Experiment Planning Document

For

Altair

A Space-Based Acquisition, Tracking, And Pointing Experiment

Department of Defense
Strategic Defense Initiative Organization
The Pentagon, Washington, DC 20301-7100

EXPERIMENT PLANNING DOCUMENT

FOR

ALTAIR

A SPACE-BASED ACQUISITION, TRACKING, AND POINTING EXPERIMENT

23 April 1991

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"When you can measure what you are
speaking about and express it in numbers,
you *know something* about it,
but when you cannot measure it,
when you cannot express it in numbers,
your knowledge is of a *meager*
and unsatisfactory kind."

Lord Kelvin

EXPERIMENT PLANNING DOCUMENT
FOR
ALTAIR

12 April 1991

- The mission of the ALTAIR experiment is to answer critical technical questions that address the feasibility of target acquisition, precision tracking, and beam pointing for Directed Energy Weapon systems.

- The purpose of this *Experiment Planning Document* (EPD) is to give clear guidance from SDIO to the Phillips Laboratory (PL) and the Applied Physics Laboratory (APL) regarding the critical technical issues, the functional traceability criteria, and the performance scalability criteria that should be considered in planning the ALTAIR experiment. The EPD defines the proper trade space for the experiment designer to evaluate cost-effective experiment concepts suitable for the ALTAIR mission.

- SDIO requests that PL and APL use this EPD as the chief rationale for formulating specific mission requirements and performing the extensive trade studies leading up to the System Requirements Review.

- As an outcome of the System Requirments Review, SDIO, PL, and APL will agree to a cost-effective ALTAIR mission description that best addresses this EPD. PL and APL will document the cost-effective mission description in the *Mission Requirments Document*. The portion of the EPD covered by the agreed-to mission description shall be incorporated in the *Experiment Requirements Document*, co-signed by SDIO and the executing agents, and act as the formal agreement of ALTAIR experiment requirements.

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BACKGROUND

The conceptual basis of the Strategic Defense Initiative (SDI) program involves establishing and operating a multi-layered defense. Each layer will be capable of destroying a large fraction of those targets that manage to reach the layer. The SDI program is pursuing Directed Energy (DE) concepts as potential cost effective options for maintaining Strategic Defense System (SDS) effectiveness over a wide range of threats and performance regimes. Directed Energy Weapons (DEW) offer promise for blocking threat responses designed to degrade the effectiveness of the SDS and for increasing performance of the SDS to levels that can deny an attacker his objectives even in intense ballistic missile attacks.

Specifically, the various directed energy weapon programs identify and validate the technology for systems that can:

- Destroy large numbers of enemy booster and post-boost vehicles (PBV) in the tens to a few hundreds of seconds that the missiles are in their boost phase.

- Discriminate decoys from warheads in the midcourse phase by probing them with a directed energy beam that interacts with the target and scatters radiation from the nuclear warhead or creates other identifying signatures.

These missions, boost-phase intercept and midcourse discrimination, are keys to achieving high levels of ballistic missile defense effectiveness against the most capable threats. Directed energy concepts provide alternatives or enhancements to kinetic energy weapons for boost-phase intercept and interactive discrimination in the midcourse phase. Over the long term, directed energy weapons appear to hold the key to defeating some of the more stressing threats that might be deployed by the enemy.

Currently the SDI program is pursuing two basic directed energy thrusts identified as promising approaches to meeting the needs of a multi-layered strategic defense. These thrusts are neutral particle beams and space-based lasers such as chemical or free electron lasers. These weapons are well suited for boost and post-boost phase intercept and also provide promise as excellent discriminators of midcourse decoys.

As currently envisioned, DE systems could be deployed in space as autonomous weapons whose highly capable acquisition, tracking and pointing (ATP) subsystems and lethal beams enable them to perform a variety of strategic defense missions. DE systems can detect, track, identify, intercept, destroy, and assess damage.

The technologies involved and the required performance levels for the acquisition, tracking, and pointing/fire control (ATP/FC) functions of all directed energy concepts are similar to a considerable extent. In addition to a development program to advance the state-of-the-art in ATP/FC technology, there is a need for a space-based experiment to resolve certain fundamental physics issues for ATP. An experiment can be designed to answer critical questions and address the critical issues of ATP that face each DE weapon (DEW) system concept.

The dominant technology issue is the development of an integrated system that permits sensing the target, determining its dynamic state, and directing a beam with the accuracy and stability to place a small spot on the target. Such a system has never been demonstrated in the performance regime (altitude, range, acceleration, and line-of-sight stabilization) required for SDI applications. Previous DOD programs which were planned to address ATP/FC functions in space include Talon Gold and Starlab. Both programs were canceled before launch.

This document presents the explicit requirements for a space-based experiment to be called ***ALTAIR***. The mission of ALTAIR is to answer critical technical questions that address the feasibility of target acquisition, precision tracking, and beam pointing for Directed Energy Weapon systems.

ACQUISITION, TRACKING AND POINTING/FIRE CONTROL FUNCTIONS

The principal job of the acquisition, tracking, and pointing/fire control (ATP/FC) system of a space-based weapon platform is to detect the target and then to estimate the target's position, velocity, acceleration, rotation, and aspect with sufficient detail for a weapon to engage and destroy the target. The attributes of the target are collectively referred to as the state vector of the target. The purpose of an ATP/FC system is to estimate the target's state vector well enough to engage and destroy it with a weapon. For a directed energy system, this means pointing a beam at a vulnerable location on the target. For a kinetic energy weapon, this means pointing the interceptor so that it can strike the hardbody.

During either the boost, post-boost, or midcourse phase, beam pointing must be accomplished with great precision, in some cases to a specific location on the target. This precision pointing requires sensors capable of resolving the target to detect specific detail. In addition, the sensor platform must track several targets so as to ensure that all assigned targets are engaged within the allocated time.

Multi-target tracking requires optical sensors with a large field of view or a number of optical sensors each with a more modest FOV. However, a single optical sensor cannot simultaneously provide sufficient resolution to locate vulnerable areas of the booster and maintain sufficient field of view to ensure rapid engagement of subsequent targets. As a result, it is envisioned that a series of sensors will be required, each providing successively more precise target location information. This series of sensors can be expected to operate over different spectral regimes (ultraviolet, visible and infrared) and thereby take advantage of varying target and background phenomenology effects. Figure 1 illustrates the sensor handovers required for target acquisition and fine tracking.

Many DEW ATP/FC functions are valid for other SDI concepts as well. The principal difference between weapons systems will be in the details of the implementation and in the degree of state vector accuracy required to engage the target.

A philosophy of DEW design is to provide for autonomous system operation starting from target cueing by a surveillance platform component of the SDS. In an operational system, it is necessary to acquire and track a number of targets (i.e. boosters, post boost vehicles, or reentry vehicles) while engaging only one target at a time. Figure 1 describes the procedure being considered for boost-phase and midcourse acquisition and track. The boost-phase procedure uses a hierarchy of sensors that initially acquire and coarse track multiple targets and provide handover information to successively smaller field of view sensors in order to support precision weapon beam pointing. The acquisition of a plume is followed by a passive intermediate track of the plume in the next smaller field of view. Next, active imaging, possibly with the assistance of passive tracking data, is used to provide the aimpoint location. The sequence of autonomous ATP/FC functions for a DEW system follows:

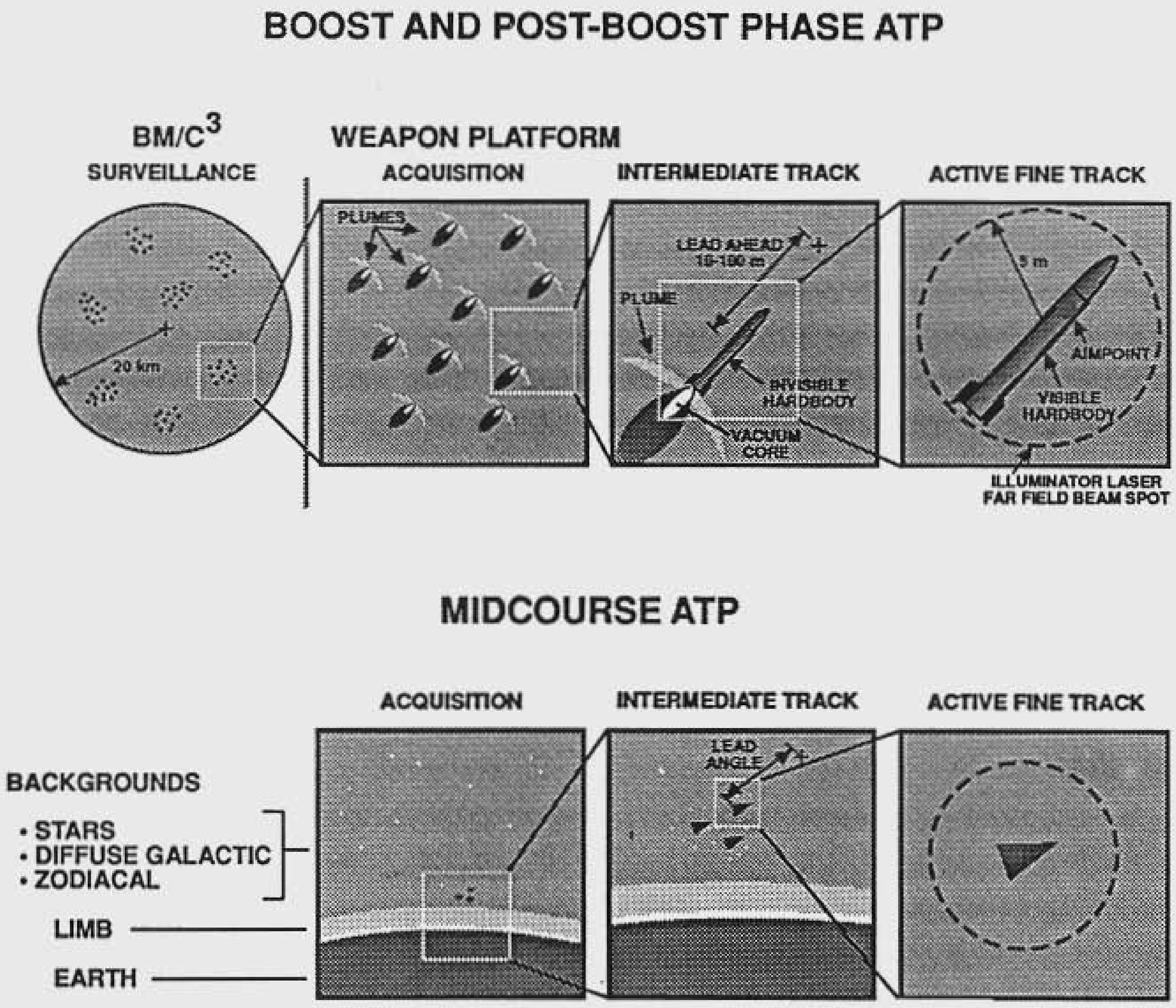


Figure 1: DEW ATP/FC Sensor Handover Concept

1. Battle Management and Target Cueing. DEW system receives target location and target state vector from a surveillance or command and control component of the SDS. The DEW system slews its acquisition system to the expected target location.

2. Target Acquisition. DEW system detects and tracks the target (or cluster of targets) with a wide FOV acquisition (capture) sensor.

3. Multi-Target Track and Target Identification. The DEW system tracks multiple targets in the presence of hard earth, earth limb, or celestial background while using discrimination techniques to determine target type.

4. Target Sequencing. While tracking multiple targets, the highest priority targets are selected for engagement with the weapon.

5. Passive Track Handover. Acquisition sensor track data is used to point an intermediate FOV tracker at the target. Hand-off from the acquisition tracker to the passive intermediate tracker occurs.

6. Passive Plume Track. The passive intermediate tracker continues to stabilize the line-of-sight to the plume.

7. Plume-to-Hardbody Handover. Using the passive plume image, a fire control processor determines the likely position of the hardbody and calculates the separation between the passive track point and the most likely hardbody position.

8. Illuminator Point Ahead. By using an estimated range to the target and the measured line-of-sight rate, the ATP/FC system offsets the illuminator aimpoint from the stabilized passive track null to account for the amount the target will move during the time it takes light to reach the sensor and then return to the target.

9. Active Track Handover. The ATP system points the illuminator beam at the target hardbody by properly accounting for both the physical separation between the passive track point and the hardbody, as well as the point ahead offset due to the speed of light. The active track sensor detects the reflection of the illuminator beam from the target.

10. Hardbody Discrimination and Active Fine Track. Laser illumination is used to unambiguously determine the hardbody position from the plume. Then, using the reflected illuminator energy and a fine resolution active sensor, a stable active track is established.

11. Aimpoint Selection. Using the active tracker imagery the ATP/FC system determines the location of the vulnerable aimpoint on the target and computes the physical separation

between the track point and the aimpoint, possibly with the assistance of the passive track point.

12. Weapon Beam Point-Ahead. By using the detected range to the target and the measured line-of-sight rate, the ATP/FC system offsets the aimpoint from the stabilized active track null to account for the amount the target will move during the time it takes light to reach the sensor and then return to the target.

13. Aimpoint Designation. Taking into account the active track point, the aimpoint selection, and the weapon beam point ahead, the ATP/FC system points a reference line-of-sight at the aimpoint.

14. Precision Beam Pointing/Line-of-Sight Stabilization. The weapon beam is stabilized and pointed in alignment with the reference line-of-sight to the aimpoint.

15. Aimpoint Maintenance. By looking through the stabilized beam path, the ATP/FC system references the beam position with the aimpoint by observing the interaction of the DEW with the target. The precise aimpoint may be updated or refined by detecting the interaction of the DEW with the target.

16. Kill Assessment. By observing the tracker imagery the ATP/FC system determines when the engagement has resulted in target destruction.

17. Rapid Retargeting. The ATP/FC system resumes the autonomous process for the next most critical target.

The performance of these subfunctions is complicated by the phenomenology associated with the rocket plumes. Different targets (e.g., solid boosters, liquid boosters, post-boost vehicles) can have significantly different signatures, and the signatures are constantly changing as the target altitude increases and as the missile stages. Add to this the variety of naturally occurring and perturbed backgrounds and serious questions arise about the ability of a sensor to detect and track multiple targets simultaneously while extracting the information necessary to define fully the target's state vector.

Use of the procedure for locating midcourse objects is shown in the lower portion of Figure 1 and involves isolating the object images from the background through the use of similar sequential field-of-view reduction techniques as the boost-phase methods. ATP/FC functions that specifically apply to the midcourse phase include:

18. Midcourse Object ATP. The ATP/FC system acquires and tracks a midcourse object and points a DEW system at the midcourse object. The DEW system receives initial target cueing from a surveillance or a command and control component of the SDS. The sequential process looks like steps 1 through 17, but with LWIR acquisition and tracking and without the problem of identifying the hardbody in the presence of the plume radiation. This function is particularly relevant to NPB concepts.

19. Midcourse Object Tracking—TTP/IPP. The ATP/FC system can measure the position and state vector of a midcourse object with sufficient accuracy to provide threat tube prediction (TTP) and impact point prediction (IPP) for metric discrimination, and handback data to other weapon system platforms for target reacquisition. This function is particularly relevant to NPB concepts.

20. Midcourse Object Tracking—ΔV. The ATP/FC system can measure the change in velocity of a midcourse object as it encounters an interactive discrimination technique. The change in velocity can be used to infer the mass of the midcourse object. This function is relevant to SBL concepts for midcourse discrimination.

As a consequence of its sophisticated precision and aperture size, the ATP/FC system for a DEW system can provide additional special functions that aid in target discrimination and tracking during post-boost and midcourse phase. Functions that can be employed during post-boost phase:

21. PBV Bus Watching—ΔV. The ATP/FC system measures the difference in PBV and ejected object velocities during deployment accurately enough to infer the mass of ejected objects.

22. PBV Precision Bus Tracking/Deployment Trajectory Projection—TTP/IPP. The ATP/FC system measures the position and state vector of the PBV with sufficient accuracy that it can provide a threat tube prediction (TTP) of objects ejected from the PBV, an impact point prediction (IPP) of each reentry vehicle, and handback data to other weapon system platforms for target reacquisition.

23. PBV Bus Watching—Observables. The ATP/FC imagers observe radiometric and reflective features associated with the UV, visible, and IR signatures of PBV's and ejected objects which have utility in discriminating RV's from decoys.

Of these twenty-three functions, ALTAIR can address all those which do not require a high energy DEW device on the ALTAIR spacecraft (e.g., sequence number 15 and 16). Rapid retargeting issues (sequence number 17) will be addressed in the laboratory rather than in this experiment.

ATP/FC TECHNOLOGY

Examination of ATP/FC concepts for SDI programs reveals a substantial commonality of functional requirements. This, in turn, leads to common design approaches for achieving these functions for the different weapon concepts. Shown in Figure 2 is a schematic representation that SDI performance requirements exceed the current demonstrated capabilities in many technology areas. In some cases, basic data necessary to develop equipment and algorithms is lacking. Figure 3 displays specific examples of technologies in which major advances in the state-of-the-art are required to achieve SDI system performance levels. Areas that need to be developed to support the needs shown in Figure 2 are:

- Beam Stabilization — capability to point a beam or sensor at moving targets while the space platform is moving (slewing); and isolate the beam or sensor from base motion disturbances.

- Handover — capability to provide pointing and tracking data of an object, and the necessary techniques to enable a different sensor to locate the object.

- Coarse Pointing — capability to determine state vectors of a body and provide pointing information to a tracking sensor that will maintain the body image in a sensor field of view.

- Passive Tracking — capability to track boosters, post-boost vehicles, and midcourse objects using passively emitted or reflected radiation.

- Active Imaging — capability to spatially characterize a target by illuminating it with a laser and receiving reflected radiation in a high resolution sensor.

- Beam Pointing with Precision Boresight and Point Ahead — capability to point the beam to the required precision against a dynamically moving target.

- Multiple Target/Repointing — capability to rapidly transition pointing and sensing between individual targets in a multiple target engagement.

- Phenomenology — a database of high resolution plume phenomenology, midcourse object signatures, and background signature data across a spectral range from ultraviolet to infrared.

- Fire Control — capability of each DEW platform to efficiently perform decision functions and to control the sequencing of all functions required to maximize the total number of successful target kills.

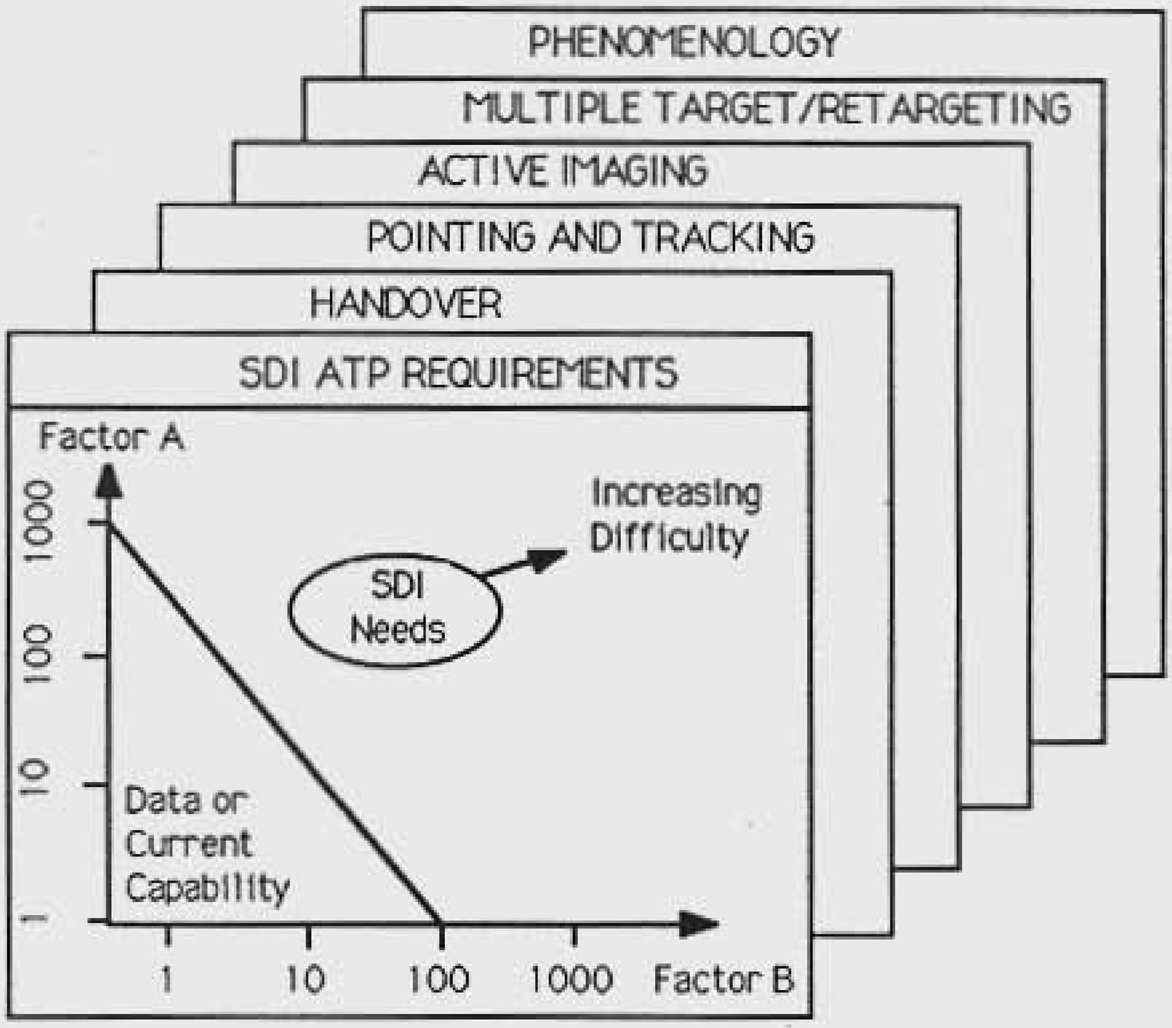


Figure 2: SDI Technology advances are needed in many areas related to ATP/FC functions

Technology issues can be grouped according to the sensors needed for a given task. Different phases of the process and different weapon concepts may have different phenomenological issues. For example, in the boost phase, plumes provide high intensity short wavelength IR signatures, whereas in the midcourse phase there are no plumes. Thus, to detect and identify targets in midcourse long wavelength infrared sensors and possibly active imagers will be necessary.

The envisioned succession of sensors begins with the surveillance sensor. Surveillance is the process of identifying and locating a threat, in this case a group of boosters, post-boost vehicles, or midcourse objects. The surveillance sensor may be located on a separate platform in a different orbit than the weapon platform. This sensor must search a large area in order to detect multiple threats. A

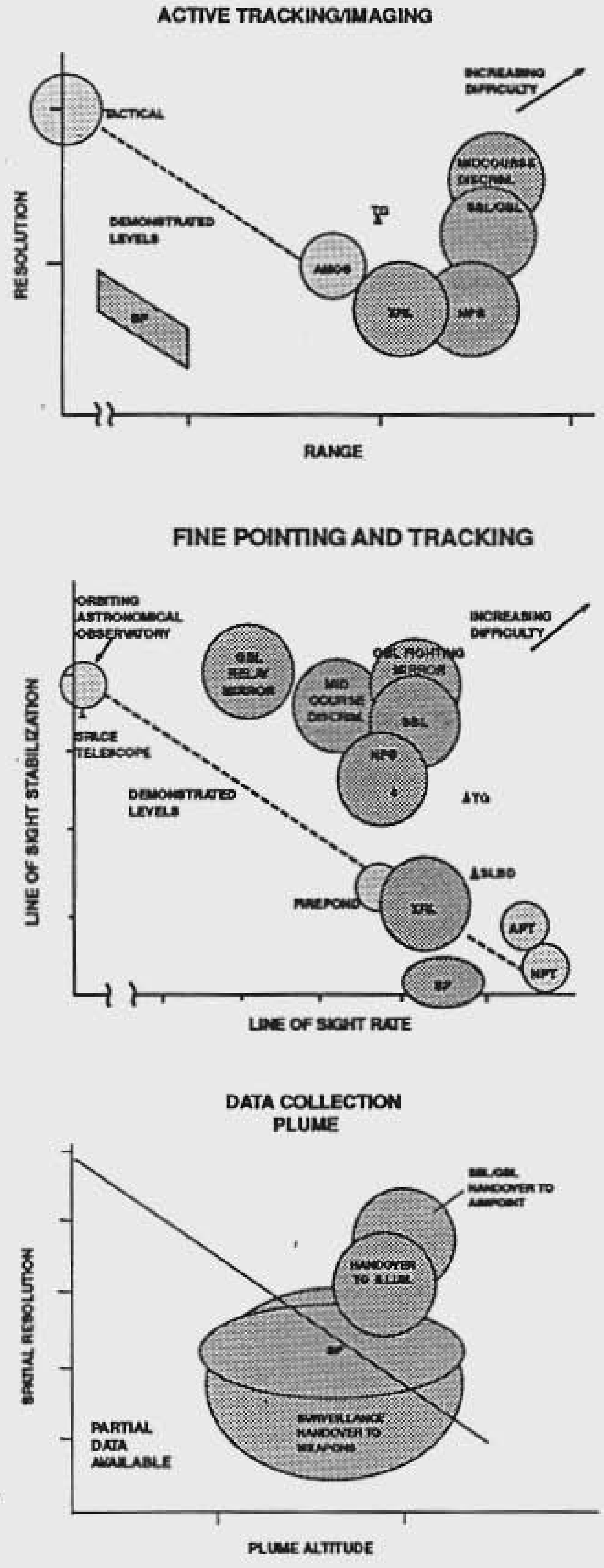


Figure 3: Specific examples of SDI technology needs in comparison with currently demonstrated capabilities or data bases.

surveillance platform might provide a target state-vector estimate accurate enough for a directed energy platform to locate the targets within the handover error volume of the surveillance platform.

Once surveillance is complete, the state vector of the threat is passed to the directed energy platform where the acquisition coarse track (ACQ) sensor must identify the threat and begin the process of engaging individual targets. The ACQ sensor must operate successfully under a diverse set of phenomenological conditions that result from variations in target/background observables such as missile type, aspect angle, earth and space features, solar illumination conditions, weather, and sensor characteristics.

Each sensor's primary function can be divided into a set of subfunctions. In this case, the major subfunctions are slewing the ACQ sensor and/or spacecraft to point to the area where the targets are located, searching the area for targets, discriminating the targets from the background and clutter; initiating multiple-target tracking (typically a weapon-platform ACQ sensor will track many targets while the weapon is engaging a single target), improving the estimate of the target state vector, selecting an optimal target engagement sequence to ensure that the weapon platform can effectively kill the targets within the window of opportunity available; and handing the improved target state vector information over to a more accurate sensor.

Technical issues related to the ACQ are:

- Plume phenomenology
- Background clutter rejection and false alarm rates
- Suitable target identification and selection algorithms
- Separation of crossing trajectories
- Track correlation of multiple targets
- Transition from earth background to limb and space backgrounds
- Tracking in the presence of disturbed backgrounds

The requirement to span the gap from the ACQ sensor resolution to the active, fine track sensor resolution needed to support precision pointing may create the need for a passive intermediate track (PIT) concept. The primary purpose of the PIT would be to further refine the state vector of an individual target and to provide imagery which can be used to predict the likely hardbody location relative to the plume. This improved state vector information is necessary for the transition from passive plume and hardbody tracking to active sensor tracking of the desired aimpoint.

Technical issues related to the PIT are:

- Plume-to-hardbody handover (i.e., how to distinguish a hardbody from the plume or background clutter, or how to estimate the hardbody position solely based on the passive plume imagery).

- Level of tracking precision achievable

- Approaches that minimize transition time from coarse tracking to active fine tracking

The active fine-track (AFT) sensor provides the final precision tracking functions and uses an active laser illuminator to provide precision pointing information on the target hardbody aimpoint. The functions of the AFT are to unambiguously locate the hardbody, locate and track the aimpoint, compute the lead-ahead angle (the amount the booster will move during the time it takes light to reach and then return from the booster), measure and control the illuminator beam at the target so as to minimize effects of disturbances, and assess the damage to the booster.

Technical issues related to the AFT are:

- Pointing an illuminator beam at a moving target while the weapon platform is moving (slewing).

- Maintaining the weapon beam within the aimpoint limits (usually a fraction of the booster's diameter).

- Obtaining sufficient illuminator power to meet the signal-to-noise and frame rate requirements of the tracker for required target range and expected target signature

- Accurately pointing the illuminator beam onto the hardbody location which permits tracking a specific location on the hardbody (distinguishing the hardbody reflection from plume reflection)

- Rapidly obtaining accurate tracking data, converging on the required gain, threshold, and track gate settings in a small fraction of a second

- Performing tracking which is relatively insensitive to natural and countermeasure glints on the target

- Providing an accurate and stable boresight function, possibly with lead-angle compensation in the tracker, to the weapon pointing function

- Providing sufficient image stabilization while tracking to meet the required tracking accuracy

- Determining the phenomenology associated with a damaged or destroyed missile that can be detected by the AFT (or PIT)

The pointing part of the ATP function is differently implemented for laser weapons and neutral particle beam weapons. In both cases the functional requirements are similar, that is, to accurately point the weapon on to the vulnerable part of the target with sufficiently low beam jitter, and maintain it with the required accuracy for the time required to kill or discriminate against decoys.

Technical issues related to pointing are:

- Accurately transferring the tracking boresight to the beam pointing direction a long time after boresight calibration

- Providing a precision point-ahead or lead angle to the beam pointing direction

- Accurately measuring the beam pointing direction to address the above two issues

- Stabilizing the beam to attenuate base motion disturbances

- Rapidly retargeting the high energy beam

CRITICAL QUESTIONS AND TECHNICAL ISSUES TO BE ADDRESSED BY ALTAIR

CRITICAL TECHNICAL ISSUES TO BE ADDRESSED BY ALTAIR

	TECHNICAL ISSUE	BOOSTER	PBV	MIDCOURSE
I.	COARSE POINTING/TARGET ACQ	√	√	Note 1
II.	TARGET TRACK/TARGET ID	√	√	Note 1
III.	PASSIVE TRACK HANDOVER	√	√	Note 1
IV.	PASSIVE INTERMEDIATE TRACK	√	√	Note 1
V.	PLUME-TO-HARDBODY HANDOVER	√	√	Note 2
VI.	ILLUMINATOR POINT AHEAD/ ACTIVE TRACK HANDOVER	√	√	√
VII.	HARDBODY DISCRIMINATION/ ACTIVE FINE TRACK/ AIMPOINT SELECTION	√	√	Note 3
VIII.	PRECISION POINT AHEAD/ AIMPOINT DESIGNATION	√	√	√
IX.	PRECISION BEAM POINTING AT RATE	√	√	√
X.	AUTONOMOUS SEQUENCING	√	√	Note 1
XI.	PBV BUS TRACKING—TTP, IPP, HANDBACK DATA	—	√	—
XII.	PBV BUS WATCHING—ΔV	—	√	√
XIII.	PBV BUS WATCHING—OBSERVABLES	—	√	√
XIV.	ACTIVE FINE TRACK OF MIDCOURSE OBJECTS	—	—	√
XV.	MIDCOURSE OBJECT—TTP, IPP, HANDBACK DATA	—	—	√
XVI.	MIDCOURSE OBJECT—ΔV	—	—	√
XVII.	GENERAL PLUME PHENOMENOLOGY	√	√	Note 2
XVIII.	GENERAL BACKGROUND CLUTTER	√	√	Note 1

Note 1: Since the ALTAIR experiment does not incorporate a LWIR sensor, ALTAIR will not have a traceable function for mid-course object acquisition and passive track. For midcourse targets, the ALTAIR experiment will focus on issues regarding active track and precision beam pointing.

Note 2: This issue does not apply to midcourse targets since midcourse objects have no plume.

Note 3: This issue does not apply to midcourse since it involves the illumination and active track of an *extended target* under *thruster acceleration* in the *presence of a plume*. Midcourse active tracking is considered in Issue XIV.

CRITICAL QUESTIONS AND TECHNICAL ISSUES

The purpose of the ALTAIR experiment is to answer critical technical questions that address the feasibility of target acquisition, precision tracking, and beam pointing for directed energy weapon systems. Furthermore, ALTAIR will provide a significant advancement in ATP/FC technology by demonstrating in space the suitability and feasibility of current technical concepts for DEW applications.

ALTAIR is a significant demonstration and validation of ATP/FC technology for either a Neutral Particle Beam or a Space-Based Laser. In this regard, ALTAIR must address a wide set of acquisition, tracking, pointing, and phenomenology issues against a number of representative targets. The ALTAIR experiment will be traceable and scalable to SBL and NPB ATP/FC concepts. ALTAIR should also be able to address certain surveillance and discrimination functional concepts advanced by the Brilliant Eyes and Space-Based Laser Radar Programs. The target set addressed by ALTAIR spans booster, post-boost vehicles, and midcourse objects.

In this section of the *Experiment Planning Document* each of the critical technical issues addressing the feasibility of space-based ATP/FC will be discussed in detail in order to guide the experiment design team. Satisfactory answers to the critical questions shall be the single most important measure of success for the ALTAIR experiment. The format for the critical issue discussion follows:

- *Critical Technical Issue*—A description of a core feasibility issue in the form of a question.

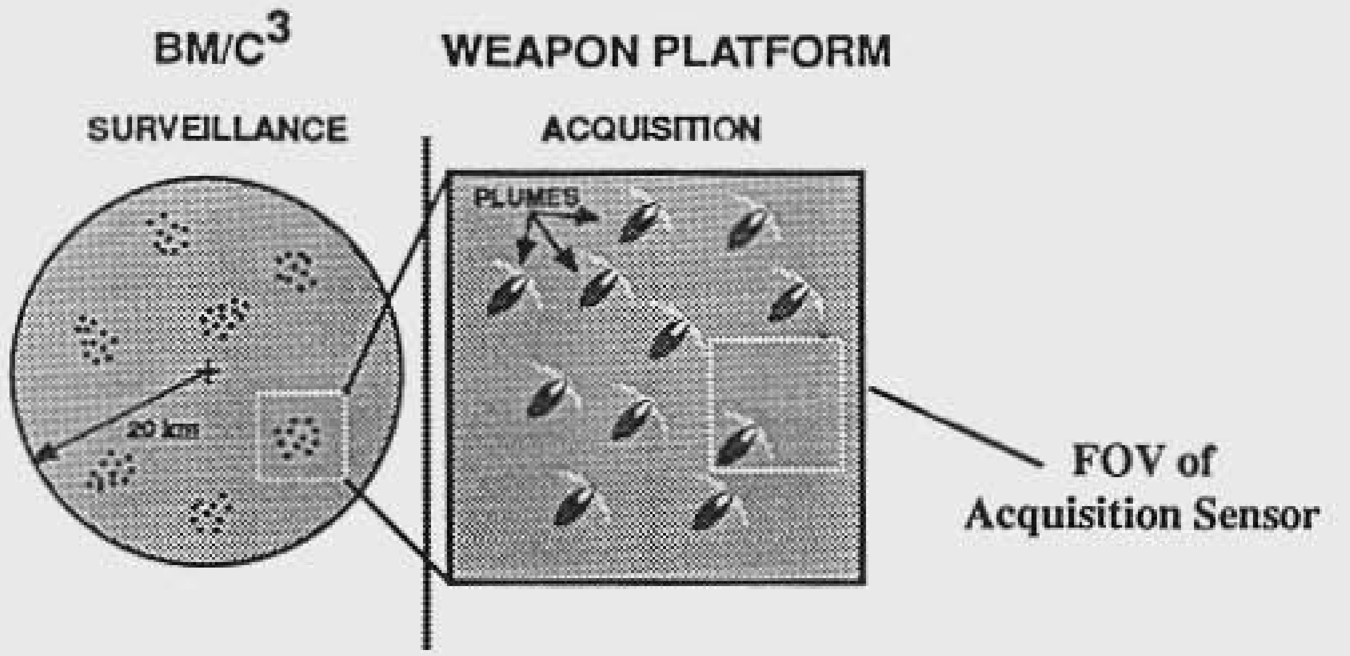
- *Scalability Criteria* —*Scalability* means that the appropriate engineering parameters that measure system performance, size, and rates are in the correct ratio with respect to actual DEW system requirements. Scalability is an essential quality for traceable experiments whose hardware does not match the "dimensions" or specifications expected in a prototype DEW system. Scalable results allow weapon prototype designers to extrapolate the ALTAIR experiment parameters and measured performance to DEW system requirements via well-understood relationships.

- *Traceability Criteria*—*Traceability* means that the functions, methods, and design approach demonstrated in the experiment are relevant and transferable to proposed DEW system designs in a fashion that critical technical issues are resolved for weapon prototype designers. The functions and configurations should "look like" operational systems.

The critical issues and the corresponding criteria for scalability and traceability should be a chief rationale used by the experiment designer in order to flow down specific experiment objectives, the experimental concept, hardware and software specifications, and the data analysis plan. The experimenter will document the flow down in the ALTAIR Mission Requirements Document and the ALTAIR Experiment Data Management Plan.

Appendix A provides a notional optical diagram for the ALTAIR experiment. The diagram is meant only to identify hardware units that are referred to in the text of this document and to show the generic function of these units on the context of a notional experiment system.

ISSUES



Battle Manager provides state vectors for target clusters. Weapons platform uses passive sensor for initial acquisition.

Target and Weapon Platform State Vectors are Used to Determine Slew Angle and Rate.

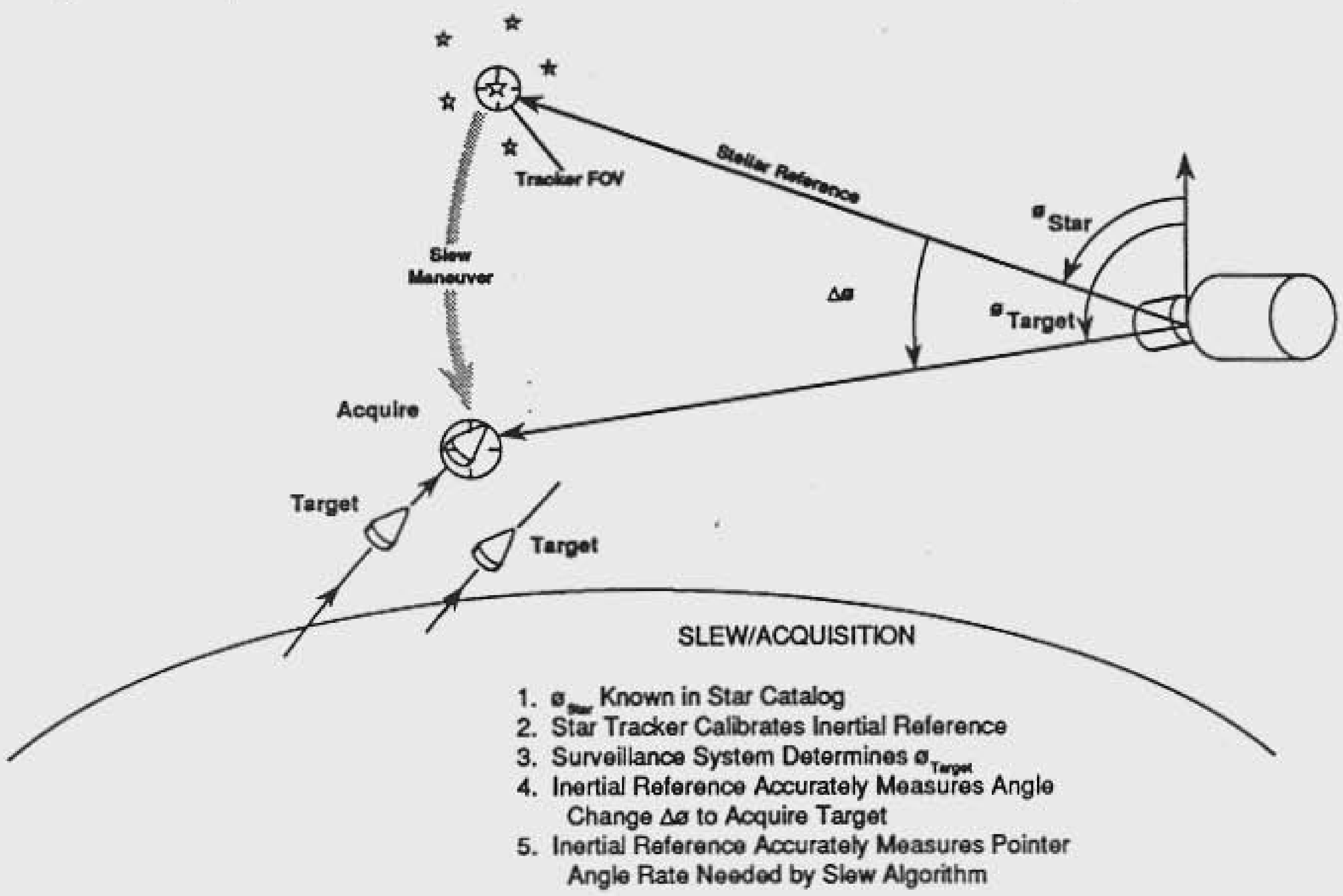


Figure I: Coarse Pointing/Target Acquisition

ISSUE I. COARSE POINTING/TARGET ACQUISITION.

Given the Battle Manager provided target state vectors, can the ATP/FC system point the spacecraft with sufficient accuracy that the wide field-of-view acquisition (capture) sensor can detect the target (booster, PBV)?

The ATP-FC system must compute pointing commands for the spacecraft to control the angular position and slew rate of the acquisition sensor field-of-view so that it will view the predicted location of the assigned targets. Target state vector data must be compared with the DEW platform state vector (including inertial attitude) to compute the required pointing direction and slew rate in inertial space. The acquisition sensor is passive and operates in appropriately selected wavebands. Operational systems may require multiple waveband capabilities for different classes of targets. For booster and post-boost vehicle targets, the acquisition sensor will detect the plume in the SWIR or MWIR, while midcourse objects will require LWIR wavebands. In general, the acquisition sensor will view multiple targets and must be capable of detecting targets individually. The essential technology elements are to demonstrate spacecraft initial slew and pointing using target state vector data and initial detection of the designated target or targets. Design of the experiment will require integration of pointing accuracy and stability, sensor field of view, wavebands, and focal plane performance and target detection algorithms to achieve acquisition.

Scalability Criteria

- *Coarse Pointing Accuracy:* Consistent with handover to the acquisition tracker.

- *Coarse Pointing Stability:* Consistent with handover to the acquisition tracker.

- *Time Scaling:* Speed of acquisition should be scalable to DEW requirements using such parameters as spacecraft slew time constants, acquisition camera frame rate, and computer operation cycles.

Traceability Criteria

- *SWIR/MWIR Acquisition Sensor Waveband.* Day and night acquisitions must be demonstrated in wavebands traceable to DEW platforms. The primary waveband for the acquisition sensor shall be SWIR/MWIR. The SWIR waveband shall be chosen from the H_2O band—nominally 2.7 to 2.95 microns; the MWIR waveband shall be chosen from the CO_2 band—nominally 4.2 to 4.45 microns. Below-the-horizon background clutter rejection techniques shall be used.

- *Visible Acquisition Sensor Adjunct.* Visible acquisition shall be implemented as a risk reduction adjunct to the IR acquisition capability.

- *No LWIR Requirement.* There is no requirement for ALTAIR to incorporate a LWIR sensor for midcourse target detection.

ISSUE II. TARGET TRACK/TARGET ID.

Can the individual targets (boosters, PBV's) be reliably tracked and typed in the presence of hard earth, earth limb, and celestial background clutter using the acquisition sensor imagery?

