IADC-13-05
May 2013

Inter-Agency Space Debris Coordination Committee

International 24-hr LEO Space Debris Measurement Campaign 2008

Working Group 1

IADC Action Item 25.1

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DLR

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1. Introduction

The Inter-Agency Space Debris Coordination Committee (IADC) provides the forum for periodic international measurement campaigns of the space debris environment. The IADC has conducted two types of campaigns: high altitude campaigns designed to measure the debris environment at near-geostationary altitudes using mostly optical telescopes, and low altitude campaigns using primarily radars. One of the goals of the low altitude campaigns is to collect data for 24 contiguous hours. This way, all orbit planes can be sampled. Multiple sensors are used, each with its own strengths and weaknesses, to provide a more complete understanding of the environment. Comparing results between sensors also provides a better understanding of the potential biases resulting from any one sensor. Conducting the campaigns at roughly regular intervals over a long period also allows researchers to examine trends and growth of the environment over time. For this reason, low altitude campaigns are anticipated at two-year intervals. This is the 7th IADC low altitude campaign conducted. The first campaign was conducted in 1996 and two campaigns were conducted in 1999. The 2002 campaign was delayed until January 2003 because of scheduling conflicts, and the fifth and sixth campaigns were conducted in 2004 and 2006.

This report covers the results obtained from the low altitude campaign conducted in 2008. The Objectives of Action Item 25.1, "International 24 Hour LEO Space Debris Measurement Campaign 2008" included:

- Update statistical characterization of the dynamic low Earth orbit (LEO) debris population
- Compare data collected over a common collection period
- Encourage participation by organizations that may not have contributed in past campaigns
- Concentrate on altitudes less than 2000 km

The LEO debris population is not static. It changes over time because of loss of particles by atmospheric drag and reentry and by sudden injection of particles from explosions and collisions. The concept of conducting a LEO campaign every two years was adopted by Working Group 1 in 2002. The two-year schedule does not preclude member agencies from more frequent or continuous measurements. However, comparison of data collected during a common collection period is needed periodically.

The strategy of routinely measuring the LEO environment has been validated by events in 2007 and 2009. Significant on-orbit fragmentations occurred during those years. The 2006 campaign provided a good baseline to compare against later campaigns, which will show the effects on the environment from these major events.

Four of the five radars that participated in the 2006 24-hour campaign also participated in the 2008 campaign. The European Incoherent Scatter Scientific Association (EISCAT) Svalbard Radar (ESR) was not funded for participation in the 2008 campaign. However, the

FGAN/TIRA, Haystack, Haystack Auxiliary (HAX), and Cobra Dane radars participated in both the 2006 and 2008 campaigns. The data collection and processing for each of these radar systems was essentially the same for both campaigns. Therefore, to maintain these reports as stand-alone documents, but simultaneously reduce the repetitive nature of the report, details of the operation and data reduction for each radar will be moved to the appendices. This report will concentrate more on the results collected in 2008 and its comparison with the 2006 results.

Two different types of radars were used in the campaign: pencil-beam radars and phased-array radars.

2. Pencil-Beam Radars

Three pencil-beam radars were used during the 2008 24-hour campaign: the Tracking and Imaging RAdar (TIRA) sponsored by the European Space Agency (ESA) and operated by FGAN (now Fraunhofer) Research Institute for High Frequency Physics and Radar Techniques (FHR); and the Haystack and HAX radars sponsored by NASA and operated by the Massachusetts Institute of Technology's Lincoln Laboratory (MIT/LL). In addition to the TIRA radar operated in a mono-static mode, it also operated in a bi-static mode with TIRA acting as the transmitter, and the Effelsberg radio telescope operated by the Max-Planck Institute for Radioastronomy acting as a receiver. However, the Effelsberg data has not yet been processed and will not be included in this report.

Each of the pencil-beam radars was operated in a staring mode. In this mode, the radar was pointed at a fixed azimuth and elevation and recorded data on objects as they passed through the narrow beam of the radar.

The orbital inclination of an object detected by a monopulse radar operating in the staring mode can be measured from the time history of the position of the object through the beam determined from the open loop monopulse azimuth and elevation voltage ratios. The direction and angular velocity, along with the range, range rate, and time, are transformed into the classic orbital elements, including inclination. However, the narrow field-of-view of the radars provides a very small arc of the orbit and a relatively small amount of measurement noise quickly degrades the velocity determination making the derived values of inclination and eccentricity invalid. Inclination can also be estimated from range rate information if circular orbits are assumed. Inclination derived by this method will be referred to as Doppler inclination. The Doppler is the frequency shift from the transmitted signal to the received signal caused by the line-of-sight relative motion of the target, or range rate.

If the assumption of a circular orbit is used, the line-of-sight velocity can be related to the orbital inclination of the object for an antenna beam that is not pointed vertically. An error is introduced, of course, if the orbit is non-circular (i.e., ecc $\neq 0$). However, the error is not significant for modest eccentricities. In practice, the Doppler inclination has proved more accurate than determining inclination from the monopulse signals as the object passes through the main lobe of the radar beam.

2.1 TIRA Radar

The TIRA radar is located at 50.62º N. latitude, 7.13º E. longitude, at an elevation of 293 m. The radar was staring at azimuth 93.00º, elevation 76.12º during the campaign. The TIRA radar detected 786 objects in the 24 hours starting at ~12:30 GMT on 25 November 2008. Appendix A describes the operation and data processing used to collect the data. In addition, it also includes a list of the detections. The detection list provides the time of the detection, the slant range to the target, the range rate of the target relative to the line-of-site of the radar, and the radar cross section of the target. In addition to these raw measurements, the list also includes the derived parameters of altitude, Doppler inclination, and characteristic length. The characteristic length was derived from the NASA Size Estimation Model (SEM), described in Appendix E. Characteristic lengths for detections from all of the radars participating in the 2008 campaign are derived using the SEM.

In addition, NASA compared the measured detection time, range, and range rate against predicted values for objects in the United States Strategic Command (USSTRATCOM) catalog using software provided by the U.S. Air Force Space Command. Possible correlations with tracked objects for appropriate detections are also noted in the detection list.

Figure 1 shows the cumulative size distribution collected over the entire range window from 300 – 2000 km. Figure 2 shows the altitude vs. Doppler inclination for each of the 786 detections.

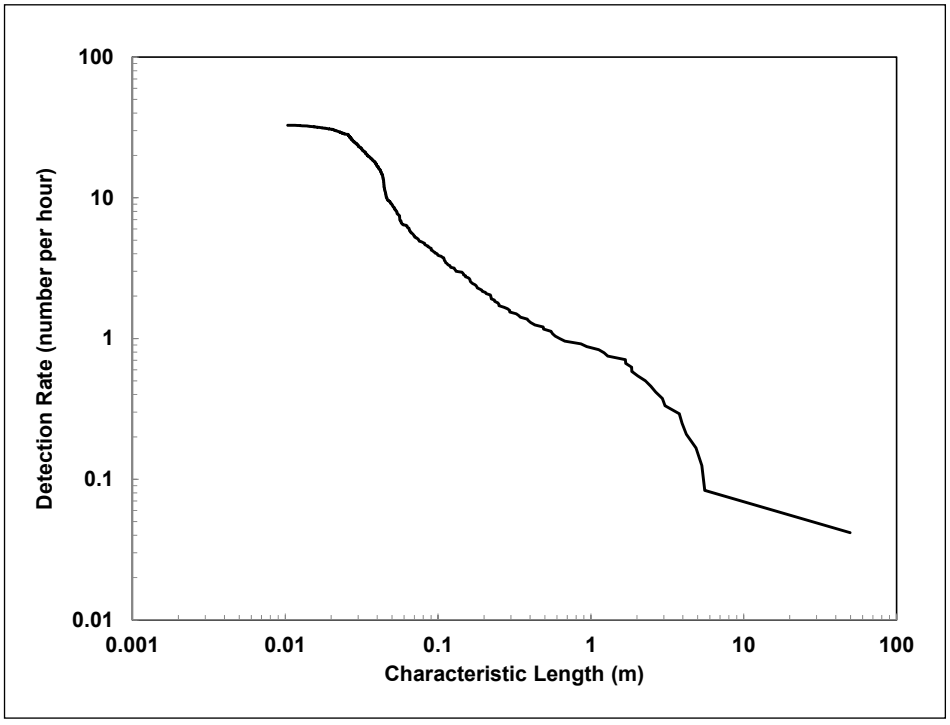

Figure 1. Size distribution for all objects detected by TIRA in the 2008 campaign.

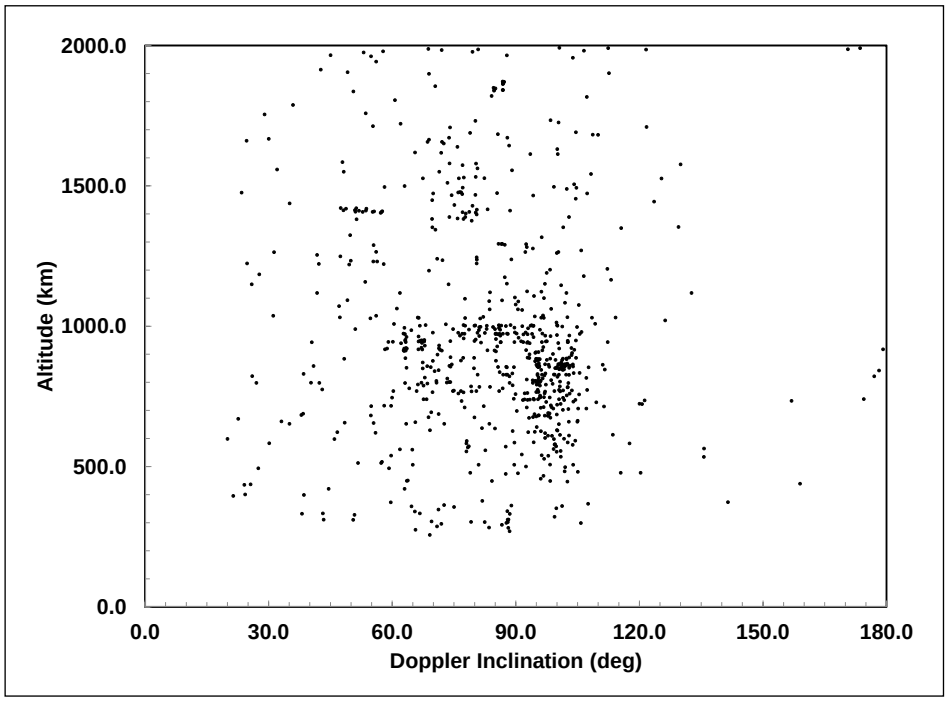

Figure 2. Distribution of altitude vs. Doppler–inclination for TIRA detections in the 2008 campaign.

There are two features of these results that appear unusual. There is one object that has a radar cross section (RCS) of 32.9 dBsm, corresponding to a characteristic length of ~50 m. The detection correlated to Satellite Number 16865, which is listed as SL-8 debris. The characteristic length in this case is obviously erroneous. A plausible potential explanation is that the radar observed a glint off of the debris which gave it an enhanced RCS.

The second feature is the near horizontal grouping in Figure 5 near 1400 km and an inclination of 50º. This grouping of detections is consistent with mainlobe and sidelobe detections of the GlobalStar constellation at 1414 km altitude and 52º inclination. This feature was also seen in the 2006 data.

2.2 Haystack Radar

The Haystack radar is located at 42.62º N. latitude, 71.49º W. longitude, at an elevation of 1157 m. The radar was staring at 90º azimuth and 75º elevation during the 24-hour campaign. The radar collected data for ~24 hours starting at 13:15 GMT on 18 November 2008. However, there were breaks in the data collection for calibration checks and other routine operations. During the 24 hours, 20.6 hours of staring data were collected and 328 objects were detected.

Appendix B describes the operation and data processing used to collect the data. Appendix B also includes a list of the detections. The detection list provides the same measured and derived parameters as reported for the TIRA radar.

Figure 3 shows the cumulative detection rate as a function of size for all valid detections observed by Haystack during the campaign. Figure 4 is a scatter plot of Doppler inclination vs. altitude.

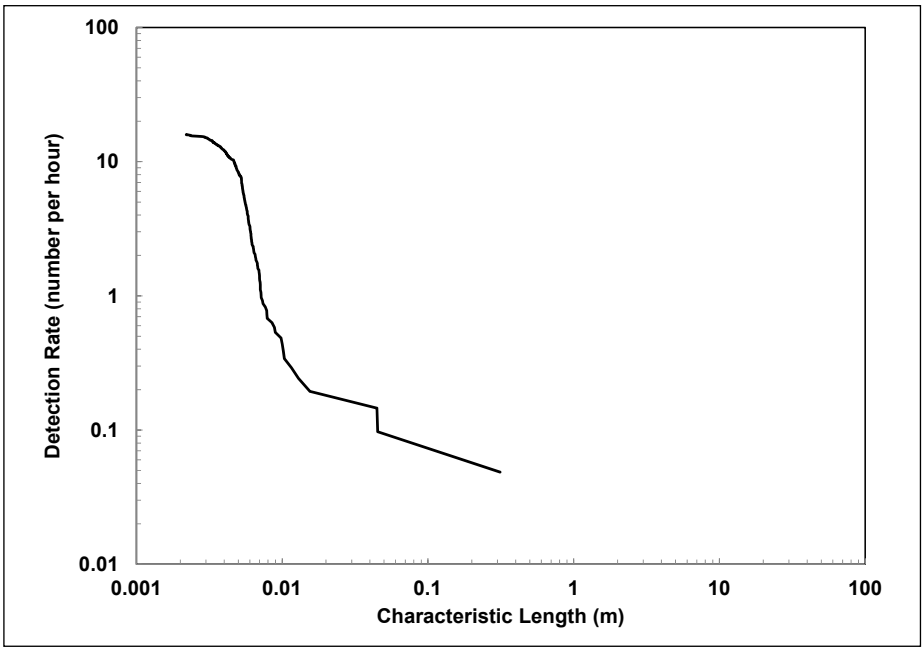

Figure 3. Size distribution for all objects detected by Haystack in the 2008 campaign.

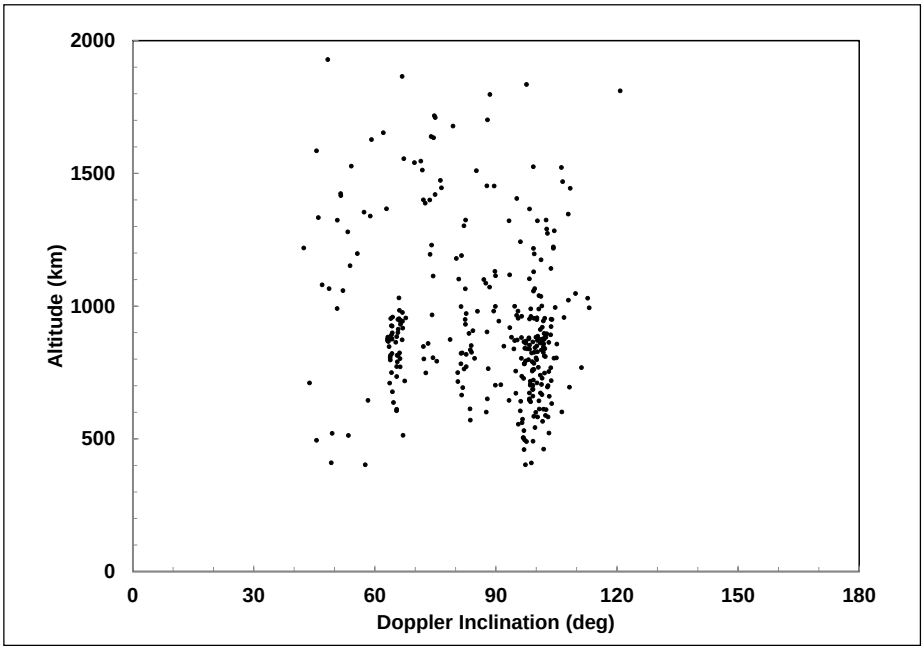

Figure 4. Distribution of altitude vs. Doppler–inclination for Haystack detections in the 2008 campaign.

2.3 HAX Radar

The HAX radar is located ~100 m southeast of the Haystack radar. HAX shares some of the data collection and processing hardware with Haystack; however, they can still be operated simultaneously.

For the 2008 24-hour campaign, HAX was pointed in the same direction as Haystack providing simultaneous observations of some of the larger objects detected by Haystack. HAX has much lower sensitivity than Haystack, but a wider beamwidth. HAX detected 31 objects in 19.0 hours of operation.

Appendix C provides operations and data processing descriptions along with the detection list.

Figure 5 shows the cumulative detection rate as a function of size for all valid detections observed by HAX during the campaign. Figure 6 is a scatter plot of Doppler inclination vs. altitude.

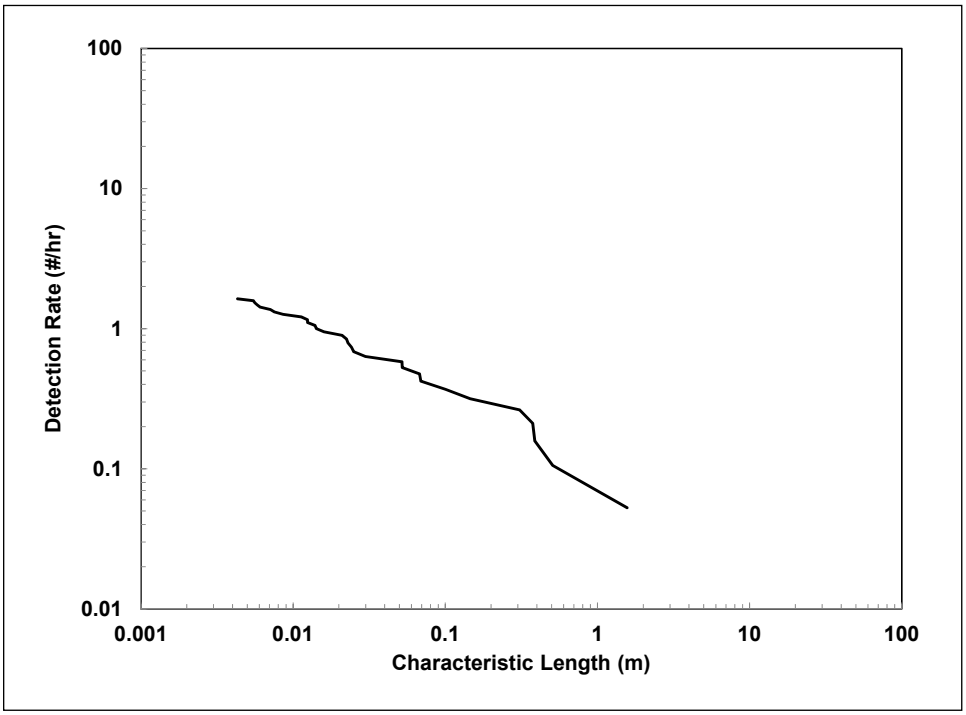

Figure 5. Size distribution for all objects detected by HAX in the 2008 campaign.

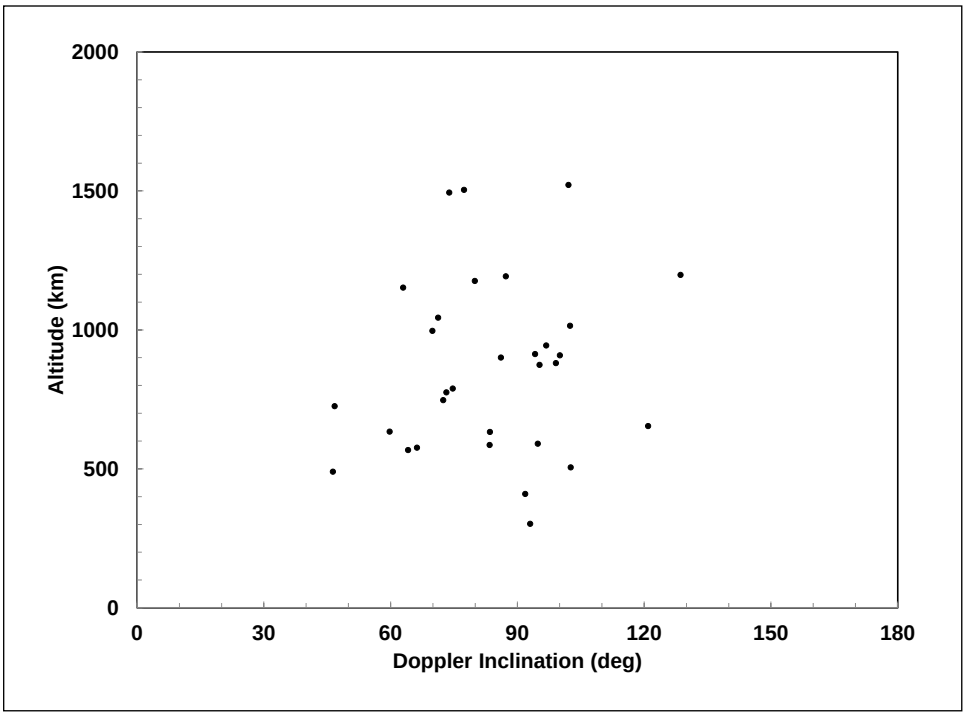

Figure 6. Distribution of altitude vs. Doppler–inclination for HAX detections in the 2008 campaign.

3. Phased-Array Radars

3.1 Cobra Dane

The AN/FPS-108 Cobra Dane radar (Figure 23) is operated by the U.S. Department of Defense. It is located on Shemya Island, Alaska at 52.7° N. latitude and 174.1° E. longitude. The face of the radar is aligned at an azimuth of 319°.

For the 24-hour campaign, the Cobra Dane is operated much differently from the pencil-beam radars discussed above. For pencil-beam radars, the entire dish, typically weighing hundreds to thousands of kg, must be moved to point the radar in a different direction. However, phased-array radars can be electronically steered almost instantaneously within some angular limits. For this campaign the antenna beam is rapidly moved in a long, narrow pattern to create a virtual fan beam, or fence. Each individual beam position in the fence is revisited often enough that orbiting objects cannot travel the width of the fence between revisits. The fence is therefore referred to as a "leak-proof" fence. When an object is detected in the fence, some of the radar's resources can be used to track the object while maintaining the fence. To maintain the leak-proof fence, only uncorrelated detections (objects not in the USSPACECOM catalog or analysts objects) were tracked.

During the campaign, a 40°-wide fence, at an elevation angle of 50.3° and covering the azimuth range from 299° – 339° was erected. The fence was one beamwidth wide, or 0.6°. The radar detected objects crossing this fence at slant ranges from 415 – 2501 km. Cobra Dane operated for 24 hours starting at 00:00:00 GMT on 17 November 2008. There were 1452 uncorrelated objects detected and tracked during the 24 hours. Using Air Force Space Command-provided software, 4702 objects in the USSPACECOM catalog should have passed through the fence during the same period. In addition, 1890 "analyst" satellites (satellites routinely tracked by the Space Surveillance Network [SSN], but not yet in the regular USSPACECOM catalog) were also predicted to pass through the fence. This provides a total of 8044 detections.

Information on the operation of the Cobra Dane and the list of uncorrelated detections collected during the campaign can be found in Appendix D.

Unfortunately, object size information is missing from the uncorrelated targets (UCTs) for ~ 2 hours during the campaign from 11:28 to 13:28 GMT. Therefore, when calculating detection rates for the campaign, all detections from this time period are excluded. Also, size information is missing for 1649 analyst satellites.

The size distribution for Cobra Dane detections is shown in Figure 7.

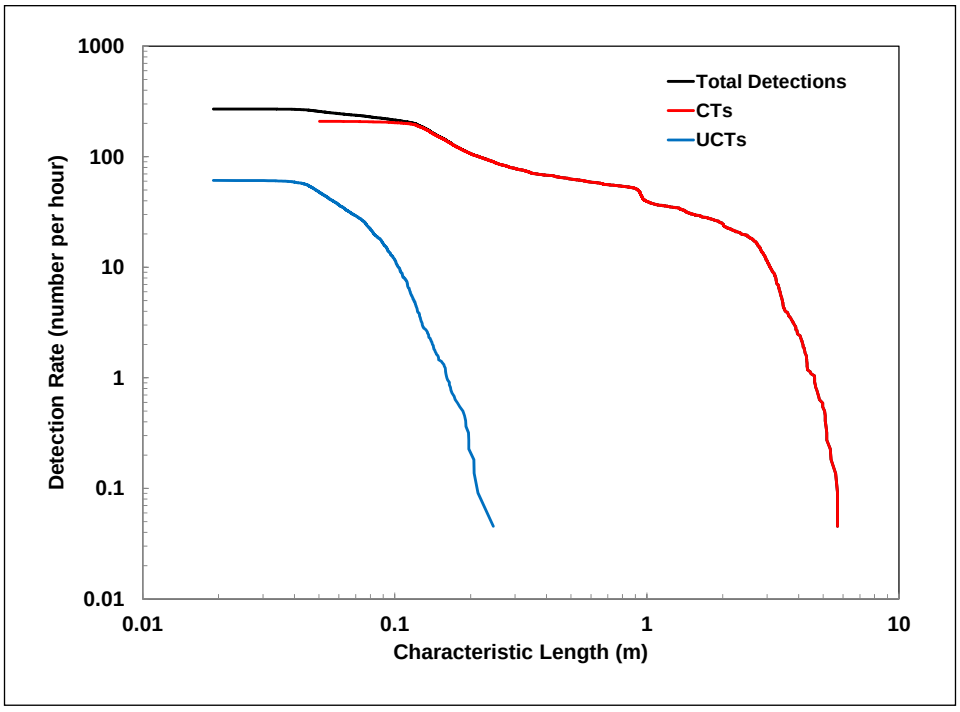

Figure 7. Size distribution for all UCTs detected by Cobra Dane in the 2008 campaign. In addition, cataloged objects which were predicted to pass through the Cobra Dane fence are shown in a cumulative distribution.

Figure 8 shows altitude as a function of inclination for regular, analyst, and uncorrelated detections.

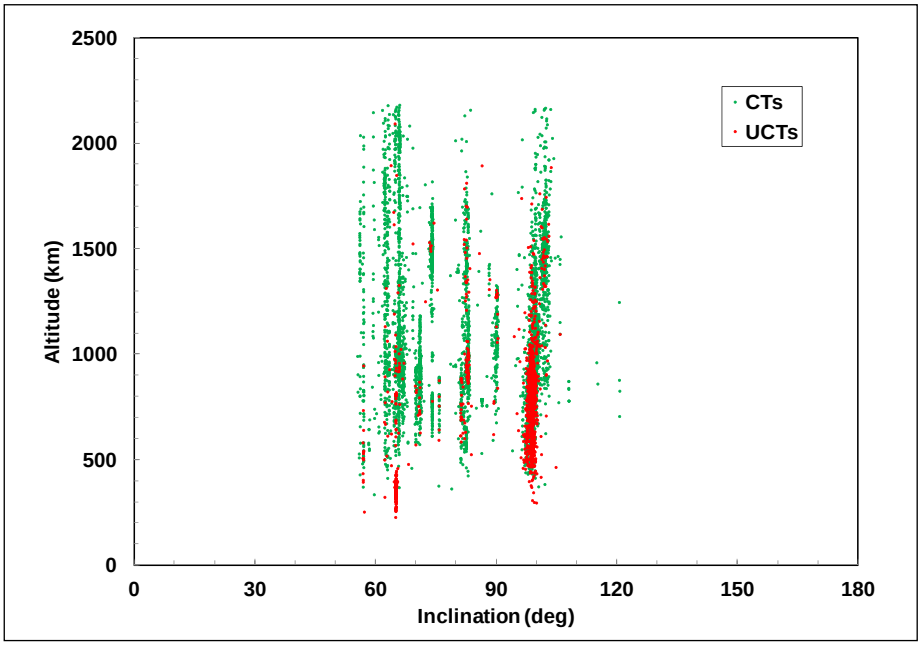

Figure 8. Distribution of altitude vs. Doppler–inclination for Cobra Dane UCT detections and predicted known objects in the 2008 campaign.

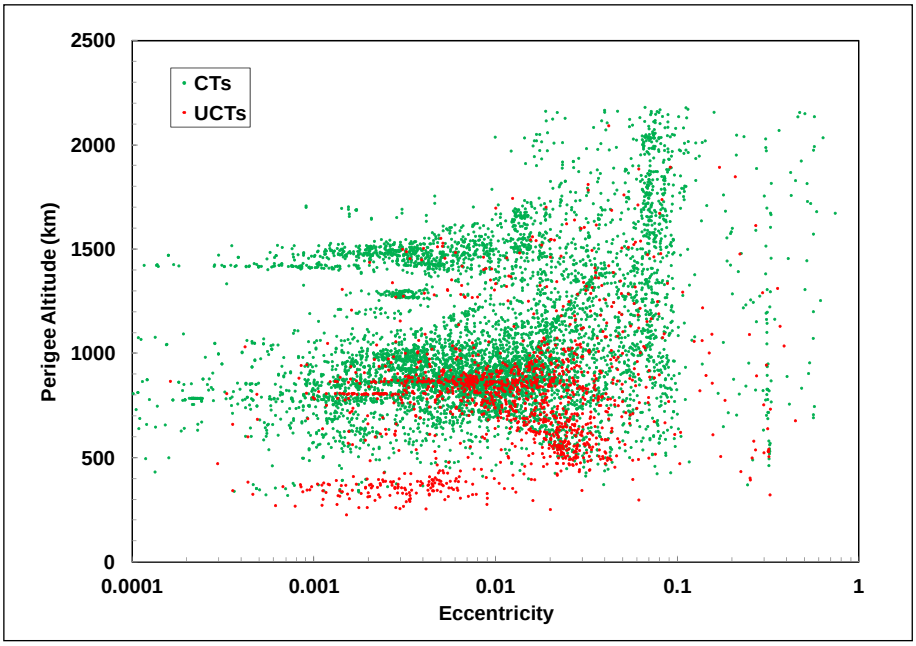

Figure 9. Distribution of altitude vs. Eccentricity for Cobra Dane UCT detections and predicted known objects in the 2008 campaign.

One of the unique attributes of a phased-array radar such as Cobra Dane is the ability to track a detected UCT while still maintaining the detection fence described above. This allows the radar to collect enough information to estimate the eccentricity of the object to an acceptable level. Figure 9 shows the altitude distribution of detections as a function of orbit eccentricity for those objects for which an orbit could be calculated. Figure 10 shows the inclination vs. eccentricity distribution.

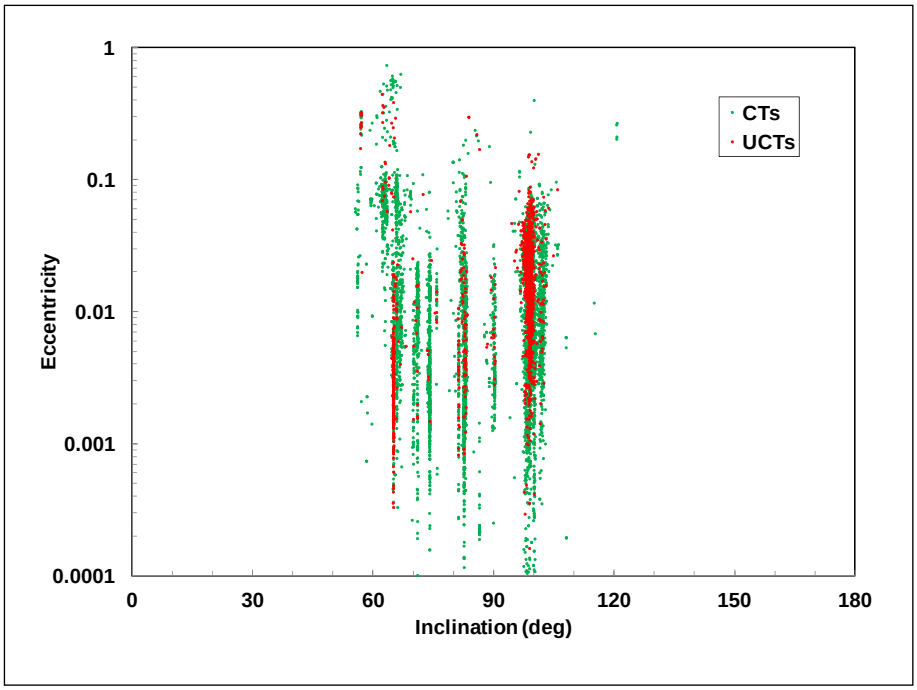

Figure 10. Distribution of eccentricity vs. inclination for Cobra Dane UCT detections and predicted known objects in the 2008 campaign.

4. Comparison with the 2006 24-Hour Campaign

4.1 On-orbit Fragmentations

In addition to the normal space traffic from launches and natural decays, 16 on-orbit fragmentations occurred between the time of the 2006 24-hour campaign and the 2008 campaign [1, 2]. A list of the fragmentations is provided in Table 1. Two fragmentations, the Beidou 1D rocket body and the USA 193 satellite, had inclinations (25.0º and 29.0º, respectively) that were too low to be seen by the configurations of any of the radars participating in the 2008 campaign.

Of the remaining fragmentations, the largest in terms of producing the largest number of cataloged objects was by far the fragmentation of Fengyun 1C at an inclination of 98.6º.

Table 1. List of known on-orbit fragmentations that occurred between the 2006 and 2008 24 hour campaigns.

