NASA-CR-204042

35

022764

Analysis of Space Coherent LIDAR Wind Mission

Contract No. NAS8-38609

Delivery Order No. 151

Contract Period 9/22/95 - 9/21/96

Final Report

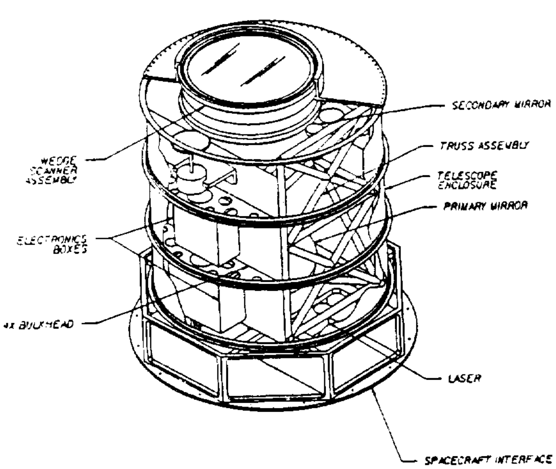
Date 3/28/97

Gary D. Spiers
Center for Applied Optics
University of Alabama in Huntsville
Huntsville
AL 35899
(205) 890 6030 ext. 420

1) IPO Related Activities

A design concept for a 100 mJ/0.5 m 2 μm coherent Doppler lidar feasability demonstration mission was developed with Air Force Phillips Laboratory. The mission was jointly proposed by NASA Marshall Space Flight Center, Airforce Phillips Laboratory and NOAA's National Center for Environmental Prediction to the Integrated Product Office (IPO) responsible for the National Polar-Orbiting Operational Environmental Satellite System (NPOESS). NPOESS is the converged NOAA and DOD weather satellite system intended to replace the separate NOAA and DOD satellites currently in use. The first NPOESS launch is anticipated to take place in the 2007/8 time frame and the IPO is currently looking for potential new sensors that will help to reduce the number of Unaccommodated Environmental Data Records (UEDR) of the current system. The measurement of winds is currently the highest priority UEDR.

After submission of the mission concept, the IPO requested merging of this proposal with an earlier one submitted by NASA MSFC, JPL and NOAA for lidar component technology development and the development of a roadmap showing how the lidar technology would be ready for the 2007/8 time frame. As a consequence of the merging of these proposals and the development of a viable roadmap to an operational mission the requirements for the initial demonstration mission changed somewhat. The following portion of this section briefly summarises the initial design presented by NASA MSFC, AF/PL and NOAA NCAR to the IPO and a subsequent report will address the revised design that is currently under development.



Laser Wavelength, (μm)	2.06
Laser Pulse Energy, (J)	0.1
Laser Pulse Length, (μs)	0.2
Laser PRF, (Hz)	10
Telescope Diameter, (m)	0.5
Laser Beam Nadir Angle, (deg)	30
Scan Type	Conical
Detection Technique	Heterodyne
Data Rate, (Mbit/s)	~4
Instrument Diameter, (m)	1.3
Instrument Height, (m)	1.4
Instrument Mass, (kg)	230
Instrument Power, (W)	400

Figure (1-1) Instrument Schematic and Parameters

1.1 Description of the Instrument

The proposed instrument, shown schematically in Figure (1-1), is a Shuttle bay mounted experiment designed to serve as a critical demonstration of Doppler wind lidar technology capability in space. The instrument was based on one of the AEOLUS designs developed previously[1]. The instrument does its own pointing but must be Earth looking. A low altitude (~350 km), high inclination orbit (~50 deg.) was preferred to maximize both signal-to-noise ratio (SNR) and Earth coverage. The orbital parameters (altitude, inclination, etc.) were, however, flexible although they should be known sufficiently well in advance to configure instrumentation hardware for proper lag-angle compensation of the signal.

The natural atmospheric aerosol backscatter varies spatially and temporally by several orders of magnitude and consequently, signal sensitivity can be traded for a reduced size telescope and laser (hence lower cost) with resultant loss of wind measurements in areas having aerosol backscatter below the instrument sensitivity threshold. The proposed Shuttle instrument (0.5 m telescope, 100 mJ laser, low orbital altitude) attempts to minimize the mission cost while still providing scientifically valuable atmospheric wind data.

The key elements of this technology demonstration mission would address the technical issues which are critical to a successful Doppler lidar being flown in space. Key aspects of the envisioned system are the use of fiber optics and solid state diode laser pumps. This will allow the demonstration of a system that is more robust, compact, and lighter than previously proposed space-based coherent Doppler wind lidar systems. The use of a fiber optics net eliminates many mirrors and beamsplitters from the system and thus reduce failure modes due to misalignment and contamination. The critical photomixing of the received and local oscillator signals can also be accomplished within the fiber net, eliminating any possibility of post launch misalignments from occurring. The array of laser diodes used to pump the solid-state laser crystal permit the system to be "fail soft" such that if a diode pump were to fail, the system's performance would only be fractionally affected. Depending upon the final laser transmitter design, it may also be possible to couple the diode pump energy into the laser transmitter crystal via fiber optics. This would allow the remote placement of the diode pump module(s) away from thermally sensitive elements to a location where the waste heat could be most efficiently removed.

1.2 Performance Evaluation of the Instrument

The following plots summarise the anticipated performance of the instrument for a mid-latitude summer atmosphere. The first plot, Figure (1-2), shows the backscatter sensitivity as a function of altitude for a 1 km vertical range resolution. This range resolution is adequate through most of the atmosphere except in the boundary layer where the higher turbulence makes a shorter range resolution of ~250 m desirable. Figure (1-3) shows the effect of range resolution on sensitivity. We can combine these two figures into a summary table (Table (1.1)).