The acquisition sensor must provide target detection data adequate to maintain coarse tracking of single targets or of individual objects in multiple target clusters. Closely spaced objects, cluttered backgrounds, low contrast targets, and large dynamic range of target brightness create challenging conditions for sensor design and track processor performance. In addition, acquisition sensor data may provide target radiometric data that can be used to classify boosters. Experimental demonstration of passive tracking under realistic conditions is essential to establishing the validity of the concept of acquisition, coarse track, and classification by passive multi-wavelength sensors.

Scalability Criteria

- *Pixel Scaling at the Target Plane.* The optical parameters of the ALTAIR acquisition (ACQ) sensor shall scale at the pixel level with acquisition sensors proposed in DEW concepts. That is, for representative booster and PBV targets:

  - *Resolution.* The ACQ sensor resolution in meters at the target plane shall be essentially the same (within a factor of 3) for the ALTAIR experiment as for DEW concepts.

  - *Pixel Sampling.* The number of pixels subtending the resolution blur circle of the target's image shall be essentially the same for the ALTAIR experiment as for DEW concepts. This means that the pixel sampling of the blur circle diameter should be nearly the same for ALTAIR as for a DEW concept. For acquisition sensors, it is generally good practice to match the pixel dimension (IFOV) to the diameter of the resolution blur circle.

  - *Signal-to-Noise Ratio.* The per pixel SNR shall be nearly the same or greater for ALTAIR as for a DEW concept.

See Appendix B for a full set of pixel scaling laws for sensors used for acquisition, passive intermediate tracking, and active fine tracking.

Traceability Criteria

- *SWIR/MWIR Acquisition Sensor Waveband.* Day and night acquisition must be demonstrated in wavebands traceable to DEW platforms. The primary waveband for the acquisition sensor shall be SWIR/MWIR. The SWIR waveband shall be chosen from the H_2O band - nominally 2.7 to 2.95 microns; the MWIR waveband shall be chosen from the CO_2 band - nominally 4.2 to 4.45 microns. Below-the-horizon background clutter rejection techniques shall be used.

- *Visible Acquisition Sensor Adjunct.* Visible acquisition shall be implemented as a risk reduction adjunct to the IR acquisition capability.

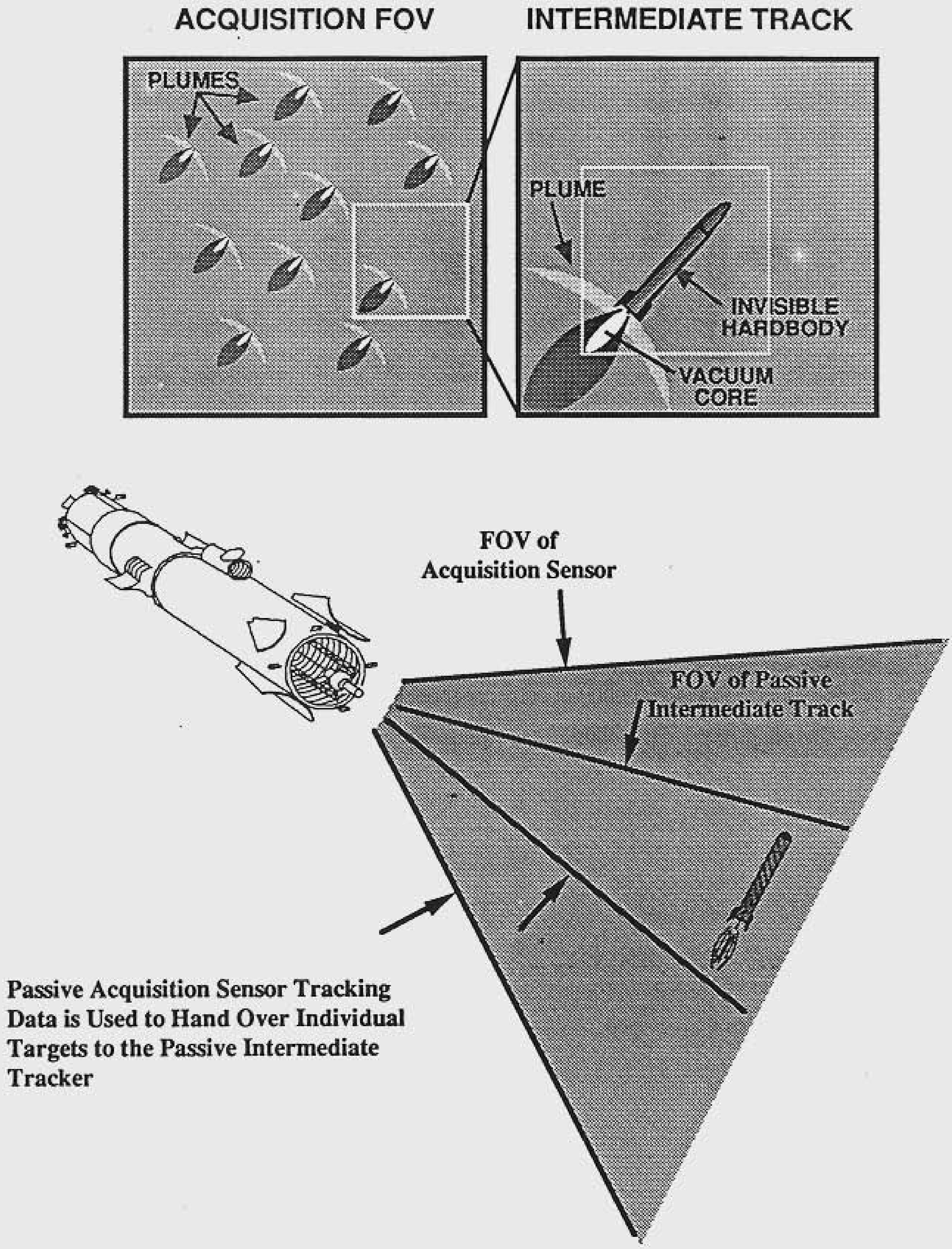


Figure III: Passive Track Handover

ISSUE III. PASSIVE TRACK HANDOVER.

Can the acquisition tracker determine the line-of-sight to the target (booster, PBV) with enough accuracy and stability to effect a handover to the passive intermediate resolution tracker?

The multiple targets simultaneously tracked by the acquisition tracker are handed over individually to the intermediate tracker. Coarse tracking by the acquisition sensor and the multiple track prediction algorithm must be adequate to place individual targets within the field-of-view of the intermediate tracker. Passive coarse tracking and intermediate tracking experiment functions should demonstrate sensor waveband selection, design of optics and focal planes, and target detection/clutter rejection capabilities adequate to track booster plumes or post boost vehicles against cluttered Earth, limb, and space backgrounds.

Scalability Criteria

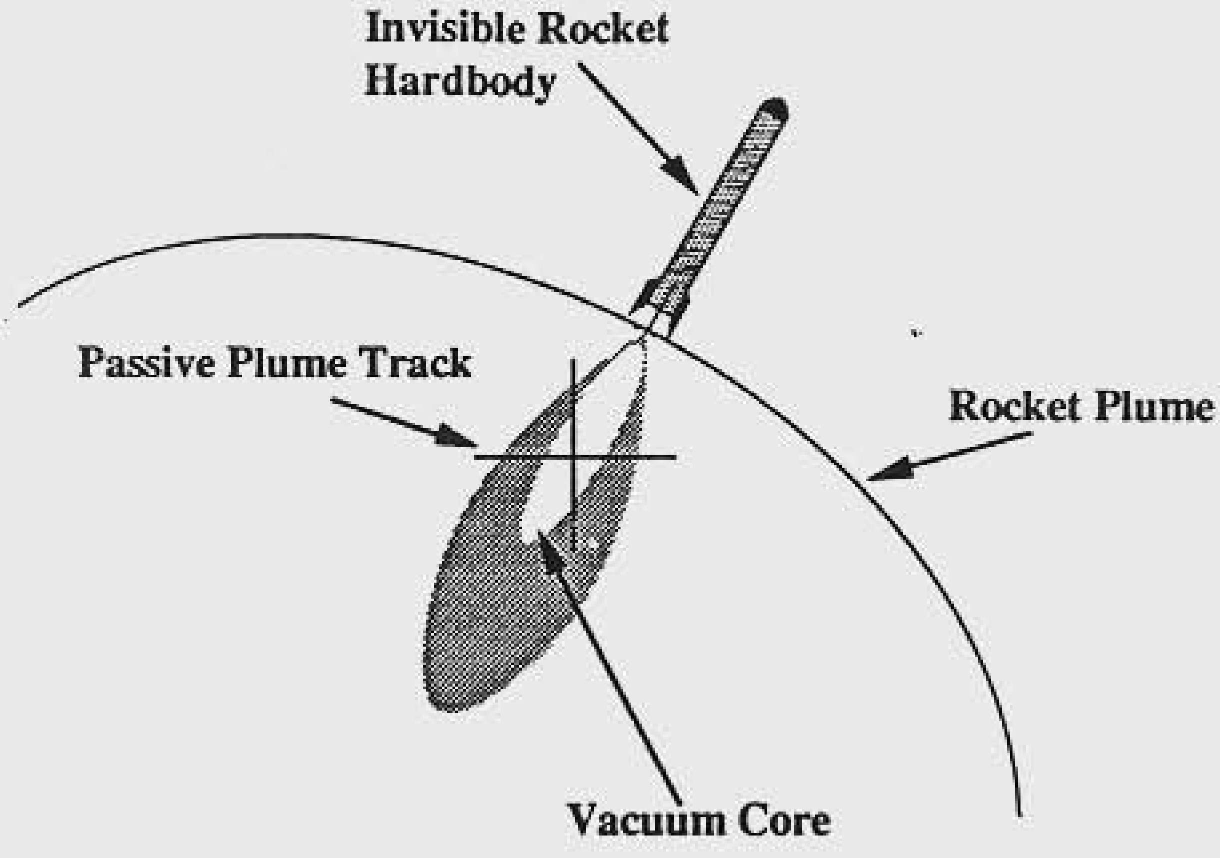
- *Acquisition Tracker (ACQ) Handover Accuracy:* Consistent with handover to the passive intermediate tracker

- *ACQ Noise Equivalent Angle (NEA):* Consistent with handover to the passive intermediate tracker.

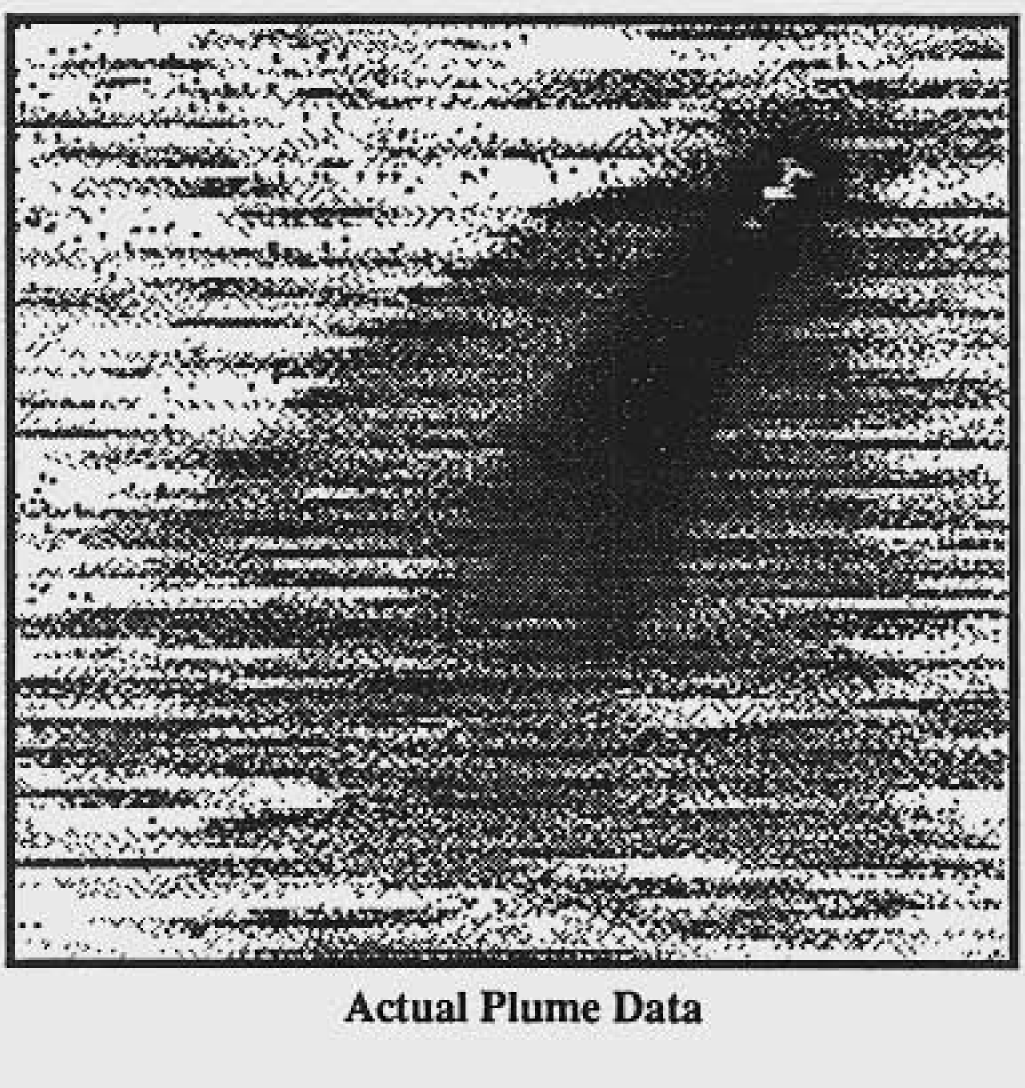
Traceability Criteria

- *SWIR/MWIR Passive Sensor:* The wavelength of the acquisition tracker (ACQ) and passive intermediate tracker (PIT) sensors should be selectable in SWIR and MWIR since ATP concepts for DEW systems are presently postulated to use infrared for target acquisition and passive tracking of missile plumes. IR sensors allow acquisition and tracking in daytime of plumes against low contrast, solar-illuminated backgrounds. The use of below-the-horizon background clutter rejection algorithms shall be evaluated by ALTAIR.

- *Visible Passive Sensor Adjunct:* The ALTAIR experiment shall incorporate visible (and possibly ultraviolet) acquisition and intermediate track capability as a risk reduction adjunct to insure a successful functional demonstration of ATP and to investigate tracking using the phenomenology of these alternate wavelengths. Furthermore, the visible acquisition sensor is traceable to the coarse track visible surveillance sensor in the Brilliant Eyes concept.



The Passive Intermediate Track (PIT) Function Establishes a Stable Track on the Target Plume.



Actual Plume Data

Figure IV: Passive Intermediate Track

ISSUE IV. PASSIVE INTERMEDIATE TRACK.

Does the plume signature of a boosting target (booster, PBV) provide robust enough phenomenology to provide a stable track source for a passive intermediate resolution tracker?

Passive Intermediate Tracking (PIT) Sensor design requires technology trades and demonstration of robust tracking performance of varied targets under all background conditions. The ALTAIR PIT should be capable of tracking booster plumes and maneuvering PBV plumes and providing a stable line-of-sight for handover to the active fine track sensor. The essential technology elements to be demonstrated are sensor waveband selection, resolution, and tracking algorithms.

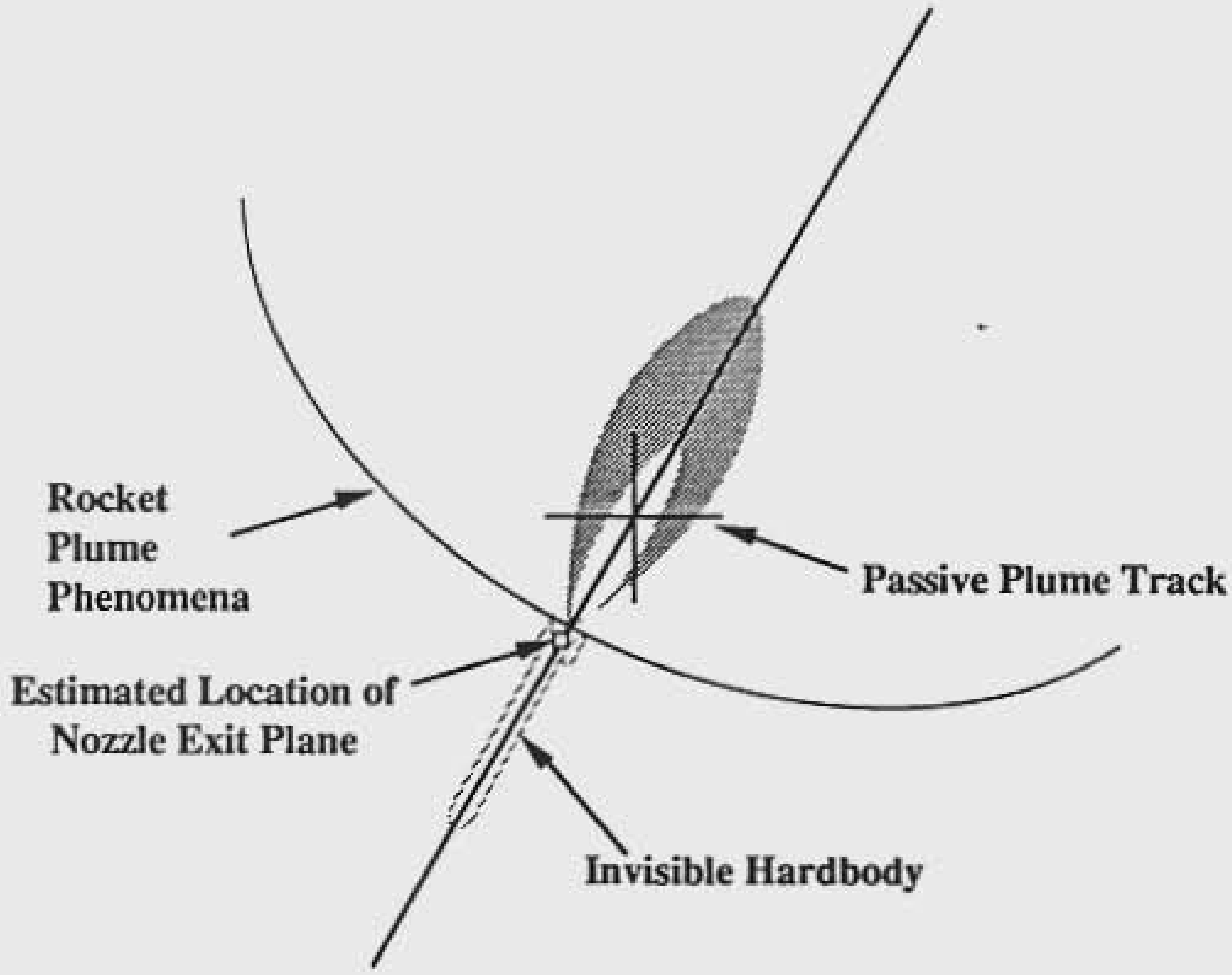
Scalability Criteria

- *Passive Intermediate Tracker NEA.* Consistent with precision angle-angle measurements of the target line-of-sight; consistent with handover to the active fine tracker.
- *Pixel Scaling at the Target Plane.* The optical parameters of the ALTAIR Passive Intermediate Tracker (PIT) sensor shall scale at the pixel level with PIT sensors proposed in DEW concepts. That is, for representative booster and PBV targets:
  - *Resolution.* The PIT sensor resolution in meters at the target plane shall be essentially the same (within a factor of 3) for the ALTAIR experiment as for DEW concepts. The PIT sensor resolution shall be consistent with estimating the hardbody location relative to the texture in the passive plume imagery with enough precision to aim the illuminator beam.
  - *Pixel Sampling.* The number of pixels subtending the resolution blur circle of the target's image shall be essentially the same for the ALTAIR experiment as for DEW concepts. This means that the pixel sampling of the blur circle diameter should be nearly the same for ALTAIR as for a DEW concept. For tracking extended targets it is generally good practice to oversample the resolution blur circle, if enough SNR can be preserved.
  - *Signal-to-Noise Ratio.* The per pixel SNR shall be nearly the same or greater for ALTAIR as for a DEW concept.

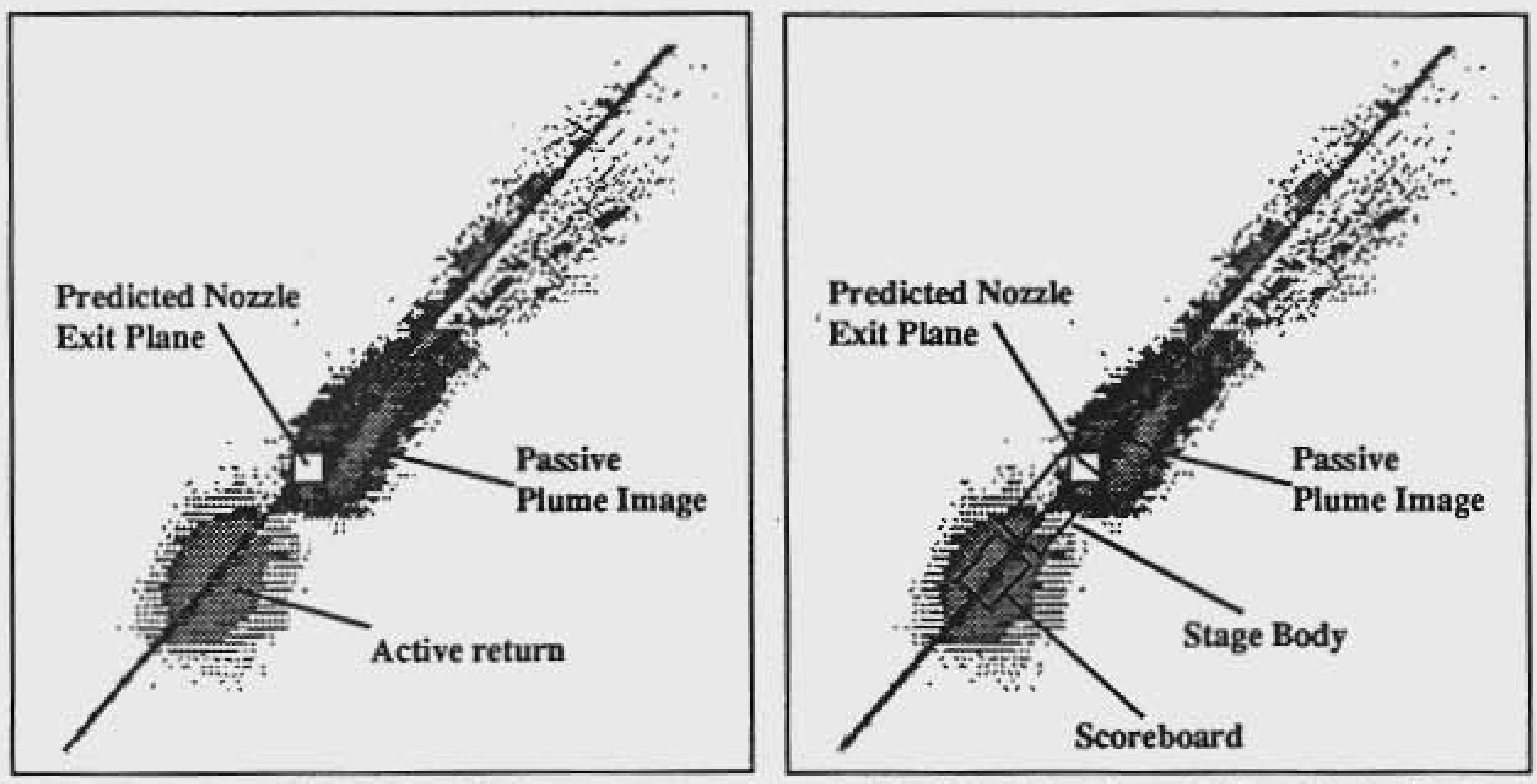
See Appendix B for a full set of pixel scaling laws for sensors used for acquisition, passive intermediate tracking, and active fine tracking.

Traceability Criteria

- *Track Through Staging and Maneuver Transients.* The PIT should be employed during all phases of target track including booster ignition, booster cut-off, booster separation, coast period, and PBV maneuvering.



Handover algorithms are used to estimate the location of the booster body in relation to plume phenomena measured by the PIT. The illustration below shows the application of a handover algorithm during tracking of the Starbird development test flight.



Algorithm Prediction

Initial Registration of Hardbody Data

Starbird Data Collection and Hardbody Prediction

Figure V: Plume-to-Hardbody Handover

ISSUE V. PLUME-TO-HARDBODY HANDOVER.

Does the plume signature of a boosting target (booster, PBV) provide robust enough phenomenology to allow a fire control processor using the imagery from an intermediate resolution tracker to accurately determine the hardbody location "relative" to the passively tracked target scene?

Plume-to-hardbody handover is the process of locating a missile hardbody from information derived from passive plume imagery. During the boost and post-boost phase, the rocket plume will change intensity and spatial distribution due to altitude, velocity, motor design, and changes in the tracker's aspect angle of view with respect to the rocket nozzle. The image of the missile plume will also change due to background conditions (e.g., earthlimb, atmospheric, and solar effects). Chuffing and other temporal variations in plume intensity and spatial distribution have been observed. Only a limited data set of plumes above 30 km of altitude has been available for analysis. ALTAIR shall demonstrate the feasibility of current plume-to-hardbody algorithms and shall collect data enabling the development of even more robust algorithms.

Scalability Criteria

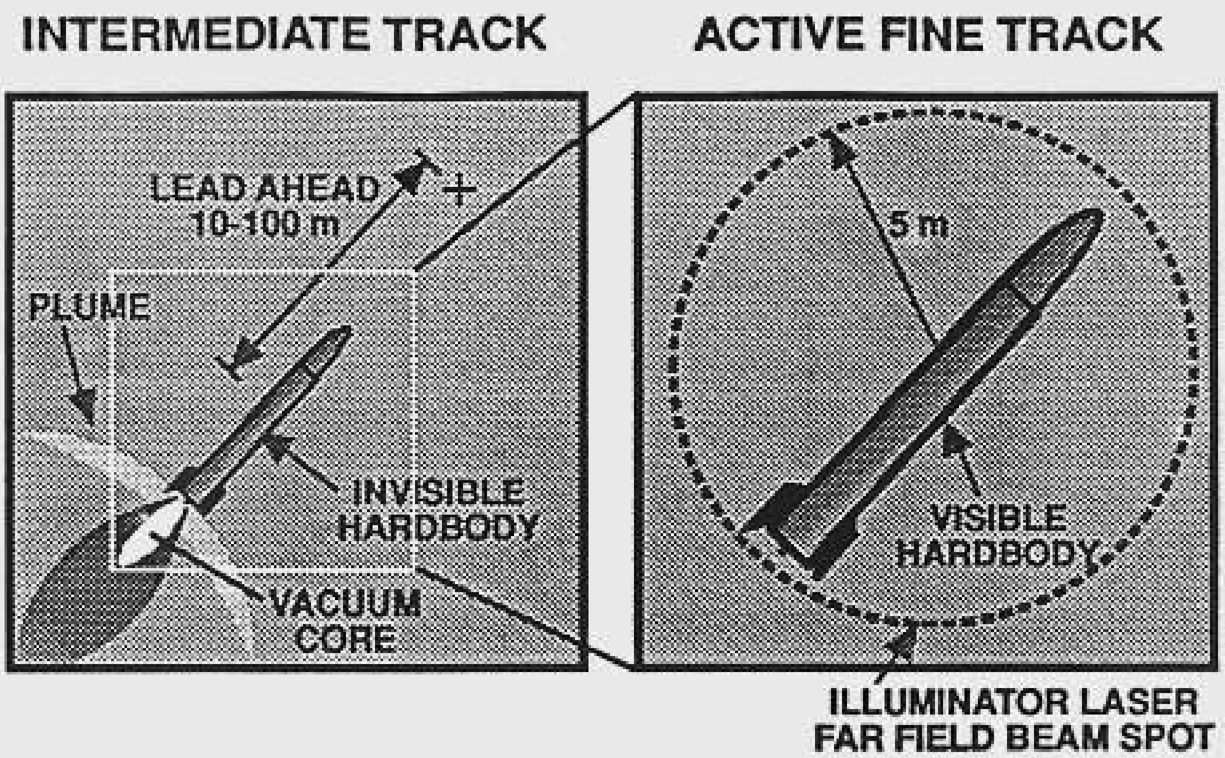
- *Pixel Scaling at the Target Plane.* Fire control performance parameters can be scaled with sensor characteristics to provide confidence for critical issue resolution. For example, the performance of the fire control algorithm in identifying the hardbody position can be scaled to some fraction of a resolution element or pixel when presented with spatially extended scenes at representative sensor SNR's. For this reason, in order to demonstrate scalable fire control algorithms, the pixel scaling conditions discussed in Issue IV must be achieved.

- *Accuracy of Determining the Hardbody Position.* Consistent with accurate pointing of the illuminator beam and subsequent handover to the active fine tracker.

Traceability Criteria

- *Fire Control and Tracker Algorithms, Processing, and Logic Shall "Tend Toward" Traceability.* The tracker algorithm, tracker image processing, and fire control logic used by the ALTAIR experiment to predict the hardbody position from the passive plume imagery should "tend toward traceability." Although it may be necessary in the beginning to design for the particular rocket motor and observation angle used in the encounter, the ALTAIR architecture should be flexible enough to change as more robust algorithms are invented. As data is analyzed, it is anticipated that progressively more general and more robust plume-to-hardbody handover algorithms can be designed for ALTAIR. The actual phenomenological data gathered in orbit must be recorded with sufficient fidelity and dynamic range to be useful in testing advanced algorithms in ground simulations. ALTAIR software should be flexible enough to allow for on-orbit modifications of the plume-to-hardbody handover algorithm based on experience from prior engagements.

- *Flexible Tracker Processors*. The particular process used by the passive intermediate tracker (PIT) in determining the passive track point will affect the degree of difficulty in assessing the physical separation between the passive track point and the probable hardbody position. Therefore, the experiment should include alternative passive track processors (such as centroid, correlation, and edge trackers, etc.) flexible enough to assess various techniques and to allow for on-orbit modifications in response to experience from prior engagements.



Predicted lead angle allows for the speed of light and the location of the desired aimpoint. Actual lead angles may be many times larger than the illuminator beam spot, so that accurate prediction and illuminator pointing are required.

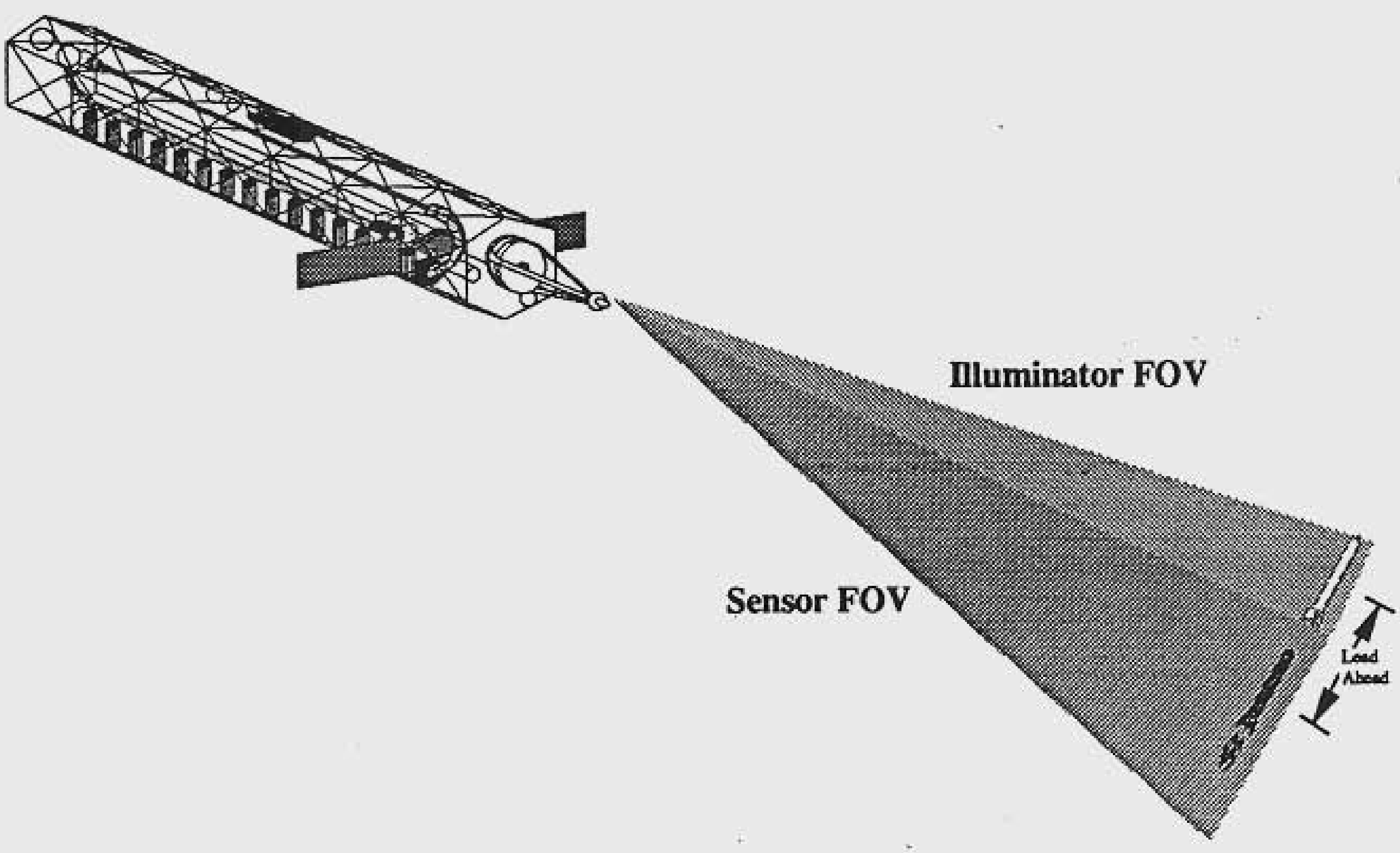


Figure VI: Illuminator Point-Ahead/Active Track Handover

ISSUE VI. ILLUMINATOR POINT-AHEAD/ACTIVE TRACK HANDOVER.

Can an ATP/FC system accurately point the illuminator beam at the target hardbody (booster, PBV, midcourse object) by properly accounting for both

the physical separation between the passive track point and the hardbody, as well as the point-ahead offset due to the speed of light?

The active track lead angle for pointing the illuminator beam is computed from the predicted hardbody offset from the plume tracking point, the inertial line-of-sight rate and the range to the target. Until active track is established, range will not be accurately determined, and the handover to active track must allow for this uncertainty, as well as for errors in plume tracking and hardbody prediction. This may be achieved by scanning or spreading the illuminator beam, but these approaches may require increases in illuminator power or time to accomplish the handover. The experiment should demonstrate point ahead prediction and active track handover performance using a traceable implementation of design trades.

Scalability Criteria

- Point ahead angle = $2V_{normal}/c = 2R\dot{\theta}/c$, where V_{normal} is the total relative velocity between the ATP system and the target in a plane that is normal to the tracker line-of-sight; R is the estimated range to the target (based on track file source information); $\dot{\theta}$ is the inertial angular rate measurement.

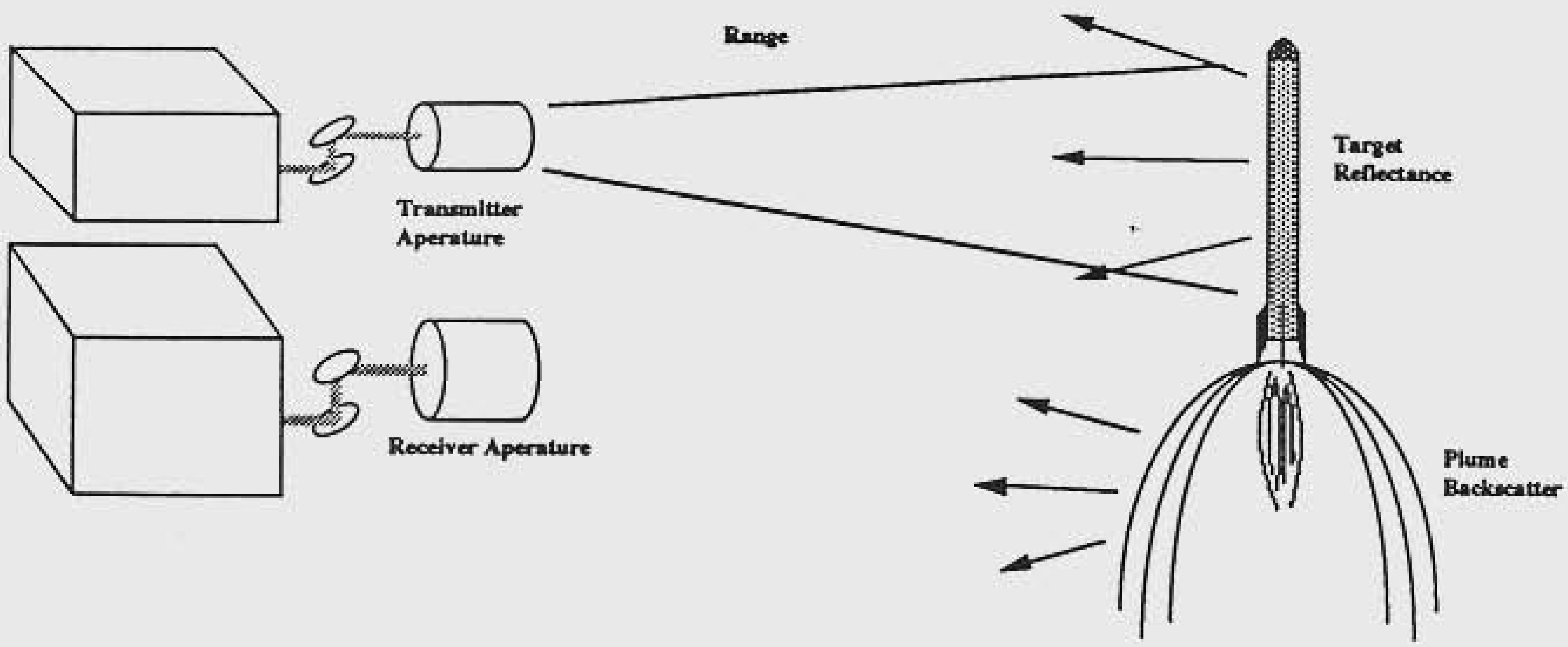
- *Representative Point Ahead.* The experiment shall be performed with representative point ahead requirements; i.e., point ahead angle greater than 10 μrad.

- *Balanced and Audited Uncertainty Budget.* Uncertainty in determining an accurate total point ahead (physical separation plus speed of light delay) should be low enough to acquire the reflected illuminator energy in the AFT after the first pulse in the case of a flood/staring illuminator, or within the scan period for a scanning illuminator. The experimenter shall show how uncertainties scale with errors in determining range to target, target angle rate, and other system error contributors.

Traceability Criteria

- *Illuminator Steering Mirror.* Illuminator point ahead shall be accomplished with an illuminator steering mirror outside of the optical path of the tracker imagers.

- *Point Ahead Angle Measurements.* Point ahead angle shall be calculated from measurements of the inertial angle rate and relative range to the target based on track file source information.



Active tracking of an unenhanced booster in the presence of its plume has not been adequately demonstrated. In the figure below, the performance of the STARLAB active tracking system is predicted for enhanced targets.

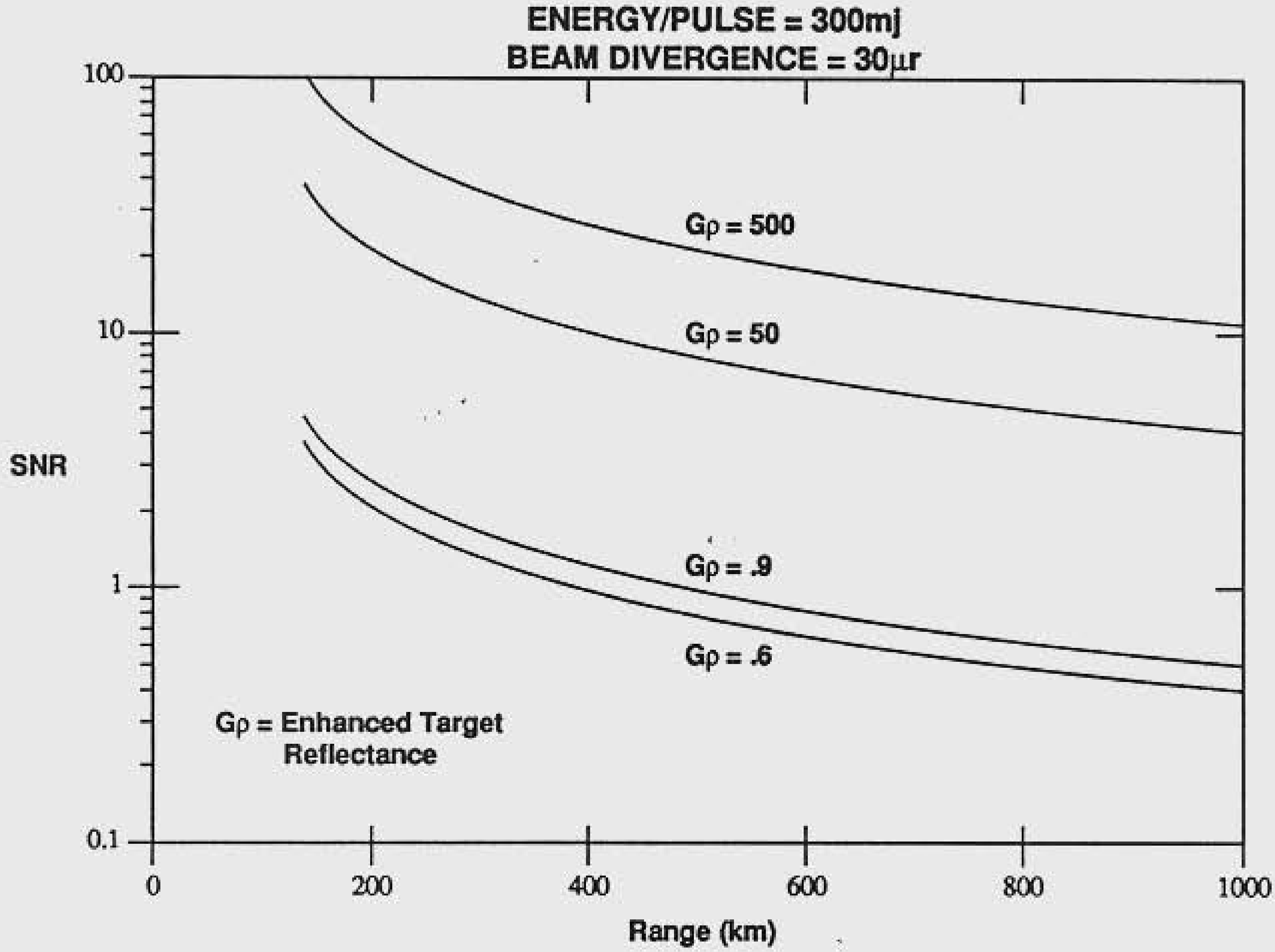


Figure VII: Hardbody Discrimination/Active Fine Track/Aimpoint Selection

ISSUE VII. HARDBODY DISCRIMINATION/ACTIVE FINE TRACK/ AIMPOINT SELECTION.

Does the illumination of the boosting target (booster, PBV) provide robust enough phenomenology

to allow an active tracker to discriminate the hardbody from the plume, and
to actively track the hardbody with sufficient precision for jitter stabilization, and
to allow the aimpoint selection processor to choose an aimpoint for a directed energy weapon?

Hardbody tracking is significant because it is the technique that will unambiguously determine the aimpoint. If the hardbody is not accurately located, a correct aimpoint will not be established. The interfering backscatter from the partially illuminated plume may complicate the active tracking of the hardbody. If the plume return is greater than or equal to the hardbody return, the tracker will have a difficult time locating and tracking the hardbody.

