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SPNDL: A CONCEPT FOR A SMALL SATELLITE DOPPLER LIDAR WIND SOUNDER

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ABSTRACT

Given current resources and the technical challenges in developing a full coverage space-based Doppler lidar wind measuring system such as LAWS (Laser Atmospheric Wind Sounder), it is not likely that the science community will have data streams with which to work before the end of this decade. Currently, a "fast track" demonstration mission is being seriously considered by several U.S. agencies. Such a mission would have as its primary objectives the demonstration of coherent Doppler lidar technology in space and the delivery of wind observations for science algorithm evaluation and development.

However, for such a mission to be achieved at modest costs and within a short time frame, deviations from the full system design are required. Simulation models have been developed over the last decade to aide in the design of Doppler lidar missions and to provide simulated data for use in wind computation algorithm development. SWA has used both models to examine some options that might be cost-effective for a demonstration mission. Over the past few months, Simpson Weather Associates has been studying SPNDL (Spinning Platform with a Non-rotating telescope Doppler Lidar), a new concept for Doppler lidar wind observations from space. Science and Technology Corporation has an interest in participating in an engineering and shuttle accommodation study for SPNDL.

INTRODUCTION

Knowledge of the tropospheric winds is required for understanding and predicting weather and changes in the earth's climate. With the exception of in situ data obtained within densely populated regions of the globe, today's atmospheric models rely upon estimates of the winds derived from satellite-sensed temperature and moisture fields. Observing System Simulation Experiments (OSSEs) for a space-based Doppler lidar wind sounder have indicated a significant impact of direct wind measurement.

Since the late 1960's, lidar has been studied as a potential means of obtaining these winds. Early in NASA's EOS program, LAWS (Laser Atmospheric Wind Sounder) was identified as an

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instrument to provide winds to the global climate study. Phase A/B studies defined a rather demanding system (20 J laser, 1.6 m telescope, 800 kg, 4 kW) to meet the EOS mission requirements. The projected cost and perceived technical risks have contributed to a delayed new start for this ambitious program.

Recognizing that there is a role for a demonstration class wind sounder mission, several proposals have been made. In 1985, NASA (1) considered a shuttle mission (Figure 1) based upon NOAA's WINDSAT study (2) but decided a 7-day mission would not justify the costs. Within the last year, the LAWS Science Team recommended a more modest version of LAWS (5 J, .75 m telescope, 600 kg, 2 kW) which would still provide a significant science return. More recently, a NASA call for "quicker, better, cheaper" space instruments has been made. Emmitt (3), a member of the LAWS Science Team, has proposed SPNDL (.2 J, .6 m telescope, 350 kg, .6 kW) for a techno/science mission that would achieve the following:

- demonstate that a coherent lidar can be launched, aligned, operated and remain aligned for a reasonable period of time;
- obtain data streams that can be used to validate/ calibrate data product algorithms;
- generate low density/high quality soundings that will help build confidence in the feasibility of the "full-up" LAWS.

SPNDL could be launched from a shuttle, boosted into a higher orbit and then left to a lifetime limited by orbit degradation. Another scenario is for the concepts of SPNDL to be tested from the shuttle bay with the instrument returned for post flight evaluation. At this time, both options are considered feasible. The remainder of this presentation describes the measurement concept and identifies key technological and scientific issues that could be addressed with a shuttle mission.

SYSTEM DESCRIPTION

In Table 1, several key design considerations are listed along with their advantages in terms of cost-reduction and performance enhancement. These general considerations are translated into system requirements for the measurement concept called SPNDL, which is outlined in Table 2.

A major departure of SPNDL from the original LAWS design concept is the use of a spinning platform to achieve scanning with a single, fixed (non-rotating) telescope (Figure 2).

While details of the technical feasibility of SPNDL are currently being evaluated, the scan pattern and characterization of the quality and quantity of the resulting wind data have been

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simulated. In Figure 3, the horizontal projection of the shot pattern within the earth's troposphere is shown for two revolutions of SPNDL. The prf is 10 Hz and the platform revolution rate is 1 rpm. The plan would be to only pulse the laser near the intersections of scans, resulting in a 3-5% duty cycle.