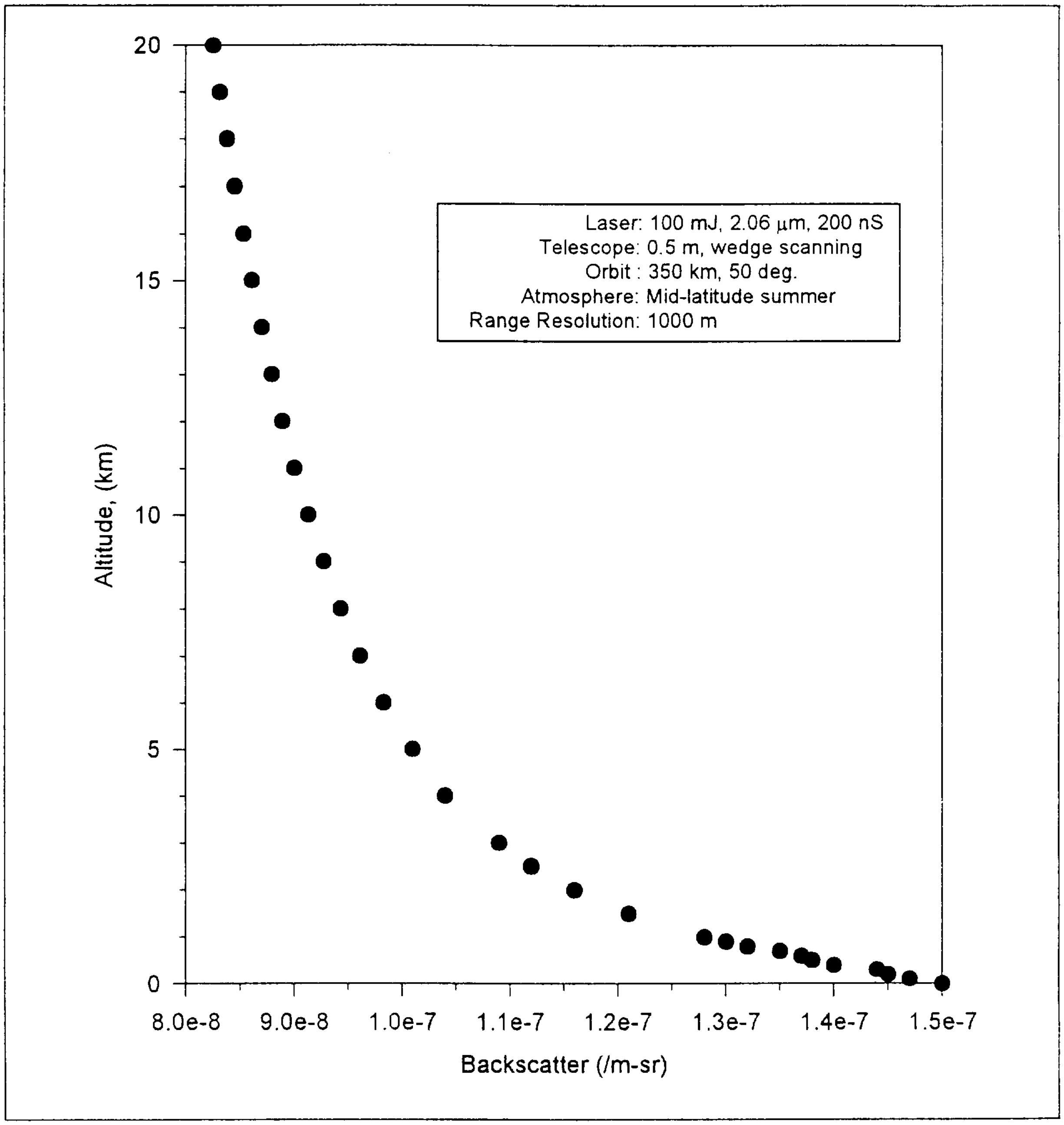


Figure (1-2) Backscatter sensitivity as a function of altitude

Atmospheric Region	Range Resolution	Sensitivity ($\beta(50\%)$)
Boundary Layer	250 m	~ 4×10^{-7}
Mid/Upper Troposphere	1000 m	8×10^{-8} -> 1×10^{-7}