A significant technology issue is achieving high signal-to-noise ratio (SNR) and tracker update rate during active tracking of the boosters and PBVs. Signal level is determined by tracker aperture diameter, optics transmittance, and detector quantum efficiency, and also by the peak-pulse energy and beam angular width of the illuminator laser. There are phenomenology issues concerned with real target signatures under active illumination, i.e., reflectivity, glints, and countermeasures. Active track image resolution and stability (tracking jitter) must be adequate to locate and maintain the aimpoint on the target.

Scalability Criteria

- *No Target Enhancement.* In order to provide scalability to hardbody handovers, the target should not be enhanced. Ideally, the ratio of hardbody reflectance to plume backscatter should be the same for the ALTAIR target as it is for operational representative targets. Only in this way can an important limitations of hardbody tracking be assessed.

- *Absolute Minimal Target Enhancement.* However, due to the limitations in sensor aperture and illuminator power, some modest amount of hardbody enhancement may be needed to achieve sufficient tracker SNR. If so, the backscatter of the plume at the level of 1/3 the expected unenhanced hardbody reflectance must be measurable when the image of the enhanced target is unsaturated. A nominal hardbody has an average reflectivity coefficient of 0.05/str. Therefore, assuming shot noise limited systems, in order to measure plume backscatter at the level of 0.05/str with a modest SNR of 3, the sensor noise floor must be set to a level where materials with a reflectivity coefficient of 0.005/str provide a SNR of 1. In this case, assuming a sensor with an instantaneous dynamic range of over 100, a hardbody with an enhanced reflectivity coefficient of 0.5/str can be observed without saturation.

- *Pixel Scaling at the Target Plane.* Fire control performance parameters can be scaled with sensor characteristics to provide confidence for critical issue resolution. A key scalability criterion is the performance of the active tracker in stabilizing the line-of-sight within some fraction of a resolution element or pixel when presented with a spatially extended image of the test target. The optical parameters of the ALTAIR Active Fine Track (AFT) sensor shall scale at the pixel level with AFT sensors proposed in DEW concepts. That is, for representative booster and PBV targets:

    - *Resolution.* The AFT sensor resolution in meters at the target plane shall be essentially the same (within a factor of 3) for the ALTAIR experiment as for DEW concepts. The AFT sensor resolution shall be consistent with the task of aimpoint selection. The resolution in the target plane is expected to be some moderate fraction (1/2 to 1/3) of the target's smallest dimension (e.g., the rocket diameter for boosters).

    - *Pixel Sampling.* The number of pixels subtending the resolution blur circle of the target's image shall be essentially the same for the ALTAIR experiment as for DEW concepts. This means that the pixel sampling of the blur circle diameter should be nearly the same for ALTAIR as for a DEW concept. For tracking extended targets it is generally good practice to oversample the resolution blur circle, if enough SNR can be preserved.

    - *Signal-to-Noise Ratio.* The per pixel SNR for the AFT sensor shall be nearly the same or greater for ALTAIR as for a DEW concept.

See Appendix B for a full set of pixel scaling laws for sensors used for acquisition, passive intermediate tracking, and active fine tracking.

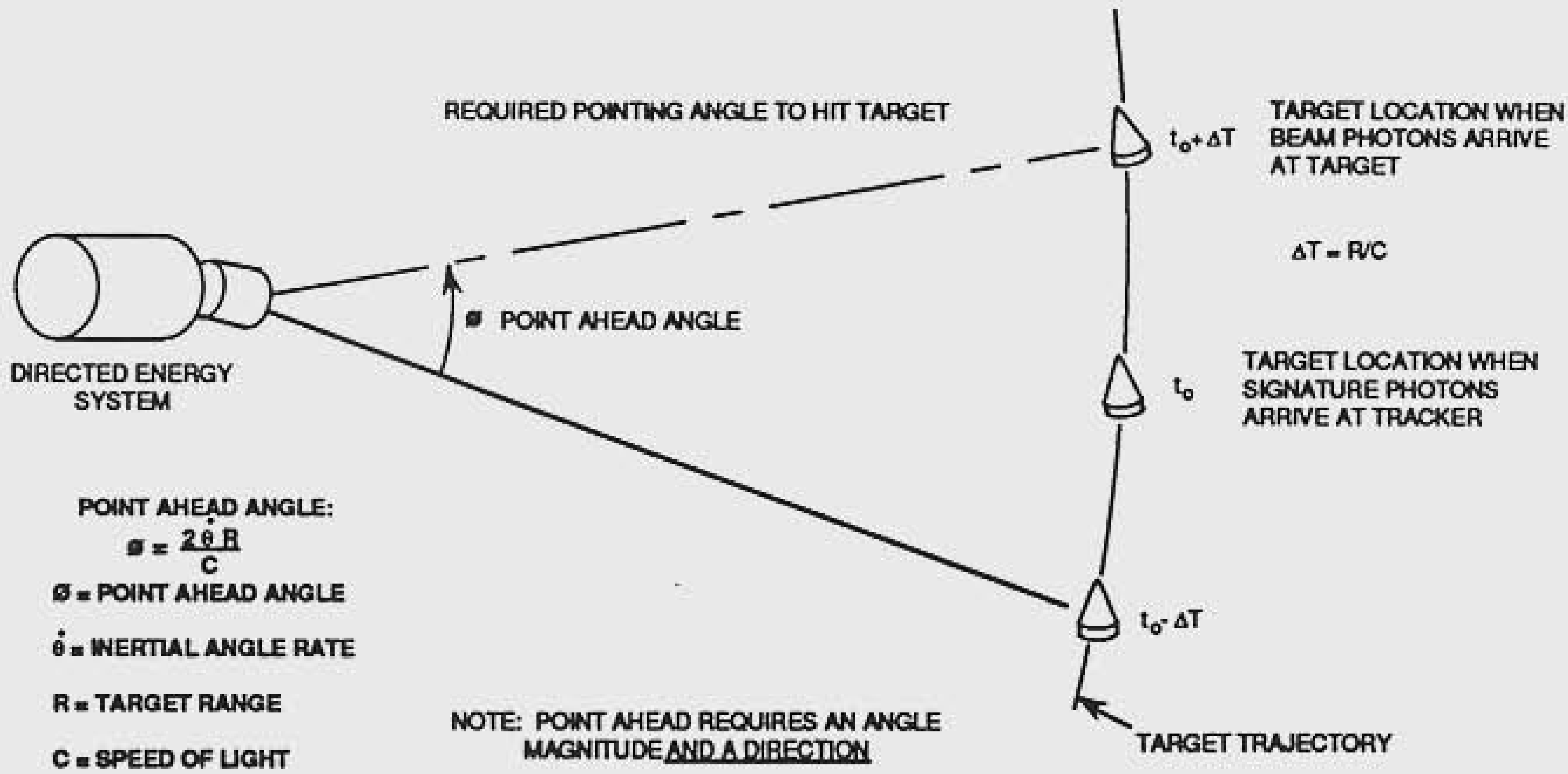
- *Active Fine Tracker NEA:* Consistent with ultra-low line-of-sight stabilization; consistent with angle-angle measurements of the target line-of-sight.

- *Illuminator Pulse Duration:* Consistent with precision range measurements to support precision point ahead, IPP, TPP, and handback.

- *Kinematic Scaling and Tracker Bandwidth Scaling:* In order to scale aperture and illuminator power of the ALTAIR experiment with actual DEW systems, it is likely that the ALTAIR target encounters will be performed at significantly shorter ranges than actual DEW target encounters. Therefore, the acceleration of line-of-sight rates and the change of the acceleration of line-of-sight rate with respect to time can be more stressing on ALTAIR than on DEW concept systems. On the other hand, the latency due to the speed of light is not as stressing for the shorter range ALTAIR experiment. The experimenter must show how the tracker bandwidth as well as the platform jitter stabilization scales with these differences in slew rate dynamics and encounter geometry.

Traceability Criteria:

- *Illuminator Characteristics*. The illuminator wavelength shall be mid-visible to near IR.
  - The active fine track sensor shall use a narrow bandpass filter designed to optimize the laser return and minimize the background signature.
  - The illuminator coherence length shall be consistent with minimizing the effects of speckle on the tracker image.
  - The illuminator repetition rate shall be consistent with the tracker bandwidth required for precision pointing at boosting targets.
  - The illuminator divergence and beam quality shall be consistent with handover to the fine tracker.
- *Track Through Staging and Maneuver Transients*. The AFT should be employed during all phases of target track including booster ignition, booster cut-off, booster separation, coast period, and PBV maneuvering.



Point ahead angle is computed to allow for the finite speed of light from the target to the DEW sensor and from the DEW to the target. Tracking jitter, inertial sensor noise and scale factor errors contribute to errors in determining the angular rate and direction. Point ahead accuracy is critical for DEW concepts, such as NPB, that are internally boresighted with open loop pointing. "Target Loop" pointing control can correct low bandwidth pointing and boresight errors.

Figure VIII: Precision Point Ahead/Aimpoint Designation

ISSUE VIII. PRECISION POINT AHEAD/AIMPOINT DESIGNATION.

Can an ATP/FC system accurately and precisely offset the DEW line-of-sight by properly accounting for both

the physical separation between the active track point and the aimpoint selection,

as well as

the point-ahead offset due to the speed of light?

In precision pointing, the observed line-of-sight rate as well as the detected range to the target are used to estimate where the target will be in the time it takes light to reach the weapon system platform sensor and to return to the target. This line-of-sight correction, as well as the aimpoint selection, is used to offset the line-of-sight of the DEW beam direction. In addition, any change in the boresight calibration must be measured and corrected. Tracking jitter, inertial sensor noise, target glints or countermeasures may degrade the prediction of point ahead angle and the capability to maintain the line-of-sight on the desired aimpoint

Scalability Criteria

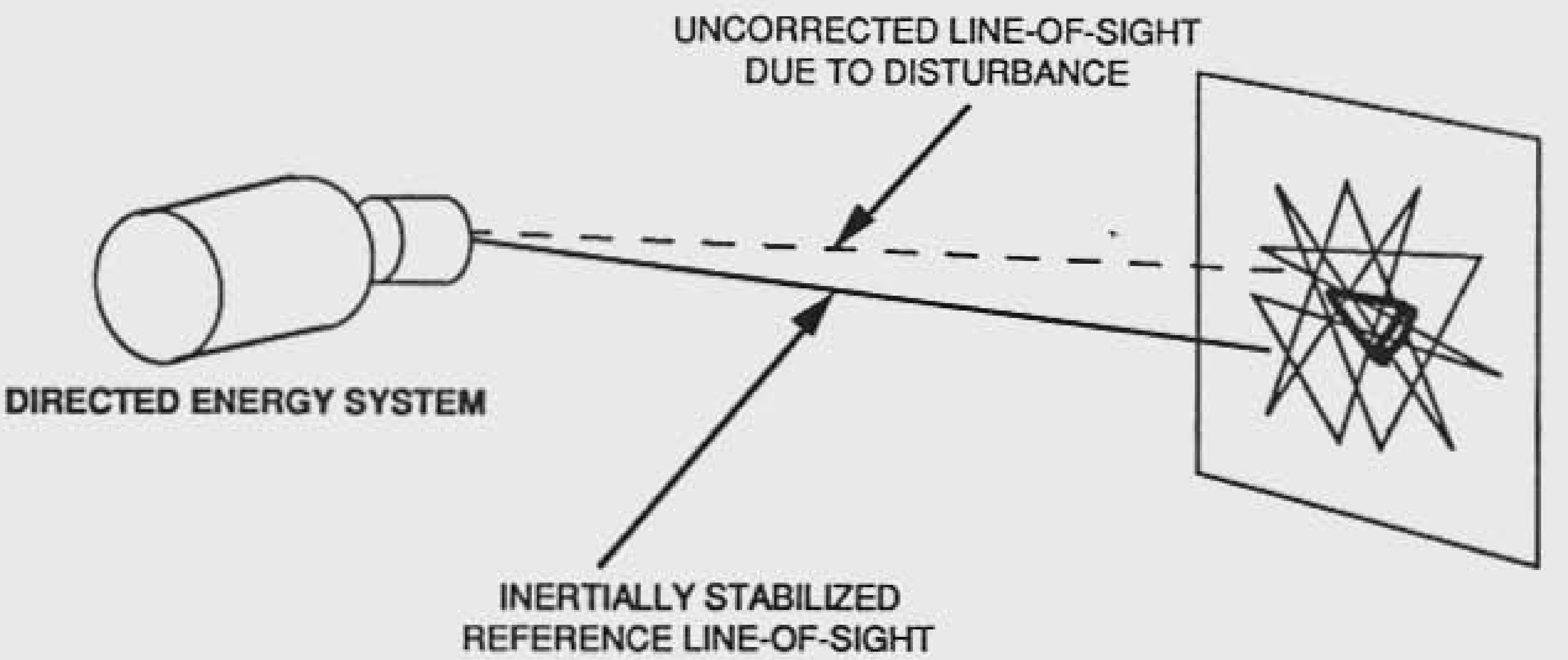
- Point ahead angle = $2\,V_{normal}/c = 2\,R\dot{\theta}/c$, where V_{normal} is the total relative velocity between the ATP system and the target in a plane that is normal to the tracker line-of-sight; R is the laser ranger measurement of range to target; $\dot{\theta}$ is the inertial target angular rate measurement.

- *Representative Point Ahead.* The experiment shall be performed with representative point ahead requirements; i.e., point ahead angle greater than 10 µrad.

- *Balanced and Audited Uncertainty Budget:* Point ahead precision for the DEW aimpoint should be demonstrated at a level equal to the total pointing jitter performance. The experimenter shall show how uncertainties in point ahead angle scale with uncertainties from the laser ranger, the angular inertial instrument, and other system error contributions.

Traceability Criteria

- *Point Ahead Angle Measurements.* Point ahead angle shall be calculated from measurements of the inertial angle rate and the relative range to the target as measured by the laser range finder.



Beam pointing disturbances must be measured and attenuated in order to deliver lethal energy to the target. The figures at the right illustrate measurement of line-of-sight disturbances by tracking and inertial sensors.

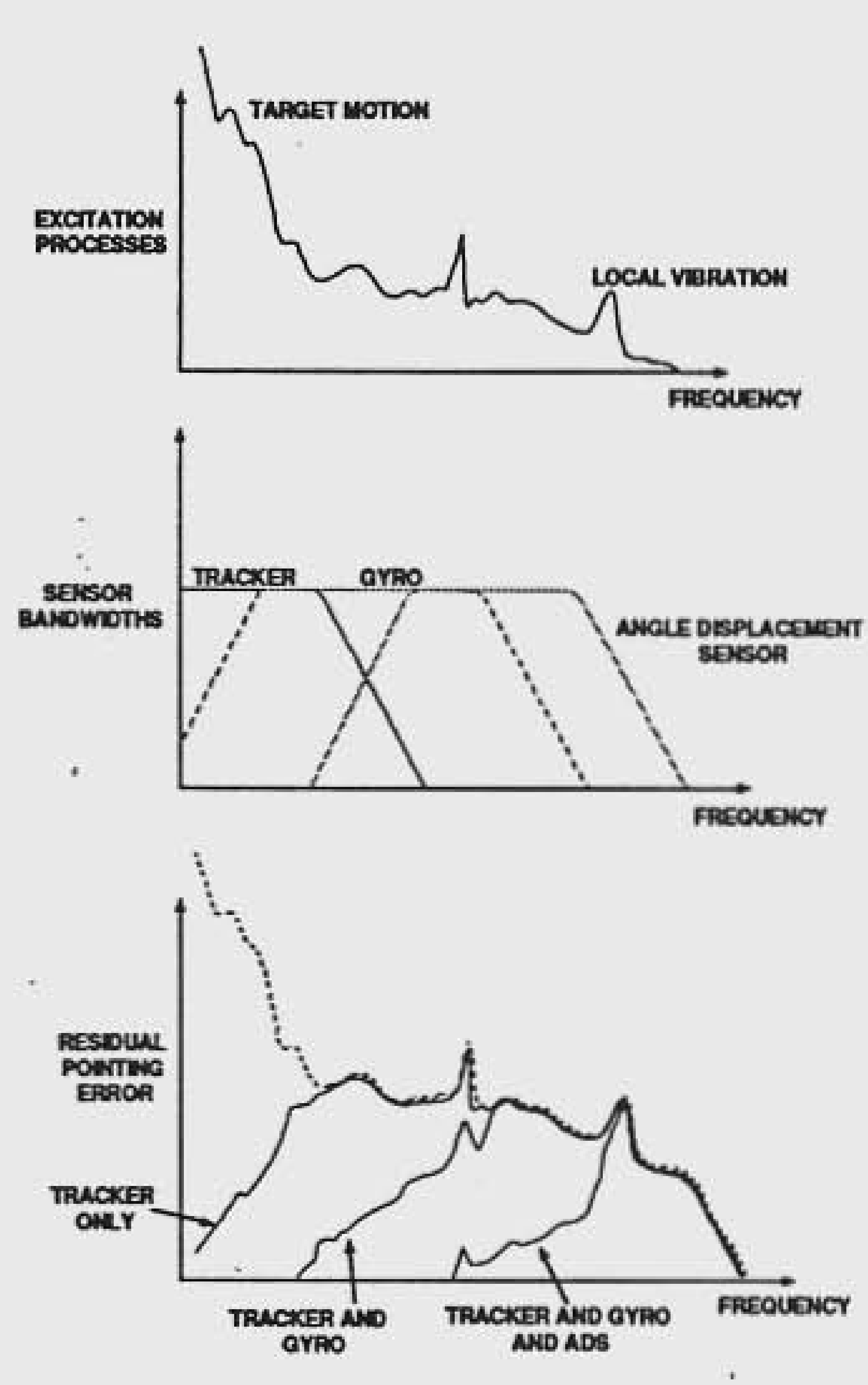


Figure IX: Precision Beam Pointing at Rate

ISSUE IX. PRECISION BEAM POINTING AT RATE.

Can a space-based pointer system stabilize the line-of-sight to an accelerating target (booster, PBV, midcourse object) with low enough jitter to permit directed energy weapon lethality?

The function of precision pointing maintains a high-energy beam (or marker beam for the purpose of the ALTAIR experiment) on a selected area of a moving target for a lethal period of time. Line-of-sight pointing error is composed of three components sorted by frequency: bias, drift, and jitter. The bias and drift associated with target motion are low frequency terms (less than 1 Hz) primarily addressed by the tracker servo loop. The tracker is an inherently low bandwidth controller due to the latencies associated with the speed of light and image processing, as well as the relatively low image sample rates. Other bias terms are controlled by offsetting steering mirrors to account for boresight errors, point-ahead angles, and the dynamic hang-off associated with the type of servo loop employed.

The high frequency component of pointing error (often called jitter) is not directly related to target motion, but rather the local vibration of the pointing platform coupled into the optical line-of-sight. Motion sensors such as laser probe detectors, inertial reference units, and accelerometers are used to observe jitter and provide feedback to fast steering mirrors to reduce the high frequency pointing errors.

Scalability Criteria

- *Residual Line-of-Sight Pointing Error as Measured at the Target:*
    - The rms value of the residual pointing jitter shall be related (via a classified factor) to the radius of the diffraction limited spot size of the marker beam in the far-field.
    - The bias value (low frequency offset) of the residual pointing error shall be equivalent to the rms value of the residual pointing jitter.
    - The final precision pointing accuracy of ALTAIR should be within an order of magnitude of DEW system requirements.
- *Unambiguous Far-Field Scoring of Pointing Error.* In order to measure the residual pointing error in the far-field, the experiment must incorporate a marker laser on the pointing platform and an instrumented scoreboard on the boosting target vehicle. The scoreboard should have an accuracy of ±10% in measuring jitter and bias and should have the capability of

measuring jitter and bias at least 5 times greater than anticipated. The bandwidth of the jitter measurement should be adequate to observe the far-field consequences of the measured platform vibration. Nominal bandwidth of the scoreboard sensors should be 250 Hz.

- *Self-Scoring Alternatives for Measuring Residual Pointing Error.* For the midcourse target pointing demonstration some alternate form of scoring may be proposed by the experimenter if the midcourse targets can not suitably carry scoreboards. (For example, an alternate scoring method may be ALTAIR self scoring using a retroreflector on the midcourse object that is narrowly filtered around the marker laser wavelength. Another method: observe the angle of arrival at the ALTAIR satellite of a laser diode beacon radiating from the midcourse target. In either case, the ALTAIR sensor should be a high bandwidth quadcell with sufficient sensitivity and linearity to measure the residual pointing error.)

- *Balanced and Audited Jitter Budget.* The end-to-end system pointing error is a resultant of many components: boresight misalignments, tracker NEA, unrejected base motion, etc. The ALTAIR experiment must measure each source component of pointing error well enough to understand its ultimate consequence as determined by the ALTAIR system design. In this way ALTAIR experimental results can be scaled to other traceable concepts. As a scalable experiment ALTAIR shall be designed to balance the contributions from each constituent of jitter so that a single noise component does not overwhelm the answer.

- *Non-Representative Platform Base Motion.* There is no requirement for ALTAIR to provide a simulated vibration spectrum associated with a DEW beam generation system, nor is there any requirement for ALTAIR to specifically match bending modes or structural similarities with a DEW platform. These vibration spectra are too design specific to be of value for ALTAIR. ALTAIR shall control base motion in the most quiescent environment possible consistent with spacecraft limitations, attitude control, and associated noise disturbances.

- *Kinematic Scaling and Tracker Bandwidth Scaling.* In order to scale aperture and illuminator power of the ALTAIR experiment with actual DEW systems, it is likely that the ALTAIR target encounters will be performed at significantly shorter ranges than actual DEW target encounters. Therefore, the acceleration of line-of-sight rates and the change of the acceleration of line-of-sight rate with respect to time can be more stressing on ALTAIR than on DEW concept systems. On the other hand, the latency due to the speed of light is not as stressing for the shorter range ALTAIR experiment. The experimenter must show how the tracker bandwidth as well as the platform jitter stabilization scales with these differences in slew rate dynamics and encounter geometry.

- *Line-of-sight Angular Rates.* Angular rate of the line-of-sight during precision pointing shall be demonstrated at the following values:

    - At least, 1 degree per second.

    - At most, adequate to follow a scientifically significant portion of the MX PBV trajectory.

Traceability Criteria

- *Precision Pointing with Tracker Commanded Target Line-of-Sight.* ALTAIR shall demonstrate precision pointing in a fashion which is traceable to DEW concepts for booster and post-boost vehicle engagements. That is, the pointer line-of-sight is constantly updated by the active tracker error signals and associated image processing.

- *Precision Pointing with Inertially Commanded Target Line-of-Sight.* ALTAIR shall demonstrate precision pointing in a fashion which is traceable to the NPB midcourse pointing concept. That is, after the target has been actively tracked for a period of time sufficient to accurately update its state vector the pointer line-of-sight is controlled solely by inertial commands and not by tracker imagery.

- *Marker Beam: Surrogate HEL, Surrogate Beam-Line Reference, Instrumentation Tool.* In the ALTAIR experiment the marker beam can be considered a surrogate for the HEL beam in a SBL system or a surrogate for the beam-line reference laser in a NPB system. But most importantly, the marker beam is an instrumentation mechanism to enable an unambiguous measurement of residual pointing error in the far-field. The sensor system for measuring the marker beam pointing direction shall be inertially referenced in order to be traceable to beam line reference concepts used by DEW designers.

- *Isolation and Control of Base Motion Disturbances* shall be made in a fashion traceable to DEW concepts by using techniques such as beam path stabilization, inertial stabilization, image stabilization, flexible body jitter control, fast steering mirrors, and adaptive noise cancellation.

- *Laser Alignment Probe.* The ALTAIR experiment shall use an inertially referenced laser probe beam for beam path stabilization (active optical alignment control) and sensor boresight. For beam path stabilization, the laser probe and its sensor reject the locally induced line-of-sight jitter due to broadband mechanical disturbances such as platform vibration, structural mode excitations, and thermally induced disturbances. Used for sensor boresight, the laser probe provides a single common inertially referenced beam for dynamically boresighting the lines-of-sight of separate telescopes such as the illuminator output telescope and the fine tracker input telescope.

- *Inertially Referenced Boresight.* Some DEW system concepts (e.g. NPB) call for two laser spots to be simultaneously referenced on the same FPA with the active tracker target image: the inertially referenced optical alignment beam, and the DEW beam-line reference. This common FPA provides precision inertial measurements of relative angular displacements between the three separate lines-of-sight. There is no absolute requirement that ALTAIR provide such a common FPA. However, without a common FPA for inertially referenced boresight, ALTAIR shall provide for a highly stable mechanical method to index separate FPA's and alignment sensors so that measurements of the target centroid can be inertially referenced to the marker alignment sensor and the optical alignment sensor.

- *Angular Inertial Instruments.* Proper implementation of inertially referenced angular measurement instruments is essential for ALTAIR to demonstrate traceable DEW functions such as stellar reference, slew maneuvers for target acquisition, precision tracking, pointer stabilization, retargeting slew maneuvers, target handback, impact point prediction, and threat tube prediction. The ALTAIR implementation shall co-reference the tracker line-of-sight, the alignment/boresight laser, and the marker laser with the angular inertial instruments. Specific functions which ALTAIR shall demonstrate with a traceable angular inertial instrument include:

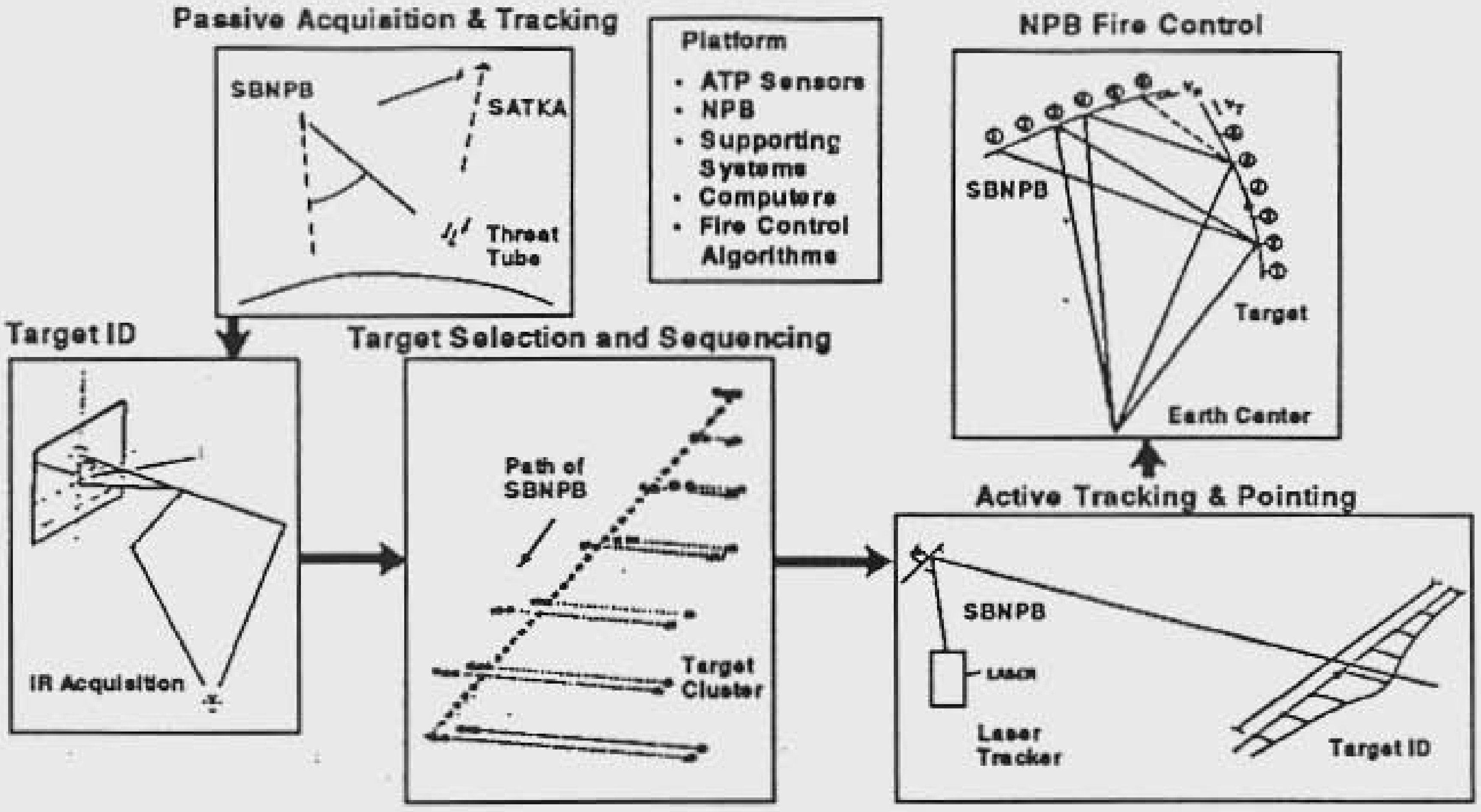
  - *Absolute Angle Reference*—Provide a means for designating target coordinates and pointer slew angles in inertial coordinates.

  - *Target Angle Rate Measurement*—Provide a means to measure target angular rate measurement needed for point ahead and for pointing maintenance during periods when the image trackers are inoperative. Provide pointer rate measurement for slew control.

  - *Tracker/Beam Pointing Stabilization*—Provide an angular reference, beyond the tracker sensor bandwidth, for measuring and correcting the deleterious effects of local vibration.

- *Strapdown vs. Stabilized Platform Angular Inertial Instruments*. Regardless of which IRU approach is used, the experiment shall be constructed in such a manner that the limitations or advantages of the approach taken can be assessed in a traceable fashion to DEW concepts. This implies a certain sophistication in the telemetry used to monitor the particular areas of concern for the particular approach taken.

NPB FIRE CONTROL SEQUENCE



SBL FIRE CONTROL SEQUENCE

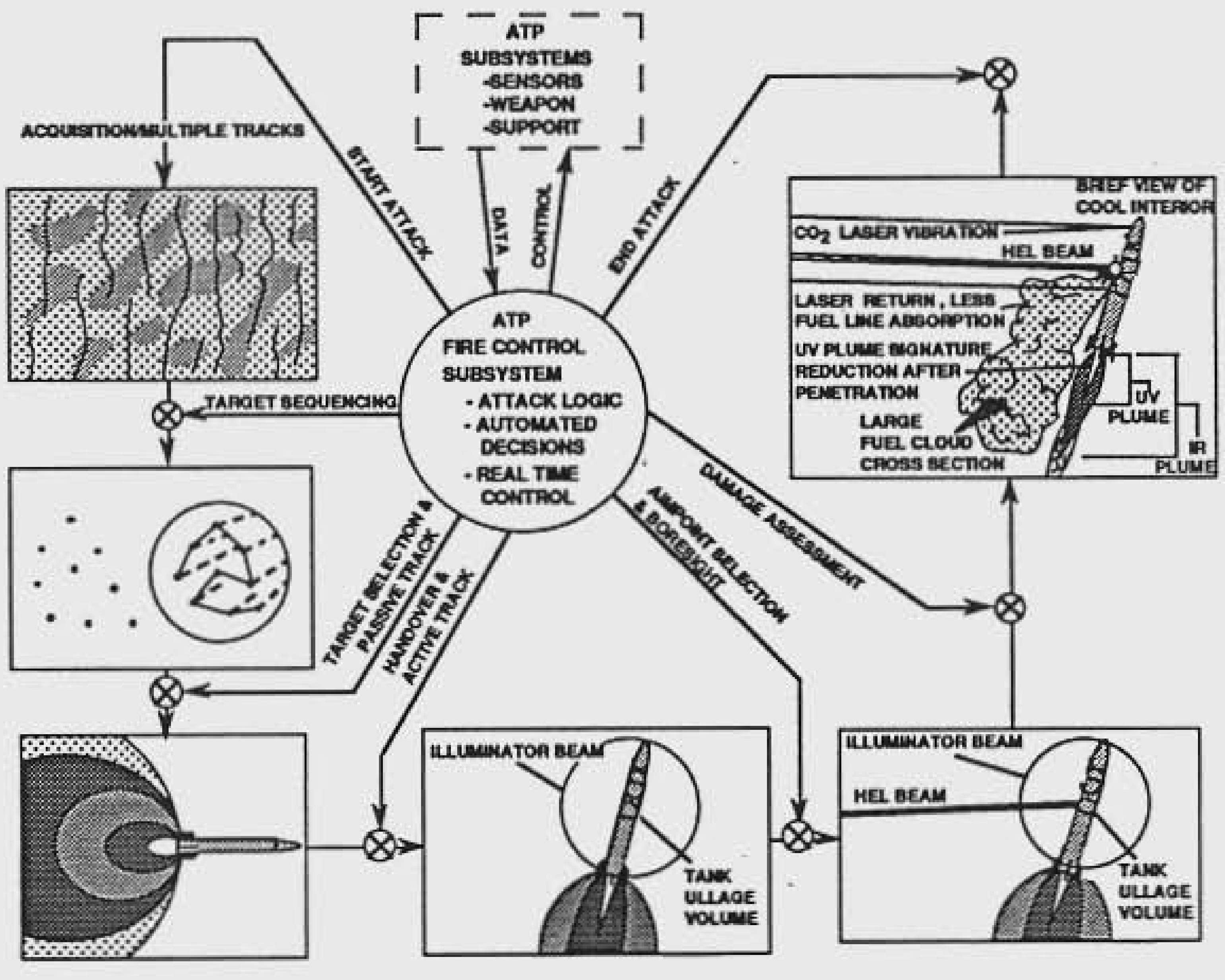


Figure X: Autonomous Sequencing

ISSUE X. AUTONOMOUS SEQUENCING.

Can a DEW fire control system conduct end-to-end autonomous acquisition, tracking, and pointing control?

Autonomous operation of DEW platforms and rapid execution of multiple target engagements will require the development and demonstration of complex mode control logic and autonomous decision-making algorithms. The autonomous capabilities required by an ATP/FC experiment will be considerably less complex but may be made traceable within the scope of the experiment. An experiment with a significant degree of autonomous functional performance will provide confidence in the technology for developing more complex logic and for achieving operational system engagement timeline goals.

Scalability Criteria

- *Time Scaling*. The experimenter must show how the speed of autonomous operations is scalable to DEW system requirements. The time it takes to sequence and transition through each successively higher mode of operation shall be scalable with number of tracker image frames, computer operation cycles, control system time constants, laser illuminator pulses, and other latency periods in such a way that the speed of autonomous upmoding can be compared with operational requirements. The intent is to set-up the experiment in such a way that post-mission analysts can confidently extrapolate faster sequencing by operational systems by ratioing the temporal period of ALTAIR frames, cycles, constants, pulses, and periods with the corresponding times of a postulated concept.

Traceability Criteria

- *The Fire Control Logic in ALTAIR Shall "Tend Toward" Traceability* by providing the same level of function as required by a DEW system, but by providing the function in a way that can be flexibly altered as the experiment evolves. In other words, it may be necessary to "point design" the tracker algorithm, image process, or fire control logic for the particular rocket motor and observation angle used in the target encounter. However, as data is analyzed, it is anticipated that progressively more general and more robust algorithms, processes, and logic can be designed to support ALTAIR autonomous sequencing. Therefore, ALTAIR software and hardware shall be flexible and modular enough to allow for on-orbit modifications to support the development of increasingly more traceable autonomous sequencing functions.

- *Single Target vs. Multiple Target Track.* The ALTAIR experiment shall emphasize the single target engagement. This decision to focus ALTAIR's purpose is taken to ensure that proper understanding of the physics and phenomenology associated with single target encounters is fully validated with space experiment data. A validated understanding of single target track is fundamental and necessary before confident extrapolations can be made to a "many targets--minimum time" scenario.

- *"1 Out Of 'n' Targets."* Notwithstanding the guidance in the preceding paragraph, it is highly desirable for ALTAIR to demonstrate tracking a single target in a way that is traceable to multi-target tracking, i.e., "1 out of 'n' targets." Although ALTAIR may not actually demonstrate multi-target tracking due to hardware limitations (such as a limited telescope FOV) it is conceivable that the track functions (including handoff from ACQ to PIT to AFT) for single target tracking can be traceable to multi-target methods. The idea is to simulate a single retargeting episode from a multi-target engagement. The episode should demonstrate all the upmodes, hand-offs, and target file manipulations required from the moment of the retarget command to the moment of stable beam pointing. Examples of "1 out of 'n' targets" methodology follow:

    - Incorporating a single target track file that looks like "1 out of 'n' target track files." The single target track file shall have the capability of predicting future target location, perhaps with a Kalman filter estimator.

    - Offsetting the line-of-sight from the target and then reacquiring.

    - Commanding the tracker to establish track alternately between two targets.

Threat tube equation: Prediction accuracy is driven by PBV velocity track accuracy on deployment axis (RIA)

$$\sigma_p = \frac{\sigma_m}{\sqrt{N}}$$

$$\sigma_v = \frac{\sigma_p}{T}\sqrt{\frac{12}{N}}$$

$$R_p^{(t)} = \sigma_p + \sigma_v (t - t_m)$$

σ_m = Single look 3-D measurement error (m)

σ_p = 1σ 3-D position error (m)

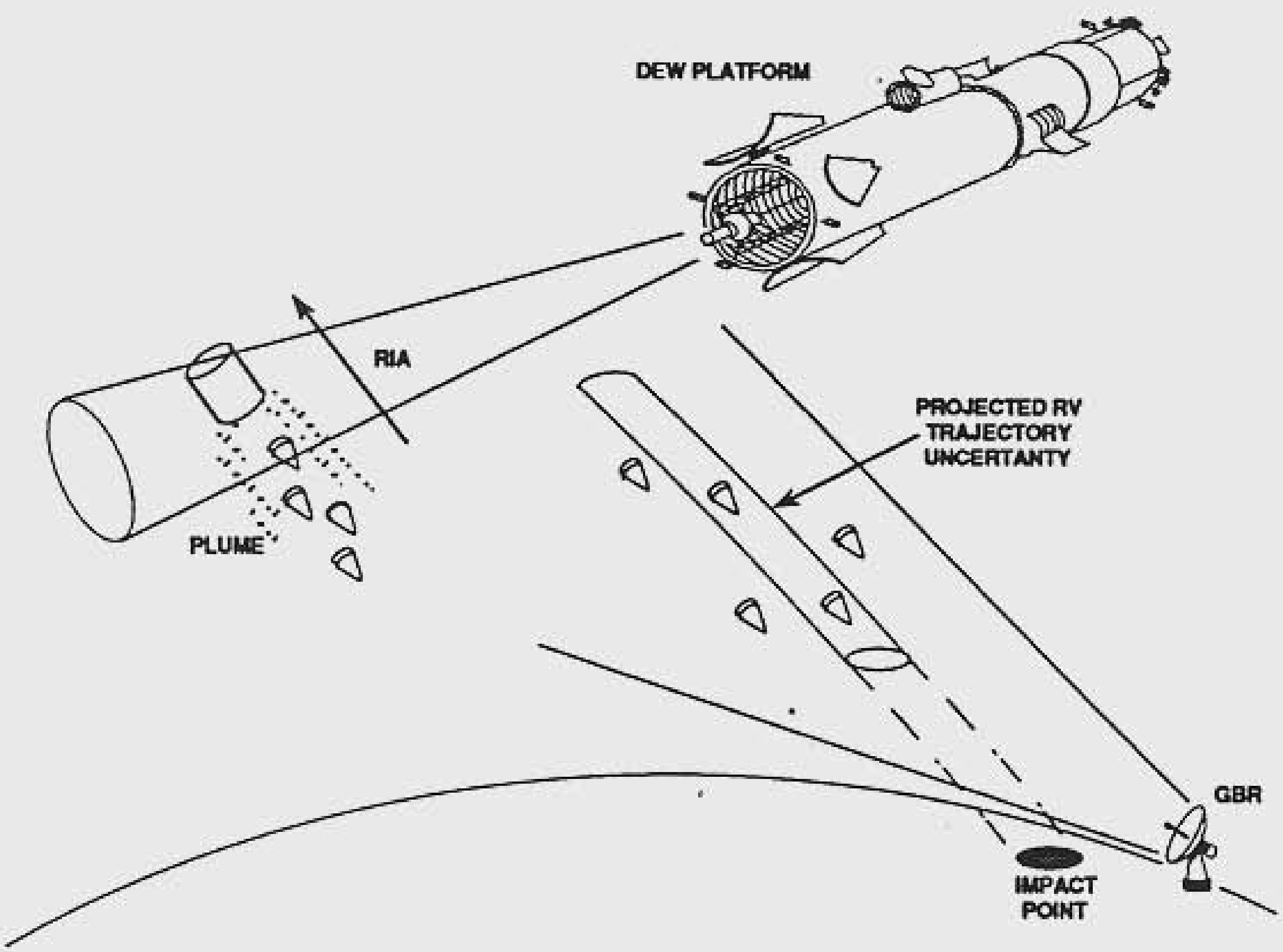
σ_v = 1σ 3-D velocity error (m/s)

N = Number of measurements

T = Total measurement time (s)

t_m = Time of last measurement

$R_p^{(t)}$ = Threat tube uncertainty



DEW ATP sensors are inherently capable of precision measurements required to discriminate midcourse objects by observing PBV maneuvers.

Figure XI: Post Boost Vehicle (PBV) Bus Tracking/Deployment Trajectory Projection--TTP, IPP, Handback

ISSUE XI. POST BOOST VEHICLE (PBV) BUS TRACKING/ DEPLOYMENT TRAJECTORY PROJECTION—TTP, IPP, HANDBACK.

Can a passive intermediate tracker, active fine tracker, and high resolution laser range finder determine the state vectors of a thrusting PBV with enough accuracy to provide

threat tube prediction (TTP),

impact point prediction (IPP), and

handback data to other weapon system platforms for reacquisition?

The ATP/FC system on a DEW platform has more than enough optical performance to expand its role from classical ATP to discrimination. In a discrimination technique known as deployment trajectory projection (see Brilliant Eyes Concept Definition), the PBV is tracked in range and angle as it thrusts along the deployment axis--also known as the range insensitive axis (RIA). Using this track file one can project ahead the position in range and angle that any object deployed by this PBV will occupy along the threat trajectory. This information can be projected ahead allowing impact point prediction. This is useful for preferential adaptive defense. Further, to the extent that decoys suffer radial displacements due to plume induced velocity perturbations that are greater than the cross range velocity measurement uncertainties, these decoys will lie outside the predicted threat tube and can be considered discriminated. After handback to other SDS systems the few targets which are still credible threats can then be subjected to midcourse interactive discrimination, terminal discrimination, or interceptor targeting. ALTAIR shall demonstrate bus tracking and deployment trajectory projection techniques and validate the sources of error in making these types of measurements.

Scalability Criteria

- *Measurement Uncertainties*. The table below indicates estimated allowable uncertainties in bus tracking measurements (position and velocity) and the resulting uncertainties in threat Tube Prediction, Impact Point Prediction, and handback vector accuracy. These values are dependent to some degree on the number of measurements, revisit interval, and total track time. They are to be used as criteria for establishing scalable performance goals for the ALTAIR experiment.