BREAKUP DATE	SATELLITE NAME	INTERNATIONAL DESIGNATOR	US SATELLITE NUMBER	SATELLITE OWNER	SATELLITE TYPE	SATELLITE MASS (KG)	LAUNCH DATE	APOGEE (KM)	PERIGEE (KM)	INCLINATION (DEG)	ASSESSED CAUSE	ADDITIONAL INFORMATION
10-Jun-06	COSMOS 2022-24 ULLAGE MOTOR	1989-039G	20081	USSR	OP. DEBRIS	55	31-May-89	18410	655	65.1	PROPULSION	PROTON-K BLOCK DM SOZ
8-Aug-06	ALOS-1 R/B	2006-002B	28932	JAPAN	ROCKET BODY	~3000	24-Jan-06	700	550	98.2	UNKNOWN	H-IIA SECOND STAGE
~1-Sep-06	COSMOS 2371 ULLAGE MOTOR	2000-036E	26398	RF	OP. DEBRIS	55	4-Jul-00	21320	220	46.9	PROPULSION	PROTON-K BLOCK DM SOZ
4-Nov-06	DMSP 5D-3 F17 R/B	2006-050B	29523	USA	ROCKET BODY	2850	4-Nov-06	865	830	98.8	UNKNOWN	DELTA IV SECOND STAGE
17-Nov-06	COSMOS 2423	2006-039A	29402	RF	PAYLOAD	~6000	14-Sep-06	285	200	64.9	DELIBERATE	SELF-DESTRUCT
3-Dec-06	COBE R/B	1989-089B	20323	USA	ROCKET BODY	920	18-Nov-89	790	685	97.1	UNKNOWN	DELTA SECOND STAGE
28-Dec-06	IGS 3A R/B	2006-037B	29394	JAPAN	ROCKET BODY	~3000	11-Sep-06	490	430	97.2	UNKNOWN	H-IIA SECOND STAGE
11-Jan-07	FENGYUN 1C	1999-025A	25730	PRC	PAYLOAD	950	10-May-99	865	845	98.6	DELIBERATE	HYPERVELOCITY IMPACT
2-Feb-07	BEIDOU 1D R/B	2007-003B	30324	PRC	ROCKET BODY	2740	2-Feb-07	41900	235	25.0	UNKNOWN	CZ-3A FINAL STAGE
14-Feb-07	KUPON ULLAGE MOTOR	1997-070F	25054	RF	OP. DEBRIS	55	12-Nov-97	14160	260	46.6	PROPULSION	PROTON-K BLOCK DM SOZ
18-Feb-07	CBERS 1	1999-057A	25940	PRC/BRAZIL	PAYLOAD	1450	14-Oct-99	780	770	98.2	UNKNOWN	
19-Feb-07	ARABSAT 4 BRIZ-M R/B	2006-006B	28944	RF	ROCKET BODY	2600	28-Feb-06	14705	495	51.5	PROPULSION	PROTON-K BRIZ-M STAGE
11-Nov-07	USA 197 R/B	2007-054B	32288	USA	ROCKET BODY	2850	11-Nov-07	1575	220	29.0	UNKNOWN	DELTA IV SECOND STAGE
21-Feb-08	USA 193	2006-057A	29651	USA	PAYLOAD	2275	14-Dec-06	255	245	58.5	DELIBERATE	HYPERVELOCITY IMPACT
14-Mar-08	COSMOS 2421	2006-026A	29247	RF	PAYLOAD	3000	25-Jun-06	420	400	65.0	UNKNOWN	COSMOS 699 CLASS
4-Jul-08	COSMOS 1818	1987-011A	17369	USSR	PAYLOAD	2500?	1-Feb-87	800	775	65.0	UNKNOWN	

1. BREAKUP DATE AND ORBIT ARE FOR FIRST EVENT ONLY IF MULITPLE EVENTS OCCURRED
2. DOES NOT INCLUDE SATELLITE BREAKUPS IF VEHICLE WAS ON REENTRY TRAJECTORY AT THE TIME OF THE EVENT

Several other smaller fragmentations are listed that are close to the 98.6º inclinations and have overlapping altitudes with the Fengyun debris. Any uncorrelated targets detected in this inclination region could potentially be from any of these fragmentations. However, the vast majority are most likely from the Fengyun breakup.

4.2 TIRA Radar

Figure 11 shows the comparison of the cumulative size distributions collected in 2006 and 2008. As can be seen in the plot, there were more objects detected in 2006 with sizes above about 10 cm characteristic length. But for all sizes, the detection rate increased from just under 20 objects per hour in 2006 to more than 30 detections per hour in 2008, an ~50% increase above the 2006 rate.

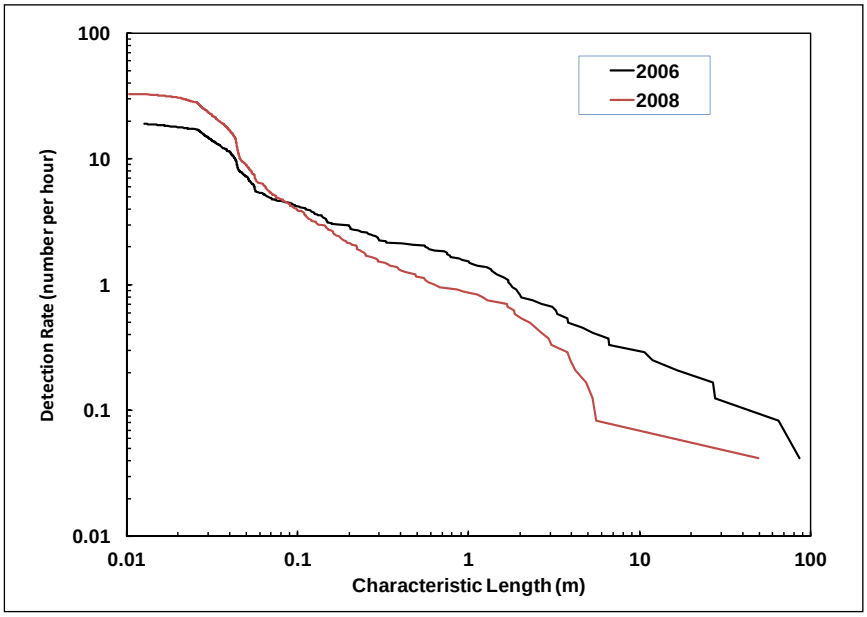

Figure 11. Comparison of size distributions from the TIRA 2006 and 2008 campaigns.

Figure 12 shows the altitude distributions for the two campaigns, while Figure 13 shows the inclination distributions. Major increases in detections between 550 - 1050 km altitude and 80º - 110º, peaking in the 95º - 100º bin, are apparent.

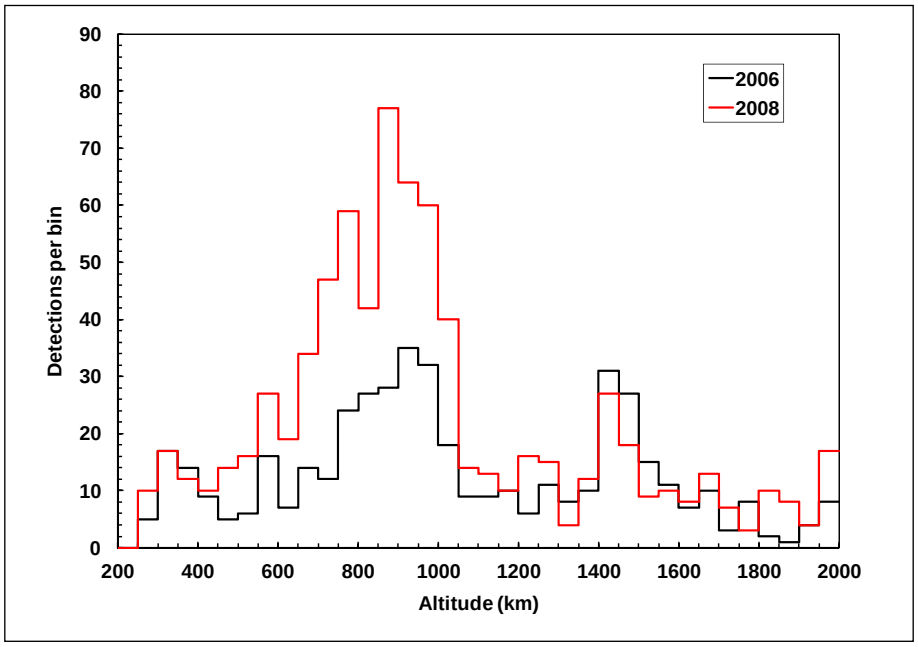

Figure 12. Comparison of altitude distributions from the TIRA 2006 and 2008 campaigns.

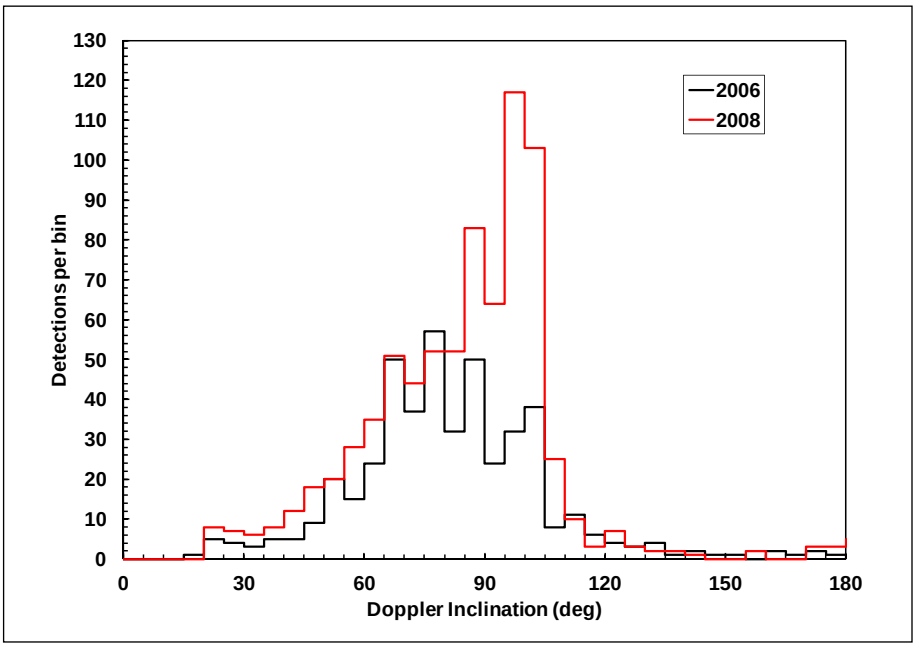

Figure 13. Comparison of the Doppler-inclination distributions from the TIRA 2006 and 2008 campaigns.

4.3 Haystack Radar

NASA has been reexamining its database of Haystack data. It has found that some calibration parameters collected during calibrations of the radar had been incorrectly applied. These errors resulted in the misreporting of the size (characteristic length) of objects in the 2006 24-hour campaign report. Figure 14 shows the cumulative size distribution for the new interpretation of the 2006 data (black line) compared to the 2008 data (red line). For completeness, the old, erroneous data from the 2006 report is shown as well. Like the TIRA data, Haystack shows more objects in 2006 above 10 cm characteristic length and more objects smaller than 10 cm in the 2008 data. Again, the detection rate for all sizes shows an ~50% increase above the 2006 detection rate.

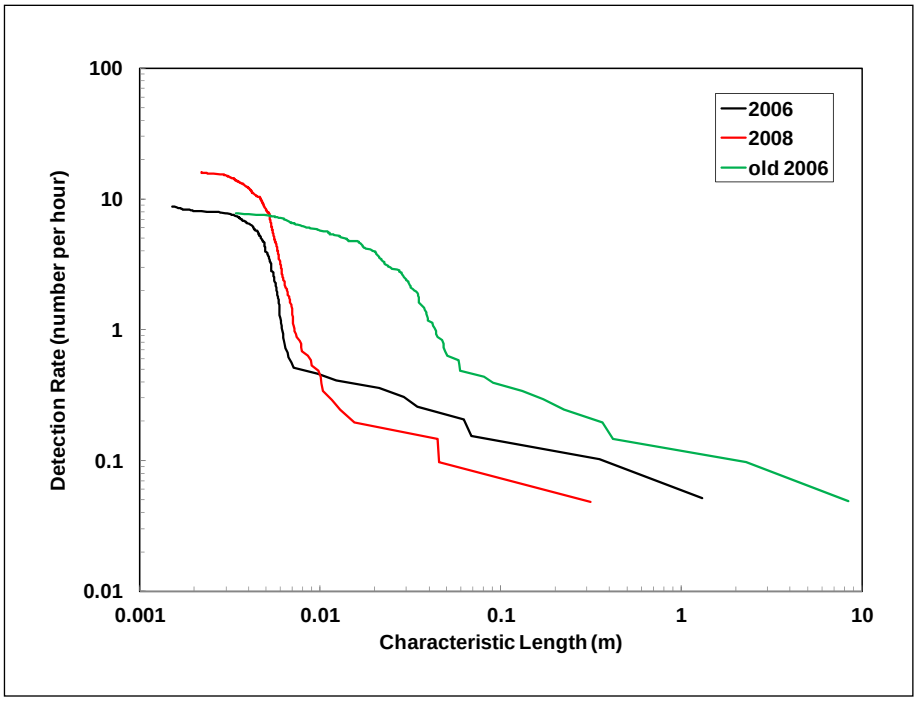

Figure 14. Comparison of size distributions from the Haystack 2006 and 2008 campaigns. The green line is the size distribution originally reported in the 2006 campaign report. The black line is the 2006 size distribution after re-processing.

Figure 15 shows the altitude distributions for the two campaigns, while Figure 16 shows the inclination distributions. Major increases in detections between 400- to 1000-km altitude and a tight grouping between 95º - 100º are apparent. The 2008 rates between 95º - 100º inclination are nearly 400% above the 2006 rates for the same inclination band.

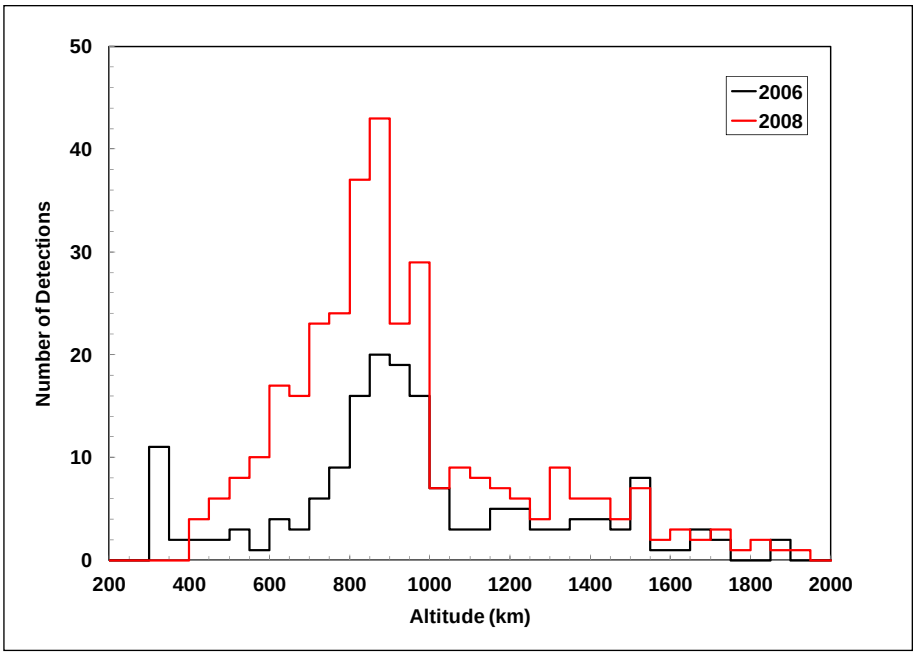

Figure 15. Comparison of the altitude distributions from the Haystack 2006 and 2008 campaigns.

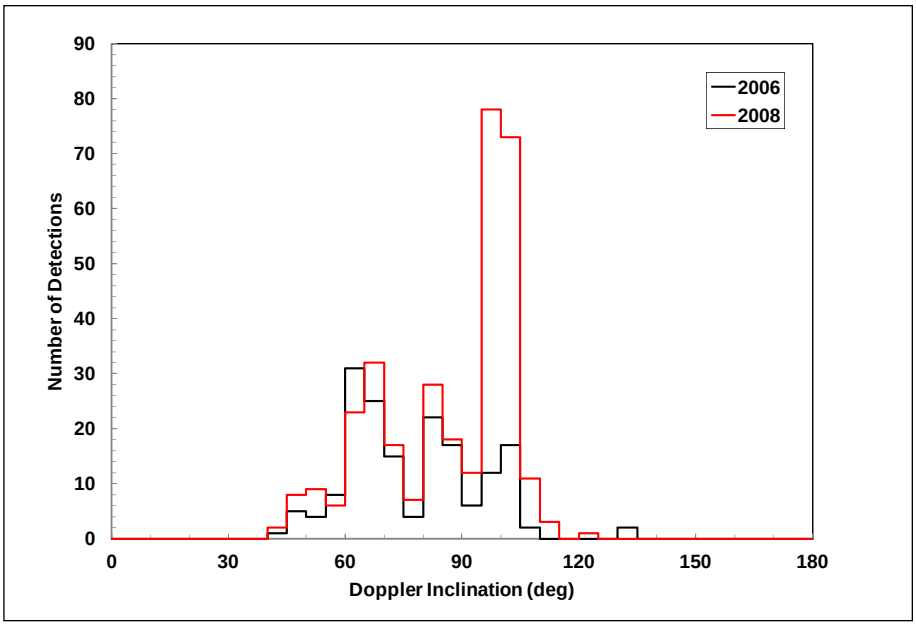

Figure 16. Comparison of the Doppler-inclination distributions from the Haystack 2006 and 2008 campaigns.

4.4 HAX Radar

With only 23 detections in 2006 and 31 detections in 2008, the statistics accumulated during the short 24 campaigns are not sufficient to show meaningful trends between the two campaigns.

4.5 Cobra Dane Radar

Figure 17 shows the cumulative size distributions measured by Cobra Dane for the 2006 and 2008 campaigns. The uncorrelated lines are not, by themselves, particularly meaningful. However, the process of cataloging can be painfully slow at times. Even in 2013, the SSN is still adding Fengyun 1C debris pieces from the January 2007 event to the official catalog. Therefore adding the uncorrelated objects and the analyst satellites to the cataloged population gives a more accurate picture of the on-orbit population at the time of the campaign. Cobra Dane shows more objects in 2006 above 2 m in size. At these larger sizes, the differences are due exclusively to cataloged objects. One possible explanation, other than a true decrease in this population, is a change in the way that the SSN calculates and reports radar cross section. The two populations are then nearly identical between 2 m and ~40 cm. There are more objects below 40 cm in the 2008 data. Once again, this radar shows a detection rate in 2008 for all objects that is ~50% above the rate measured in 2006.

Figure 18 shows the detection rate as a function of altitude for 2008. This plot compares favorably to the spatial density of cataloged objects shown in Figure 19.

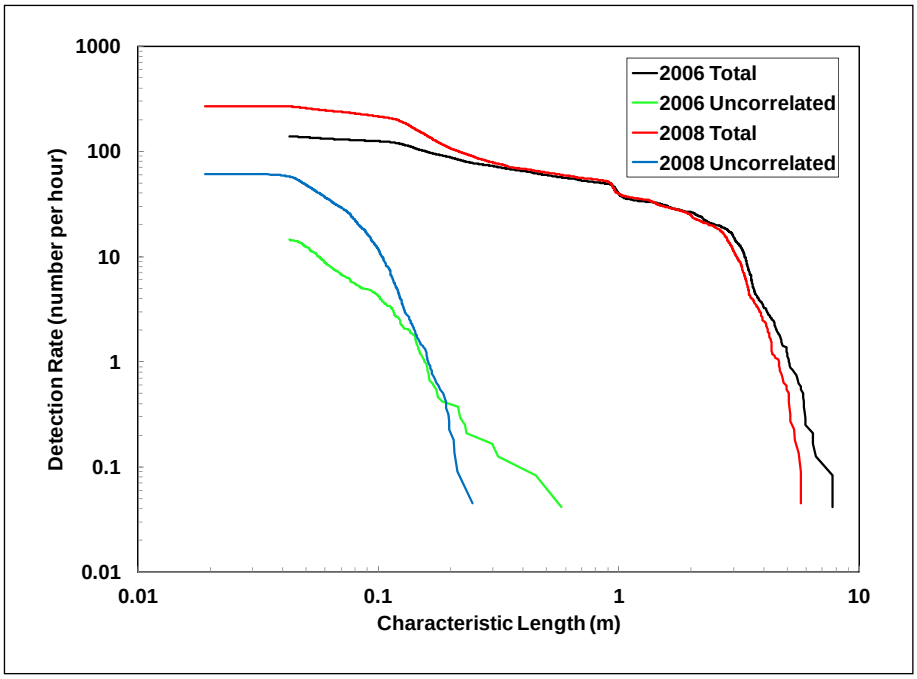

Figure 17. Comparison of size distributions from the Cobra Dane 2006 and 2008 campaigns.

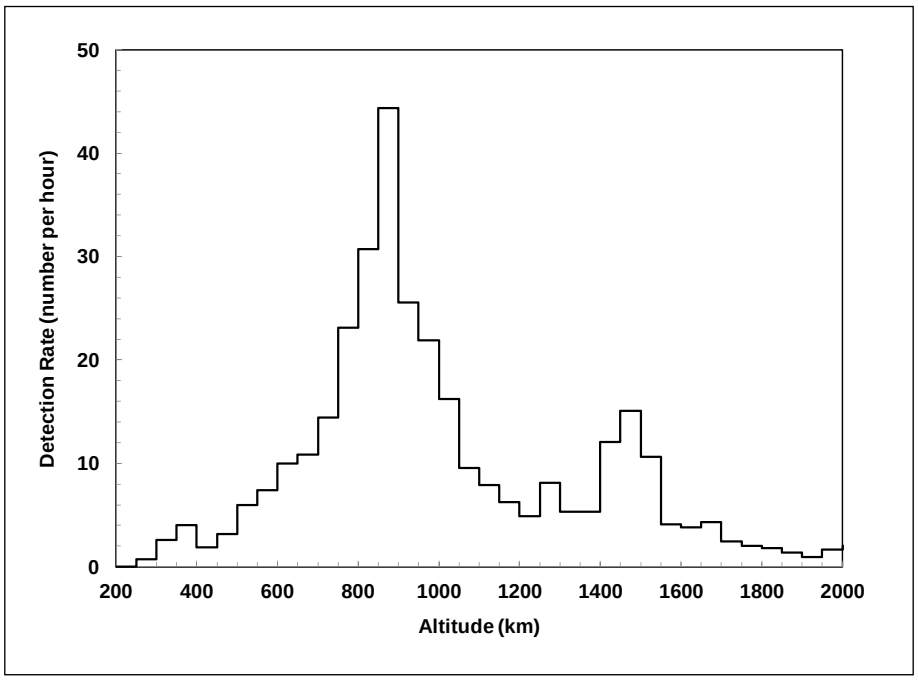

Figure 18. Altitude distribution of Cobra Dane detections for the 2008 campaign.

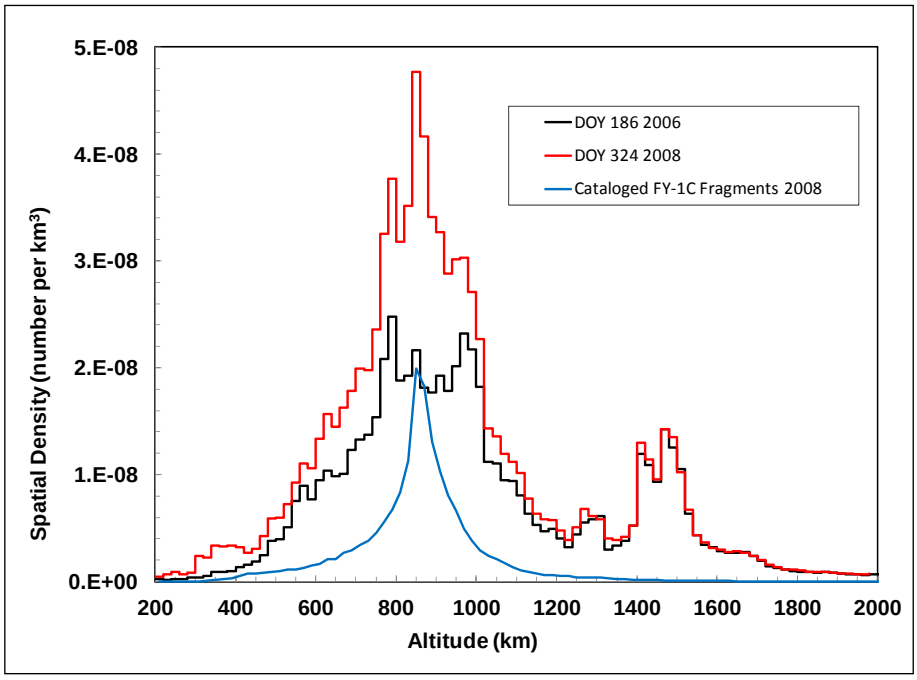

Figure 19. Spatial density plot of catalog objects with epochs during the 2006 and 2008 campaigns.

In 2006, the detection altitude was not provided for all cataloged and uncorrelated detections. In that report, perigee altitude calculated from the two-line element sets was used for plots. Figure 20 shows the difference between detected altitude and perigee altitude distributions for the 2008 campaign. Figure 21 then shows the comparison of perigee altitudes between the 2006 and 2008 campaigns.

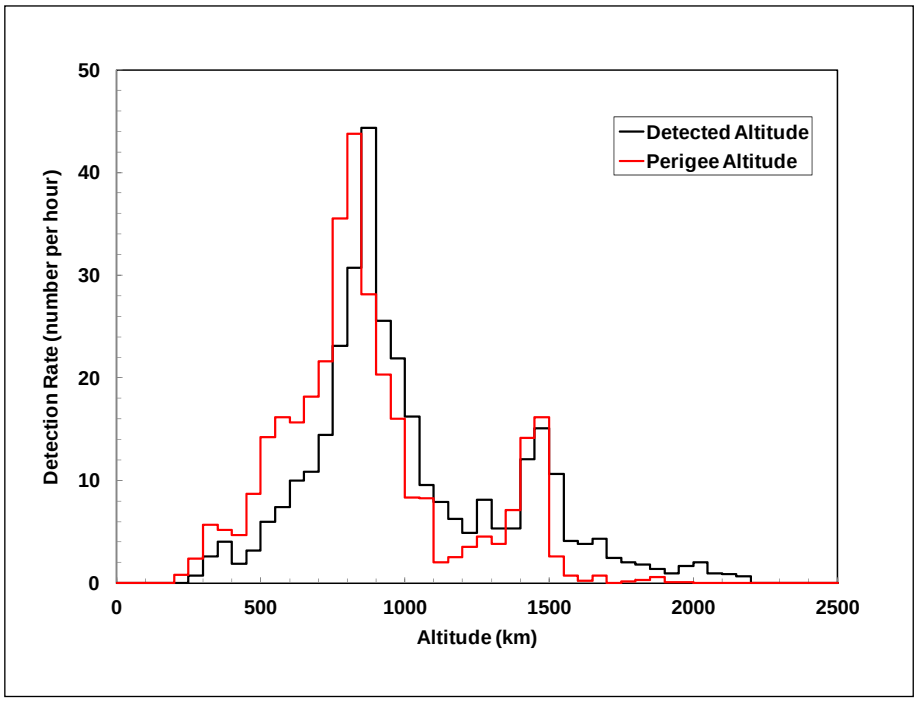

Figure 20. Comparison of distribution of detected altitude and calculated perigee altitude for the Cobra Dane 2008 campaign.

Figure 22 shows the inclination distribution for Cobra Dane from the two campaigns.

In addition to the large increase in the population of the orbits associated with Fengyun, there is also a population apparent in the uncorrelated targets shown in Figure 8. This population has an inclination of about 65º and altitudes below 500 km. Evidence of this population can also be seen in Figures 21 and 22, compared to 2006. These pieces are most likely from the multiple fragmentations of Cosmos 2421. Cosmos 2421 reportedly shed about 500 total debris objects during at least three different times from March to June 2008 [3]. Although the debris lifetimes of these objects would be relatively short at these altitudes, there was still a noticeable population in November 2008 when the Cobra Dane participated in the IADC campaign.

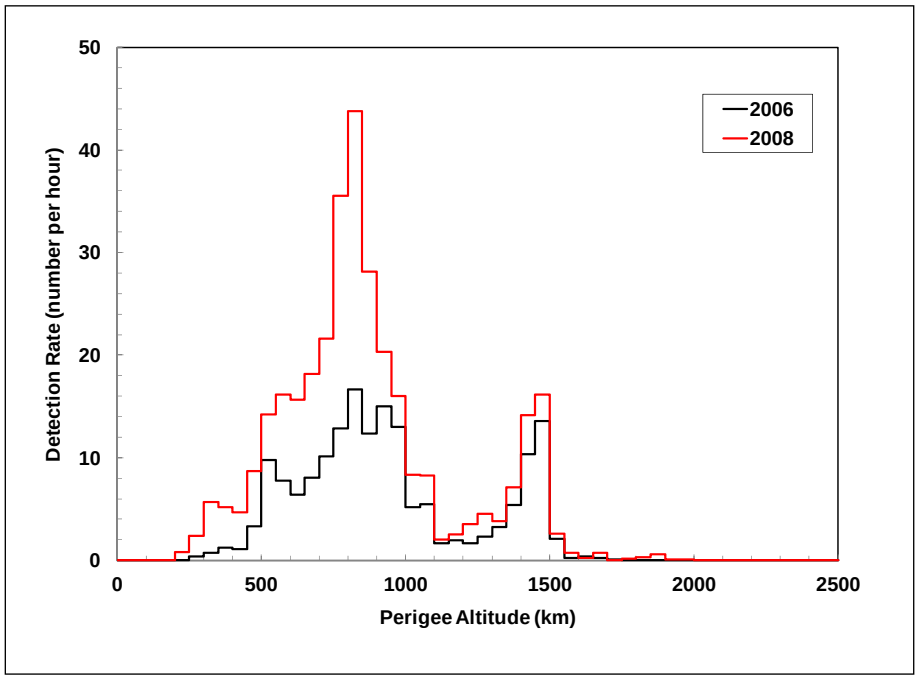

Figure 21. Comparison of the perigee altitude distributions for Cobra Dane for the 2006 and 2008 campaigns.

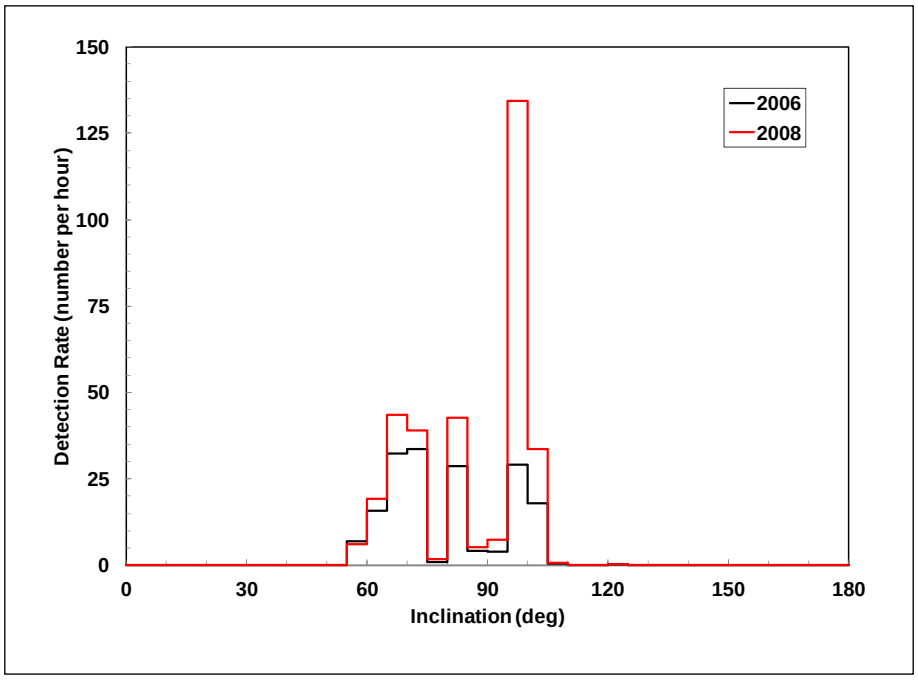

Figure 22. Comparison of the inclination distributions for Cobra Dane for the 2006 and 2008 campaigns.

5. Conclusion

The IADC 24-hour campaigns provide snapshots of the dynamic LEO debris environment. Significant changes occurred between the time of the 2006 and 2008 campaigns. Each radar that participated in both campaigns, with the possible exception of HAX, showed similar results when comparing the measured environments. The 16 on-orbit fragmentations produced a measured environment up to ~50% higher in 2008, compared to 2006, for objects smaller than 10 cm. Much of the increase occurred in an inclination and altitude band consistent with the Fengyun fragmentation.

6. References

[1] Johnson, N., Stansbery, E., Whitlock, D., Abercromby, K., and Shoots, D. *History of On-orbit Satellite Fragmentations, 14th Edition.* NASA/TM-2008-214779. NASA/JSC, Houston, TX, USA, June, 2008.

[2] Johnson, N., Private communication. Fragmentation list maintained by Johnson.