Using only static lag angle compensation, the optimal range (a fixed distance from the satellite) is located at varying altitudes within the troposphere during a scan (Figure 4). If a 3 dB loss due to uncompensated lag angle is tolerable, then the vertical range of return will be ~ ± 25 km from the optimal range.

The result of the SPNDL pattern of observations is the placement of more than 40 bi-perspective shots into a 50x50 km area. Very accurate ($\sigma_v < .2$ m s^{-1}) wind measurements are possible but are spaced ~ 300-400 km along the satellite track. In Figure 5, an example of 24 hours of SPNDL coverage at 1000 mb is shown for a simulation using fields from a global circulation model for input to the LAWS LSM.

CONCLUSION

SPNDL, an SWA concept, offers an alternative to a scaled down version of the full LAWS for use in a wind measuring demonstration mission. Further evaluation of this concept is underway within NASA. Either a smallsat mission or a shuttle small payload mission presently is being considered.

REFERENCES

1. D. Fitzjarrald, R. Beranek, J. Bilbro, and J. Mabry, "Preliminary Plan for a Shuttle Coherent Atmospheric Lidar Experiment (SCALE)", Proc. NASA Sympo. on Global Wind Measurements, (1985), 207-214.

2. NOAA, "Global Wind Measuring Satellite System - WINDSAT", NOAA Final Report under Contract NA79RAC00127, (1981).

3. G.D. Emmitt, "System Simulation Studies in Support of a Technology and Product Demonstration Mission for a Space-Based Coherent Doppler Lidar Wind Sounder", Proc. 7th Conf. Coherent Laser Radar Applications and Technology, (1993), 103-106.

TABLE 1

DESIGN CONSIDERATIONS

SPECIFICATION	ADVANTAGES	PROBLEMS
Daytime operation only	Reduced solar array Reduced battery weight	
Fixed telescope with platform spin	Reduced weight/cost Simplicity in optics Retain bi-perspective measurements	Platform stability(?)
Lag angle compensation	Static only reduces complexity	
5-10% duty cycle operations	Reduced power requirements Eliminate active thermal control	Laser stability(?)
Relaxed pointing control	Reduced subsystem costs	Increased burden on data processing
Trade swath width for observation accuracy	Use nadir angle for maximum SNR	
Target ß(50) = 10 E-8	Obtain aerosol returns from PBL and cloud tops	
Maximize shot density	Reduce random system and atmospheric turbulence Oversampling to be used to define minimum density needed for full LAWS	
Relax mission life requirements	Reduce costs of components	

TABLE 2

DRAFT Requirements for

A LAWS/SMALLSAT CONCEPT
(Based upon SWA's SPNDL Concept)

ORBIT

- 98° inclination

- time of day asynchronous with location [to achieve diurnal sampling]

- 350-400 km altitude at equator (~ 379 at poles)

- 1 yr without reboost (orbit degradation of 50 km is tolerable

PLATFORM

- Rotates (~ 1-10 rpm) on axis perpendicular to orbit plane

- Solar panels deployed have continuous sun exposure (98° orbit) and are edge on to motion vector to minimize drag (see figure)

- Passive thermal radiators directed to dark sky

- Lidar beam exits satellite with a fixed angle ~ 20° from orthogonality to spin axis (exit location not critical)

- Beam scanning achieved from satellite spin

TABLE 2 (cont.)

LASER

- **9.11 or 9.25 μm**
- **pulse spectrum (TBD)**
- **output angle jitter (TBD)**
- **.2-1.0 j (end-of-mission)**
- **5% duty cycle**
- **10 Hz minimum design = ~ 2 x 10^7 shots/year**
- **capable of on/off cycling to achieve 5% duty cycle**

OPTICS

- **.75→1.0 m telescope**
- **Bearing free scanning (scanning achieved through platform spin)**
- **Static lag angle compensation [active lag angle compensation is desirable if cost acceptable]**
- **Pointing accuracy: 10 mrad**
  knowledge: 100 μrad
  boresight alignment: 3 μrad

TABLE 2 (cont.)

