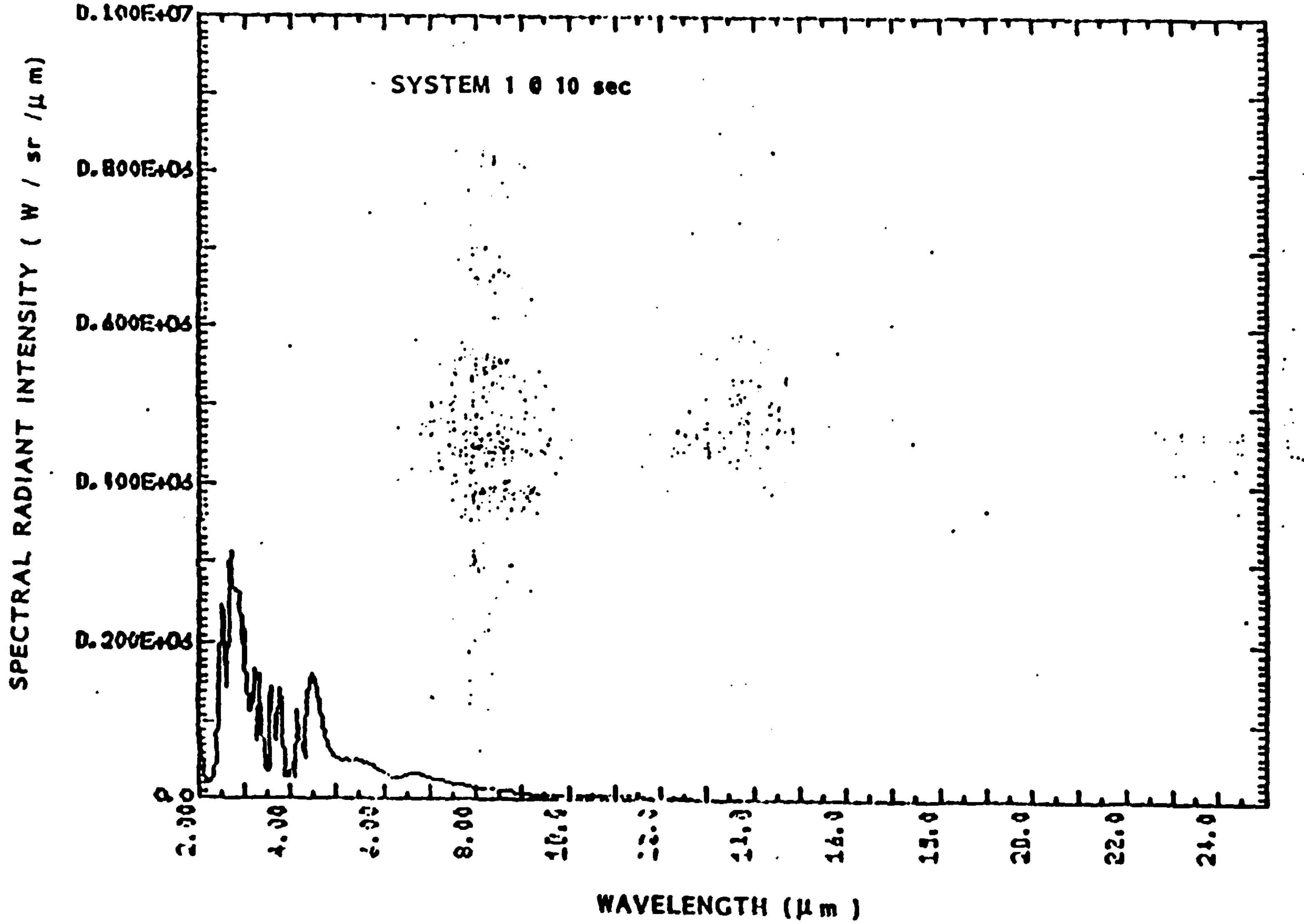

- DERIVATIVE CURVES = ∫ WAVE LENGTH

ATO3/HH

# Typical CALC / IMPERICAL Result In NRC TL86-088

This chart shows a typical result from the calculations utilizing the methodology described in the previous chart. Note that the signatures are available from wavelength of 2 to 24m. The signatures supplied to TMDAS were derived from signatures similar to this by integrating these results over the desired wavelengths.

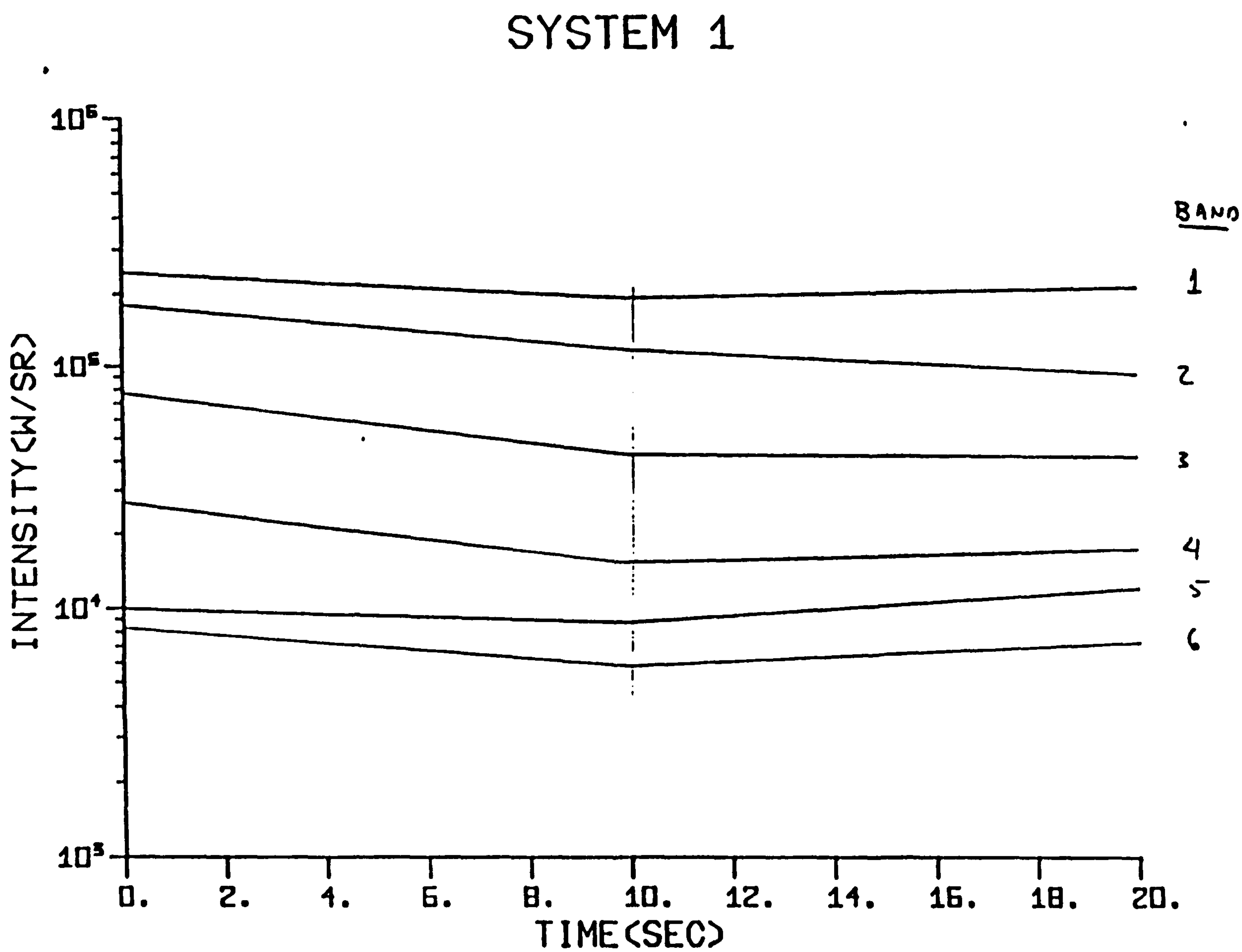
## TYPICAL CALC / EMPIRICAL RESULT IN NRC-TL-86-088




ATO34H

## System 1

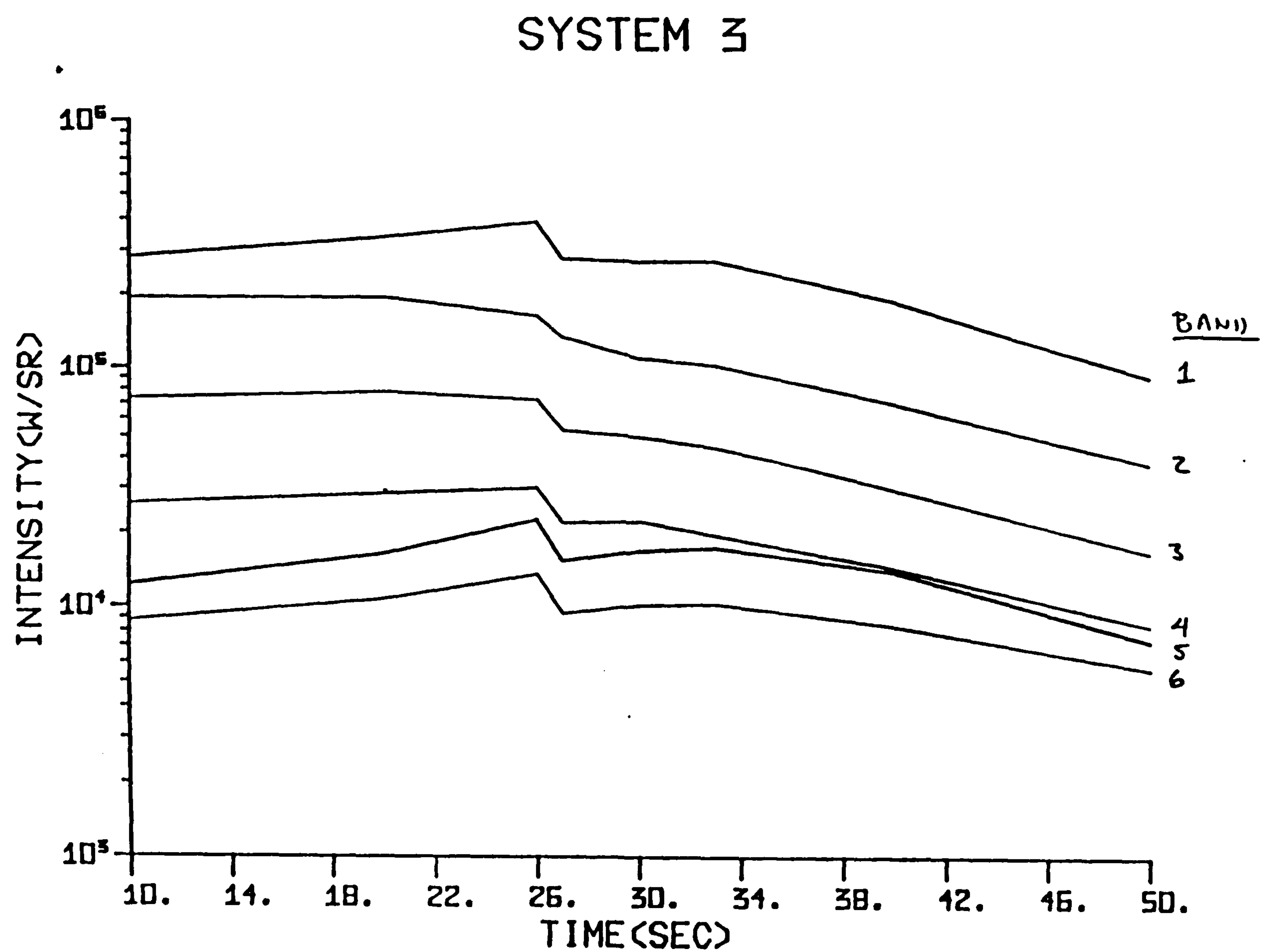
This chart shows the intensity versus time expected for System 1 based on the integration on signatures as described in the previous charts.



SYSTEM 1
INTENSITY(W/SR)
10⁶
10⁵
10⁴
10³
0.
2.
4.
6.
8.
10.
12.
14.
16.
18.
20.
TIME(SEC)
BAND
1
2
3
4
5
6

## System 3

This chart presents the radiometric signature for System 3 derived as described in the preceding charts.


SYSTEM 3
$10^6$
$10^5$
$10^4$
$10^3$
INTENSITY(W/SR)
10.
14.
18.
22.
26.
30.
34.
38.
42.
46.
50.
TIME(SEC)
BAND
1
2
3
4
5
6

THIS PAGE LEFT INTENTIONALLY BLANK

# APPENDIX E

## ANALYSIS OF: LOW COST AIRBORNE TACTICAL OPTICAL RECONNAISSANCE (LOCATOR) SYSTEM

Following are facing page text for the charts indicated.

## OUTLINE LOW COST AIRBORNE TACTICAL OPTICAL RECONNAISSANCE (LOCATOR) (U)

This chart presents an outline of the entire presentation. The presentation begins with an executive summary which summarizes the requirements, objectives, concepts, overall approach and status. This is followed by five more detailed descriptions of the efforts and results from five of the sub-tasks required to develop the LOCATOR system. The presentation concludes with a review of the reference case and the interim conclusions and recommended plans.