[3] *Orbital Debris Quarterly News*. Vol. 12, No. 3. July, 2008. http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv12i3.pdf

7. Definitions and Acronyms

Al_2O_3	Aluminum oxide
EISCAT	European Incoherent Scatter Scientific Association
EL	Elevation Difference
ESA	European Space Agency
ESR	European (incoherent scatter) Svalbard Radar
FHR	FGAN (now Fraunhofer) Research Institute for High Frequency Physics and Radar Techniques
HAX	Haystack Auxiliary
IADC	Inter-Agency Space Debris Coordination Committee
LEO	Low Earth orbit
MIT/LL	Massachusetts Institute of Technology's Lincoln Laboratory
OP	Orthogonal Polarization
PP	Principal Polarization
RCS	Radar cross section
SEM	Size Estimation Model
SNR	Signal-to-noise ratio
SSN	Space Surveillance Network
TIRA	Tracking and Imaging
TR	Traverse Difference
TWT	Traveling Wave Tube
UCTs	Uncorrelated targets
USSTRATCOM	United States Strategic Command

Appendix A

TIRA Radar

A.1 Introduction

The Tracking and Imaging Radar (TIRA) radar's participation in the Inter-Agency Space Debris Coordination Committee's (IADC) 2008 24-hour campaign was sponsored by the European Space Agency (ESA). The radar was operated by FGAN (now Fraunhofer) Research Institute for High Frequency Physics and Radar Techniques (FHR). At FHR in Wachtberg, Germany, the TIRA system (see Figure A-1) was developed to support experimental radar research. TIRA consists of two monostatic coherent radars supported by one 34-m parabolic antenna: a narrow-band L-band tracking radar and a high-resolution Ku-band imaging radar. Both radars may operate simultaneously on the same object. TIRA has participated in many beam park experiments dating back to 1993. The data processing of beam-park experiments is thoroughly described in Rosebrock et al. [1] and Banka et al. [2].

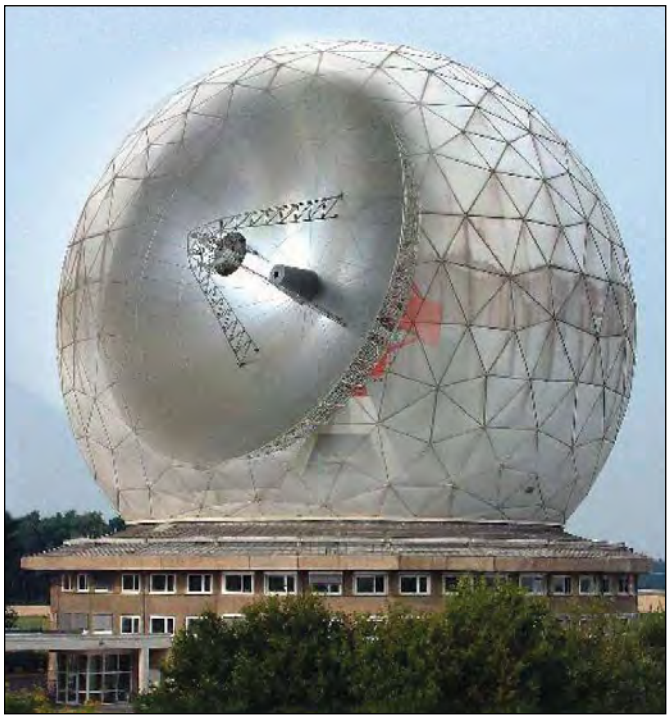

Figure A-1. The TIRA System at Wachtberg, Germany.

A.2 Experiment Setup

Since BPE-1/2000, all beam-park experiments at TIRA have been performed with a virtually identical setup. Tables A-1 and A-2 list the instrument and campaign parameters for the 2008 campaign.

Table A-1. Instrument parameters used by the TIRA radar for the 2008 campaign.

TIRA Instrument Parameters		
Geocentric latitude of sensor	50.62	deg
Geocentric longitude of sensor	7.13	deg
Geodetic altitude	0.293	km
Wavelength	0.225	m
Beam width for incoherent integration	0.49	deg
Antenna constant (Gain)	49.7	dB
Transmitted power (peak)	1500.0	kW
Pulse period	29	msec
Pulse duration	1	msec
Desired false alarm time (Marcum)	36000	sec
Number of independent threshold decisions per pulse	5667	
Maximum number of pulses to integrate	89	
Noise equivalent RCS (NRCS)	-47.5	dB m^2
Transmitted power for NRCS	1500	kW
Pulse duration for NRCS	1	msec
Range for NRCS	1000	km

Table A-2. Campaign parameters for the TIRA radar for the 2008 campaign.

Campaign Parameters		
Campaign Start	25 Nov 2008 12:30 UT	
Maximum range	2000	km
Minimum range	300	km
Azimuth of line of site	93.0	deg
Elevation of line of site	76.12	deg
Duration of campaign	24	hrs
Total recorded data	24.0	hrs

A.3 Processing

In Figure A-2, an overview of the processing is given. It starts with detecting possible object echoes in raw radar data by incoherent integration over several pulse records. This is limited only by a false alarm time of 10 h. Consecutive pulse records containing possible object echoes are grouped.

During reprocessing of these grouped data, range and Doppler-frequency shift are determined more precisely, and tracks of the detections are kept. For each object, time, signal amplitude, range, and Doppler-frequency values, as well as the monopulse angle

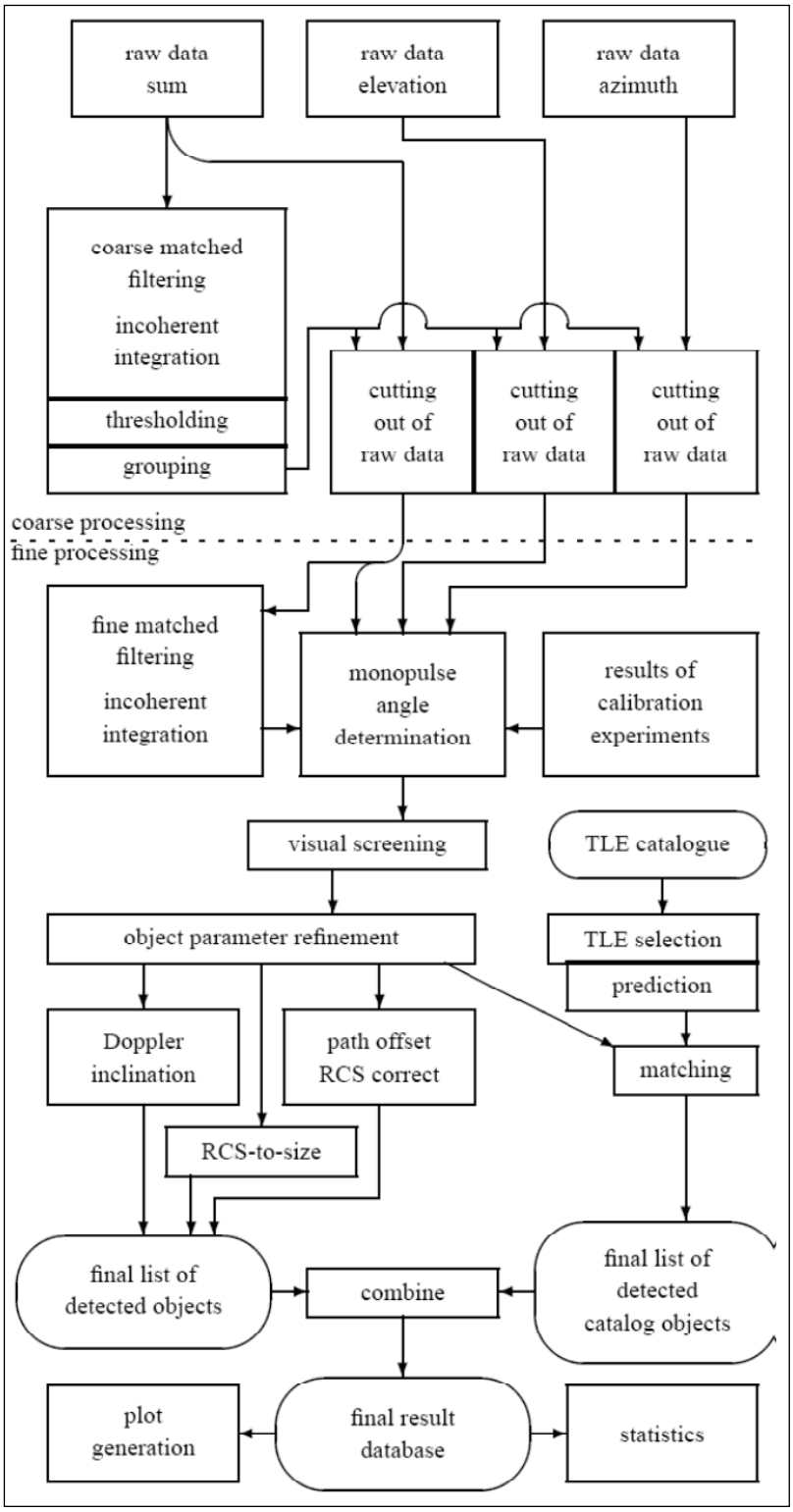

Figure A-2. Processing flow chart.

offsets of consecutive echoes, are determined. The squared amplitudes lead to the radar cross section (RCS) of the objects.

There is a problem of side lobe detections using radars for BPEs. The identification is difficult because, in many cases, the visual screening does not give any consistent clues that would not be plausible for main lobe detections also. Consider TIRA's L-band far field pattern in Figure A-3.

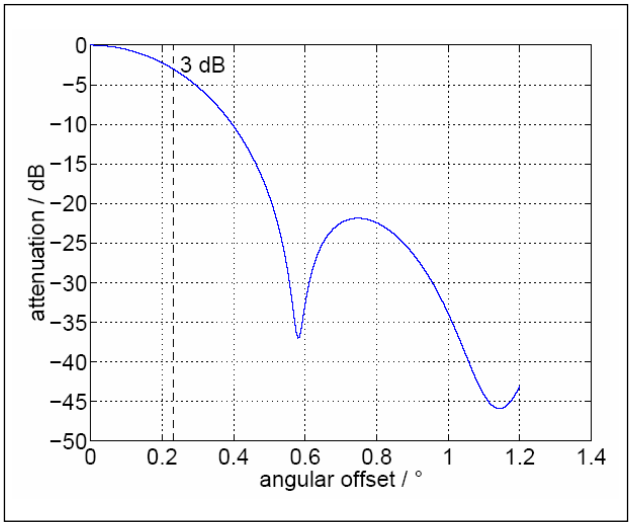

Figure A-3. TIRA's L–band far field radiation pattern (one–way).

The 3-dB beam width of the 34-m parabolic antenna at L-band frequency is 0.5°; the corresponding angular offset is half of this value, namely 0.25°. The first null of the antenna radiation pattern appears at an angular offset of 0.6°, and the maximum of the first side lobe at 0.74°. The maximum of the first side lobe is about 22 dB below the main beam (one-way pattern). For reliable monopulse angle measurements, the angular offset must be <0.35°. Side lobe detections might happen when a larger space object (which is most likely catalogued) passes outside the main beam but crossing, e.g., the first side lobe. It would appear as a small object passing the main beam. However, the maximum signal-to-noise ratio (SNR) is not generated at point of closest approach, but is generated when the object crosses, e.g., the maximum of TIRA's sidelobe several seconds before or after the time of closest approach (TCA), which is computed for the cross-check. Another hint for side lobe detections are look angle differences of more than 0.6°.

RCS is converted to a characteristic length using the NASA Size Estimation Model (SEM), which is described in Appendix E.

A.4 Beamshape

From detailed analysis, it was found that TIRA's L-band beam is circular symmetric with respect to its line-of-sight (LOS) to sufficient accuracy. The (linear) intensity loss factor L_I at positions off the LOS may thus be modelled as a 1-D radial function of the path

offset DF (combined azimuth and elevation offset). This function is fitted by polynomial of degree 10 with neglectable errors in the path offset range $0° \leq \Delta\Phi \leq 0.58°$:

$$L_I = \sum_{i=0}^{10} a_i \Delta\Phi^i ,$$

where $\Delta\Phi$ is given in degrees and the coefficients are provided in the Table A-3 .

A.5 Detection List

Table A-3. Coefficients for loss factor polynomial fit.

a10	-3420.319965
a9	10866.733826
a8	-12673.586251
a7	4832.444768
a6	2699.133493
a5	-3474.882785
a4	1326.159178
a3	-163.994797
a2	-11.501799
a1	-0.457249
a0	1.003540

The TIRA radar detected 786 objects in the 24 hours starting at ~12:30 GMT on 25 November 2008. Table A-4 provides the list of detections observed by the TIRA radar during the 2008 campaign. A determination of correlation between detections and known, or cataloged, objects was not provided by TIRA. Therefore, the column showing possible correlations with the U.S. Space Surveillance Network catalog of known objects was produced by NASA using U.S. Air Force Space Command-provided software.

Table A-4. Detections observed by the TIRA radar for the 2008 campaign.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
1	330	12	32	18.4	1034.1	4.201	-36.16	1003.9	68.1	0.031	
2	330	12	32	18.5	1871.7	-0.678	-19.39	1817.0	107.2	0.090	
3	330	12	32	18.5	1031.8	-0.251	-39.05	1001.7	94.3	0.028	
4	330	12	32	18.6	1068.5	2.609	-31.39	1037.3	31.1	0.039	
5	330	12	42	2.9	1511.0	0.517	-26.00	1466.8	74.4	0.045	
6	330	12	43	27.3	889.7	0.592	-34.53	863.7	74.5	0.033	
7	330	12	47	16.6	1458.0	0.293	-31.87	1415.4	80.5	0.038	22650
8	330	12	47	35.6	802.0	0.070	-38.77	778.6	86.8	0.028	25342
9	330	12	47	39.7	807.6	0.315	-40.56	784.0	81.2	0.026	25342
20	330	12	49	5.9	629.1	-0.654	-39.74	610.7	102.9	0.027	
21	330	12	50	44.0	656.1	0.299	-34.09	636.9	81.8	0.034	22626
22	330	12	58	20.9	683.3	-0.739	-42.15	663.4	105.0	0.025	
23	330	12	59	14.2	841.3	0.868	-38.00	816.8	67.9	0.029	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
24	330	13	5	29.7	872.5	-0.524	-34.22	847.0	100.5	0.034	
25	330	13	7	30.2	977.8	0.869	-34.37	949.2	67.2	0.034	
26	330	13	14	41.8	879.6	-0.822	-37.97	853.9	107.7	0.029	12553
27	330	13	14	47.7	876.7	-0.481	-30.66	851.1	99.6	0.041	12553
28	330	13	15	11.5	2041.3	-0.636	-20.86	1981.7	106.5	0.067	21523
29	330	13	17	20.9	1017.1	-0.316	-31.28	987.4	95.8	0.040	
30	330	13	19	50.6	1257.9	1.150	-31.75	1221.2	58.0	0.039	
31	330	13	20	1.4	1267.7	1.233	-25.89	1230.7	55.4	0.045	
32	330	13	20	29.3	763.8	-0.260	-37.52	741.5	94.3	0.029	5560
33	330	13	22	33.1	1759.4	0.505	-20.47	1708.0	74.0	0.072	
34	330	13	23	1.8	924.4	-0.644	-30.71	897.4	103.5	0.041	
35	330	13	27	19.5	974.0	-0.379	-30.83	945.6	97.3	0.040	
36	330	13	27	50.5	604.3	-0.268	-21.32	586.6	94.3	0.063	
37	330	13	31	12.1	886.2	-0.587	-37.04	860.3	102.1	0.030	12179
38	330	13	32	13.1	515.4	-0.185	-27.16	500.3	92.5	0.044	30586
39	330	13	32	13.6	372.0	-0.019	-57.31	361.1	88.9	0.014	
40	330	13	33	19.1	903.6	0.137	-21.00	877.2	85.2	0.066	
41	330	13	33	57.7	910.7	1.568	-38.16	884.1	48.3	0.028	
42	330	13	33	58.9	1577.9	0.295	-28.80	1531.8	80.3	0.043	16593
43	330	13	34	5.3	1573.0	0.446	13.47	1527.1	76.2	5.322	16593
44	330	13	37	2.4	879.8	0.802	-32.69	854.1	69.4	0.037	15334
45	330	13	42	11.3	1301.8	1.908	-35.68	1263.8	31.3	0.032	
46	330	13	42	12.1	1220.6	2.434	-40.24	1185.0	27.7	0.027	
47	330	13	42	39.5	871.8	-0.553	-38.93	846.4	101.2	0.028	
48	330	13	44	25.7	931.6	-0.649	-36.82	904.4	103.7	0.030	
49	330	13	44	47.1	1017.5	0.088	-35.43	987.8	86.2	0.032	
50	330	13	49	32.8	1556.0	0.549	-21.92	1510.6	73.4	0.057	
51	330	13	51	50.6	928.4	-0.455	-41.52	901.2	99.0	0.026	
52	330	13	56	14.0	1133.2	-0.350	-30.86	1100.1	96.8	0.040	
53	330	13	56	21.1	794.2	-0.571	-28.59	771.1	101.5	0.044	31291
54	330	14	5	36.1	703.0	-0.321	-39.53	682.5	95.6	0.027	
55	330	14	10	56.9	343.0	1.025	-23.66	333.0	66.7	0.052	33421
56	330	14	15	34.2	1534.0	-0.538	-21.51	1489.2	102.4	0.062	
57	330	14	16	55.2	943.5	-0.669	-25.12	915.9	104.2	0.047	
58	330	14	17	29.2	820.0	0.847	-28.64	796.1	68.5	0.044	
59	330	14	17	51.5	1109.9	-0.069	-36.72	1077.5	90.0	0.030	
60	330	14	21	16.5	788.0	0.802	-35.50	764.9	69.8	0.032	
61	330	14	24	32.0	1183.6	2.405	-35.04	1149.1	25.9	0.033	
62	330	14	27	30.7	977.5	-0.682	-37.30	948.9	104.6	0.029	
63	330	14	29	45.1	880.5	0.116	-27.73	854.8	85.7	0.044	
64	330	14	30	53.6	588.1	0.042	-25.37	571.0	87.6	0.046	19274
65	330	14	30	56.0	732.0	-0.189	-49.41	710.6	92.7	0.019	
66	330	14	30	56.9	462.0	0.201	-52.20	448.5	84.2	0.017	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
67	330	14	30	58.3	589.6	0.449	-43.34	572.4	78.6	0.024	19274
68	330	14	37	14.4	821.3	1.063	-7.24	797.4	63.1	0.490	9982
69	330	14	37	47.2	1859.5	0.937	-20.65	1805.2	60.7	0.069	19294
70	330	14	38	44.6	1430.7	-0.568	-27.45	1388.9	102.9	0.044	
71	330	14	39	19.8	452.5	-2.620	-45.41	439.3	159.0	0.022	
72	330	14	39	35.6	1027.3	0.160	-34.49	997.3	84.5	0.033	22889
73	330	14	39	42.6	1034.4	0.457	-35.67	1004.2	77.3	0.032	
74	330	14	41	46.1	556.4	-0.361	-19.25	540.2	96.3	0.093	
75	330	14	43	43.9	600.8	2.220	-26.71	583.2	30.2	0.045	
76	330	14	43	53.0	976.2	-0.601	-36.58	947.7	102.6	0.030	
77	330	14	46	10.5	1430.8	0.402	-24.78	1389.0	77.7	0.048	
78	330	14	46	25.3	975.3	0.890	-36.71	946.8	66.7	0.030	
79	330	14	49	26.8	881.2	-0.549	-36.47	855.5	101.2	0.030	
80	330	14	49	50.8	882.8	-0.580	-27.19	857.0	101.9	0.044	
81	330	14	52	46.3	871.4	-0.573	-36.86	846.0	101.7	0.030	
82	330	14	53	25.2	736.5	0.275	-37.49	715.0	82.2	0.029	25578
83	330	14	54	14.1	1667.7	0.810	-12.56	1619.0	65.5	0.250	4621
84	330	14	57	4.4	876.3	-0.498	-30.48	850.7	99.9	0.041	
85	330	14	58	35.4	875.6	0.367	-19.30	850.0	79.8	0.092	82004
86	330	14	59	2.9	759.8	-0.704	-20.07	737.6	104.5	0.079	29837
87	330	15	0	42.1	1811.6	1.163	-30.99	1758.7	53.6	0.040	
88	330	15	0	42.5	1763.9	1.120	-18.29	1712.4	55.3	0.111	
89	330	15	2	10.9	1706.2	0.579	-25.35	1656.4	72.1	0.046	8295
90	330	15	2	53.7	886.5	-0.556	-30.83	860.7	101.3	0.040	
91	330	15	3	51.3	869.7	-0.562	-20.79	844.3	101.4	0.068	
92	330	15	7	24.2	883.4	-0.575	-24.35	857.6	101.8	0.050	
93	330	15	7	38.8	985.4	0.461	-37.60	956.6	77.3	0.029	
94	330	15	8	2.1	977.5	0.878	-32.75	949.0	67.0	0.037	
95	330	15	8	3.6	974.3	0.903	-34.34	945.9	66.4	0.034	
96	330	15	10	41.2	1732.2	-0.788	-20.47	1681.6	110.0	0.072	
97	330	15	10	43.4	1733.1	-0.744	-19.88	1682.5	108.7	0.082	
98	330	15	12	6.5	1626.9	0.289	-31.75	1579.4	80.3	0.039	
99	330	15	12	50.5	528.0	1.581	-44.22	512.6	51.7	0.023	
100	330	15	16	58.9	758.0	-1.390	-25.37	735.9	121.3	0.046	
101	330	15	17	6.3	744.2	-1.368	-27.30	722.5	120.6	0.044	
102	330	15	17	15.7	1894.5	0.118	-24.55	1839.2	84.7	0.049	
103	330	15	17	19.4	1902.4	0.104	-30.12	1846.9	85.1	0.042	
104	330	15	17	39.6	1904.8	0.121	-25.53	1849.2	84.6	0.046	
105	330	15	17	48.7	1897.9	0.115	-21.89	1842.5	84.8	0.057	
106	330	15	18	13.0	762.0	-0.533	-47.03	739.7	100.5	0.020	
107	330	15	18	14.0	890.6	-0.512	-16.77	864.6	100.3	0.143	89268
108	330	15	20	24.5	852.0	-0.598	-33.01	827.1	102.2	0.036	
109	330	15	22	23.3	877.4	1.037	-21.76	851.8	63.5	0.058	81162

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
110	330	15	25	7.1	1039.2	-0.863	-26.45	1008.8	109.3	0.045	
111	330	15	27	23.2	883.5	0.837	-29.33	857.7	68.5	0.043	
112	330	15	33	25.4	508.9	1.298	-45.75	494.1	59.2	0.022	
113	330	15	41	53.4	1896.9	0.043	-20.30	1841.5	86.8	0.075	
114	330	15	41	53.5	937.4	0.136	-36.69	910.0	85.2	0.030	
115	330	15	42	10.1	1896.6	0.040	-24.18	1841.2	86.9	0.050	
116	330	15	44	43.7	794.6	-0.663	-35.64	771.4	103.6	0.032	
117	330	15	46	59.9	1921.4	0.036	-18.79	1865.3	87.0	0.101	
118	330	15	47	8.2	278.0	0.003	-54.75	269.9	88.5	0.015	
119	330	15	47	11.6	1922.5	0.039	-15.99	1866.3	86.9	0.162	
120	330	15	47	39.8	1926.8	0.030	-18.36	1870.6	87.2	0.110	
121	330	15	52	11.6	1389.8	-1.038	-22.34	1349.3	115.6	0.056	
122	330	15	52	30.4	996.2	-0.614	-33.84	967.1	103.0	0.035	
123	330	15	53	18.7	880.4	-0.502	-39.48	854.7	100.0	0.027	
124	330	15	54	2.0	805.8	-0.617	-41.71	782.2	102.6	0.026	
125	330	15	56	15.0	968.7	0.872	-35.62	940.4	67.2	0.032	
126	330	15	58	18.9	1068.2	1.260	-20.87	1037.0	56.1	0.067	81337
127	330	16	0	10.4	1030.7	0.030	-11.56	1000.6	87.6	0.285	12735
128	330	16	0	38.0	890.5	-0.521	-38.54	864.5	100.5	0.028	
129	330	16	1	57.1	776.0	-0.612	-35.14	753.4	102.4	0.032	26260
130	330	16	3	50.7	1962.0	2.683	-17.81	1904.7	49.2	0.121	
131	330	16	4	12.2	768.4	-0.330	-34.17	746.0	95.9	0.034	
132	330	16	9	23.8	858.3	-0.674	-41.22	833.2	104.0	0.026	
133	330	16	13	26.1	890.3	-0.585	-34.49	864.3	102.0	0.033	
134	330	16	16	59.0	888.6	-0.549	-21.06	862.6	101.2	0.065	
135	330	16	17	57.6	319.9	1.701	-41.77	310.5	50.5	0.026	
136	330	16	18	12.3	816.0	0.940	-37.36	792.2	66.2	0.029	
137	330	16	18	13.1	1717.9	2.241	-31.37	1667.8	30.0	0.040	
138	330	16	18	13.6	1807.4	2.174	-31.50	1754.6	29.0	0.039	
139	330	16	18	13.7	1692.8	-0.010	-27.48	1643.4	88.4	0.044	
140	330	16	20	35.1	627.9	-0.469	-38.17	609.6	98.8	0.028	28413
141	330	16	21	32.5	1512.0	0.302	-22.66	1467.8	80.2	0.056	21305
142	330	16	24	13.6	1277.4	0.678	-16.07	1240.1	70.9	0.160	87038
143	330	16	28	28.8	1602.2	-0.036	-20.57	1555.4	89.1	0.070	
144	330	16	29	3.2	1384.2	0.678	-27.95	1343.8	70.5	0.044	85377
145	330	16	37	53.9	906.2	-0.482	-22.77	879.8	99.6	0.056	
146	330	16	37	58.8	825.7	-0.302	-29.85	801.6	95.3	0.042	
147	330	16	44	25.9	847.1	2.216	-39.22	822.3	26.0	0.027	
148	330	16	47	28.6	1034.2	-0.018	-29.15	1004.0	88.7	0.043	11736
149	330	16	47	33.9	1031.9	0.224	-31.66	1001.8	83.0	0.039	11736
150	330	16	49	1.2	1006.7	0.761	-34.51	977.3	69.9	0.033	87090
151	330	16	50	58.6	1521.0	0.457	-26.61	1476.6	76.0	0.045	
152	330	16	53	44.0	976.0	0.353	-28.73	947.5	80.0	0.043	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
153	330	16	59	29.3	893.0	-0.605	-31.37	866.9	102.5	0.040	
154	330	17	2	33.8	628.3	-0.424	-30.23	610.0	97.8	0.041	
155	330	17	5	30.3	1000.5	0.112	-34.61	971.3	85.7	0.033	20578
156	330	17	5	37.5	1002.3	0.451	-30.78	973.0	77.5	0.041	
157	330	17	9	5.0	639.0	1.386	-41.21	620.4	56.0	0.026	5010
158	330	17	14	1.0	2050.2	-0.828	-14.24	1990.4	112.4	0.204	
159	330	17	16	4.5	796.2	-0.529	-31.48	772.9	100.5	0.039	31872
160	330	17	16	26.2	890.2	-0.571	-35.41	864.2	101.7	0.032	
161	330	17	26	28.8	1443.7	0.396	-30.33	1401.5	77.8	0.041	
162	330	17	27	40.3	1425.2	0.473	-27.77	1383.6	75.9	0.044	
163	330	17	30	52.5	1001.7	0.138	-33.15	972.5	85.1	0.036	87608
164	330	17	31	14.2	993.4	-0.426	-19.57	964.4	98.5	0.087	31146
165	330	17	31	16.3	809.2	-0.536	-20.74	785.5	100.7	0.068	28064
166	330	17	35	58.7	570.5	0.479	-43.77	553.9	78.0	0.023	13068
167	330	17	36	40.2	1125.6	1.475	-26.99	1092.7	49.1	0.045	
168	330	17	39	12.0	896.7	-0.542	-28.82	870.5	101.0	0.043	85267
169	330	17	42	50.1	989.8	-0.252	-28.57	960.9	94.3	0.044	
170	330	17	45	12.1	806.7	-0.619	-36.56	783.1	102.6	0.030	
171	330	17	46	0.4	1550.9	-0.603	-21.92	1505.6	104.2	0.057	
172	330	17	47	37.7	949.9	1.025	-21.12	922.2	63.3	0.065	26504
173	330	17	48	16.7	488.7	-4.851	-48.14	474.4	187.9	0.020	
174	330	17	48	45.6	384.7	-2.223	-39.67	373.5	141.5	0.027	
175	330	17	48	54.7	821.4	-0.624	-38.26	797.4	102.8	0.028	16969
176	330	17	48	58.5	361.9	-0.541	-46.70	351.3	99.8	0.021	
177	330	17	49	0.3	815.9	-0.292	-37.22	792.0	95.1	0.029	16969
178	330	17	49	4.0	492.2	0.444	-53.29	477.8	79.0	0.016	
179	330	17	49	10.1	369.1	1.108	-15.82	358.3	64.7	0.165	
180	330	17	49	27.9	410.9	3.272	-26.79	398.9	38.6	0.045	
181	330	17	49	41.4	464.1	4.459	-44.42	450.5	63.8	0.023	
182	330	17	50	51.2	825.1	0.615	-39.76	801.0	74.1	0.027	13242
183	330	17	52	30.4	2038.6	0.992	-25.22	1979.1	57.8	0.047	
184	330	17	53	0.6	948.5	1.018	-23.34	920.8	63.5	0.054	26506
185	330	17	53	5.4	764.0	-0.049	-40.20	741.7	89.5	0.027	
186	330	17	53	42.5	1209.9	0.038	-40.71	1174.5	87.3	0.026	
187	330	17	57	51.3	1363.9	1.386	-26.11	1324.1	49.8	0.045	27772
188	330	17	58	54.1	915.3	-0.621	-23.30	888.5	103.0	0.054	
189	330	18	2	38.8	609.8	-0.723	-40.59	592.0	104.4	0.026	26121
190	330	18	3	53.4	782.6	-0.641	-36.26	759.8	103.1	0.031	
191	330	18	3	54.5	949.9	-0.641	-45.18	922.2	103.5	0.022	
192	330	18	3	54.8	726.0	-0.634	-47.19	704.8	102.8	0.020	
193	330	18	3	55.9	885.9	-0.631	-25.65	860.0	103.1	0.046	31756
194	330	18	5	13.2	1541.2	1.080	-29.83	1496.2	58.1	0.042	
195	330	18	5	14.0	1721.7	0.517	-23.20	1671.4	73.8	0.054	3874