Table (1.1) Summary of the instrument performance

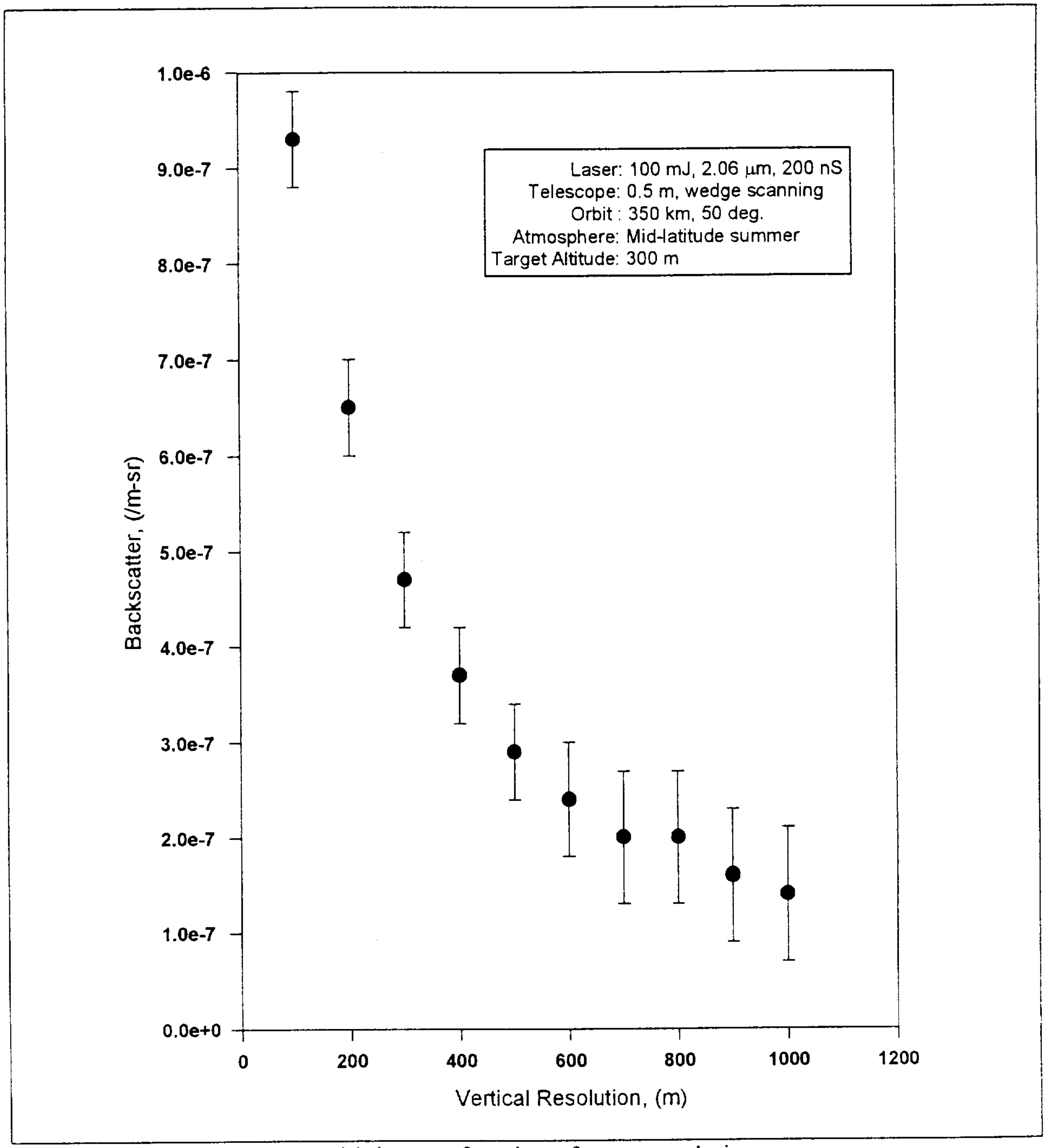


Figure (1-3) Backscatter sensitivity as a function of range resolution

1.3 References

[1] Approximately design #4 in Kavaya, Spiers et al, Proc. SPIE 2214, 237-249 (1994)

2) Earth System Science Pathfinder

2.1 Introduction

An evaluation of the performance of a coherent Doppler lidar proposed by a team comprising of the NASA Marshal Space Flight Center, Lockheed Martin Space Company, University of Wisconsin and Los Alamos National Laboratory to NASA's Earth System Science Pathfinder (ESSP) program was performed. The design went through several iterations and only the performance of the final design is summarised here.

The following table is a summary of the instrument parameters used.

LASER			**ORBIT**		
Wavelength	9.1145187	µm	Orbit height	350	km
Pulse energy	0.5	J	Inclination angle	~98	deg
Pulse length	1.5	µs	Max. nadir angle at this height	71.428	deg
Duty cycle	1				
P.R.F.	20	Hz	**RECEIVER/DETECTOR**		
Additional spectral width (FWHM)	0.8	MHz	Type	Complex	
Gaussian spectral width	0.125	MHz	Geometry	Wang	
Frequency	32891748.634	MHz	Mixing efficiency	0.42	
Min. vertical range resolution	191.03	m	Heterodyne quantum efficiency	0.4	
			Detector truncation efficiency	1	
OPTICS			Detector shot noise efficiency	1	
Telescope diameter	0.8	m	Detector nonlinearity efficiency	1	
Nadir angle	30	deg	System efficiency	0.401	
Transmit intensity fraction	0.955		Total detection efficiency	0.076	
Transmit optics	0.8				
Receive optics	0.8		**SCANNING**		
Polarisation efficiency	0.97		Scan type	Conical	
Wavefront aberration loss	0.95		Min. beam diameter	0.8	m
Receive/lo misalignment angle	3.75	µrad	Effective beam diameter	0.8	m
Misalignment Loss	0.552	dB	Plot duration	1	mins
Misalignment efficiency	0.881		Telescope rotation rate	5	rpm
SYSTEM					
Margin for unexplained loss	0.5				

The following table summarises the other miscellaneous parameters used in the model, the table shown is for the case of a 500 m vertical range resolution measurement and it can be seen that $\beta(50\%)$ is 4.82×10^{-9} $(m\text{-}sr)^{-1}$.

TARGET			**SIGNAL PROCESSING**		
Atmospheric Model	Midlat Summer		Horiz. velocity search space	+/-20	m/s
Aerosol Model	Clear		LOS velocity search space	+/- 10.55	m/s
Aerosol altitude	500	m	Probability of a good estimate	0.5	
backscatter (lambda)	4.82E-9	/(m-sr)	Line of sight range resolution	588.51	m
Max. horizontal wind	+/-100	m/s	Observation time	2.43	µs
Horizontal wind velocity uncertainty	0	m/s	Effective time between samples	0.216	µs
Vertical wind velocity uncertainty	0	m/s	Effective digitisation frequency	4.63	MHz
Wind variance between shots	0	m/s	Effective no. samples /obs.	11.23	
Vertical range resolution	500	m	Phi	3.1	
Target nadir angle	31.83	deg	Signal width	0.195	MHz
Line of sight range to this altitude	407.33	km	Omega	0.47	m/s
Coherence length	29.06	m	Sigmav/w	0.98	
One way Intensity Transmission	0.83		No. of shots/ wind estimate	1	
Maximum line of sight velocity	+/- 52.74	m/s	Bandwidth (wide band)	23.15	MHz
			Bandwidth (narrow band)	0.195	MHz
OTHER PARAMETERS			Bandwidth (search band)	4.63	MHz
Satellite velocity	7704.3	m/s			
ground track velocity	7303.1	m/s			
Earth rotation velocity at equator	463.3	m/s	**RESULTS**		
Nadir angle at ground	31.83	deg	Wideband SNR	-12.5	dB
Slant range to ground	407.9	km	Narrowband SNR	8.2	dB
Time for one orbit	5481.5	s	Searchband SNR	-5.5	dB
Swath radius (conical/wedge scan)	203.7	km	P(bad)	0.50	
Optimum mirror flip time (line scan)	33.433288	s	P(good)	0.50	
Solid angle subtended at target	3.487E-13	sr	sigmavlos - instrument	0.87	m/s

The following plots summarise the anticipated performance of the instrument for a vertical resolution of 500 m.