NRC



# OUTLINE LOW COST AIRBORNE TACTICAL OPTICAL RECONNAISSANCE (LOCATOR) (U)

- EXECUTIVE SUMMARY (REQUIREMENTS, OBJECTIVES, CONCEPT, APPROACH, STATUS)

- SUBTASK STATUS/RESULTS

  1) PLATFORM SELECTION
  2) SENSOR CHARACTERIZATION
  3) PERFORMANCE ANALYSIS
  4) COST ANALYSIS
  5) GEOMETRIC ANALYSIS

- REVIEW REFERENCE CASE

- INTERIM CONCLUSIONS & PLANS

## REQUIREMENT TO DEFINE LOW COST (U)

This chart summarizes the requirements which led to this study. The major requirement was absence of a good reference point for a low cost tactical optical sensor systems support TMD. The chart refers to similar systems such as AIRS and BOSS indicating their short-fall relative to the task undertaken by LOCATOR. The final bullet refers to strategic systems which tend to push the state-of-the-art and therefore are very high cost approaches relative to that required for TMD.

# REQUIREMENT TO DEFINE LOW COST (U)



- NO GOOD REFERENCE POINT
- AIRS
  - SIMILAR TASK BUT COST ~ B$'s
  - PLATFORM @ 20KM; FUEL = $H_2$
  - SCALED FROM AOA
  - A/C MANUFACTURER
- BOSS
  - DIFFERENT TASK (CLOSE-RANGE; APRIORI KNOWLEDGE)
  - BASED ON IRIS
  - TEST PROGRAM
  - COST (& DERIVATION) NOT AVAILABLE @ NRC
- AOA, AOS, FAS, OAMP . . .
  - DIFFERENT TASKS (STRATEGIC AND/OR R&D)
  - PUSHING STATE-OF-ART IN MANY AREAS

## OBJECTIVES OF LOW COST AIRBORNE TACTICAL OPTICAL RECONNAISSANCE (LOCATOR) STUDY (U)

This chart summarizes the objectives of this study. The major objective is to define what low cost means for TMD application where the low cost achieved by taking advantage of the large boost signature and stereo viewing. The study is limited to techniques which fall within the existing state-of-the-art. Two other objectives are to define representative performance for the system and to develop a tool for cost trade-offs.

NRC

# OBJECTIVES OF LOW COST AIRBORNE TACTICAL OPTICAL RECONNAISSANCE (LOCATOR) STUDY (U)

- DEFINE "LOW COST" FOR OPTICAL SYSTEM TO OBSERVE TACTICAL BOOSTERS
  - TAKE ADVANTAGE OF LARGE SIGNATURE AND STEREO VIEWING
  - LIMIT TO "EXISTING STATE-OF-THE-ART"
- DEFINE REPRESENTATIVE PERFORMANCE FOR LOCATOR
- DEVELOP TOOL FOR COST-PERFORMANCE TRADE-OFF

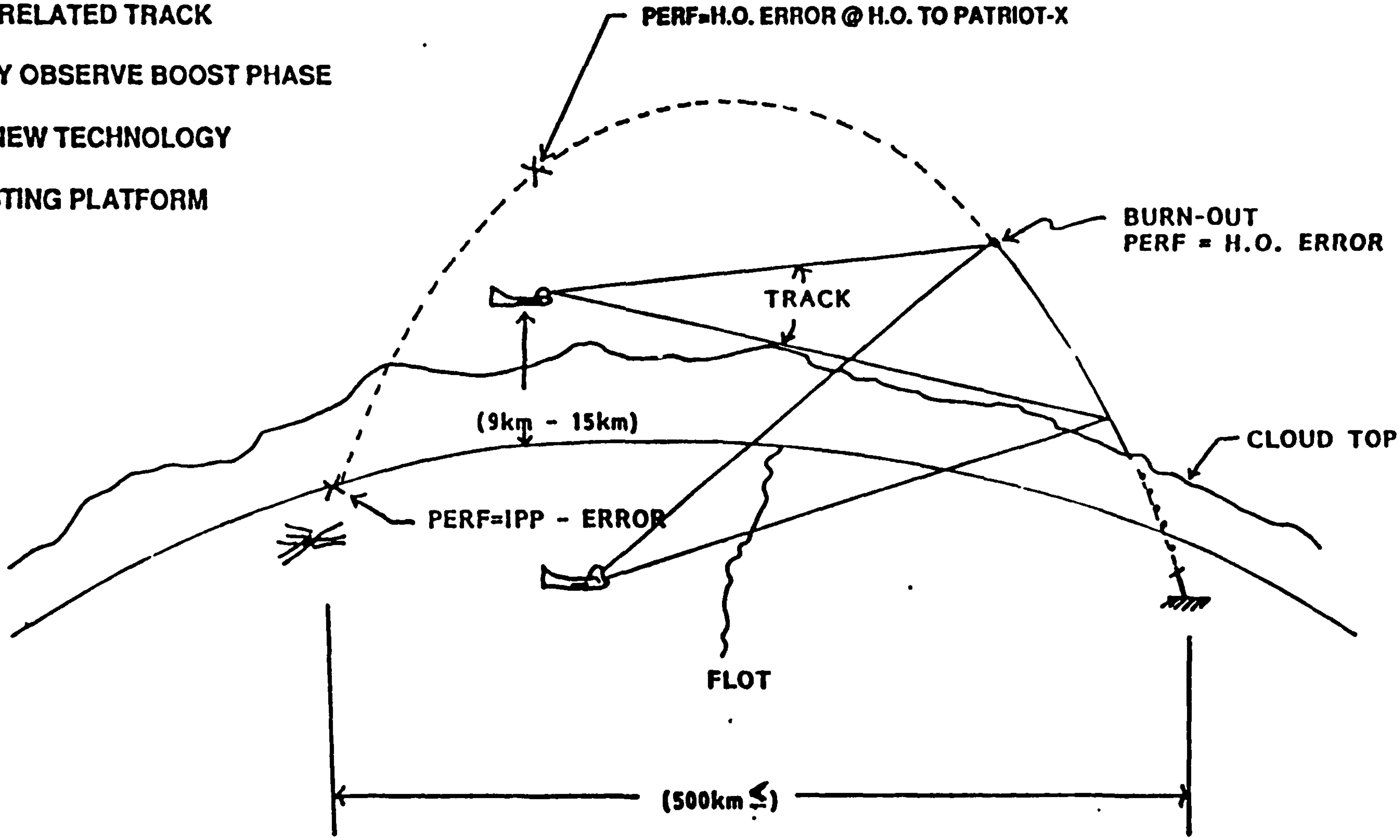
## LOCATOR CONCEPT (U)

This chart gives an overview of the LOCATOR concept. Note that there are at least two platforms to provide stereo viewing for the track. Viewing is only considered during the period after emergence from the cloud and prior to burnout. Performance measures, which will be calculated, are the handover error at burnout, the handover error at a handover altitude appropriate to the PATRIOT system or its derivitives and the impact point prediction (IPP) error. The major constraints on the analysis are summarized in the upper left hand corner.

# LOCATOR CONCEPT (U)

UNCLASSIFIED

- CORRELATED TRACK
- ONLY OBSERVE BOOST PHASE
- NO NEW TECHNOLOGY
- EXISTING PLATFORM




UNCLASSIFIED

## POTENTIAL LOCATOR APPLICATIONS (U)

This chart reviews some of the possible applications of the LOCATOR concept. The major application is an optical adjunct or an alternative to a radar fence for Europe. In this role it could perform cueing functions, IPP functions, handover functions, threat identification and launch site location. The LOCATOR concept, because of its mobility, offers an opportunity to perform similar tasks for TMD protection of rapid deployment forces or for third country threats. A third possible role is in defense of SLBM threats against CONUS and Europe.

NRC

# POTENTIAL LOCATOR APPLICATIONS (U)

- EUROPE - OPTICAL ADJUNCT AND/OR RADAR FENCE ALTERNATIVE
  - CUEUING
  - IPP
  - HANDOVER
  - THREAT IDENTIFICATION
  - LAUNCH SITE LOCATION
- RAPID DEPLOYMENT - SIMILAR TASKS FOR TMD PROTECTION OF RAPID DEPLOYMENT FORCES
- POSSIBLE ROLE IN SLBM DEFENSE OF CONUS & EUROPE

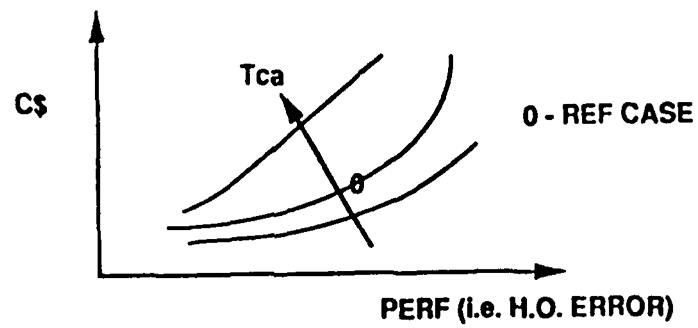
# APPROACH (U)

This chart outlines the approach that has been used to derive the cost and capabilities of the LOCATOR system. The first step is to estimate the cost and performance as a function of the same design parameters constraints and assumptions. This allows calculation of both the cost and the performance for a typical set of these parameters. This was accomplished to define the reference case and indicate the meaning of low cost. The third step in the approach, is to introduce a scenario parameter which will define characteristics of the scenario in a few numbers and thus allow trade-offs between performance scenario and cost. The scenario parameter selected is the threat coverage area. That is the area in which the threat can exist and be covered by a single pair of platforms.

# APPROACH (U)



- RELATE COST & PERFORMANCE TO SYSTEM DESIGN PARAMETERS FOR CONSTRAINTS & ASSUMPTIONS APPROPRIATE TO LOCATOR
  - SYSTEM COST (C$): C$ = f{D,Ifov,Fno,Nd,Td,Mtld,Alts,Ns}
  - PERFORMANCE: Perf = f{Ft,Amp,Amb} (ALL ERROR VALUES 3σ)
  - WHERE: Ft = f{Mtld,Nd,Td}; Amp = f{D}; Amb = f{Naver}
- EVALUATE FOR TYPICAL (Ie REF) CASE => "LOW COST"
- INTRODUCE A "SCENARIO PARAMETER" AND PERFORM COST-PERF-SCENARIO TRADE-OFFS
  - THREAT COVERAGE AREA (Tca) = f{Rmax,Ns,Fovaz,Geom.}
  - RESULT:



## STATUS (U)

This chart summarizes the current status of the analysis, defines the reference case which for a the threat produced position errors of 240m at burnout, a handover ellipse having a major axis of 8.2km and a minor axis of .84 and .4km at a typical handover altitude. Three sigma IPP error for this reference system is a 1 x 12.2km. It is estimated that the sensor would weight 80 lbs. which could be carried on an amber RPV. The acquisition cost for the platform and sensor would be the order of $900,000. The R&D effort required for the sensor would be 2.3 million dollars and since an existing RPV is used there will be no R&D cost for the platform.

# STATUS (U)



- DERIVED COST & PERFORMANCE RELATIONSHIPS
- EVALUATED REFERENCE CASE:

THREAT: BR3500
$3\sigma$ HANDOVER ERROR @ BURN OUT = 240M
@ TYPICAL PATRIOT RADAR
ACQUISITION = 8.2 X 0.84 X 0.4KM

| | |
|---|---|
| $3\sigma$ IPP ERROR = 1.0 X 12.2KM | SENSOR WT - 80 Lb |
| NO PLATFORMS - VARIABLE | PLATFORM = AMBER |
| DETECTOR - PbSe | 1 SENSOR / PLATFORM |
| OPTICS DIAMETER - 5CM | NAVER = 10M |

ACQUISITION COST (PLATFORM & 1-SENSOR) = 900K$

| | |
|---|---|
| SENSOR R&D (15 * C$s1) | = 2.3M$ |
| AVG COST 1ST 25 SENSORS | = 95K$ |
| AMBER COST | |
| - AIR VEHICLE | = 600K$ |
| - JAM RESISTANT DATA LINK | = 200K$ |

## UNMANNED AIR VEHICLE (U)
## - EXERPTS FROM UAV-JPO MASTER PLAN (U)
## (JUNE 1989) - (U)

This chart is the first chart describing the platform considerations. It reviews the categories and capabilities of the planned unmanned air vehicles as of June 1989. The vehicle which best meets the needs for the LOCATOR is the endurance vehicle, both because of its long time on station and its relatively high altitude capabilities.