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
196	330	18	6	28.1	911.7	-0.595	-30.45	885.0	102.3	0.041	
197	330	18	9	45.1	823.0	0.755	-32.17	799.0	70.8	0.038	10120
198	330	18	14	20.7	1666.6	0.591	0.66	1618.0	71.9	1.217	25365
199	330	18	16	48.3	1093.7	-0.425	-22.82	1061.8	98.6	0.055	
200	330	18	20	50.1	1451.2	1.182	-29.33	1408.9	55.6	0.043	25771
201	330	18	28	25.3	1001.8	0.011	-30.88	972.5	88.1	0.040	22782
202	330	18	31	34.4	1032.0	0.879	-34.50	1001.8	66.7	0.033	
203	330	18	31	35.1	902.8	0.778	-23.65	876.4	69.9	0.052	87386
204	330	18	31	41.7	861.9	0.099	-21.75	836.7	86.1	0.058	87725
205	330	18	32	52.7	550.9	-0.573	-28.93	534.8	100.9	0.043	
206	330	18	42	11.7	1130.8	0.432	-18.61	1097.8	77.7	0.105	
207	330	18	42	11.8	350.4	1.077	-44.92	340.1	65.5	0.022	
208	330	18	45	7.5	679.4	-0.646	-38.38	659.6	102.9	0.028	
209	330	18	47	10.4	585.2	0.461	-45.89	568.1	78.3	0.021	
210	330	18	47	10.9	600.0	0.474	-48.64	582.5	78.0	0.019	
211	330	18	55	15.5	991.0	1.012	-34.56	962.0	63.5	0.033	
212	330	18	59	14.2	877.8	-0.626	-22.76	852.2	103.0	0.056	
213	330	18	59	52.0	1135.6	-0.061	-33.32	1102.5	89.8	0.036	19071
214	330	19	4	10.6	714.1	0.827	-38.53	693.3	69.5	0.028	
215	330	19	6	16.1	888.8	-0.412	-39.63	862.9	98.0	0.027	28050
216	330	19	6	20.1	982.8	0.133	-25.91	954.1	85.2	0.045	
217	330	19	8	16.7	1043.5	-0.481	-21.90	1013.0	99.9	0.057	
218	330	19	8	16.9	822.5	3.038	-29.19	798.5	40.3	0.043	
219	330	19	9	51.8	723.4	-0.577	-37.30	702.3	101.4	0.029	
220	330	19	12	16.3	645.4	-0.036	-40.75	626.6	89.2	0.026	16987
221	330	19	14	14.9	1002.8	0.019	-36.03	973.5	87.9	0.031	
222	330	19	17	5.3	1722.0	0.004	-28.47	1671.7	88.0	0.044	
223	330	19	22	58.8	822.0	2.201	-35.65	798.0	27.0	0.032	
224	330	19	23	0.2	675.1	1.394	3.46	655.4	55.5	1.680	
225	330	19	23	1.2	822.0	1.789	-45.27	798.0	42.3	0.022	
226	330	19	23	4.0	675.8	1.644	-41.63	656.1	48.5	0.026	
227	330	19	24	23.0	378.5	-0.900	-48.99	367.4	107.6	0.019	
228	330	19	24	32.3	389.1	0.317	-49.88	377.7	81.9	0.018	
229	330	19	24	39.7	383.8	1.318	-51.86	372.6	59.6	0.017	
230	330	19	24	49.1	412.5	2.456	-48.55	400.5	24.3	0.019	
231	330	19	24	51.8	407.6	2.774	-50.40	395.7	21.4	0.018	
232	330	19	24	59.0	433.3	3.485	-40.75	420.7	44.6	0.026	
233	330	19	26	23.8	735.8	-1.002	-39.28	714.3	111.4	0.027	
234	330	19	27	36.5	672.2	0.701	-35.11	652.6	72.6	0.032	22477
235	330	19	28	35.9	616.9	-0.600	-21.82	598.9	101.7	0.058	31694
236	330	19	28	45.6	569.5	-0.525	-24.59	552.9	99.9	0.049	
237	330	19	32	26.6	1538.0	-0.624	-23.93	1493.1	104.7	0.052	81804
238	330	19	32	28.5	851.6	-0.627	-26.77	826.8	102.9	0.045	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
239	330	19	32	44.9	1423.8	0.703	-27.95	1382.3	69.7	0.044	
240	330	19	40	22.8	1734.8	0.088	-29.47	1684.2	85.7	0.043	29284
241	330	19	47	51.0	595.8	-0.499	-25.70	578.4	99.4	0.046	
242	330	19	48	17.0	1274.4	0.305	-27.60	1237.2	80.6	0.044	
243	330	19	55	33.3	1156.7	-0.324	-23.33	1123.0	96.2	0.054	
244	330	19	56	14.7	320.7	0.016	-54.24	311.4	88.2	0.016	
245	330	19	56	16.8	311.6	0.023	-54.76	302.5	88.1	0.015	
246	330	19	56	58.7	1710.5	2.081	-32.43	1660.6	24.6	0.037	
247	330	19	56	59.4	1260.7	2.329	-18.89	1223.9	24.8	0.100	
248	330	19	57	0.6	1256.2	3.099	-35.09	1219.5	49.5	0.032	
249	330	19	57	6.8	305.1	0.795	-59.90	296.2	71.9	0.013	
250	330	19	57	8.6	671.8	1.087	-51.56	652.2	63.4	0.017	
251	330	19	57	8.9	812.3	0.886	-21.85	788.6	67.6	0.058	4311
252	330	19	58	16.8	1061.5	-0.327	-37.24	1030.5	96.2	0.029	8860
253	330	19	59	40.5	301.1	0.095	-59.92	292.4	86.6	0.012	
254	330	20	0	10.0	823.5	0.650	-38.81	799.5	73.3	0.028	
255	330	20	1	58.7	914.0	-0.691	-36.15	887.3	104.6	0.031	
256	330	20	3	15.0	337.7	1.682	-47.59	327.8	50.9	0.020	
257	330	20	4	28.9	638.0	-0.392	-27.40	619.4	97.1	0.044	
258	330	20	6	33.8	791.9	0.592	-35.68	768.8	74.8	0.032	13149
259	330	20	6	41.2	802.4	1.027	-39.06	779.0	64.1	0.028	
260	330	20	8	12.3	858.6	-0.734	-39.93	833.5	105.5	0.027	29499
261	330	20	8	16.7	852.6	-0.471	-38.23	827.7	99.3	0.028	29499
262	330	20	9	14.3	574.7	0.268	-20.99	557.9	82.6	0.066	5117
263	330	20	12	34.4	554.7	-0.433	-46.54	538.5	97.9	0.021	
264	330	20	13	24.7	1200.2	-0.984	-20.96	1165.2	113.1	0.066	
265	330	20	21	28.4	877.4	-0.537	-19.65	851.8	100.9	0.086	26821
266	330	20	23	21.2	707.8	0.752	-25.61	687.1	71.3	0.046	5778
267	330	20	24	10.2	671.1	-0.540	-35.44	651.5	100.5	0.032	
268	330	20	24	47.0	690.3	2.611	-41.65	670.2	22.6	0.026	
269	330	20	28	4.8	311.7	0.296	-58.96	302.6	82.5	0.013	
270	330	20	30	42.4	459.9	-0.657	-54.22	446.4	102.5	0.016	27838
271	330	20	30	45.0	470.4	-0.356	-44.54	456.7	96.1	0.023	27838
272	330	20	32	43.5	973.3	1.139	-24.17	944.9	60.2	0.050	81567
273	330	20	33	54.4	1332.4	0.060	-26.23	1293.5	86.7	0.045	
274	330	20	34	50.9	2043.3	0.544	-21.16	1983.6	72.0	0.064	
275	330	20	35	18.8	341.5	0.001	-51.83	331.5	88.5	0.017	
276	330	20	35	22.2	737.9	1.214	-40.82	716.3	59.7	0.026	
277	330	20	37	18.9	311.9	0.455	-58.59	302.8	79.1	0.013	
278	330	20	38	26.3	906.6	-0.394	-21.88	880.1	97.5	0.057	31740
279	330	20	43	55.3	940.8	0.684	-13.50	913.3	72.0	0.223	729
280	330	20	44	41.6	911.3	-0.558	-25.77	884.7	101.4	0.046	
281	330	20	44	47.2	798.1	1.777	-39.93	774.8	43.0	0.027	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
282	330	20	47	44.6	1331.7	0.068	-21.43	1292.8	86.5	0.062	18427
283	330	20	50	53.6	1455.9	1.325	8.30	1413.4	51.0	2.936	25770
284	330	20	55	55.4	977.3	1.026	-34.24	948.8	63.2	0.034	
285	330	20	57	46.6	1033.6	-0.231	-33.32	1003.4	93.8	0.036	
286	330	20	58	10.2	1015.4	0.962	-17.52	985.7	64.6	0.127	141
287	330	21	0	19.1	508.7	2.863	-41.36	493.9	27.5	0.026	
288	330	21	0	37.7	578.5	4.229	-43.69	561.6	61.9	0.023	
289	330	21	1	15.2	1332.3	0.095	-20.40	1293.4	85.8	0.073	81705
290	330	21	6	27.7	1158.0	-0.183	-29.67	1124.2	92.8	0.042	
291	330	21	7	25.4	762.8	-2.941	-42.41	740.5	174.5	0.024	
292	330	21	7	26.4	647.2	-0.526	-32.73	628.3	100.1	0.037	28649
293	330	21	9	18.6	1498.2	-0.622	-16.44	1454.4	104.5	0.151	7134
294	330	21	10	38.7	357.4	0.819	-56.35	346.9	71.2	0.014	
295	330	21	10	45.4	490.5	-0.095	-41.63	476.2	90.5	0.026	27392
296	330	21	11	15.9	480.9	-0.386	-47.12	466.8	96.7	0.020	
297	330	21	11	19.7	487.9	0.044	-46.01	473.7	87.6	0.021	27391
298	330	21	11	30.2	1454.0	-0.017	-29.38	1411.6	88.6	0.043	
299	330	21	11	35.5	291.6	0.247	-59.57	283.1	83.5	0.013	
300	330	21	11	37.9	1459.0	0.193	-28.69	1416.4	83.2	0.043	21784
301	330	21	17	12.8	1061.4	-0.827	-26.53	1030.4	108.5	0.045	
302	330	21	19	18.9	787.5	0.483	-39.13	764.5	77.3	0.028	24842
303	330	21	19	23.2	808.2	-3.502	-39.98	784.6	180.2	0.027	
304	330	21	19	31.0	741.8	-0.514	-32.04	720.1	100.0	0.038	
305	330	21	21	50.7	1069.8	-0.344	-32.41	1038.5	96.6	0.037	4980
306	330	21	26	23.9	1308.4	-0.693	-27.77	1270.2	105.9	0.044	
307	330	21	26	42.5	1005.4	0.245	-28.39	976.0	82.5	0.044	15359
308	330	21	27	32.4	981.0	0.339	-9.14	952.3	80.3	0.383	12964
309	330	21	30	26.7	694.3	-0.447	-19.90	674.1	98.4	0.082	87008
310	330	21	33	54.1	1521.2	0.431	-23.08	1476.8	76.7	0.055	
311	330	21	40	32.7	1125.0	0.066	-26.75	1092.1	86.7	0.045	
312	330	21	43	22.8	595.0	-0.698	-34.25	577.6	103.8	0.034	
313	330	21	43	24.4	603.3	-0.643	-33.04	585.7	102.6	0.036	
314	330	21	48	28.5	1573.1	0.216	-29.53	1527.2	82.4	0.043	
315	330	21	48	36.6	949.0	0.710	-39.18	921.3	71.3	0.027	
316	330	21	48	53.8	945.1	1.217	-37.07	917.5	58.2	0.030	
317	330	21	49	19.5	1002.0	0.097	-16.61	972.8	86.0	0.147	16510
318	330	21	52	1.5	1275.3	-0.028	-29.49	1238.0	88.9	0.043	
319	330	21	52	2.8	1328.8	0.035	-18.41	1290.0	87.3	0.109	
320	330	21	52	39.4	779.6	-0.740	-23.53	756.9	105.4	0.053	31045
321	330	21	53	56.8	528.2	1.368	-35.68	512.8	57.3	0.032	15354
322	330	21	59	46.8	330.7	-0.524	-56.01	321.1	99.4	0.015	
323	330	22	0	18.1	313.9	0.904	-61.83	304.7	69.6	0.012	
324	330	22	0	21.1	1517.2	0.679	-13.54	1472.9	70.0	0.222	13164

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
325	330	22	5	42.3	825.3	0.628	-22.10	801.2	73.8	0.057	87384
326	330	22	6	8.2	1461.6	1.239	-31.72	1418.9	53.7	0.039	
327	330	22	6	9.0	1033.9	-0.488	-27.65	1003.7	100.0	0.044	
328	330	22	6	9.2	1480.8	1.754	-31.68	1437.5	35.1	0.039	
329	330	22	6	9.5	1059.1	3.456	-40.20	1028.1	54.7	0.027	
330	330	22	7	14.8	1233.8	0.760	-27.78	1197.8	68.9	0.044	
331	330	22	9	1.8	1023.7	0.101	-35.31	993.8	85.9	0.032	
332	330	22	9	8.4	1017.8	0.403	-33.74	988.1	78.7	0.035	
333	330	22	11	43.4	1192.6	1.317	-37.48	1157.8	53.4	0.029	
334	330	22	19	11.6	939.5	1.045	-36.90	912.0	62.9	0.030	
335	330	22	20	31.7	295.5	0.847	-56.79	286.8	70.9	0.014	
336	330	22	29	56.5	987.7	-0.100	-22.25	958.8	90.7	0.056	
337	330	22	30	36.9	366.7	0.643	-54.80	356.0	75.0	0.015	
338	330	22	31	16.2	972.5	1.179	-25.92	944.1	59.1	0.045	
339	330	22	33	27.5	831.7	-0.249	-19.66	807.4	94.1	0.086	30056
340	330	22	34	39.0	1089.6	-0.134	-27.81	1057.8	91.5	0.044	
341	330	22	36	25.8	1033.7	0.102	-29.57	1003.5	85.9	0.042	12092
342	330	22	36	31.4	1033.2	0.340	-35.56	1003.0	80.1	0.032	
343	330	22	36	53.7	791.9	0.510	-35.93	768.8	76.7	0.031	10520
344	330	22	39	7.0	971.9	1.023	-34.61	943.5	63.3	0.033	
345	330	22	40	19.3	992.6	0.899	-35.21	963.6	66.4	0.032	
346	330	22	41	19.5	1062.0	-1.050	-14.62	1031.0	114.2	0.195	31861
347	330	22	47	13.0	914.6	-0.193	-28.40	887.9	92.9	0.044	
348	330	22	50	25.7	1029.2	-0.541	-30.53	999.2	101.3	0.041	
349	330	22	50	55.9	968.0	-0.505	-36.09	939.8	100.3	0.031	
350	330	22	55	7.4	815.6	-0.390	-40.39	791.8	97.3	0.027	
351	330	22	58	54.2	462.8	1.132	-53.09	449.3	63.6	0.016	
352	330	23	3	44.0	1152.1	-0.570	-17.44	1118.5	102.3	0.129	31236
353	330	23	6	9.4	1019.4	0.561	-36.86	989.7	74.8	0.030	
354	330	23	9	50.4	980.2	1.024	-31.52	951.6	63.2	0.039	
355	330	23	13	8.0	857.1	-0.381	-10.32	832.1	97.2	0.336	5694
356	330	23	13	9.1	1002.0	-0.717	-44.17	972.7	105.5	0.023	
357	330	23	15	0.1	942.0	0.223	-39.84	914.5	83.1	0.027	
358	330	23	15	0.9	807.7	0.203	4.31	784.2	83.8	1.853	25471
359	330	23	15	2.1	671.9	0.217	-48.40	652.3	83.6	0.019	
360	330	23	20	7.0	1875.2	0.138	-23.80	1820.5	84.1	0.052	
361	330	23	27	4.9	1002.3	0.062	7.43	973.1	86.9	2.653	9044
362	330	23	36	43.1	755.6	0.507	-20.70	733.5	76.9	0.069	18274
363	330	23	38	52.0	945.0	0.909	-35.65	917.5	66.4	0.032	
364	330	23	38	56.0	1032.1	0.094	-36.41	1001.9	86.1	0.031	
365	330	23	44	25.2	1714.5	0.688	-19.17	1664.4	68.9	0.094	22841
366	330	23	44	58.6	343.0	1.955	-41.50	333.0	43.2	0.026	
367	330	23	46	41.2	727.8	-0.737	-30.14	706.6	105.1	0.042	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
368	330	23	49	42.8	967.7	-0.213	-26.02	939.5	93.4	0.045	
369	330	23	49	57.7	1270.4	1.407	6.09	1233.3	49.9	2.275	
370	330	23	56	46.2	1032.0	0.348	-27.86	1001.9	80.0	0.044	12835
371	330	23	56	48.9	1463.6	1.427	-32.66	1420.9	47.5	0.037	
372	330	23	57	19.8	1065.8	-0.263	-29.10	1034.7	94.6	0.043	
373	330	23	58	6.7	852.0	-0.480	-41.26	827.1	99.5	0.026	
374	330	23	58	9.4	852.0	0.030	-45.61	827.1	87.7	0.022	
375	331	0	8	13.2	837.9	0.643	-18.24	813.4	73.4	0.112	26968
376	331	0	9	47.3	941.0	0.150	-20.37	913.5	84.8	0.074	14406
377	331	0	12	55.1	1452.0	1.118	-30.19	1409.6	57.6	0.042	25873
378	331	0	19	48.3	581.5	-1.958	-34.66	564.5	135.7	0.033	
379	331	0	19	48.7	600.0	-1.287	-31.93	582.5	117.6	0.038	
380	331	0	19	49.0	616.5	2.558	-49.93	598.5	20.0	0.018	
381	331	0	20	29.7	2051.7	-0.434	-22.94	1991.8	100.6	0.055	
382	331	0	31	6.1	512.6	-0.626	-25.84	497.7	102.0	0.046	
383	331	0	34	5.1	2020.4	2.861	-14.13	1961.5	54.8	0.207	
384	331	0	34	6.5	579.4	-0.491	-44.53	562.5	99.2	0.023	28942
385	331	0	34	7.2	522.3	-0.456	-46.42	507.0	98.3	0.021	
386	331	0	36	55.6	1007.2	-0.170	-21.67	977.8	92.4	0.059	80932
387	331	0	37	47.8	1282.9	0.306	-22.34	1245.5	80.5	0.056	81921
388	331	0	41	22.9	994.2	0.303	-22.69	965.1	81.1	0.056	12753
389	331	0	48	2.5	1706.2	0.702	-24.88	1656.4	68.6	0.048	
390	331	0	48	46.1	696.8	-0.259	-37.32	676.5	94.2	0.029	
391	331	0	48	55.0	695.8	0.377	-36.62	675.4	80.0	0.030	
392	331	0	49	11.1	1062.0	0.893	-40.75	1031.0	66.2	0.026	
393	331	0	53	47.1	1183.8	0.584	-33.91	1149.2	73.7	0.035	4255
394	331	0	58	8.7	879.8	-0.052	-38.41	854.1	89.6	0.028	8845
395	331	0	59	30.9	1623.9	-1.452	-22.26	1576.5	130.0	0.056	32144
396	331	1	1	12.2	1393.0	0.705	-22.48	1352.3	69.7	0.056	
397	331	1	1	33.9	679.5	-0.735	-27.45	659.6	104.9	0.044	
398	331	1	9	9.9	1031.5	-0.248	-26.57	1001.4	94.2	0.045	
399	331	1	12	24.1	1019.5	3.320	-38.88	989.8	51.1	0.028	
400	331	1	13	43.6	696.4	0.858	-33.78	676.0	68.8	0.035	
401	331	1	20	22.2	706.4	-0.514	-34.15	685.8	100.0	0.034	23605
402	331	1	20	23.9	852.0	-0.523	-46.65	827.1	100.5	0.021	
403	331	1	20	25.9	707.2	-0.274	10.87	686.5	94.6	3.943	23605
404	331	1	20	26.8	852.0	0.062	-45.86	827.1	87.0	0.021	
405	331	1	30	3.6	926.8	-0.212	-21.38	899.7	93.3	0.063	
406	331	1	30	18.4	1141.2	-0.252	-27.74	1107.8	94.4	0.044	7069
407	331	1	30	58.2	841.4	-0.311	-24.56	816.8	95.5	0.049	13569
408	331	1	31	13.4	2050.7	-2.456	-24.54	1990.8	173.6	0.049	
409	331	1	34	7.5	532.2	1.359	-46.53	516.6	57.5	0.021	
410	331	1	34	7.8	969.5	-0.187	-24.05	941.2	92.8	0.051	89323

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
411	331	1	34	34.6	909.7	-0.596	-35.35	883.1	102.3	0.032	13778
412	331	1	34	41.9	913.2	-0.211	-35.98	886.5	93.3	0.031	
413	331	1	34	51.8	1572.2	-1.326	-18.37	1526.3	125.4	0.110	
414	331	1	34	51.9	736.5	1.396	-29.94	715.0	54.9	0.042	
415	331	1	36	22.5	702.0	-0.384	-39.43	681.5	97.0	0.027	
416	331	1	36	24.9	972.0	-0.057	-41.28	943.6	89.7	0.026	
417	331	1	36	25.1	829.9	-0.276	10.53	805.7	94.7	3.791	23324
418	331	1	43	3.4	1538.5	0.416	-5.12	1493.6	77.1	0.626	8891
419	331	1	52	20.3	780.9	-0.068	-36.85	758.1	89.9	0.030	
420	331	1	53	1.2	1000.9	-0.191	-24.15	971.7	92.9	0.050	
421	331	2	11	34.2	972.0	-0.194	-38.10	943.6	92.9	0.028	
422	331	2	11	34.6	972.0	-0.600	-41.96	943.6	102.6	0.026	
423	331	2	11	35.7	832.4	-0.305	-6.28	808.1	95.4	0.548	23753
424	331	2	11	36.8	972.0	-0.147	-36.77	943.6	91.8	0.030	
425	331	2	25	27.9	2037.0	0.292	-15.23	1977.5	79.5	0.179	
426	331	2	26	40.9	572.3	-0.569	-31.26	555.6	100.9	0.040	
427	331	2	32	33.9	1060.9	0.884	-27.73	1030.0	66.4	0.044	
428	331	2	32	56.1	825.3	-0.325	-19.74	801.2	95.8	0.084	87012
429	331	2	33	7.9	577.2	1.049	-23.84	560.4	64.9	0.052	
430	331	2	35	56.1	1700.5	0.565	-23.29	1650.8	72.5	0.054	
431	331	2	36	22.7	1225.9	-0.373	-27.76	1190.1	97.5	0.044	85081
432	331	2	38	7.8	1620.9	0.408	-26.45	1573.6	77.1	0.045	7831
433	331	2	38	13.1	1627.5	0.523	-27.98	1580.0	73.9	0.044	7831
434	331	2	42	7.4	699.2	-0.293	-24.13	678.8	95.0	0.051	
435	331	2	45	2.6	935.2	-0.305	-31.60	907.9	95.5	0.039	
436	331	2	45	4.3	932.2	-0.272	-31.34	905.0	94.7	0.040	
437	331	2	45	32.8	817.4	-0.302	-7.30	793.6	95.3	0.487	22828
438	331	2	45	33.5	942.0	-0.345	-44.29	914.5	96.5	0.023	
439	331	2	46	26.6	911.0	-0.428	-13.06	884.4	98.4	0.236	31084
440	331	2	52	0.1	307.8	-0.831	-57.04	298.8	105.8	0.014	
441	331	2	55	8.5	1687.9	0.449	-24.01	1638.6	75.8	0.051	21403
442	331	2	56	4.6	1430.8	0.546	-23.20	1389.0	73.9	0.054	
443	331	2	56	54.6	1327.5	1.215	-25.78	1288.7	55.5	0.046	
444	331	2	57	23.6	1038.3	1.114	-32.18	1007.9	60.4	0.038	
445	331	2	59	57.6	603.0	-0.055	-36.56	585.4	89.7	0.030	
446	331	3	0	3.8	609.0	0.470	-45.99	591.2	78.1	0.021	
447	331	3	5	11.6	1315.4	-0.235	-24.02	1277.0	94.2	0.051	
448	331	3	6	11.3	1597.1	1.369	-17.38	1550.5	48.2	0.130	
449	331	3	6	11.5	1632.0	1.370	-31.90	1584.3	47.9	0.038	
450	331	3	14	26.0	1001.1	1.024	-31.51	971.9	63.1	0.039	
451	331	3	17	57.9	1575.5	0.402	-4.46	1529.5	77.4	0.676	5553
452	331	3	21	28.9	971.1	0.085	-20.28	942.8	86.3	0.076	87714
453	331	3	22	10.2	901.8	-0.272	-31.83	875.5	94.7	0.039	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
454	331	3	27	35.6	1186.0	0.018	-33.06	1151.4	87.8	0.036	
455	331	3	27	45.2	1003.1	1.037	-32.95	973.8	62.7	0.036	
456	331	3	31	21.5	942.3	-0.177	-42.90	914.8	92.5	0.024	
457	331	3	31	21.7	1051.1	-1.487	-21.10	1020.4	126.3	0.065	
458	331	3	31	21.9	1002.0	-0.237	-26.07	972.7	93.9	0.045	
459	331	3	33	27.0	868.9	0.726	13.85	843.5	71.3	5.556	23705
460	331	3	33	27.5	732.0	0.478	-44.83	710.6	77.6	0.022	
461	331	3	36	34.4	497.6	-0.622	-46.35	483.1	101.9	0.021	
462	331	3	38	20.2	995.5	0.088	-33.71	966.4	86.2	0.035	11736
463	331	3	38	22.6	768.4	-0.433	-43.52	745.9	98.2	0.023	
464	331	3	41	2.7	972.0	-0.602	-39.71	943.6	102.6	0.027	
465	331	3	41	3.9	827.2	-0.536	5.08	803.0	100.7	2.024	6788
466	331	3	41	5.5	972.0	-0.994	-43.08	943.6	112.3	0.024	
467	331	3	42	25.3	1772.9	0.909	-15.32	1721.1	62.0	0.177	
468	331	3	42	58.8	1180.6	-0.516	-25.76	1146.1	101.0	0.046	4818
469	331	3	44	1.7	1060.5	-0.353	-28.61	1029.5	96.8	0.044	
470	331	3	45	11.2	701.5	-0.417	-27.09	681.1	97.8	0.044	
471	331	3	48	40.2	888.9	-0.287	-28.73	863.0	95.0	0.043	81352
472	331	3	50	40.2	857.0	-0.035	-39.87	831.9	89.2	0.027	
473	331	3	51	1.3	1302.4	-0.480	-18.91	1264.4	100.4	0.099	32362
474	331	3	53	4.7	854.9	-0.300	-15.69	829.9	95.3	0.168	30670
475	331	3	54	2.8	1032.5	0.077	-27.72	1002.4	86.5	0.044	7593
476	331	3	59	2.8	1152.1	1.035	11.44	1118.5	61.9	4.210	
477	331	4	1	41.2	616.0	-0.490	-19.99	598.0	99.2	0.080	32137
478	331	4	2	7.2	1020.1	0.226	-32.94	990.3	82.9	0.036	19826
479	331	4	3	16.2	875.5	0.881	-30.47	849.9	67.4	0.041	
480	331	4	6	19.5	1572.6	0.760	-24.55	1526.7	67.5	0.049	
481	331	4	6	51.7	829.1	4.560	-34.11	804.8	70.7	0.034	
482	331	4	9	37.7	1662.0	-0.448	-32.55	1613.4	100.2	0.037	
483	331	4	9	39.6	1518.6	0.103	4.28	1474.3	85.4	1.846	23793
484	331	4	9	41.6	1662.0	-0.202	-32.48	1613.4	93.5	0.037	
485	331	4	11	18.0	850.2	-0.300	-40.68	825.4	95.3	0.026	
486	331	4	13	11.1	909.7	-0.293	-29.01	883.1	95.2	0.043	
487	331	4	15	19.3	631.1	-0.555	-38.85	612.7	100.7	0.028	
488	331	4	15	23.5	910.4	-0.282	-35.27	883.8	94.9	0.032	
489	331	4	16	32.3	1154.5	0.184	-33.00	1120.8	83.8	0.036	
490	331	4	17	18.5	997.6	-0.490	-34.72	968.4	100.0	0.033	
491	331	4	18	36.5	783.4	0.538	-28.82	760.5	76.0	0.043	17764
492	331	4	19	55.5	1588.9	-0.746	-26.35	1542.5	108.3	0.045	
493	331	4	20	1.1	941.6	1.049	-31.22	914.1	62.8	0.040	
494	331	4	20	42.2	907.2	-0.310	-39.35	880.7	95.6	0.027	
495	331	4	21	15.7	884.4	-0.316	-33.39	858.6	95.7	0.035	
496	331	4	27	19.4	914.2	0.473	-18.34	887.5	77.2	0.110	28953