Uncertainty in Metric Discrimination Measurements

Parameter	Position Uncertainty	Velocity Uncertainty
Tracking relative measurement	In-range < 1 m Cross-range < 4 m	< 0.1 m/sec
Tracking absolute measurement	< 50 m	< 0.3 m/sec
Threat tube radius, handback vector	< 50 m + 0.3 m/sec x T T = time since last measurement	< 0.3 m/sec
Fine impact point prediction	< 330 m	--
Coarse impact point prediction	< 5 km	--
Gross impact point prediction	TBD	--
Closely Space Object discrimination	TBD	--

Traceability Criteria

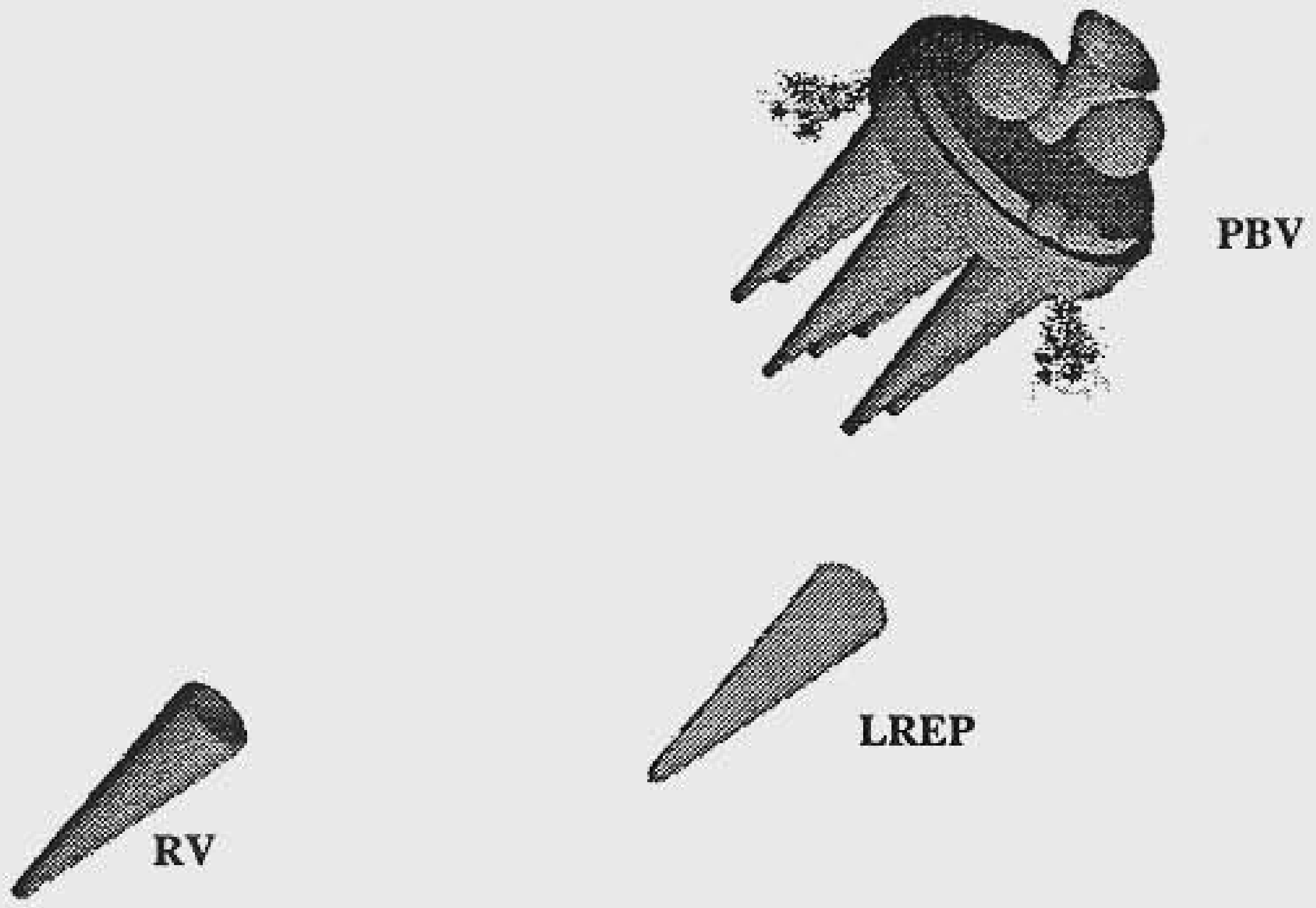
- *No Requirement for Real Time TTP, IPP, and Handback.* In the ideal case, the most traceable experiment is defined as one which generates in real time handback vectors, impact point predictions, and threat tube volumes consistent with the interface protocol established by the SDS. However, unless there is going to be a real-time demonstration of handback or metric discrimination, there is no requirement for the ALTAIR experiment to provide this information in real time.

- *Post-Mission Reconstruction.* The ALTAIR experiment shall be designed to measure all parameters required by a system concept which provides IPP, TPP, and handback to the SDS in real time; however, for the purposes of ALTAIR the experimenter may calculate IPP, TPP, and handback data files during post-mission data reduction and compare the calculations to truth data collected by other range assets. Truth data shall be collected for both the ALTAIR and target position to document the actual trajectories and vehicle dynamics during the encounter. Care must be taken to insure that all such data is referenced to a common coordinate system and time standard.

- *Experiment Configuration Option #1:* ALTAIR can measure the PBV state vector by:
    - Using an inertially referenced MWIR tracker to determine angular position of the PBV with respect to the ALTAIR satellite.

- Using high resolution laser radar to determine relative range from ALTAIR to the PBV.
- Using an inertial reference unit to determine the absolute position of the pointing platform at the time of the measurement.

- *Experiment Configuration Option #2:* ALTAIR can measure the PBV state vector by:
  - Using an inertially referenced active fine tracker to determine the angular position of the PBV with respect to the ALTAIR satellite.
  - Using high resolution laser radar to determine relative range from ALTAIR to the PBV.
  - Using an inertial reference unit to determine the absolute position of the pointing platform at the time of the measurement.



DEW ATP sensors are capable of precise measurements required to discriminate objects deployed in the midcourse phase of flight by observing the change in velocity during the deployment sequence.

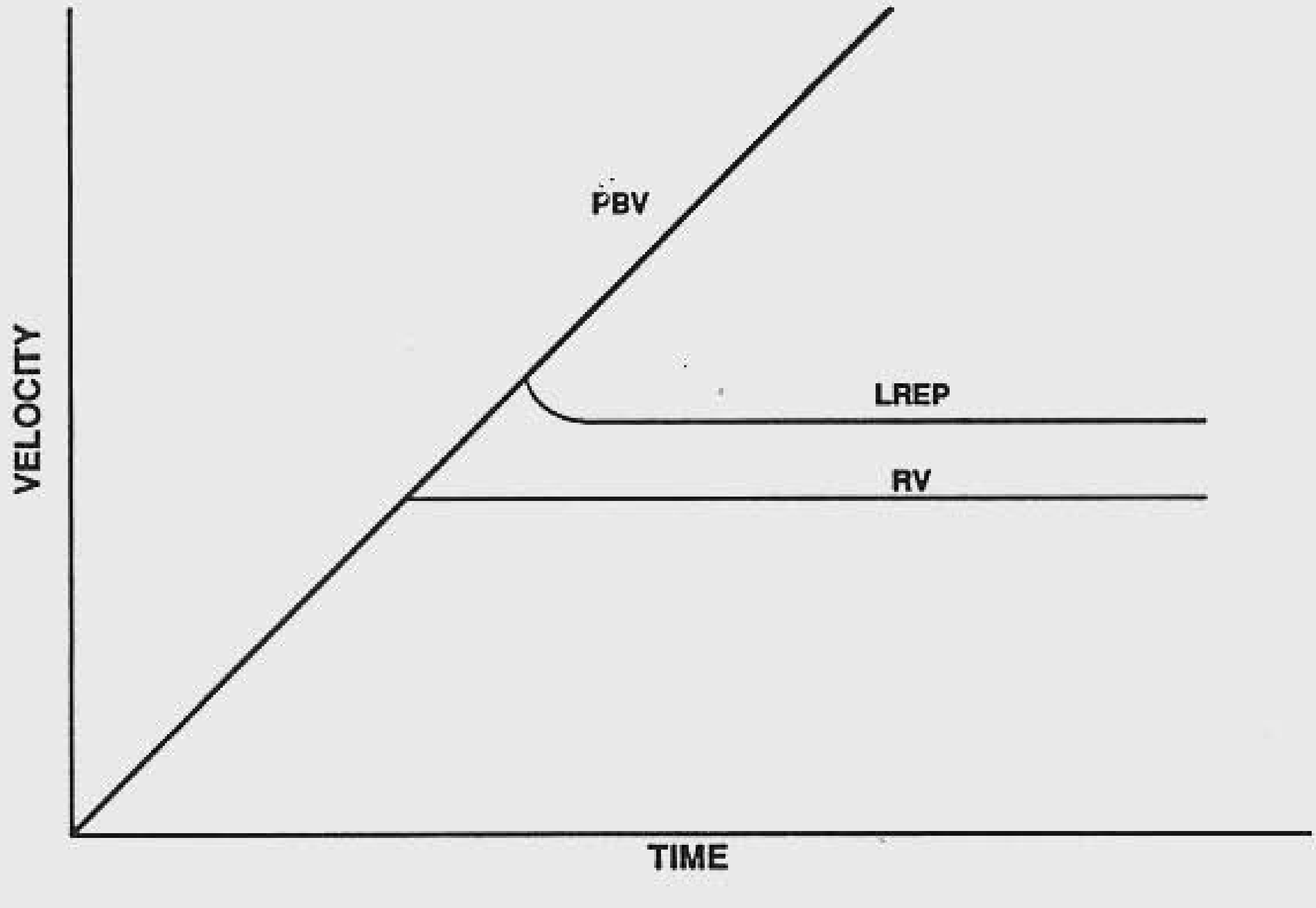


Figure XII: Post-Boost Vehicle Bus Watching/Discrimination Via Plume Perturbation--ΔV Measurement

ISSUE XII. POST-BOOST VEHICLE BUS WATCHING/DISCRIMINATION VIA PLUME PERTURBATION—ΔV MEASUREMENT

Can an active fine tracker and high resolution laser ranger measure the ΔV of a deployed object with respect to the PBV with enough accuracy to infer the mass of the ejected object?

Another type of deployment phase discrimination is known as bus watching. In this case the RV and decoys deployed by a bus are observed during deployment and the trajectory relative to the bus is measured. Light decoys are given a large axial kick by the PBV plume. By sensing this axial velocity kick a discrimination can be made at the time of deployment. This technique has the advantage of discriminating every object deployed by the bus, rather than just defining a threat volume. The price that must be paid for this more robust discriminant is that RV-sized objects must be measured, requiring a more capable laser radar than was needed to measure PBV's.

Scalability Criteria

- *Precision of ΔV measurement:* < 1 m/sec.

Traceability Criteria

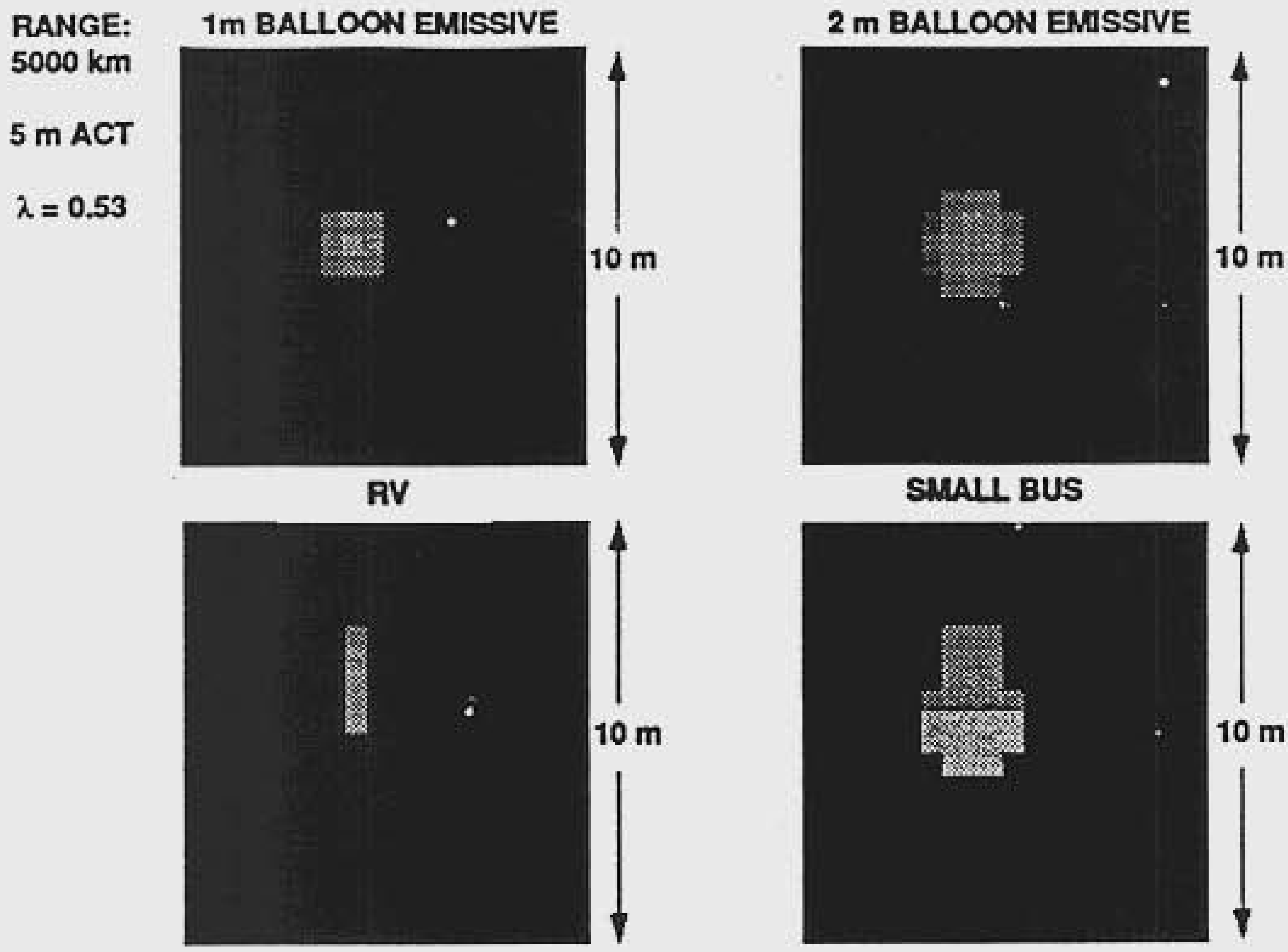
- *Measurement of Induced Velocity:* ALTAIR shall infer the plume induced ΔV by using the active fine tracker and the laser ranger to measure the deployed object trajectory relative to the PBV.

- *Down-range Displacement* of the deployed object relative to the PBV can be determined by measuring the time interval between the double pulse returns of the illuminator laser. The illuminator spot size must be sufficiently large to accommodate both objects during this measurement.

- *Cross-range Displacement* of the deployed object relative to be PBV can be determined by:

    - *Measuring the Angular Separation* between the two objects' positions with the active fine track imagery. The illuminator spot size must be sufficiently large to accommodate the two objects during this measurement.

    - *Measuring the Angular Separation* between the two objects' positions with the high resolution visible fine track imagery while operating in a wideband passive mode. There must be sufficient solar radiation to illuminate both targets for the fine tracker.



(Above) Simulated active track signatures of midcourse objects. These figures illustrate the potential performance of a visible band tracker/imager using a six-meter beam expander as the receiving aperture. (Below) Simulated passive signatures illustrating different sensor aperture diameters, target ranges and aspect angles.

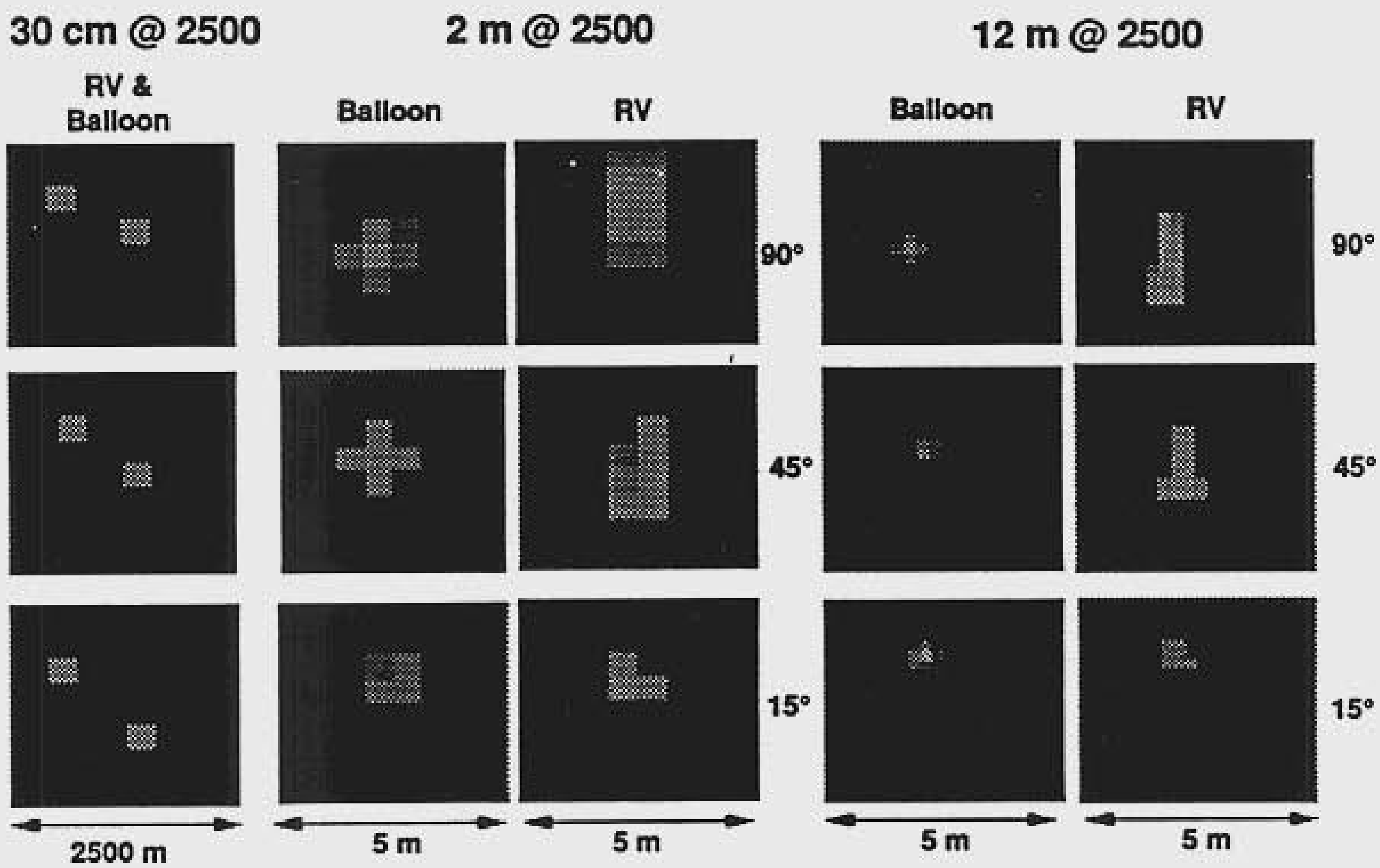


Figure XIII: Post-Boost Vehicle Bus Watching--Discriminating Observables

ISSUE XIII. POST-BOOST VEHICLE BUS WATCHING—DISCRIMINATING OBSERVABLES.

Are there discriminating features associated with either active signatures or passive UV, visible, or IR signatures which have utility in discriminating RV's from decoys?

Another type of laser radar that has been considered for discrimination is one which produces a high resolution image, just as a camera would. At sufficiently high resolution such an image could view objects being deployed by a bus and, for instance, tell the difference in size and shape between a canister and a RV. Likewise, it is conceivable that certain passive sensors can distinguish between the characteristic signatures of deploying RV's versus deploying decoys. The plume impingement dynamics may differentiate decoys from RV's; inflation signatures may identify certain decoys. A number of possibly distinguishing signature differences can be postulated; however, so little data is available from space observations of PBV deployment events that it is critical that ALTAIR make these observations.

Scalability Criteria

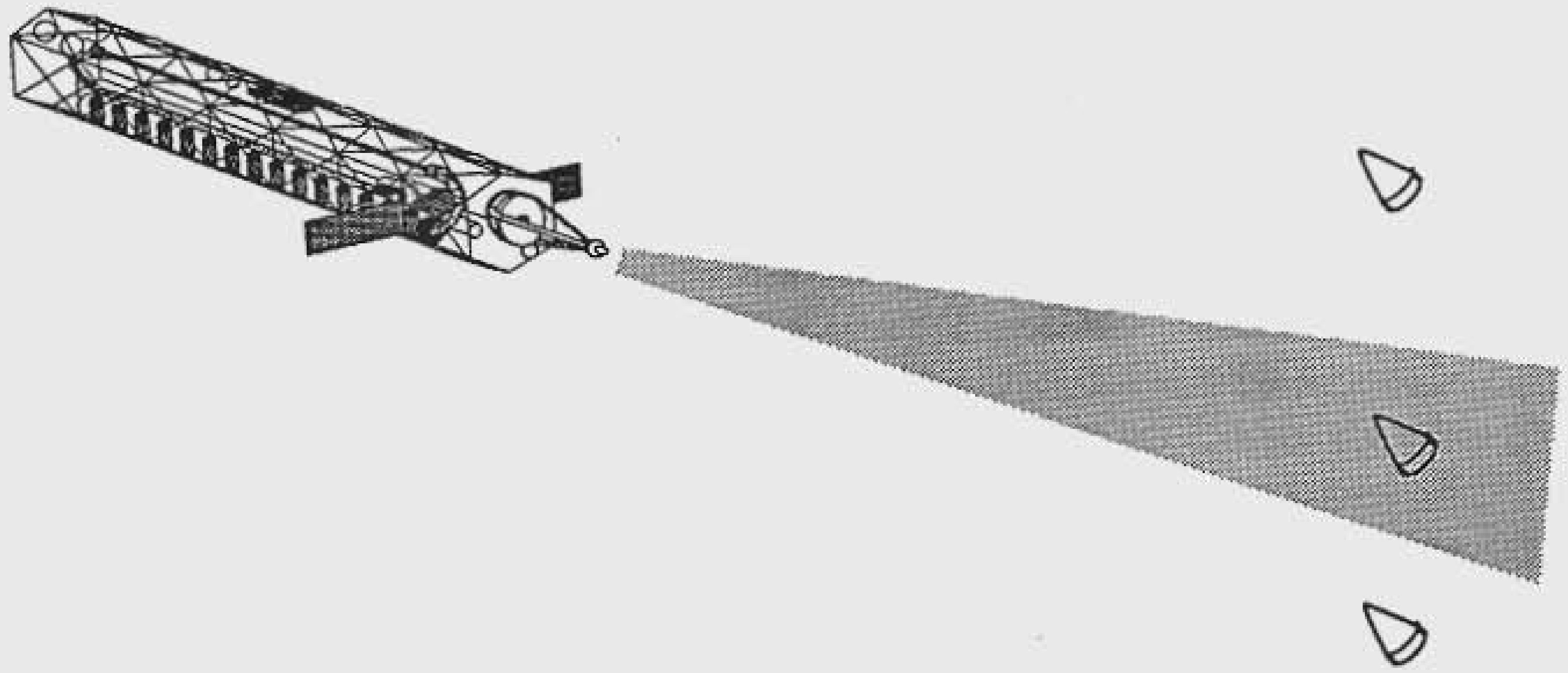
- *Resolution Scaling*. Image resolution shall be scaled in meters at the target plane.

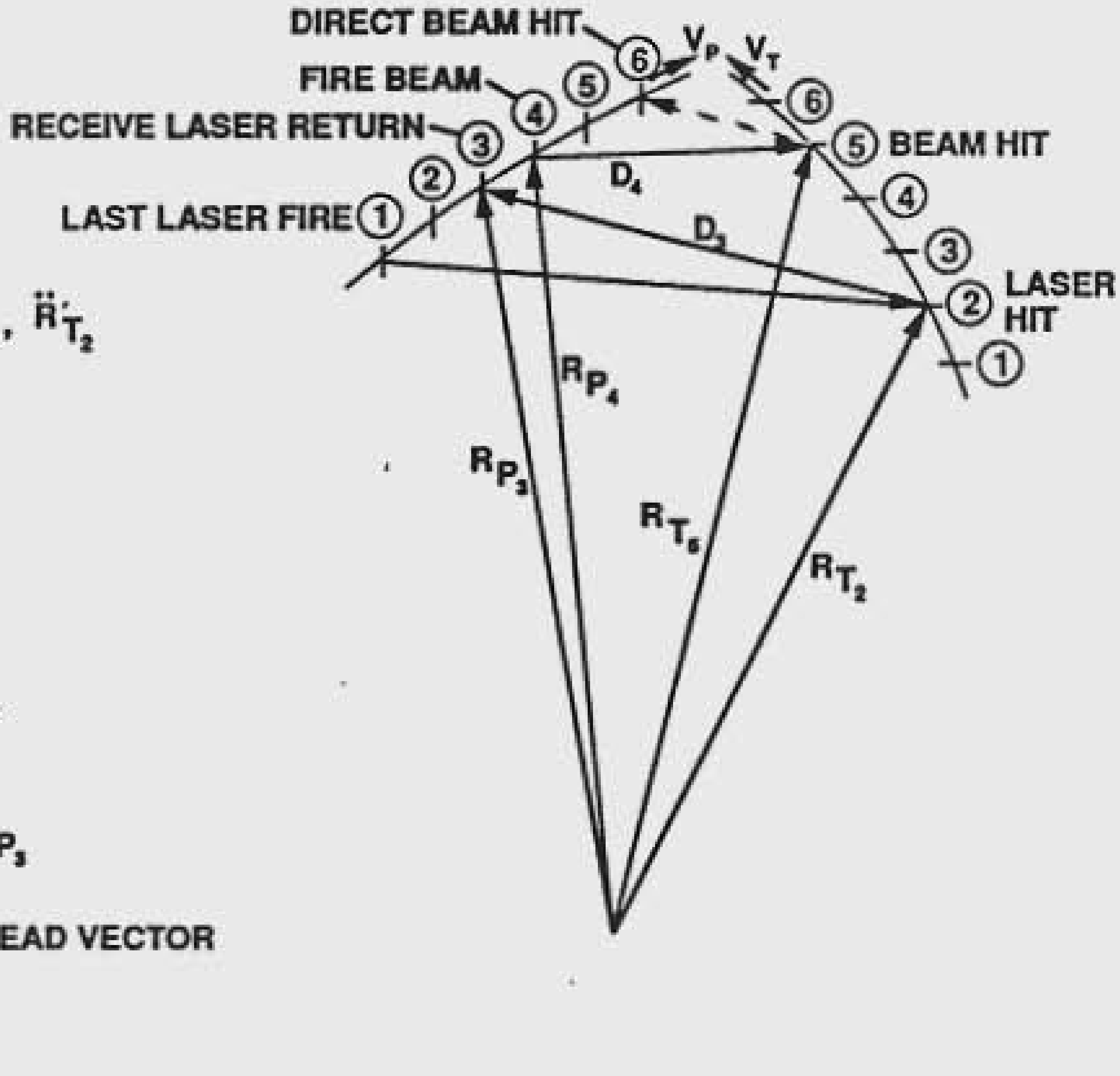
Traceability Criteria

- *Representative PBV's and Midcourse Objects* shall be observed by ALTAIR in various solar lighting conditions.

- *Multi-Wavelength Synergy*. Conduct simultaneous observations with both active and passive sensors to search for synergistic value in multi-wavelength imagery.

Multiple laser tracking pulses are used to reduce fine track errors before firing the DEW beam. However, timeline constraints dictate that only a few illuminator pulses can be used for each target. Active track signal-to-noise ratio and tracking filter design must be adequate to meet tracking accuracy and timeline constraints.





LASER ESTIMATES: R'_{T_2}, $\dot{R}'_{T_2}$, $\ddot{R}'_{T_2}$

$$t' = t_5 - t_2$$

$$= \frac{|D_3|}{c} + t_c + \frac{|D_4|}{kc}$$

$$t' \approx t_c + \frac{(k+1)}{kc}|D_3|$$

$$R'_{T_5} = R'_{T_2} + \dot{R}'_{T_2} t' + \frac{1}{2}\ddot{R}'_{T_2} t'^2$$

$$R'_{P_4} \approx R_{P_3}\cos\omega t_c + \frac{\sin\omega t_c}{\omega}\dot{R}_{P_3}$$

$$D'_4 = R'_{T_5} - R'_{P_4} = \text{POINT AHEAD VECTOR}$$

Figure XIV: Active Fine Track of Midcourse Objects

ISSUE XIV. ACTIVE FINE TRACK OF MIDCOURSE OBJECTS.

Does the reflected energy from the illumination of a midcourse object provide robust enough phenomenology to allow active tracking of the midcourse object with sufficient precision to stabilize the line-of-sight for a directed energy weapon?

Ultimate track accuracy is driven by single sample measurement error as well as the improvement in accuracy afforded by making multiple centroid measurements and processing them with an optimal track filter. Single sample measurement accuracy includes the effects of platform jitter as well as centroid estimate errors. The accuracy improves as more measurements are made and put in the track filter. Due to the large numbers of midcourse targets that must be addressed, real systems will have significant constraints on the length of time that can be spent refining a target track solution. It is necessary that ALTAIR perform fundamental measurements addressing the accuracy of active fine track of midcourse objects in order to guide the weapon system designers who are making trades between single sample accuracy and integration time.

Scalability Criteria

- *Midcourse Object Enhancement.* The type of midcourse object enhancement for the active tracker demonstration must be carefully chosen in order to retain the scalability of the single sample measurement error.

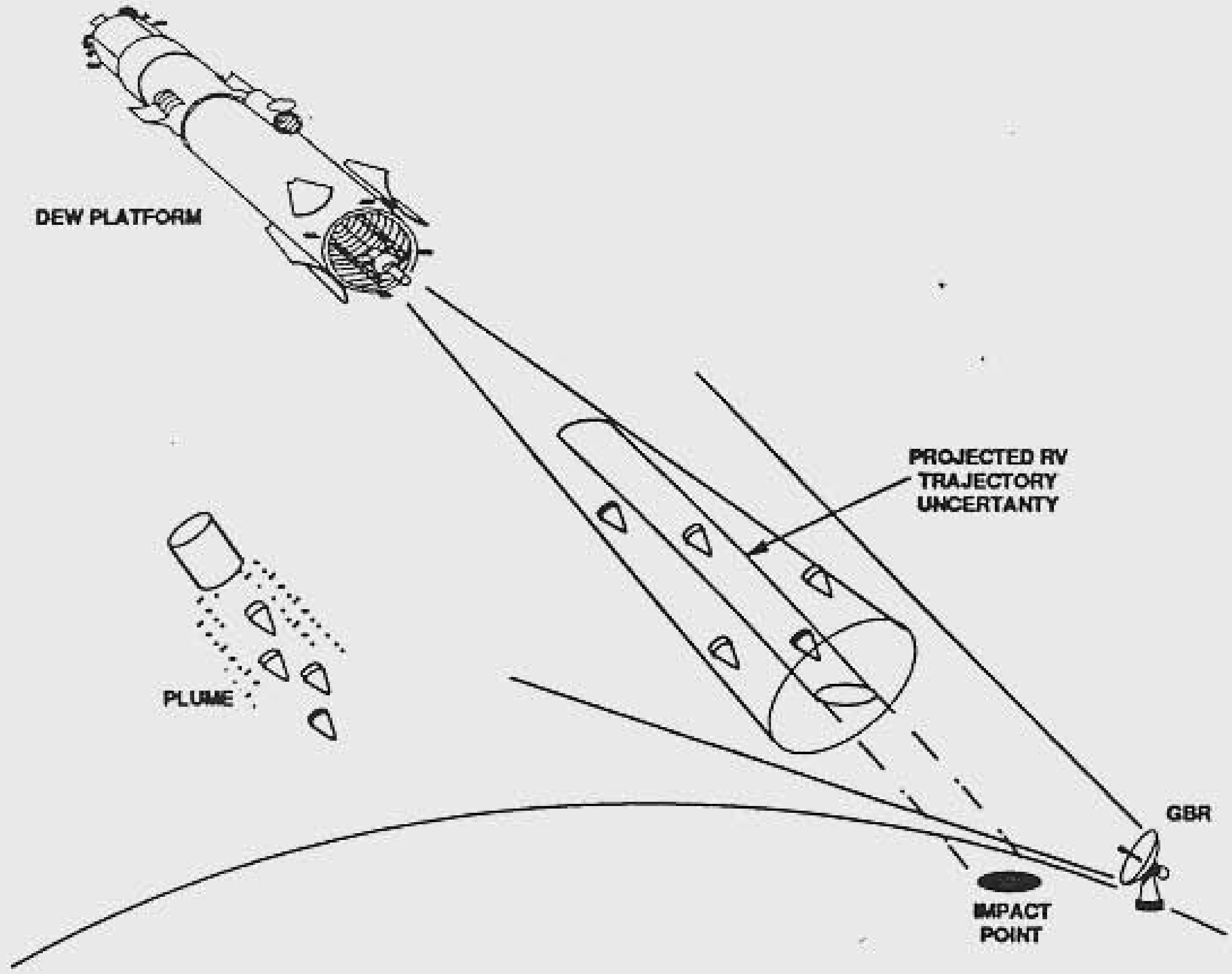
- *Kinematic Scaling and Tracker Bandwidth Scaling.* In order to scale aperture and illuminator power of the ALTAIR experiment with actual DEW systems, it is likely that the ALTAIR target encounters will be performed at significantly shorter ranges than actual DEW target encounters. Therefore, the acceleration of line-of-sight rates and the change of the acceleration of line-of-sight rate with respect to time can be more stressing on ALTAIR than on DEW concept systems. On the other hand, the latency due to the speed of light is not as stressing for the shorter range ALTAIR experiment. The experimenter must show how the tracker bandwidth as well as the platform jitter stabilization scales with these differences in slew rate dynamics and encounter geometry.

- *Active Fine Track NEA.* Consistent with ultra-low line-of-sight stabilization; consistent with precision angle-angle measurements of the target line-of-sight.

Traceability Criteria

- *Active Fine Track Supports Inertially Commanded Line-of-Sight.* For the ALTAIR experiment, precision active fine tracking shall be used to update the state vector of the midcourse target in an inertial reference system. The track file representing the target position in inertial space shall be updated by the active tracker error signals and associated image processing through a traceable Kalman filter estimator. Ultimately ALTAIR shall demonstrate precision pointing in a fashion which is traceable to the NPB midcourse pointing concept. That is, after the midcourse target has been actively tracked for a period of time sufficient to accurately update its state vector, the pointer line-of-sight will be controlled solely by inertial commands from the track file estimator instead of by tracker imagery.

- *No LWIR*. There is no requirement to provide a LWIR tracking sensor on ALTAIR for the midcourse target tracking demonstration. Midcourse target acquisition can be aided by a beacon, cornercube, or carefully chosen solar lighting conditions. ALTAIR shall perform traceable active track and laser ranging functions.



High PRF active tracking and integration over a large number of pulses can enable the DEW ATP system to achieve very small position errors for midcourse objects. (Figure below based on theoretical analysis for various cases of single sample measurement uncertainty.)

MINIMUM VARIANCE ANGULAR POSITION ERROR AT $t = t_n$
(PRF = 100 Hz)

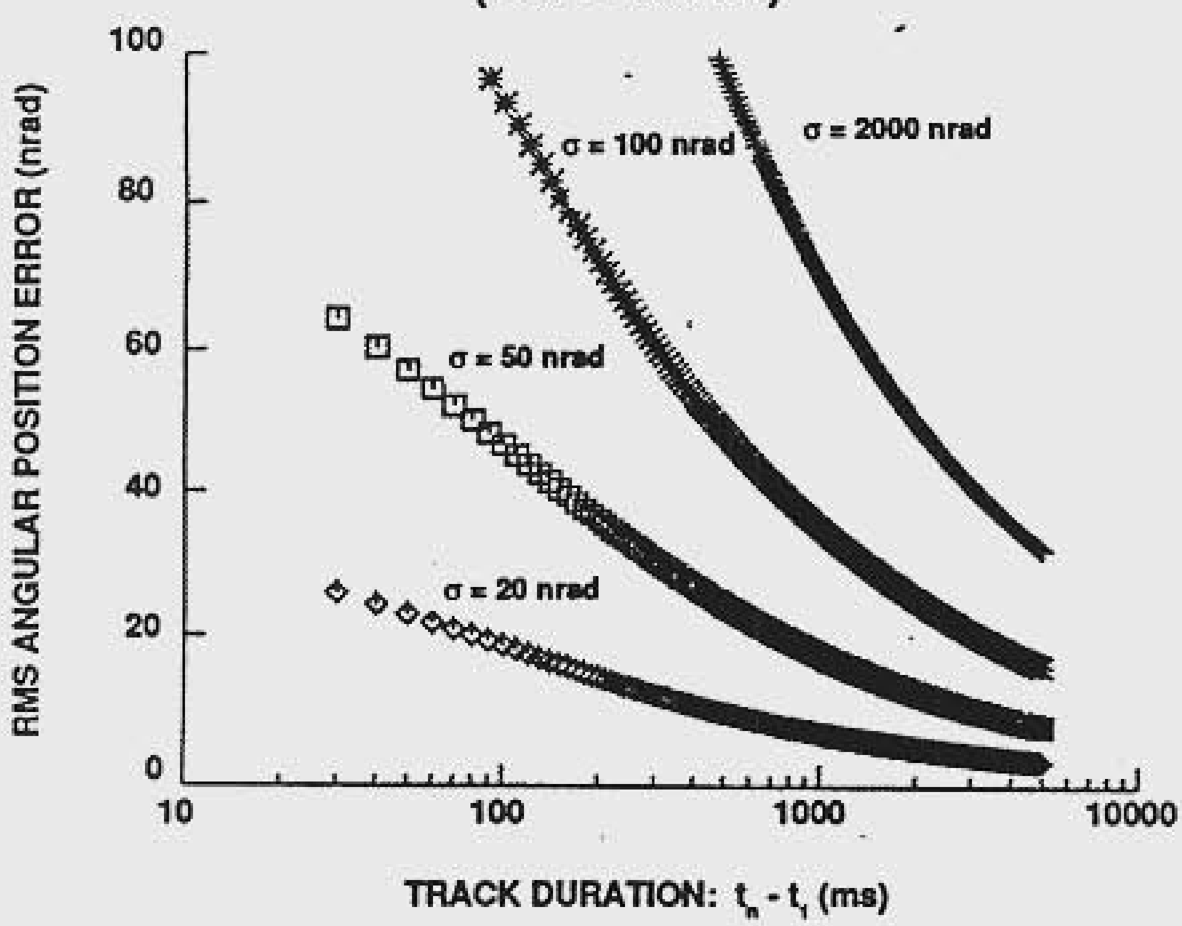


Figure XV: Midcourse Object Metric Discrimination--TTP, IPP, Handback

ISSUE XV. MID-COURSE OBJECT METRIC DISCRIMINATION—TTP, IPP, HANDBACK.

Can an active fine tracker, and high resolution laser range finder measure the midcourse object state vector with sufficient accuracy to provide

threat tube prediction,
impact point prediction, and
handback data to other SDS weapon system platforms for target reacquisition?

This issue is complementary to Issue XI. To the extent that decoys suffer radial displacements due to plume induced velocity perturbations that are greater than the uncertainty in the PBV cross-range velocity measurement made during the time of deployment, the decoys will lie outside the threat tube and theoretically can be discriminated. However, discrimination concepts which rely on deployment trajectory projection typically do not employ the metric discrimination technique until later in midcourse. The issue addressed here is the accuracy that can be achieved in making this metric discrimination measurement during midcourse. Does the achievable accuracy support TTP, IPP, or handback?

Scalability Criteria

- *Measurement Uncertainties*. The table below indicates estimated allowable uncertainties in tracking measurements (position and velocity) and the resulting uncertainties in threat tube prediction, impact point prediction, and handback vector accuracy. These values are dependent to some degree on the number of measurements, revisit interval, and total track time. They are to be used as criteria for establishing scalable performance goals for the ALTAIR experiment.

Uncertainty in Metric Discrimination Measurements

Parameter	Position Uncertainty	Velocity Uncertainty
Tracking relative measurement	In-range < 1 m Cross-range < 4 m	< 0.1 m/sec
Tracking absolute measurement	< 50 m	< 0.3 m/sec
Threat tube radius, handback vector	< 50 m + 0.3 m/sec x T T = time since last measurement	< 0.3 m/sec
Fine impact point prediction	< 330 m	--
Coarse impact point prediction	< 5 km	--
Gross impact point prediction	TBD	--
Closely Spaced Object discrimination	TBD	--

- *Target Enhancement.* The type of midcourse object enhancement for the active tracker demonstration must be carefully chosen in order to retain scalability of the single sample measurement error.

Traceability Criteria

- *No Requirement for Real Time TTP, IPP, and Handback.* In the ideal case, the most traceable experiment is defined as one which generates real time handback vectors, impact point predictions, and threat tube volumes consistent with the interface protocol established by the SDS. However, unless there is going to be a real time demonstration of handback or metric discrimination, there is no requirement for the ALTAIR experiment to provide this information in real time.

- *Post-Mission Reconstruction.* The ALTAIR experiment shall be designed to measure and record all parameters required by a system concept which provides IPP, TPP, and handback to the SDS in real time; however, for the purposes of ALTAIR it may be sufficient to calculate IPP, TPP, and handback data files during post-mission data reduction and compare the calculations to truth data collected by other range assets. Truth data shall be collected for both the ALTAIR and target position to document the actual trajectories and vehicle dynamics during the encounter. Care must be taken to insure that all such data is referenced to a common coordinate system and time standard.

- *Experiment Configuration Option #1:* ALTAIR can measure the midcourse object state vector by:

  - Using an inertially referenced visible fine tracker operating in a wideband passive mode to determine angular position of the midcourse object with respect to the ALTAIR satellite. This approach assumes proper solar lighting conditions.

  - Using high resolution laser radar to determine relative range from ALTAIR to the midcourse object.

  - Using an inertial reference unit to determine the absolute position of the pointing platform at the time of the measurement.

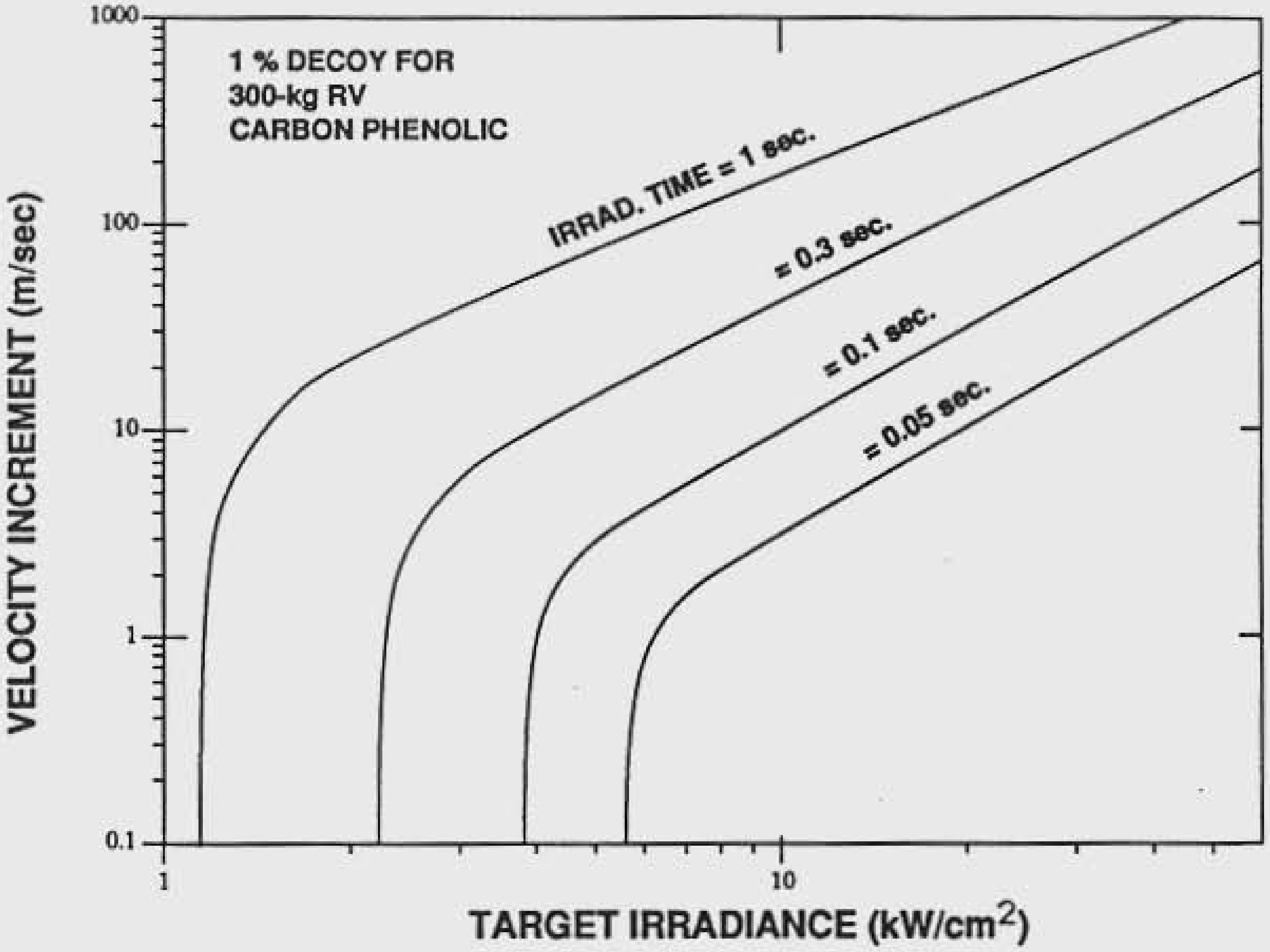
- *Experiment Configuration Option #2:* ALTAIR can measure the midcourse object state vector by:

    - Using an inertially referenced active fine tracker to determine the angular position of the midcourse object with respect to the ALTAIR satellite.