# UNMANNED AIR VEHICLE (U) - EXCERPTS FROM UAV-JPO MASTER PLAN (JUNE 1989) - (U)

## CATEGORIES

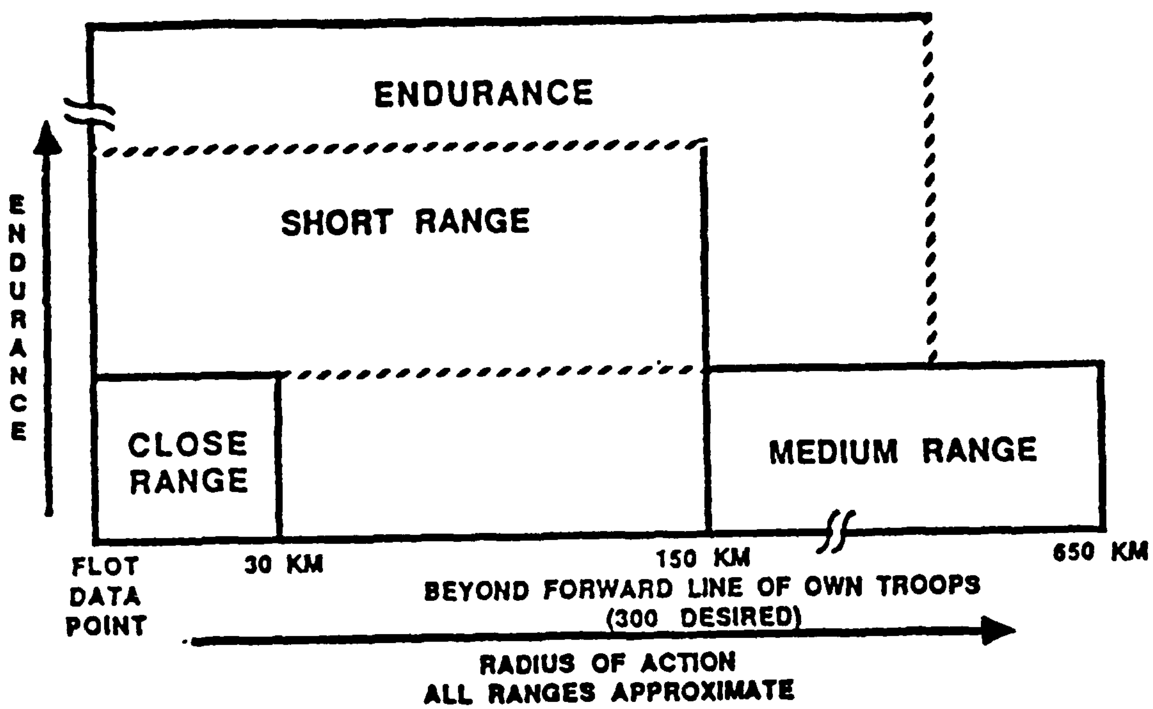



Figure III-1

**ENDURANCE UAV MILESTONES**

COMPLETE AMBER ADV. DEV. - FY90

BEGIN OPERATIONAL TESTING WITH AMBER - FY90

COMPLETE MISSION NEED STATEMENT - FY90

ENDURANCE DEMO/VALIDATION - FY90-FY92

FULL SCALE DEVELOPMENT - FY93

# AMBER UAV CHARACTERISTICS (U)

An existing prototype exists for the endurance UAV. This is the amber vehicle, and four of these vehicles were built prior to 1989. During FY89, one complete system, including the ground station six air vehicles, has been procured. Cost data is provided based on telephone conversations with the manufacturer of the amber vehicle. The performance capabilities are summarized and show that the existing amber has already demonstrated the capability to carry the required payload for the reference system in excess of 36 hours with an altitude sufficient to over fly cloud cover in Europe.

NRC

# AMBER UAV CHARACTERISTICS (U)

UNCLASSIFIED

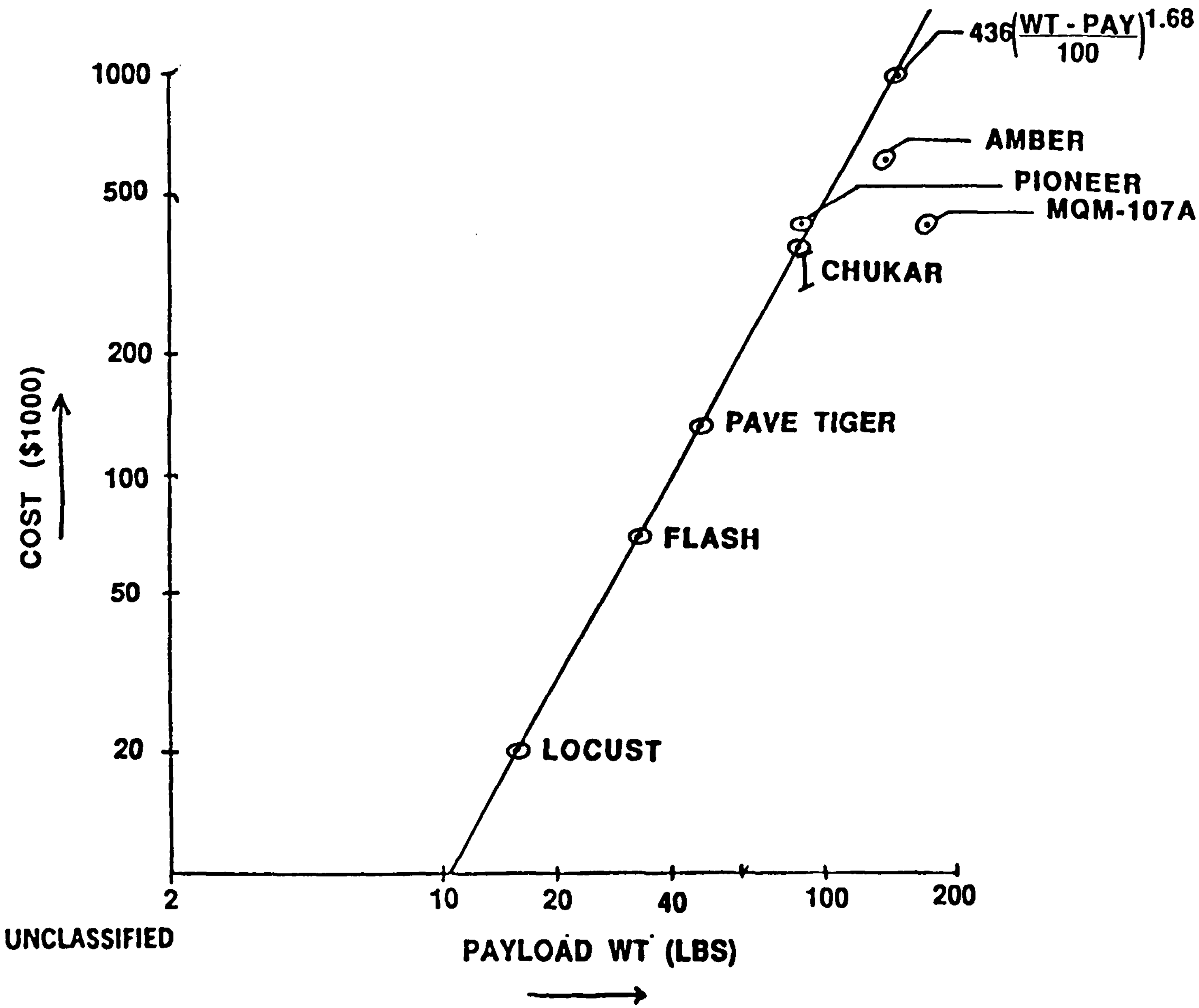
- HISTORY
  - 4 VEHICLES BUILT PRIOR TO 1989
  - 1 COMPLETE SYSTEM (GROUND STATION + 6 AIR VEH) PROCURED BY UAV-JPO IN FY89
- COST (TELECON LEADING SYSTEMS, INC. OCT 1989):
  - AIR VEHICLE $600K
  - JAM RESISTANT DATA LINK $200K
- AIR VEHICLE CONTROL: (3 AXIS DIGITAL PLATFORM) PREPROGRAMMED / REPROGRAM IN AIR / REMOTE
- PERFORMANCE
  - LAUNCH & RECOVERY: LAND & SHIPBOARD
  - ENDURANCE: >36 HRS (38 HR DEMONSTRATED @ 85 Lb PAYLOAD)
  - PAYLOAD: 150 Lb (PROPOSED AMBER-3 565 Lb)
  - TAKE-OFF WT: 800Lb (PROPOSED AMBER-3 1200 Lb)
  - PAYLOAD VOLUME: 5-15 $FT^3$
  - CEILING: 9.1 KM (30,000FT)

UNCLASSIFIED

## UAV COST vs PAYLOAD WEIGHT (U)

This chart shows a plot of the payload weight versus cost of UAV type vehicles. This chart shows that the amber vehicle falls relatively close to the best fit line to experience in the development of these vehicles. This chart also provides a bases for estimating the expected cost of a new vehicle which might be required if smaller or larger payloads were necessary.

# UAV COST Vs PAYLOAD WEIGHT



## OCCURRENCE OF CLOUD COVER OVER EUROPE (U)

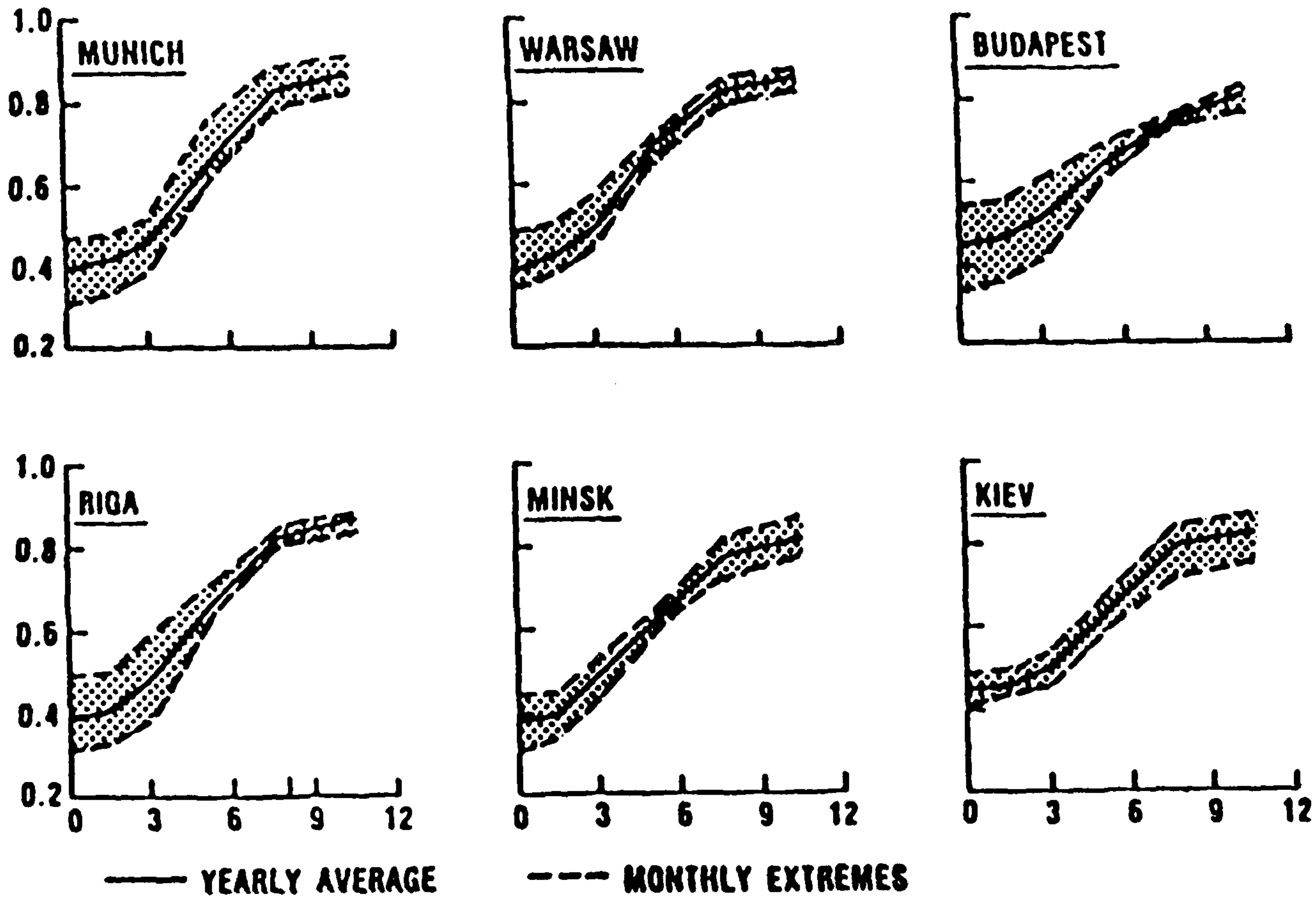
This chart summarizes the probability of cloud free line-of-sight from a syncronous altitude to the given cloud-top height indicated. Notice that the knee in these curves occurs below 9km for all six cities shown. Notice also, that on the chart giving the amber performance, the amber ceiling was in excess of 9km. Most of the cloud cover occurring above this knee is not significant for the LOCATOR concept, because cloud cover occurring above the tropisphere consist either of cumulus peaks rising above the tropopause over the center of a cumulus cloud or very thin high cirus clouds. Because of the high signatures of the boosters the thin cirus should cause little difficulty, and because of the small spacial location of each individual cumulus top surrounded by a relatively large area of clear sky the LOCATOR aircraft can fly in one of these clear areas between the cumulus peaks.