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
497	331	4	27	42.1	1958.4	-0.847	-22.35	1901.2	112.6	0.056	
498	331	4	29	46.2	769.6	-0.372	-24.30	747.2	96.8	0.050	27676
499	331	4	30	42.5	351.3	0.028	-51.05	341.0	88.0	0.018	
500	331	4	38	59.0	883.3	-0.294	-31.51	857.5	95.2	0.039	
501	331	4	39	30.4	995.4	0.497	-32.39	966.4	76.4	0.037	
502	331	4	40	32.7	909.5	-0.306	-32.02	882.9	95.5	0.038	
503	331	4	42	31.7	784.0	-0.166	-41.43	761.1	92.2	0.026	
504	331	4	45	59.5	1267.4	1.202	-32.48	1230.4	56.3	0.037	
505	331	4	46	6.5	1151.9	1.688	-40.47	1118.3	41.8	0.027	
506	331	4	46	8.6	1286.6	1.480	3.50	1249.1	47.4	1.688	
507	331	4	46	10.6	1422.5	1.323	-34.64	1380.9	51.3	0.033	
508	331	4	46	13.9	1291.7	1.643	-29.66	1254.0	41.8	0.042	
509	331	4	49	47.7	756.3	-2.430	-44.33	734.2	157.0	0.023	
510	331	4	52	20.7	522.0	-0.712	-46.67	506.7	103.9	0.021	
511	331	4	52	24.0	649.1	-0.520	-27.49	630.1	100.0	0.044	31598
512	331	4	52	50.2	762.1	0.865	-33.72	739.9	68.4	0.035	
513	331	4	54	7.0	852.0	0.018	-42.51	827.1	88.0	0.024	
514	331	4	54	9.5	852.0	0.330	-46.22	827.1	80.7	0.021	
515	331	4	55	6.7	822.0	-0.006	-49.58	798.0	88.5	0.019	
516	331	4	55	7.1	1092.0	-0.092	-41.10	1060.1	90.5	0.026	
517	331	4	55	7.7	955.9	0.121	-10.59	928.0	85.5	0.324	12671
518	331	4	55	8.6	1092.0	0.192	-39.86	1060.1	83.6	0.027	
519	331	4	56	3.1	826.1	-0.286	-18.40	802.0	95.0	0.109	
520	331	4	57	7.6	767.8	1.197	-32.35	745.4	60.0	0.037	89067
521	331	4	57	18.6	790.9	0.399	-42.90	767.8	79.3	0.024	
522	331	4	57	18.9	745.5	-1.345	-28.00	723.7	120.0	0.044	
523	331	5	3	52.8	1356.4	-0.317	-30.64	1316.8	96.3	0.041	
524	331	5	7	59.9	744.7	-0.552	-38.76	723.0	100.9	0.028	
525	331	5	9	39.1	784.8	-0.195	-25.11	761.9	92.8	0.047	30206
526	331	5	11	20.6	811.9	-0.326	-21.39	788.2	95.9	0.063	80160
527	331	5	11	21.1	975.0	-0.389	-20.67	946.6	97.5	0.069	30365
528	331	5	11	42.1	979.8	0.847	-33.30	951.2	67.8	0.036	
529	331	5	15	20.1	880.2	-0.306	-22.13	854.5	95.5	0.057	
530	331	5	16	38.9	904.2	0.496	-31.59	877.8	76.7	0.039	
531	331	5	17	11.6	1417.0	0.343	-29.89	1375.6	79.3	0.042	
532	331	5	19	58.4	834.3	-0.188	-35.98	809.9	92.7	0.031	
533	331	5	20	17.3	905.4	-0.297	-25.60	878.9	95.3	0.046	
534	331	5	22	28.6	710.2	-0.436	-41.40	689.5	98.2	0.026	
535	331	5	22	45.5	912.3	-3.726	-24.37	885.6	182.2	0.049	
536	331	5	22	45.5	971.0	1.789	-27.15	942.6	40.5	0.044	
537	331	5	22	45.6	945.2	-3.321	-23.81	917.6	179.2	0.052	
538	331	5	22	45.9	555.1	1.265	-50.94	538.9	59.7	0.018	
539	331	5	22	46.4	854.9	1.889	-44.07	830.0	38.5	0.023	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
540	331	5	22	46.7	846.2	-3.127	-45.45	821.5	177.0	0.022	
541	331	5	23	48.0	865.0	0.767	-23.47	839.8	70.3	0.053	81673
542	331	5	24	18.0	1891.2	1.231	-19.90	1836.0	50.6	0.082	
543	331	5	27	7.4	1003.2	-0.341	-16.69	973.9	96.4	0.145	6160
544	331	5	27	40.7	825.5	-0.293	-29.27	801.3	95.1	0.043	23828
545	331	5	29	4.8	813.4	-0.038	-36.97	789.6	89.3	0.030	24945
546	331	5	29	13.2	881.5	-0.312	-28.21	855.8	95.6	0.044	
547	331	5	29	22.2	792.0	1.180	-43.22	768.8	60.3	0.024	
548	331	5	29	22.2	648.2	0.852	32.87	629.3	69.2	49.672	16865
549	331	5	29	23.8	522.0	1.057	-53.46	506.7	65.0	0.016	
550	331	5	35	39.8	678.0	0.994	-24.63	658.2	65.6	0.048	4664
551	331	5	35	58.6	495.6	-0.766	-48.43	481.1	105.0	0.019	
552	331	5	36	8.1	290.3	0.018	-56.67	281.8	88.2	0.014	
553	331	5	36	30.1	974.3	0.849	-35.42	945.8	67.7	0.032	
554	331	5	36	54.3	550.8	-1.969	-31.71	534.7	135.7	0.039	
555	331	5	39	14.6	1185.4	-0.357	-21.07	1150.8	97.1	0.065	
556	331	5	40	29.5	1002.5	0.130	12.71	973.2	85.2	4.873	8874
557	331	5	45	59.6	909.5	-0.320	-20.63	882.9	95.8	0.070	31534
558	331	5	47	20.6	958.7	0.845	-28.35	930.7	67.9	0.044	81497
559	331	5	48	40.0	1449.5	1.194	-28.12	1407.1	55.2	0.044	25884
560	331	5	48	45.7	641.4	1.717	-37.96	622.7	46.7	0.029	
561	331	5	48	48.6	1455.7	1.410	-26.37	1413.2	48.2	0.045	25884
562	331	5	48	55.1	462.0	-0.463	-60.92	448.5	98.4	0.012	
563	331	5	48	56.1	597.1	-0.505	-27.22	579.7	99.5	0.044	
564	331	5	48	58.9	1544.7	0.917	-25.33	1499.6	63.0	0.046	
565	331	5	58	13.9	1272.4	0.630	-27.87	1235.2	72.2	0.044	
566	331	5	58	38.0	1463.1	1.314	-32.44	1420.4	51.3	0.037	
567	331	5	58	59.9	1423.5	0.418	-21.38	1382.0	77.3	0.063	
568	331	6	2	39.9	370.2	-0.607	-43.33	359.4	101.2	0.024	
569	331	6	2	39.9	373.8	0.753	-45.26	362.9	72.6	0.022	
570	331	6	3	10.2	615.7	3.400	-47.10	597.8	46.0	0.020	
571	331	6	3	15.0	830.1	-0.334	-27.03	805.8	96.0	0.044	
572	331	6	4	32.8	846.6	-0.004	-41.39	821.9	88.5	0.026	
573	331	6	5	55.6	882.5	-0.317	-31.38	856.7	95.7	0.040	31268
574	331	6	9	15.8	320.5	0.025	-55.69	311.2	88.0	0.015	
575	331	6	10	59.9	1022.3	-0.196	-13.57	992.4	93.0	0.221	29819
576	331	6	11	0.5	882.0	-0.302	-44.95	856.2	95.4	0.022	
577	331	6	11	22.4	840.4	-0.805	-39.09	815.9	107.1	0.028	
578	331	6	11	26.1	972.0	-0.338	-44.77	943.6	96.3	0.022	31294
579	331	6	11	27.9	972.0	0.084	-39.58	943.6	86.4	0.027	
580	331	6	12	26.1	1522.3	0.443	-26.14	1477.8	76.4	0.045	13168
581	331	6	12	28.8	809.5	0.403	-33.59	785.9	79.1	0.035	
582	331	6	12	43.0	308.5	0.041	-54.27	299.5	87.7	0.016	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
583	331	6	15	8.2	1448.9	1.124	-27.20	1406.6	57.4	0.044	
584	331	6	15	33.4	761.9	-0.310	-47.96	739.7	95.4	0.020	
585	331	6	15	33.8	1032.0	-0.221	-40.91	1001.8	93.6	0.026	
586	331	6	15	34.8	894.2	-0.311	-5.73	868.0	95.6	0.583	29891
587	331	6	15	36.2	1032.0	-0.492	-39.04	1001.8	100.1	0.028	
588	331	6	16	5.3	1472.1	0.332	-22.36	1429.2	79.5	0.056	27056
589	331	6	16	11.2	1475.0	0.497	-25.57	1432.0	75.1	0.046	
590	331	6	18	59.7	794.2	0.583	-32.60	771.0	75.0	0.037	11112
591	331	6	22	26.2	1492.8	0.691	-25.27	1449.2	69.7	0.047	87955
592	331	6	24	57.9	620.0	-0.395	-35.96	601.9	97.1	0.031	26703
593	331	6	30	14.5	791.2	-0.542	-29.96	768.1	100.8	0.042	82105
594	331	6	30	31.6	730.9	-0.340	-29.89	709.5	96.1	0.042	
595	331	6	38	49.2	849.6	-0.372	-16.43	824.8	96.9	0.151	29773
596	331	6	42	39.4	783.8	-0.377	-40.24	760.9	97.0	0.027	
597	331	6	43	47.3	1095.0	1.074	-17.47	1063.0	61.1	0.128	537
598	331	6	46	22.0	1058.3	0.289	-34.18	1027.4	81.4	0.034	
599	331	6	49	12.1	870.1	-0.338	-40.82	844.7	96.2	0.026	
600	331	6	51	37.6	890.4	-0.375	-38.08	864.4	97.1	0.028	
601	331	6	53	25.2	1103.8	1.545	-32.21	1071.5	47.1	0.038	
602	331	6	54	52.0	788.5	-0.289	-36.69	765.5	95.0	0.030	22078
603	331	6	55	53.7	1911.1	0.610	-19.09	1855.3	70.5	0.096	
604	331	6	57	3.8	492.0	-1.425	-52.92	477.6	120.3	0.016	
605	331	6	57	4.9	631.7	-1.112	-11.95	613.2	113.6	0.271	
606	331	6	57	5.8	492.0	-1.224	-56.40	477.6	115.5	0.014	
607	331	6	57	41.7	852.4	-0.347	-32.69	827.5	96.4	0.037	
608	331	7	4	7.4	790.4	-0.383	-22.47	767.3	97.1	0.056	30094
609	331	7	4	10.8	1121.0	-0.096	-32.13	1088.3	90.6	0.038	
610	331	7	4	44.1	890.1	-0.662	-37.12	864.1	103.9	0.030	
611	331	7	5	11.5	2047.4	0.649	-27.88	1987.6	68.8	0.044	
612	331	7	5	11.6	2045.2	-1.115	-12.56	1985.5	121.6	0.250	
613	331	7	5	11.8	2046.5	-2.291	-6.08	1986.8	170.6	0.560	
614	331	7	5	40.4	880.8	0.030	-38.10	855.1	87.7	0.028	14484
615	331	7	5	58.1	1597.0	0.616	-2.36	1550.4	71.4	0.860	5554
616	331	7	6	32.5	832.2	-0.444	-28.08	807.9	98.6	0.044	
617	331	7	9	9.9	775.4	-0.330	-28.45	752.8	95.9	0.044	30997
618	331	7	10	2.8	796.9	-0.304	-41.00	773.7	95.3	0.026	
619	331	7	11	40.0	888.3	-0.609	-36.34	862.4	102.6	0.031	
620	331	7	15	13.3	769.3	-0.332	-34.58	746.8	95.9	0.033	
621	331	7	15	31.5	1786.0	-0.376	-25.24	1733.9	98.5	0.047	
622	331	7	15	38.7	1007.2	-0.062	-38.28	977.8	89.8	0.028	
623	331	7	15	47.5	1006.3	0.319	-37.22	976.9	80.7	0.029	16368
624	331	7	21	50.0	719.0	-0.081	-28.36	698.0	90.2	0.044	
625	331	7	22	53.5	761.7	-0.164	-20.58	739.5	92.1	0.070	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
626	331	7	30	9.5	838.4	-0.355	-33.27	813.9	96.5	0.036	
627	331	7	30	46.9	1783.9	4.360	-12.71	1731.8	80.2	0.246	
628	331	7	30	47.1	1956.3	0.655	-13.63	1899.2	68.9	0.220	
629	331	7	31	7.2	733.4	-0.370	-20.16	712.0	96.8	0.078	
630	331	7	33	34.6	790.0	-0.307	-33.87	766.9	95.4	0.035	85090
631	331	7	35	22.3	948.5	1.041	-35.72	920.8	62.9	0.032	
632	331	7	39	39.0	818.9	-0.460	-28.42	795.0	98.9	0.044	
633	331	7	43	21.8	1062.6	1.552	-25.73	1031.6	47.3	0.046	
634	331	7	43	21.9	948.1	3.738	-30.39	920.4	58.8	0.041	
635	331	7	43	52.4	944.7	0.873	-30.90	917.1	67.3	0.040	
636	331	7	46	59.5	967.9	1.067	-30.79	939.6	62.1	0.041	13243
637	331	7	49	31.0	1925.9	0.038	-17.85	1869.6	86.9	0.120	
638	331	7	49	45.0	1928.0	0.042	-27.91	1871.7	86.8	0.044	
639	331	7	49	54.4	1918.8	0.041	-24.91	1862.7	86.8	0.048	
640	331	7	50	14.7	752.2	-0.397	-25.86	730.3	97.4	0.045	
641	331	7	50	18.9	871.4	-0.984	-35.54	845.9	111.6	0.032	7734
642	331	7	53	23.7	2034.5	1.129	-19.85	1975.1	53.1	0.083	5240
643	331	7	54	30.7	1971.4	2.467	-29.03	1913.8	42.7	0.043	
644	331	7	54	31.2	2011.5	-3.441	-14.70	1952.7	183.6	0.193	
645	331	7	54	31.4	2000.8	1.049	-8.95	1942.4	56.1	0.392	
646	331	7	54	32.0	2024.7	2.515	-29.94	1965.6	45.0	0.042	
647	331	7	57	8.5	934.6	-0.279	-35.91	907.3	94.9	0.031	
648	331	7	58	44.5	543.5	-0.389	-38.92	527.7	96.9	0.028	
649	331	8	3	37.4	995.1	-0.371	-29.70	966.1	97.1	0.042	4615
650	331	8	5	10.5	759.2	-0.587	-29.22	737.0	101.8	0.043	
651	331	8	5	15.9	760.7	-0.221	-35.53	738.5	93.4	0.032	
652	331	8	5	25.1	881.0	-0.419	-22.38	855.3	98.1	0.056	
653	331	8	7	9.2	1509.8	-0.232	-27.91	1465.7	94.2	0.044	
654	331	8	7	14.2	2046.1	0.245	-23.81	1986.3	80.9	0.052	
655	331	8	8	38.8	1609.4	4.545	-18.94	1562.4	80.7	0.099	
656	331	8	8	39.1	1520.0	2.090	-18.27	1475.7	23.4	0.112	
657	331	8	10	2.5	1541.7	-0.420	-28.80	1496.7	99.2	0.043	
658	331	8	17	35.8	970.3	0.286	-33.67	942.0	81.6	0.035	18821
659	331	8	17	42.3	975.3	0.595	-38.01	946.8	74.1	0.029	
660	331	8	18	51.1	1487.1	-1.289	-17.89	1443.7	123.6	0.119	
661	331	8	20	24.3	282.9	1.088	-64.72	274.7	65.6	0.010	
662	331	8	30	36.2	702.6	1.410	-41.11	682.1	54.8	0.026	
663	331	8	34	3.8	1027.9	0.287	-35.26	997.9	81.4	0.032	10355
664	331	8	39	53.8	1449.8	1.270	-28.02	1407.5	52.8	0.044	32263
665	331	8	41	24.4	1450.3	1.324	-30.99	1408.0	51.1	0.040	
666	331	8	41	36.0	759.2	-0.148	-20.33	737.0	91.7	0.075	31020
667	331	8	45	43.1	1302.3	-0.162	-27.56	1264.3	92.3	0.044	
668	331	8	46	18.6	759.5	-0.197	-37.33	737.3	92.9	0.029	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
669	331	8	48	7.3	1657.9	-3.678	-23.90	1609.5	184.3	0.052	
670	331	8	48	35.4	789.1	-0.312	-11.30	766.1	95.5	0.295	23277
671	331	8	48	45.7	1260.8	0.308	-32.02	1223.9	80.5	0.038	
672	331	8	49	50.9	1320.6	-0.175	-28.20	1282.0	92.7	0.044	
673	331	8	51	14.4	1680.1	-0.442	-18.55	1631.1	100.1	0.106	12274
674	331	8	54	54.4	702.5	-0.316	-8.67	682.0	95.5	0.406	17316
675	331	8	57	8.2	1298.7	-0.465	-21.69	1260.8	100.0	0.059	82944
676	331	8	58	13.2	1331.2	-0.170	-17.35	1292.3	92.5	0.131	87509
677	331	8	59	9.5	796.1	-0.820	-34.10	772.8	107.3	0.034	
678	331	8	59	33.8	2023.8	0.004	-20.34	1964.7	87.8	0.075	
679	331	8	59	44.6	953.7	-0.354	-27.20	925.8	96.7	0.044	
680	331	9	2	12.5	1024.9	-0.057	-33.87	994.9	89.7	0.035	7095
681	331	9	2	20.7	1026.8	0.300	-30.07	996.8	81.1	0.042	
682	331	9	4	3.2	948.0	-0.517	-21.35	920.4	100.5	0.063	
683	331	9	4	42.1	974.7	-0.126	-33.72	946.2	91.3	0.035	
684	331	9	4	42.1	1302.7	3.349	-26.85	1264.7	56.1	0.045	
685	331	9	6	3.0	1777.9	-0.446	-20.57	1726.0	100.4	0.070	
686	331	9	8	17.9	1019.4	0.141	-24.80	989.6	85.0	0.048	10141
687	331	9	11	52.0	1741.7	-0.599	-21.14	1690.9	104.6	0.065	
688	331	9	15	11.5	559.1	-0.138	-42.36	542.8	91.5	0.025	
689	331	9	25	33.4	844.8	-0.508	-18.14	820.1	100.1	0.114	30350
690	331	9	25	42.1	879.2	0.023	-0.03	853.5	87.8	1.124	22699
691	331	9	27	15.3	1002.5	0.472	-30.81	973.2	77.0	0.041	
692	331	9	34	36.7	882.0	0.605	-46.36	856.2	74.2	0.021	
693	331	9	34	37.8	738.3	1.279	-18.03	716.8	58.0	0.117	3896
694	331	9	36	12.7	1003.3	-0.079	-33.45	974.0	90.2	0.035	20528
695	331	9	36	21.1	1015.9	0.304	-36.23	986.2	81.1	0.031	20528
696	331	9	38	19.1	792.0	-0.480	-39.68	768.8	99.4	0.027	
697	331	9	38	20.9	660.2	-0.300	8.64	641.0	95.1	3.050	29710
698	331	9	44	58.1	1008.9	-0.733	-22.53	979.5	105.9	0.056	80351
699	331	9	48	40.1	693.7	-0.214	-28.69	673.4	93.2	0.043	80710
700	331	9	57	27.3	1030.4	-0.136	-24.27	1000.3	91.6	0.050	
701	331	10	2	38.4	821.9	-0.252	-24.17	797.9	94.1	0.050	
702	331	10	3	54.0	681.0	2.905	-38.19	661.1	33.1	0.028	
703	331	10	4	27.0	959.3	0.708	-15.94	931.3	71.4	0.163	23707
704	331	10	6	15.8	642.6	-0.280	-30.65	623.9	94.6	0.041	
705	331	10	8	22.4	342.0	3.308	-42.45	332.0	38.1	0.024	
706	331	10	8	23.1	264.4	0.935	-43.27	256.7	69.1	0.024	
707	331	10	14	46.4	792.0	0.958	-42.59	768.8	65.9	0.024	
708	331	10	14	47.3	925.9	0.728	-13.13	898.9	71.0	0.234	22292
709	331	10	16	43.1	1237.5	-0.404	-11.31	1201.3	98.3	0.294	7179
710	331	10	17	42.6	1062.9	-0.588	-25.61	1031.8	102.5	0.046	4743
711	331	10	18	6.7	1006.1	0.513	-33.94	976.7	76.0	0.035	

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
712	331	10	20	47.9	1116.2	-0.560	-27.79	1083.6	102.0	0.044	4705
713	331	10	25	41.3	913.0	1.039	-15.45	886.4	63.2	0.174	116
714	331	10	25	49.6	1448.6	0.425	-8.40	1406.3	77.1	0.429	3840
715	331	10	25	54.0	641.4	-0.208	-34.20	622.6	93.0	0.034	28649
716	331	10	28	16.7	739.8	-0.447	-16.21	718.2	98.5	0.157	26127
717	331	10	28	33.1	1121.9	0.195	-31.54	1089.1	83.5	0.039	
718	331	10	28	33.8	1064.4	0.257	-21.14	1033.3	82.1	0.065	82893
719	331	10	30	31.1	905.7	-0.551	-26.13	879.2	101.2	0.045	
720	331	10	35	33.6	1060.1	0.438	-23.20	1029.1	77.7	0.054	511
721	331	10	37	20.1	822.9	0.904	-23.53	798.8	67.1	0.053	
722	331	10	40	13.5	1000.0	0.091	-15.98	970.8	86.2	0.162	27437
723	331	10	43	3.2	672.0	2.969	-44.01	652.4	35.0	0.023	
724	331	10	43	4.2	320.4	3.525	-52.94	311.0	43.4	0.016	
725	331	10	43	4.5	704.6	3.040	-29.65	684.0	38.0	0.042	
726	331	10	55	57.7	1739.2	0.333	-24.42	1688.4	78.9	0.049	
727	331	10	57	3.3	761.9	0.895	-43.07	739.6	67.6	0.024	
728	331	10	57	4.4	897.0	0.877	-10.07	870.8	67.4	0.346	4135
729	331	10	57	4.7	1032.0	0.442	-37.34	1001.9	77.7	0.029	
730	331	11	1	59.2	753.4	-0.683	-33.03	731.4	104.0	0.036	32206
731	331	11	3	59.2	1515.1	0.422	-1.59	1470.9	77.0	0.939	14617
732	331	11	4	22.5	1392.8	-0.517	-25.80	1352.1	101.5	0.046	
733	331	11	7	43.0	1107.7	-0.695	-27.96	1075.4	105.3	0.044	
734	331	11	8	14.0	1842.1	2.337	-15.17	1788.3	35.9	0.181	
735	331	11	8	14.2	1761.5	-1.172	-14.92	1710.1	121.7	0.187	
736	331	11	9	17.6	1000.4	-0.148	-29.96	971.2	91.8	0.042	
737	331	11	10	29.9	645.0	-0.347	-25.38	626.2	96.1	0.046	
738	331	11	16	12.6	1394.0	-1.497	-29.75	1353.3	129.5	0.042	
739	331	11	16	46.7	433.1	1.163	-49.31	420.4	63.0	0.019	
740	331	11	16	46.7	450.0	2.855	-51.20	436.9	25.6	0.017	
741	331	11	18	9.4	761.1	-0.266	-29.47	738.9	94.4	0.043	30864
742	331	11	21	57.6	1027.1	-0.688	-23.21	997.1	104.9	0.054	31198
743	331	11	23	3.3	1003.1	0.132	-19.11	973.8	85.2	0.095	24678
744	331	11	23	54.1	940.9	1.029	-33.18	913.4	63.3	0.036	
745	331	11	27	34.5	448.1	2.443	-42.70	435.0	24.1	0.024	
746	331	11	30	26.4	884.9	0.617	-26.61	859.0	73.9	0.045	
747	331	11	30	32.9	882.0	-0.664	-34.04	856.3	103.9	0.034	
748	331	11	32	24.7	1517.4	-0.722	-29.73	1473.1	107.3	0.042	
749	331	11	33	12.2	914.1	0.361	-32.68	887.4	79.9	0.037	6393
750	331	11	33	16.8	916.5	0.601	-36.73	889.7	74.1	0.030	6393
751	331	11	35	52.5	1037.4	0.630	-23.14	1007.1	73.0	0.054	
752	331	11	37	14.5	709.4	3.050	-34.80	688.6	38.4	0.033	
753	331	11	37	14.5	738.5	-4.282	-31.21	716.9	185.4	0.040	
754	331	11	39	9.7	1445.9	1.131	-27.56	1403.7	57.2	0.044	
755	331	11	39	16.7	1453.7	1.296	-25.90	1411.2	51.9	0.045	26084

Table A-4. Detections observed by the TIRA radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
756	331	11	40	57.6	1259.0	2.829	-34.36	1222.2	42.2	0.034	
757	331	11	40	57.7	1240.3	-0.943	-34.92	1204.1	112.2	0.033	
758	331	11	40	57.9	1202.4	-3.331	-24.17	1167.3	180.1	0.050	
759	331	11	40	58.2	727.8	-0.823	-41.95	706.6	107.1	0.026	
760	331	11	40	58.3	1151.9	-1.662	-34.61	1118.3	132.6	0.033	
761	331	11	41	1.8	1604.9	1.788	-18.09	1558.1	32.0	0.115	
762	331	11	41	33.8	727.7	-0.474	-41.17	706.5	99.1	0.026	
763	331	11	41	59.0	1213.9	-0.728	-26.31	1178.4	106.5	0.045	
764	331	11	49	37.6	888.9	-0.960	-28.70	863.0	111.1	0.043	
765	331	11	49	37.6	883.8	1.808	-28.42	858.0	40.9	0.044	
766	331	11	49	38.0	867.5	-3.239	-40.48	842.1	178.2	0.027	
767	331	11	50	42.0	1449.4	0.363	1.18	1407.1	78.7	1.292	18337
768	331	11	57	40.5	751.0	-0.921	-19.51	729.1	109.6	0.088	15615
769	331	12	5	43.1	1024.1	1.022	-31.24	994.2	63.0	0.040	
770	331	12	5	55.2	1454.3	1.244	-19.42	1411.9	53.6	0.090	32264
771	331	12	6	1.3	1461.6	1.389	-25.99	1418.9	48.8	0.045	32264
772	331	12	6	58.5	2015.1	-0.549	-25.74	1956.3	103.8	0.046	
773	331	12	7	20.3	733.1	-0.455	-37.50	711.7	98.7	0.029	
774	331	12	21	16.5	711.6	-0.421	-34.89	690.8	97.9	0.033	
775	331	12	21	18.9	943.7	0.701	-36.65	916.2	71.6	0.030	
776	331	12	21	39.5	521.9	0.348	-51.15	506.6	81.0	0.017	
777	331	12	21	39.7	792.1	0.107	-43.61	769.0	86.0	0.023	
778	331	12	21	40.8	655.0	0.157	6.78	635.9	85.0	2.464	21398
779	331	12	21	42.3	521.8	-0.053	-50.53	506.6	89.6	0.018	
780	331	12	21	42.7	792.0	0.348	-43.90	768.8	80.4	0.023	
781	331	12	24	0.9	767.3	-0.575	-23.74	744.9	101.5	0.052	
782	331	12	25	6.7	951.0	0.878	-23.27	923.3	67.1	0.054	4295
783	331	12	35	32.8	589.3	-0.518	-16.64	572.1	99.8	0.147	27158
784	331	12	35	33.2	702.2	-0.427	-40.95	681.7	98.0	0.026	
785	331	12	35	42.3	1440.2	0.296	-28.60	1398.2	80.5	0.044	
786	331	12	35	43.6	1447.1	0.304	-29.89	1404.8	80.3	0.042	22651

References

[1] Rosebrock, J., Leushacke, L. and Mehrholz, D. *Cooperative Debris Tracking and Development of Algorithms for Mid-Size Debris Detection with Radar*, Final Report of Study Contracts, ESA/ESOC, Darmstadt, Germany, 1999.

[2] Banka, D., Leushacke, L. Mehrholz, D. Rosebrock, and J. Kübbeler, K.-H. Advanced Methods for Detection and Tracking of Small-Size Space Debris and Meteoroids and Radar Measurements of the Space Environment, Final Report of Study Contract, ESA/ESOC, Darmstadt, Germany, 2002.

Appendix B

Haystack Radar

B.1 Introduction

The Haystack radar's participation in the Inter-Agency Space Debris Coordination Committee's (IADC) 2008 24-hour campaign was sponsored by NASA. The radar was operated by the Massachusetts Institute of Technology's Lincoln Laboratory (MIT/LL). In addition to the IADC campaigns, the Haystack radar has been routinely observing the orbital debris environment using a fixed-stare operational mode since 1990 (see Figure B-1).

Figure B-1. Haystack radome on the right and the smaller HAX radome on the left.

The Haystack measurements have provided orbital debris researchers with the ability to detect small debris from previously unknown sources and the ability to examine continuous size distributions for sizes ranging from cataloged objects to objects smaller than 1 cm diameter. Further, Haystack has shown that the debris environment is dynamic and can change rapidly. Historic Haystack results are contained in numerous references (for example [1], [2], and [3]).

B.2 Experiment Setup

During the 2008 IADC 24-hour campaign, 20.6 hours of Haystack data were collected with the radar pointing at 75° elevation and at an azimuth of 90°. This pointing angle was chosen as a compromise between maximizing the sensitivity of the radar by minimizing the slant range to an altitude and providing enough off-vertical pointing to provide reasonable Doppler inclination resolution. The data were collected from ~13:15 GMT on 18 November 2008 until 13:15 on 19 November.

The Haystack radar is a high-power, X-band, monopulse tracking radar with very high sensitivity. To detect debris, a pulsed, single-frequency waveform is used. The operating parameters for the Haystack radar during the 2008 campaign are shown in Table B-1. For Haystack, the single pulse signal-to-noise ratio (SNR) on a 1-m2 target at 1000 km range is 59.7 dB. With Haystack, objects as small as 1 cm diameter can be observed at ranges greater than 1000 km under normal operations.

Table B-1. Instrument parameters used by the Haystack radar for the 2008 campaign.

Instrument Parameters		
Geocentric latitude of sensor	42.62	deg
Geocentric longitude of sensor	-71.49	deg
Geodetic altitude	0.1157	km
Wavelength	0.03	m
Beam width for incoherent integration	0.116	deg
Antenna constant (Gain)	67.2	dB
Transmitted power (peak)	400.0	kW
Pulse period	16.67	msec
Pulse duration	1.638	msec
Desired false alarm time (Marcum)	36000	sec
Number of independent threshold decisions per pulse	12126	
Maximum number of pulses to integrate	16	
Noise equivalent RCS (NRCS)	-65.2	dB m^2
Transmitted power for NRCS	400	kW
Pulse duration for NRCS	1.638	msec
Range for NRCS	1000	km

For debris observations, the radar is operated in a staring, or "beam-park," mode in which the antenna is pointed at a specified elevation and azimuth and remains there while debris objects randomly pass through the field-of-view. This operational mode provides a fixed detection volume important to the measurement of the debris flux, or number of objects detected per unit area per unit time. By operating the radar in a stare mode and not tracking detected debris objects, a precise measurement of the object's orbit is sacrificed. However, by examining the signals from the monopulse angle channels operating in an open-loop mode, position in the radar beam for each pulse can be determined. From this path through the beam, rough orbital elements are deduced.

B.3 Processing

In the debris mode, the signal strength for each received pulse is recorded from four separate channels: the Principal Polarization (PP) sum channel, Orthogonal Polarization (OP) sum channel, Traverse Difference (TR) channel, and Elevation Difference (EL) channel (see Figure B-2). The radar processing software determines the signal strength, signal-to-noise ratio (SNR) ratio, TR and EL voltage ratios, range and range rate. Other parameters are derived from these measurements. For an orbiting object passing through the radar field-of-view, the key step in the data processing is determining the location of the debris object in the radar beam for each radar pulse. From these locations, the motion of the object through the beam can be recreated and used to estimate rough orbital elements. Also, the signal strength can be augmented by the relative antenna gain determined by the antenna beam-pattern calibration discussed below. Thus, the returned signal strength can be estimated as if the object were at the center of the radar beam. The radar cross section (RCS) is determined by applying the absolute radar calibration, antenna beam shape, and the range to the object.

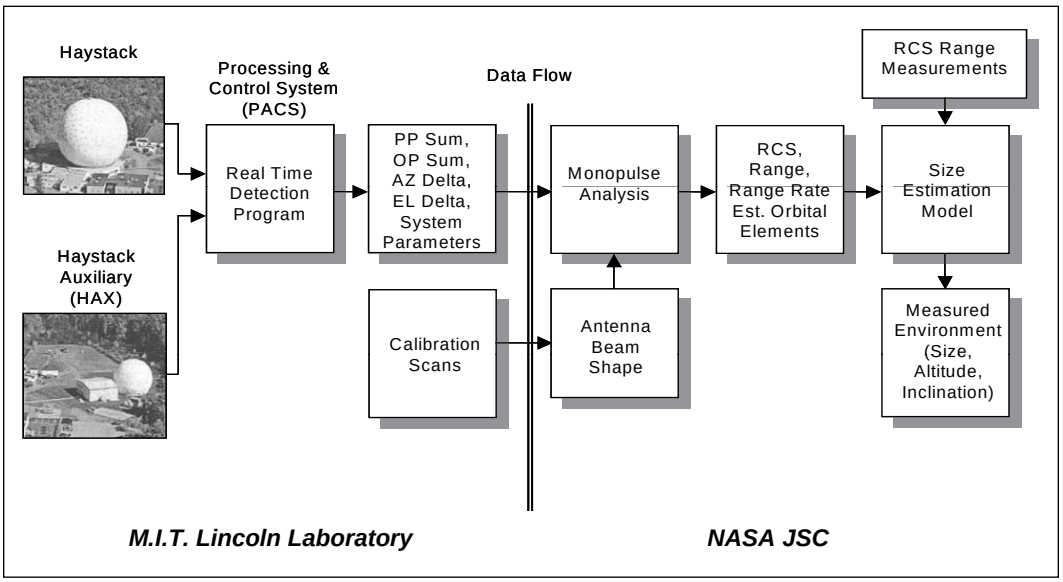

Figure B-2. An overview of the data collection and analysis.

The sensitivity of the antenna pattern is measured by scanning around a calibration sphere as it moves across the sky. This determines both the absolute calibration and the antenna beam pattern. Spheres return a circularly polarized signal with only a PP component. Test signals injected into the receiver preamplifiers are used to determine the absolute OP calibration.

A simple SNR threshold test is used for object detection. The noise floor varies, however, as a function of Doppler frequency. A "shape factor" representing the noise floor is subtracted from the signal emerging from the intermediate bandwidth filter. This shape factor is determined by averaging a large number of pulse returns which do not contain a valid detection. Figure B-3 shows the shape factor associated with the digital filter.

The Haystack radar primarily reports Doppler inclination, although the path through the beam is estimated to correct for antenna pattern loss when calculating RCS.

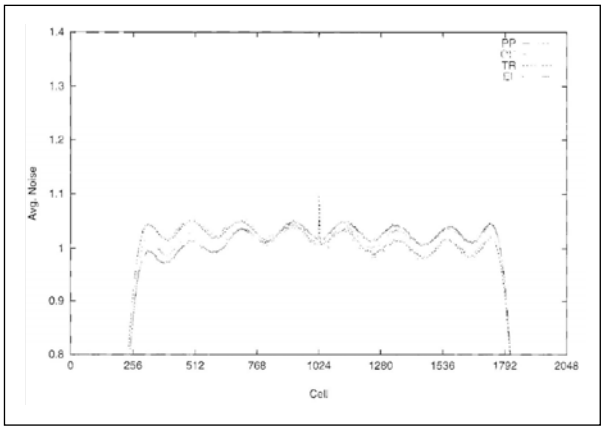

Figure B-3. Noise floor with digital filter.

B.4 Beamshape

Table B-2 contains the coefficients from which the beam intensity loss from a nominal zero dB is calculated.

The dB loss from the beam center as a function of azimuth angle, *az*, and elevation angle, *el*, away from the center, is given by:

$$Loss = \sum_{i=0}^{2} \sum_{j=0}^{2-i} Coef_{i,j}\, az^{i}\, el^{j} \quad ,$$

where *i* and *j* are indices for the coefficients and sums, but are exponents for azimuth and elevation values. Table B-2 lists the coefficients. Figure B-4 shows the RCS intensity distribution over the center of the Haystack beam.

Table B-2. Coefficients for loss factor polynomial fit.

	C0,0	C0,1	C0,2	C1,1	C1,2	C2,2
Haystack	0	-31.16866	-8124.115	-12.03326	-492.5722	-8436.755

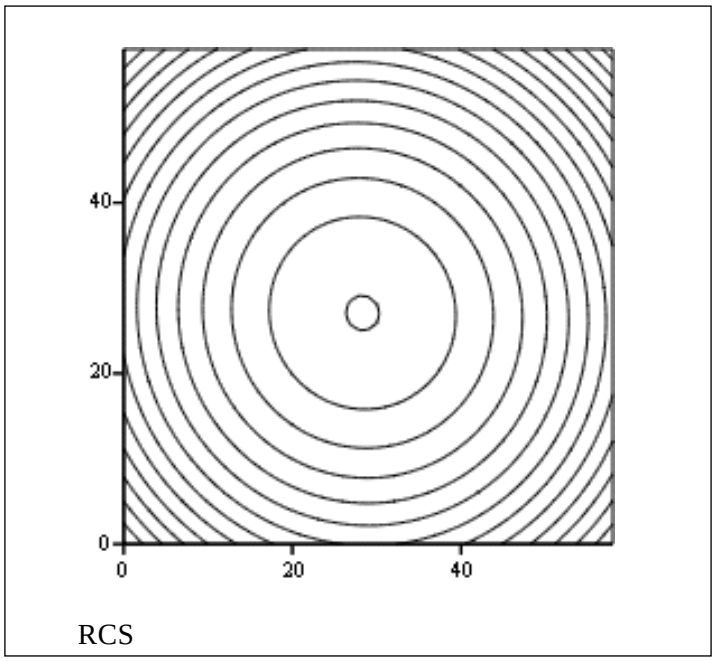

Figure B-4. Haystack RCS intensity distribution over center of beam with 1 dB contours from -0.029° to +0.029°. Geometric center at indices 29,29. Az is x axis, El is y.

B.5 Campaign Parameters

Table B-3 lists the campaign parameters for the 2008 IADC campaign.

Table B-3. Campaign parameters for the Haystack radar for the 2008 campaign.

Campaign Parameters		
Campaign Start	18 Nov 2008 13:15 GMT	
Maximum range	1885	km
Minimum range	312	km
Azimuth of line of site	90	deg
Elevation of line of site	75	deg
Duration of campaign	24	hrs
Total recorded data	20.6	hrs

B.6 Detection List

Table B-4 provides the list of detections observed by the Haystack radar during the 2008 campaign. The column showing possible correlations with the U.S. Space Surveillance Network catalog of known objects was produced using U.S. Air Force Space Command-provided software.