DETECTOR/RECEIVER

- HgCdTe at 125°K for 1 detector [active cooling may be needed if 4 detectors are used]
- Uniform LO
- Broadband for platform motion calibration.
- $| V_{search} | = \pm 25$ m s^{-1}
- $| V_{max} | = 50$ m s^{-1} (LOS)
- Spacecraft to target velocity gross Doppler shift = = 8 km/sec

POWER SUPPLY

- Instrument to draw directly from batteries
- Solar array to provide a power increment dedicated to battery recharge between shot clusters
- Design for multiple battery cycling - dependent upon power increment and instrument duty cycle

THERMAL CONTROL

- Passive for laser and detector subsystems [desirable]

TABLE 2 (cont.)

COMPANION INSTRUMENTS (OPTIONS)

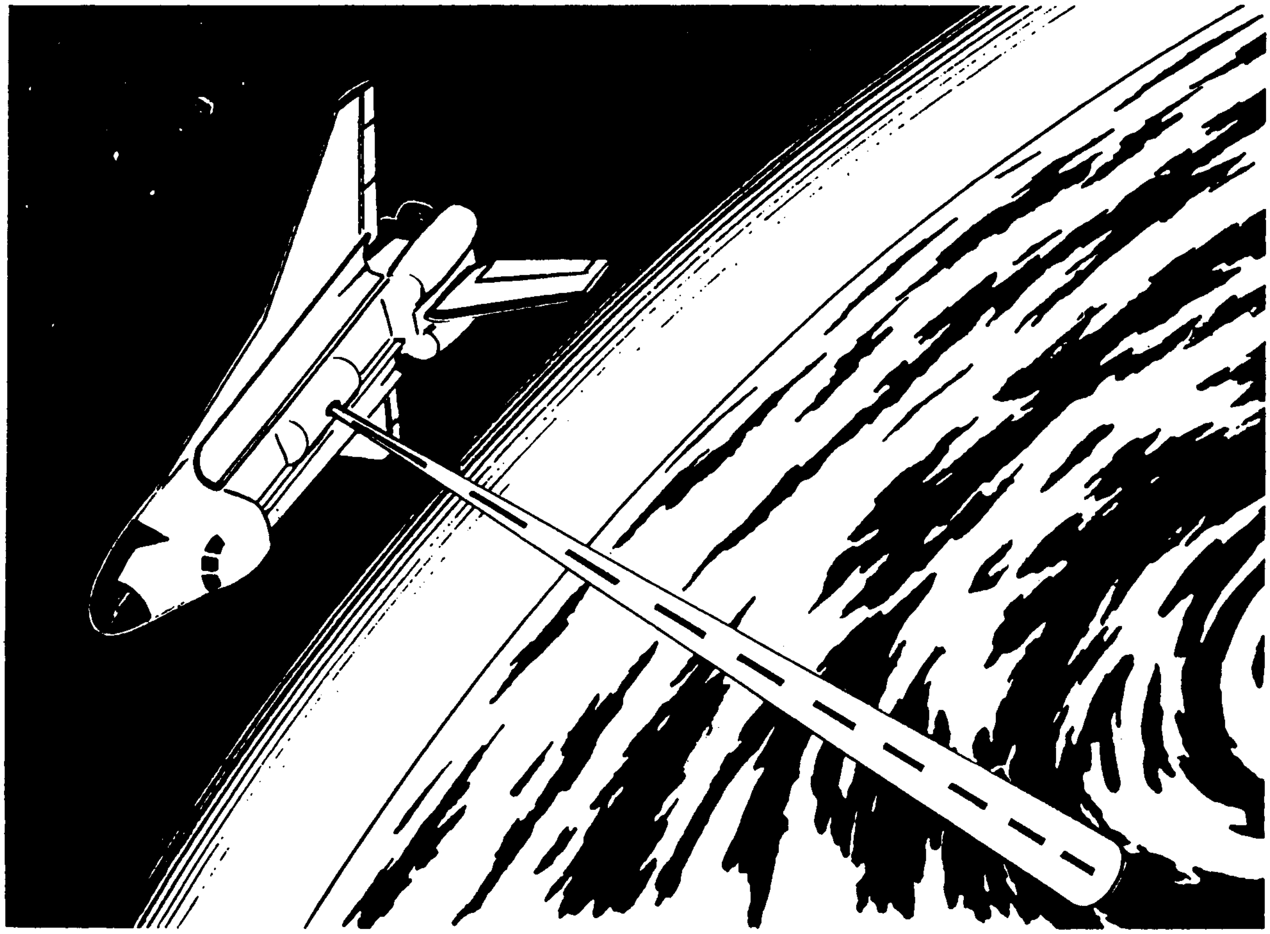
- **Passive imager to provide visual context for lidar observations - ± 50 km either side of lidar beam track**