NRC

# OCCURRENCE OF CLOUD COVER OVER EUROPE (U)

UNCLASSIFIED

- PROBABILITY OF CLOUD-FREE LINE-OF-SIGHT FROM SYNCHRONOUS ALTITUDE TO GIVEN CLOUD TOP ALTITUDE (KILOMETERS)




UNCLASSIFIED

## SENSOR CHARACTERIZATION (U)

Sensor characterization tasks first require the selection of the bands which are determined by the characteristic of the signature and the atmosphere. Then the detector is selected with the desire to obtain a room temperature or near room temperature detector and a high electronic bandwidth. The sensitivity is of secondary consideration because of the high target intensity. It is desireable to minimize the size of the objects, at least until the point that the size no longer has a strong effect on the system weight. The optics must be sufficiently large to ensure that the signal of the noise ratio is greater than the order of 6 - 10 and to ensure an adequate angular measurement precision. The angular measurement bias is primarily determined by the navigation accuracy.

# SENSOR CHARACTERIZATION (U)



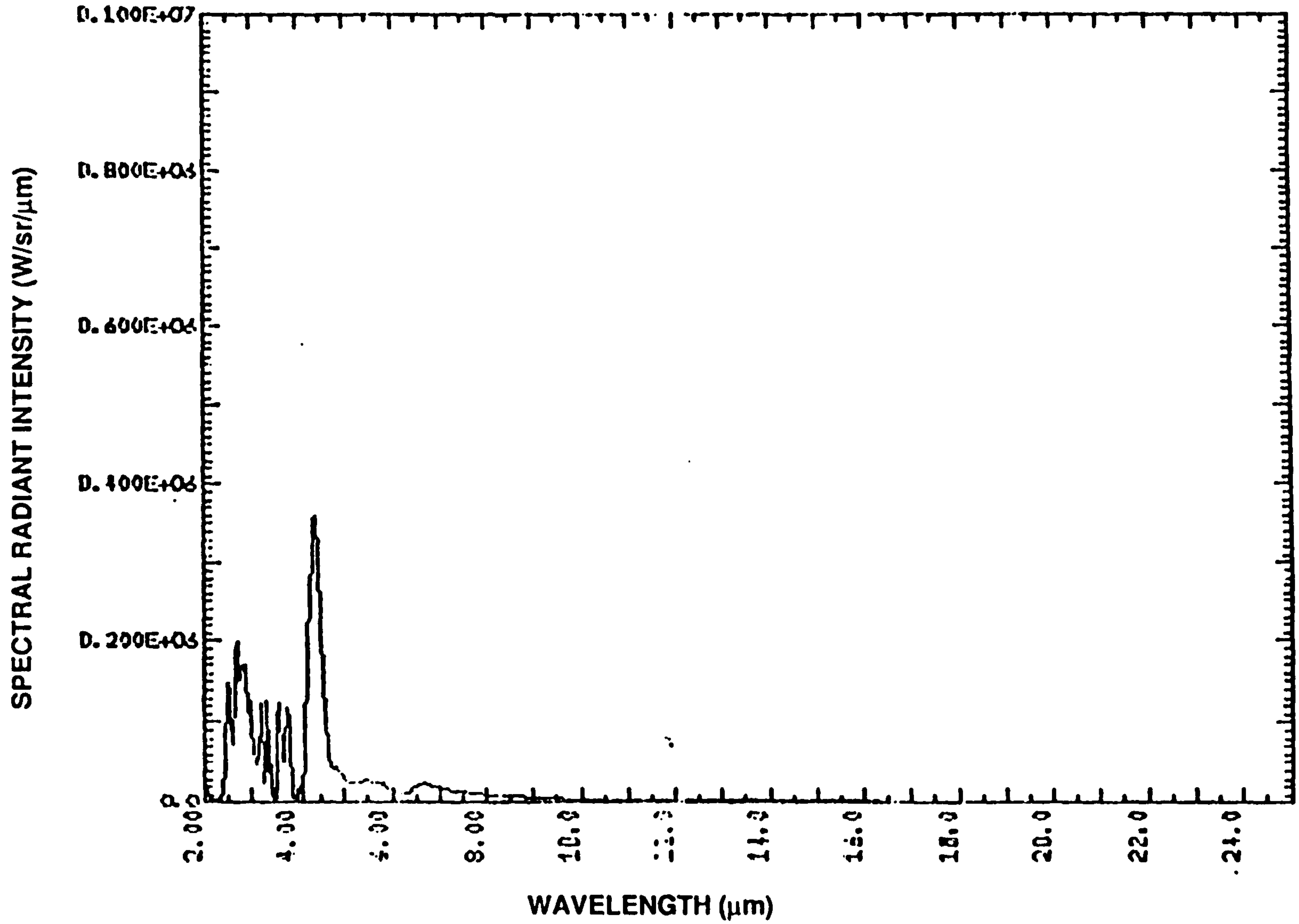
- BAND SELECTION = F{SIGNATURE, ATMOSPHERE}
- DETECTOR SELECTION:
  - ROOM TEMPERATURE
  - HIGH ELECTRONIC BANDWIDTH
  - SENSITIVITY SECONDARY
- OPTICS SIZING
  - MINIMIZE OPTICS SIZE
  - VERIFY THAT S/N IS > 6-10
  - ESTABLISH AMP-SIZE TRADE-OFF
- ANGULAR MEASUREMENT BIAS (AMB)

## SPECTRAL RADIANT INTENSITY OF TYPICAL TARGET (U)

This chart shows the spectral signature of a typical target and suggests that the most useful wavelength for the LOCATOR would be in the 2 - 6m region.

# SPECTRAL RADIANT INTENSITY OF TYPICAL TARGET (U)

UNCLASSIFIED




UNCLASSIFIED

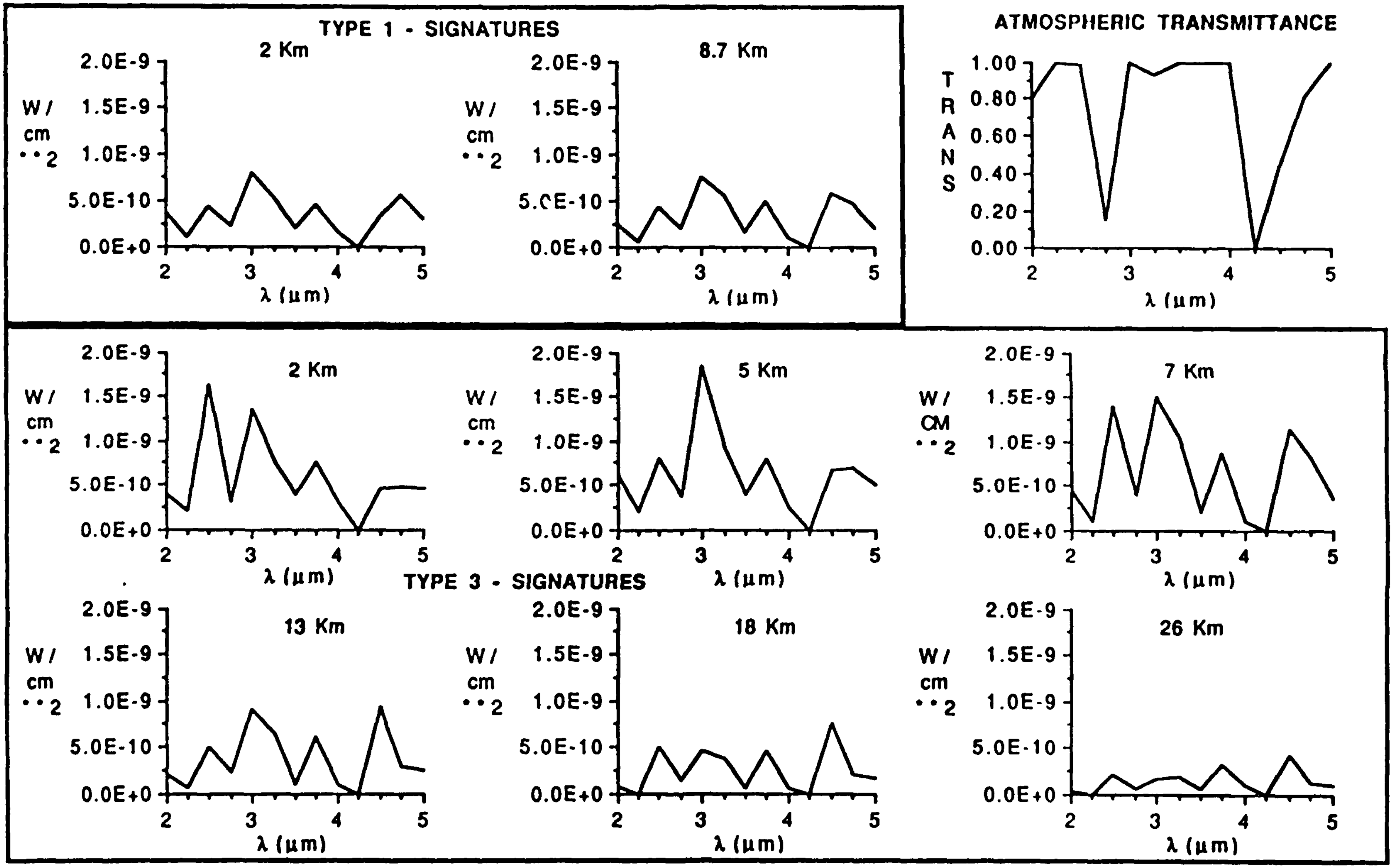
## SIGNAL-TO-NOISE CALCULATION (U)

This chart illustrates some of the steps involved in estimating the signal-to-noise ratio (SNR) for the LOCATOR system. Two major inputs to this calculation are the signatures shown for both Type 1 and Type 3 targets and the atmospheric transmission shown in the upper right hand curve. This data is used to estimate the SNR for several different ranges and target types for both day and night.

# SIGNAL-TO-NOISE CALCULATION

UNCLASSIFIED

- 13.0 Km PLATFORM ALTITUDE -




UNCLASSIFIED

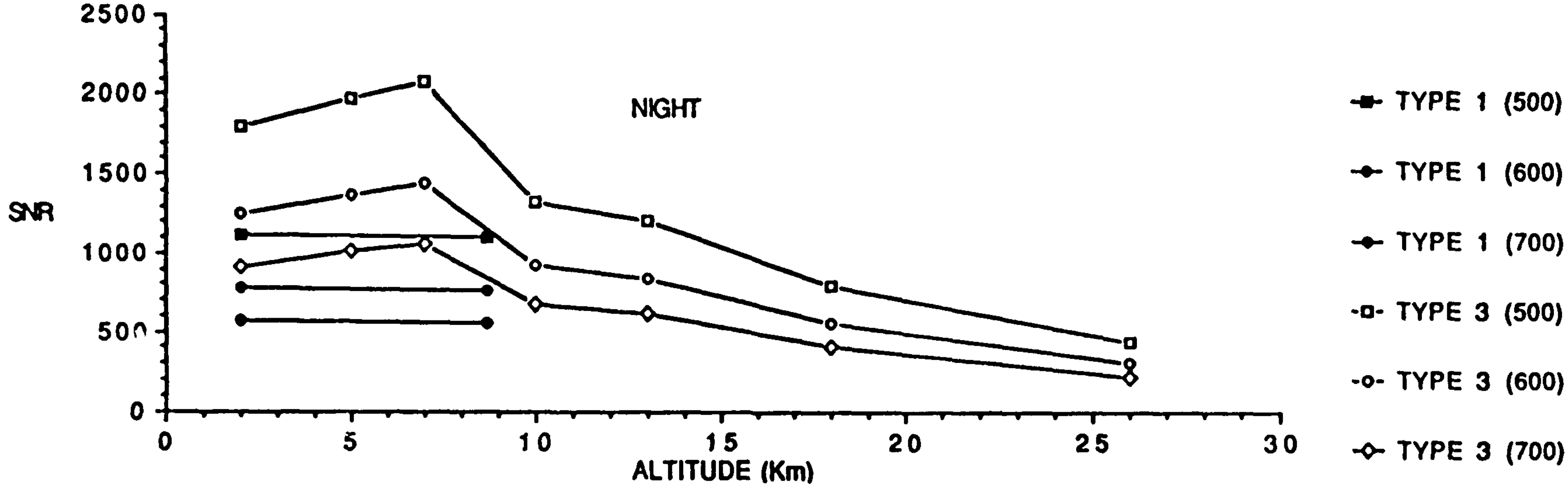
## EXPECTED SNR IS NOT A DRIVER (U)