Table B-4. Detections observed by the Haystack radar for the 2008 campaign.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
1	323	13	15	41.7	1383.8	-0.760	-47.16	1345.9	107.9	0.005	
2	323	13	22	4.5	1361.3	-0.493	-48.19	1324.0	102.5	0.005	
3	323	13	26	11.0	889.5	0.843	-49.17	863.5	65.2	0.005	
4	323	13	26	39.9	1376.1	1.007	-42.18	1338.5	58.9	0.007	
5	323	13	29	52.4	1483.5	-0.685	-45.42	1443.4	108.4	0.006	
6	323	13	34	12.9	659.1	-0.431	-47.84	639.3	98.6	0.005	
7	323	13	37	48.5	794.1	0.858	-51.38	770.7	66.3	0.005	
8	323	13	38	6.9	742.7	-0.448	-60.70	720.7	99.3	0.003	
9	323	13	38	53.8	902.1	-0.434	-56.85	875.8	98.2	0.004	
10	323	13	43	41.7	1096.4	-0.483	-41.53	1065.2	99.6	0.007	
11	323	13	43	52.6	692.8	-0.414	-62.24	672.1	98.3	0.003	
12	323	13	46	29.7	888.9	-0.579	-51.32	863.0	103.1	0.005	
13	323	13	46	56.3	899.6	0.332	-53.81	873.4	78.7	0.004	
14	323	13	49	44.5	618.0	-0.511	-53.31	599.3	99.9	0.004	
15	323	13	50	43.2	722.9	-0.452	-44.23	701.4	98.5	0.006	
16	323	13	52	37.7	1223.9	3.744	-50.31	1189.8	81.5	0.005	
17	323	14	2	51.2	1568.7	1.103	-52.67	1526.8	54.2	0.004	
18	323	14	6	28.7	670.2	-0.445	-50.06	650.2	98.3	0.005	
19	323	14	8	45.7	707.2	-0.480	-44.47	686.1	99.2	0.006	
20	323	14	10	1.1	737.2	0.312	-61.26	715.3	80.6	0.003	
21	323	14	15	4.6	782.8	-0.476	-58.31	759.7	99.2	0.003	
22	323	14	20	28.3	1588.1	0.499	-50.95	1545.8	71.4	0.005	

Table B-4. Detections observed by the Haystack radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
23	323	14	24	46.6	1509.4	-0.618	-44.09	1468.7	106.6	0.006	18429
24	323	14	26	48.1	504.8	-0.418	-69.05	489.3	97.6	0.002	
25	323	14	27	42.5	1077.4	-0.855	-55.74	1046.8	109.8	0.004	
26	323	14	28	46.8	1439.0	0.499	-50.57	1399.8	72.1	0.005	
27	323	14	29	25.5	908.8	-0.265	-37.48	882.3	93.9	0.010	
28	323	14	32	16.5	877.8	-0.394	-44.67	852.3	98.3	0.006	
29	323	14	32	58.5	1008.8	0.117	-53.43	979.8	85.4	0.004	
30	323	14	33	8.5	1009.6	-0.038	-47.59	980.5	89.5	0.005	
31	323	14	33	15.9	909.0	0.908	-40.80	882.6	63.3	0.007	
32	323	14	41	0.7	726.3	-0.453	-55.60	704.6	98.6	0.004	
33	323	14	42	20.6	884.7	0.590	-62.54	858.9	73.2	0.003	
34	323	14	45	50.0	422.1	2.324	-46.68	409.0	49.2	0.005	
35	323	14	54	1.9	918.4	-0.593	-53.31	891.7	103.6	0.004	
36	323	14	54	29.3	761.9	-0.550	-44.68	739.3	101.0	0.006	
37	323	14	54	53.2	846.0	0.887	-47.40	821.2	64.3	0.005	
38	323	14	56	46.2	1978.6	1.304	-46.67	1928.2	48.4	0.005	
39	323	14	59	13.1	983.6	-0.509	-55.38	955.2	100.2	0.004	
40	323	15	4	41.8	859.4	-0.556	-60.16	834.2	101.3	0.003	
41	323	15	5	0.1	692.8	-0.556	-46.03	672.1	101.1	0.006	
42	323	15	8	10.8	829.5	0.548	-45.06	805.2	74.4	0.006	
43	323	15	11	59.8	1253.5	-5.716	-59.19	1218.6	42.4	0.003	
44	323	15	14	49.1	572.2	-0.332	-49.54	554.8	95.6	0.005	
45	323	15	15	59.9	939.9	0.854	-47.22	912.7	65.8	0.005	
46	323	15	25	59.8	1131.8	0.058	-55.15	1099.8	87.0	0.004	
47	323	15	26	48.6	1361.1	0.223	-54.30	1323.7	82.5	0.004	
48	323	15	27	43.8	896.3	-0.469	-52.93	870.2	100.3	0.004	
49	323	15	29	27.0	1051.6	-0.794	-59.33	1021.6	108.0	0.003	
50	323	15	30	27.7	519.3	-0.383	-61.82	503.5	96.8	0.003	
51	323	15	35	59.4	1670.8	1.906	-41.39	1626.7	59.2	0.007	
52	323	15	38	23.7	1230.7	-0.474	-47.70	1196.2	99.5	0.005	
53	323	15	41	37.6	1228.7	0.540	-56.52	1194.4	73.7	0.004	
54	323	15	46	4.2	827.4	-0.680	-48.29	803.1	104.4	0.005	
55	323	15	46	46.3	1723.0	0.217	-45.14	1677.8	79.4	0.006	
56	323	16	9	14.5	680.4	-0.481	-54.64	660.1	99.2	0.004	
57	323	16	11	33.6	606.0	-0.590	-50.92	587.8	102.3	0.005	
58	323	16	17	0.7	1581.9	0.553	-47.38	1539.7	69.8	0.005	
59	323	16	18	9.2	1697.1	0.858	-27.81	1652.5	62.1	0.045	6252
60	323	16	19	26.6	792.6	-0.492	-59.24	769.2	100.6	0.003	
61	323	16	19	40.3	894.9	0.914	-45.13	868.9	63.2	0.006	
62	323	16	22	24.7	1019.5	1.327	-54.85	990.4	50.7	0.004	
63	323	16	27	3.3	725.1	-0.121	-46.67	703.5	91.2	0.005	
64	323	16	28	30.3	519.4	-0.374	-57.97	503.5	96.9	0.003	
65	323	16	29	18.2	713.7	0.231	-48.45	692.4	81.8	0.005	
66	323	16	34	5.1	670.1	0.013	-51.71	650.0	87.9	0.005	
67	323	16	42	39.8	591.4	-0.377	-46.08	573.4	96.6	0.006	
68	323	16	49	25.0	1264.3	0.453	-50.20	1229.1	74.1	0.005	

Table B-4. Detections observed by the Haystack radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
69	323	16	58	31.0	1069.5	-0.462	-46.60	1039.1	100.7	0.005	
70	323	17	3	19.6	838.6	0.879	-43.54	814.0	65.6	0.006	
71	323	17	8	57.8	473.3	-0.386	-46.77	458.8	97.0	0.005	
72	323	17	9	53.6	1319.9	-0.571	-48.30	1283.5	104.5	0.005	
73	323	18	22	5.6	1012.9	0.833	-38.31	983.7	66.1	0.009	
74	323	18	23	16.8	951.2	0.861	-43.09	923.8	64.3	0.006	
75	323	18	23	51.8	1277.5	-0.272	-52.42	1242.1	96.1	0.004	
76	323	18	25	54.0	619.8	-0.753	-60.85	601.1	106.4	0.003	
77	323	18	34	38.5	1095.5	0.167	-44.60	1064.4	82.4	0.006	
78	323	18	38	27.3	662.4	-0.542	-62.59	642.6	100.7	0.003	
79	323	18	38	55.8	873.9	-0.144	-52.97	848.4	92.0	0.004	
80	323	18	50	24.9	971.4	-0.570	-42.64	943.5	101.8	0.006	
81	323	18	50	51.2	982.2	-0.582	-46.97	954.0	102.1	0.005	
82	323	18	56	40.6	838.0	0.871	-63.33	813.5	65.8	0.003	
83	323	19	8	25.5	1022.6	-0.980	-53.73	993.3	113.1	0.004	
84	323	19	10	1.9	847.8	0.222	-56.36	823.1	81.7	0.004	
85	323	19	10	16.1	890.2	-0.563	-55.43	864.2	101.5	0.004	
86	323	19	13	38.2	1492.0	-0.119	-50.82	1451.8	89.6	0.005	
87	323	19	18	33.8	885.3	-0.404	-48.55	859.4	97.4	0.005	
88	323	19	21	13.0	1144.9	0.457	-55.23	1112.6	74.5	0.004	
89	323	19	27	48.6	899.8	-0.488	-48.29	873.6	100.8	0.005	
90	323	19	30	32.1	1009.9	-0.270	-44.73	980.9	95.5	0.006	
91	323	19	30	59.6	1404.7	2.259	-45.71	1366.4	62.9	0.006	
92	323	19	33	2.7	1161.4	-0.472	-53.23	1128.7	99.4	0.004	
93	323	19	42	55.3	1017.5	-0.467	-44.03	988.5	100.6	0.006	
94	323	19	49	54.7	947.3	-0.562	-43.60	919.9	101.5	0.006	
95	323	19	53	3.4	917.1	0.876	-46.47	890.4	64.1	0.006	
96	323	19	54	52.9	684.8	0.245	-48.68	664.3	81.6	0.005	
97	323	19	57	58.6	850.7	-0.443	-51.04	825.7	99.5	0.005	
98	323	19	58	20.8	731.2	0.935	-61.35	709.4	63.7	0.003	
99	323	20	4	32.5	977.3	0.851	-41.68	949.2	65.7	0.007	
100	323	20	14	15.3	876.6	0.130	-54.30	851.0	83.9	0.004	
101	323	20	15	0.7	1358.1	-0.418	-41.92	1320.8	100.3	0.007	
102	323	20	18	9.8	989.1	-0.396	-63.09	960.7	98.7	0.003	
103	323	20	18	14.5	852.3	-0.519	-54.26	827.3	100.3	0.004	
104	323	20	19	27.3	1023.5	-0.620	-52.33	994.2	104.7	0.004	
105	323	20	19	57.1	791.0	-0.943	-47.46	767.7	111.2	0.005	
106	323	20	20	55.0	1149.4	-0.251	-52.65	1117.0	93.4	0.004	
107	323	20	23	11.3	1563.7	-0.688	-43.36	1521.8	106.2	0.006	
108	323	20	27	8.7	900.2	-0.533	-42.78	874.0	102.0	0.006	
109	323	20	27	14.7	1134.1	-0.434	-48.30	1102.2	98.3	0.005	
110	323	20	38	16.6	958.7	0.178	-57.93	931.1	82.5	0.003	
111	323	20	38	54.3	510.6	-0.388	-61.41	495.0	97.2	0.003	
112	323	20	48	20.1	980.1	0.840	-51.53	951.8	66.0	0.005	
113	323	20	51	36.6	886.4	-0.498	-43.42	860.5	101.0	0.006	

Table B-4. Detections observed by the Haystack radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
114	323	21	1	53.8	1914.2	1.659	-43.23	1865.0	66.8	0.006	
115	323	21	40	23.0	536.8	2.109	-55.91	520.5	49.4	0.004	
116	323	21	41	23.4	890.2	-0.474	-53.95	864.3	99.2	0.004	
117	323	21	42	30.4	848.2	0.855	-51.05	823.3	66.2	0.005	
118	323	21	49	44.9	908.7	-0.452	-43.69	882.3	99.9	0.006	
119	323	21	51	34.0	806.0	0.239	-57.96	782.2	81.3	0.003	
120	323	21	56	27.0	875.0	-0.511	-51.23	849.5	100.1	0.005	
121	323	21	58	18.6	1029.8	-0.494	-40.30	1000.3	101.4	0.007	
122	323	22	0	3.6	933.9	0.161	-45.23	906.9	84.3	0.006	
123	323	22	2	11.0	860.2	0.140	-53.62	835.0	83.7	0.004	
124	323	22	3	8.2	827.3	-0.319	-51.87	803.0	96.3	0.005	
125	323	22	8	43.3	722.7	-0.446	-56.91	701.2	99.2	0.004	
126	323	22	12	8.8	769.8	-0.592	-54.81	747.1	102.1	0.004	
127	323	22	16	47.7	1251.8	-0.467	-38.74	1217.0	99.3	0.009	
128	323	22	21	34.3	1459.3	0.397	-50.42	1419.6	75.0	0.005	
129	323	22	22	59.6	715.5	-0.809	-55.48	694.2	108.3	0.004	
130	323	22	28	3.1	850.1	-0.533	-48.25	825.1	101.8	0.005	
131	323	22	30	23.8	871.6	-0.530	-48.24	846.1	101.8	0.005	
132	323	22	30	53.5	631.6	0.191	-51.28	612.5	83.6	0.005	
133	323	22	36	41.4	1000.0	0.225	-57.25	971.3	82.7	0.004	
134	323	22	37	34.8	953.6	0.867	-44.14	926.0	64.1	0.006	
135	323	22	38	45.6	414.4	1.252	-68.51	401.5	57.6	0.002	
136	323	22	46	17.7	908.1	-0.538	-39.44	881.7	102.1	0.008	
137	323	22	49	22.6	938.6	-0.543	-58.99	911.5	101.0	0.003	
138	323	22	49	52.9	882.0	-0.658	-47.49	856.4	105.1	0.005	
139	323	22	52	31.9	842.4	0.183	-50.33	817.7	82.7	0.005	
140	323	22	54	23.5	989.6	-0.307	-51.64	961.1	96.4	0.005	
141	323	22	56	32.5	864.5	-0.544	-57.57	839.3	102.1	0.003	
142	323	23	8	23.0	1117.7	0.040	-48.59	1086.1	87.5	0.005	
143	323	23	11	57.4	900.8	-0.559	-62.19	874.7	101.4	0.003	
144	323	23	11	59.2	680.3	-0.615	-47.86	660.0	103.2	0.005	
145	323	23	15	53.9	980.6	0.912	-55.99	952.3	64.0	0.004	
146	323	23	18	13.2	1628.1	1.302	-48.46	1584.9	45.6	0.005	
147	323	23	32	25.1	1089.1	1.268	-44.72	1058.0	52.1	0.006	
148	323	23	38	27.7	977.4	0.178	-52.52	949.3	82.4	0.004	
149	323	23	49	34.6	883.1	-0.530	-56.11	857.3	101.8	0.004	
150	323	23	57	21.2	1315.5	1.133	-49.70	1279.3	53.3	0.005	
151	324	0	5	52.2	827.1	0.145	-59.61	802.9	84.7	0.003	
152	324	0	9	28.2	863.2	-0.242	-48.37	837.9	94.5	0.005	
153	324	0	11	49.2	721.4	-0.598	-49.40	699.8	103.0	0.005	
154	324	0	12	21.6	716.2	-0.592	-60.50	694.8	102.8	0.003	
155	324	0	13	27.4	722.9	-0.066	-43.79	701.3	89.9	0.006	
156	324	0	16	25.5	958.2	0.831	-40.92	930.6	66.4	0.007	
157	324	0	18	21.3	630.2	-0.566	-62.81	611.1	101.8	0.003	
158	324	0	19	31.2	1463.2	1.196	-54.45	1423.6	51.6	0.004	

Table B-4. Detections observed by the Haystack radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
159	324	0	21	15.4	1444.1	-0.315	-49.38	1404.9	95.2	0.005	
160	324	0	24	3.5	628.5	-0.591	-53.41	609.5	102.4	0.004	
161	324	0	32	7.9	697.6	0.919	-66.30	676.7	64.4	0.003	
162	324	0	37	40.7	976.7	-0.508	-46.92	948.5	100.1	0.005	
163	324	0	43	17.9	757.7	-0.368	-59.10	735.3	96.4	0.003	28255
164	324	0	47	21.2	923.4	-0.530	-61.34	896.6	102.0	0.003	
165	324	0	55	57.6	795.5	0.889	-45.72	772.1	65.5	0.006	
166	324	1	19	19.3	583.2	-0.564	-56.82	565.6	101.6	0.004	
167	324	1	25	33.6	1755.8	0.361	-42.50	1709.8	75.0	0.006	
168	324	1	26	29.7	740.4	-0.659	-44.56	718.5	103.7	0.006	
169	324	1	27	21.2	421.6	-0.471	-64.06	408.6	98.8	0.003	
170	324	1	28	38.0	929.0	0.024	-40.66	902.0	87.8	0.007	
171	324	1	29	9.8	559.0	-0.489	-50.02	542.0	99.7	0.005	
172	324	1	31	35.4	1102.0	-0.063	-49.04	1070.8	88.5	0.005	
173	324	1	31	37.6	1326.4	-0.503	-44.86	1289.8	102.6	0.006	
174	324	1	36	16.8	731.7	-0.485	-45.55	709.9	100.2	0.006	
175	324	1	37	38.9	828.5	-0.663	-60.58	804.2	105.0	0.003	
176	324	1	44	41.8	820.5	0.908	-47.64	796.3	63.9	0.005	
177	324	1	45	14.7	830.2	0.907	-51.68	805.8	63.8	0.005	
178	324	1	45	44.3	1762.9	0.465	-43.57	1716.7	74.8	0.006	
179	324	1	52	42.8	599.9	-0.531	-61.04	581.8	100.4	0.003	
180	324	1	57	7.5	977.7	-0.596	-54.33	949.4	103.9	0.004	
181	324	1	57	23.9	600.2	-0.616	-49.91	582.0	102.9	0.005	
182	324	2	0	13.8	652.0	-0.670	-49.26	632.5	103.8	0.005	
183	324	2	2	33.6	749.9	-0.534	-49.53	727.6	101.5	0.005	
184	324	2	10	39.8	725.8	-0.531	-46.25	704.2	101.3	0.006	
185	324	2	18	56.4	790.8	-0.614	-39.75	767.5	103.6	0.008	
186	324	2	19	39.0	686.8	-0.572	-54.13	666.2	101.5	0.004	
187	324	2	29	52.9	794.7	0.227	-45.11	771.2	82.7	0.006	
188	324	2	35	34.5	1391.6	1.049	-47.79	1353.4	57.3	0.005	
189	324	2	37	55.2	1597.5	0.719	-43.43	1554.9	67.2	0.006	
190	324	2	38	52.2	828.9	-0.507	-60.07	804.5	100.0	0.003	
191	324	2	40	27.3	706.4	-0.444	-48.26	685.3	99.1	0.005	25919
192	324	2	57	11.6	1514.1	0.432	-40.16	1473.3	76.3	0.007	
193	324	2	57	39.6	623.9	-0.329	-41.44	605.1	96.1	0.007	
194	324	3	6	58.7	770.6	0.587	-27.69	747.7	72.7	0.045	19102
195	324	3	8	16.5	814.0	-0.470	-48.38	790.1	99.0	0.005	
196	324	3	11	4.0	908.6	-0.549	-47.54	882.1	102.4	0.005	
197	324	3	13	28.3	619.1	-0.001	-67.66	600.4	87.7	0.002	
198	324	3	13	40.8	1252.4	-0.571	-48.43	1217.5	104.2	0.005	
199	324	3	16	10.4	898.8	0.825	-41.07	872.7	66.8	0.007	
200	324	3	18	7.0	624.2	0.919	-68.25	605.3	65.4	0.002	
201	324	3	29	17.8	1174.6	-0.560	-46.05	1141.6	103.7	0.006	
202	324	3	30	7.4	1027.6	-0.054	-41.52	998.1	89.9	0.007	
203	324	3	35	32.0	732.0	1.605	-46.14	710.3	43.8	0.006	
204	324	3	39	22.8	1207.7	-0.537	-44.73	1174.0	101.2	0.006	

Table B-4. Detections observed by the Haystack radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
205	324	3	42	32.5	739.6	0.825	-54.88	717.5	67.4	0.004	
206	324	3	42	49.4	838.4	0.903	-45.92	813.8	63.9	0.006	
207	324	3	53	4.4	414.4	-0.407	-70.20	401.6	97.3	0.002	
208	324	3	56	24.8	1257.4	-0.643	-46.39	1222.4	104.3	0.006	
209	324	4	0	13.4	895.7	-0.297	-35.51	869.7	94.7	0.016	
210	324	4	8	20.0	588.0	0.187	-55.44	570.2	83.7	0.004	
211	324	4	8	36.0	969.4	0.830	-40.99	941.5	66.4	0.007	
212	324	4	10	56.6	537.9	-0.636	-69.26	521.5	103.2	0.002	
213	324	4	19	24.9	602.8	-0.492	-59.07	584.5	99.4	0.003	
214	324	4	21	31.5	1370.1	1.358	-51.60	1332.7	46.0	0.005	
215	324	4	23	23.2	945.4	-0.250	-50.80	918.0	93.5	0.005	
216	324	4	24	38.4	923.6	0.199	-36.53	896.8	83.3	0.013	
217	324	4	35	29.1	1551.3	0.126	-48.39	1509.6	85.2	0.005	
218	324	4	38	3.0	824.8	0.635	-53.03	800.5	72.2	0.004	
219	324	4	41	37.9	912.9	-0.519	-50.88	886.4	100.4	0.005	
220	324	4	46	38.0	1438.3	0.446	-47.14	1399.3	73.6	0.005	
221	324	5	1	21.0	1018.3	-0.449	-39.51	989.1	98.6	0.008	
222	324	5	3	56.8	1096.6	1.333	-44.38	1065.5	48.7	0.006	
223	324	5	10	54.1	970.4	0.812	-36.99	942.4	66.9	0.012	
224	324	5	13	53.8	475.4	-0.592	-57.36	460.7	101.9	0.004	
225	324	5	15	48.0	922.0	-0.604	-42.83	895.2	102.6	0.006	
226	324	5	20	42.7	978.3	-0.642	-45.41	950.1	103.7	0.006	
227	324	5	26	31.3	850.5	0.175	-53.78	825.5	84.0	0.004	
228	324	5	27	38.1	825.5	0.854	-49.67	801.3	66.3	0.005	
229	324	5	28	2.0	1358.3	-0.248	-51.43	1321.1	93.3	0.005	
230	324	5	37	27.8	1027.4	0.213	-55.76	998.0	81.4	0.004	
231	324	5	43	34.0	872.8	0.635	-43.66	847.3	72.0	0.006	
232	324	5	43	49.4	901.4	0.875	-48.32	875.1	64.2	0.005	
233	324	5	53	50.6	506.1	-0.475	-68.62	490.6	99.2	0.002	
234	324	6	28	10.7	578.1	-0.372	-51.01	560.5	96.5	0.005	
235	324	6	30	29.6	1028.1	-0.297	-50.30	998.6	94.7	0.005	
236	324	6	32	4.9	1110.8	1.405	-50.40	1079.3	47.0	0.005	
237	324	6	36	51.5	1339.0	0.237	-41.03	1302.2	82.1	0.007	
238	324	6	37	54.1	1231.9	1.130	-45.51	1197.5	55.7	0.006	
239	324	6	38	53.8	898.0	-0.322	-48.03	871.9	95.3	0.005	
240	324	6	43	56.1	776.0	-0.633	-48.99	753.0	103.1	0.005	
241	324	6	50	20.8	509.6	1.631	-50.12	493.9	45.6	0.005	
242	324	6	50	26.3	1066.4	-0.543	-50.54	1036.1	101.2	0.005	
243	324	6	57	37.3	992.9	-0.316	-37.67	964.4	95.2	0.010	
244	324	7	3	12.4	787.2	0.008	-54.54	764.0	88.1	0.004	
245	324	7	10	31.4	1309.5	-0.587	-46.52	1273.4	102.8	0.005	
246	324	7	10	44.9	813.8	0.881	-47.60	789.8	65.6	0.005	
247	324	7	16	11.2	1163.3	-0.115	-54.58	1130.6	89.8	0.004	
248	324	7	18	6.8	970.8	0.819	-40.58	942.9	66.7	0.007	
249	324	7	24	16.1	1682.9	0.402	-52.15	1638.5	74.0	0.005	
250	324	7	25	12.9	927.2	0.858	-43.27	900.2	65.8	0.006	

Table B-4. Detections observed by the Haystack radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
251	324	7	25	59.9	985.0	-0.760	-44.52	956.6	106.9	0.006	
252	324	7	26	54.0	1492.6	-0.055	-47.55	1452.4	87.8	0.005	
253	324	7	30	58.5	986.7	0.849	-44.71	958.3	64.4	0.006	
254	324	7	33	18.9	970.8	-0.145	-54.75	942.8	90.8	0.004	
255	324	7	38	46.7	1145.9	-0.051	-39.48	1113.8	89.9	0.008	
256	324	7	44	26.8	1133.7	0.223	-55.72	1101.5	80.8	0.004	
257	324	7	47	34.1	978.8	-0.439	-58.06	950.6	98.4	0.003	
258	324	7	49	59.5	691.8	-0.308	-58.70	671.2	95.0	0.003	
259	324	7	52	19.7	907.7	-0.362	-57.27	881.3	96.3	0.004	
260	324	7	58	42.8	777.8	-0.471	-59.45	754.8	99.0	0.003	
261	324	7	59	50.0	1004.1	0.807	-55.34	975.3	66.9	0.004	
262	324	8	10	32.6	1844.6	0.014	-41.11	1796.9	88.5	0.007	
263	324	8	18	3.5	665.4	-0.445	-45.63	645.5	98.3	0.006	
264	324	8	19	10.5	902.2	0.873	-42.03	876.0	64.3	0.007	
265	324	8	24	8.5	1360.7	1.198	-53.97	1323.4	50.7	0.004	
266	324	8	25	51.9	528.9	0.873	-70.16	512.7	67.0	0.002	
267	324	8	30	27.5	1455.2	1.197	-50.37	1415.7	51.6	0.005	
268	324	8	47	35.8	982.1	-0.330	-43.81	953.9	95.5	0.006	
269	324	8	50	19.5	1746.9	-0.070	-49.79	1701.3	87.9	0.005	
270	324	9	0	28.6	892.0	0.909	-40.79	866.1	63.4	0.007	
271	324	9	2	26.1	777.4	-0.307	-47.30	754.5	94.9	0.005	
272	324	9	3	25.9	785.9	0.248	-43.67	762.7	82.1	0.006	
273	324	9	9	51.6	891.3	-0.387	-44.54	865.3	97.0	0.006	
274	324	9	47	4.4	815.8	0.513	-40.82	791.8	75.4	0.007	16864
275	324	9	53	45.3	664.5	-0.237	-58.66	644.6	93.3	0.003	
276	324	9	59	16.4	656.1	0.919	-60.74	636.3	64.7	0.003	
277	324	10	0	11.7	817.2	-0.405	-54.29	793.2	97.4	0.004	
278	324	10	3	20.8	872.6	0.906	-41.95	847.1	63.6	0.007	
279	324	10	4	36.1	906.3	-0.435	-44.98	879.9	98.2	0.006	
280	324	10	7	44.4	889.2	-0.397	-46.35	863.4	97.2	0.006	
281	324	10	12	21.9	664.0	1.149	-38.43	644.1	58.3	0.009	29006
282	324	10	18	58.5	1087.0	-0.472	-48.69	1056.2	99.3	0.005	
283	324	10	25	24.7	749.7	-0.386	-50.42	727.4	96.9	0.005	
284	324	10	34	27.1	836.3	-0.585	-53.84	811.8	102.0	0.004	
285	324	10	35	32.8	1212.8	0.238	-44.01	1178.9	80.2	0.006	8326
286	324	10	36	45.3	630.9	-0.522	-49.21	611.8	100.8	0.005	
287	324	10	40	35.7	983.0	0.781	-54.61	954.7	67.7	0.004	10531
288	324	10	40	45.1	756.5	0.865	-56.51	734.1	65.4	0.004	
289	324	10	51	28.8	863.9	-0.419	-47.32	838.6	97.8	0.005	
290	324	10	52	47.9	995.1	0.489	-48.24	966.5	74.2	0.005	
291	324	10	55	30.7	1060.5	0.829	-42.13	1030.2	66.0	0.007	
292	324	10	56	19.6	981.9	-0.425	-57.52	953.6	99.4	0.004	
293	324	10	58	7.3	629.4	0.916	-51.30	610.4	65.5	0.005	
294	324	11	4	52.0	893.2	-0.406	-53.94	867.2	97.5	0.004	
295	324	11	6	4.0	950.0	-0.592	-50.11	922.5	103.7	0.005	
296	324	11	6	18.6	821.4	-0.432	-50.90	797.4	98.1	0.005	

Table B-4. Detections observed by the Haystack radar for the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)	(m)	US SSN #
297	324	11	6	56.8	1553.7	0.577	-40.95	1512.1	71.8	0.007	
298	324	11	7	32.0	1882.6	-0.389	-40.60	1834.3	97.6	0.007	
299	324	11	12	31.5	868.4	-0.495	-46.90	843.0	99.7	0.005	
300	324	11	13	13.7	847.7	-0.463	-45.08	822.9	98.9	0.006	
301	324	11	18	34.7	833.9	-0.597	-59.59	809.5	102.3	0.003	
302	324	11	21	29.0	807.8	-0.486	-47.92	783.9	99.4	0.005	
303	324	11	22	39.5	863.0	-0.396	-49.42	837.7	98.4	0.005	
304	324	11	34	16.1	925.4	0.866	-45.35	898.6	64.3	0.006	
305	324	11	38	31.6	806.8	-0.391	-37.79	783.0	97.0	0.010	
306	324	11	40	13.5	660.6	-0.357	-52.60	640.9	96.2	0.004	
307	324	11	42	15.7	1185.1	1.194	-45.86	1151.8	53.9	0.006	
308	324	11	42	53.1	738.2	-0.453	-61.55	716.1	98.6	0.003	
309	324	11	42	54.5	1858.5	-1.091	-49.17	1810.5	120.8	0.005	
310	324	11	43	35.7	1426.0	0.486	-37.58	1387.2	72.5	0.010	
311	324	11	44	9.7	865.7	-0.396	-47.00	840.3	97.2	0.005	
312	324	11	48	15.0	805.1	-0.393	-43.93	781.4	97.1	0.006	
313	324	11	58	17.4	784.5	-0.488	-53.67	761.3	99.5	0.004	
314	324	11	58	30.1	771.5	0.274	-46.26	748.8	80.6	0.006	
315	324	11	59	19.6	822.0	-0.512	-47.88	797.8	100.1	0.005	
316	324	12	4	42.5	1678.1	0.477	-46.36	1633.8	74.6	0.006	
317	324	12	6	49.5	973.1	0.826	-55.81	945.1	66.5	0.004	
318	324	12	10	53.9	943.8	0.814	-54.18	916.5	66.9	0.004	
319	324	12	20	40.7	1403.7	-0.427	-45.32	1365.3	98.4	0.006	
320	324	12	21	29.3	1566.5	-0.455	-11.15	1524.7	99.3	0.312	7029
321	324	12	34	4.2	910.8	0.830	-42.71	884.5	65.4	0.006	
322	324	12	38	36.6	528.2	1.370	-68.24	512.0	53.5	0.002	
323	324	12	40	20.5	902.0	0.913	-42.58	875.7	63.2	0.006	
324	324	12	52	0.9	547.1	-0.391	-49.05	530.5	97.0	0.005	
325	324	12	52	50.8	1059.2	-0.962	-40.79	1029.1	112.7	0.007	
326	324	12	53	39.4	771.8	0.909	-44.06	748.9	64.1	0.006	
327	324	13	0	39.9	846.4	0.232	-54.98	821.6	81.4	0.004	
328	324	13	5	14.4	1484.9	0.425	-49.98	1444.8	76.5	0.005	

References

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[2] Settecerri, T. J., Stansbery, E. G., and Hebert, T. J. *Radar Measurements of the Orbital Debris Environment: Haystack and HAX Radars October 1990 – October 1998*; NASA/JSC Publications JSC-28744, JSC-27844A, JSC-27844B; Houston TX, October 1999.

[3] Stokely, C. L., Foster Jr., J. L., Stansbery, E. G., Benbrook, J. R., and Juarez, Q. *Haystack and HAX Radar Measurements of the Orbital Debris Environment; 2003*. NASA/JSC Publication JSC-62815, Houston TX, November 2006.

Appendix C

Haystack Auxiliary Radar

C.1 Introduction

The Haystack Auxiliary (HAX) radar's participation in the Inter-Agency Space Debris Coordination Committee's (IADC) 2008 24-hour campaign was sponsored by NASA. The radar was operated by the Massachusetts Institute of Technology's Lincoln Laboratory (MIT/LL). HAX began routinely supplementing Haystack observations of the orbital debris environment in 1994. The HAX radar has a shorter wavelength but transmits and collects over a much smaller antenna, giving a reduced size detection capability but increased statistics for larger objects. HAX is located approximately 100 m southeast of Haystack (see Figure C-1).

Figure C-1. Haystack radome on the right and the smaller HAX radome on the left.

The Haystack and HAX measurements have provided orbital debris researchers with the ability to detect small debris from previously unknown sources and the ability to examine continuous size distributions for sizes ranging from cataloged objects to objects smaller than 1 cm diameter. Historic HAX results are contained in numerous references (for example [1] and [2]).

C.2 Experiment Setup

During the 2008 IADC 24-hour campaign, 19.0 hours of HAX data were collected with the radar pointing at 75° elevation and at an azimuth of 90°. This is the same pointing angle as Haystack. The close proximity of the two radars means that the field-of-view should essentially overlap over the data collection window. HAX is not nearly as sensitive as Haystack and does not provide many additional detections. However, by overlapping the two fields-of-view, some of the larger Haystack detections are also seen by HAX, thereby providing a second estimate of size measured at a second wavelength. The Haystack pointing angle was chosen as a compromise between maximizing the sensitivity of the radar by minimizing the slant range to an altitude and providing enough off-vertical

pointing to provide reasonable Doppler inclination resolution. Both Haystack and HAX data were collected starting at ~13:15 GMT on 18 November 2008, and running until 13:15 on 19 November.

The operating parameters for the HAX radar during the 2008 campaign are shown in Table C-1.

Table C-1. Instrument parameters used by the HAX radar for the 2008 campaign.