- **IR radiometer to provide complementary data for deriving cloud properties in vicinity of lidar samples - co-sighted with lidar beam**

SCALABILITY

- **Basic measurement principles must be scalable**

  - **laser subsystem**
  - **scanned beam**
  - **detection mode**



NASA National Aeronautics and Space Administration

Figure 1. From NASA SP-433, Final Report of Atmospheric Lidar Working Group, 1979.

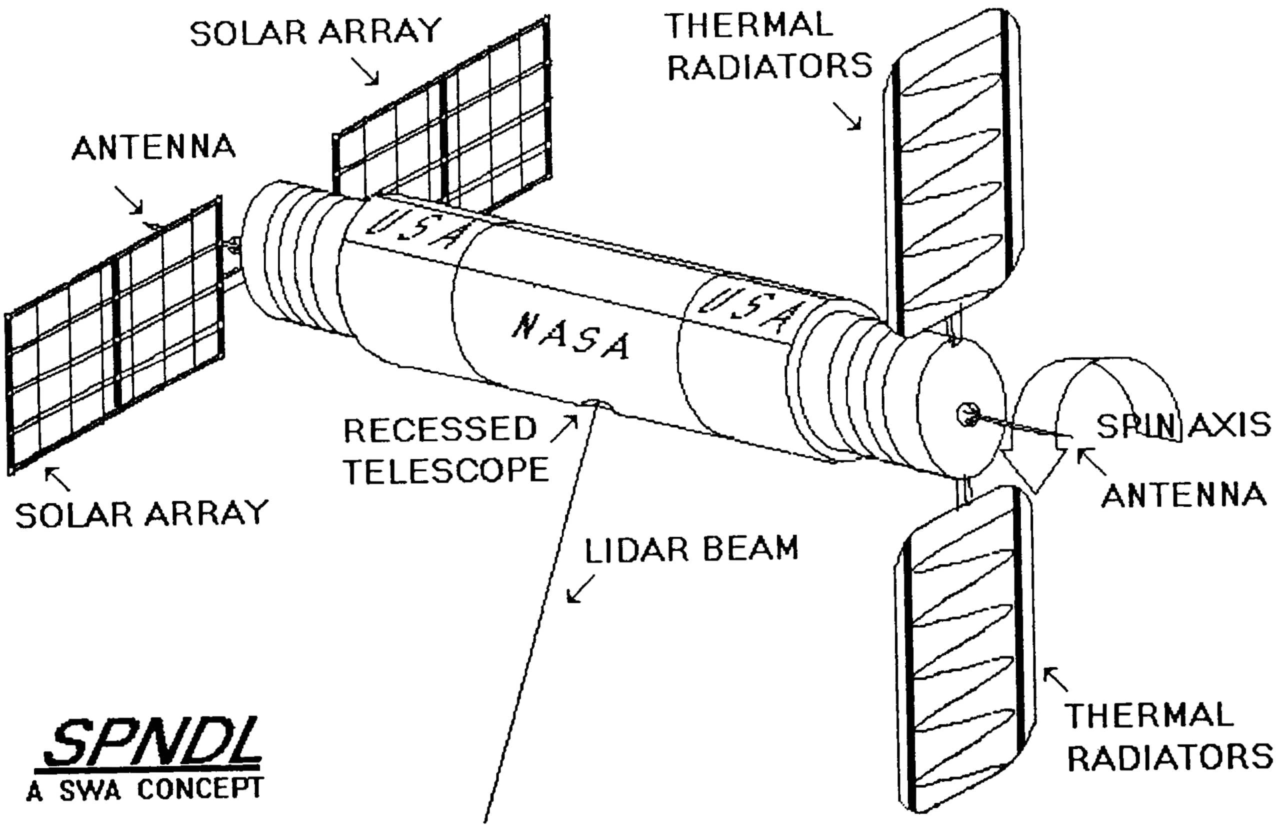

SOLAR ARRAY
THERMAL RADIATORS
ANTENNA
USA
NASA
USA
RECESSED TELESCOPE
SPIN AXIS
ANTENNA
SOLAR ARRAY
LIDAR BEAM
THERMAL RADIATORS
SPNDL
A SWA CONCEPT