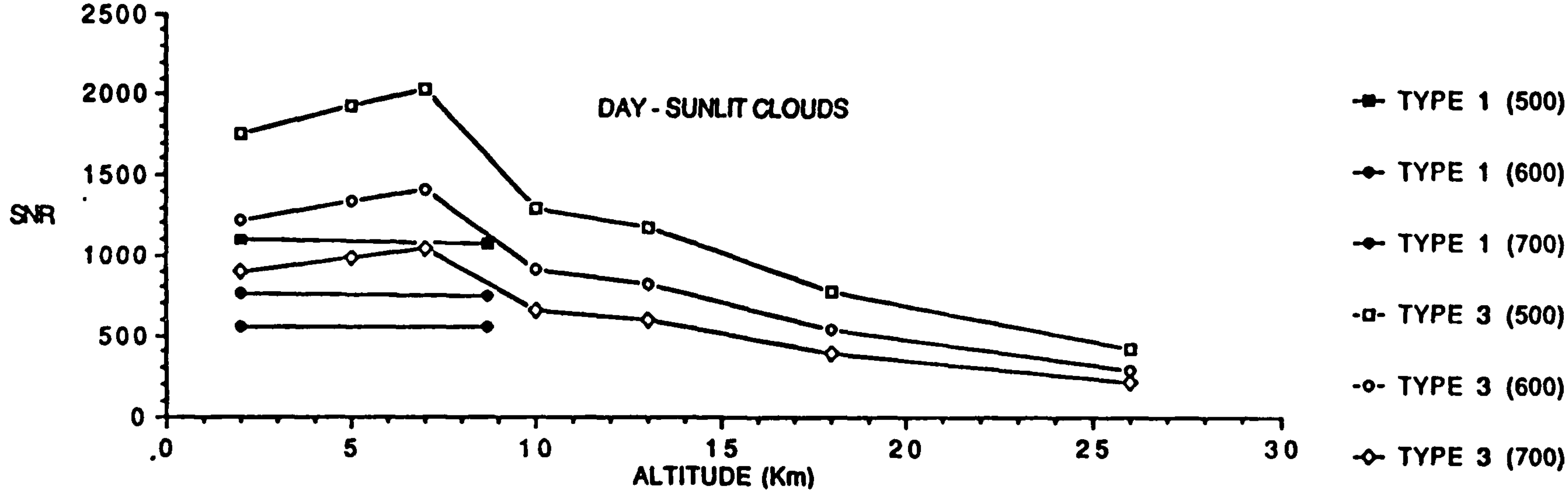
This chart summarizes the signal-to-noise ratios calculated as described in the previous chart. The major result of this chart is that the signal and noise ratios are all significantly larger than 10, and thus signal and noise ratio is not a driver for this design.

UNCLASSIFIED

# EXPECTED Snr IS NOT A DRIVER

- 13.0 Km PLATFORM ALTITUDE
- 5 cm APERTURE DIAMETER



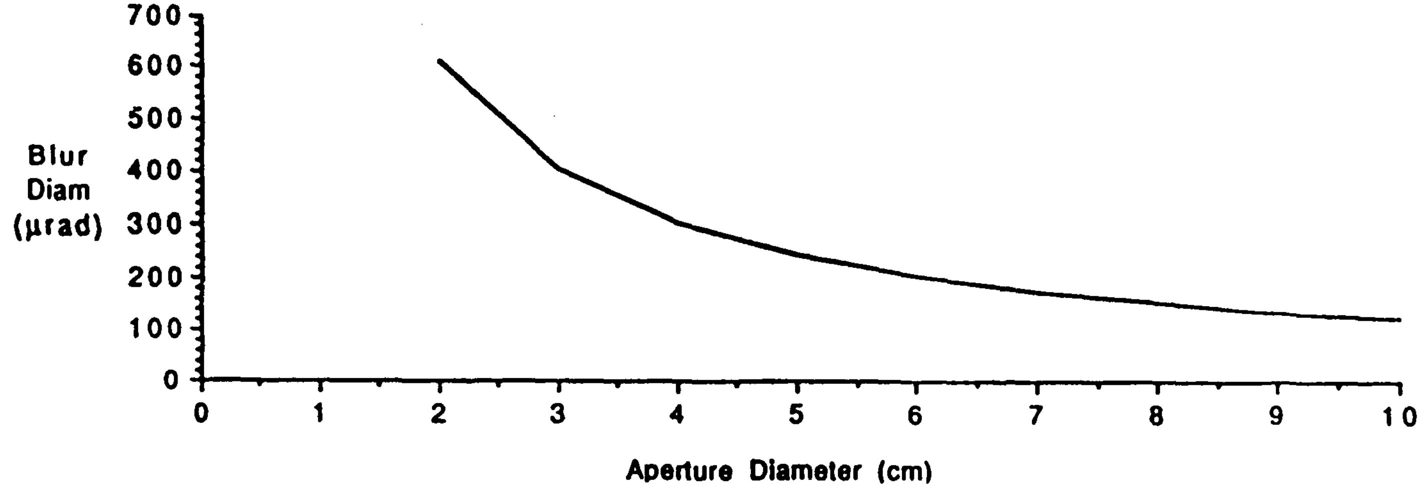



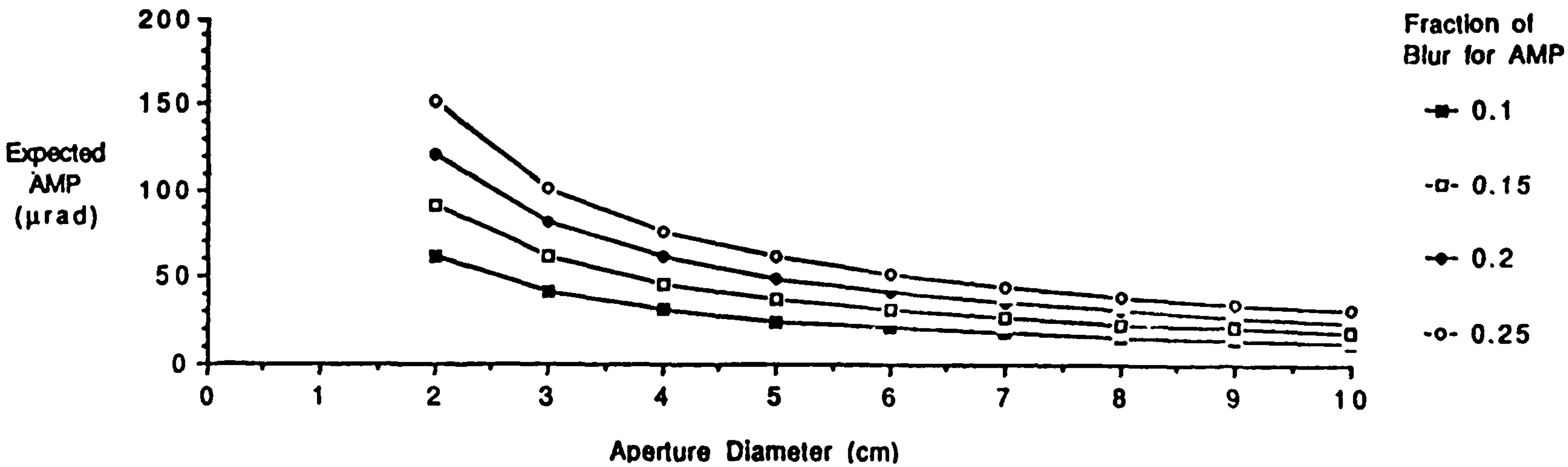

UNCLASSIFIED

## FOR HIGH SNR AMP DRIVES DIAMETER

This chart shows the relationship between aperature diameter and expected angular measurement precision (AMP). The blur diameter is a direct function of the aperature diameter and the wavelength. The AMP can be expected to lie somewheres between a tenth and a quarter of the blur diameter, and thus the lower curve shows the relationship between the aperture diameter and the expected AMP for the LOCATOR.

# FOR HIGH Snr AMP DRIVES DIAMETER



## ANGULAR MEASUREMENT BIAS (AMB) (U)

This chart shows the relationship between angular measurement bias (AMB) and the major contributors to this bias. There is an instrument contribution of less than 30m an atmospheric contribution which is relatively small and a contribution due to the navigational range error. For navigational erros in excess of 10 meters this is the dominant contributor. Navigation errors is a function of navigational methods are also shown on this chart which indicates that either radar tracking or beacon track techniques will easily eliminate this as a major source. It is still significant but of the same order as the instrument bias if one uses a four sattellite GPS navigation system.

# ANGULAR MEASUREMENT BIAS (AMB) (U)

$AMB = RMS\{AMB_{INST}, Naver/RANGE, AMBatm\}$

FOR AMB IN MICRO RADIANS:

AMB(INST) $\lesssim 0\{30\}$

AMBatm = ONLY @ LOW ELEVATION ANGLES, MOSTLY CORRECTABLE

$\lesssim 0\{10's\}$

Naver/RANGE $\sim 0\{10^3 - 10^4 Naver\}$ $\left(\frac{Naver}{RANGE} \times \frac{\mu RAD}{RAD}\right)$

| METHOD | Naver (KM) | AMB CONTRIBUTION |
|---|---|---|
| DME | $\sim 1.0$ | $10^4$ |
| GPS (>4 SATELLITES) | $\sim 0.01$ (10M) | $10^2$ |
| RADAR TRACKING | $\lesssim 10^{-4}$ (CM) | <1 |
| BEACON TRACK TECH's | $\sim 10^{-4}$ (CM) | 1 |

## PERFORMANCE TRADE-OFF'S (U)

This chart outlines the performance trade-off effort. For this study the performance consist of the position and velocity errors at burnout and their projection to impact. The estimation of these errors was based on a correlated track of an accelerating target from two sensors using the LOCATOR sensor characteristics. The existing NRC simulation codes required the addition of the IPP calculation in order to provide the desired performance outputs. The preliminary analyses were performed to derive the hand-over and the velocity errors at burnout. These are useful for showing the major sources of the variability and the characteristics of the fundamental error which is propagated along the trajectory.

NRC

# PERFORMANCE TRADE-OFF'S (U)



- CONSISTS OF BURN-OUT ERRORS (POSITION, VELOCITY & TIME), AND THEIR PROJECTION TO IMPACT
  - CORRELATED TRACK FROM 2-SENSORS
  - ACCELERATING TARGET
  - LOW COST SENSOR CHARACTERISTICS
- IPP CALCULATION ADDED TO TRACK SIMULATION CODE
- PRELIMINARY RUNS FOR H.O. ERROR AND VELOCITY ERROR AT BURN-OUT
  - SHOW MAJOR SOURCES OF VARIABILITY
  - SHOW LESS THAN 30 SEC TRACK DEFINES BURN-OUT CONDITIONS
  - SHOW KNEE IN VELOCITY ERROR @ 50-60 SEC OF TRACK
- PERFORMANCE EVALUATION FOR IPP AND H.O. ERROR @ B.O. AND PATRIOT H.O.
  - REF PERFORMANCE
  - TRADE-OFF STUDIES

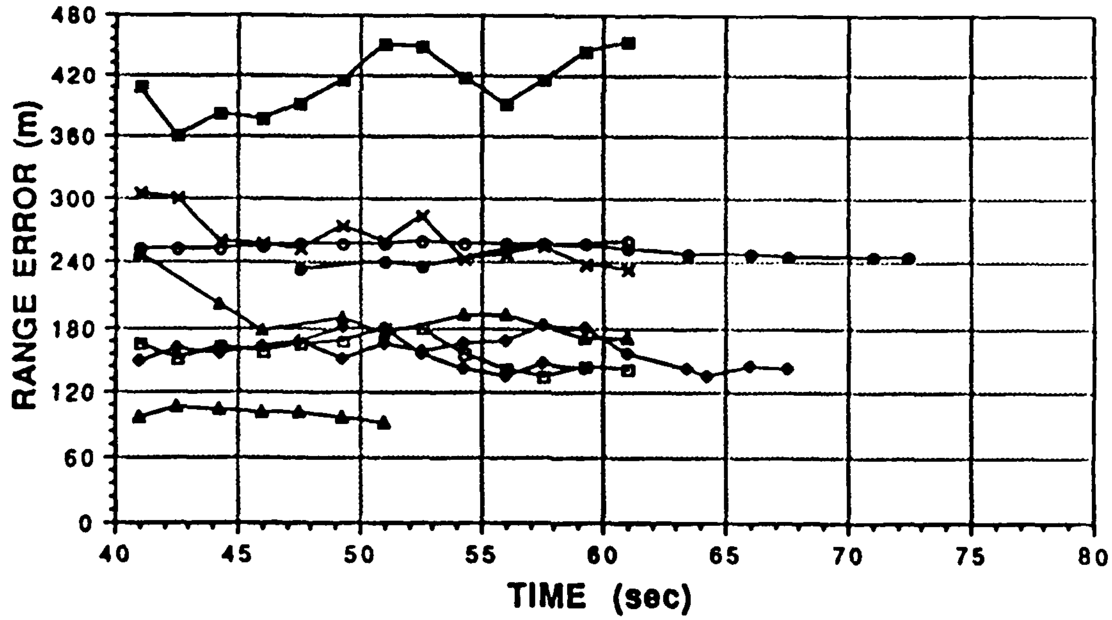
## RANGE ERROR AT BURN-OUT (m) (U)

This chart shows the range error at burnout as a function of time. Not shown on the timescale are the 40 seconds which include the 20 seconds of track initialization using the batch filter and the time required to reach an altitude above the clouds. These charts show that there is very little additional range accuracy achieved after this initiation of the track.