    - Using high resolution laser radar to determine relative range from ALTAIR to the midcourse object.

    - Using an inertial reference unit to determine the absolute position of the pointing platform at the time of the measurement.

- *No LWIR*. There is no requirement to provide a LWIR tracking sensor on ALTAIR for the midcourse target TTP, IPP, or handback demonstrations. Mid-course target acquisition can be aided by a beacon, cornercube, or carefully chosen solar lighting conditions. ALTAIR shall perform traceable active track and laser ranging functions.



Results of theoretical analysis of velocity increment resulting from HEL irradiation of lightweight decoys. Direct measurement of velocity changes of one to a few m/sec is required for this discrimination technique.

Figure XVI: Midcourse Object Interactive Discrimination - ΔV Approach

ISSUE XVI. MID-COURSE OBJECT INTERACTIVE DISCRIMINATION - ΔV APPROACH.

Can a direct detection laser radar measure the ΔV of a midcourse object well enough to be used in interactive discrimination?

The concept of interactive discrimination of midcourse objects by measuring momentum changes induced by high energy laser radiation depends upon the capability to measure small changes in target velocity. A demonstration of velocity measurement using active sensors will provide experimental verification of this capability.

Scalability Criteria

- *Precision of ΔV Measurement:* < ± 1 m/sec

Traceability Criteria

- *Measurement of Active Fine Track:* ALTAIR shall measure ΔV by using the active fine tracker to determine angular position of the midcourse object with respect to the ALTAIR satellite, and by using a high resolution laser radar to determine relative range from ALTAIR to the midcourse object.

IR Plume Image

UV Plume Image

Plume phenomena data is needed with spatial and spectral resolution to validate predictive codes and to develop plume-to-hardbody handover algorithms. Above: spatially resolved plumes. It is essential to establish the hardbody location with respect to plume features. Below: plume spectral data points in the UV and IR. The solid line is earth background radiance.

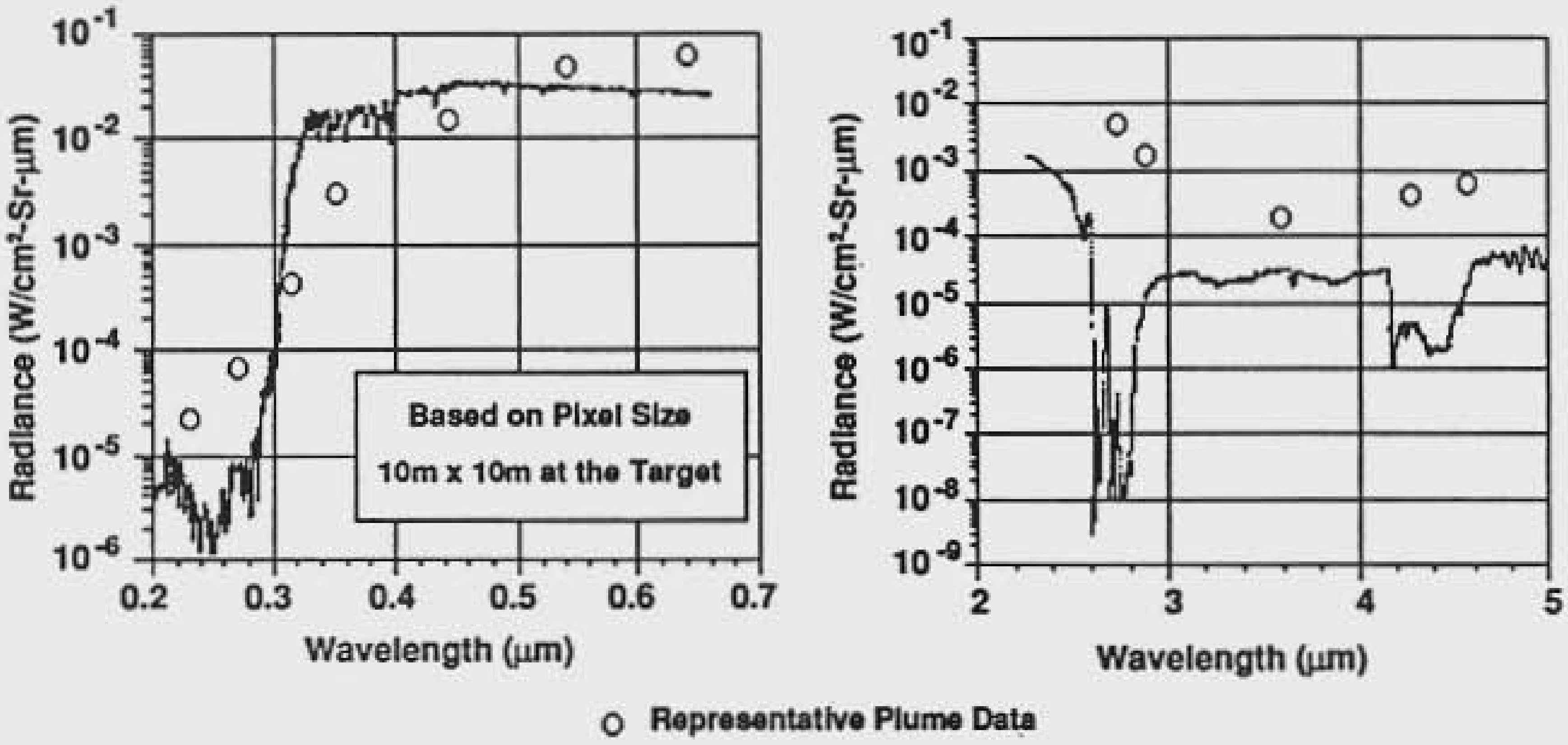


Figure XVII: Plume Phenomenology

ISSUE XVII. PLUME PHENOMENOLOGY.

Do particular bands of MWIR, SWIR, visible, or UV offer advantages for passive acquisition and precision tracking of boosters and PBV's and for accurately determining the hardbody location "relative" to the passively tracked target scene?

Understanding the spectral, spatial, and temporal character of booster and PBV plumes is critical for successful design and testing of an SDI system. Plume emissions are used to acquire, track, and locate the hardbody of a missile or PBV. The important role of plume phenomenology is clearly evident in the ATP issues already discussed. High quality plume phenomenology data is required on representative targets in the UV, visible, and IR.

The ALTAIR experiment offers the opportunity to gather passive plume phenomenology in many wavelengths while performing autonomous acquisition, tracking and pointing experiments. A variety of environmental and aspect angle variations will be encountered against target boosters and PBVs representative of the threat. Understanding the effect of these variations will help develop plume-to-hardbody handover algorithms, as well as validate plume radiance predictive computer codes which are necessary for full analyses of the variability in the expected target signatures.

The ALTAIR plume data will be used to develop and test advanced acquisition, tracking, and plume-to-hardbody handover algorithms through ground simulations. Since the ALTAIR sensors will have a known relative alignment to the active fine tracker, the actual hardbody position can be indexed to all passive cameras. In this way, analysts who use the imagery data to design hardbody handover algorithms will have truth data indicating the unambiguous position of the hardbody in reference to the plume.

Additionally, the high resolution multi-spectral plume data collected by ALTAIR will be used to verify/modify computer programs that are designed to predict plume spectral and spatial characteristics throughout the wide range of interest for a booster or a PBV encounter. The predictive models are needed to generate target signature predictions for acquisition, tracking, and fire control algorithm development. An SDI system must be capable against both current and near-term future threats. The number of possible threats and ways that an SDI element might engage it are enormous. The signatures of these threats are dependent on details of their trajectories and the angles and ranges at which observed. Confronted with this large matrix of possible engagements and targets, and our limited knowledge of both present and future threats, SDI is forced to depend heavily on simulations for testing any system. Flight tests are critical, but to insure that a system can successfully operate over the full range of situations that it might encounter, the system can only be adequately proven with simulation. In this regard, the plume models being developed by SDIO are critical.

ALTAIR shall gather high resolution imagery of the nearfield plume (i.e., the vacuum core) and the near-body, far-field plume in the subsonic and rarefied region. ALTAIR shall also gather more coarsely resolved imagery of the extended far-field where radiation is caused by the collision of atmospheric gases with the rocket exhaust. SDIO requires a limited set of space-based observations to validate our expectations of rocket plume radiance in the atmospheric absorption bands which are to be used by the operational systems.

Plume Targets

The table of ALTAIR Plume Targets indicates all classes of rocket signatures of vital interest to SDIO. The priority assessed to each target can be explained. First priority signatures correspond to threat types which represent the most direct concern to the U.S. and for which the least amount of data currently exists: large liquid ICBMs and post-boost vehicles (PBVs).

The signature of liquid fueled rockets is more stressing to model than solid rockets (particularly in the UV/visible). The signatures are largely influenced by combustion processes and atmospheric interactions for which the chemical pathways are poorly understood. The potential variablity in target signature is greater due to the various fuel types, and the sensitivity to trajectory (altitude/velocity profile) and to slight variations in rocket manufacture. The high altitude nature of large ICBM and PBV trajectories places the chemical processes in a region where a long mean-free path exists between reactants. The numerical methods for predicting chemical behavior and radiation transfer in this region are tedious and computationally intensive. The emission mechanisms are not fully understood in many spectral regions of interest.

ALTAIR PLUME TARGETS

	Priority 1A	Priority 1B		Priority 2		Priority 3	
	ICBM Liquid	PBV		ICBM Solid		IRBM Class	
Type	Amine-fueled Upper Stage	Amine-fueled Liquid	Non-Al_2O_3 Solid Gas Generator	Hydro-carbon & Double-base	Al_2O_3 Upper Stage	Liquid	Solid
Example	Titan II, Delta	MX, * Firebird, ODES	C4	Trident C4	Minute-man, MX*	Lance, Scud-like	Orbus I
Altitude	100 - 250 km	200 - 500 km		100 - 250 km		From Launch To 50 - 100 km	
Velocity	2.5 - 6 km / sec	>5 km / sec		2.5 - 6 km / sec		From Launch To 1 - 2 km / sec	
Angle-of-attack	Typical	0° - 180°		Typical		Typical	
Solar Lighting	Night	Night		Night And Day		Night And Day	
Aspect Angle	< 30° To Broadside	< 30° To Broadside		< 30° To Broadside		< 30° To Broadside	

* The MX Is The Only Non-dedicated Target Identified. The ALTAIR Payload, Spacecraft And Orbit Shall Be Designed To Acquire A Scientifically Significant Portion Of The MX PBV Plume Data

PBVs can be liquid fueled or propelled by non-aluminized solid-fuel gas generators. In either case, no data exists of sufficient spatial and spectral resolution to validate an understanding of these high altitude plume signatures. It is this high altitude, liquid plume signature of the most immediate and prevalent threat that places large liquid ICBMs and their respective PBVs at the top of the list of desired plume signatures. Of high interest are simulated PBVs such as Firebird and targets of opportunity such as the MX bus. More than one type of PBV should be observed. Velocity is an important driver for signature. There is no interest in observing a lofted trajectory of a PBV engine; for ALTAIR, velocity above 5 km/sec is required.

The next most critical signature is that of a large ICBM-class solid rocket. For ALTAIR, rockets using double-base propellants (such as the Trident) should be the highest priority solid target. Much less is understood about signatures resulting from double-base propellants than from Al_2O_3 composite propellants.

The signature of aluminized composites is of lesser priority for ALTAIR only because the dominant reaction mechanism is well-known. The signature is dominated by the intrinsic core radiance which is driven by the emission of the Al_2O_3 particles in the missile exhaust. The precise emissivity of the Al_2O_3 particles is a function of wavelength and temperature. The radiance is influenced by the total temperature of the particles and the cooling rates. The color temperature is probably near 2300°K, the temperature of molten Al_2O_3, and the relaxation or cooling is determined by the particle size distribution.

Although significant understanding of Al_2O_3 based fuels have been achieved, it remains for ALTAIR to validate the solid rocket signature at high altitude, inside the absorption bands unavailable for observation on the ground or by aircraft, and at the spatial resolution (3-6 meters) of importance to plume-to-hardbody handover algorithms. Also, since the Minuteman ICBM flies at higher velocities, more significant far-field plume interaction is expected than has been previously measured. There still remains the issue—how much influence do chemical processes (non-blackbody radiation transfer) have on the high altitude signatures of large solid rocket booster plumes. ALTAIR, properly equipped with a UV spectrometer, can provide a significant step forward in unwrapping this particular mystery for both solids and liquids.

Of course, IRBM targets are of particular interest to SDIO. The aluminum loaded solid-fuel variety as represented by Starbird are particularly well understood in the altitude regime around 60 to 100 km due to a dedicated and disciplined collection effort on 17 Dec 90. Other propellants such as hydrocarbon fuels and double-base propellants are much less understood because of our lack of understanding of the non-equilibrium processes during high pressure combustion. It is these latter propellants that are found frequently in Third World missiles. Many of the IRBMs use kerosene fuels that can form soot in a non-equilibrium process, the concentration of which depends upon the oxidizer to fuel ratio and chamber pressure. Some of the IRBMs use double base propellants or composite modified double base. Clearly, the priority of identifying U.S. analogs should be highest where our modeling capability is poorest. Many of these observations can be conducted with ground-based and aircraft sensor platforms. ALTAIR offers the opportunity to validate an understanding of low-altitude liquid rocket signatures from space. This type of collection ought to be done especially in light of SDIO's urgency regarding Global Protection Against Limited Strike.

Instrument Waveband Requirements

Specific sensor parameters for UV, visible, and IR sensors are displayed in charts accompanying this section.

IR Sensor Requirements. It is important to realize that a unique IR phenomenology sensor was not considered. This is because the basic requirements for the ATP demonstration have set certain sensor characterisitics. Phenomenology requirments can be met by proper use of either the NFOV and WFOV IR sensors. The purpose of the IR NFOV sensor from a phenomenological point of view is to resolve the extended near-field emissions in atmospheric absorption bands and near body atmospheric interactions. The instrument will also locate emission features relative to the

ALTAIR IR IMAGER REQUIREMENTS

Sensor Parameter	IR Narrow FOV			IR Wide FOV		
Waveband, Unfiltered	~2 - 5 μm*			~2 - 5 μm*		
Field-of-view At Target	At Least 500 m			At Least 5000 m		
Minimum Spatial Resolution At Target, FWHM	3-6 m			Reqmt: <100 m Desired: <50 m		
Image Frame Rate	At Tracker Rate			Eng Reqmt: At Tracker Rate Plume Science Reqmt: ≥ 5Hz		
Intrameasurement Dynamic Range	At Least 4000			Plume Science Reqmt: ≥ 1000 Background Reqmt: ≥ 4000		
Number Of Filters	8			8		
Absolute Radiometric Accuracy	±1dB (~25%)			±1dB (~25%)		
Sensitivity, W/cm² /str/μm	2.7 μm	4.3 μm	4.6 μm*	2.7 μm	4.3 μm	4.6 μm*
Titan Upperstage (Reqmt)	9×10^{-7}	3×10^{-6}	3×10^{-6}	4×10^{-8}	4×10^{-8}	4×10^{-8}
Delta II Or PBV (Goal)	3×10^{-7}	9×10^{-7}	9×10^{-7}	10^{-8}	10^{-8}	10^{-8}
Background, NEDSR****	3.8×10^{-7}**	7.5×10^{-8}**	7.5×10^{-8}**	1.5×10^{-8}***	3×10^{-9}***	3×10^{-9}***
Filter Selection	TBD	TBD	TBD	TBD	TBD	TBD

* Simultaneous SWIR And MWIR Is A Goal. Ability To Change From SWIR To MWIR Measurement In 3 sec Is Required Throughout The Engagement. A 4.6 Micron Filter Is A Goal.

** Sensitivity Calculated For Structure 200 m In Extent and No Spatial Coadding

*** Sensitivity Calculated For Structure 1 km In Extent and No Spatial Coadding

**** NEDSR Is Noise Equivalent "Delta" Spectral Radiance, I.e., The Change In Spectral Radiance That Has A S/N of 1 For The Stated Footprint.

Range To Target Is 200 To 400 km. Sensor Sensitivity And Radiometric Accuracy Shall Drive Pixel-to-pixel Uniformity, Off-axis Rejection, And Out-of-band Rejection. Pixel-to-pixel Uniformity Shall Be Known To 0.1%. Expected Fluctuation In Target Brightness Shall Drive Management Of Interscene Dynamic Range. Spectral Filters Shall Be Mechanized For Rapid Change; Less Than 1 Second For Selected Filter Transition Is Ideal For Plume Observations. Internal Calibration Sources Shall Be Considered For All FPAs missile hardbody. The purpose of the IR WFOV sensor is to resolve extended far-field emissions in the atmospheric absorption bands. Additional data will be required in order to boresight the NFOV imager to the WFOV imager so that plume features can be located absolutely.

Precise filter wavebands are TBD. At the minimum, an ability to change from SWIR to MWIR fast enough to exceed the rockets's time scale is required; hence the requirement to switch filters within 3 seconds throughout the engagement. Serious consideration should be given for separate SWIR and MWIR focal planes so that data can be taken by the two simultaneously. If there are two focal planes, there should be pixel-to-pixel registration to enable data correlation at the pixel level. This will become valuable as sensor fusion work develops.

UV Sensor Requirements. ALTAIR is necessary to measure the mid-UV signature of booster plumes since the solar-blind signature is unavailable to ground or aircraft based sensors. Presently there is no theoretical basis for relating mid-UV radiance to radiance observed in the near UV or visible. Precise filter wavebands are TBD.

ALTAIR UV IMAGER REQUIREMENTS

Sensor Parameter	UV (Without Imaging Spectrometer)		UV (With Imaging Spectrometer)	
Waveband, Unfiltered	Reqmt: .2 - .32 µm Goal: 0.15 - .32 µm		.2 - .32 µm	
Field-of-view At Target	At Least 2 km		At Least 500 m (Spectrometer Has 2 km FOV)	
Minimum Spatial Resolution At Target, FWHM	Required 10 - 30 m Desired 2 - 5 m		Required 10 - 30 m Desired 2 - 5 m	
Image Frame Rate	>1 Hz		>1 Hz	
Intrameasurement Dynamic Range (1 sec)	>100		>100	
Number Of Filters	8		8	
Absolute Radiometric Accuracy	≤ 25%		≤ 25%	
Sensitivity (30 m Footprint; 40 nm Bandwidth)	3×10^{-8} W/cm^2/str/µm		3×10^{-8} W/cm^2/str/µm	
Filter Selection	TBD		TBD	
Out Of Band Rejection	Bright Earth Target	Solid Rocket Target	Bright Earth Target	Solid Rocket Target
.3 - .34 µm	10^5	10^6	10^5	10^6
.34 - 0.7 µm	10^5	10^7	10^5	10^7
> 0.7 µm	10^6	10^8	10^6	10^8

Range To Target Is 200 To 400 km. Sensor Sensitivity And Radiometric Accuracy Shall Drive Pixel-to-pixel Uniformity, Off-axis Rejection, And Out-of-band Rejection. Pixel-to-pixel Uniformity Shall Be Known To 0.1%. Expected Fluctuation In Target Brightness Shall Drive Management Of Interscene Dynamic Range. Spectral Filters Shall Be Mechanized For Rapid Change; Less Than 1 Second For Selected Filter Transition Is Ideal For Plume Observations. Internal Calibration Sources Shall Be Considered For All FPAs. Platform Pointing Stability May Be Biggest Driver On Final System Resolution. Platform Stability Must Be Controlled To Prevent Image Smearing.

Visible Sensor Requirements are shown in the table. Filters are TBD.

ALTAIR VISIBLE IMAGER REQUIREMENTS

Sensor Parameter	NFOV (AFT)	IFOV (PIT)	WFOV (ACQ)
Waveband, Unfiltered	0.4 - 0.7 μm	Reqmt: 0.4 - 0.9 μm Goal: 0.3 - 0.9 μm	Reqmt: 0.3 - 0.7 μm Goal: 0.3 - 0.9 μm
Field-of-view At Target	Per Tracker	Per Tracker	Per Tracker
Minimum Spatial Resolution At Target, FWHM	Per Tracker	Per Tracker	Per Tracker
Image Frame Rate	At Track Rate	At Track Rate	At Track Rate
Intrameasurement Dynamic Range	≥ 200	≥ 1000 At Tracker Frame Rate	≥ 1000 In 1 sec
Number Of Filters	2	6	6
Absolute Radiometric Accuracy	≤ 25%	≤ 25%	≤ 25%
Sensitivity, $w/cm^2/str/\mu m$	TBD	Reqmt: TBD Goal*: 10^{-8} In 1 sec	Reqmt: TBD Goal*: 10^{-9} In 1 sec
Filter Selection	0.53 μm, 0.4 - 0.7 μm	TBD	TBD

*To Be Achieved In A Night Observation.

Range To Target Is 200 To 400 km. Sensor Sensitivity And Radiometric Accuracy Shall Drive Pixel-to-pixel Uniformity, Off-axis Rejection, And Out-of-band Rejection. Pixel-to-pixel Uniformity Shall Be Known To 0.1%. Expected Fluctuation In Target Brightness Shall Drive Management Of Interscene Dynamic Range. Spectral Filters Shall Be Mechanized For Rapid Change; Less Than 1 Second For Selected Filter Transition Is Ideal For Plume Observations. Internal Calibration Sources Shall Be Considered For All FPAs

Spectral Filters shall be mechanized for rapid change. There shall be less than 1 second for selected filter transitions during plume observations.

Sensor Field-of-View

The FOV is driven by competing needs: on one hand, to observe the near-field structure well enough to support plume-to-hardbody handover; on the other hand, to preserve enough FOV to observe the complete far-field interaction region in order to measure the full source of rocket plume emissions.

IR FOV. The IR FOV should be on the order of 5000 m at the target plane due to the large atmospheric interaction region.

UV FOV. The detectable size of the UV far-field region is expected to be only 2000 m, hence the smaller FOV requirement as compared to the IR sensor.

Spatial Resolution

The requirement for 3-6 meter resolution at the target plane is driven by the final use of this data—namely to improve and develop plume-to-hardbody handover algorithms. Fortunately, this resolution requirement is totally consistent with the ATP experiment which also relies on a successful plume-to-hardbody handover.

Frame Rate

From an engineering point of view, in order to understand precisely what the fire control algorithm did with the input data, it is important to record for post-mission analysis every bit-per-pixel that was processed by the tracker and plume-to-hardbody handover algorithms. Frame rate requirements for plume science are indicated on the charts and are less stressing than the ATP engineering requirements.

Intrameasurement Dynamic Range

A dynamic range of 4000 is necessary to study the nature of the extended far-field IR plume which is considerably dimmer than the vacuum core but amounts to well over half of the total plume signature due to the large volumetric size of the far-field region.

The UV sensor has smaller dynamic range requirement: greater than 100.

The expected fluctuation in target brightness shall drive the management of interscene dynamic range.

Sensor Sensitivities

The sensitivities required for each sensor are based totally on expected target signatures. In all cases, the signature was driven by the relatively dim signature of a second stage liquid booster or PBV.

Radiometric Accuracy

An absolute radiometric accuracy of 25% is required. Together with the sensitivity requirements, this accuracy should drive pixel-to-pixel uniformity, off-axis rejection, and out-of-band rejection. Pixel-to-pixel uniformity shall be known to 0.1% for all sensors. Flat field internal calibration sources shall be considered for all FPAs in order to achieve the 25% accuracy. As a matter of fact, flat field internal calibration sources may also be needed for the ATP algorithms to compensate for non-uniformity.

UV Spectrometer

The UV spectrometer is necessary for a full understanding of the source of radiance from the UV portion of the plume. 10 Angstroms of resolution was judged adequate to provide identification of species causing the UV radiation.

ALTAIR UV SPECTROGRAPH REQUIREMENTS

Sensor Parameters	
Wavelength Coverage	.15 - .35 μm
Field-of-view At Target	At Least 2 km
Minimum Spatial Resolution (For Imaging Spectrograph)	As Available, Goal: 200 m
Measurement Time To Achieve Sensitivity Specified	5 sec
Intrameasurement Dynamic Range	≥100
Spectral Resolution *	≤10Å
Absolute Radiometric Accuracy (At 100 Photoelectron Counts)	≤25%
Sensitivity (At 10 Photoelectron Counts)	Reqmt: 10 W/str/μm Goal: 1 W/str/μm

* Spectral Bin Size Should Be On The Order Of 1/5 Of The Spectral Resolution.

Range To Target Is 200 - 400 km. Sensor Sensitivity And Radiometric Accuracy Shall Drive Pixel-to-pixel Uniformity, Off-axis Rejection, And Out-of-band Rejection. Expected Fluctuation In Target Brightness Shall Drive Management Of Interscene Dynamic Range. Platform Pointing Stability Must Be Controlled To Prevent Image Smearing

The FOV of the spectrometer should match the FOV of the imager so that images can be matched to their spectral content. However, if an imaging spectrometer is possible, the FOV of the spectrometer can be increased to approximately 2 km. This increased spectrometer FOV will permit a finer resolution for the UV imager as indicated on the attached instrument requirement tables. The finer UV imager resolution will aid the development of plume-to-hardbody handover algorithms which use the phenomenology inherent in the UV waveband.

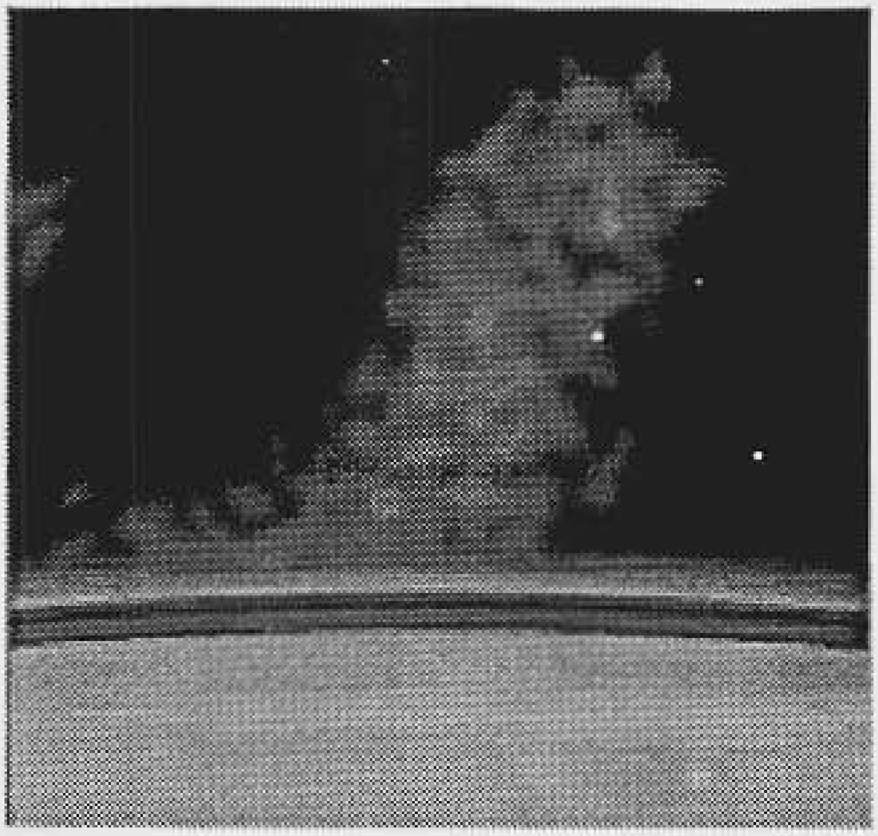
Data Recording Devices

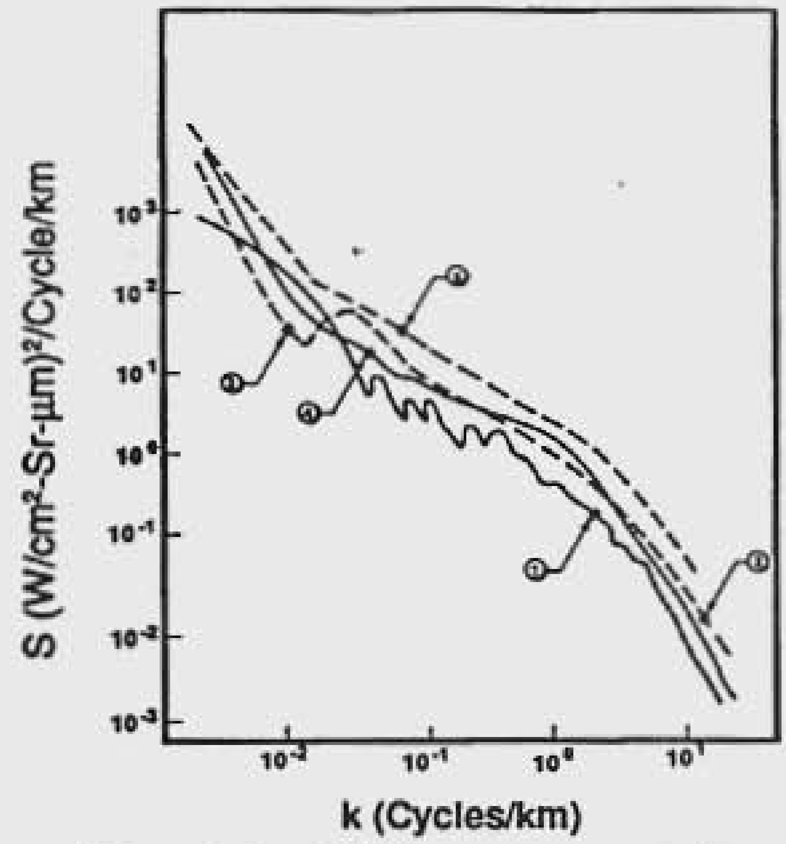
The importance placed on phenomenology data has implications on the type of data recording devices used. The imagery channels must be recorded on some high bandwidth medium that preserves the fidelity of the data as it comes from the sensor. Ideally this recording system should be digital with adequate bits per pixel to preserve the dynamic range of the original signal. If data compression techniques are used, then the experimenter should be very careful not to limit the utility of the data for these three purposes:

- To provide radiometrically calibrated data to validate plume signature predictions.
- To provide target/background imagery that can be used by tracker algorithm developers on the ground.
- To measure and validate tracker performance (i.e., NEA).

High Bandwidth Measurements

Consideration should be given to providing a high bandwidth radiometer to measure the high frequency fluctuation of plume radiance. No spatial resolution would be required for this measurement. Measurement bandwidth of at least 1000 Hz and as much as 10,000 Hz would provide a signal which could be used to correlate exhaust signature fluctuation with structural resonances. Such a signal could be useful in typing the target and thereby aiding threat warning and attack assessment.





Three illustrations of the background clutter issue. Above left: DEW sensors must view targets against hard Earth, Earthlimb, and space backgrounds. Each has complex spectral and spatial features. Above right: Example of hard earth background clutter Weiner spectrum characteristics in the CO_2 band (4.1-4.5 μm). The curves are spatial power spectral densities for different types of terrain and percent cloud cover (from the DARPA Background Measurements Program, 1976). Below: Mean earth background radiance in the ultraviolet under average maximum and minimum conditions (Based on article in "Handbook of Geophysics and the Space Environment", AFGL, 1985, by Robert E. Huffman, PL/GP/LIM).

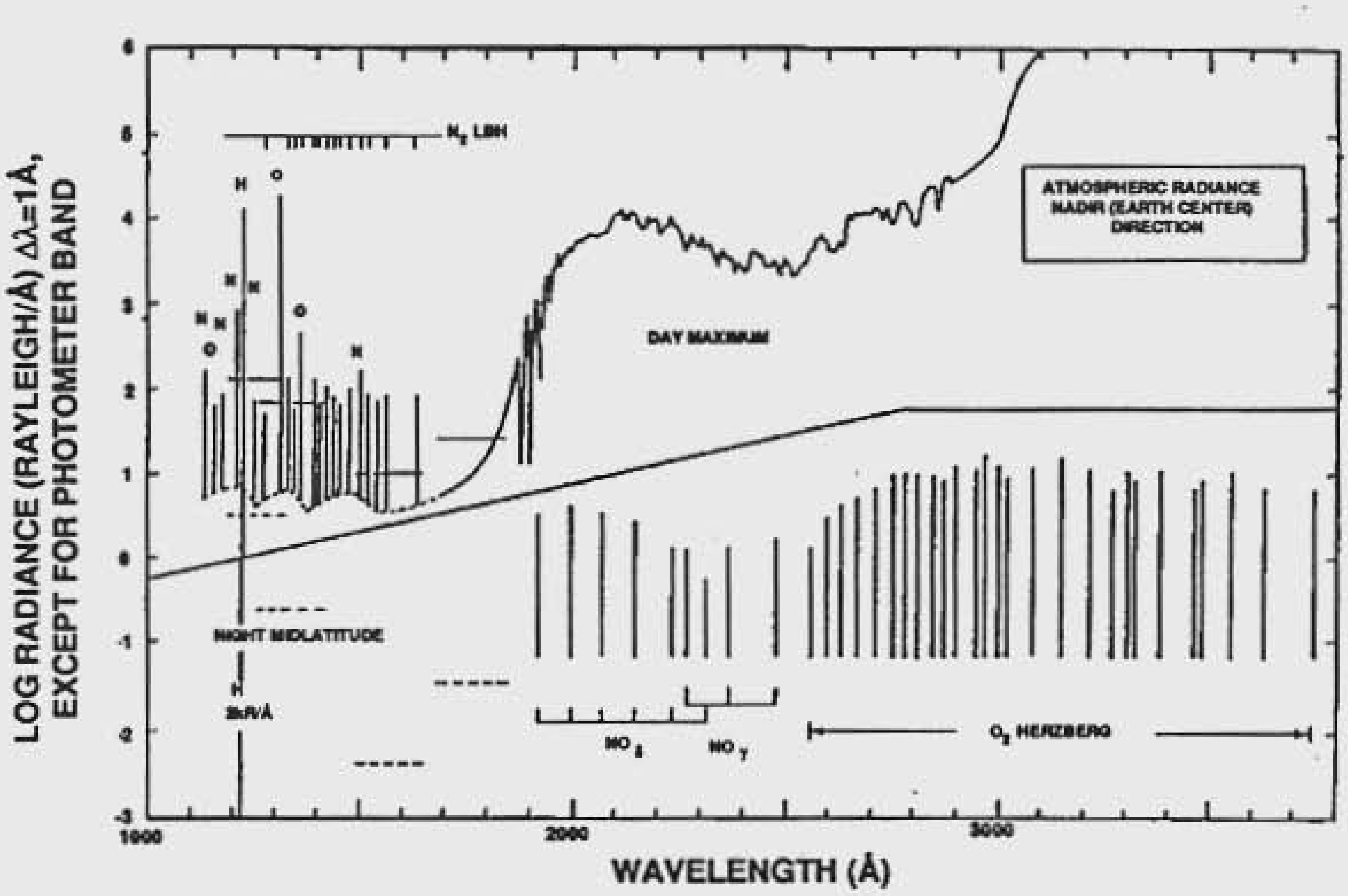


Figure XVIII: Background Radiance

ISSUE XVIII. BACKGROUND CLUTTER.

Do particular bands of SWIR, MWIR, Visible, or UV offer advantages in reducing background clutter for acquisition and tracking systems for DEW systems?

The ability to detect and track a target against a structured background[1] is fundamental to all layers of a strategic defense system. For some scenarios, the structured background is earth limb or celestial sphere. However, virtually every sensor concept contemplated by SDIO will require the acquisition and tracking of potentially dim targets against the hard earth or low earth limb background; DEW platforms are an obvious example. Target phenomenology, along with assumed characteristics of the background structure, have led most concepts for the boost and post-boost tiers to certain bandpasses in the SWIR (2.7 micron) and MWIR (4.3 micron). The background radiance in these wavebands is reduced due to atmospheric absorption at 2.7 microns by H_2O and at 4.3 microns by CO_2. The solar blind UV region is also assumed to offer the advantage of reduced earth background clutter, although in this waveband the target phenomenology is far more speculative.

In order to increase the signal-to-background ratio, acquisition and tracker systems will rely on a variety of potential background suppression algorithms. The most simple algorithm subtracts the constant DC value of the background. What's left is background clutter. The driving issue with any sensor concept that involves tracking targets against a structured background is the clutter leakage. In particular, if the target signal is low enough to be of the same order of magnitude as the signals induced by background clutter, simple target acquisition and tracking schemes will no longer be useful, and very sophisticated signal processing techniques must be applied with the concomitant heavy computing loads.

Therefore, any determination of the minimum detectable target requires background data in candidate spectral bands at appropriate levels of sensitivity and spatial frequency. Knowledge of the background structure is critical for the determination of sensor design variables such as spectral bandpass, footprint, modulation transfer function, detector sensitivity and cooling scheme, array design, etc., as well as the signal processing schemes, required on-board processing, down-link capability, and the like. Some of these variables can with proper selection have a critical impact on the overall cost, weight, and performance of the system. The ability of a space-based IR or UV

[1] Important papers regarding background data requirements and data collection techniques that should influence ALTAIR's background program include:

Simmons, F.S., *Infrared Background Data Requirements for Performance Evaluation of Earth-Viewing Sensors*, Aerospace Report No. TOR-0089(4091-01)-1, 18 July 1989.

Meng, C.I. and O'Neil, R.R., *Earth Limb and Auroral Backgrounds—Contributions to the MSX Science Modeling Requirements Document*, Johns Hopkins University/Applied Physics Laboratory and Geophysics Laboratory/Hanscom Air Force Base Report, October 1990.

sensor to detect upper stages and PBVs against hard earth or low earth limb backgrounds is currently in question due to the lack of such data.

System design for DEW, KEW, and TW/AA systems is proceeding on the basis of some very thin assumptions regarding SWIR and MWIR earth backgrounds at the appropriate spectral bandpasses, sensitivities, spatial resolutions, and dynamic ranges. The current database is sparse or even non-existant. In the critical SWIR and MWIR bands, data cannot be collected from aircraft due to atmospheric absorption and the requirement to collect data above the highest clouds and in all weather conditions. Thus, in these spectral regions space-based sensors are required. The same may be said for the solar blind UV region.

The most interesting aspect of the backgrounds data will be the possibility of obtaining clutter data. A number of analysis techniques will be used to identify the level of background clutter and its effect on false alarm rates, tracker noise, and the degree of sophistication needed by clutter suppression algorithms. Among other techniques, analysts will compute power spectral densities using the ALTAIR obtained background data.

There are four factors governing sensor specifications for earth background measurements: spectral bands, footprint, sensitivity, and dynamic range. Detailed sensor requirements are provided in charts included in Issue XVII, Plume Phenomenology.

Spectral Bandpass

Spectral bandpass is a key determinant of the amount of clutter leakage a sensor will yield. In atmospheric absorption regions it is generally desirable to operate in as wide a bandpass as possible to maximize signal, without going so far over the band edge that the sensor begins to view the lower atmospheric (or perhaps ground) structure. Thus, spectral distribution of the background signal is required for efficient and effective sensor design.

Infrared Background Data. Data is desired at about 1 part in 300 in the SWIR, and 1 part in 500 in the MWIR. In the MWIR, the blue cutoff is sharply defined at 4.21 micron, and a sequence of filters ranging in the red from 4.31 micron out to 4.38 micron will see structure at varying altitudes. In the SWIR, a filter wheel that allows sampling of at least 2 points on the band edges at 2.7 micron and 2.76 micron, and 2 or 3 points at the 2.8 micron edge, would be adequate. In both the SWIR and MWIR the detailed specification of the filters are TBD.

Ultraviolet Background Data. There is a background associated with every target measurement, of course, but many of the targets will be at night, where the background will be very small. In the course of the mission, dedicated backgrounds measurements on a noninterference basis will be done, primarily in the daytime and using pointing directions in the earth limb, which are the stressing cases for backgrounds. Briefly, UV backgrounds are due to airglow, aurora, and scattering. They are completely different in altitude of emission and character from IR backgrounds, since they all originate between roughly 20 and 200 km in the atmosphere. Staring scans, if done using the excellent pointing and tracking of ALTAIR, will be to look at specific tangent altitudes rather than at ground targets. Thus, separate staring experiments for the UV and the IR will be necessary. The most interesting aspect of the backgrounds data will be the possibility of obtaining clutter data.

The current range of the UV camera is from 200 to about 350 nm. Consideration should be given to obtaining measurements at shorter wavelengths (i.e., down to 150 nm) both for target and background reasons. There are missile plume target emissions in this region known from previous measurements. Briefly, the situation appears to be that solids give considerably lower target emissions at the shorter wavelengths. Liquids, which can provide emissions lower than solids in the UV, have poorly understood emissions at wavelengths below 200 nm. There is little actual data on plume signatures below 200 nm.

The backgrounds, however, are much different, with the radiance values at wavelengths shorter than 200 nm being several hundred times less than in the 200 to 300 nm region in the daytime. While all UV backgrounds tend to be small, there could be great advantages in using the low background region centered at about 155 nm to detect weak targets such as liquids in the daytime. In order to validate these desirable properties, the necessary measurements must be made.

Visible Background Data. There is the least interest in gaining new information in the visible because of the wealth of understanding accumulated over the years. The predominant advantage to the visible detectors for background measurements is to record the cloud and auroral structure during IR and UV background measurements. For this purpose, the sensor resolution should be at least as good as the WFOV IR (x 1/2 would be better).

Footprint

Sensor footprint (IFOV) at the earth is critical, in that clutter at spatial scales of the same order of magnitude as the operational sensor footprint will contribute to the false alarm rate. Given current surveillance and KEW system concepts, it is unlikely that sensor footprints on the ground of less than 50 m will occur operationally. Kinetic kill vehicle concepts such as Brilliant Pebbles may have footprints on the ground ranging from 100 m to several hundred meters. Surveillance and tracking systems can be expected to have footprints on the ground ranging from between several hundred to a few thousand meters. Thus, from a strictly operational perspective it is required that background variations at spatial scales from 50 m to 2000+ m be measured. It is highly desirable that the collected data overlap with the existing database, in particular the data collected by the RM-19 sensor, which was only able to measure clutter at spatial frequencies less than about 1 cycle/km.