2.2 Single shot sensitivity

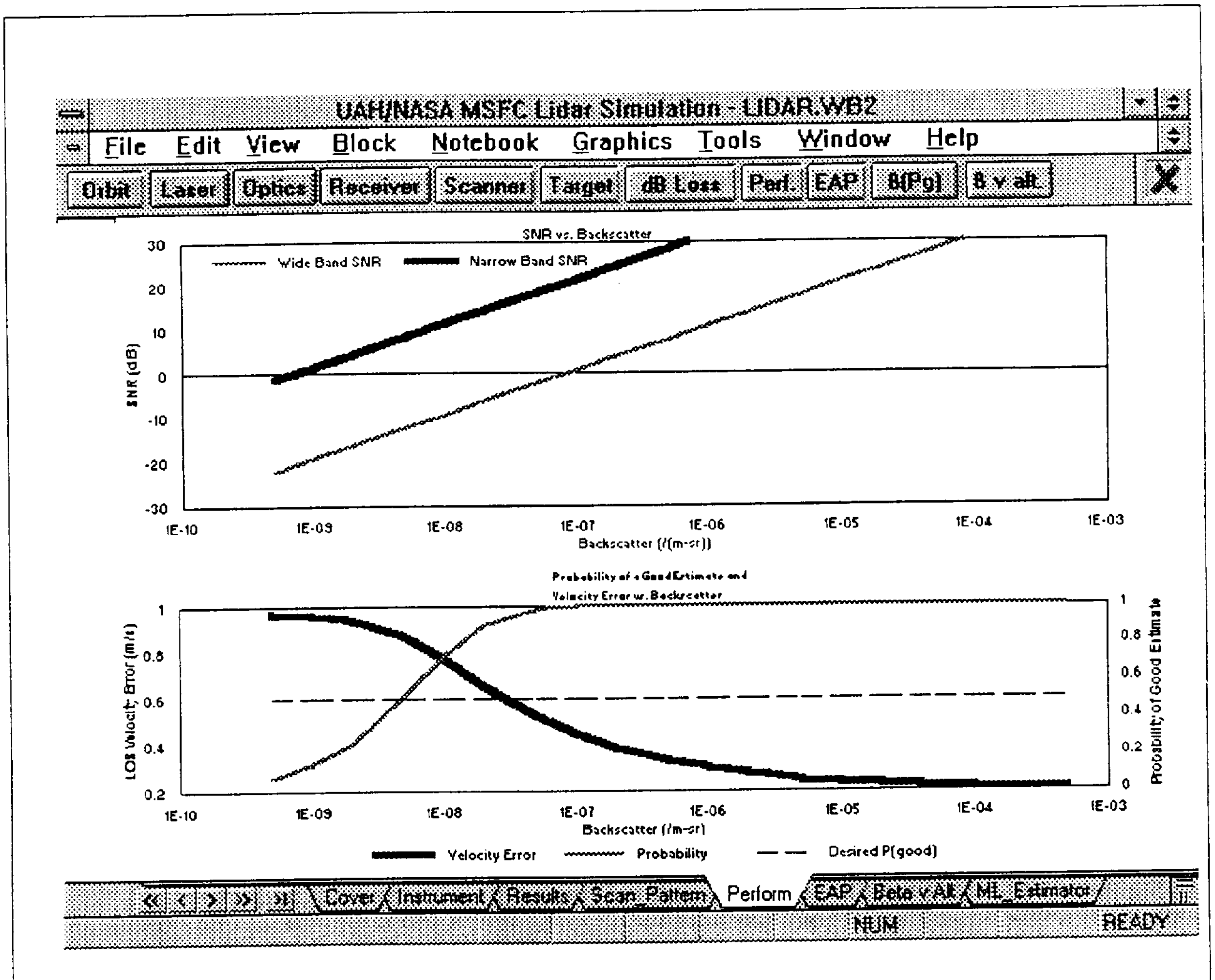


Figure (2-1) Performance curves for the ESSP mission with a 500 m vertical resolution.

2.3 Laser energy and telescope aperture trades

For a given orbit height, nadir angle and wavelength, there are three basic parameters that can be adjusted to vary the sensitivity of an instrument. These are the laser pulse energy, telescope diameter and lidar boresight stability during the round trip time. There are two ways of looking at this analysis, either the analysis is target constrained ie a particular backscatter sensitivity is required or else the analysis is instrument constrained by technology limitations.

For a nominal target backscatter value of 1×10^{-8} /(m-sr) then a family of solutions can be derived.