# RANGE ERROR AT BURN-OUT (m)

UNCLASSIFIED

| CURVE | TRAJECTORY | FRAME TIME (sec) | AMP (μrad) | AMB (μrad) | TRACK INITIATION ALTITUDE (TIME) [Km (sec)] | SENSOR SEPARATION ANGLE (°) |
|---|---|---|---|---|---|---|
| open square | 3500 | 0.33 | 200 | 30 | 10.6 (31) | 120 |
| small diamond | 3300 | 0.33 | 200 | 30 | 10.6 (31) | 120 |
| filled square | 3500 | 0.33 | 500 | 30 | 10.6 (31) | 120 |
| filled diamond | 3500 | 0.33 | 200 | 30 | 15 (38) | 120 |
| x | 3500 | 0.33 | 200 | 30 | 10.6 (31) | 20 |
| open circle | 3500 | 0.33 | 200 | 1000 | 10.6 (31) | 120 |
| filled triangle | 3500 | 0.50 | 200 | 30 | 11 (31) | 120 |
| filled triangle | 3500 | 0.05 | 200 | 30 | 10.6 (31) | 120 |
| filled circle | 3500 | 0.50 | 50 | 100 | 15 (38) | 120 |




UNCLASSIFIED

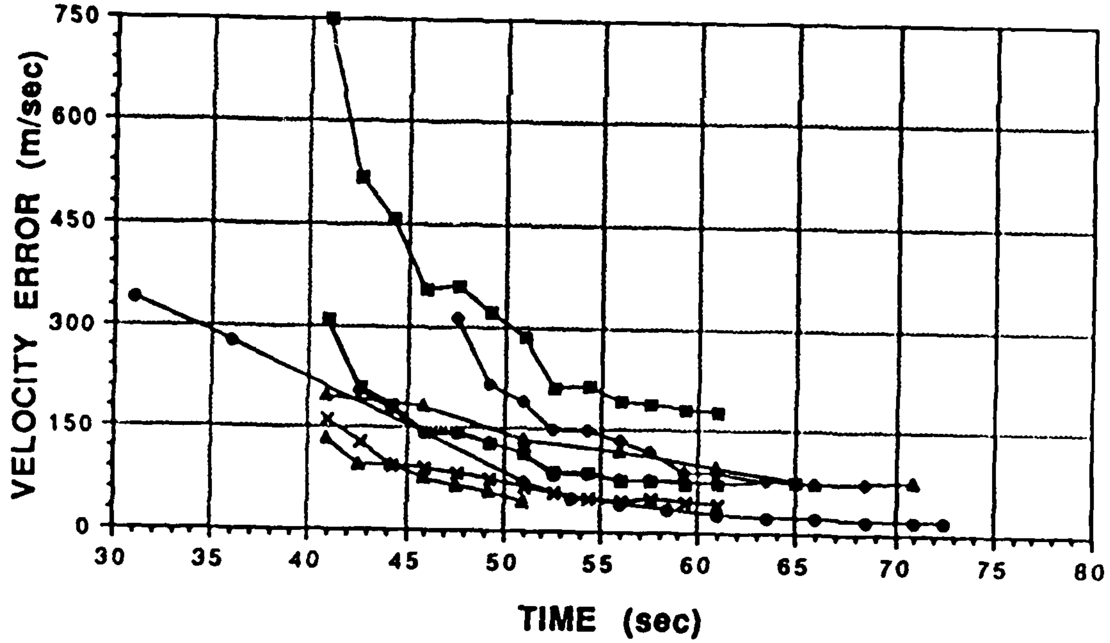
# VELOCITY ERROR AT BURN-OUT (m/sec) (U)

This chart shows the velocity error at burnout versus time. All but one of these histories was initiated with 20 seconds of track. The one curve indicated with the circles had an intialization time of 10 seconds, thus it has been shown 10 seconds earlier than the other tracks. This chart shows that most of the velocity information has been obtained by 45 - 55 seconds after launch.

# VELOCITY ERROR AT BURN-OUT (m/sec)

UNCLASSIFIED

| CURVE | TRAJECTORY | FRAME TIME (sec) | AMP (μrad) | AMB (μrad) | TRACK INITIATION ALTITUDE (TIME) [Km (sec)] | SENSOR SEPARATION ANGLE (°) |
|---|---|---|---|---|---|---|
| —□— | 3500 | 0.33 | 200 | 30 | 10.6 (31) | 120 |
| —◆— | 3300 | 0.33 | 200 | 30 | 10.6 (31) | 120 |
| —■— | 3500 | 0.33 | 500 | 30 | 10.6 (31) | 120 |
| —◆— | 3500 | 0.33 | 200 | 30 | 15 (38) | 120 |
| —×— | 3500 | 0.33 | 200 | 30 | 10.6 (31) | 20 |
| —○— | 3500 | 0.33 | 200 | 1000 | 10.6 (31) | 120 |
| —▲— | 3500 | 0.50 | 200 | 30 | 11 (31) | 120 |
| —△— | 3500 | 0.05 | 200 | 30 | 10.6 (31) | 120 |
| —●— | 3500 | 0.50 | 50 | 100 | 15 (38) | 120 |




UNCLASSIFIED

## PERFORMANCE TRADE-OFF RESULTS (U)

This chart tabulates the burnout error in range and velocity similar to that presented in the previous two charts. The IPP error both up-range and cross-range and the handover error at 35 seconds prior to impact showing the major and two minor axis of the error elipse are also tabulated. These results are presented for the refernce case as well as the number of variations in trajectory, frametime, AMP, AMB, track initiation altitude and sensor seperation.

## PERFORMANCE TRADE-OFF RESULTS

| VARIATION | RNG (KM) | FRAME TIME (SEC) | AMP (ur) | AMB (ur) | TRACK INIT ALT (KM) | SENSOR SEP (deg) | B.O. ERROR RANGE (M) | B.O. ERROR VEL (M/s) | IPP ERROR UR (KM) | IPP ERROR CR (KM) | H.O. ERROR @-35s MAJ (KM) | H.O. ERROR @-35s (KM) | H.O. ERROR @-35s (KM) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ref | 500 | 0.50 | 50 | 100 | 15.0 | 120.0 | 233.8 | 17.0 | 12.3 | 1.0 | 8.2 | 0.8 | 0.4 |
| traj | 300 | 0.50 | 50 | 100 | 15.0 | 120.0 | 280.8 | 26.6 | 25.2 | 2.0 | 16.4 | 0.7 | 1.4 |
| frame-t | 500 | 0.10 | 50 | 100 | 15.0 | 120.0 | 277.1 | 8.2 | 3.9 | 0.8 | 2.8 | 0.7 | 0.3 |
| frame-t | 500 | 1.00 | 50 | 100 | 15.0 | 120.0 | 263.1 | 21.1 | 22.5 | 1.4 | 15.1 | 1.2 | 0.5 |
| amp | 500 | 0.50 | 100 | 100 | 15.0 | 120.0 | 239.3 | 33.9 | 18.9 | 1.7 | 12.7 | 1.5 | 0.8 |
| amp | 500 | 0.50 | 30 | 100 | 15.0 | 120.0 | 233.0 | 10.2 | 10.2 | 0.7 | 7.0 | 0.7 | 0.3 |
| amb | 500 | 0.50 | 50 | 30 | 15.0 | 120.0 | 76.0 | 17.0 | 12.3 | 0.8 | 8.2 | 0.7 | 0.4 |
| amb | 500 | 0.50 | 50 | 10000 | 15.0 | 120.0 | 23243.1 | 38.1 | 15.6 | 55.6 | 51.4 | 8.5 | 14.0 |
| trkinalt | 500 | 0.50 | 50 | 100 | 10.6 | 120.0 | 246.0 | 11.4 | 9.9 | 0.9 | 6.6 | 0.8 | 0.3 |
| trkinalt | 500 | 0.50 | 50 | 100 | 24.6 | 120.0 | 274.7 | 33.8 | 21.9 | 1.7 | 14.7 | 0.7 | 1.5 |
| trkinalt | 500 | 0.50 | 50 | 100 | 33.5 | 120.0 | 268.3 | 72.7 | 61.2 | 3.7 | 40.9 | 3.3 | 1.7 |
| senssep | 500 | 0.50 | 50 | 100 | 15.0 | 5.0 | 1456.1 | 18.0 | 12.0 | 0.3 | 8.0 | 0.3 | 2.8 |
| senssep | 500 | 0.50 | 50 | 100 | 15.0 | 15.0 | 475.0 | 11.7 | 10.5 | 0.3 | 7.1 | 0.3 | 1.0 |

## COST SUMMARY (U)

This chart outlines the approach to estimating the cost for the LOCATOR system. The cost estimates are based on estimating a cost of the first unit based on past experience for similar systems. The AMP unit and R&D cost are then a function of this cost. The relationships used for the sensor cost, the sensor weight and UAV cost are summarized.

# COST SUMMARY (U)

- Nth UNIT AND R&D = f{1st UNIT COST (C$s1)}
- SENSOR

  EXTENDED PREVIOUS RESULTS TO DIAMETER ~ 4CM

  $C\$s1 = 13\ Wss\ Nd^{0.15}\ \exp\{-(0.03D + 0.009T_d)\}$

  ANALYSIS OF 9 SENSORS + PREVIOUS STUDIES:

  $Wss = 38 + D^{1.7}$

  (Wss - SENSOR WT., Nd - No DETECTORS; D - Optics Diam; $T_d$ - Optics Temperature)

- UAV
  - AMBER (MFG = LEADING SYSTEMS, INC. - $600K)
  - C$s1 VS Wss LINEAR ON LOG-LOG

# GEOMETRIC ANALYSIS (U)

This chart outlines the objectives and approach to the geometric analysis used.

NRC

# GEOMETRIC ANALYSIS (U)



- OBJECTIVE: 1) DEFINE THREAT COVERAGE AREA WITH FEW PARAMETERS

  2) DEFINE VARIATION OF Tca WITH PARAMETERS

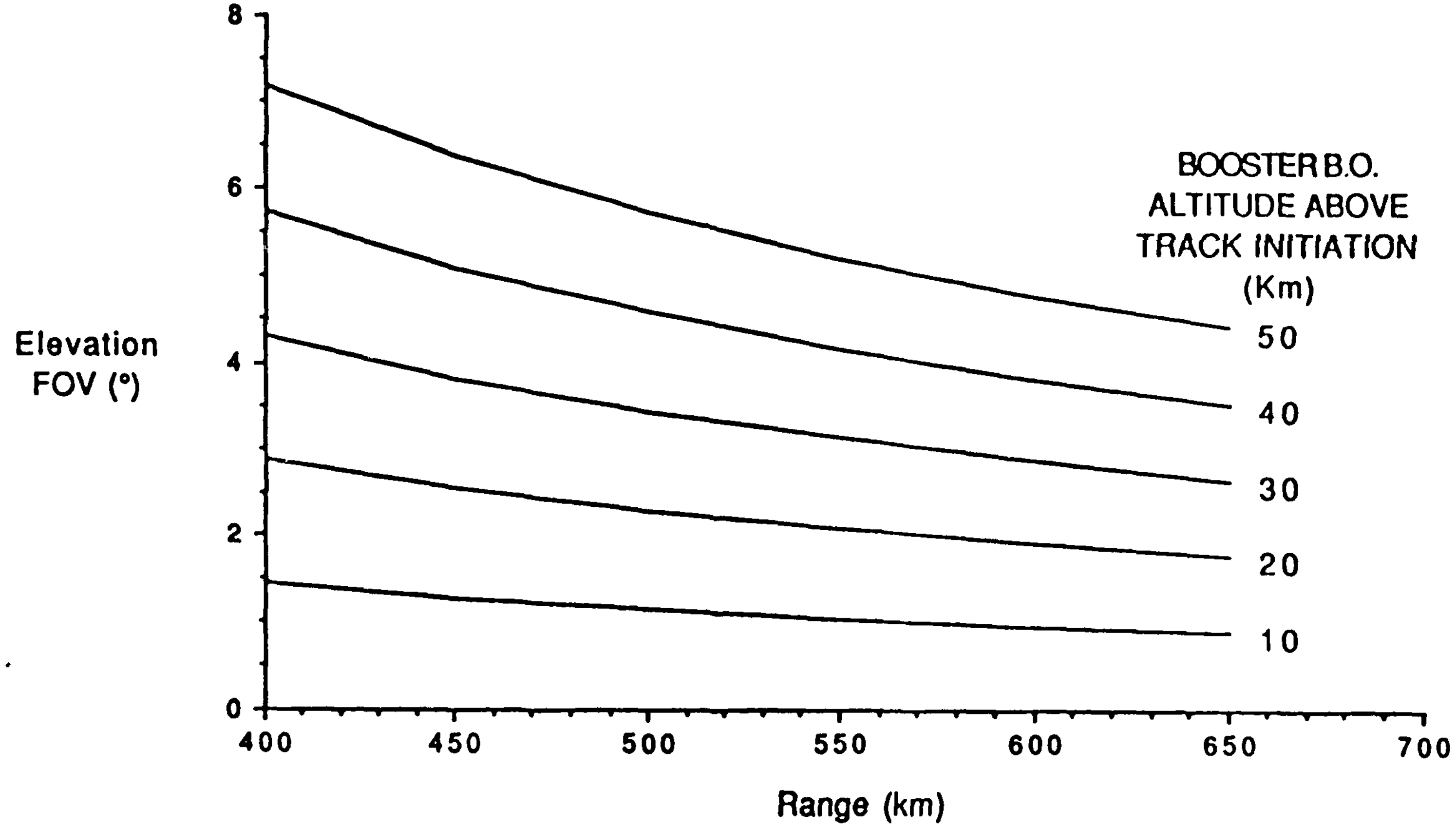
- SELECT SIMPLE GEOMETRY WITH SENSORS IN A LINE AND THREAT DEPLOYED BETWEEN THE LINE OF SENSORS AND A PARALLEL LINE LOCATED "De" FROM THE LINE OF SENSORS

## ELEVATION FOV REQUIRED vs RANGE (U)

One of the outputs of the analysis of the geometry is the elevation field-of-view required. This field-of-view decreases as the booster burnout altitude above track initiation decreases and as the range from the sensor to the target increases. This chart shows that over the ranges of 400 - 650km and from 10 - 50km burnout altitudes, the elevation field-of-view is under 8°.