The high spatial frequency requirement implies a sensor footprint of 50 m or less nadir viewing on the ground, and a frame rate such that image blur due to sensor motion negligibly impacts sensor MTF. Furthermore, it is required that two-dimensional data be collected at the spatial scales of interest; this implies a cross-track total footprint of about 5 km (e.g. about 100 pixel array). Of course, it is easy to measure arbitrary small in-track spatial frequencies.

Current DEW system concepts call for sensor footprints of the passive intermediate tracker to be less than 10 m at the target plane. Similar footprints on the ground will occur operationally. Therefore, the measurable background clutter that can exist above the sensor noise at these spatial resolutions is especially interesting to the high resolution sensors that will be used on DEW systems.

Sensitivity Criteria

In order to properly design a background measurement experiment the expected target signatures must be considered. In the MWIR emissions at altitudes above about 150 km are dominated by the vacuum core; values can range from as low as 300 W/str-micron for small (i.e., 1000 lbf thrust UDMH/NTO) PBV engines to 100 kW/str-micron for large upper stages. (These numbers assume a 100 m x 100 m footprint at the target.) Thus, if we assume thresholds will be set to about 1/2 minimum signal level, clutter statistics down to intensities of about 150 W/str-μm are of interest to the systems designer at the relevant footprints. Since the data collection sensor must be able to clearly classify a signal as a real variation in the background rather than sensor noise, the noise performance of the MWIR sensor should be about 30 W/str-micron.

The sensor sensitivity (specified in the ALTAIR IR Imager Requirements table in the previous section) is a noise equivalent "delta" spectral radiance (NEDSR) that has a S/N of 1. Spread over a 1 km x 1 km footprint, the 30 W/str/μm target intensity implies a NEDSR of 3×10^{-9} W/cm^2/str/μm for the WFOV sensor. Spread over a 200 m x 200 m footprint, 30 W/str/μm implies a NEDSR of 7.5×10^{-8} W/cm^2/str/μm for the NFOV sensor.

Certain advantages can be realized if the full sensitivity enhancement from spatial coadding (or super pixel processing) is permitted by the sensor design. In this case, the per pixel NEDSR can be degraded by $(N^2)^{1/2}$ where N is the number of subpixels along a single dimension of the super-pixel. For example, if the WFOV sensor has a 50 m pixel footprint at nadir, then a NEDSR of 3×10^{-9} W/cm^2/str/μm can be realized over a region that is 1000 m x 1000 m (20 x 20 pixels) in extent, if a per pixel NEDSR of $3 \times 10^{-9} \times 20 = 6 \times 10^{-8}$ W/cm²/str/μm is achieved over a 50 m x 50 m pixel.

If it is desirable to detect cold targets in the MWIR against the hard earth, the data collection requirement will be much more difficult to meet. A system requirement to detect a 10 m² target at 300° K implies a background measurement sensor with a noise limit of better than 0.1 W/str-micron.

In the SWIR, the upper stage plume will always be an extended source (aside from an extremely dim vacuum core). Assuming a nominal 100m x 100m footprint at the target, the brightest pixel can yield signals as low as about 1.5 kW/str-μm (we consider here target altitudes below 300 km as being representative of cases where the earth background will be an issue in this spectral region) for a small (e.g. PBV-class) motor to as high as 40,000 kW/str-μm for large ICBM boosters at cloud break. Thus, following the same logic as before, a sensor noise figure of less than about 150 W/str-μm is required in this band. The SWIR NEDSR (reported in the ALTAIR IR Imager Requirements table) was calculated using the same logic as for the MWIR specifications.

Dynamic Range

The dynamic range requirement for IR background measurements is quite high. The most stressing background radiance before background subtraction can be orders of magnitude higher than the minimum acceptable target noise equivalent radiance. For both the NFOV and WFOV IR sensors, a dynamic range of 4000 is required.

The dynamic range requirements for visible background measurements is less: 1000. Due to the very low expected UV background, UV dynamic range requirements for background measurements are set at 100.

Scene Priorities

Auroral Activity and CO_2 Concentrations. The MWIR spectral regions being considered are dominated by the CO_2 absorption in the atmosphere. By appropriate selection of spectral bandpass (and hence selection of the depth in the atmosphere the sensor can see), and because of the more uniform distribution of CO_2 in the atmosphere than of H_2O, it is assumed that benign background conditions will hold. However, several mechanisms have been proposed that can cause clutter significant to sensors designed to detect the relatively dim targets (e.g., upper stages, PBVs) for which an MWIR bandpass would be used. In particular, exitation pathways are known to exist for the 4.3 micron CO_2 emissions that have as their origin the continuous, and fluctuating, solar wind. Although clutter due to this process can be expected to be always present in the higher latitudes, its extreme manifestation is in Class III auroras, where observed variations in the 4.3 micron emissions (and, it should be noted, in NO-gamma solar blind UV emissions) would render tracking of even bright targets inoperative. Most of the solar electron flux occurs in the auroral oval even under "quiescent" conditions. The most significant spatial structure is known to occur primarily in the northern most portion of the oval. Thus, high latitude coverage (above 60°N) is a requirement. Furthermore, the essential three dimensional character of the background structure implies that the clutter as viewed from nadir can be very different from that at other grazing angles. Thus, near nadir measurements are required, and therefore, orbital inclinations of greater than 60° are required.

Cloud Structure and H_2O Concentrations. As noted earlier, clutter in the SWIR will usually be driven by cloud structure, since H_20 absorption limits the depth in the atmosphere that can be seen by the sensor in this spectral region. However, in high northern latitudes (i.e. greater than about 60°N) the H_20 concentration may be very low, with significant amounts confined to low altitude (<5 km); the time of year is a critical factor. Under these conditions a sensor operating in the SWIR may see sunlight reflected off terrain features. Indeed, even in regions where H_20 concentrations are nominal solar glints off water or ice can be significant; naturally, this is a very strong function of sensor bandpass. Aside from the variability in H_20 atmospheric absorption, the type and amount of cloud cover varies with latitudes and time of year. Thus it is required that background data be collected at high latitudes, at least greater than 60° and preferably 75°. In order to collect this data at all grazing angles, a high inclination orbit is called for (i.e., greater than 60°). Lower inclination orbits will be unable to collect high latitude data at high grazing angles (i.e. near nadir). If we assume that the grazing angle variability of the measured background does not begin to behave in an anomalous fashion (i.e. other than simple foreshortening) until grazing angles of less than about 45°, lower inclination orbits can be satisfactory. It is important to realize, however, that the notion of extrapolating nadir-viewing background behavior from data collected at even moderate deviations from nadir is at best intuitive, and not backed up by any data.

Line-of-Sight Geometry. An operational sensor will view the earth at grazing angles ranging anywhere from 90° (i.e. nadir viewing) to 0° (i.e. horizon viewing). The very limited database suggests that both the intensity and the spatial structure of the background may not be a simple function of grazing angle. Variations in grazing angle are important since clutter is inherently a three-dimensional problem. Oblique angles are necessary to see the striations in the radiance structure as a function of tangent height. The nadir shot acts to integrate the intensity from a number of stacked striations. Both patterns need to be collected since the background phenomenologists are uncertain if the nadir shot will validate an understanding of oblique views, or if oblique views will validate the nadir view.

Additional IR Scene Priorities. In addition to the priorities mentioned above, scene priorities that should be considered by the ALTAIR experiment designers include:

- Any background condition representative of threat corridors. In fact this priority should especially motivate the higher latitude observations articulated above.
- Solar specular regions are particularly stressing due to their high radiance
- Regions of high clouds are also stressing due to their high radiance
- Terminator crossings
- Land-sea interfaces
- Clear line-of-sight, structured terrain
- Uniform cloud decks
- Clear line-of-sight, open seas
- Various nighttime scenes

Additional UV Scene Priorities:

- Polar limb regions
- Auroral regions
- Polar mesospheric clouds
- Temperate limb regions
- Polar nadir regions
- Temperate nadir regions
- Ozone holes
- Uplooking celestial backgrounds

Modes of Data Collection

Fixed Point Stare or Step-Stare. In this mode of background data collection, the line-of-sight is locked at a selected inertial point and a series of frames collected. Ideally, the footprint does not move. The amount of time for collecting the frames is driven by the pointing accuracy which affects image smearing and the distortion of the varying lines-of-sight which causes the scene to foreshorten with spacecraft motion. After each data collection, the spacecraft is stepped to the next inertial point—hence the term step-stare. The step-stare mode is preferable in that as spectral filters are sequenced, variations due to changing viewing angles are apt to be less significant than those due to changes in the scene structure. The spectral filters should be sequenced at maximum rate in the step-stare mode to cover the candidate wavebands in the SWIR, MWIR, UV, and visible. Space background should be observed in each collection period to facilitate fixed pattern removal. The experiment designer should seriously consider providing an internal flat field calibration source for each sensor in order to compensate for FPA non-uniformities.

Pushbroom Scan. The other mode for background data collection is the pushbroom mode. In this mode the line-of-sight is fixed at a certain nadir angle so the footprint velocity will equal the orbital velocity. Here the image is smeared during the frame time by the velocity of the satellite. For example, a 1/30 second frame time from an 8 km/sec satellite will result in a minimum of a 266 meter footprint.

Other Ground Rules for Scene Selection. Data collections should proceed with repetitive observations to provide statistical variations in each category. Near real time assessments of data quality and quantity should govern proceeding to lower priority scenes. As well, initial results might dictate emphasis on data collection in certain wavebands. This methodology should be relaxed only if necessary to obtain sample data in each category.

EXPERIMENT PHILOSOPHY

ALTAIR is fundamentally both an experiment and a demonstration. To provide mission success, a proper balance must be achieved for each of these important purposes. On one hand ALTAIR must collect the scientific and engineering data required to answer feasibility questions. On the other hand ALTAIR will demonstrate critical ATP/FC functions *for the first time!*

As an experiment[1] ALTAIR shall be principally dedicated to answering critical questions regarding the feasibility of target acquisition, precision tracking, and beam pointing for DEW systems. Mission success requires that the fundamental target encounter data required to substantively answer the critical questions be obtained, recorded, and transmitted to the ground for analysis. The fundamental data of concern is *target imagery* essential to the performance of acquisition, tracking, and fire control, as well as, *control system instrumentation* essential to the understanding of precision closed-loop tracking, beam pointing, and ultra-low line-of-sight stabilization.

ALTAIR is also a demonstration[2] in space of current ATP/FC concepts for DEW applications. The experiment designers must be realistic and mindful of the technical risk of demonstrating the essential functions of ALTAIR:

- High resolution passive tracking
- Plume-to-hardbody handover
- Illuminator pointing and handover to a narrow field-of-view active fine tracker
- Discrimination of a hardbody in the presence of the plume
- Active fine tracking
- Aimpoint selection
- Precision point-ahead for the marker beam
- Beam jitter stabilization while tracking an accelerating target

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[1]An *experiment* is an action, operation, or process used to discover something not yet known, to evaluate the validity of a hypothesis, or to test the efficacy of something previously untried.

[2]A *demonstration* is any action, operation, or process employed to prove an idea or illustrate system performance through practical application, exemplification, or evidence.

These functions have *never* been attempted in space and have *never* been demonstrated by a completely integrated system with the accuracy and precision required by ALTAIR. It is therefore imperative that the risk associated with the demonstration aspects of ALTAIR be managed in such a way that ALTAIR is assured of collecting the span of fundamental data paramount for mission success.

As much as possible, ALTAIR shall be simple in design, clean and robust in operation. Because feasibility is the central issue, success can not be completely dependent on a full-up autonomous demonstration, for instance. Neither can mission success be dependent on a series of uncertain, high-risk events. The experiment should be robust and redundant against failure modes, contain sufficient back-up capability to cope with uncertainty, and be planned for a logical build-up from simple tests to more sophisticated experiments.

The Role of System Engineering in Risk Management

The ALTAIR experiment shall be managed with the highest standard of system engineering. This discipline requires that mathematical models be developed and validated in order to predict the expected outcome of experiments, as well as to explain the results of each experiment. Only in this way can it be understood why the system works the way it does. The reason for this level of concern is quite simple. In order to solve unexpected glitches on-orbit, the experiment team will depend on a full system understanding as embodied in the mathematical model or computer simulation. This tool must be fine-tuned and validated during ground system tests to be useful for operational troubleshooting.

A disciplined approach to error budgeting shall be implemented. In order to achieve the required pointing jitter accuracies, care must be taken in minimizing the error due to a wide variety of noise sources including tracker noise, alignment system noise, point-ahead errors, as well as the jitter measurement system itself. The experiment will be most successful if no single noise or error source is so large that it swamps the remaining error sources. It is necessary that a careful accounting of error sources and their effect on line-of-sight jitter be made all the way through the design, fabrication, component testing, ground system testing, and finally on-orbit testing. In order to understand the final outcome of the experiment, each source of error shall be properly instrumented so that its constituent value can be observed independently from the rest of the sources of error. In addition, arrangements shall be made to apply coherence analysis techniques to understand the cause and effect relationships between observed jitter and its root source. The base motion and environmental disturbances that affect the ATP experiment must be instrumented with a precision that exceeds the jitter goal.

Sensor Characterization and Calibration

It is essential that the sensor systems used as trackers be well-characterized. Furthermore, the sensors must be calibrated so that a true radiometric and spatial understanding of the target signature can be made. In a large way ALTAIR is really an imagery experiment. The nature of the plume as manifested in tracker imagery will have a great deal to do with the performance of the tracker and the fire control algorithms, and the success in isolating the target hardbody from the brighter plume. Experimental discipline requires that five things are necessary for each imager and optical sensor:

- A report that consolidates in one place all the characterization and calibration data taken for each sensor during component tests, subsystem tests, and end-to-end system tests. The characterization data should address topics such as dark current subtraction, interpixel response, pixel-to-pixel uniformity, amplitude linearity, point spread function, dynamic range, mechanical obscuration effects, persistence effects, spectral response variations, out-of-band response, polarization effects, and off-axis rejection.

- Each sensor system end-to-end noise equivalent performance in terms of noise equivalent spectral radiance (NESR) for extended targets (in units of $w/cm^2/str/micron$) and noise equivalent spectral intensity (NESI) for point sources (in units of W/str/micron). The noise equivalent system performance must account for the entire optical system from the entrance aperture to the focal plane array or quad cell. The filter selection as well as the background emissions from warm optics must be considered in reporting this sensitivity.

- Calibration procedures to be performed on-orbit to correct for day-to-day drift, temperature variations, and sensor aging effects so that absolute radiometric precision is achieved.

- A methodology for converting raw data to radiometrically calibrated data. A description of the methodology should provide the parametric equations for this conversion as well as specify how each parameter value is derived either from test data or suitable calculation. An uncertainty should be calculated for the calibrated output.

- Internal calibration sources shall be considered for all FPAs in order to achieve the desired radiometric measurement uncertainty of 25%.

The experiment executing agents shall be responsible to data users for calibration. To assist that end, the subcontractors who developed the sensor systems should be responsible to the experiment executing agent for providing the characterization report inputs and calibration methodology. Ideally, the sensor vendors should be full partners with the analysis team in validating the correctness of the calibrated output post-mission.

Plume Phenomenology

As a consequence of the stable line-of-sight achievable with ALTAIR's trackers, the high resolution of the ALTAIR sensors can be utilized without the usual concern of image smearing during camera gate times. ALTAIR can answer critical questions concerning both passive and active signatures of plumes and hardbodies.

This importance placed on phenomenology data has implications on the type of data recording devices used. The imagery channels must be recorded on some high bandwidth medium that preserves the fidelity of the data as it comes from the sensor. Ideally this recording system should be digital with adequate bits per pixel to preserve the dynamic range of the original signal. If data compression techniques are used, then the experimenter should be very careful not to limit the utility of the data for these three purposes:

- To provide radiometrically calibrated data to validate plume signature predictions.
- To provide target/background imagery that can be used by advanced tracker algorithm developers on the ground.
- To measure and validate tracker performance (i.e., NEA).

Target Representivity

ALTAIR was originally envisioned as a free-flyer experiment to be traceable and scalable to the acquisition, tracking, and pointing concepts of interest to DEW systems. To that end, the ATP/FC experiment should address post-boost and midcourse phases, as well as boost phase which was the sole emphasis of the Starlab program. Both space-based laser and neutral particle beam concepts rely heavily on an ATP/FC subsystem during each of these target phases.

The experiment team shall pay careful attention to detail when choosing test targets (boosters, PBV's, and midcourse objects). The targets do not necessarily have to be exact replicas. However, the targets must represent in a scalable fashion the specific features which affect the performance of the function being demonstrated or the critical issue being addressed.

Traceability and Scalability

The experiment does not require each hardware component or system function be identical to current DEW system specifications. For cost reasons as well as performance limitations it may be appropriate to use equipment that is generally available in order to execute the experiment. However, for the experiment to be useful, the system functions must be *traceable* to DEW system architecture and the performance must be *scalable* to DEW system requirements.

Traceability means that the functions, methods, and design approach demonstrated in the experiment are relevant and transferable to proposed DEW system designs in a fashion that critical technical issues are resolved for weapon prototype designers. The functions and configurations should "look like" operational systems.

Scalability means that the appropriate engineering parameters that measure system performance, size, and rates are in the correct ratio with respect to actual DEW system requirements. Scalability is an essential quality for traceable experiments whose hardware does not match the "dimensions" or specifications expected in a prototype DEW system. Scalable results allow weapon prototype designers to extrapolate the ALTAIR experiment parameters and measured performance to DEW system requirements via well-understood relationships.

Considerable discussion of traceability and scalability is provided in the **Critical Questions and Technical Issues** Section. Appendix C provides additional information in chart form showing the relationship of all traceability and scalability criteria to the appropriate critical technical issue.

The Need for Space Experiments

Key ATP experiments must be performed in space in order to satisfy concerns regarding the effects of the space and upper atmospheric environment on a ballistic missile engagement. The unique conditions presented in space (micro-gravity, hard vacuum, etc.) dictate the design specifications of traceable ATP concepts, because the weapons must ultimately operate in space. Proper determination of the effects of jitter, for example, depends upon the realistic response of optical systems to their movement in space. These movements are affected by the micro-gravity environment which imposes different frictional loads than a 1-g environment and therefore different base motion processes than can be reasonably simulated in ground laboratories.

Only space can effectively replicate the range and dynamics of an actual engagement. The long ranges to the target are unaffected by atmospheric attenuation and turbulence. This long range vacuum line-of-sight is necessary for properly measuring the tiny residual pointing errors without corruption from atmospheric disturbances. Especially critical to pointing performance is the high relative crossing velocity between the target and the space weapon. Due to the finite velocity of light , the outgoing laser tracker beam must lead the tracking line-of-sight by up to 60 microradians for a nominal crossing velocity of 9 km/sec. It's unclear how such crossing velocities could be simulated in a ground laboratory for a fully integrated weapon system demonstrator. Similarly, other factors, such as beam propagation to the target, are affected by engagement kinematics characterized by long distances, vacuum, and atmospheric conditions. Many of these factors cannot be simulated in a laboratory without substantial cost and technical compromise.

Data gathering experiments also require space deployment to assess the correct phenomenology. Only a space engagement presents the appropriate target and background environment to the optical sensor. The characterization of high altitude missile plumes, and the backgrounds against which they will be measured, is essential for the development of targeting algorithms. Due to atmospheric transmission losses in the IR and UV this task can be achieved accurately only by recording the phenomena from space. In addition the signature associated with rocket plumes varies with rocket altitude, casting doubts on the utility of low-altitude ground measurements for use in predicting high-altitude (>30 km) plume characteristics. Certainly the transient phenomena associated with rocket staging, PBV maneuvering, and midcourse object ejection can only be observed with high resolution, high SNR sensors from space-based platforms.

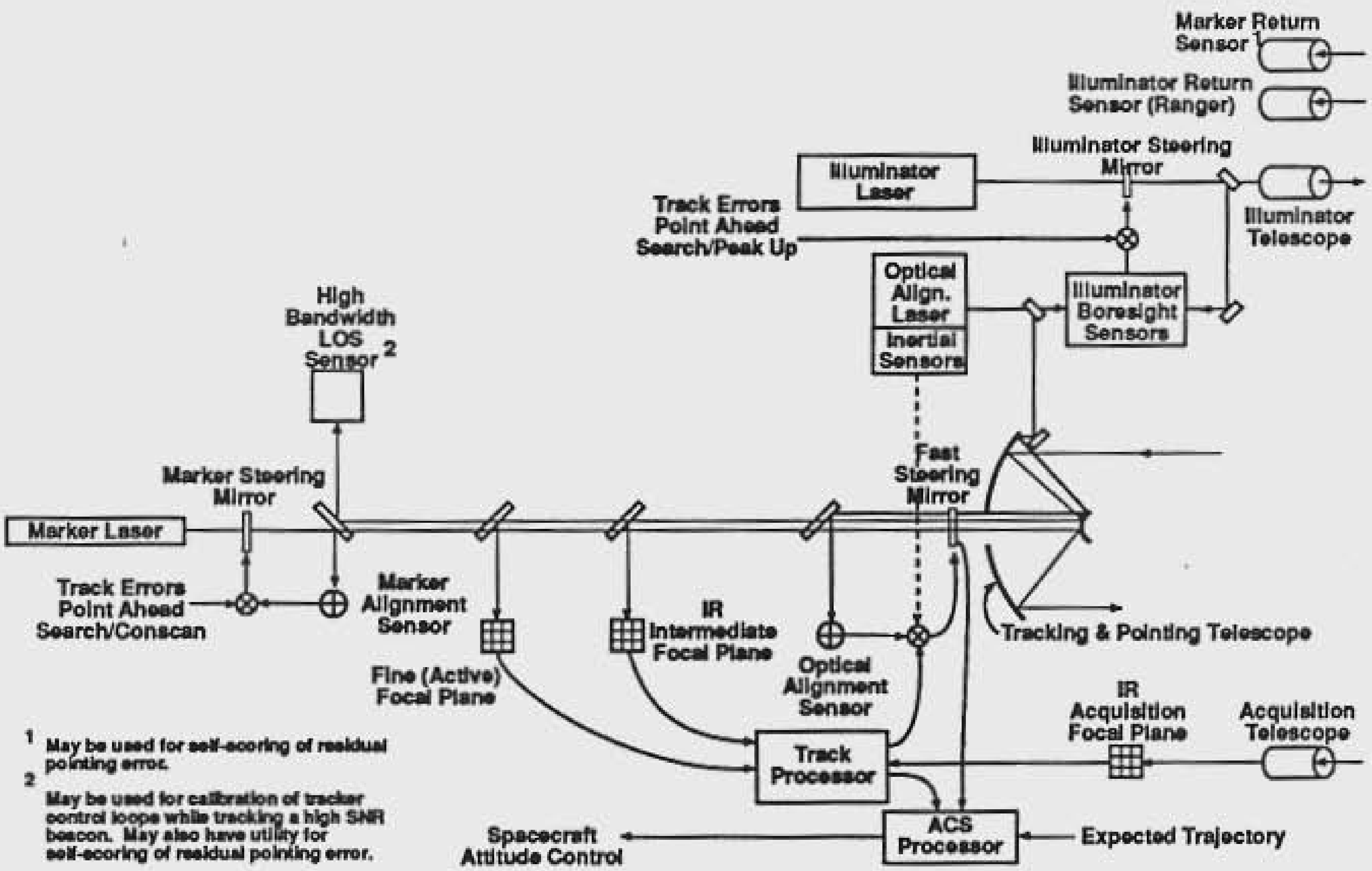
For purposes of handover experiments, the resolution at the target plane is critical for exercising the algorithms against the expected spatial patterns. Testing the algorithms and techniques for handover is a critical space issue because the information processing and pointing control are interactive and so dependent on the actual scene information.

When these factors are considered together, it is apparent that we need a space experiment to validate our current understanding of ATP/FC design tools and technology. ALTAIR addresses many of the key items which require space testing and has been chosen as the next logical step in establishing confidence in ATP/FC feasibility for DEW.

APPENDIX A

NOTIONAL OPTICAL DIAGRAM FOR ALTAIR EXPERIMENT

NOTIONAL OPTICAL DIAGRAM FOR ALTAIR EXPERIMENT



1 May be used for self-scoring of residual pointing error.

2 May be used for calibration of tracker control loops while tracking a high SNR beacon. May also have utility for self-scoring of residual pointing error.

The optical diagram provides only a notional concept for ALTAIR's optical lay-out. The purpose of the diagram is to identify hardware units that have been referred to in the text of the *Experiment Planning Document* and show the function of these units in the context of the experiment system.

APPENDIX B

SCALING RELATIONSHIPS

Appearing in appendix B is a compiled listing of relevant parameters and scalability relationships that describe the sensor elements of a typical DEW ATP subsystem. Appendix B is intended to be an initial exercise in identifying and characterizing the scalability of select portions of an acquisition, tracking and pointing subsystem. This effort should ultimately lend itself to defining a set of sensor parameters for the ALTAIR experiment. Having defined the ALTAIR sensor parameters in accordance with a set of scalability criteria, the experiment's performance and size will be in the correct ratio with respect to actual DEW system requirements. The major emphasis at this point is on attempting to plan the ALTAIR experiment with enough foresight so that at the program's completion there remain no unresolved issues regarding scalability and traceability thus minimizing the need for further experimentation. Additionally, appendix B contains a matrix which further illustrates the relationships between the ATP sensor characteristics and the hierarchical system modes.

Table B-1. ATP Sensor Scaling Relationships

SYSTEM CHARACTERISITC	SCALING RELATIONSHIP	RANGE K	SBL [1]	NPB [1]	ALTAIR
ACQUISITION TRACK					
- System NEA, NEA_{ACQ}	$NEA_{ACQ} = K_{A1} P_{ACQ}$	$.1 < K_{A1} < .3$	K_{A1}	K_{A1}	K_{A1}
- Sensor Resolution, r_{ACQ}	$r_{ACQ} = K_{A2} r_{PIT}$	$10 < K_{A2} < 100$	K_{A2}	K_{A2}	K_{A2}
- Sensor Pixel, P_{ACQ}	$P_{ACQ} = K_{A3} r_{ACQ}$	$.5 < K_{A3} < 1$	K_{A3}	K_{A3}	K_{A3}
- SNR_{ACQ}	$SNR_{ACQ} = 10 K_{A4}$	$.6 < K_{A4} < 1$	K_{A4}	K_{A4}	K_{A4}
PASSIVE INTER-MEDIATE TRACK					
- System NEA, NEA_{PIT}	$NEA_{PIT} = K_{I1} P_{PIT}$	$.1 < K_{I1} < .3$	K_{I1}	K_{I1}	K_{I1}
- Sensor Resolution, r_{PIT}	$r_{PIT} = K_{I2} L_{tgt}$	$.3 < K_{I2} < .5$	K_{I2}	K_{I2}	K_{I2}
- Sensor Pixel, P_{PIT}	$P_{PIT} = K_{I3} r_{PIT}$	$.33 < K_{I3} < 1$	K_{I3}	K_{I3}	K_{I3}
- SNR_{PIT}	$SNR_{PIT} = 10 K_{I4}$	$.6 < K_{I4} < 1$	K_{I4}	K_{I4}	K_{I4}
ACTIVE FINE TRACK					
- System NEA, NEA_{AFT}	$NEA_{AFT} = K_{F1} P_{AFT}$	$.1 < K_{F1} < .3$	K_{F1}	K_{F1}	K_{F1}
- Sensor Resolution, r_{AFT}	$r_{AFT} = K_{F2} X_{tgt}$	$.33 < K_{F2} < .5$	K_{F2}	K_{F2}	K_{F2}
- Sensor Pixel, P_{AFT}	$P_{AFT} = K_{F3} r_{AFT}$	$.33 < K_{F3} < 1$	K_{F3}	K_{F3}	K_{F3}
- SNR_{AFT}	$SNR_{AFT} = 10 K_{F4}$	$.6 < K_{F4} < 1$	K_{F4}	K_{F4}	K_{F4}

NEA specified in rms-meters at target plane
Sensor resolution ($1/e^2$ blur circle) specified in meters at target plane
Sensor pixel specified in meters at target
SNR specified per pixel
X_{tgt} - Booster body diameter (m)
L_{tgt} - Target length (m)
1 - SBL and NPB K factors appear in a classified listing of this document

Table B-2. Scalability Relationships for DEW Acquisition and Tracking Sensors

SYSTEM CHARACTERISTICS	SYSTEM MODES: ACQUISITION TRACK	PASSIVE INTERMEDIATE TRACK	ACTIVE FINE TRACK
SYSTEM NEA (rms-meters at target plane)	NEA_{ACQ} ≈ 10% to 30% P_{ACQ}	NEA_{PIT} ≈ 10% to 30% P_{PIT} (consistent with handover to AFT)	NEA_{AFT} ≈ 10% to 30% P_{AFT} (consistent with precision pointing requirement)
SENSOR RESOLUTION, r (meters at target plane of $1/e^2$ point of blur circle)	$r_{ACQ} \approx 10 r_{PIT}$ to $100 r_{PIT}$	$r_{PIT} \approx 5 r_{AFT}$ to $10 r_{AFT}$ $r_{PIT} \approx 1/2 L_{tgt}$	$r_{AFT} \approx 1/3 X_{tgt}$ to $1/2 X_{tgt}$
SENSOR PIXEL, P (meters at target)	$P_{ACQ} \approx .5 r_{ACQ}$ to $1 r_{ACQ}$	$P_{PIT} \approx 1/3 r_{PIT}$ to $1 r_{PIT}$	$P_{AFT} \approx 1/3 r_{AFT}$ to $1 r_{AFT}$
SNR (per pixel)	SNR_{ACQ} ≈ 6 to 10	SNR_{PIT} ≈ 6 to 10	SNR_{AFT} ≈ 6 to 10

NEA specified in rms-meters at target plane
Sensor resolution specified in meters at target plane of $1/e^2$ blur circle
Sensor pixel specified in meters at target
SNR specified per pixel

X_{tgt} - Booster body diameter (m)
L_{tgt} - Target length (m)

The list is categorized by the ATP subsystem's sensor characteristics and modes of operation (i.e., acquisition track, passive intermediate track, and active fine track). Each mode is characterized by a set of four parameters which are somewhat interrelated by a set of scaling relationships that define a parameter in terms of another system parameter and some constant of multiplication (K-factor). For example, the acquisition pixel, (P_{ACQ}), is defined as the constant K_{A3} times the acquisition sensor resolution, r_{ACQ}. K_{A3} lies in the interval of .5 to 1 so P_{ACQ} is determined to be: $.5r_{ACQ}<P_{ACQ}<1r_{ACQ}$. It should be stated at this point that the scaling relationships and the corresponding constants are in a sense "rules of thumb" and are intended to provide only a rough, first order approximation to ATP sensor scaling. The relationships do offer a means of gaining an intuitive understanding of the sensor design but are not necessarily design conventions.

APPENDIX C

TRACEABILITY CRITERIA

Criteria for scalability of performance and traceability of design are discussed within each of the eighteen critical issues. In this appendix, summary tables are provided to cross-reference the criteria and the issues. These tables indicate the degree of commonality of various scalability and traceability criteria to each critical issue. They are to be used by the ALTAIR experiment planner to audit the quality of traceability and scalability for each critical technical issue.

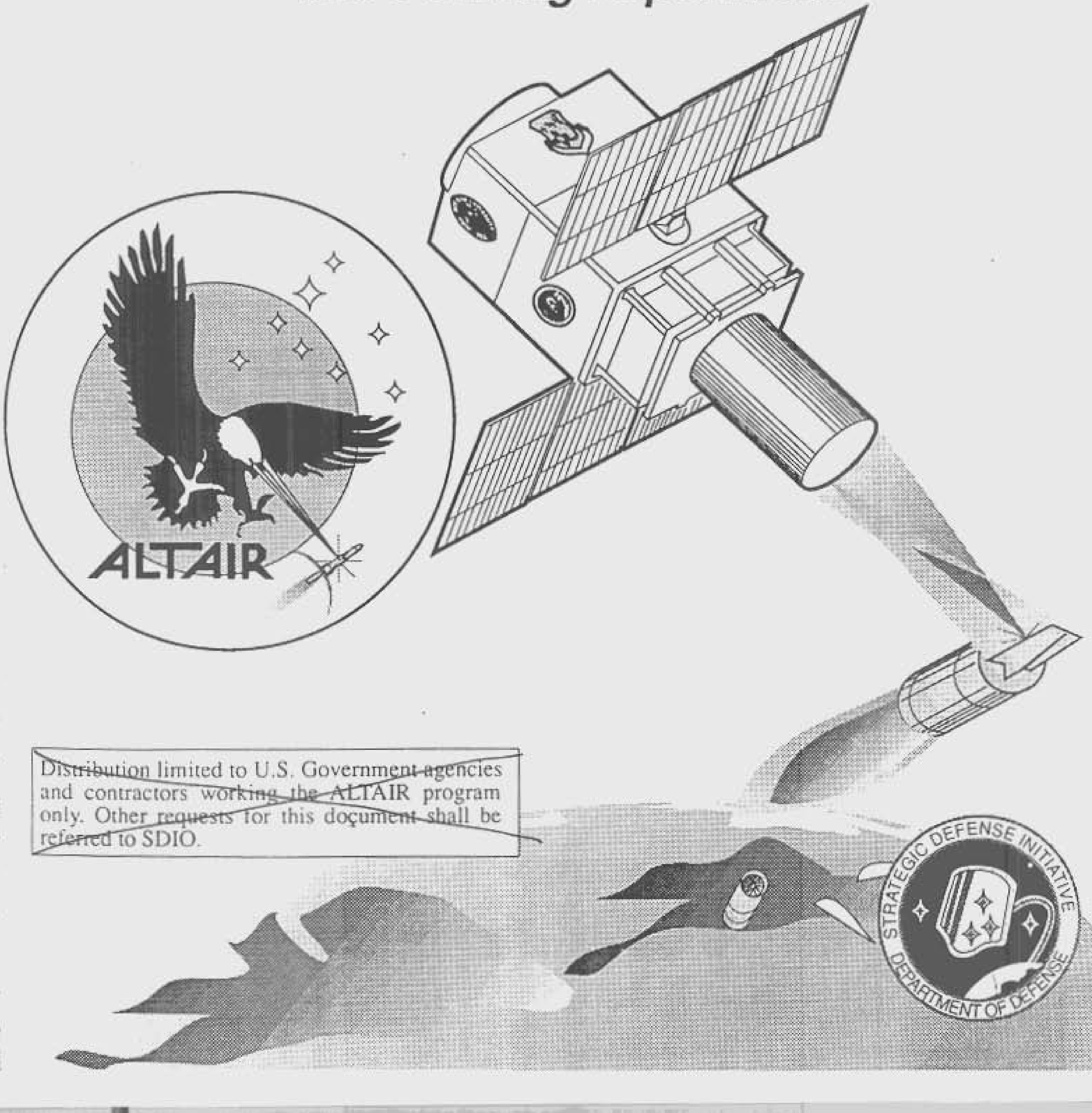
SCALABILITY CRITERIA MATRIX

SCALABILITY CRITERIA	CRITICAL TECHNICAL ISSUE																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Representative Booster	√	√	√	√	√	√	√	√	√	√							√	√
Representative PBV	√	√	√	√	√	√	√	√	√	√	√	√	√				√	√
Representative Midcourse Object						√		√	√			√	√	√	√	√		
IR Sensor Requirements	√	√	√	√	√					√	√		√				√	√
Visible Sensor Requirements	√	√	√	√	√		√		√	√	√	√	√	√	√	√	√	√
UV Imager Requirements													√				√	√
UV Spectrometer Requirements													√				√	√
Funneling FOVs	√	√	√	√	√	√	√	√	√	√				√				
Pixel Scaling at Target Plane		√		√	√		√				√	√	√	√	√	√	√	√
Time Scaling	√									√								
Precision Angle-Angle Measure				√			√				√	√		√	√	√		
Representative Point-Ahead						√		√			√	√	√	√	√	√		
Balanced Error Budget for Point Ahead						√		√			√	√	√	√	√	√		
Minimal-to-No Scoreboard Enhancement							√											
Precision Range Measurements							√	√			√	√		√	√	√		
Kinematic Scaling/Tracker Bandwidth Scaling							√		√					√				
Residual Pointing Jitter/Bias									√									
Far-Field Jitter Scoring									√									
Self-Scoring Alternatives									√					√				
Balanced Jitter Budget									√					√				
Representative Angular Rate (<1°/sec)									√					√				
Balanced Error Budget for Metric Discrimination											√				√			
Plume Perturbation Precision (ΔV<1m/sec)												√						
Scalable Midcourse Object Enhancement														√	√	√		
Interactive Discrimination Precision (ΔV<1m/sec)																√		
High Priority Plume Targets																	√	
Variation in Solar Background																		√
High Latitude Background																		√
Sensor Characterization/Calibration	√	√	√	√	√		√		√	√	√	√	√	√	√	√	√	√

TRACEABILITY CRITERIA MATRIX

TRACEABILITY CRITERIA	CRITICAL TECHNICAL ISSUE																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Representative Booster	√	√	√	√	√	√	√	√	√	√							√	√
Representative PBV	√	√	√	√	√	√	√	√	√	√	√	√	√				√	√
Representative Midcourse Object						√		√	√			√	√	√	√	√		
SWIR/MWIR Sensors	√	√	√	√	√					√	√		√				√	√
Visible Sensors	√	√	√	√	√		√		√	√	√	√	√	√	√	√	√	√
UV Sensors													√				√	√
Multi-Wavelength Synergy													√				√	√
Background Clutter Rejection	√	√	√	√	√						√		√					
Single Target Track Traceable to Multi-Target Track										√								
Flexible Tracker Processors		√	√	√	√	√	√		√	√	√	√	√	√	√	√		
Tracker Algorithms and Fire Control "Tend toward Traceability"					√		√			√								
Illuminator Steering Mirror						√	√				√	√	√	√	√	√		
Illuminator Characteristics						√	√				√	√	√	√	√	√		
Angular Inertial Instruments						√		√	√		√			√	√			
Point Ahead Angle Measurements						√		√			√	√	√	√	√	√		
Precision Range Measurements							√	√			√	√		√	√	√		
Precision Angle-Angle with PIT											√							
Precision Angle-Angle with AFT											√	√		√	√	√		
Isolation and Control of Base Motion									√									
Laser Alignment Probe									√									
Inertially Referenced Boresight									√									
Traceable Strapdown or Stable Platform Inertial Sensor									√									
Tracker Command Pointing									√					√				
Inertially Commanded Pointing									√					√				
Marker Beam Traceable to Beam-Line Reference									√									
Post Mission Reconstruction of TPP, IPP, Handback											√				√			

Mission Requirements Document For ALTAIR
11 October 1991
A Space Based Acquisition, Tracking, and Pointing Experiment



~~Distribution limited to U.S. Government agencies and contractors working the ALTAIR program only. Other requests for this document shall be referred to SDIO.~~

MISSION REQUIREMENTS DOCUMENT
FOR
ALTAIR

ALTAIR is an SDIO funded space experiment. The Air Force Phillips Lab (PL) along with the Johns Hopkins University Applied Physics Lab (APL) is responsible for the development of the ALTAIR space vehicle and on-orbit operations. The mission of the ALTAIR experiment is to answer critical technical questions that address the feasibility of target acquisition, precision tracking, and beam pointing for Directed Energy Weapon Systems.

The Missions Requirements Document (MRD) is the Air Force document for addressing the requirements of the Experiment Requirements Document (ERD), and establishing functional requirements. The ERD is the contract between SDIO and the Air Force that delineates the agreed upon technical experiment goals for the ALTAIR program and provides top level objectives, mission requirements, and ALTAIR system characteristics.

____
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Approved by: ______________________________
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1.0 INTRODUCTION

1.1 GENERAL

ALTAIR is an SDIO funded space experiment whose purpose is to answer critical technical questions that address the feasibility of target acquisition, tracking, and precision beam pointing for Directed Energy Weapons (DEW) systems. The ALTAIR mission will be accomplished by conducting critical ATP and fire control (ATP/FC) experiments on orbit which are traceable and scalable to Space Based Laser (SBL) and Neutral Particle Beam (NPB) weapon system concepts. As such, the dominant technology issue is the development of an integrated system that will sense a target, determine its dynamic state, and place a directed energy beam on the target with sufficient accuracy and stability. The Air Force Phillips Lab (PL) along with the Johns Hopkins University Applied Physics Lab (JHU/APL) are responsible for the development of the ALTAIR system and mission operations.

Much of the ALTAIR configuration derives from the Starlab experiment design which was a Shuttle based experiment cancelled because of funding and Shuttle schedule limitations. It is expected that prudent use will be made of the residual Starlab hardware and other mission support equipment. The ATP experiment payload, mated to a supporting spacecraft, (the mated vehicle is referred to as the satellite) will be carried into orbit on a medium class Expendable Launch Vehicle (ELV) launched from Cape Canaveral Air Force Station (CCAFS). Launch is planned for CY 1995 and over a period of approximately 12 months, engagements will be conducted against a suite of dedicated target boosters, ground targets, and space objects.

1.2 MRD PURPOSE

The purpose of this document is to provide top level functional requirements and goals for the ALTAIR space based acquisition, pointing, and tracking (ATP) experiment. Segmentation between collateral goals and requirements is also maintained via the MRD with detailed description of the collateral experiments included in Appendix A. The MRD is an ALTAIR Program Office document and provides an interpretation of the Mission Goals and is consistent with the Experiment Requirements Document (ERD).

Top level requirements are defined based on the overall Mission goals and represent experiment performance outputs (e.g. far field pointing performance) or critical ATP technology demonstrations. Functional requirements express those functions necessary to perform the experiment. While it is not the intent of a functional requirement to dictate configuration, it will be reasonable in some cases to express functional requirements in terms of an assumed or currently baselined configuration. The flowdown of detailed system and subsystem performance specifications are contained in the *ALTAIR System Requirements Document* .

1.3 MISSION OVERVIEW AND OBJECTIVES

The *primary mission objective* of the ALTAIR experiment is to:

Demonstrate the feasibility of DEW ATP/FC against representative thrusting booster targets under both day and night conditions. An example of the primary mission booster engagement is shown in Figure 1.1.

The ALTAIR satellite will have the inherent capability to address, to some extent, technical issues outside the primary mission requirements. These collateral goals are not currently ALTAIR program commitments. Rather, each of the goals are objectives which, due to programmatic considerations (cost, schedule, technical risk), cannot be accepted as implementable requirements at this time. However, if a goal is accepted by the ALTAIR Program Office for inclusion, and appropriate funding and schedule are allocated, that accepted goal will be incorporated as a program requirement. Otherwise, it will be retained as a goal, wherein a reasonable attempt will be made to achieve the goal, but without design impact to the ALTAIR system (See 3.0 below).