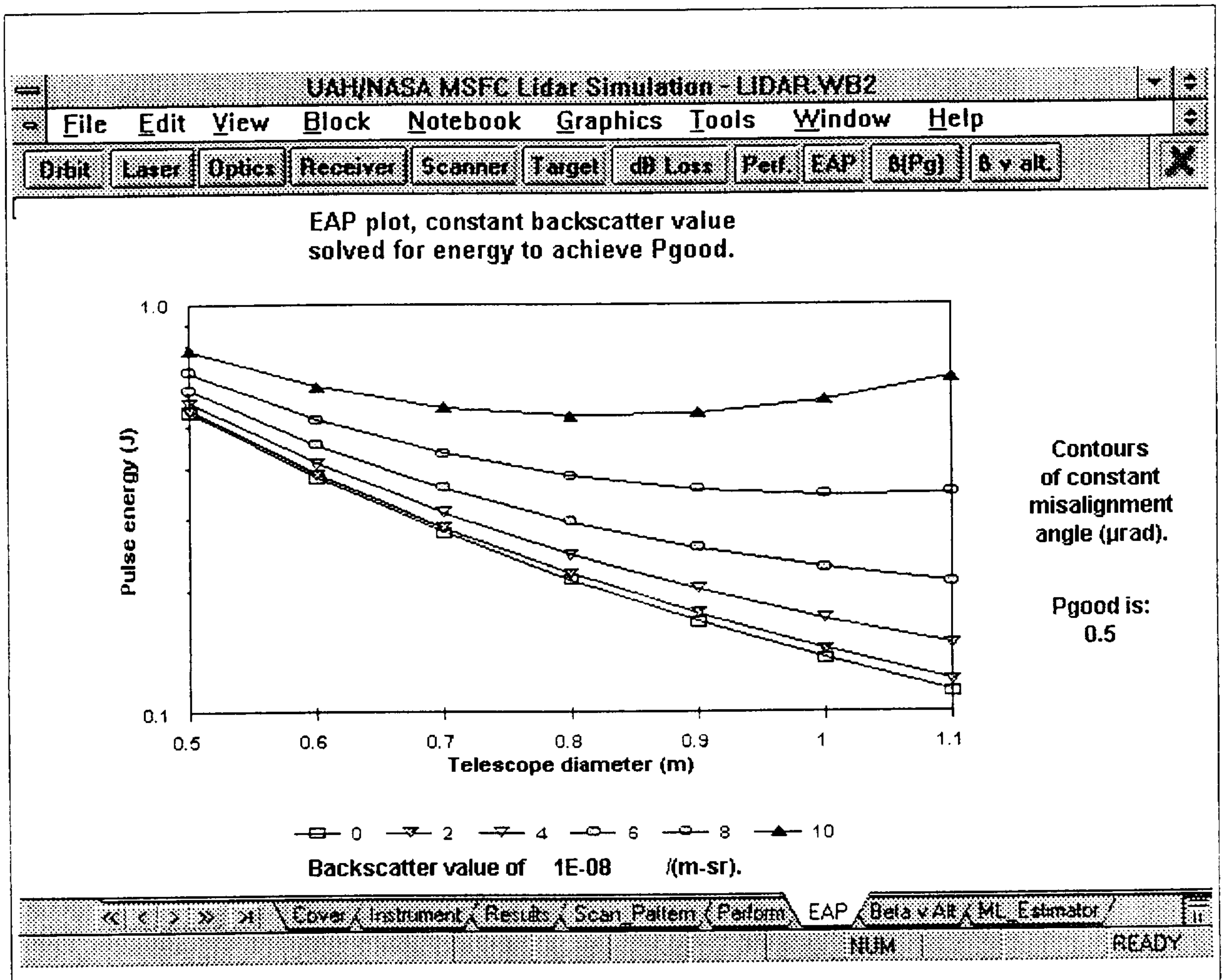


Figure (2-2) Target constrained energy-aperture trade space.

It can be clearly seen that for large boresight jitter during the round trip time, the use of large telescopes can result in the need for greater laser pulse energy than a smaller telescope would require.

For this particular instrument, the instrument design team provided a boresight stability specification of 3.75 μrad and so an instrument consrained analysis was also conducted.

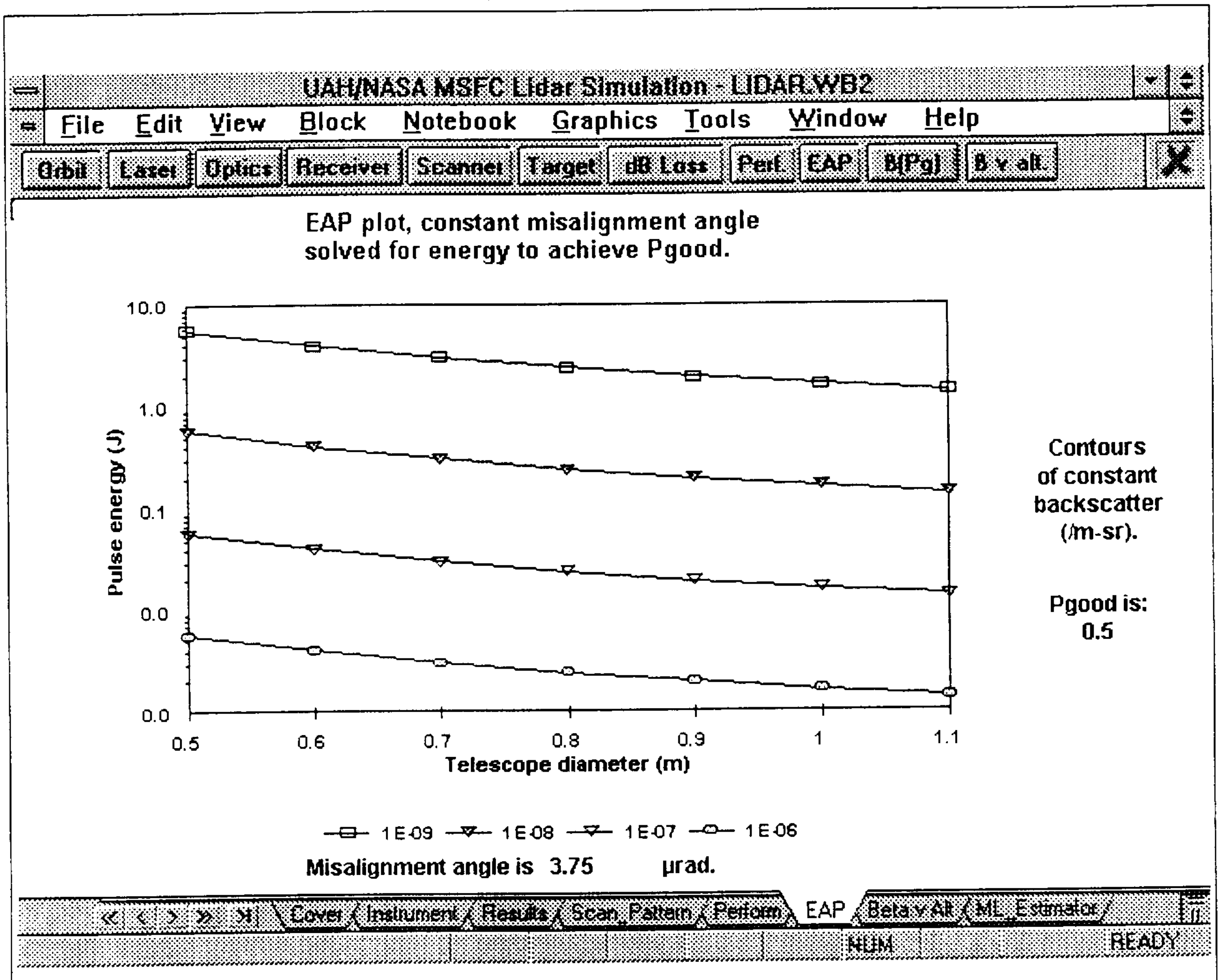


Figure (2-3) Instrument constrained energy-aperture trade-space

It can be seen from the figure that for the boresight alignment tolerance provided, either increasing the telescope diameter or increasing the laser pulse energy would result in an increase in sensitivity however for the design team concluded that neither of these options was feasible for this mission.