# ELEVATION FOV REQUIRED vs RANGE





## CURVATURE AND THE MINIMUM OBSERVATION HEIGHT (Hmo) LIMITS THE GROUND RANGE (Rg) (U)

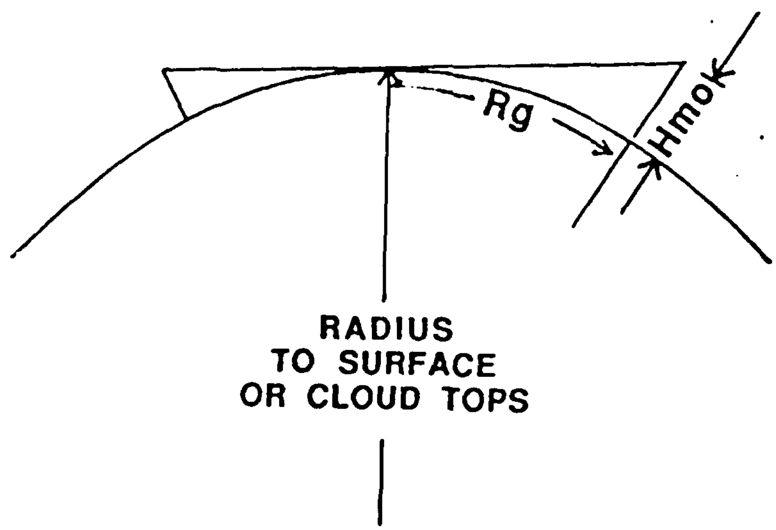
This chart shows the relationship between observer and target heights and range in order to provide a clear line-of-sight. In this chart the minimum observation height (Hmo) shown as the abscissa on the figure and represent either the height of the observer or the height of the target. Thus if one has an observer at 9km above the cloud level one can read off of the chart that this will allow a range of 250km to the tangent point. If the target is 18km above the cloud height the chart shows that this gives a range component of 350km. Thus the total range that can be observed by an observer 9km above the cloud and a target 18km above the cloud is the sum of these two ranges or 600km. Notice that the critical point for the cloud cover is not the observer or target location but the tangent point.

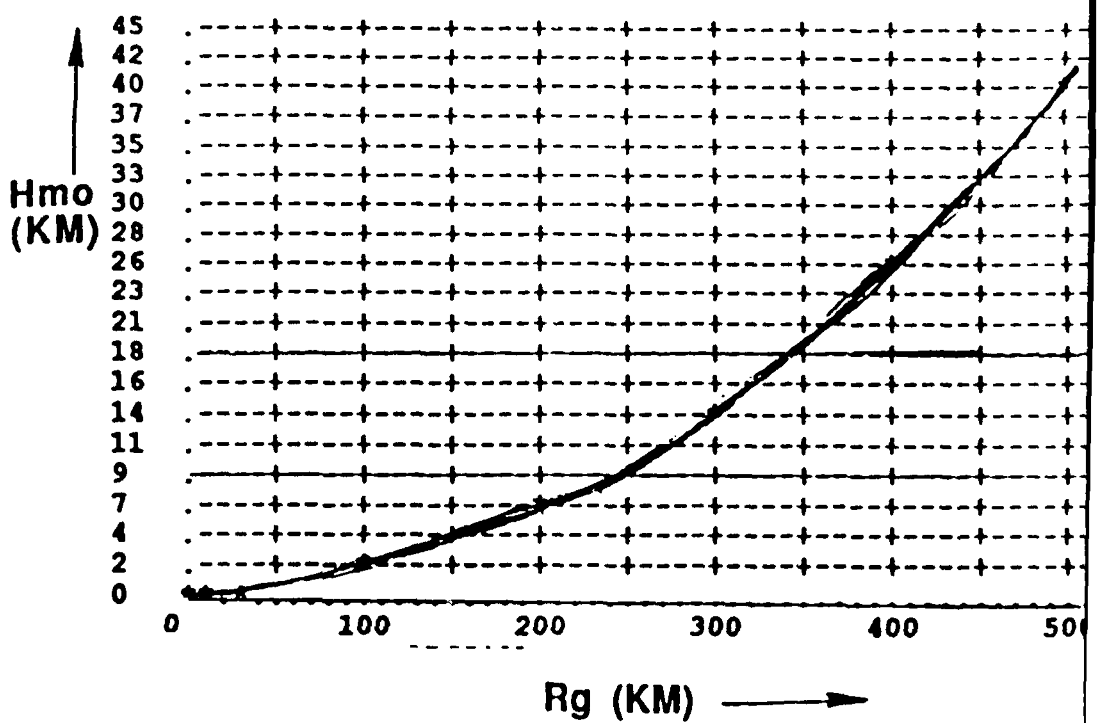
UNCLASSIFIED

# CURVATURE AND THE MINIMUM OBSERVATION HIGHT (Hmo) LIMITS THE GROUND RANGE (Rg)

(APPLIES BOTH TO OBSERVER AND TARGET)

OBS @ 9KM + TARGET @ 18KM ⇒ RANGE = (250 + 350) = 600KM




UNCLASSIFIED

## SENSOR DEPLOYMENT GEOMETRY USED TO DEFINE THREAT COVERAGE AREA (Tca) (U)

This chart defines the deployment geometry used to define the threat coverage area. From this chart it can be seen that the threat coverage area is a function of the maximum range, the number of sensors, the azimuth field-of-view of the sensors and the distance between the line of observers and the rear most line of the potential threat locations.

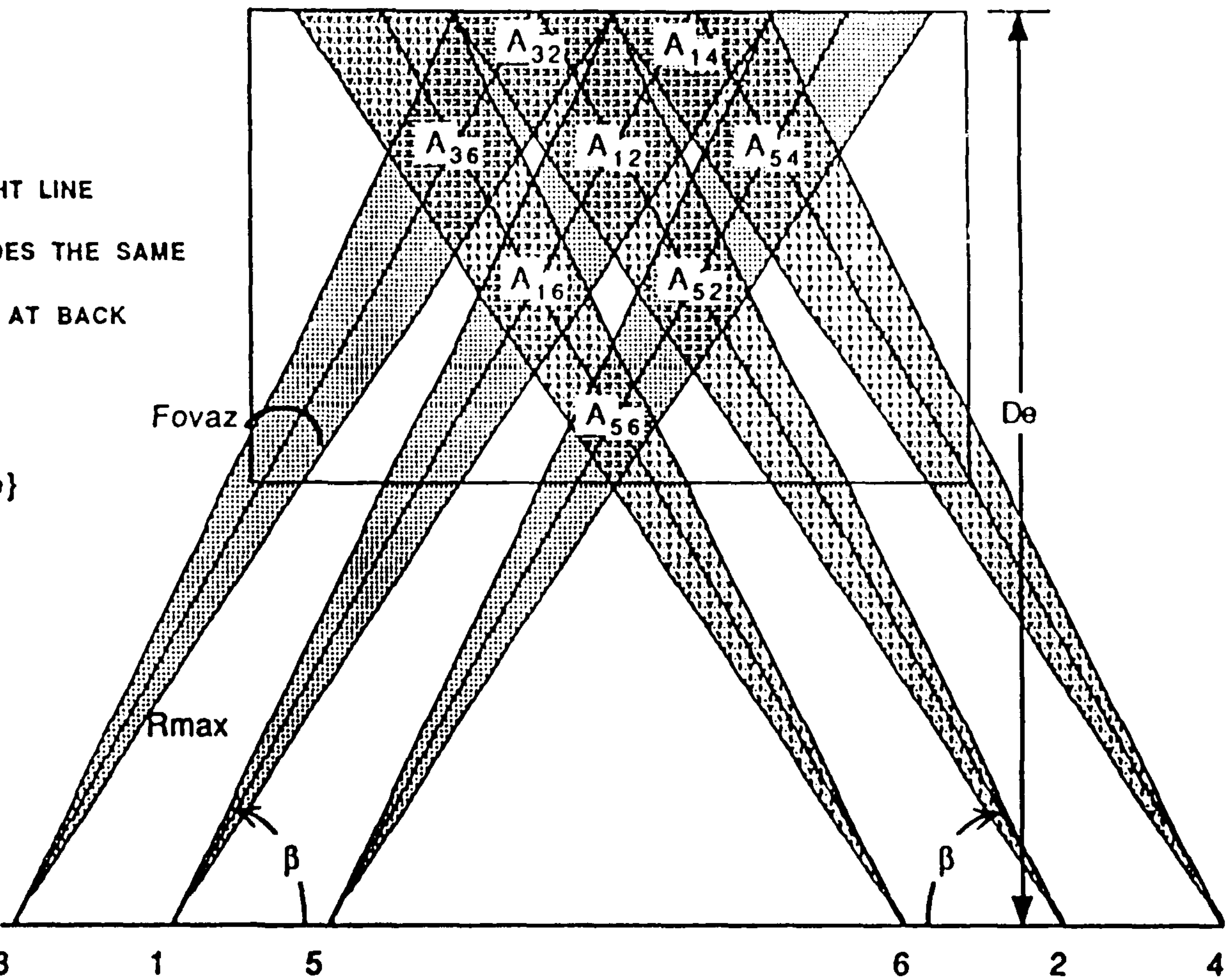
NRC

# SENSOR DEPLOYMENT GEOMETRY USED TO DEFINE THREAT COVERAGE AREA (Tca)

UNCLASSIFIED

- PLACEMENT RULES
  - SINGLE SENSOR/PLATFORM
  - PLATFORMS LOCATED ON STRAIGHT LINE
  - ALL VIEWING ANGLE (β) MAGNITUDES THE SAME
  - FIELD-OF-VIEW BOUNDARIES JOIN AT BACK EDGE OF REGION

- Tca = f{Rmax, Ns, Fovaz, De}




UNCLASSIFIED

2i

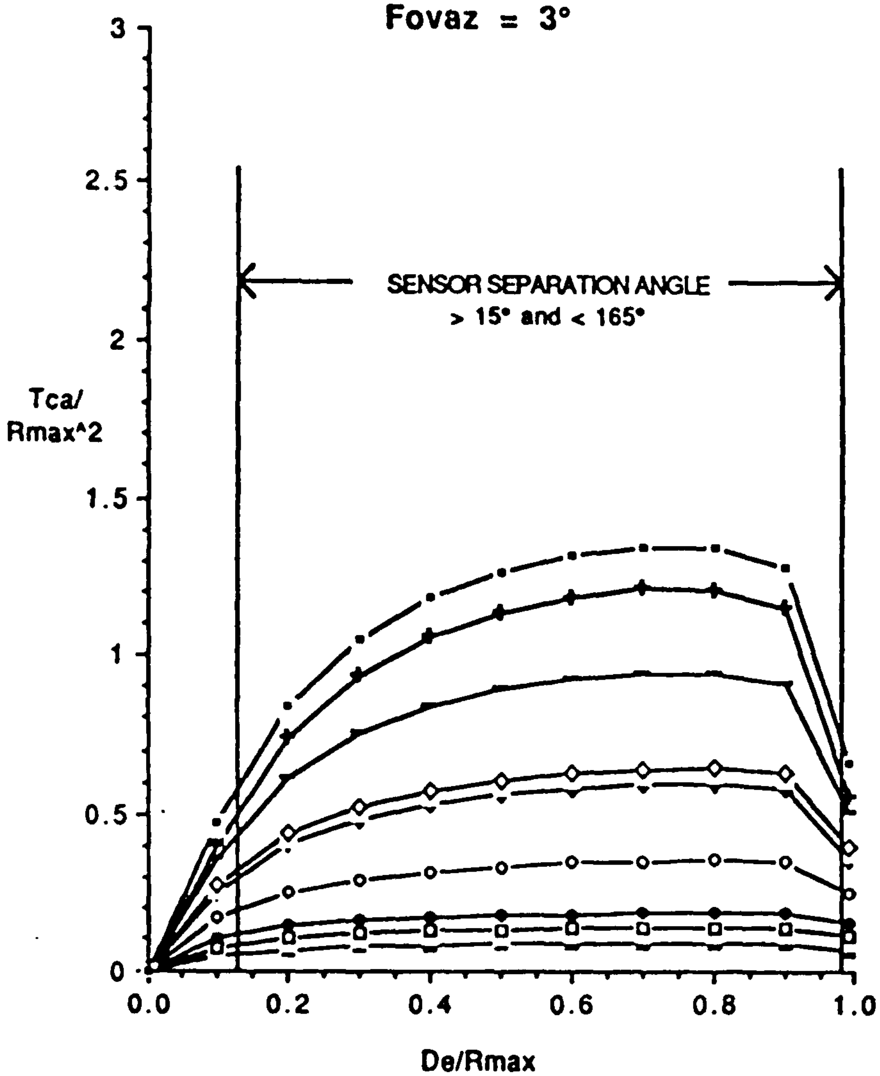
# FRACTIONAL THREAT COVERAGE AREA TRADE-OFF CURVES (U)