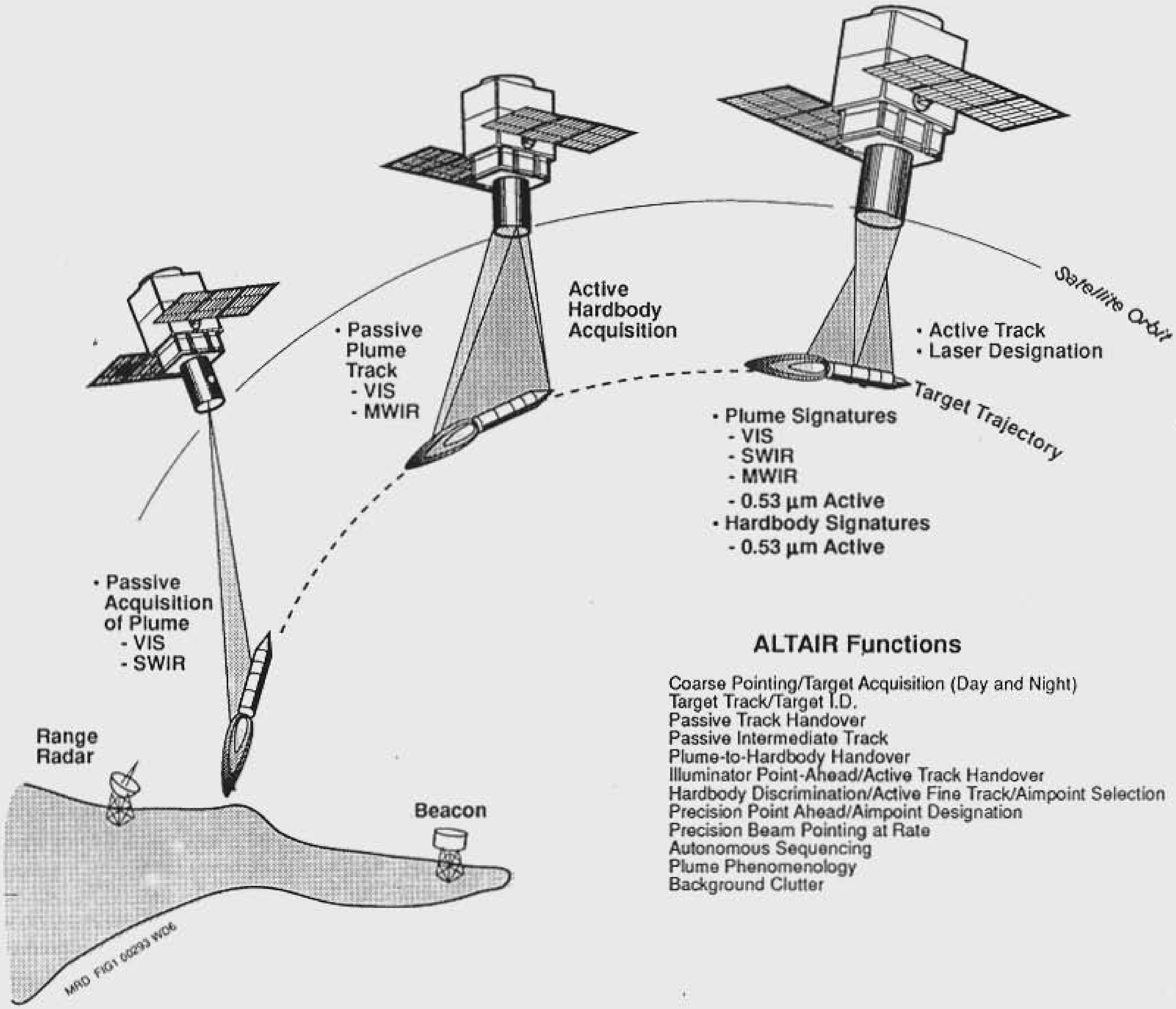


Figure 1-1. Dedicated ATP Booster Engagement (Primary Engagement)

1.4 KEY REQUIREMENTS DOCUMENTS

The Experiment Requirements Document (ERD) is an agreement between SDIO and the Air Force which delineates the top level mission requirements and collateral goals for the ALTAIR program. The MRD is the Air Force document for interpreting the ERD and establishing Top Level and Functional Requirements with Primary and Collateral requirements/goals segmentation. The System Requirements Document (SRD) provides performance requirements flowdown for the ALTAIR system and is the program system engineering document for control of the ALTAIR system characteristics down through the Center or Facility level. The ALTAIR Security Classification Guide, produced by SDIO/TND, governs the security requirements on the program. (For a full listing of key ALTAIR documents see ALTAIR System Engineering Series Memo SES-1.17-2 dated 3 September 1991)

1.5 CHANGE CONTROL

The content of the MRD is the responsibility of the ALTAIR program office. As such it is under configuration control with the ALTAIR Program Manager as the board chairman. The Chief Engineer is responsible for the administration of the MRD. Controlled copies of the MRD will be issued and a list of the custodians of these copies maintained. Following change board meetings, revised pages with marked additions and deletions will be issued to the custodians and periodically the entire document will be revised and reissued. A historical record of all changes will be maintained.

2.0 TOP LEVEL PRIMARY REQUIREMENTS

2.1 PRIMARY MISSION REQUIREMENTS

The primary mission requirement of ALTAIR is to acquire, track, and direct a marker laser beam to a thrusting target booster(s). In particular ALTAIR is to provide an unequivocal demonstration of pointing and beam stabilization in the performance domain corresponding to DEW applications.

Instruments onboard the ALTAIR satellite are to collect essential phenomenology data on these booster plumes and their interaction with upper atmosphere and space environments to support the ATP function. Critical background (celestial, earth, earth limb, etc) measurements shall be made in the visible and infrared wavelengths. The experiment is to be conducted under tightly controlled conditions corresponding to representative target engagements.

ALTAIR is also to provide validation of ATP design tools, scaling laws, and simulations required to initiate development of first generation DEW systems capable of engaging thrusting ballistic missiles. Validation is to be accomplished at both a functional and a performance level.

2.2 PRIMARY MISSION PERFORMANCE REQUIREMENTS

Technical performance requirements for ALTAIR are defined below for the primary mission. These requirements are driven by the need to demonstrate precision pointing performance against thrusting missile targets. Pointing performance is scored by measuring the pointing error on an instrumented booster. Pointing error is defined as the difference between the centroid of the marker beam footprint in the far field and the desired target aim point.

The pointing error is best characterized by considering its component parts; a systematic part consisting of a bias and drift error, and a random part, referred to as jitter. *Bias* contains the initial aimpoint selection error, aimpoint designation (marker pointing) error, and marker-fine tracker boresight error. *Drift* is predominantly residual track error reflecting control loop dynamic lag, changing track point due to target characteristics, and low frequency beam wander caused by tracker noise. *Jitter* is generally base motion induced, of a higher frequency spectrum than bias or drift, and is beyond the ability of the track loop to correct. The jitter error will be what remains after the bias and drift errors are subtracted from the data.

The errors for the marker beam centroid are given as a 2-axis mean value for the bias error, and as 2-axis, 1 sigma values for the dynamic errors (drift and jitter). The residual bias error requirement is given in meters at the target plane. The drift error requirement is given in terms of resolution elements, defined as λ/D, where λ is the wavelength of the illuminator laser and D is the diameter of the limiting aperture of the sensor telescope. The minimum measurement time for all requirements is 5 seconds. Specific requirements are:

Bias Error. The bias error shall be less than ______ meters of the selected aimpoint at initial marker beam turn-on.

Drift Error. After removal of the mean error (bias) over the sample interval, 1 sigma dynamic pointing error below 3 hertz (drift) shall be less than _____ resolution elements.

Jitter Error. The 1 sigma dynamic pointing error above 3 hertz (jitter) shall be less than _____ radians.

Tracker Traceability. ALTAIR shall be designed such that the hard body geometric image on the fine tracker focal plane, and the plume image on the passive intermediate tracker, shall subtend a number of pixels representative of an operational DEW system.

Plume-to-Hardbody Handover. ALTAIR shall demonstrate transition from IR passive intermediate track to active fine track within 10 illuminator pulses after establishing stable intermediate track.

Target Representivity. Target features that affect the performance of the function being demonstrated, or the critical issues being addressed, shall be threat representative to the maximum extent feasible.

2.3 PRIMARY MISSION FUNCTIONAL REQUIREMENTS

ALTAIR is to demonstrate critical ATP and fire control functions against the primary targets. Critical ATP functions to be demonstrated are:

Coarse Pointing/Target Acquisition
Target Track/Target ID
Passive Track Handover
Passive Intermediate Track
Plume-to-Hardbody Handover
Illuminator Point-Ahead/Active Track Handover
Hardbody Discrimination/Active Fine Track/Aimpoint Selection
Precision Pointing at Rate/Aimpoint Designation
Autonomous Sequencing
Plume Phenomenology Data Collection
Background Clutter Data Collection

2.4 OTHER TOP LEVEL REQUIREMENTS

2.4.1 SCALABILITY AND TRACEABLLILITY

In order to successfully demonstrate the critical ATP functions, the ALTAIR experiments must exhibit both scalability and traceability. Scalability means that the appropriate engineering parameters that measure system performance, size, and rates are in correct ratio with respect to

DEW system requirements. Traceability means the functions, methods, and design approach demonstrated in the experiment are relevant and transferable to proposed DEW system designs.

2.4.2 MISSION SCIENCE

A team of scientists under the direction of an ALTAIR mission scientist shall be formed to assure that ALTAIR is a scientifically sound experiment. This responsibility includes reviewing and participating in the ALTAIR development, reviewing experiment data as it is generated, resolving anomolies in science data, identifying and quantifying the ATP error sources, correlating ALTAIR errors with generic DEW errors, and assuring that science data is properly processed for archival.

3.0 COLLATERAL GOALS

There are, in addition, a number of collateral goals which, due to programmatic considerations cannot now be stated as requirements. If a collateral goal is accepted for inclusion at some future date the necessary collateral requirements to achieve that goal will be included at that time. These goals, in priority order, are defined in the ERD as:

A. Collection of *additional plume phenomenology* data in wavebands other than those required to meet the primary mission objective.

B. ATP/FC experiment and the collection of phenomenology data against a representative *liquid fueled booster* target.

C. Collection of *mid-latitude background clutter* data.

D. ATP/FC experiment and the collection of additional target phenomenology data against a representative *post-boost vehicle* (PBV).

E. ATP/FC experiment against a representative *midcourse object* using functions traceable to an NPB weapon system.

F. Experiments against representative PBV's and midcourse objects that address the feasibility of *deployment trajectory projection, metric discrimination, and handback.*

The above will either be accepted for inclusion and become collateral requirements or remain goals. A reasonable attempt will be made to achieve the goals without impact to the ALTAIR system. A more complete discussion of the mission requirements for the collateral goals is contained in Appendix A.

4.0 ALTAIR SYSTEM DEFINITION/DESCRIPTION

4.1 ALTAIR SYSTEM DEFINITION

The ALTAIR System has been partitioned into a Satellite System (the primary experiment tool) and three supporting elements (Launch Vehicle, Target, and Mission Operations). The Satellite System consists of a Payload Element and a Spacecraft element. Further, the Mission Operations Element has been partitioned into a variety of Centers and Facilities which provide the required ground-based resources for mission operations. A simplified block diagram of the ALTAIR system is contained in Figure 4.1.

4.2 SATELLITE SYSTEM DESCRIPTION

The ALTAIR Satellite System consists of a Payload Element and a Spacecraft Element. These are defined separately below. The satellite system provides an integrated, space-based platform with electro-optical sensors of appropriate sensitivity, laser power and tracking capability to engage dedicated program targets (both passively and actively) and provide the essential science measurements.

4.2.1 PAYLOAD ELEMENT DESCRIPTION

The payload element possesses the fundamental mission sensor and laser capability, optical and electrical signal conditioning, signal/image processing electronics for derivation of tracking signals and control electronics to enable mode sequencing during an engagement. The signal/image processing and mode control functions are under software (firmware) control. Additionally, the payload element contains a variety of functions to provide mission operations and on-orbit maintenance support. These include data handling/formatting control, power conditioning, mode switching control, thermal control and mechanical support.

4.2.2 SPACECRAFT ELEMENT DESCRIPTION

The spacecraft element possesses those functions necessary to assure on-orbit operation of the satellite system and provide interface with the mission operations element. These functions included electrical power generation, pointing in response to payload command, attitude control, orbit determination, data storage, command and data communications, thermal control and mechanical support.

4.3 TARGET ELEMENT DESCRIPTION

Those ALTAIR dedicated launch vehicles (and other objects yet to be defined) and associated ALTAIR-unique subsystems flown aboard this vehicle (e.g, scoreboard) which are required to support the ATP and Phenomenology functions of ALTAIR. In addition, this Element includes a Ground Target Site (GTS) to support characterization of the Satellite System.

4.4 LAUNCH VEHICLE ELEMENT DESCRIPTION

The vehicle which will launch the Satellite System into the intended orbit.

4.5 MISSION OPERATIONS ELEMENT DESCRIPTION

The Mission Operations element is a ground-based assembly of Centers and Facilities which provide operational support during the launch and on-orbit phases of the ALTAIR mission. These Centers and Facilities functions are defined separately below:

4.5.1 PAYLOAD OPERATIONS CENTER (POC)

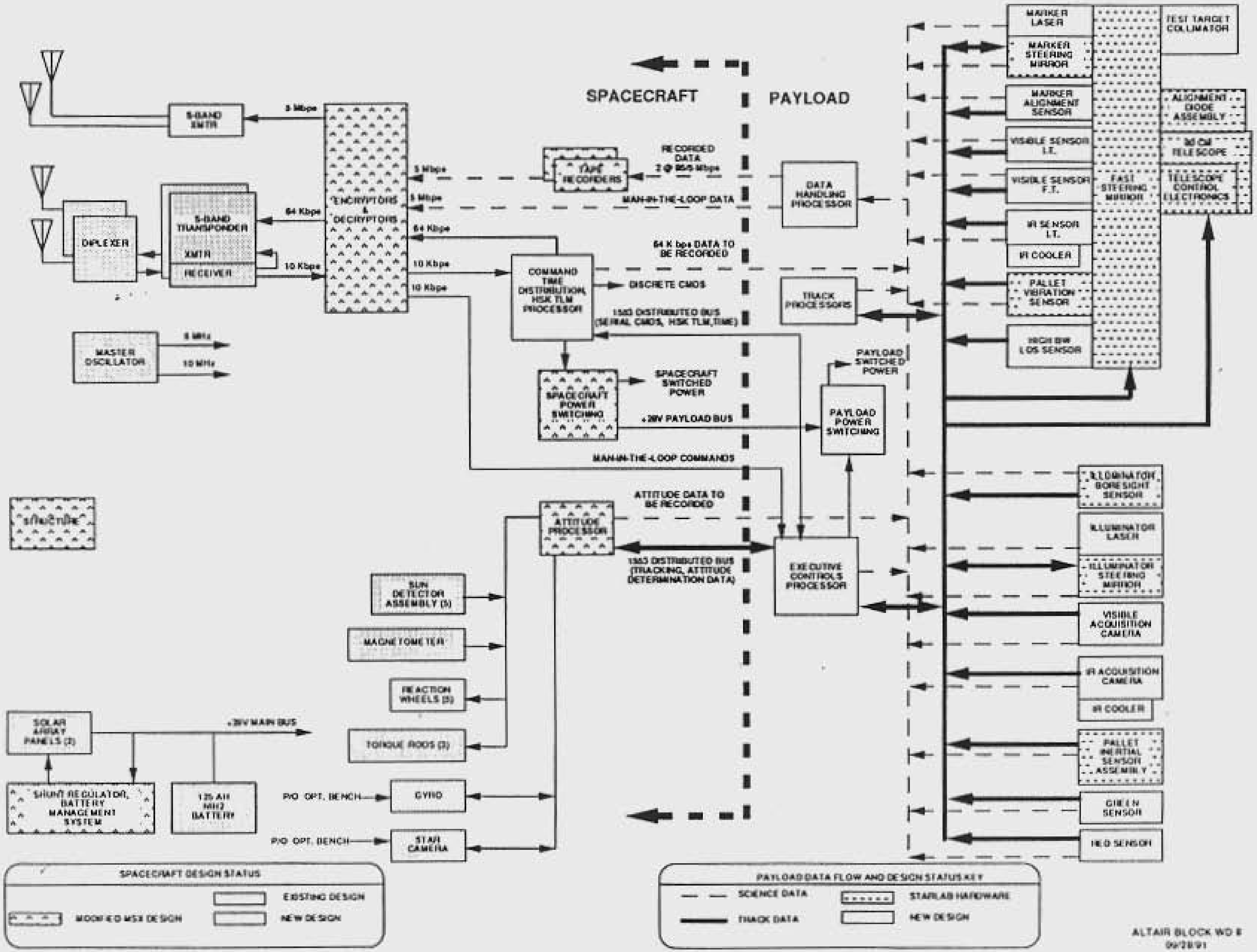
That collection of subsystems which provide primary control of the Satellite System during the on-orbit experiment or engagement phase of the mission.

4.5.2 SCIENCE OPERATIONS CENTER (SOC)

That collection of subsystems which support all science-mission data analysis and reporting for the ALTAIR mission.

4.5.3 ENGINEERING SUPPORT FACILITY (ESF)

That collection of subsystems which provides day-to-day engineering support to the POC and SOC activities. This includes support for satellite system anomaly resolution and maintenance of an ALTAIR End-to-End Simulation.


SPACECRAFT
PAYLOAD
S-BAND XMTR
3 Mbps
S-BAND TRANSPONDER
XMTR
RECEIVER
64 Kbps
10 Kbps
DIPLEXER
ENCRYPTORS & DECRYPTORS
5 Mbps
5 Mbps
64 Kbps
10 Kbps
10 Kbps
MASTER OSCILLATOR
5 MHz
10 MHz
TAPE RECORDERS
RECORDED DATA 2 @ 85/5 Mbps
MAN-IN-THE-LOOP DATA
DATA HANDLING PROCESSOR
64 K bps DATA TO BE RECORDED
COMMAND TIME DISTRIBUTION, HSK TLM PROCESSOR
DISCRETE CMDS
1553 DISTRIBUTED BUS (SERIAL CMDS, HSK TLM,TIME)
TRACK PROCESSORS
SPACECRAFT POWER SWITCHING
SPACECRAFT SWITCHED POWER
+28V PAYLOAD BUS
PAYLOAD SWITCHED POWER
PAYLOAD POWER SWITCHING
MAN-IN-THE-LOOP COMMANDS
ATTITUDE DATA TO BE RECORDED
ATTITUDE PROCESSOR
1553 DISTRIBUTED BUS (TRACKING, ATTITUDE DETERMINATION DATA)
EXECUTIVE CONTROLS PROCESSOR
STRUCTURE
SUN DETECTOR ASSEMBLY (5)
MAGNETOMETER
REACTION WHEELS (3)
TORQUE RODS (3)
P/O OPT. BENCH
GYRO
P/O OPT. BENCH
STAR CAMERA
SOLAR ARRAY PANELS (2)
+28V MAIN BUS
SHUNT REGULATOR, BATTERY MANAGEMENT SYSTEM
125 AH NiH2 BATTERY
MARKER LASER
MARKER STEERING MIRROR
MARKER ALIGNMENT SENSOR
VISIBLE SENSOR I.T.
VISIBLE SENSOR F.T.
IR SENSOR I.T.
IR COOLER
PALLET VIBRATION SENSOR
HIGH BW LOS SENSOR
FAST STEERING MIRROR
TEST TARGET COLLIMATOR
ALIGNMENT DIODE ASSEMBLY
30 CM TELESCOPE
TELESCOPE CONTROL ELECTRONICS
ILLUMINATOR BORESIGHT SENSOR
ILLUMINATOR LASER
ILLUMINATOR STEERING MIRROR
VISIBLE ACQUISITION CAMERA
IR ACQUISITION CAMERA
IR COOLER
PALLET INERTIAL SENSOR ASSEMBLY
GREEN SENSOR
RED SENSOR
SPACECRAFT DESIGN STATUS
EXISTING DESIGN
MODIFIED MSX DESIGN
NEW DESIGN
PAYLOAD DATA FLOW AND DESIGN STATUS KEY
SCIENCE DATA
STARLAB HARDWARE
TRACK DATA
NEW DESIGN
ALTAIR BLOCK WD 8
09/28/91

4.5.4 TEST SUPPORT COMPLEX (TSC)

Existing or modified government assets "tasked" to support the ALTAIR mission via coordination with the USAF Consolidated Space Test Center (CSTC). This support includes initial satellite system turn-on and checkout, verification of orbital parameters and monitoring/trending of the satellite system state-of-health. In addition, the TSC will also be responsible for satellite system command and control during non-engagement or quiescent periods.

4.5.5 GROUND TARGET SITE (GTS)

That collection of ground based subsystems which supports the characterization of far field performance during on orbit operations. The GTS will include Man-in-the-loop (MITL) capability as well as a ground target board.

4.5.6 EASTERN TEST RANGE FACILITIES (ETRF)

Includes those facilities required to support launch of the Satellite System and the suborbital target vehicles.

5.0 ALTAIR MISSION REQUIREMENTS

5.1 GENERAL

The ALTAIR mission design is to provide maximum opportunities for ATP operations and experiments from the ALTAIR satellite. General requirements are:

Launch site	CCAFS
Mission Duration	≥ 1 year
ATP Operations/Engagements	≥ 1 per week

Mission activities which are to be planned for include:

Satellite System checkout	Verify basic health and status of the satellite
Satellite Characterization	Test payload attitude control and passive track Initiate payload built-in test Demonstrate ground target site acquisition
Payload control system characterization	Optimize line-of-sight (LOS) stabilization system Initial star calibrations
Payload laser checkout and characterization	Characterize illuminator and marker beams Project laser beams
ATP dedicated booster engagements and self-scoring	Self-scoring checkout ATP demonstrations

5.2 ORBIT SELECTION AND TARGET VEHICLE TRAJECTORY

Orbit parameters and Target Vehicle trajectories shall be selected to meet the following constraints:

Satellite Altitude	> 370 km (as constrained by the experiment targets)
Eccentricity	Circular
Inclination	≥ 28°

Support for science engagements at the target sites

Meets launch vehicle capability for inserting the ALTAIR satellite into its specified orbit
MMII characteristics for target vehicle dynamics
Maximizes engagement prime science time
Maximizes science data downlink opportunities

5.3 ENGAGEMENT TIMELINES

The general requirement is to design the payload and spacecraft systems to support a total experiment sequence which includes pre-target calibrations, target engagement, post-target calibrations, data downlink, data reduction and analysis, and contingency for anomaly resolution and satellite checkout. Spacecraft power management, spacecraft data storage and downlinking capability, and ground data reduction and analysis support will be significant design issues. A nominal engagement illustrating the ATP functional sequence is shown in Fig 1.1; design parameters for a sample MMII engagement are included in Appendix C.

5.4 OPERATIONS CONCEPT

The operations concept for the ALTAIR mission is to incorporate the experience and lessons learned from the RME and AF Space Test Programs. Spacecraft command and control, orbit/attitude functions, command planning, and state of health analysis will be accomplished at the CSTC TSC. Overall mission planning, detailed engagement planning, and payload state of health analysis will be accomplished at the POC while science data processing, analysis, and archiving will be centered at the PL Science Operations Center (SOC). Communication with the satellite will be via the AFSCN, CSTC controlled transportable and/or deployable assets. The requirement for high bandwidth payload data is that it be downlinked and then sent to the POC/SOC for analysis and anomoly resolution.

5.5 RISK MANAGEMENT

Risk management is the responsibility of the Air Force PL. Mission risk is to be minimized by the following

Thoroughly testing and documenting the experiment system prior to launch
Configuring, maintaining, and using validated simulations of the experiment system before and during the space mission
Designing the payload for redundant functional capability (e.g., multiple sensors for tracking, back-up control system)
Designing in the capability for on-orbit software reconfiguration (e.g., new track algorithms)
Utilizing dedicated target vehicles (i.e., experiment controlled launch)
Maintaining an engineering capability for troubleshooting and replanning during the mission
Providing the capability to reload part or all of the onboard computer memory
Extensive pre-launch operational training and simulation with the entire operational team.
Conducting compatibility tests between the satellite and ground stations/systems.
Conducting analysis on possible hazard modes.
Providing a self test capability.
Verifying operation both preflight and on orbit.

6.0 SATELLITE REQUIREMENTS

6.1 GENERAL

The ALTAIR Satellite consists of Payload and Spacecraft elements. The Payload consists of that hardware (e.g., optics, sensors) and software, (e.g., ATP control algorithms) directly involved in performing the ALTAIR experiments. The Spacecraft consists of that hardware and software required to support the payload operation and the ALTAIR mission (e.g., power, communications).

General requirements are associated with the mission goals of engaging, acquiring, and actively tracking dedicated target booster in both night and daytime conditions. Essential science data will be recorded from high resolution imaging sensors and control system elements. Functional requirements at the Satellite level are flowed down to the Payload and the Spacecraft as appropriate. The overall satellite design reliability shall be TBD for a design life > 12 months.

6.2 FUNCTIONAL REQUIREMENTS

6.2.1 OPERATING MODES

ALTAIR must have the following general "mode" capabilities

6.2.1.1 MISSION ENGAGEMENT

This is mode in which ALTAIR performs the ATP experiment against a selected target. ATP rehearsals using ground targets or ALTAIR-deployed space objects, gyro calibrations, collection of background phenomenology, and ATP against thrusting boosters are considered engagements. MITL will be utilized in the engagement mode for positive control of the laser and as backup support to the automated ATP activity. The Payload assumes of Satellite system functions; the Spacecraft provides coarse pointing in response to pointing commands from the Payload. The critical ATP functions listed in 2.3 will be demonstrated in some or all of the ATP engagements. Specific description of these functions are included as Payload Element functional requirements.

6.2.1.2 PAYLOAD TEST

Calibration of the ALTAIR system will take place prior to the first booster target engagement and frequently throughout the mission. calibrations may involve stars, ground targets, deployed space objects or calibration sources internal to the payload. The spacecraft assumes control of the Satellite functions during this operation.

6.2.1.3 DATA DOWNLOAD

Data stored on board the spacecraft will periodically be downlinked. Although some data is downlinked during the engagement and calibration modes, the majority of the scientific data will be downlinked following each engagement and major calibration. Periodically health and status data will be downlinked. The Spacecraft assumes control of the Satellite functions during this operation.

6.2.1.4 PARK (QUIESCENT)

The primary function of the park mode is to recharge the Spacecraft batteries and allow thermal recovery between periods of high power demand (engagements and calibrations). During this mode the payload is inoperative and attitude control is performed by the spacecraft. During this mode the primary function of attitude control is to orient the solar panels toward the sun. Periodic reboosting of the satellite to maintain its orbit is performed in the park mode. The Spacecraft assumes control of the Satellite functions during this operation.

6.2.1.5 SAFE

This is an emergency mode for recovery of the satellite following a failure. It utilizes a simplified redundant control system to point the solar panels to the sun, turn off all unessential power using devices, and establish ground communication. ALTAIR is designed to support failure diagnosis and recovery from the ground. The Spacecraft assumes control of the Satellite functions during this operation.

6.2.2 ELECTRICAL POWER

Electrical power and energy shall be provided by the Spacecraft sufficient to supply both Payload and Spacecraft elements. Following the most energy demanding engagement the power subsystem shall be capable of recharging its batteries to full capacity within 48 hours.

6.2.3 THERMAL CONTROL

The Payload and Spacecraft shall each control its own thermal environment and maintain relative thermal isolation from each other. Survival heaters shall be provided where required. The satellite shall be capable of thermal recovery within 48 hours following the most demanding engagement.

6.2.4 MECHANICAL

The satellite structure shall have sufficient strength and stiffness to accommodate launch loads and vibration requirements. The satellite structure shall be compatible with the launch vehicle payload attachment structure. The satellite structural design shall minimize, to the extent practical, the introduction of jitter into the payload pointing subsystem while on orbit. Specific budgets for base motion excitation are specified in the ALTAIR SRD and controlled by the System Engineer.

The satellite shall have a launch weight consistent with a medium class launch vehicle and an orbit altitude >370 Km and inclination > 28 degrees.

6.2.5 INSTRUMENTATION AND DATA HANDLING

The satellite shall have instrumentation sufficient to characterize the experiment (its operation, its operating environment) and allow traceability of the sources that contribute to the experiment errors. The Satellite system will collect, format and store (or provide for real-time transmission) science data, MITL data and Housekeeping data. The Satellite system will receive and distribute uplink commands and memory uploads as appropriate.

6.2.6 POSITIVE CONTROL/MITL

Positive control of the illuminator laser line of sight must be maintained to ensure safe operation. This safety requirement can be satisfied by a minimum system consisting of a relatively small set of real time measurements and ground commands or by man-in-the-loop (MITL). The MITL system will employ a ground operator's station with a realtime display of the target image and controls for manual operation of the laser and its pointing control system.

MITL is a firm requirement for ALTAIR. It shall have the capability for satisfying positive control safety requirements, assisting in the on-orbit adjustment of the automated ATP system and providing manual backup to ATP operations.

6.2.7 LAUNCH VEHICLE INTERFACE

The integrated spacecraft must be compatible with the launch vehicle's payload adapter, comply with volume constraints imposed by its payload fairing, and comply with the center of mass and structural strength and stiffness requirements.

6.2.8 COMMUNICATIONS

6.2.8.1 COMMAND AND CONTROL UPLINK

Command and control of the ALTAIR satellite will consist of automated onboard control, ground control of the automated functions, and ground control of the satellite. Automated on board control functions (e.g. the Science Engagement, safe mode operation, etc) and routine operating procedures, such as the collection of health and status data, shall be included. Examples of functions routinely commanded and controlled from the ground include the initiation of experiment events and sequences, maintaining positive control of the laser, MITL, updating onboard data, and satellite orbit maintenance.

6.2.8.2 DATA DOWNLINK

Data downlink functions include Science, Housekeeping, and MITL data. MITL rates must support realtime command and control of the satellite; science downlink rates and opportunities are to be consistent with the 48 hour quick look report and anomoly resolution requirements.

7.0 PAYLOAD REQUIREMENTS

7.1 GENERAL

The payload consists of a telescope, an optical relay and control system, imaging sensors, marker and illuminator lasers, track and experiment processors, the experiment software, and associated structural (e.g., optical bench) and electrical components. The payload is to be designed to meet the primary experiment requirements, to be compatible with the launch vehicle constraints, to have redundant functional capabilities, to have uploadable software configuration for critical algorithms, and to have man-in-the-loop (MITL) capability for positive control of laser operations and support of on-orbit operations. Prudent use of existing hardware and software wherever possible is desirable where it is consistent with acceptable technical performance. Flight software shall be developed and tested via flight simulators and by thorough engagement sequencing during payload system ground testing.

7.2 FUNCTIONAL REQUIREMENTS

7.2.1 OPERATING MODES

The payload operational modes are to be consistent with those of the satellite. During Mission Engagements the Payload element is in control of the Satellite system functions and issues pointing commands to the spacecraft during the engagement. In all other modes, control of the Satellite system functions is assumed by the spacecraft.

7.2.2 ATP FUNCTIONS

Critical ATP functions (section 2.3) are to be demonstrated by the Payload during Science Engagements. A description of these functions is as follows:

Coarse Pointing/Target Acquisition: Pointing the spacecraft with initial target state vectors and detecting the booster target in the wide field-of view acquisition (capture) sensor.

Target Track/Target ID: Coarse tracking the individual booster target in the presence of background clutter using the acquisition sensor imagery.

Passive Track Handover: Determining the line-of-sight to the target with enough accuracy and stability to effect a handover to the passive intermediate resolution tracker (PIT)

Passive Intermediate Track: Stably tracking the booster plume.

Plume-to-Hardbody Handover: Determining the hardbody location "relative" to the passively tracked target scene.

Illuminator Point-Ahead/Active Track Handover: Pointing the laser illuminator "ahead" to obtain an active return off the missile hardbody. The point ahead must account for plume-hardbody separation and offset due to the speed of light.

Hardbody Discrimination/Active Fine Track/Aimpoint Selection: Actively tracking the hardbody (not the return from the plume) using the illuminator laser return and selecting an aimpoint for the marker laser.

Precision Pointing at Rate/Aimpoint Designation: Pointing the marker laser to the selected aimpoint and stabilizing the line-of-sight about that aimpoint.

Autonomous Sequencing: Demonstration of end-to-end autonomous fire control against a booster target (i.e. acquisition through precision pointing at rate and marker beam scoring)

Plume Phenomenology Data Collection: Collection of high resolution MWIR, SWIR, and visible imagery during all stages of the target booster's flight.

Background Clutter: Collection of high resolution MWIR, SWIR, and visible imagery of backgrounds typical for DEW system engagements.

All functions are to be performed in a scalable and traceable manner as described in section 2.4.

7.2.3 OPTICS

The optics consist of the primary optical components of the payload. This shall include all relay optics (from the marker laser to the output telescope), the illuminator optics, the various separate and shared aperture sensor optics, the auto alignment optics, as well as the main telescope. Focussing capability shall be provided. Consideration of optical quality and throughput at the tracker and marker wavelengths is of particular importance as this shall drive many hardware choices (e.g., laser illuminator). Design trades should include the desirability of using residual hardware and software from Starlab. All on-board optics must be capable of supporting a 12 month mission life.

Coating design analysis must account for space environmental effects and show acceptable performance for mission life. Shielding shall be provided to protect the optics from contamination and pitting and the sensor from inadvertent exposure to the sun. The design of the optical structure should account for expected temperature environments and minimize resultant performance degradation.

7.2.4 OPTICAL ALIGNMENT

Active control is required to maintain alignment through the optical train. Elements may include fixed optics, steerable mirrors, alignment lasers and detectors, and beam sampling elements.

7.2.5 POINTING

Laser beam pointing shall be consistent with the top level performance requirements. This function is to be accomplished by controlling the spacecraft pointing and optical steering components in the payload. The requirement is for an integrated control system which can respond to programmed line of sight (LOS) trajectories, sensor inputs (e.g. tracker or Kalman filter errors), or uplinked steering commands (e.g., from a hand controller). During an engagement the spacecraft is viewed as a control element of the overall pointing system. Because of the fairly narrow field of view of the main telescope, the spacecraft shall be required to provide for large angle steering (perhaps as an offload command from the optical system) while the optical system steers out the remainder.

The control system shall be capable of maintaining the marker laser beam on accelerating targets and very precise jitter stabilization shall be maintained during slew.

7.2.6 LASERS

The design of the laser systems shall be consistent with technical requirements flowed down from the overall experiment design. The marker (scoring) laser shall be focused on the target by the experiment primary telescope and shall be used to score far field pointing and LOS stabilization performance. Power and beam quality performance must be consistent with these goals. The laser range finder receiver must support the ranging requirements for booster engagements.

7.2.7 SENSORS

A suite of sensors shall be required for tracking and for phenomenology data collection. Sensitivities and fields of view are driven by the target engagements. In particular, sensor specifications must be consistent with expected target signature, engagement ranges, recorder dynamic range, and optical system transmission.

All sensors are to be viewed as significant data collectors and require calibration and adequate recording dynamic range. Sensors shall be calibrated sufficiently to allow true radiometric measurements. This shall require:

(a) careful ground calibration and characterization with results detailed in a calibration report

(b) capability for on-orbit calibration

(c) data reduction procedures for validating sensor performance during and after on-orbit engagements.

The infrared sensor(s) shall likely require cooling for proper operation. This system is to provide cooling for a minimum of one full-up engagement per day of the life of mission.

The self-scoring sensors are to be of a bandwidth to support self-scoring operations. Relative fields of view for handover to intermediate and fine track modes should provide adequate margin to allow for sensor boresight error. In addition to the above required sensors, a visible sensor which allows a backup capability for acquisition and intermediate track is desirable.

The video distribution system should be flexible to allow for the selection of various sensors for particular functions. For example, passive track functions which could use IR or visible sensor outputs reduce the risk of losing this function due to a sensor malfunction.

7.2.8 ACQUISITION/TRACKING

Acquisition/tracking hardware and software consists of the track processors and the fire control algorithms. Centroid, edge track, and correlation algorithms are to be provided at a minimum. Data rates should be consistent with low bandwidth imaging sensors and high bandwidth non-imaging sensors (e.g., quad cells). Critical parameters and specific algorithms must be changeable via software uploads to minimize experiment risk due to unknown phenomenology. Data latency due to the track processor must be consistent with its use in the closed track loop.

7.2.9 EXPERIMENT CONTROLLER

The experiment computer which shall control the payload operation during an engagement is to be configured with uploadable software capability for critical (and changeable) parameters, and shall have the capability for reprogramming as judged feasible by the system designer. In particular, the capability to alter fire control algorithms after the satellite is on orbit is required. The fire control algorithms which control the autonomous mode sequencing for an engagement are to be scalable to operational DEW approaches. Target state vectors are to be maintained in realtime by the experiment computer using track sensor, laser range finder, and inertial reference sensor inputs. A predictor shall be used for updating the target state vector with respect to inertial space and demonstrating inertial-only pointing. Realtime knowledge of the spacecraft position during a target engagement is necessary to the accuracy required to successfully perform the engagement. Following the engagement the capability shall exist to reconstruct a more accurate determination of the spacecraft position.

7.2.10 SOFTWARE

The software for the payload shall contain all functional modes of the payload (such as engagement control, self test, quiescent operation, and data management) as well as specific pointing and tracking algorithms. The software language selected is to be consistent with the overall ALTAIR objectives (e.g. operational flexibility and ease of on-orbit checkout) and minimize development risk. Requirements for Independent Verification and Validation (IV&V) testing are to be assessed in the context of the entire system test sequence.

7.2.11 INSTRUMENTATION AND DATA HANDLING

All essential science data is to be recovered and formatted by the Payload element. This data is then to be transferred to the Spacecraft element for storage/downlink transmission . Recording data rates are to be consistent with the function which is being instrumented. Detailed instrumentation requirements shall be driven by the payload design. "Types" of data which are to be provided are:

control systems	all control error signals (e.g., track error) actuator outputs (e.g., mirror positions) critical design values (e.g., torques)
algorithm data	timelines critical events parameter values ancillary calculations (e.g., pixel sums) state vector values
sensor data	pixel values background counts
environmental data	vibration measurements thermal data optical throughput measurements
laser systems	output power measured range

7.2.12 ELECTRICAL POWER

All Payload electrical power shall be supplied by the Spacecraft.

7.2.13 THERMAL CONTROL

To the extent possible, the payload will provide its own thermal control independent of the Spacecraft. Heat transfer across the Payload/Spacecraft interface shall be minimized. Payload component and sub-system temperatures shall be controlled to their required ranges - typically an operating temperature range and a broader quiescent or survival temperature range. Specialized thermal requirements include laser heat dissipation and IR sensor cooling.

7.2.14 MECHANICAL

The structural subsystem must be capable of supporting the payload configuration and satisfy the spacecraft interface and center of gravity (CG) and mass requirements. It must provide adequate stiffness, strength, and durability to survive the launch and ascent environment. On-orbit structural behavior relative to the thermal and vibration environment is to be consistent with the pointing error budget.

8.0 SPACECRAFT REQUIREMENTS

8.1 GENERAL

The spacecraft is a one-of-a-kind vehicle procured to be compatible with the ALTAIR mission requirements and experiment payload. Utilization shall be made of existing hardware where feasible. Spacecraft systems and consumables are to provide a margin in excess of the expected experiment duration to allow for anomaly isolation and resolution, and to provide for performing additional experiments after the main ALTAIR objectives are accomplished. The spacecraft must be able to sustain orbital operations and support the mission timeline. The Attitude Control System (ACS) must provide a safe mode and a quiescent mode capability.

8.2 FUNCTIONAL REQUIREMENTS

The overall function of the Spacecraft is to support the Payload in performing the ALTAIR mission. Specific functional requirements are the following:

Provide Structural Support for Spacecraft and Payload Systems.
Furnish Power to All Satellite Systems
Provide Data Uplink and Downlink
Provide Data Storage and Playback
Determine Satellite Attitude and Provide Attitude Control Actuation
Provide Thermal Control
Provide Instrumentation
Provide control offload authority to the payload (for coarse pointing during the Engagements)

8.2.1 OPERATING MODES

The spacecraft is to support the Satellite operating requirements and functions as outlined in 6.2. The spacecraft is functional during all satellite operating modes and is in control of the satellite at all times except during the Mission Engagements.

8.2.2 ATTITUDE CONTROL

The spacecraft attitude control subsystem (ACS) must be capable of providing 3-axis control and maneuverability to support engagement requirements. It must provide target tracking support to assist in payload pointing in accordance with the payload tracking dynamic range capability. Accurate real time attitude measurements in darkness and sunlight must be provided. The attitude control system must be designed to smoothly change the satellite's orientation in response to commands via a stored attitude trajectory or by commands from the payload. An additional requirement is to slew while maintaining very low jitter stabilization.

Additional ACS requirements are:

<u>LOS Angular Velocity and Acceleration</u>: The spacecraft shall be capable of generating angular velocities and accelerations great enough to satisfy Mission Engagement requirements plus a design margin of 50%.

<u>Open Loop Pointing Accuracy</u>: Open loop pointing accuracy shall be sufficient to inertially point the payload LOS to a target within the acquisition tracker FOV

<u>Base Motion Jitter</u>: Allowable base motion jitter (motion at frequencies above 3 Hz) is determined by the top level specification for jitter of the outgoing beam in the far field, and

the capability of the payload pointing control system to reject spacecraft base motion jitter. Spacecraft base motion jitter shall be small enough to satisfy the top level jitter requirement.

8.2.3 SOFTWARE

The software for the spacecraft computer shall be capable of supporting normal spacecraft housekeeping functions such as thermal control, power system management, orbit maintenance, attitude control, recorder control, and power system management. It should also support open loop pointing capabilities and a capability to handoff the attitude control system commanding to the payload computer during an engagement.

8.2.4 INSTRUMENTATION

The spacecraft shall be instrumented to allow adequate characterization of the experimental environment. Instrumentation specs shall be consistent with performance requirements. Measurements shall include base motion disturbances, thermal histories, state of health of various subsystems, and instrumentation to support command and control.

8.2.5 DATA HANDLING

Housekeeping and Payload science data are to be recovered, stored, and/or transmitted by the spacecraft during the mission. The science data acquisition and recording approach must be capable of recording/retrieving the high rate sensor data that are generated on-board the satellite during each of the engagements. The telemetry system must be compatible with the SGLS uplink and downlink rates and be capable of recording payload and spacecraft health and status data as well as specified experiment discrete signals. A storage system should also be provided for delayed execution command uploads.

8.2.6 COMMUNICATIONS (TELEMETRY, TRACKING, AND COMMAND)

Multiple contacts with the ALTAIR spacecraft shall be required to provide timely support for the large number of complex engagements planned during the mission. Low-bandwidth command control, and telemetry capability for the payload and spacecraft operations shall be provided thorough the SGLS system. The ability to downlink very high data-rate signals must be addressed to support the transmission of science and performance data. This approach shall include the recording of data on-board during the engagement for downlink at a later time and the ability to perform high data-rate transfer during the engagement itself. Uplink/downlink capability must be capable of supporting positive control operations that can control the track sensors line-of-sight during engagements to ensure safe operation and provide backup to the automated systems. Encryption of data transmissions is required to support program security requirements as defined in the ALTAIR security classification guide. A GPS receiver may be required to allow for acquisition of other space objects, for open loop pointing, and for determining the actual target location in three dimensional space.

8.2.7 ELECTRICAL POWER

The electrical power subsystem must be capable of supporting payload and spacecraft power requirements for pre-launch, launch, and on-orbit operations. During engagements the peak power demand may be more than an order of magnitude greater than during quiescent periods between engagements. The electrical power system battery recovery time shall be < 48 hours between peak draws. The electrical power system shall be designed to support a > 12-month mission.

8.2.8 THERMAL CONTROL

The Spacecraft shall provide its own thermal control independent of the Payload and shall minimize heat transfer across the spacecraft/payload interface.

8.2.9 MECHANICAL

The structural subsystem must be capable of supporting the payload configuration and spacecraft subsystems. The spacecraft/payload (satellite) must be compatible with the medium launch vehicle interface and comply with the usable weight and volume envelope. It must provide adequate stiffness, strength, and durability to survive the launch and ascent environment (loads, thermal, etc) while minimizing excessive vibrations that may be transmitted to the payload. In addition, it must comply with the payload center of gravity (CG) constraints and the launch vehicle natural frequency constraints. On-orbit structural behavior relative to the thermal and vibration environment is to be consistent with the pointing error budget.

9.0 LAUNCH VEHICLE REQUIREMENTS

9.1 GENERAL

It has been determined that a medium class launch vehicle shall be used to insert the satellite into orbit from CCAFS. The altitude/orbit selection shall be primarily driven to meet the ATP requirements against the booster target vehicles which are to be launched from CCAFS.

9.2 LAUNCH VEHICLE PARAMETERS

Specific information regarding the launch vehicle physical interface, fairing usable volume envelope, payload CG constraints, and modal frequency and mode shape constraints shall be provided in the launch vehicle payload planners guide.