Instrument Parameters		
Geocentric latitude of sensor	42.62	deg
Geocentric longitude of sensor	-71.49	deg
Geodetic altitude	0.1157	km
Wavelength	0.0167	m
Beam width for incoherent integration	0.2	deg
Antenna constant (Gain)	64.0	dB
Transmitted power (peak)	60.0	kW
Pulse period	16.67	msec
Pulse duration	1.638	msec
Desired false alarm time (Marcum)	36000	sec
Number of independent threshold decisions per pulse	12126	
Maximum number of pulses to integrate	16	
Noise equivalent RCS (NRCS)	-44.5	dB m^2
Transmitted power for NRCS	43.35	kW
Pulse duration for NRCS	1.638	msec
Range for NRCS	1000	km

For debris observations, the radar is operated in a staring, or "beam-park," mode in which the antenna is pointed at a specified elevation and azimuth and remains there while debris objects randomly pass through the field-of-view. This operational mode provides a fixed detection volume important to the measurement of the debris flux, or number of objects detected per unit area per unit time. By operating the radar in a stare mode and not tracking detected debris objects, a precise measurement of the object's orbit is sacrificed. However, by examining the signals from the monopulse angle channels operating in an open-loop mode, position in the radar beam for each pulse can be determined. From this path through the beam, rough orbital elements are deduced.

C.3 Processing

In the debris mode, the signal strength for each received pulse is recorded from four separate channels: the Principal Polarization (PP) sum channel, Orthogonal Polarization (OP) sum channel, Traverse Difference (TR) channel, and Elevation Difference (EL) channel (see Figure C-2). The radar data processing software determines the signal strength, signal-to-noise ratio (SNR), TR and EL voltage ratios, range and range rate. Other parameters

are derived from these measurements. For an orbiting object passing through the radar field-of-view, the key step in the data processing is determining the location of the debris object in the radar beam for each radar pulse. From these locations, the motion of the object through the beam can be recreated and used to estimate rough orbital elements. Also, the signal strength can be augmented by the relative antenna gain determined by the antenna beam-pattern calibration discussed below. Thus, the returned signal strength can be estimated as if the object were at the center of the radar beam. The radar cross section (RCS) is determined by applying the absolute radar calibration, antenna beam shape, and the range to the object.

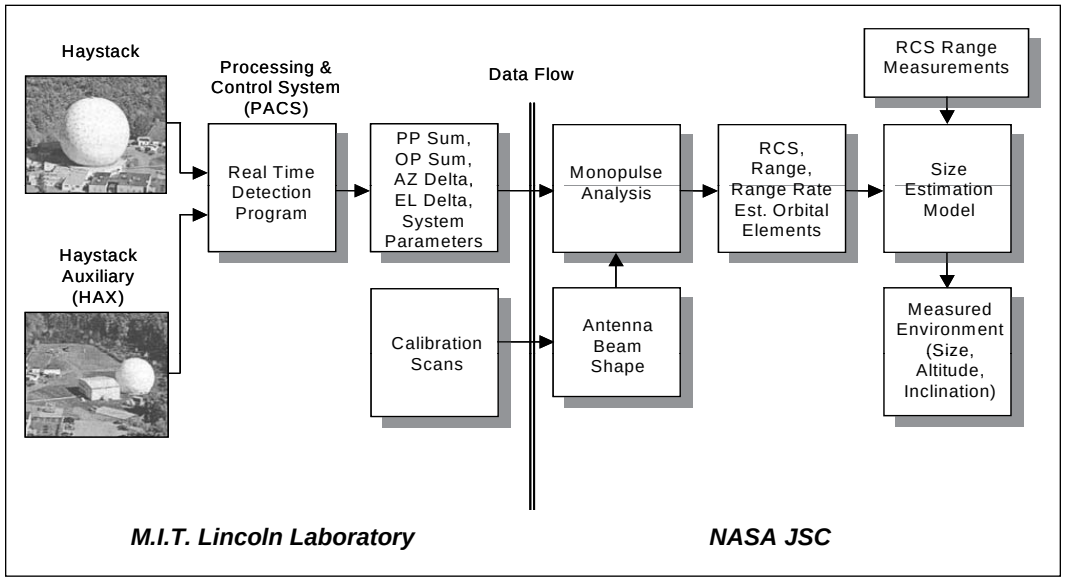

Figure C-2. An overview of the data collection and analysis.

The sensitivity of the antenna pattern is measured by scanning around a calibration sphere as it moves across the sky. This determines both the absolute calibration and the antenna beam pattern. Spheres return a circularly polarized signal with only a PP component. Test signals injected into the receiver preamplifiers are used to determine the absolute OP calibration.

A simple SNR threshold test is used for object detection. The noise floor varies, however, as a function of Doppler frequency. A "shape factor" representing the noise floor is subtracted from the signal emerging from the intermediate bandwidth filter. This shape factor is determined by averaging a large number of pulse returns, which do not contain a valid detection. Figure C-3 shows the shape factor associated with the digital filter.

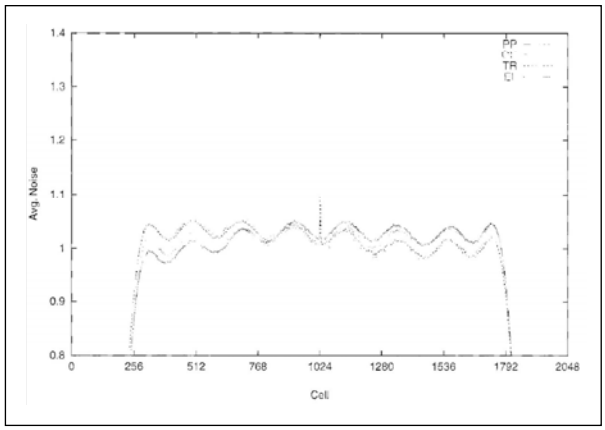

Figure C-3. Noise floor with digital filter.

Both the Haystack and HAX radars primarily report Doppler inclination, although the path through the beam is estimated to correct for antenna pattern loss when calculating RCS.

C.4 Beamshape

Table C-2 contains the coefficients from which the beam intensity loss from a nominal zero dB is calculated.

The dB loss from the beam center as a function of azimuth angle, *az*, and elevation angle, *el*, away from the center, is given by:

$$Loss = \sum_{i=0}^{2} \sum_{j=0}^{2-i} Coef_{i,j}\, az^{i}\, el^{j} \quad ,$$

where *i* and *j* are indices for the coefficients and sums but are exponents for azimuth and elevation values. Table C-2 lists the coefficients. Figure C-4 shows the RCS intensity distribution over the center of the HAX beam.

Table C-2. Coefficients for loss factor polynomial fit.

	C0,0	C0,1	C0,2	C1,1	C1,2	C2,2
HAX	0	-8.301698	-2056.675	-0.065833	53.39635	-2501.303

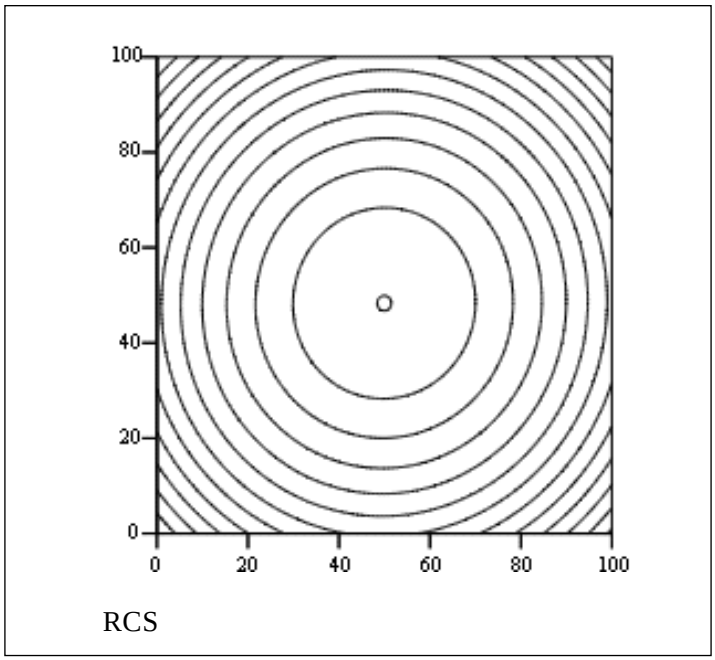

Figure C-4. HAX RCS intensity distribution over center of beam with 1 dB contours from -0.05 to +0.05°. Geometric center at indices 50,50. Az is x axis, El is y.

C.5 Campaign Parameters

Table C-3 lists the campaign parameters for the 2008 IADC campaign.

Table C-3. Campaign parameters for the HAX radar for the 2008 campaign.

Campaign Parameters		
Campaign Start	18 Nov 2008 13:15 GMT	
Maximum range	1885	km
Minimum range	312	km
Azimuth of line of site	90	deg
Elevation of line of site	75	deg
Duration of campaign	24	hrs
Total recorded data	19.6	hrs

C.6 Detection List

Table C-4 provides the list of detections observed by the HAX radar during the 2008 campaign. The column showing possible correlations with the U.S. Space Surveillance Network catalog of known objects was produced by using U.S. Air Force Space Command- provided software.

Table C-4. Detections observed by the HAX radar for the 2008 campaign.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Doppler Inclination	Characteristic Length	Possible Correlation		
NO.	doy	hr	min	sec	(km)	(km/ sec)	(dBsm)	(km)	(deg)	(m)	US SSN #		Comment
1	324	4	25	58.259	311.7	4.173	-42.51	301.6	93.1	0.006			
2	323	14	45	50.045	422.6	2.329	-41.10	409.1	91.9	0.008		*	
3	324	10	22	11.3	505.3	1.640	-40.46	489.3	46.4	0.009		#	
4	324	1	57	23.93	521.5	-0.613	-44.99	505.0	102.6	0.004		*	
5	324	9	1	32.013	585.4	0.960	-38.90	567.1	64.2	0.011		*	Haystack phase issue
6	324	10	58	7.321	594.4	0.917	-42.64	575.8	66.3	0.005		*	
7	324	4	16	31.556	604.5	0.214	-32.78	585.6	83.5	0.025	18214	#	Haystack sidelobe detection
8	324	2	57	39.554	608.9	-0.322	-42.30	589.9	94.9	0.006		*	
9	324	11	52	42.36	652.7	0.210	2.86	632.4	83.6	1.568	18153		
10	324	10	12	21.882	653.9	1.148	-41.35	633.7	59.8	0.007	29006	*	
11	324	5	41	27.601	674.5	-2.716	-42.04	653.5	121.0	0.006			
12	323	23	2	12.332	747.7	1.547	-38.22	724.7	46.8	0.012	25114	*	Below Haystack threshold
13	324	3	6	58.798	770.2	0.592	-37.20	746.6	72.5	0.014	19102	*	
14	323	14	5	55.714	799.3	0.621	-37.35	774.9	73.2	0.014	15482	#	Haystack sidelobe detection
15	324	9	47	4.045	813.4	0.495	-24.41	788.7	74.7	0.068	16864	*	
16	323	14	29	25.584	900.8	-0.261	-33.43	873.6	95.3	0.023		*	
17	324	11	56	2.111	906.9	-0.415	-26.75	879.7	99.1	0.052			
18	324	1	28	37.96	927.7	0.025	-36.30	899.8	86.1	0.016		*	
19	323	21	33	57.449	936.2	-0.528	-31.36	908.1	100.1	0.030	30656		
20	324	4	0	13.371	940.7	-0.297	-33.04	912.7	94.2	0.024		*	
21	324	6	57	37.282	972.7	-0.318	-38.19	943.7	96.8	0.012		*	
22	323	21	34	13.182	1026.2	0.641	-6.91	995.8	69.9	0.509			
23	323	18	24	30.368	1045.3	-0.529	-26.69	1014.1	102.5	0.052	4992	#	
24	323	19	20	32.608	1075.1	0.664	-34.14	1043.4	71.3	0.021			
25	323	15	19	42.499	1186.3	0.936	-24.26	1151.8	63.0	0.069			
26	324	10	35	32.785	1211.0	0.239	-21.01	1175.9	80.0	0.100	8326	*	
27	323	14	8	9.814	1227.7	0.063	-9.28	1192.1	87.3	0.388	15935	*	Haystack noise spike
28	323	21	39	6.066	1232.7	-2.721	-33.60	1197.1	128.6	0.022			
29	324	7	30	25.253	1536.8	0.529	-11.28	1493.9	73.9	0.308	16451	#	
30	323	21	34	55.249	1546.4	0.410	-17.80	1503.6	77.4	0.145	14999		
31	324	12	21	29.281	1564.1	-0.455	-9.55	1521.0	102.1	0.376	7029	*	
* Seen by Haystack simultaneously													
# Seen by Haystack but past the 1/2 power contour													

References

[1] Settecerri, T. J., Stansbery, E. G., and Hebert, T. J. *Radar Measurements of the Orbital Debris Environment: Haystack and HAX Radars October 1990 – October 1998*; NASA/ JSC Publications JSC-28744, JSC-27844A, JSC-27844B; Houston TX, October 1999.

[2] Stokely, C. L., Foster Jr., J. L., Stansbery, E. G., Benbrook, J. R., and Juarez, Q. *Haystack and HAX Radar Measurements of the Orbital Debris Environment; 2003*. NASA/ JSC Publication JSC-62815, Houston TX, November 2006.

Appendix D

Cobra Dane Radar

D.1 Introduction

The AN/FPS-108 Cobra Dane radar is located on Shemya Island, Alaska at 52.7° N latitude, and 174.1° E longitude, and is operated by the U.S. Department of Defense. As such, some of the parameters associated with the operation of the radar are not available to the general public.

D.2 Experiment Setup

Cobra Dane (Figure D-1) is an L-band (23-cm wavelength) phased-array radar, which first became operational in 1977. The radar generates approximately 15.4 MW of peak RF power (0.92 MW average) from 96 Traveling Wave Tube (TWT) amplifiers arranged in 12 groups of 8. This power is radiated through 15,360 active array elements. The face of the radar is aligned at an azimuth of 319°, true.

Figure D-1. Cobra Dane phased array radar.

The Cobra Dane is different from the pencil-beam radars in that it is an electronically steered, phased-array radar. This means that the antenna beam can be instantaneously moved within some angular limits. What is typically done with phased-array radars is to rapidly move the beam in a long, narrow pattern to create a virtual fan beam, or fence. If

each individual beam position in the fence is revisited often enough that orbiting objects cannot travel the width of the fence between revisits, then the fence is referred to as a "leak-proof" fence. While maintaining the fence, some radar time and transmit power is typically allocated for tracking objects detected by the fence. The instrument parameters for Cobra Dane used in the 2008 campaign are shown in Table D-1.

Table D-1. Instrument parameters for the Cobra Dane radar used during the 2008 campaign.

Instrument Parameters		
Geocentric latitude of sensor	52.737	deg
Geocentric longitude of sensor	174.091	deg
Geodetic altitude	0.091	km
Wavelength	0.23	m
Beam width (fence)	0.6 x 40	deg
Antenna constant (Gain)	unavailable	
Transmitted power (peak)	15.4	MW
Pulse period	varies	msec
Pulse duration	1.5	msec
Desired false alarm time (Marcum)	unavailable	
Number of independent threshold decisions per pulse	unavailable	
Maximum number of pulses to integrate	unavailable	
Noise equivalent RCS (NRCS)	unavailable	
Transmitted power for NRCS	unavailable	
Pulse duration for NRCS	unavailable	
Range for NRCS	unavailable	

D.3 Data Collection

Cobra Dane operated for 24 hours from ~00:00:00 GMT on 17 November to 00:00:00 GMT on 18 November 2008. During the campaign, a 40°-wide fence at an elevation angle of 50.3° and covering the azimuth range from 299° – 339° was erected. The fence was one beamwidth wide, or 0.6°. The radar detected objects crossing this fence at slant ranges from 415 – 2501 km. A 1500-µsec pulse was used for detection. Objects passing through the fence were checked against known objects in the U.S. Space Surveillance Network (SSN) catalog (including analyst, or 80,000 series satellites). If the detection was correlated with a known object, then no further tracking was done. In this way, radar resources (time and transmit power) could be conserved for use with UCTs. UCTs detected crossing the fence would be tracked to estimate orbital elements and to acquire RCS information. Campaign parameters for Cobra Dane during the 2008 campaign are shown in Table D-2.

It should be noted that RCS data for the uncorrelated targets are missing for about 2 hours.

Table D-2. Campaign parameters for the Cobra Dane radar used during the 2008 campaign.

Campaign Parameters		
Campaign Start	17 Nov 2008 00:00 GMT	
Maximum range	2501	km
Minimum range	415	km
Azimuth of line of site	299 - 339	deg
Elevation of line of site	50.3	deg
Duration of campaign	24	hrs
Total recorded data	24 (22 RCS)	hrs

D.4 Detection List

Table D-3 provides the list of detections of uncorrelated objects observed by the Cobra Dane radar during the 2008 campaign. In order to conserve radar resources for a leak-proof fence, only objects that did not correlate to the USSPACECOM catalog were tracked and recorded.

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1	322	0	1	29.3	1680.5	5.315	-19.399	738.3	98.5	0.060	0.087
2	322	0	1	54.3	1366.4	-1.418	-31.738	620.5	99.1	0.017	0.037
3	322	0	3	40.3	1520.8	-1.173	-18.773	551.5	99.1	0.022	0.101
4	322	0	4	17.3	1128.9	-1.454	-26.918	681.9	98.8	0.025	0.045
5	322	0	5	22.2	2065.7	5.893	-19.433	492.9	99.7	0.061	0.086
6	322	0	5	22.0	1379.0	4.896	-26.598	866.4	98.0	0.021	0.046
7	322	0	6	35.3	1656.4	-0.906	-19.363	1003.4	98.6	0.149	0.089
8	322	0	7	53.0	730.0	-1.121	-26.028	563.9	99.3	0.002	0.047
9	322	0	8	6.3	1405.7	-1.224	-24.658	677.8	99.1	0.028	0.050
10	322	0	9	46.0	2001.6	5.157	-19.730	851.9	98.0	0.024	0.080
11	322	0	9	52.3	798.0	-1.559	-20.025	495.7	99.2	0.026	0.076
12	322	0	10	59.0	950.5	-1.740	-35.257	554.4	98.6	0.007	0.033
13	322	0	11	30.3	1394.8	3.253	-20.838	1056.9	90.2	0.009	0.067
14	322	0	14	23.3	1128.1	0.962	-21.540	831.2	70.1	0.012	0.062
15	322	0	15	29.3	1095.7	-1.957	-24.111	400.2			0.051
16	322	0	17	2.3	1551.1	-3.950	-20.726	1001.9	82.1	0.050	0.068
17	322	0	17	23.3	696.7	-1.344	-30.387	501.4	99.2	0.030	0.039
18	322	0	18	38.3	1403.2	4.844	-22.195	863.3	98.2	0.009	0.058
19	322	0	20	15.0	2266.1	0.197	-18.096	575.6	99.1	0.024	0.115
20	322	0	22	20.3	1072.3	5.061	-21.178	662.9	98.0	0.003	0.064
21	322	0	30	26.3	1503.6	-1.127	-18.899	559.1	99.1	0.023	0.100
22	322	0	31	25.3	2425.7	0.151	-17.605	540.4			0.123
23	322	0	32	40.4	999.5	-1.718	-19.427	500.7	99.2	0.027	0.086

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
24	322	0	32	45.5	2319.3	-0.486	-16.027	1605.7	101.1	0.031	0.159
25	322	0	32	50.3	2119.8	-0.225	-19.242	804.8	99.5	0.007	0.093
26	322	0	33	47.3	1720.6	-3.858	-24.748	989.3	82.8	0.007	0.049
27	322	0	35	51.3	2115.3	3.617	-18.630	1474.3	99.3	0.068	0.103
28	322	0	35	59.5	1699.0	-0.918	-20.984	623.1	99.3	0.019	0.066
29	322	0	36	15.5	1639.2	-0.951	-18.798	850.2	99.9	0.006	0.101
30	322	0	36	37.3	635.3	-1.553	-19.772	470.7	98.1	0.019	0.080
31	322	0	37	0.5	1427.1	-1.283	-22.909	797.2	99.8	0.010	0.055
32	322	0	38	15.3	1739.6	2.575	-19.819	950.2	83.2	0.020	0.079
33	322	0	40	45.5	1220.2	-3.450	-26.561	898.8	83.1	0.004	0.046
34	322	0	40	47.0	1145.6	3.951	-28.668	872.5	98.0	0.027	0.043
35	322	0	41	44.3	1784.1	-0.956	-15.731	1037.0	65.0	0.385	0.165
36	322	0	41	58.5	884.7	-1.200	-35.708	701.4	98.9	0.021	0.032
37	322	0	42	10.3	1930.8	-3.792	-15.333	682.9	65.0	0.009	0.174
38	322	0	44	2.5	1704.2	-0.845	-17.727	544.8	99.1	0.021	0.120
39	322	0	44	10.3	845.2	-1.319	-21.785	628.0	99.5	0.016	0.060
40	322	0	44	45.5	1314.7	-1.523	-25.266	790.4	98.6	0.001	0.048
41	322	0	44	51.3	1650.6	-1.028	-19.619	656.3	98.9	0.027	0.082
42	322	0	45	28.3	1793.7	-0.776	-22.190	712.5	98.8	0.030	0.058
43	322	0	47	47.0	849.5	-1.566	-25.169	490.4	99.2	0.027	0.048
44	322	0	49	54.0	1825.5	3.706	-22.170	1479.6	99.1	0.081	0.058
45	322	0	51	18.3	2085.6	-0.142	-18.354	553.8	99.0	0.023	0.110
46	322	0	52	38.3	1676.0	4.572	-21.317	1138.7	102.2	0.006	0.063
47	322	0	53	56.2	1585.6	-1.089	-18.771	692.6	98.9	0.023	0.101
48	322	0	54	0.3	1506.9	5.728	-21.748	586.6	97.8	0.040	0.061
49	322	0	57	40.3	2141.6	4.925	-19.181	1004.5	100.0	0.062	0.095
50	322	0	59	27.3	1567.8	5.287	-20.435	738.7	98.0	0.018	0.071
51	322	1	0	19.0	1798.9	3.957	-21.406	1372.5	101.9	0.012	0.063
52	322	1	0	46.3	1071.9	-1.520	-29.739	693.7			0.040
53	322	1	1	54.3	1874.4	1.947	-22.227	874.0	81.3	0.003	0.058
54	322	1	3	0.3	2074.2	5.080	-18.236	789.9	98.9	0.069	0.112
55	322	1	5	26.3	1104.3	-1.445	-29.095	696.9	98.9	0.021	0.041
56	322	1	6	2.3	2364.2	1.646	-16.589	1811.4	82.6	0.032	0.149
57	322	1	7	35.3	1181.8	3.764	-28.13	923.5	97.9	0.024	0.043
58	322	1	8	28.3	2055.6	-0.426	-17.699	824.2	99.3	0.025	0.121
59	322	1	9	46.3	1757.3	-0.826	-19.367	491.5	99.2	0.043	0.089
60	322	1	11	30.0	1346.3	2.616	-25.641	1021.8	83.0	0.004	0.047
61	322	1	12	2.3	1349.1	2.833	-21.853	924.0	83.0	0.005	0.060
62	322	1	15	49.3	1979.2	-3.017	-18.61	1504.7	82.7	0.004	0.104
63	322	1	16	8.3	1021.5	4.214	-25.656	778.7	97.9	0.015	0.047
64	322	1	16	11.3	1782.4	5.122	-22.199	850.5	98.3	0.009	0.058
65	322	1	17	2.3	700.3	-1.361	-18.706	470.6	99.3	0.028	0.102
66	322	1	19	32.3	1111.4	-1.410	-23.929	663.7	99.0	0.032	0.052
67	322	1	20	16.3	1748.6	4.105	-19.437	1289.1	99.5	0.033	0.085

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
68	322	1	20	33.5	1303.2	-1.382	-29.020	539.3	99.5	0.011	0.041
69	322	1	20	42.3	1689.3	-0.850	-19.278	567.4	99.1	0.025	0.092
70	322	1	24	47.0	1482.0	5.085	-19.122	843.2	98.4	0.015	0.096
71	322	1	26	3.3	1209.7	2.877	-21.741	764.7	81.2	0.003	0.061
72	322	1	26	6.3	1289.2	4.892	-20.412	881.2	99.9	0.055	0.071
73	322	1	27	11.3	1398.9	5.026	-22.608	829.1	98.4	0.016	0.056
74	322	1	30	44.3	1897.7	5.560	-17.844	589.2	97.8	0.038	0.118
75	322	1	31	46.0	1546.1	3.928	-20.587	1140.8	98.9	0.026	0.069
76	322	1	32	20.0	1651.3	5.911	-24.086	466.6	98.9	0.005	0.051
77	322	1	32	55.3	1352.4	-1.472	-21.093	640.7	98.8	0.015	0.065
78	322	1	38	30.3	1527.8	5.219	-19.378	858.3	98.3	0.044	0.089
79	322	1	39	25.3	1449.5	-1.149	-17.012	543.7	99.2	0.028	0.140
80	322	1	42	53.3	2321.0	0.372	-17.476	552.6	99.0	0.034	0.125
81	322	1	43	19.3	1572.0	5.005	-21.820	794.4	97.7	0.023	0.060
82	322	1	46	28.5	2068.1	-0.065	-19.262	498.7	99.1	0.028	0.093
83	322	1	46	33.3	2194.6	4.405	-17.421	1326.9	99.0	0.038	0.129
84	322	1	47	10.2	1050.6	-1.670	-24.845	472.2	99.5	0.025	0.049
85	322	1	48	47.3	2066.0	3.516	-22.005	1616.9	103.0	0.036	0.059
86	322	1	49	35.3	1961.6	5.177	-19.597	835.3	98.5	0.015	0.083
87	322	1	51	23.3	836.5	-1.050	-26.799	690.5	99.9	0.014	0.045
88	322	1	53	19.3	1715.1	4.493	-23.139	1243.7			0.054
89	322	1	54	56.3	1130.0	4.012	-20.103	876.9	98.7	0.008	0.075
90	322	1	55	51.3	1580.4	5.692	-21.783	558.5	97.6	0.028	0.060
91	322	1	56	25.3	1185.0	4.160	-21.953	889.9	98.0	0.005	0.059
92	322	1	57	28.3	895.8	-2.509	-22.674	734.2	56.9	0.324	0.056
93	322	1	58	10.3	2095.4	4.282	-19.426	1323.4	98.8	0.031	0.086
94	322	1	58	16.3	1445.1	4.582	-23.627	903.5	98.0	0.022	0.052
95	322	2	0	7.3	1251.2	5.007	-26.827	789.3	100.0	0.003	0.045
96	322	2	0	30.3	1514.5	-3.999	-21.880	897.5	82.7	0.006	0.060
97	322	2	1	1.3	2495.2	0.436	-14.555	858.6	98.8	0.155	0.197
98	322	2	1	27.3	1607.5	-4.093	-23.889	908.1	82.9	0.008	0.052
99	322	2	2	29.0	1624.9	5.473	-24.026	775.7	98.6	0.045	0.051
100	322	2	4	53.5	1675.2	-0.869	-19.347	751.9	99.8	0.011	0.090
101	322	2	5	16.3	1777.2	5.236	-19.894	735.1	97.4	0.022	0.078
102	322	2	6	23.3	870.1	4.997	-24.973	588.0	98.3	0.040	0.049
103	322	2	6	57.5	1592.5	-1.724	-20.870	1219.7	99.4	0.137	0.067
104	322	2	8	46.3	2276.1	-0.353	-14.581	918.3	98.4	0.012	0.196
105	322	2	8	59.3	2273.3	-0.076	-19.397	970.2			0.087
106	322	2	10	9.3	2127.0	5.296	-16.198	512.4	97.5	0.028	0.157
107	322	2	11	8.3	1852.0	5.217	-19.228	685.8	97.6	0.019	0.094
108	322	2	11	29.3	1288.1	-1.268	-25.389	725.4	99.9	0.013	0.048
109	322	2	12	3.0	1853.9	5.158	-23.746	844.4	98.7	0.017	0.052
110	322	2	13	10.3	1024.5	-1.527	-20.146	468.3	99.4	0.026	0.075
111	322	2	15	17.2	1528.8	-1.012	-19.695	344.3	99.2	0.030	0.081

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
112	322	2	15	16.3	1122.4	5.695	-29.765	500.1	96.8	0.012	0.040
113	322	2	15	24.3	2241.7	-3.376	-19.384	1711.0			0.088
114	322	2	15	50.0	1261.3	1.507	-24.761	778.1	74.1	0.001	0.049
115	322	2	17	33.3	1319.4	5.607	-20.064	650.9	97.9	0.035	0.076
116	322	2	18	42.3	1754.9	4.414	-22.329	1225.8	99.4	0.043	0.057
117	322	2	19	43.9	1696.1	-1.018	-17.067	822.3	99.1	0.003	0.138
118	322	2	20	5.3	1905.2	4.704	-18.023	1046.3	98.3	0.029	0.116
119	322	2	23	14.5	1209.2	-1.415	-14.716	710.1	99.0	0.026	0.191
120	322	2	23	14.3	1318.1	4.638	-22.939	896.2	100.0	0.007	0.055
121	322	2	24	55.0	1236.9	5.655	-27.604	581.0	97.4	0.024	0.044
122	322	2	25	25.3	1126.5	-1.680	-17.655	507.7	98.9	0.012	0.122
123	322	2	25	39.3	1909.5	-0.445	-19.376	507.0	99.1	0.039	0.089
124	322	2	26	28.0	1851.0	4.721	-21.830	1017.2	98.9	0.019	0.060
125	322	2	27	19.3	2046.8	5.158	-19.375	842.2	98.6	0.014	0.089
126	322	2	27	52.3	2183.8	4.416	-19.451	1249.5	99.0	0.025	0.085
127	322	2	28	1.3	1558.0	-1.413	-26.112	472.7	97.8	0.000	0.047
128	322	2	29	15.0	1708.3	5.203	-19.981	851.0	98.7	0.011	0.077
129	322	2	29	18.3	1444.3	4.341	-22.480	1080.7	99.7	0.041	0.057
130	322	2	35	6.3	1469.4	5.036	-24.691	833.5	97.9	0.009	0.050
131	322	2	35	30.5	2349.3	0.266	-17.678	694.5	98.8	0.021	0.121
132	322	2	35	34.3	1260.6	-0.050	-19.853	931.1	65.9	0.009	0.078
133	322	2	36	57.3	1793.8	5.356	-23.259	750.2			0.054
134	322	2	40	50.0	1729.8	4.515	-21.319	1067.5	98.8	0.019	0.063
135	322	2	42	50.5	1366.2	-3.797	-26.493	917.2	82.7	0.005	0.046
136	322	2	42	55.3	1778.3	5.101	-22.005	873.3	99.3	0.018	0.059
137	322	2	43	25.3	687.8	4.674	-20.100	503.0	97.8	0.007	0.075
138	322	2	48	25.3	1917.2	-0.504	-17.775	573.6	98.8	0.016	0.119
139	322	2	49	30.3	1770.9	4.206	-21.642	1181.5	98.6	0.023	0.061
140	322	2	53	43.3	2071.0	-0.050	-18.162	544.7	99.3	0.024	0.114
141	322	2	54	11.3	1222.6	4.173	-23.533	883.6	98.2	0.026	0.053
142	322	2	56	1.3	1149.6	5.908	-19.558	503.3	97.6	0.028	0.083
143	322	3	1	13.3	1694.9	4.822	-19.948	957.7	99.0	0.016	0.077
144	322	3	1	32.3	1343.9	3.987	-27.492	1041.7	100.1	0.002	0.044
145	322	3	2	16.3	1776.3	3.685	-22.274	1407.7	101.3	0.009	0.058
146	322	3	2	19.3	2093.0	-3.168	-17.576	1541.9	82.5	0.017	0.123
147	322	3	2	52.3	1805.6	4.525	-20.591	1106.4	98.2	0.039	0.069
148	322	3	3	4.0	1665.7	4.692	-21.42	971.6	99.1	0.027	0.063
149	322	3	6	3.3	1007.8	0.369	-24.566	810.1	65.0	0.002	0.050
150	322	3	7	41.0	1447.2	4.794	-23.372	849.2	98.1	0.026	0.053
151	322	3	7	59.3	1016.9	0.314	-25.506	809.2	65.0	0.001	0.048
152	322	3	9	7.3	1304.5	-4.917	-30.593	799.4	75.7	0.012	0.039
153	322	3	9	25.3	1256.4	3.985	-24.777	956.1	99.1	0.020	0.049
154	322	3	9	39.3	1026.0	0.293	-25.356	808.1	65.0	0.002	0.048
155	322	3	10	48.3	1044.0	0.242	-26.750	805.9	65.0	0.002	0.045