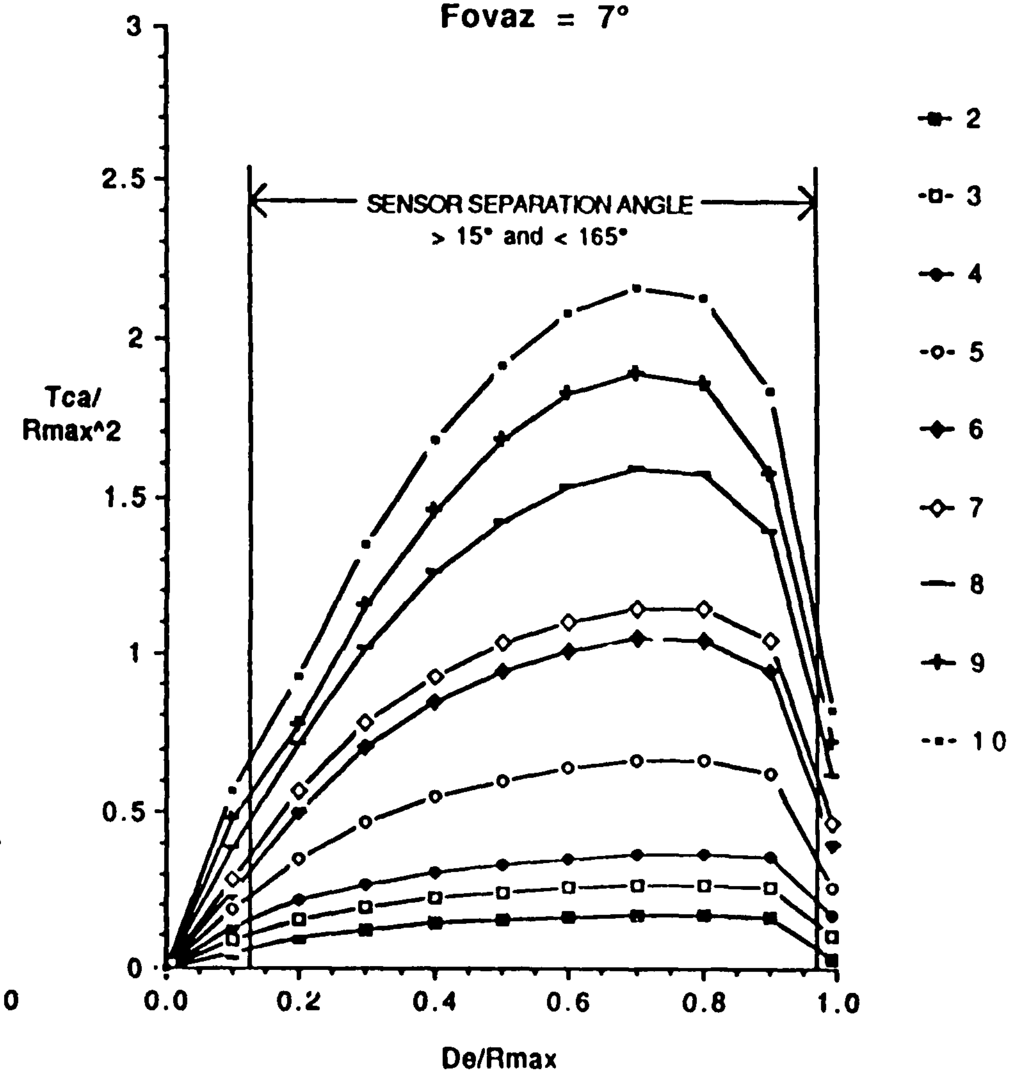
This chart presents *non-dimensional relationships* between the threat coverage area, the maximum range, the number of sensors and the distance between the line of observers and the rear most line of threats. In chart 27 this relationships is presented for the 3° and 7° azimuth fields-of-view.

# FRACTIONAL THREAT COVERAGE AREA TRADE-OFF CURVES



Tca/Rmax = f{De/Rmax, Fovaz, Ns}



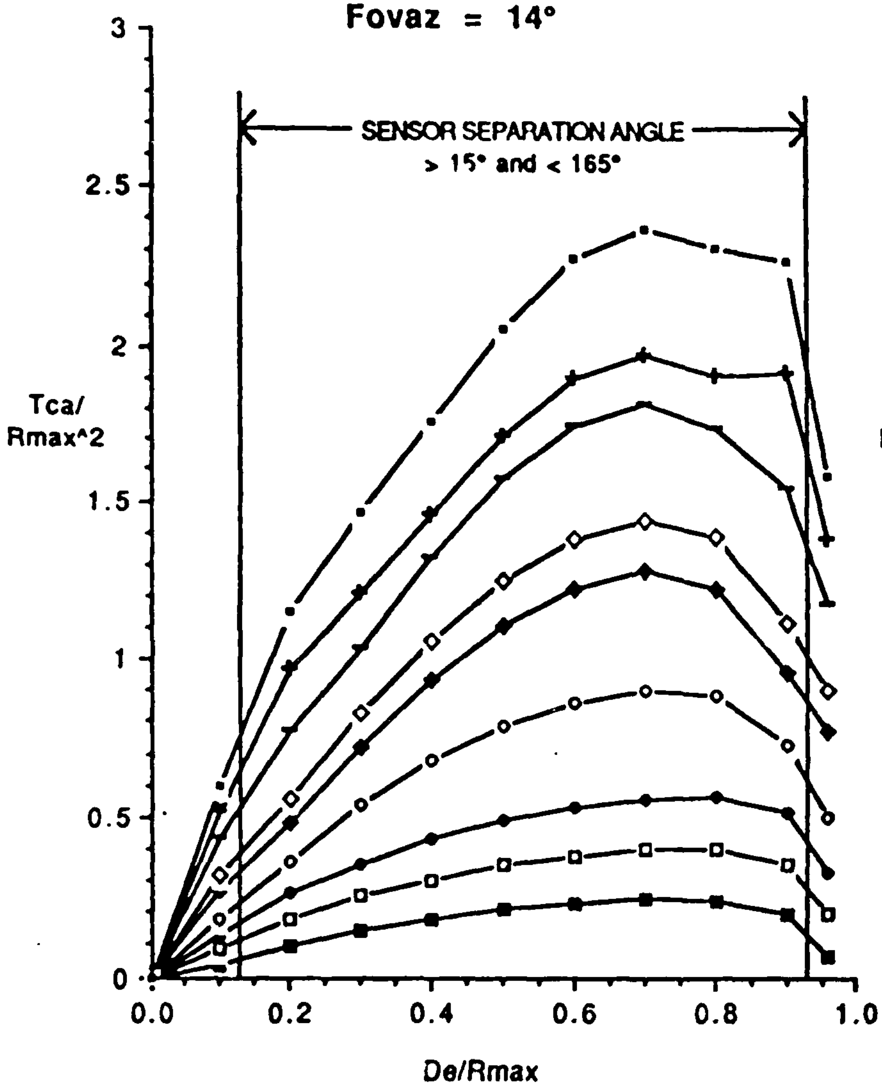



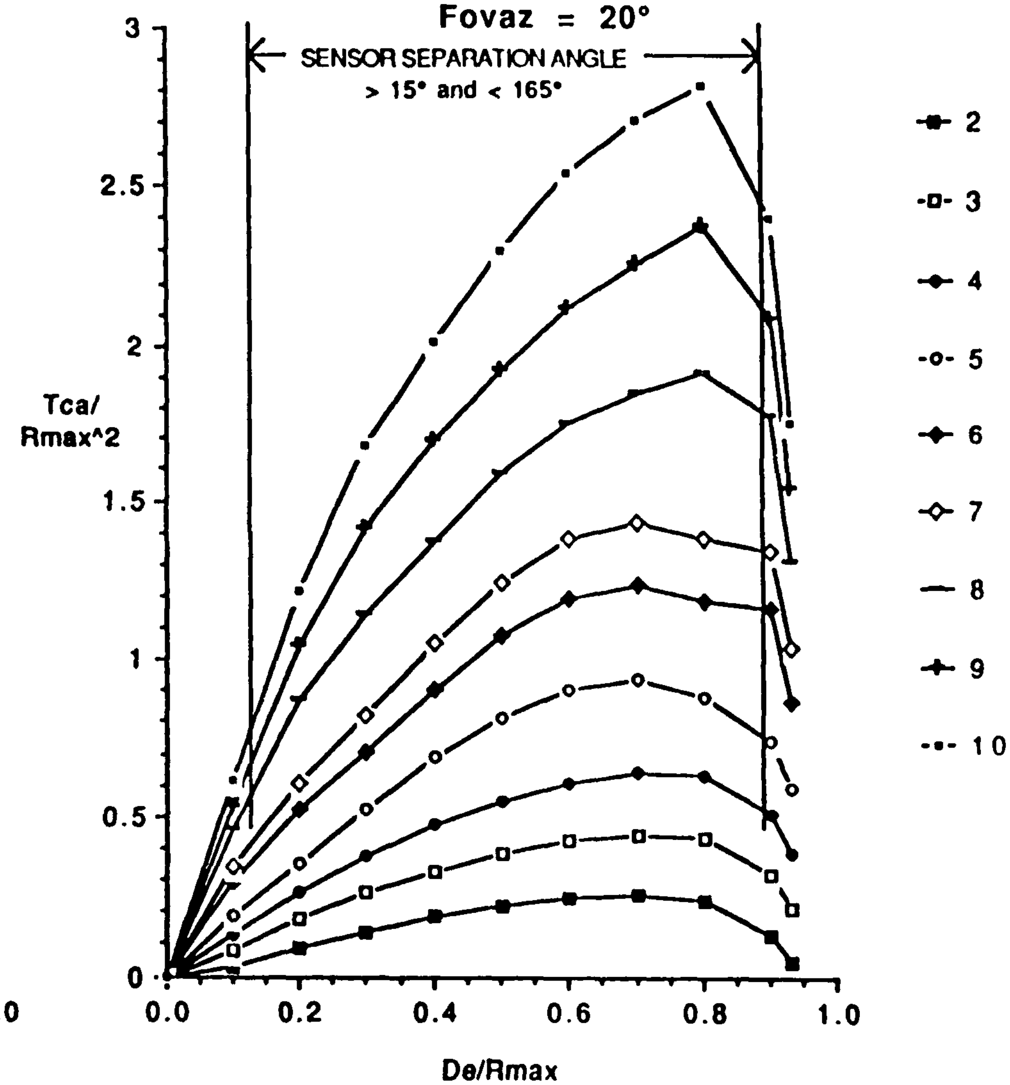
## FRACTIONAL THREAT COVERAGE AREA TRADE-OFF CURVES (U)

Chart 28 presents information similar to Chart 27 except for azimuth fields-of-view of 14° and 20°.

# FRACTIONAL THREAT COVERAGE AREA TRADE-OFF CURVES

Tca/Rmax = f{De/Rmax, Fovaz, Ns}



## INTERIM CONCLUSIONS & PLANS (U)

Chart 29 summarizes the interim conclusions reference case and plans. We conclude that for TMD applications low cost is less than the order of $100,000 for sensors and $2 - $3 million for the sensor R&D. Low cost systems require platforms that should cost less than $500,000 - $1 million apiece. The reference case consists of a sensor platform with an acquisition cost of $900,000; can be expected to have a three sigma handover error at burnout of 240m, and at a typical PATRIOT acquisition altitude, a handover elipse with a maximum diameter of 8.2km and an IPP error elipse of 12.2km by 1km. Plans for the future include creating trade-off studies of cost performance and threat coverage area and responding to any special TMDAPO request.

NRC

# INTERIM CONCLUSIONS & PLANS (U)

UNCLASSIFIED

- FOR TMD APPLICATIONS "LOW COST" IS:

  LESS THAN 100 K$ FOR SENSOR

  2-3 M$ FOR SENSOR R & D

  LESS THAN 0.5 - 1 M$ FOR PLATFORM

- REFERENCE CASE: ACQUISITION COST = $900K/PLATFORM + SENSOR

  $3\sigma$ H.O. ERROR @ B.O. ---------------------------------------- 240M

  @ TYPICAL PATRIOT ACQUISITION --- 8.2 x 0.8 x 0.4 KM

  $3\sigma$ IPP ---------------------------------------------------------- 1.0 x 12.2 KM

- PLANS

  - CREATE TRADE-OFF's COST-PERF-Tca

  - RESPOND TO TMDAPO REQUESTS

UNCLASSIFIED