FIGURE 2

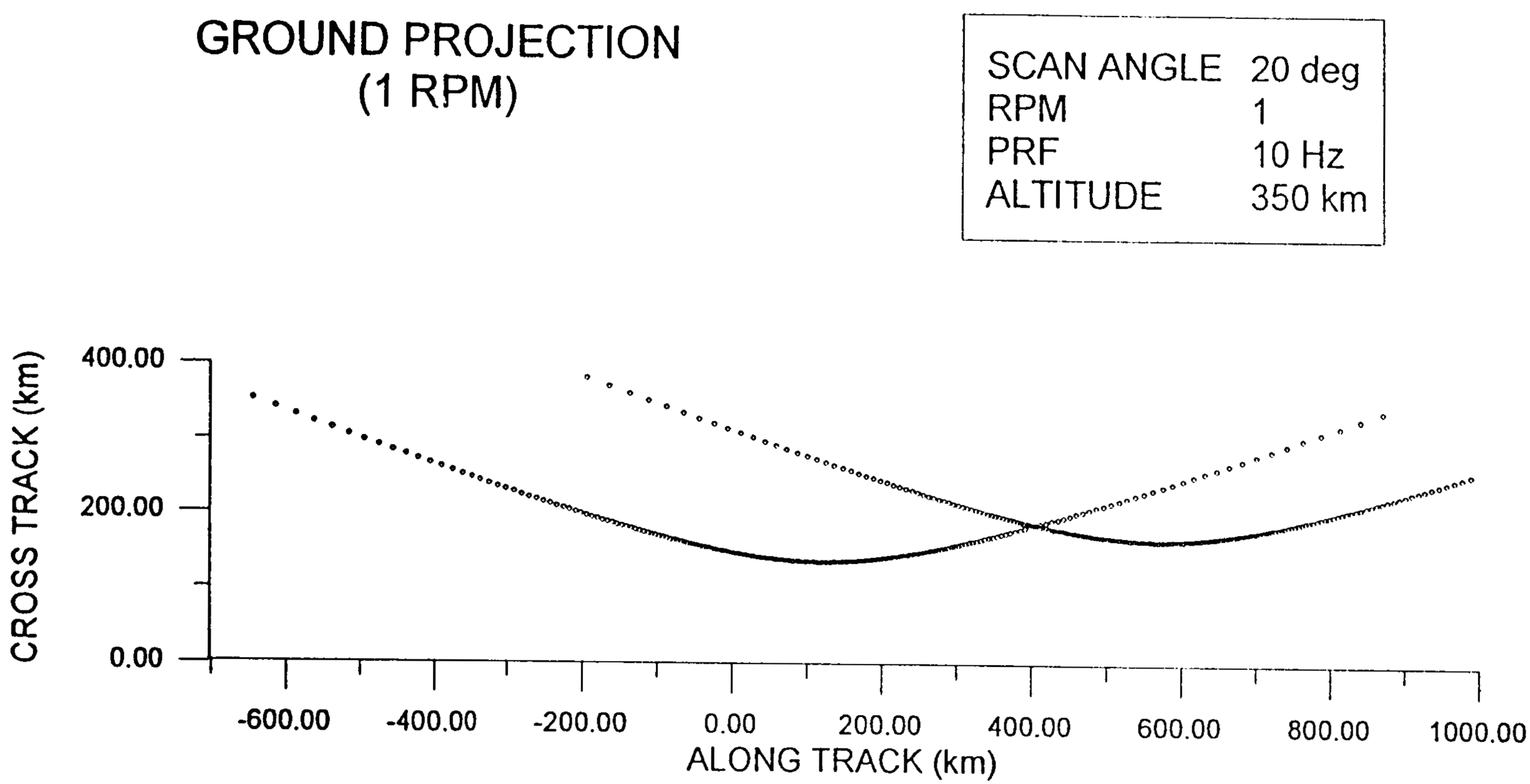

GROUND PROJECTION
(1 RPM)
SCAN ANGLE 20 deg
RPM 1
PRF 10 Hz
ALTITUDE 350 km
CROSS TRACK (km)
400.00
200.00
0.00
-600.00
-400.00
-200.00
0.00
200.00
400.00
600.00
800.00
1000.00
ALONG TRACK (km)