2.4 Single shot performance as a function of altitude

As the target altitude increases, the range to the target and the atmospheric extinction experienced by the laser pulse reduces and so the sensitivity of the instrument is increased.

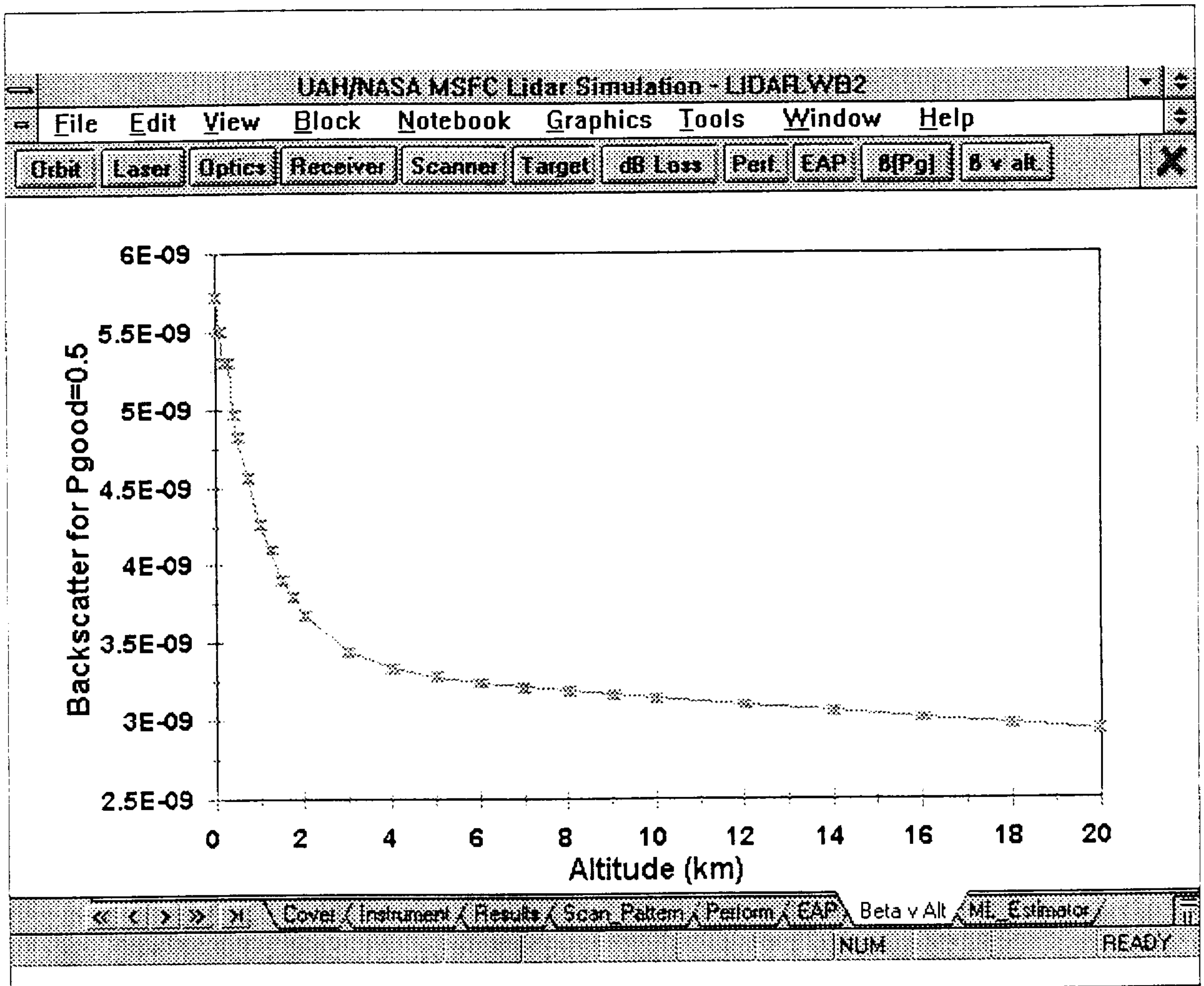


Figure (2-4) Instrument performance as a function of altitude.

Similar analyses to the above were carried out for several range resolutions and are summarised as a function of altitude in Figure (2-5).