9.3 LAUNCH LOADS

Preliminary ascent load data to include the vibro-acoustic environment and separation shock shall be provided to assist in preliminary payload structural sizing and design.

9.4 INTEGRATION AND LAUNCH FLOW

The integrated mission schedule must allow for nominal integration and launch flow times. These are to include satellite flow requirements from delivery to launch site to launch to orbit.

9.5 LIFT CAPABILITY

The launch vehicle lift capability shall be greater than 8500 lbs for an orbit > 370 km and an inclination > 28 degrees.

9.6 ORBITAL INSERTION ACCURACY

The launch vehicle shall be capable of inserting the ALTAIR satellite into a circular orbit to an accuracy consistent with experiment and mission requirements.

10.0 TARGET REQUIREMENTS

10.1 GENERAL

General requirements are to:

- support mission timelines
- provide a representative phenomenological environment
- provide provisions for performance scoring

For the Primary Mission booster target bodies are to be "unaugmented" in order to preserve correct phenomenological relationships. The dedicated ATP targets are to be instrumented with target boards for far field scoring. Data bandwidths and formats are to be consistent with establishing not only the far field pointing performance but also the underlying residual error contributions.

10.2 FUNCTIONAL REQUIREMENTS

Functional requirements for the primary ATP mission are for:

-Day and Night Launches
-Adequate Observation Time at Required Altitude and Velocity
-Representative Signatures
-Scalable Signatures
-Support Far Field ALTAIR Performance Scoring
-Attitude Control to Support Scoring and Phenomenology
-Active and Passive Signature Characterization
-Encrypted Data Handling (TBR)

10.3 ATP DEDICATED BOOSTER TARGET AND SCOREBOARD

An ATP dedicated booster shall be selected and launched from an appropriate launch site. For initial trades, this engagement should include the use of a MM II from CCAFS. It shall carry an instrumented scoreboard capable of measuring the far field jitter pattern of the marker beam. It must also be instrumented with optical sensors capable of sensing the illuminator laser beam to indicate the target is being illuminated during the active track periods. The booster configuration must support determining the precise hardbody location from engagement data (e.g., from an optical beacon). All measured far field performance data measured by the scoreboard is classified secret and must be handled accordingly. Day and night launch capability is required.

10.4 GROUND TARGET SITE

A Ground Target Site (GTS) shall be required to support laser beam point ahead characterization, spacecraft tracking at rate, target simulation (if required), and laser boresight verification. The GTS must have the capability of communicating with the mission ops center and ground tracking stations. Man-in-the-loop control capability in conjunction with use of the GTS is a requirement to support ground tracking engagements.

11.0 MISSION OPERATIONS REQUIREMENTS

11.1 GENERAL

The ALTAIR ground system shall be comprised of several facilities to command, control and communicate with the satellite, to plan and conduct payload operations, to verify the alignment of the satellite's optical system, to verify system operations, to respond to payload anomalies, and to process and analyze the data.

11.2 TEST SUPPORT COMPLEX (TSC)

The focal point of spacecraft operations will be the TSC at CSTC. It will provide support to the overall mission planning and detailed engagement planning. Orbit determination, prediction, command planning and command storage, memory generation and management are functions to be performed in the TSC. Spacecraft state of health analysis/maintenance and spacecraft command and control will also be conducted primarily from the TSC with orbit maintenance functions, attitude determination, attitude modeling, and maneuver planning carried out in conjunction with the Payload Operations Center (POC). Appropriate spacecraft telemetry processing and data display capabilities will be provided within the TSC to support realtime operations and non-realtime analysis throughout the mission. The use of existing CSTC assets will be maximized in order to minimize mission operations technical, schedule, and cost risks.

11.3 PAYLOAD OPERATIONS CENTER (POC)

The POC shall be the focal point and control facility for ALTAIR Mission Operations. All mission and program direction will flow from this facility to the Ground Target Site, Test Support Complex, Man-in-the-loop operations, and Target Launch operations. All payload command planning will be conducted from the POC where mission and engagement timelines will be planned, generated, and executed. Detailed engagement design, maneuver generation, and attitude determination, attitude modeling, and maneuver planning are shared functions to be carried out in conjunction with the Test Support Complex. Payload state-of-health analysis and maintenance will be conducted within the POC to support the engagement timeline. Appropriate displays and data processing capability shall be provided within the POC to support realtime operations and non-realtime analysis for anomaly resolution throughout the mission.

11.4 SCIENCE OPERATIONS CENTER (SOC)

The SOC shall be designed to support all science activities for the ALTAIR mission. The SOC shall be capable of providing rapid turn around of collected experimental data to provide quick look analysis and reporting in support of mission replanning. The SOC shall also be capable of performing long term, detailed data analysis. The SOC shall provide the required data analysis capabilities such as data acquisition, data recording, data processing, archival, access to lab and system test results, and simulation capability. It is desired that the SOC shall be located in the vicinity of the GTS.

11.5 ENGINEERING SUPPORT FACILITY (ESF)

The ESF shall provide day-to-day engineering support, as required, to the POC and the SOC. Prior to the mission operations phase, the ESF shall be the main location for payload hardware and software testing. The ESF shall also house the ALTAIR end-to-end simulation. All design documentation and as-built drawings shall be archived at the ESF to support satellite anomaly resolution activities.

11.6 GROUND STATION COMMUNICATION

An S-band command and control capability is required at or near the Ground Target Site and target launch vehicle sites. This capability is required to communicate with the satellite during ground target and target launch vehicle engagements. It must support telemetry receipt and command transmission for MITL (positive control) operations. It is envisioned that this requirement will be met with a CSTC controlled deployable asset at the ground target site for the length of the ALTAIR mission. At ETR, use of the CSTC controlled Transportable Vehicle Checkout System (TVCS) is planned. If these existing assets cannot support ALTAIR mission requirements, an additional CSTC controlled deployable asset may be required.

12.0 GENERAL SYSTEM ENGINEERING REQUIREMENTS

12.1 GENERAL

This section addresses those requirements associated with the system engineering process for design and testing the ALTAIR satellite which are not treated elsewhere in this document and which are primarily technical rather than managerial issues.

12.2 MISSION BUDGETS

Budgets shall be maintained for major system parameters which must be allocated to major subsystems, and for which contingency reserves must be managed. These budgets shall be established as early in the design process as appropriate. The definition of allocations and reserves shall derive from trade studies and formal establishment shall occur as major systems are selected (e.g., the launch vehicle) or their design requirements frozen (e.g., processors). Budgets shall be maintained for weight, power and energy, pointing error, propellant, data rates and storage, and reliability.

12.3 MISSION ASSURANCE

12.3.1 OVERALL DESIGN REQUIREMENTS

Satellite design performance and system test verification must support the mission lifetime requirement. Ground systems design shall be consistent with rapid assessment of payload and spacecraft performance, troubleshooting, and reconfiguration of on orbit systems. Diagnostics shall be built into the spacecraft and payload to allow self-test capability of critical subsystems.

12.3.2 RELIABILITY/QUALITY ASSURANCE

12.3.2.1 DESIGN PHILOSOPHY

The ALTAIR design philosophy for reliability and quality assurance is to use high reliability parts (grade level 2) where possible and to utilize redundancy to increase reliability where such use is indicated. Single point failures are not apriori justification for redundancy.

12.3.2.2 R&QA PLAN

The ALTAIR R&QA Plan shall define requirements and criteria for assuring that the materials, parts, designs, and manufacturing processes are consistent with the environment and performance specifications. It shall define facilities, equipment and procedures for assuring that the inspection testing, analysis and simulation of the satellite at system, subsystem, part and material level are adequate. It shall define the technical reviews, technical expertise, and documentation required to assure the reliability and quality of the ALTAIR satellite.

12.3.3 SENSOR CALIBRATIONS

It is essential that the sensor system aboard ALTAIR be characterized and calibrated so that a valid radiometric understanding of the measured target and background signatures can be made. Appropriate data shall be collected for each sensory system during component test, subsystem tests, and end-to-end system tests including uniformity tests and measurements of the system modulation transfer function (MTF). Calibration procedures shall be performed on-orbit to correct for day-to-day drift, temperature variations, and sensor aging effects. A complete documentation set shall be provided to the end product data users to ensure full understanding of experimental data.

12.3.4 ERROR BUDGET FLOWDOWN

A balanced and verifiable error budget flowdown tree shall be developed and maintained under configuration control by the Chief Engineer. Baseline error estimates shall be traceable to an identifiable subsystem and component level technology. Total system performance shall be predicted and validated by an integrated system simulation. Achieved values for the elements of the error budget shall be provided (as available) by component measurements, integrated system experiments, or analysis.

12.3.5 SIMULATIONS/MODELS

The ALTAIR development shall require a variety of simulations and models of different size, complexity, and specialization, including a complete end-to-end simulation of the ALTAIR vehicle and mission. Simulations shall be coordinated to avoid unnecessary duplication and aid in verification of math models and simulation results. This coordination shall not constrain the analyst in specializing his/her simulation to address unique problems.

The end-to-end simulation shall be the design reference model for ALTAIR and shall be maintained under configuration control. It shall be used to characterize performance during development. The models shall be verified by test and analysis prior to flight,and the simulation will be used for mission planning and performance prediction. As flight data becomes available the simulation models shall be further updated. The end-to-end simulation shall eventually be a completely documented model of the ALTAIR vehicle and mission traceable to the flight test data results.

12.4 SOFTWARE

A single point of control shall be established for software management and a software development plan created which defines such criteria as language, architecture, verification criteria and techniques, and documentation requirements.

Requirements shall vary widely from very stringent for flight software to none for a desktop analysis program. Five general categories of controlled software modules are: flight, ground support, prelaunch, operations, and simulation software.

12.5 SYSTEM TEST REQUIREMENTS

12.5.1 TEST PLANS

A comprehensive test plan including such elements as schedules, facilities, equipment environments, and training shall be developed. This plan shall also address such issues as the objectives and rationale of the program as it relates to technical risks, operational issues, and system performance. The plan shall show how testing outside the ALTAIR program, such as vendor testing, and tests completed on subsystems used from other programs, is utilized. The plan shall explain the relationship of the various simulations, subsystem tests, and integrated systems test to the mission objectives. More detailed test plans shall be prepared for the individual test facilities and test programs.

12.5.2 GROUND TESTING

The ground test program shall include acceptance testing, qualification testing, environmental testing, integration testing, and development testing. The goals of this testing shall be to validate the system design, perform complete system characterization and calibration of the satellite, validate system simulations, ensure functional capability prior to launch, ensure compatibility with command and control ground systems, and satisfy launch vehicle interface and other mission design constraints (e.g., safety).

Integration testing shall support and monitor payload, spacecraft and satellite integration . The purpose of the test shall be to assure that elements which operated according to specifications continue to do so when integrated with other elements into larger systems. Additionally these tests shall establish the functional capabilities and characteristics of the integrated system which cannot be measured prior to that time.

Environmental testing shall be performed to demonstrate that the ALTAIR system shall survive adverse environments, such as the launch environment, and shall function properly in the space environment.

12.5.3 END-T0-END TESTING

End-to-end functional and performance testing of the optical payload, and the integrated satellite, is required against simulated engagements prior to launch. Representative simulated targets shall be required as part of this testing. Functional tests shall include exercising the actual flight software in as realistic conditions as possible (e.g., it may not be possible to slew the actual satellite but the slew commands can be simulated). Performance testing shall include far field jitter measurements and control subsystem characterization (frequency responses and error measurements). The optical subsystem shall be tested to verify optical quality, transmission, and other key design factors. Special attention should be paid to measuring base motion disturbances and characterizing LOS stabilization to on-orbit levels.

12.6 CONTAMINATION

12.6.1 GENERAL

A contamination control plan shall be developed for ALTAIR which covers its design, fabrication, assembly, test, storage, transportation, launch, and operation. This plan shall contain requirements, specifications and procedures covering the following: material selection, facility design and operation, environments (including clean rooms and other areas), contamination testing and monitoring, allowable cleanliness levels, bakeout procedures, contamination budgets, appropriate actions to be taken when allowable levels have been exceeded, and documentation. The plan shall identify contamination issues requiring analysis and a recommended approach.

12.6.2 SOURCES

Sources of contamination consist of: materials used in the manufacture of the spacecraft, particularly organic materials; environment contamination during manufacture, assembly, storage, test and transportation; and environmental contamination during operation on orbit.

12.6.3 DESIGN

Contamination shall be reduced by appropriate design. This includes material selection and physical design to minimize the effects of volatile materials. Thermal vacuum bakeout of hardware shall be used to reduce contamination from outgassing. The use of covers, bags, filters and similar devices to trap contaminants, or direct them away from sensitive optical surfaces are examples of other design procedures for reducing contamination.

12.6.4 HANDLING

Controlled environments and procedures shall be used to control contamination. Environments shall vary from clean rooms with strict standards for equipment, materials, dress, and procedures to manufacturing areas where grinding or machining may product large quantities of contaminants. In every specialized area the environment, equipment, and procedures shall be controlled in accordance with the contamination control plan. As parts and assemblies flow into increasingly cleaner environments the procedures shall assure that they are cleaned and packaged to conform to the higher standards.

12.6.5 STANDARDS AND BUDGETS

Budgets and standards shall be established to control cleanliness in the manufacture and operation of ALTAIR including tolerances and waiver procedures.

12.6.6 TEST, ANALYSIS, AND DOCUMENTATION

Test and monitoring procedures shall be developed for assuring that the environments and the manufactured or assembled products are in accordance with requirements. Documentation shall include test records, standardized procedures, and a log of clean room status including any unusual contaminating occurrences and the corrective actions used to restore the facility and its contents to an acceptable level of cleanliness. Documentation shall also include the results of studies and analyses of cleanliness issues.

12.7 SATELLITE ENVIRONMENTS

The ALTAIR satellite shall be subject to many adverse environmental conditions: thermal, vacuum, vibration, radiation, contamination, electrostatic, and electromagnetic. Specifications, design guidelines, tests and analyses shall be developed to assure that the ALTAIR satellite shall survive and operate properly in these environments. In addition to the launch and on orbit environments,the manufacturing, storage, transportation, assembly and test environments shall be addressed.

12.8 SAFETY, SECURITY, AND ENVIRONMENTAL IMPACT

12.8.1 SAFETY

Safety requirements for the ALTAIR program shall include, in addition to the established industrial standards for the workplace, special safety considerations for laser operation and for spacecraft operation during launch, on orbit, and subsequent reentry.

12.8.1.1 LASER SAFETY

Appropriate action shall be taken to ensure that all laser eye safety requirements are met. Laser eye safety requirements include safe eye exposure distances, laser beam footprints on the ground, ground testing of components and systems, on-orbit operations approach, and the proper documentation. Appropriate actions shall be taken to ensure the safety of all related hardware from laser damage.

12.8.1.2 LASER CLEARING HOUSE AUTHORIZATION

The project office shall work closely with the Laser Clearing House to ensure that appropriate procedures are implemented and predictive avoidance requirements are met. Positive control of the laser line of sight during any engagement to a prescribed angular volume shall be provided.

12.8.1.3 LAUNCH SAFETY ASSESSMENT

The Air Force project office shall ensure that all appropriate safety requirements as assessed by the launch control authority shall be met for both the launch vehicle and target vehicles.

12.8.1.4 SPACE DEBRIS ANALYSIS

General analysis of the probability and consequences of (i) a collision between the spacecraft and a target booster, (ii) intentional destruction of any of the target systems, (iii) other possible equipment failures which could pose a space hazard shall be performed.

12.8.2 SECURITY REQUIREMENTS

12.8.2.1 GENERAL GUIDELINES

SDIO shall serve as the risk acceptance authority and shall generate the ALTAIR security classification guide. In general ALTAIR is an unclassified experiment with mission objectives and plans generally open for release. The program emphasis shall be on regarding ALTAIR as an experiment with unclassified raw data with selected performance data being classified.

12.8.2.2 EXPERIMENTAL DATA

Raw data from the experiment subsystems shall be treated as unclassified unless otherwise designated. Reduced data with engineering units and performance results shall be classified in accordance with the ALTAIR Security Classification Guide. Imaging data from onboard sensors may be classified for certain targets. Onboard encryption capability shall be provided and downlink bandwidths shall be compatible with experiment requirements.

12.8.2.3 EXPERIMENT HARDWARE

All experiment hardware is unclassified including exterior views and drawings.

12.8.2.4 PHYSICAL SECURITY

Appropriate action shall be taken in accordance with the ALTAIR Security Classification Guide to ensure that physical security shall be provided during system test, integration at the launch site, launch ops, and on-orbit mission operations.

12.8.2.5 DATA ENCRYPTION

Data encryptors shall be compatible with real time downlinking of spacecraft health and status data and critical payload performance parameters during the engagements.

12.8.3 ENVIRONMENTAL REQUIREMENTS

12.8.3.1 ENVIRONMENTAL ASSESSMENT

The Air Force project office shall ensure that all appropriate analysis and documentation is provided to support Environmental Assessments (EA) at the impacted ground, launch, or other support sites. Particular emphasis must be placed on the engagements that include the active illumination of the ground target and calibration sites.

13.0 SCIENCE DATA REDUCTION AND ANALYSIS

13.1 PREMISSION SIMULATION AND PREDICTION

An end-to-end simulation of the ALTAIR space experiment shall be developed and maintained under configuration control by the Chief Engineer. The experiment simulation shall be used to assist in system design, predict experiment performance, aide in system test trouble shooting, support on-orbit mission operations, and post-mission to validate system design with experimental data.

An important part of this activity shall be to determine what modifications to the ATP/FC algorithms are required between engagements to improve the probability of mission success and obtain the most useful data from the program.

13.2 SYSTEM TEST RESULTS

End item test data, appropriate lab measurements, and system test results shall be maintained in a data archival configuration to support simulation efforts and post-mission data analysis. As new data is collected, both pre-mission and post mission, it shall be used to update system simulations, error flowdowns, and performance predictions.

13.3 KEY MEASUREMENTS

To fully understand the ATP system performance and phenomenology data collected, it is important that the appropriate set of instrumented signals for both the spacecraft and payload subsystems be identified early in the design process. The data collected should include critical signals that support the systematic understanding of the contributors to the resultant ATP system performance.

13.4 QUICK LOOK, LONG LOOK ANALYSIS AND REPORTING

A science quick look analysis shall be required within 48 hours of each engagement. Initial reporting of payload and spacecraft health and status is required within 1 hour of each engagement. The science quick look shall include system and subsystem performance, comparison with pre-engagement simulations, overall system assessment, recommendations for future engagement and problem (if any) resolution. Detailed subsystem analysis shall be performed and reported within one week after major engagement. Verified and validated data for extended analysis (e.g., phenomenology data) shall be reported via technical summaries (provided at quarterly intervals).

A preliminary assessment of the extent to which test data meet scalability and traceability requirements shall be performed. If changes to the plans for future flights are required these shall be identified.

13.5 ANOMALY REPORTING AND RESOLUTION

The Science Operations Center anomaly resolution shall be directed by the Mission Scientist to ensure that mission objectives are being met. The Chief Engineer shall be responsible for ensuring proper implementation of appropriate actions that affect experiment configuration changes. The Chief Engineer shall be responsible for directing engineering support in trouble shooting and workaround proposals.

13.6 FINAL REPORT REQUIREMENTS

A final report that directly addresses the critical issues associated with the ALTAIR experiment shall be generated within 6 months after mission completion. This report shall be delivered in conjunction with the final data archival package that is to be provided to the archival center. The final report shall provide an assessment of mission success, analysis of the data collected, lessons learned, and recommendations for follow-on activities to support DEW systems development.

13.7 DATA ARCHIVAL

SDIO places strong emphasis on the importance of verifying and validating all appropriate mission data collected. The Mission Scientist for ALTAIR shall ensure that final data products are appropriately processed in accordance with procedures outlined by the lead SDIO data archival center. The lead center for the ALTAIR mission shall be designated by the ALTAIR Program Manager. A data management plan shall be developed by the Data Manager and shall serve as the guide for the appropriate data collection, processing, and archiving activities.

LIST OF ACRONYMS

ACS	Attitude Control System
AFSCN	Air Force Satellite Control Network
ARTS	Automated Remote Tracking Station
ATP	Acquisition, Tracking, and Pointing
ATP/FC	Acquisition Tracking Pointing/Fire Control
CCAFS	Cape Canaveral Air Force Station
CG	Center of Gravity
CPCA	Camp Parks Communication Annex
CSTC	Consolidated Space Test Center
DEW	Directed Energy Weapon
EA	Environmental Assessment
ELV	Expendable Launch Vehicle
EPD	Experiment Planning Document
ERD	Experiment Requirements Document
ESF	Engineering Support Facility
ETR	Eastern Test Range
FC	Fire Control
FOV	Field of View
GCS	Ground Calibration Site
GPS	Global Positioning System
GTS	Ground Target Site
H&S	Health and Status
IAW	In Accordance With
ICBM	Intercontinental Ballistic Missile
IFOV	Intermediate Field of View
IPP	Impact Point Prediction
IRBM	Intermediate Range Ballistic Missile
IRU	Interial Reference Unit
IT	Intermediate Tracker
IV&V	Integration Verification and Validation
JHU/APL	Johns Hopkins University/Applied Physics Laboratory
kbps	kilobits per second
LOS	Line of Sight
LRF	Laser Range Finder
LV	Launch Vehicle
Mbps	Megabits per second
MRD	Mission Requirements Document
MTF	Modulation Transfer Function
MWIR	Medium Wave Infrared
NEA	Noise Equivalent Angle
NPB	Neutral Particle Beam
PA	Point Ahead
PAF	Payload Attachment Fitting
PBV	Post Boost Vehicle
PIT	Passive Intermediate Tracker
PL	Phillips Laboratory
POC	Payload Operations Center
PSD	Power Spectral Density
RADC	Rome Air Development Center
RME	Relay Mirror Experiment
RMS	Root Mean Squared
SBL	Space Based Laser

SDIO	Strategic Defense Initiative Organization
SDIO/TND	Directed Energy Directorate
SGLS	Space to Ground Link System
SNR	Signal to Noise Ratio
SOC	Science Operations Center
SOH	State of Health
STR	Space Test Range
SWIR	Short Wave Infrared
TBD	To Be Determined
TBR	To Be Reviewed
TCS	Thermal Control System
TFE	Tracker Field Experiments
TSC	Test Support Complex
TTP	Threat Tube Prediction
TVCS	Transportable Vehicle Checkout System
UV	Ultraviolet
VAFB	Vandenburg Air Force Base
WSMR	White Sands Missile Range
WTR	Western Test Range

APPENDIX A - COLLATERAL GOALS FOR ALTAIR

APPENDIX A
COLLATERAL GOALS FOR ALTAIR

Six collateral goals have been developed for ALTAIR which represent additional capability for ALTAIR and the opportunity to demonstrate critical ATP functions and technology. The six collateral goals address technology issues identified by SDIO (see Appendix B) but which are not addressed by the primary mission. In addition, some of the collateral goals enhance or add to the data already being gathered by the primary mission. Engagements against additional targets (liquid boosters, post boost vehicles and midcourse objects) and satellite capability and therefore are not considered for inclusion into the mission until so directed (and funded) by SDIO. Figures A.1, A.2 and A.3 depict candidate engagements.

COLLATERAL GOAL 1 - *PLUME PHENOMENOLOGY*
Collection of additional plume phenomenology data in wavebands other than those required to meet the primary mission objective.

This will require modification to the payload to include additional sensors or enhanced sensor capability. Of primary interest is a UV spectrometer; of lesser priority is a UV imager. Enhanced IR capability is of lowest priority.

COLLATERAL GOAL 2 - *LIQUID FUELED BOOSTER TARGET ENGAGEMENT*
ATP/FC experiment and the collection of phenomenology data against a representative liquid fueled booster target.

Preliminary studies of candidate booster targets have recommended two dedicated launches of a Titan II for ALTAIR engagements. Because the signature of liquid fueled rockets is more stressing to model, particularly in the UV, and visible, the addition of UV sensors should be done if this goal becomes a requirement.

COLLATERAL GOAL 3 - *MIDLATITUDE BACKGROUND DATA*
Collection of mid-latitude background clutter data.

A significant amount of midlatitude background clutter data can be collected by the satellite configuration developed for the primary mission. The orbital inclination will determine the maximum latitude that can be achieved. If additional sensors are added as discussed in B.2, the achievement of this goal will be further enhanced.

COLLATERAL GOAL 4 - *POST BOOST VEHICLE TARGET ENGAGEMENT*
ATP/FC experiment and the collection of additional target phenomenology data against a representative post-boost vehicle (PBV).

Acquisition and tracking requirements will be more stringent than for the primary mission. If the hardware design for the primary mission is adequate with the sensor suite enhancements discussed in Goal #1, then no further payload hardware changes appear necessary. A new target, possibly launched from a site other than ETR, will require significant additional payload software and mission operations activity.

COLLATERAL GOAL 5 - *MIDCOURSE OBJECT TARGET ENGAGEMENT*
ATP/FC experiment against a representative midcourse object using functions traceable to an NPB weapon system.

In addition to new targets, possibly different launch vehicles and launch sites, this goal will probably require payload sensor upgrades beyond what is required for the primary mission (better inertial, range, and absolute position measurements for example). There will be significant increases in mission operations activity as well.

COLLATERAL GOAL 6 - *TRAJECTORY PROJECTION, METRIC DISCRIMINATION, HANDBACK*
Experiments against representative PBV's and midcourse objects that address the feasibility of deployment trajectory projection, metric discrimination, and handback.

This goal requires much better inertial, range, and absolute position measurements than the primary mission. New software algorithms, increased mission operations activity, and extensive experimental data analysis will be required to achieve this goal.

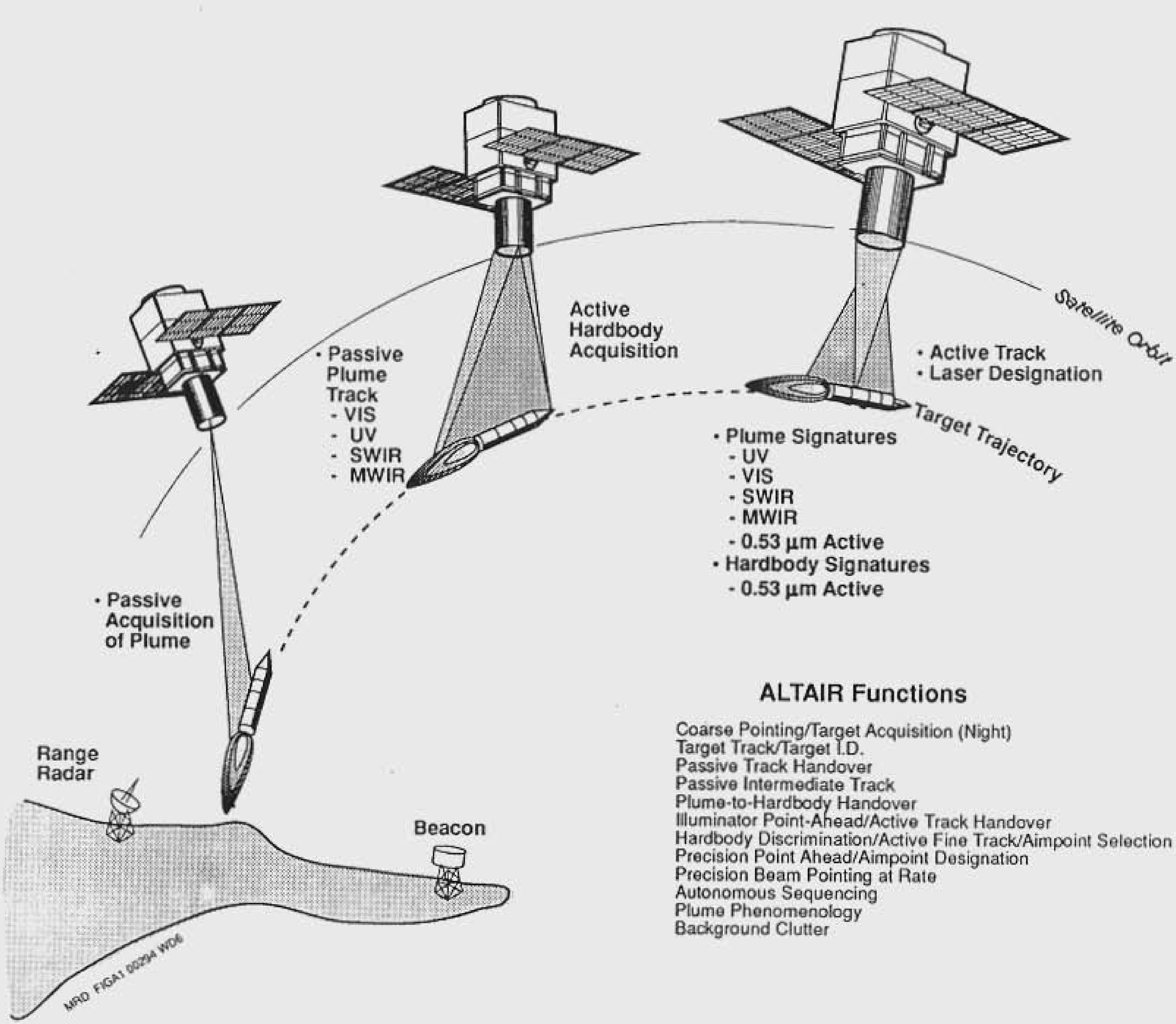


Figure A-1. Liquid-Fueled Booster Engagement (Coillateral Engagement #1)

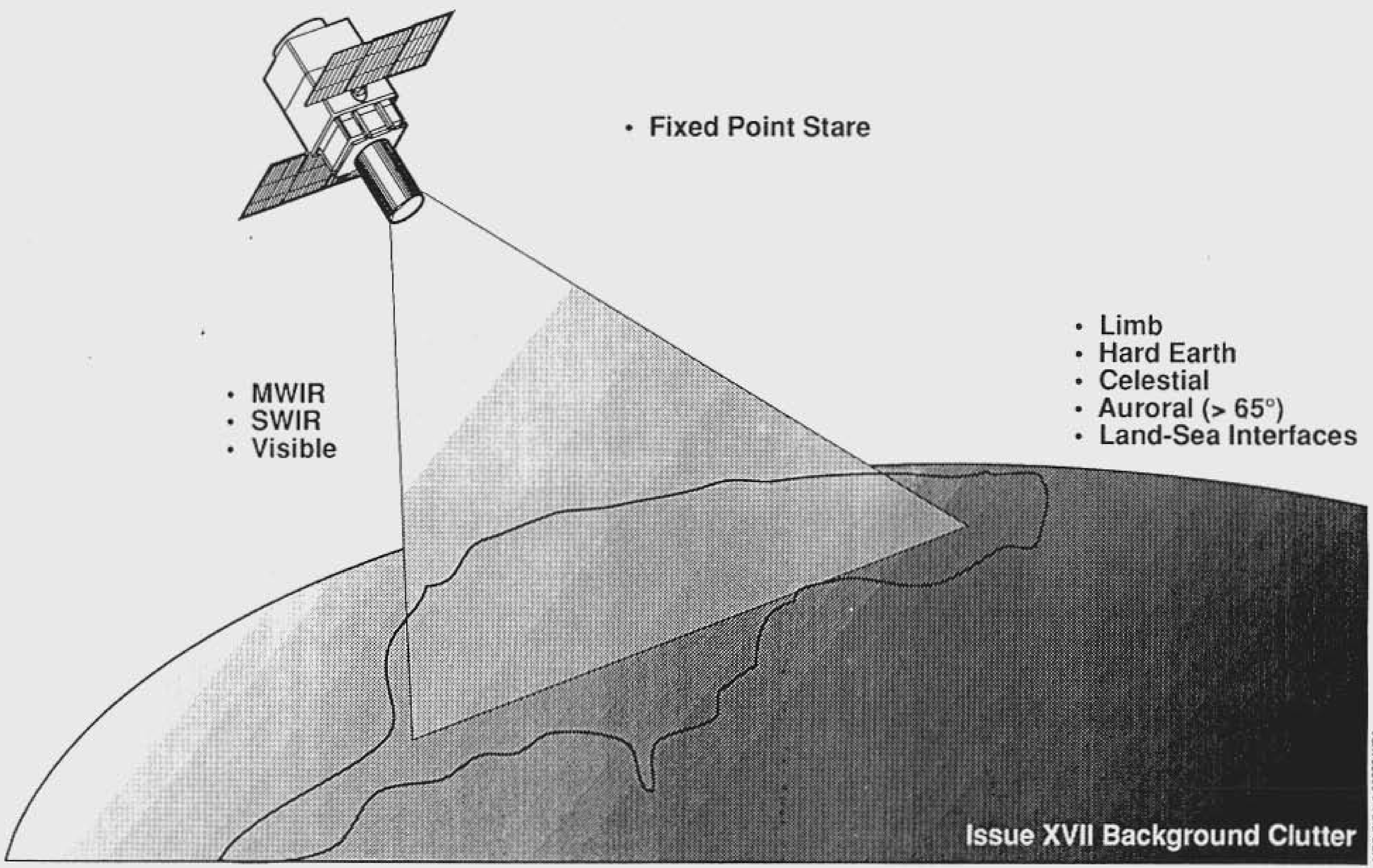


Figure A-2. Background Phenomology Data Collection (Collateral Engagement #2)

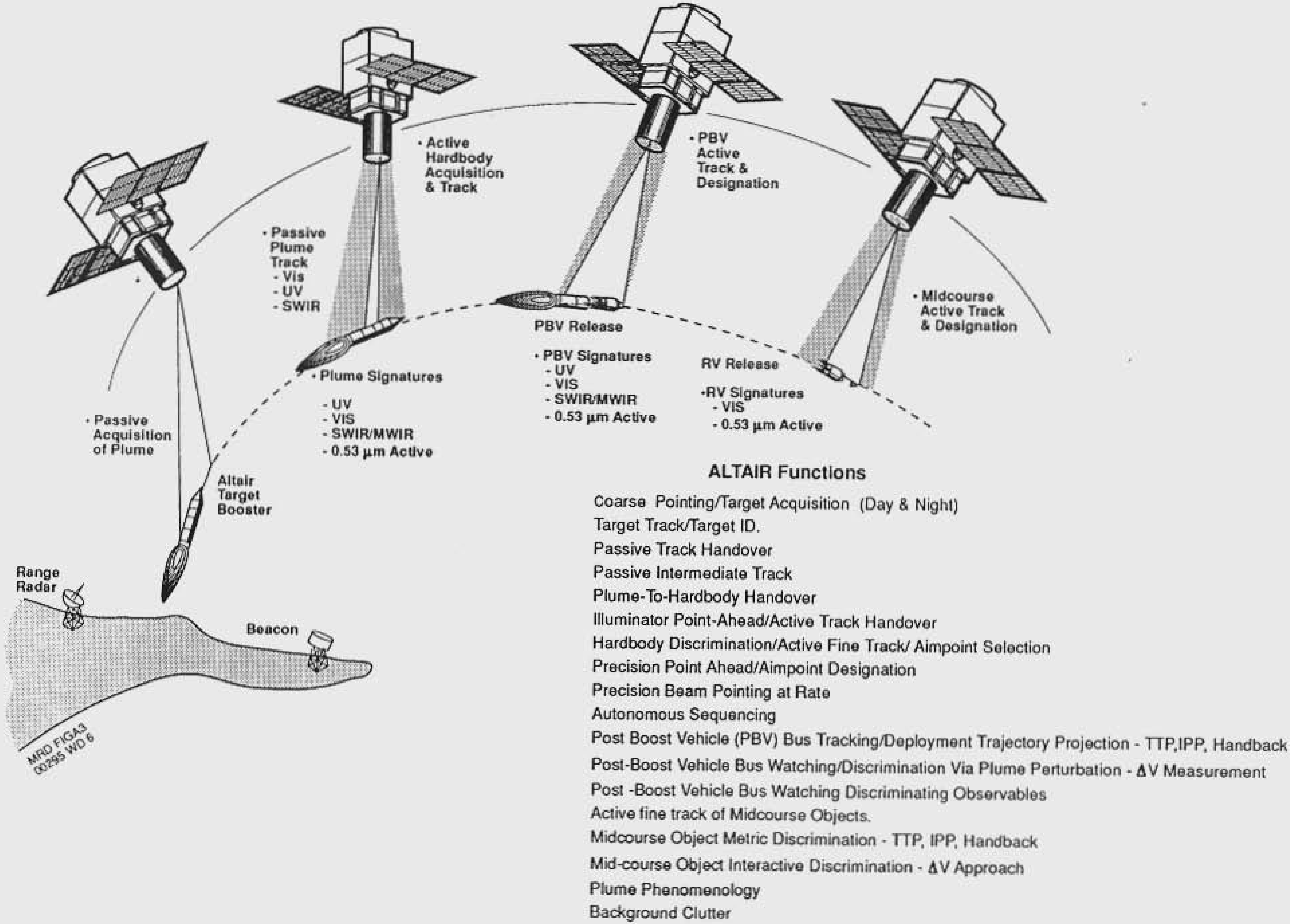


Figure A-3. PBV/Midcourse Object Engagement (Collateral Engagement #3)

APPENDIX B - CRITICAL TECHNICAL ISSUES FOR ATP SYSTEMS

APPENDIX B
CRITICAL TECHNICAL ISSUES FOR ATP SYSTEMS

The SDIO Experiment Planning Document for ALTAIR (SDIO document dated April 1991) lists 18 critical technical issues for Acquisition, Tracking, and Pointing (ATP) technology in Directed Energy Weapons (DEW) systems. The ALTAIR Primary mission (booster engagement) is configured to address issues 1-10 and 17-18 to the extent that the ALTAIR satellite sensors, configuration, and trajectory permit. Collateral ALTAIR goals have been developed to address the remaining issues although the fidelity of issue resolution is lower because of constraints on the ALTAIR design (e.g. no LWIR sensor).

Satisfactory answers to the critical issues will be an important measure of success for the ALTAIR experiment. Two important experiment design factors which will determine the degree of issue resolution are scalability and traceability. Scalability means that the appropriate engineering parameters that measure system performance, size, and rates are in correct ratio with respect to actual DEW system requirements. Traceability means the functions, methods, and design approach demonstrated in the experiment are relevant and transferable to proposed DEW system designs. Scalability and traceability are top level requirements for the ALTAIR mission.

Critical Issues addressed by the Primary mission are:

ISSUE I. Coarse Pointing/Target Acquisition
Given the Battle Manager provided target state vectors, can the ATP/FC system point the spacecraft with sufficient accuracy that the wide field-of-view acquisition (capture) sensor can detect the target (booster, PBV)?

ISSUE II. Target Track/Target ID
Can the individual targets (boosters, PBVs) be reliably tracked and typed in the presence of hard earth, earth limb, and celestial background clutter using the acquisition sensor imagery?

ISSUE III. Passive Track Handover
Can the acquisition tracker determine the line-of-sight to the target (booster, PBV) with enough accuracy and stability to effect a handover to the passive intermediate resolution tracker?

ISSUE IV. Passive Intermediate Track
Does the plume signature of a boosting target (booster, PBV) provide robust enough phenomenology to provide a stable track source for a passive intermediate resolution tracker?

ISSUE V. Plume-to-Hardbody Handover
Does the plume signature of a boosting target (booster, PBV) provide robust enough phenomenology to allow a fire control processor, using the imagery from an intermediate resolution tracker to accurately determine the hardbody location "relative" to the passively tracked target scene?

ISSUE VI. Illuminator Point-Ahead/Active Track Handover
Can an ATP/FC system accurately point the illuminator beam at the target hardbody (booster, PBV, midcourse object) by properly accounting for both the physical separation between the passive track point and the hardbody, as well as the point-ahead offset due to the speed of light?

ISSUE VII. Hardbody Discrimination/Active Fine Track/Aimpoint Selection
Does the illumination of the boosting target (booster, PBV) provide robust enough phenomenology to allow an active tracker to discriminate the hardbody from the plume, and to actively track the hardbody with sufficient precision for jitter stabilization, and to allow the aimpoint selection processor to choose an aimpoint for a directed energy weapon?

ISSUE VIII. Precision Point Ahead/Aimpoint Designation
Can an ATP/FC system accurately and precisely offset the DEW line-of-sight by properly accounting for both the physical separation between the active track point and the aimpoint selection, as well as the point-ahead offset due to the speed of light?

ISSUE X. Autonomous Sequencing
Can a DEW fire control system conduct end-to-end autonomous acquisition, tracking, and pointing control?

ISSUE XVII. Plume Phenomenology
Do particular bands of MWIR, SWIR, visible, or UV offer advantages for passive acquisition and precision tracking of boosters and PBV's and for accurately determining the hardbody location "relative" to the passively tracked target scene?

ISSUE XVIII. Background Clutter.
Do particular bands of SWIR, MWIR Visible, or UV offer advantages in reducing background clutter for acquisition and tracking systems for DEW systems?

Critical issues also included in the EPD but not addressed directly by ALTAIR are:

ISSUE XI. Post Boost Vehicle (PBV) Bus Tracking/Deployment Trajectory Projection - TTP, IPP, Handback
Can a passive intermediate tracker, active fine tracker, and high resolution laser range finder determine the state of vectors of a thrusting PBV with enough accuracy to provide threat tube prediction (TTP);,impact point prediction (IPP), and handback data to other weapon system platforms for reacquisition?

ISSUE XII. Post-Boost Vehicle Bus Watching/Discrimination via Plume Perturbation - Delta V Measurement
Can an active fine tracker and and high resolution laser ranger measure the Delta V of a deployed object with respect to the PBV with enough accuracy to infer the mass of the ejected object?

ISSUE XIII. Post Boost Vehicle Bus Watching - Discriminating Observables
Are there discriminating features associated with either active signatures or passive UV, visible, or IR signatures which have utility in discriminating RV's from decoys?

ISSUE XIV. Active Fine Track of Midcourse Objects
Does the reflected energy from the illumination of a midcourse object provide robust enough phenomenology to allow active tracking of the midcourse object with sufficient precision to stabilize the line-of-sight for a directed energy weapon?

ISSUE XV. Mid-Course Object Metric Discrimination - TTP, IPP, Handback
Can an active fine tracker, and high resolution laser range finder measure the midcourse object state vector with sufficient accuracy to provide threat tube prediction, impact point prediction, and handback data to other SDS weapon system platforms for target reacquisition?

ISSUE XVI. Mid-Course Object Interactive Discrimination - Delta V Approach
Can a direct detection laser radar measure the Delta V of a midcourse object well enough to be used in interactive discrimination?

APPENDIX C - SAMPLE ALTAIR BOOSTER ENGAGEMENT (MM II CHARACTERISTICS)

Minuteman II performance removed to expedite clearance of document for public release

APPENDIX D - SUMMARY OF REQUIREMENTS FOR PRIMARY MISSION

APPENDIX D
SUMMARY OF REQUIREMENTS FOR PRIMARY MISSION

Top Level Requirements

Quasi-static Marker Laser Beam Pointing Bias Error	Classified
Dynamic Marker Laser Beam Pointing Drift Error	Classified
Dynamic Marker Laser Beam Pointing Jitter Error	Classified
Tracker Traceability	Hardbody geometric image on fine track focal plane and the plume image on the passive intermediate tracker shall subtend a number of pixels representative of an operational DEW system
Plume to Hardbody Handover	$\leq$ 10 illuminator pulses
Targets	Threat representative
Launch Site	CCAFS
Orbital Altitude	> 370 km
Orbital Inclination	$\geq 28°$
Eccentricity	Circular
Launch Vehicle	Medium Class
Recharge batteries following most stressful engagement	< 48 hrs
Thermal recovery following most stressful engagement	< 48 hrs
Satellite Reliability	> .85 for > 12 months
Reporting (following an engagement)	
Health & Status	1 hr
Quick Look Analysis	48 hrs
Detailed Subsystem Analysis	1 week
Final Mission Report	6 months after mission complete