FIGURE 3

HEIGHT AND SIGNAL STRENGTH OF SAMPLES AT RLAG (1 RPM)

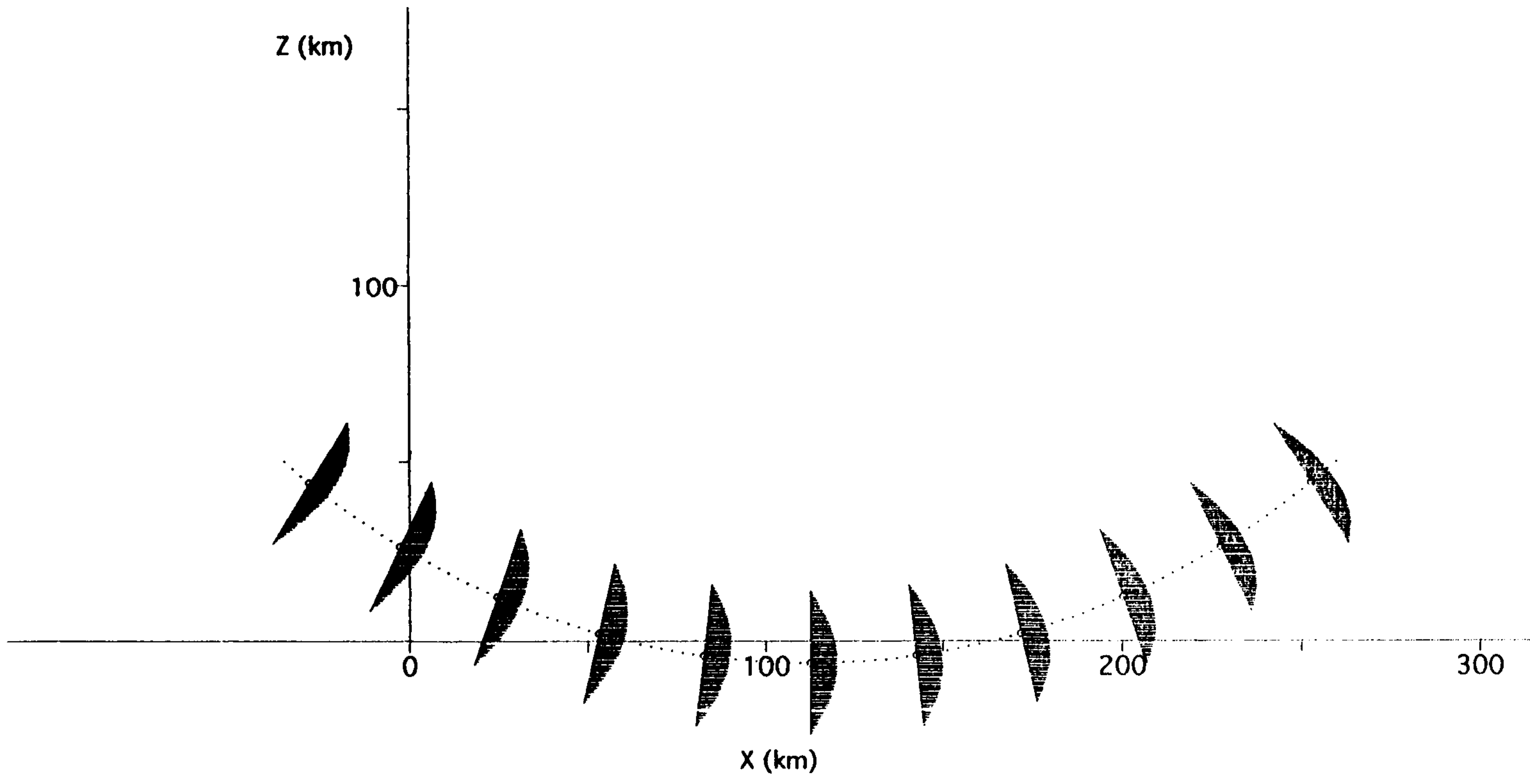


FIGURE 4

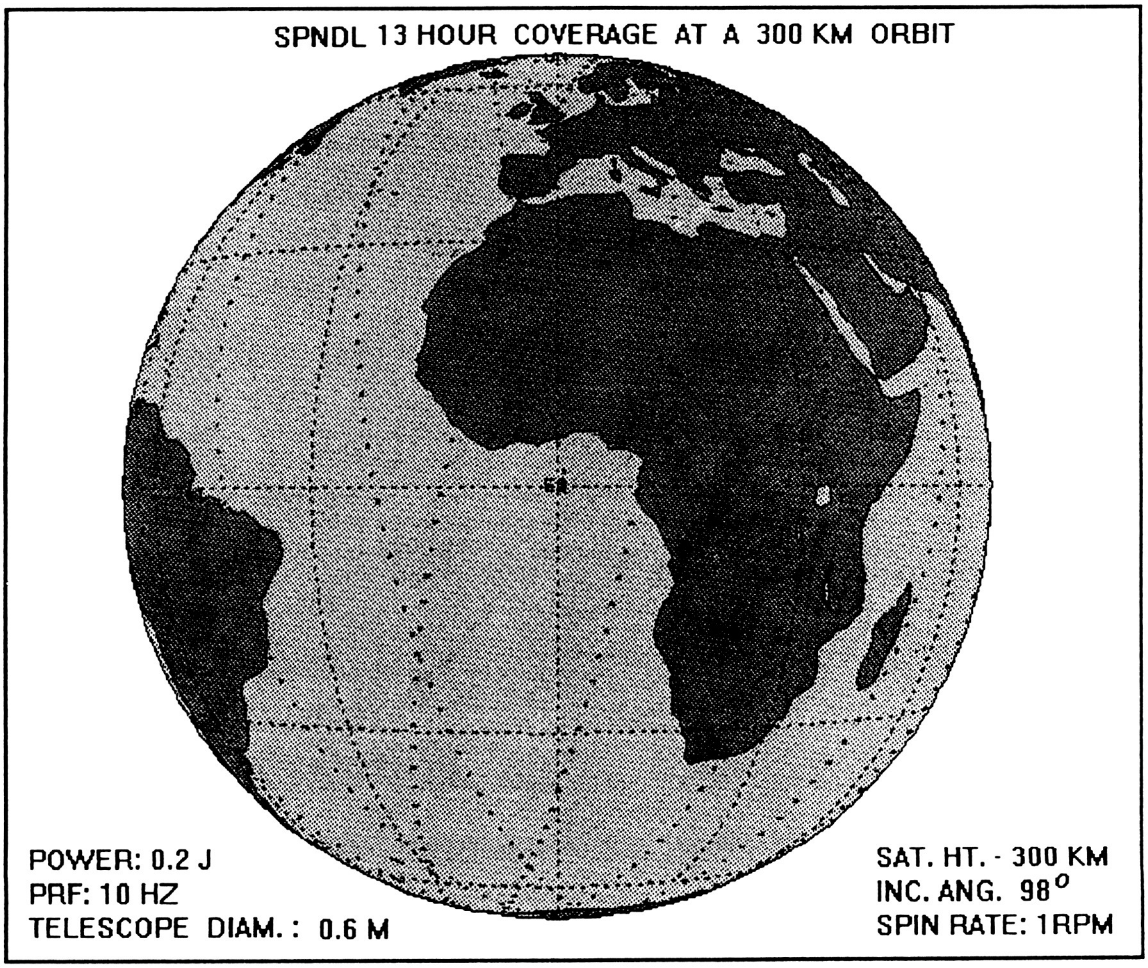

SPNDL 13 HOUR COVERAGE AT A 300 KM ORBIT
POWER: 0.2 J
PRF: 10 HZ
TELESCOPE DIAM.: 0.6 M
SAT. HT. - 300 KM
INC. ANG. 98°
SPIN RATE: 1RPM

FIGURE 5