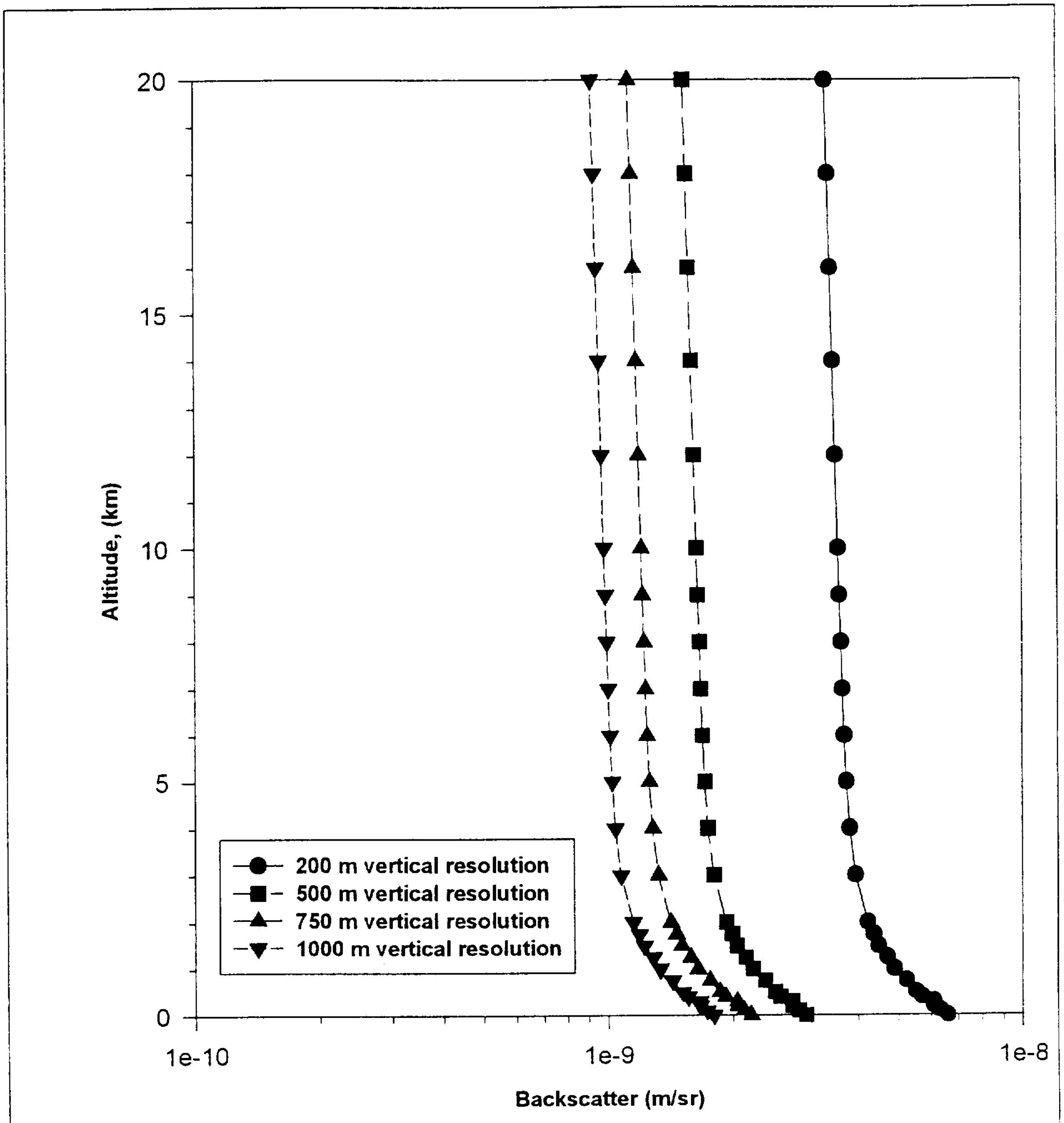


Figure (2-5) Single shot sensitivity as a function of range resolution and altitude.

2.5 Shot placement

The instrument used a step-stare shot scheme in which 4 shots would be fired at a fixed azimuth angle at a PRF of 20 Hz and then the scanner would be stepped by 16 deg to the next azimuth position. The benefit of placing four shots down at each azimuth angle is that they can be used to improve on the single pulse sensitivity by a factor of $\sim\sqrt{n}$ where n is the number of shots. Figure (2-5) and Figure (2-6) show representative plots of the orbit and swath pattern respectively whilst

Figure (2-7) shows a detailed shot pattern on a 100 km x 100 km grid scale. Even at this resolution it is not possible to resolve individual shots from each group of four as the first and last shots in the group are only seperated by ~ 1 km.

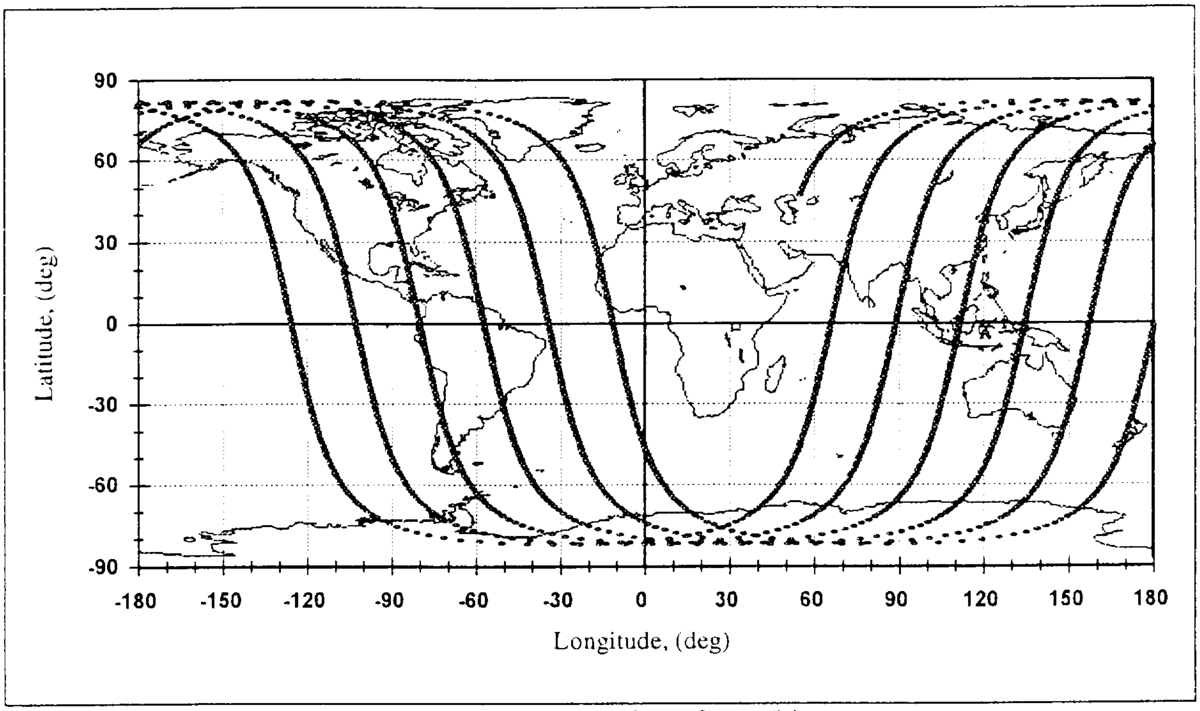


Figure (2-6) A representative ground track plot for a few orbits.

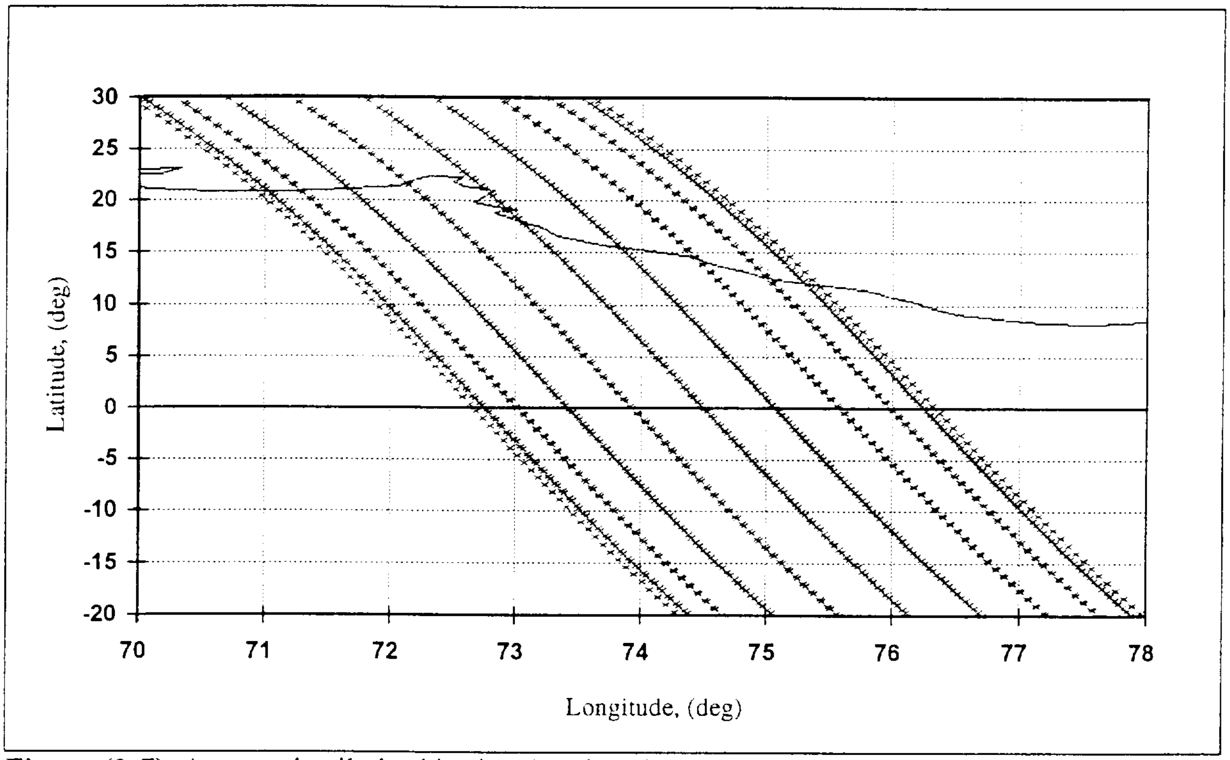


Figure (2-7) A more detailed orbit plot showing the tracks left at each azimuth angle.

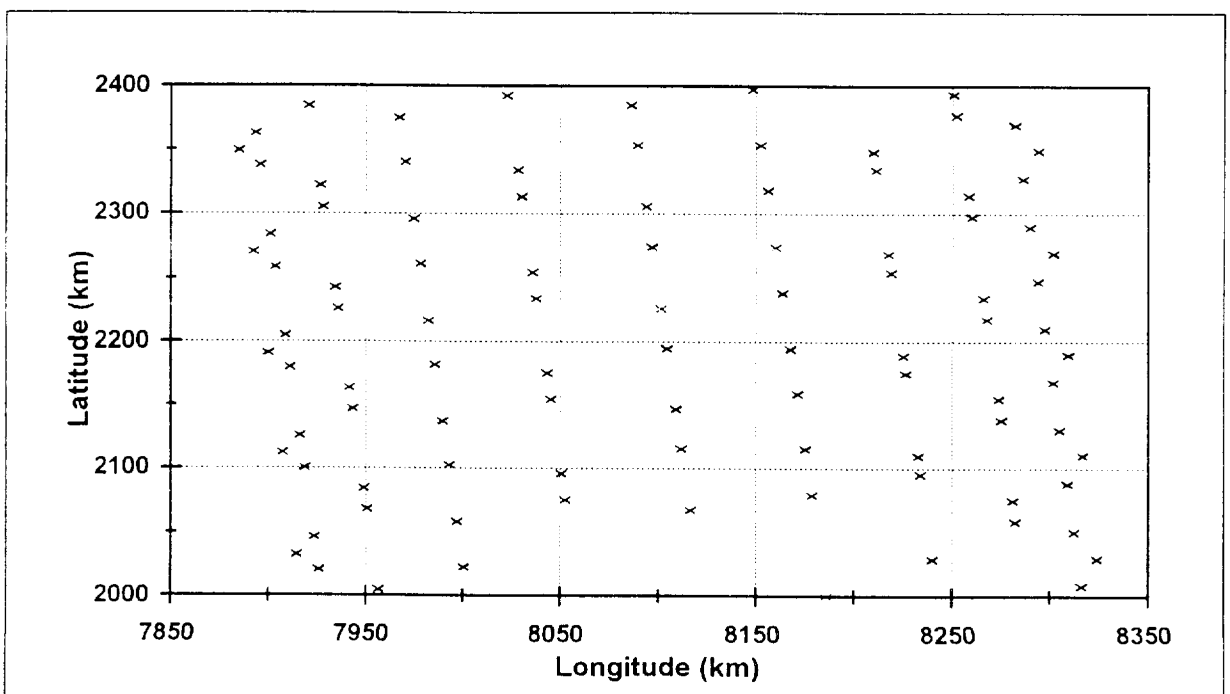


Figure (2-8) Shot pattern detail, each cross represents four shots.

National Aeronautics and Space Agency

Report Document Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Due
Analysis of Space Coherent LIDAR Wind Mission	
	6. Performing Organization Code University of Alabama in Huntsville
7. Aurthor(s) Gary D. Spiers	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address University of Alabama in Huntsville Huntsville, Alabama 35899	11. Contract or Grant No. NAS8-38609
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-001 Marshall Space Flight Center, AL 35812	13. Type of report and Period covered FINAL - 9/22/95-9/21/96
	14. Sponsoring Agency Code

15. Supplementary Notes

16.Abstract

17. Key Words (Suggested by Author(s))	18. Distribution Statement

19. Security Class. (of this report)	20. Security Class. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified		

NASA FORM 1626 OCT 86