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
156	322	3	11	16.3	1317.5	4.702	-19.984	867.0	98.6	0.005	0.077
157	322	3	11	35.3	1470.0	5.151	-19.710	795.1	99.2	0.039	0.081
158	322	3	12	0.3	1054.8	0.178	-26.604	807.1	65.0	0.003	0.046
159	322	3	13	53.5	1037.4	-1.459	-18.473	670.7	100.1	0.014	0.107
160	322	3	13	55.3	1901.7	5.554	-20.556	533.6			0.070
161	322	3	15	11.3	1063.8	0.164	-26.387	809.1	65.0	0.002	0.046
162	322	3	15	29.3	1018.1	6.296	-34.424	397.1	98.1	0.057	0.034
163	322	3	15	51.0	1769.8	5.332	-19.672	703.5	97.9	0.007	0.081
164	322	3	16	40.3	1070.8	0.146	-25.169	808.6	65.0	0.001	0.048
165	322	3	18	32.0	2210.7	5.211	-21.289	626.7	97.7	0.030	0.063
166	322	3	18	37.3	1999.3	1.968	-20.655	1521.0	82.0	0.018	0.069
167	322	3	19	1.3	2173.8	4.640	-18.501	1257.6	99.6	0.037	0.106
168	322	3	19	46.3	827.2	5.462	-20.418	503.8	97.7	0.027	0.071
169	322	3	20	48.5	1144.4	-4.642	-36.208	850.0	69.8	0.025	0.031
170	322	3	21	21.0	1102.1	-0.005	-24.853	809.9	65.0	0.002	0.049
171	322	3	22	18.3	1108.9	-0.000	-24.675	808.9	65.0	0.001	0.050
172	322	3	23	43.3	1127.6	-0.123	-24.511	805.4	65.0	0.003	0.050
173	322	3	23	54.3	1130.1	-0.127	-26.535	806.1	65.0	0.002	0.046
174	322	3	24	6.0	1153.5	4.336	-25.697	848.5	99.0	0.016	0.047
175	322	3	24	40.3	1407.3	4.963	-20.871	833.0	98.6	0.012	0.067
176	322	3	25	37.0	1132.0	-0.055	-26.078	808.7	65.0	0.002	0.047
177	322	3	25	36.5	1134.5	4.686	-30.400	782.8	99.6	0.004	0.039
178	322	3	26	22.3	1137.3	-0.155	-24.638	810.5	65.0	0.001	0.050
179	322	3	27	58.3	1353.2	4.931	-24.361	817.5	98.6	0.013	0.050
180	322	3	28	16.5	1467.9	-1.232	-21.270	792.6	99.1	0.005	0.064
181	322	3	29	37.3	1158.5	-0.250	-26.827	809.4	65.0	0.002	0.045
182	322	3	29	54.3	1155.8	4.159	-19.754	871.6	98.8	0.007	0.080
183	322	3	32	46.2	1358.9	4.489	-29.804	931.3	99.1	0.015	0.040
184	322	3	32	46.3	1178.4	-0.294	-25.394	810.2	64.9	0.004	0.048
185	322	3	34	2.0	1196.2	-0.345	-24.626	805.5	65.0	0.003	0.050
186	322	3	34	36.3	1204.3	-0.397	-26.728	807.8	65.0	0.003	0.045
187	322	3	35	26.3	1206.9	-0.350	-24.523	807.6	65.0	0.002	0.050
188	322	3	35	48.3	1211.6	-0.468	-24.671	808.5	65.0	0.002	0.050
189	322	3	35	49.3	1530.0	5.021	-19.223	861.2	99.1	0.016	0.094
190	322	3	36	47.3	1216.5	-0.483	-26.067	806.5	65.0	0.002	0.047
191	322	3	37	7.3	1220.7	-0.440	-25.013	807.7	65.0	0.002	0.049
192	322	3	37	25.3	2081.3	5.115	-18.324	808.5	98.4	0.010	0.110
193	322	3	38	17.3	1255.1	4.339	-20.033	906.1	99.0	0.011	0.076
194	322	3	39	49.3	1224.9	-0.454	-24.811	809.1	65.0	0.002	0.049
195	322	3	40	11.3	1603.0	4.723	-21.655	1081.4	99.8	0.040	0.061
196	322	3	41	41.3	1250.7	-0.585	-26.777	807.0	65.0	0.002	0.045
197	322	3	42	15.5	1024.1	-1.386	-24.441	687.7	100.2	0.018	0.050
198	322	3	42	20.3	1542.6	4.515	-20.250	1003.6	99.2	0.017	0.073

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
199	322	3	43	46.3	1346.9	3.736	-27.214	1060.0	99.2	0.018	0.045
200	322	3	45	6.3	2034.6	-0.471	-16.743	780.7	99.0	0.031	0.146
201	322	3	49	15.0	2333.9	4.788	-20.157	1286.1	99.5	0.054	0.074
202	322	3	50	21.3	1241.6	-3.799	-26.805	1014.5	64.8	0.006	0.045
203	322	3	50	29.3	1545.5	-1.725	-22.214	965.4	95.8	0.022	0.058
204	322	3	50	53.5	2022.8	-0.445	-21.795	1546.8	101.7	0.020	0.060
205	322	3	52	3.3	1162.6	4.281	-23.248	862.3	98.8	0.005	0.054
206	322	3	52	14.3	1131.5	4.179	-26.561	863.3	98.8	0.004	0.046
207	322	3	52	37.0	1326.0	-0.906	-25.447	806.9	65.0	0.002	0.048
208	322	3	55	31.3	1228.8	4.623	-26.012	835.2	98.7	0.008	0.047
209	322	3	55	31.5	1683.8	5.115	-20.180	869.1	98.9	0.007	0.074
210	322	3	55	50.3	1348.7	-1.007	-27.135	808.4	65.0	0.002	0.045
211	322	3	56	45.3	1627.6	5.193	-21.911	841.4	99.0	0.011	0.060
212	322	3	57	42.3	1722.4	4.983	-18.38	917.6	99.0	0.011	0.109
213	322	3	58	15.3	1656.6	5.088	-24.539	869.4	98.8	0.005	0.050
214	322	3	58	34.3	1304.3	-0.175	-24.179	957.9	65.9	0.003	0.051
215	322	3	58	35.3	1366.5	-1.047	-25.289	808.6	65.0	0.004	0.048
216	322	3	59	10.3	1357.7	-1.011	-25.525	808.8	65.0	0.002	0.048
217	322	3	59	57.3	1371.9	-1.046	-26.067	808.1	65.0	0.002	0.047
218	322	4	1	33.3	1824.8	5.163	-20.004	861.8	98.9	0.007	0.076
219	322	4	3	26.4	1594.7	-6.372	-25.676	645.0	65.0	0.013	0.047
220	322	4	4	47.3	1516.4	2.583	-24.201	722.0	81.1	0.006	0.051
221	322	4	6	38.3	1626.4	4.960	-19.398	915.5	98.7	0.013	0.087
222	322	4	7	8.3	1984.4	5.104	-19.646	884.4	98.9	0.008	0.082
223	322	4	7	24.3	1423.9	-6.249	-21.771	641.6	65.1	0.012	0.060
224	322	4	7	37.3	1350.8	4.775	-25.817	870.9	98.8	0.004	0.047
225	322	4	7	37.5	1523.5	5.472	-19.346	637.5	97.9	0.002	0.090
226	322	4	7	58.5	1024.5	-1.348	-21.169	681.6	99.3	0.025	0.064
227	322	4	8	8.0	2104.3	4.791	-19.570	1004.9	99.0	0.018	0.083
228	322	4	9	28.3	1699.6	-0.762	-23.256	672.8	100.1	0.015	0.054
229	322	4	10	8.3	1419.1	-1.364	-16.050	307.2	99.0	0.009	0.159
230	322	4	11	17.5	1192.7	4.801	-19.617	760.1	97.6	0.030	0.082
231	322	4	11	48.5	1498.5	-1.283	-24.523	406.4	99.0	0.009	0.050
232	322	4	11	50.3	1174.8	4.313	-29.064	863.9	98.8	0.002	0.041
233	322	4	13	19.3	1530.5	-4.054	-18.924	863.3	83.0	0.004	0.099
234	322	4	14	18.3	1274.7	4.700	-26.646	845.1	98.8	0.007	0.046
235	322	4	15	29.3	1045.7	-1.839	-17.154	369.5	98.8	0.003	0.136
236	322	4	18	20.3	1193.2	3.835	-23.564	927.6	98.5	0.026	0.053
237	322	4	20	2.0	1432.4	5.129	-22.501	836.6	98.5	0.035	0.057
238	322	4	20	3.3	1420.9	-1.151	-23.812	522.0	99.4	0.022	0.052
239	322	4	20	20.3	1670.1	5.089	-20.500	861.6	98.8	0.006	0.070
240	322	4	20	41.3	2004.6	3.968	-20.636	1319.9	99.6	0.058	0.069
241	322	4	23	11.3	2198.9	4.951	-19.337	905.8	99.1	0.013	0.091

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
242	322	4	24	59.3	1355.8	-1.162	-17.721	633.1	99.6	0.027	0.120
243	322	4	25	52.1	1357.2	-1.429	-22.822	479.4	98.9	0.011	0.055
244	322	4	25	52.3	1638.1	4.957	-20.135	914.8	99.1	0.016	0.075
245	322	4	26	26.0	2024.9	-3.419	-19.603	1062.7	62.9	0.136	0.082
246	322	4	26	40.3	1553.3	-1.791	-24.883	809.1	65.1	0.004	0.049
247	322	4	27	2.3	1614.7	-4.859	-25.892	613.9	81.0	0.009	0.047
248	322	4	27	55.3	1451.6	5.484	-18.982	690.5	98.4	0.014	0.099
249	322	4	28	50.5	1835.1	5.212	-20.941	856.1	99.0	0.009	0.066
250	322	4	28	50.3	1566.8	-1.848	-25.294	809.1	65.0	0.002	0.048
251	322	4	28	57.3	1146.3	4.135	-32.668	876.1	99.1	0.006	0.036
252	322	4	29	32.5	1583.9	-0.998	-19.817	613.5	99.3	0.020	0.079
253	322	4	29	35.3	1663.6	-3.934	-19.879	1327.0	65.8	0.018	0.078
254	322	4	30	9.3	1576.7	-1.905	-24.921	808.2	65.0	0.000	0.049
255	322	4	30	37.3	1666.2	5.179	-20.757	852.2	99.1	0.007	0.068
256	322	4	30	45.0	1410.7	5.161	-22.024	774.9	98.8	0.017	0.059
257	322	4	31	8.0	1572.7	5.121	-22.759	860.0	98.9	0.006	0.056
258	322	4	34	47.3	1497.4	4.969	-18.820	875.9	99.0	0.008	0.101
259	322	4	35	50.0	1448.8	4.593	-22.431	955.8	99.4	0.015	0.057
260	322	4	37	40.3	1648.2	5.115	-19.386	845.6	98.8	0.007	0.088
261	322	4	38	13.3	1664.5	5.061	-24.079	882.7	99.1	0.007	0.051
262	322	4	38	23.3	2055.9	-0.810	-18.583	1292.1	65.5	0.294	0.104
263	322	4	38	32.3	1078.1	4.087	-17.427	831.7	98.7	0.006	0.128
264	322	4	38	35.3	1252.7	4.573	-20.112	867.2	99.0	0.001	0.075
265	322	4	39	7.0	1317.1	4.734	-27.945	867.8	98.8	0.008	0.044
266	322	4	39	25.3	1838.0	4.882	-22.326	996.1	98.7	0.028	0.057
267	322	4	39	29.0	1665.0	4.641	-20.969	1018.4	98.8	0.025	0.066
268	322	4	39	37.0	985.6	4.298	-26.169	741.6			0.046
269	322	4	40	21.3	1146.7	4.178	-19.250	867.4	98.9	0.003	0.093
270	322	4	41	43.3	1913.8	5.123	-19.597	862.9	98.8	0.002	0.083
271	322	4	41	48.3	2421.5	-3.064	-18.533	1698.0	82.7	0.010	0.105
272	322	4	42	12.3	1344.6	4.716	-23.832	889.6	98.9	0.008	0.052
273	322	4	45	43.3	1965.0	5.481	-19.865	709.9	99.6	0.006	0.078
274	322	4	46	14.3	1696.3	5.085	-22.573	860.7	98.9	0.013	0.056
275	322	4	46	35.3	1646.0	5.124	-20.289	864.5	99.0	0.003	0.073
276	322	4	47	22.3	1436.3	4.793	-23.471	853.9	98.4	0.027	0.053
277	322	4	48	26.2	1718.6	5.168	-19.904	867.9	99.0	0.006	0.078
278	322	4	48	26.3	1571.5	2.571	-27.147	675.3	82.1	0.025	0.045
279	322	4	50	39.3	2169.7	4.658	-19.350	981.7	99.0	0.045	0.090
280	322	4	53	2.3	1315.8	4.976	-21.165	874.6	100.5	0.044	0.064
281	322	4	53	10.3	2018.5	5.117	-19.210	850.5	98.9	0.011	0.094
282	322	4	53	25.3	1444.5	4.929	-18.201	865.8	98.8	0.002	0.113
283	322	4	53	58.3	1195.8	4.364	-23.21	870.0	98.9	0.004	0.054
284	322	4	54	4.3	2441.1	1.346	-15.469	968.6			0.172

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
285	322	4	54	18.3	1734.1	-2.542	-24.205	810.9	65.1	0.005	0.051
286	322	4	54	29.3	1843.3	5.160	-19.993	845.8	98.9	0.008	0.077
287	322	4	54	32.3	1496.5	4.333	-19.277	1015.1	98.6	0.033	0.092
288	322	4	57	13.3	1795.7	4.987	-25.275	887.2	98.8	0.021	0.048
289	322	4	58	9.3	2404.0	4.876	-19.744	885.4	98.9	0.007	0.080
290	322	4	58	38.3	2070.4	-0.400	-17.473	1462.9	102.6	0.020	0.125
291	322	4	59	47.3	1217.3	5.272	-19.398	664.1	98.4	0.023	0.087
292	322	4	59	57.3	2381.8	-6.036	-18.005	918.2	65.6	0.011	0.116
293	322	5	1	6.3	1656.7	5.206	-20.713	851.8	99.0	0.009	0.068
294	322	5	1	27.0	1685.5	5.103	-24.426	815.5	98.2	0.009	0.050
295	322	5	2	10.3	2333.3	5.108	-18.228	523.3	97.6	0.040	0.113
296	322	5	3	22.3	1888.6	5.323	-18.556	723.9	98.5	0.012	0.105
297	322	5	3	32.3	1629.2	5.122	-18.258	1094.9	105.8	0.084	0.112
298	322	5	3	42.3	1745.9	4.577	-19.403	1075.4	99.5	0.018	0.087
299	322	5	5	57.0	1987.2	5.134	-19.620	880.9	99.2	0.008	0.082
300	322	5	6	22.3	2357.1	4.541	-19.788	1419.7	102.1	0.007	0.079
301	322	5	6	39.3	1542.1	3.655	-21.614	1226.9	99.6	0.023	0.061
302	322	5	7	19.3	1461.8	2.707	-24.395	693.4	81.2	0.011	0.050
303	322	5	7	24.3	1435.9	-1.216	-20.261	678.2	99.4	0.025	0.073
304	322	5	8	42.3	2212.0	5.282	-20.414	473.4	98.5	0.022	0.071
305	322	5	10	3.0	1627.7	4.840	-19.751	949.3	99.2	0.011	0.080
306	322	5	11	50.3	1405.3	4.971	-28.790	857.9	99.1	0.006	0.042
307	322	5	12	26.0	1557.6	4.485	-19.372	1002.4	98.7	0.027	0.089
308	322	5	14	51.3	1586.9	4.566	-19.379	984.6	98.7	0.030	0.088
309	322	5	15	5.0	2253.0	4.995	-19.188	865.6	98.8	0.005	0.095
310	322	5	16	5.3	1487.6	-1.215	-19.746	895.5	100.4	0.143	0.080
311	322	5	17	8.3	1639.5	5.573	-20.064	644.4	98.8	0.038	0.076
312	322	5	17	11.0	2164.9	5.054	-18.700	840.6	99.1	0.018	0.102
313	322	5	17	32.3	1445.3	4.936	-17.628	865.3	99.1	0.004	0.122
314	322	5	18	3.3	1467.2	5.025	-20.564	843.3	98.9	0.004	0.069
315	322	5	19	54.3	1447.0	-1.432	-23.387	787.0	98.9	0.019	0.053
316	322	5	20	30.3	2521.2	4.773	-18.627	866.4	98.9	0.006	0.103
317	322	5	20	56.3	1129.6	3.142	-30.659	626.9	81.7	0.018	0.039
318	322	5	21	17.0	2529.5	4.588	-18.466	968.8	98.8	0.017	0.107
319	322	5	22	24.3	1138.4	4.146	-22.421	869.6	99.1	0.004	0.057
320	322	5	23	12.3	2163.8	1.772	-18.323	949.9	82.5	0.004	0.110
321	322	5	26	22.3	1591.7	5.253	-19.634	803.7	99.4	0.027	0.082
322	322	5	26	24.3	950.2	-6.011	-27.294	518.1	62.7	0.075	0.044
323	322	5	27	27.3	2143.7	5.077	-20.388	861.8			0.072
324	322	5	28	15.3	2190.6	5.085	-18.050	845.3	98.9	0.009	0.115
325	322	5	28	20.3	1745.0	-4.373	-21.813	866.0	81.4	0.001	0.060
326	322	5	29	23.5	1989.1	-0.678	-19.503	498.2	97.7	0.005	0.084
327	322	5	29	32.3	2433.3	0.190	-15.016	1560.4	103.0	0.016	0.177

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
328	322	5	30	31.3	2279.4	4.978	-14.861	875.6	99.0	0.005	0.186
329	322	5	31	59.3	932.7	5.466	-24.323	566.4	98.5	0.036	0.050
330	322	5	32	12.0	2118.0	5.082	-20.768	842.3	98.8	0.005	0.068
331	322	5	32	42.3	1721.1	5.217	-23.435	860.2	99.2	0.003	0.053
332	322	5	33	27.3	2348.5	4.916	-20.281	878.5	99.1	0.007	0.073
333	322	5	34	14.5	1239.7	-5.555	-28.951	712.0	70.5	0.009	0.042
334	322	5	34	56.0	2447.1	-0.143	-16.940	1744.5	102.4	0.012	0.141
335	322	5	35	13.0	2024.2	-0.649	-18.283	1495.5	101.9	0.034	0.111
336	322	5	40	37.3	1355.0	0.664	-24.554	868.5	70.9	0.011	0.050
337	322	5	40	49.3	1748.4	5.218	-20.706	856.4	99.2	0.006	0.068
338	322	5	42	21.3	2306.9	4.960	-18.206	864.8	98.6	0.010	0.113
339	322	5	42	22.3	1678.4	5.170	-20.045	855.8	99.1	0.007	0.076
340	322	5	42	31.3	1195.0	-4.156	-26.221	935.0	65.1	0.004	0.046
341	322	5	44	58.3	1687.4	5.163	-21.094	865.6	99.0	0.004	0.065
342	322	5	45	25.3	1180.9	4.261	-19.432	891.7	99.1	0.015	0.086
343	322	5	46	30.3	1524.7	4.686	-23.892	911.7	98.7	0.030	0.052
344	322	5	46	43.3	1869.4	5.087	-17.462	875.3	98.9	0.006	0.126
345	322	5	47	8.3	1157.7	4.283	-19.419	879.3	99.1	0.021	0.086
346	322	5	49	50.3	1342.1	4.794	-25.666	865.7	99.1	0.002	0.047
347	322	5	49	58.3	868.4	-3.816	-25.124	716.9	71.0	0.002	0.049
348	322	5	50	17.3	2274.7	-0.240	-16.078	1462.8	101.6	0.009	0.159
349	322	5	52	7.3	2114.4	5.271	-19.679	687.0	98.4	0.015	0.081
350	322	5	52	13.3	1104.0	4.344	-26.417	813.3	98.8	0.003	0.046
351	322	5	53	6.0	1721.0	-5.573	-22.712	940.1	65.9	0.009	0.056
352	322	5	53	47.0	1500.0	-5.182	-23.224	941.2	65.9	0.012	0.054
353	322	5	54	24.3	1819.5	4.744	-18.478	1093.5	100.2	0.004	0.107
354	322	5	58	39.3	1315.8	4.719	-24.857	869.8	99.0	0.004	0.049
355	322	6	1	42.3	2120.6	5.368	-18.221	529.4	98.2	0.040	0.113
356	322	6	3	50.3	2216.3	4.612	-17.421	1205.5	99.8	0.022	0.129
357	322	6	7	36.5	2295.3	-3.651	-17.445	1285.6	82.5	0.028	0.127
358	322	6	8	4.3	1629.8	5.075	-20.761	890.2	99.5	0.010	0.068
359	322	6	9	15.0	2174.2	5.076	-19.662	864.9	99.1	0.004	0.081
360	322	6	9	54.3	1186.6	5.701	-20.240	583.5	98.8	0.029	0.073
361	322	6	10	15.3	1275.4	4.076	-22.322	986.3	99.0	0.030	0.057
362	322	6	10	22.3	1477.0	5.012	-24.016	866.1	99.2	0.003	0.051
363	322	6	10	36.3	1445.0	4.766	-19.267	935.1	99.1	0.021	0.093
364	322	6	11	6.3	639.3	0.638	-34.125	227.3	64.9	0.002	0.034
365	322	6	11	27.3	497.1	1.523	-23.181	323.5	65.0	0.002	0.054
366	322	6	13	46.3	1214.2	6.074	-20.850	508.3	98.7	0.037	0.067
367	322	6	14	12.3	1343.0	4.908	-21.535	860.6	99.2	0.016	0.062
368	322	6	14	42.5	2293.6	-0.335	-18.493	1251.7	99.9	0.015	0.106
369	322	6	16	11.3	489.1	1.644	-23.981	326.1	65.0	0.000	0.051
370	322	6	16	58.0	1246.4	4.481	-20.637	900.8	99.1	0.021	0.069

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
371	322	6	17	19.3	1368.0	4.722	-25.817	902.1	99.1	0.013	0.047
372	322	6	17	32.3	2314.0	5.017	-19.212	862.5	99.2	0.002	0.094
373	322	6	17	59.3	1663.5	4.851	-21.564	935.0	98.7	0.018	0.062
374	322	6	18	52.0	473.8	1.684	-23.865	353.4	65.0	0.000	0.052
375	322	6	18	57.0	1499.2	-2.297	-22.008	674.3	65.0	0.074	0.059
376	322	6	19	11.3	2203.0	0.616	-16.868	1848.1	65.2	0.208	0.143
377	322	6	20	12.3	550.7	1.283	-21.793	371.6	65.0	0.004	0.060
378	322	6	20	27.5	880.7	5.861	-24.220	443.8	98.4	0.029	0.051
379	322	6	20	30.3	601.3	0.875	-23.45	257.0	65.0	0.003	0.053
380	322	6	20	41.3	1346.5	6.053	-25.676	476.6	98.2	0.029	0.047
381	322	6	22	4.0	1947.0	5.146	-22.438	870.9	98.9	0.008	0.057
382	322	6	22	14.0	1193.6	5.767	-27.363	532.9	98.6	0.027	0.044
383	322	6	24	26.0	1736.1	5.315	-17.906	831.3	99.3	0.011	0.117
384	322	6	25	12.3	1149.6	2.543	-34.132	884.0			0.034
385	322	6	26	6.3	2451.0	4.862	-17.225	807.0	99.1	0.019	0.135
386	322	6	27	0.3	527.8	1.240	-20.098	296.9	65.1	0.002	0.075
387	322	6	27	46.0	522.1	1.438	-27.524	370.0	65.0	0.001	0.044
388	322	6	29	7.3	608.3	1.082	-14.998	396.8	65.0	0.002	0.181
389	322	6	29	35.3	647.3	0.635	-18.569	262.0	65.0	0.002	0.105
390	322	6	30	2.3	1207.1	3.795	-19.139	923.6	98.7	0.047	0.096
391	322	6	31	44.3	1135.5	-0.872	-16.784	568.8	64.9	0.012	0.145
392	322	6	32	51.3	606.2	0.955	-28.559	332.4	65.0	0.003	0.042
393	322	6	34	5.0	1685.9	5.155	-25.646	876.7	99.5	0.008	0.047
394	322	6	34	23.3	1255.9	2.641	-23.453	884.2	81.3	0.003	0.053
395	322	6	34	57.3	2099.8	-2.652	-18.787	1702.5	82.5	0.019	0.101
396	322	6	36	51.3	646.9	0.854	-21.316	333.1	65.0	0.002	0.063
397	322	6	38	9.3	628.9	0.887	-25.681	359.8	64.9	0.003	0.047
398	322	6	38	22.3	1400.8	5.659	-22.289	622.5	98.7	0.025	0.057
399	322	6	39	19.3	2274.0	5.030	-17.950	867.3	99.1	0.002	0.117
400	322	6	39	53.3	1240.2	4.513	-18.911	870.5	99.2	0.003	0.099
401	322	6	40	50.0	2178.8	5.028	-19.37	903.2	99.0	0.013	0.089
402	322	6	40	58.3	1383.7	4.821	-19.434	862.5	98.9	0.010	0.086
403	322	6	41	23.3	1212.7	6.063	-24.320	467.0	98.4	0.025	0.050
404	322	6	42	6.3	701.9	0.576	-25.812	302.1	65.1	0.001	0.047
405	322	6	42	32.3	859.1	-3.635	-32.719	724.2	70.9	0.002	0.036
406	322	6	42	46.3	605.7	1.010	-23.127	380.3	65.1	0.001	0.054
407	322	6	42	55.3	626.2	0.940	-35.911	374.5	65.0	0.002	0.032
408	322	6	43	30.3	881.0	-0.499	-25.886	262.2	65.0	0.002	0.047
409	322	6	43	51.3	1075.8	4.201	-28.729	814.9	99.1	0.009	0.043
410	322	6	45	25.3	1464.0	4.950	-19.333	868.6	99.3	0.009	0.091
411	322	6	46	48.3	1314.9	4.706	-20.424	855.2	99.0	0.011	0.071
412	322	6	47	48.3	812.4	-0.053	-28.933	269.2	65.0	0.001	0.042
413	322	6	48	10.3	1797.6	3.564	-19.144	1449.9	101.3	0.004	0.096

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
414	322	6	48	22.3	1806.1	5.320	-21.879	776.9	98.7	0.005	0.060
415	322	6	48	50.0	1315.4	4.997	-20.991	783.0	98.2	0.001	0.066
416	322	6	48	58.3	1238.6	2.609	-21.187	975.0	83.0	0.003	0.064
417	322	6	50	11.3	740.8	0.407	-22.026	386.6	65.1	0.004	0.059
418	322	6	50	28.3	1700.8	5.147	-20.032	858.0	99.2	0.007	0.076
419	322	6	51	1.3	588.8	1.146	-15.722	425.0	65.0	0.003	0.165
420	322	6	51	7.0	1464.4	4.865	-18.433	874.2	99.1	0.012	0.108
421	322	6	51	31.3	2379.8	5.076	-18.452	962.3	99.3	0.060	0.107
422	322	6	51	47.3	2419.0	4.859	-18.569	890.3	98.9	0.009	0.105
423	322	6	52	8.5	1614.7	5.098	-19.072	869.5	99.3	0.007	0.097
424	322	6	52	12.3	1270.1	4.830	-19.195	806.5	99.0	0.013	0.094
425	322	6	53	28.0	1812.3	4.816	-19.209	1010.2	99.1	0.024	0.094
426	322	6	54	37.3	1255.5	4.566	-22.546	865.4	99.2	0.010	0.056
427	322	6	56	25.3	2042.1	5.245	-18.058	778.5	99.1	0.019	0.115
428	322	6	56	29.2	1385.7	4.803	-21.980	877.9	99.1	0.008	0.059
429	322	6	57	22.3	1313.6	4.684	-23.736	864.8	99.1	0.009	0.052
430	322	6	57	50.0	1259.7	4.560	-20.825	867.0	99.1	0.010	0.067
431	322	6	58	17.3	1841.9	4.742	-14.553	976.9	98.4	0.017	0.197
432	322	6	58	35.3	905.2	-0.367	-25.174	338.2	65.1	0.001	0.048
433	322	7	0	2.3	814.8	0.034	-49.242	326.0	65.1	0.008	0.019
434	322	7	0	56.3	875.4	-0.208	-19.923	341.9	65.0	0.001	0.078
435	322	7	1	15.3	872.4	-0.233	-23.859	345.9	65.0	0.003	0.052
436	322	7	1	47.2	1875.5	5.105	-23.141	905.0	99.2	0.009	0.054
437	322	7	1	55.3	837.6	-0.027	-23.637	345.3	65.0	0.006	0.052
438	322	7	2	46.3	901.6	4.530	-20.368	687.1	98.6	0.042	0.072
439	322	7	3	6.3	858.4	-0.183	-20.384	356.1	65.1	0.006	0.072
440	322	7	3	9.3	815.5	0.121	-22.160	404.9	65.0	0.005	0.058
441	322	7	3	13.3	972.6	-0.724	-18.229	312.3	65.0	0.002	0.113
442	322	7	3	34.5	1767.4	5.112	-18.09	864.1	98.9	0.009	0.115
443	322	7	3	35.3	970.7	4.137	-19.825	752.0	98.3	0.001	0.079
444	322	7	4	45.3	1016.6	5.622	-19.386	592.2	99.5	0.047	0.088
445	322	7	5	2.3	2272.6	4.998	-19.106	861.7	99.1	0.004	0.097
446	322	7	6	10.3	974.7	-0.681	-17.66	334.7	65.1	0.001	0.122
447	322	7	6	16.5	1238.6	-3.508	-23.869	908.8	83.1	0.002	0.052
448	322	7	6	25.3	1575.8	4.847	-22.417	948.7	99.2	0.018	0.057
449	322	7	6	41.3	1402.7	5.237	-19.398	745.8	98.8	0.012	0.087
450	322	7	6	55.3	992.1	5.765	-25.299	472.8	98.6	0.040	0.048
451	322	7	6	57.3	1295.4	-1.595	-18.985	898.5	98.6	0.079	0.099
452	322	7	7	11.3	2213.0	2.798	-18.155	1738.9	96.3	0.082	0.114
453	322	7	7	43.3	806.8	0.020	-20.466	338.1	65.1	0.005	0.071
454	322	7	7	47.3	978.6	-0.792	-21.790	290.3	65.0	0.003	0.060
455	322	7	8	3.3	1993.0	5.223	-19.525	799.7	98.9	0.005	0.084
456	322	7	8	23.5	1576.4	-1.356	-22.057	1217.7	99.1	0.062	0.059

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
457	322	7	9	4.3	1391.3	4.940	-20.318	850.0	99.2	0.006	0.072
458	322	7	9	20.5	1690.2	-0.586	-19.161	561.4	100.1	0.031	0.095
459	322	7	9	27.3	1464.7	5.023	-21.239	858.9	99.3	0.003	0.064
460	322	7	9	37.3	1732.2	-0.945	-20.105	727.3	99.0	0.006	0.075
461	322	7	9	54.5	2489.0	-0.340	-19.155	1687.5	101.4	0.043	0.095
462	322	7	10	18.3	1694.0	4.643	-23.885	1010.9	99.9	0.037	0.052
463	322	7	10	35.1	1747.3	5.298	-21.734	847.7			0.061
464	322	7	10	29.3	895.7	-0.329	-25.156	382.4	65.0	0.003	0.048
465	322	7	10	36.3	2349.9	-4.255	-18.877	1673.2	64.5	0.080	0.100
466	322	7	12	14.3	1822.8	5.182	-18.524	783.7	98.1	0.005	0.106
467	322	7	13	12.3	1434.8	5.048	-24.190	821.6	99.2	0.011	0.051
468	322	7	13	25.3	1369.9	4.813	-27.093	875.1	99.2	0.006	0.045
469	322	7	14	30.3	1038.8	-1.018	-18.674	320.9	65.1	0.003	0.103
470	322	7	14	42.5	845.4	-0.059	-28.085	355.5	65.1	0.003	0.043
471	322	7	14	44.3	646.1	0.686	-26.717	396.1	64.6	0.004	0.045
472	322	7	16	22.0	1078.0	-1.118	-28.363	327.1	65.1	0.002	0.043
473	322	7	17	13.3	1050.7	-1.113	-37.255	315.7	65.0	0.002	0.030
474	322	7	17	24.0	1679.5	3.776	-19.393	1084.3	94.4	0.047	0.088
475	322	7	19	57.3	1156.6	-1.363	-22.909	359.0	65.0	0.002	0.055
476	322	7	20	26.3	982.0	-0.679	-29.759	346.3	65.0	0.001	0.040
477	322	7	21	51.3	1318.2	5.342	-20.658	697.8	98.8	0.015	0.069
478	322	7	21	56.3	1293.6	4.855	-32.026	813.8	98.9	0.010	0.037
479	322	7	21	58.3	2279.9	4.636	-18.985	988.0	98.3	0.017	0.099
480	322	7	22	11.3	1012.3	-0.914	-19.614	327.4	65.0	0.003	0.082
481	322	7	22	32.3	1774.1	5.225	-25.346	813.9	98.9	0.009	0.048
482	322	7	22	50.3	1847.9	5.080	-22.287	814.6	98.8	0.026	0.057
483	322	7	23	36.3	1044.0	-1.003	-23.330	315.3	64.9	0.005	0.053
484	322	7	25	32.0	1237.1	5.750	-33.791	583.2	98.7	0.024	0.035
485	322	7	26	0.3	966.5	-0.571	-25.968	395.2	65.0	0.005	0.047
486	322	7	27	8.3	1070.1	-1.007	-22.950	355.7	65.0	0.006	0.055
487	322	7	27	28.3	1151.1	-1.397	-22.467	356.1	65.0	0.003	0.057
488	322	7	29	29.3	950.6	5.781	-30.646	499.1	98.4	0.024	0.039
489	322	7	30	1.3	1005.2	-0.829	-22.915	292.1	65.1	0.003	0.055
490	322	7	31	7.4	2413.8	4.613	-18.535	963.3	98.5	0.017	0.105
491	322	7	31	7.0	2098.4	5.394	-19.939	668.3	99.1	0.013	0.077
492	322	7	31	15.3	1115.7	-1.192	-16.067	386.5	65.0	0.004	0.159
493	322	7	31	20.3	769.5	4.788	-38.717	564.5	99.7	0.051	0.029
494	322	7	31	51.5	1249.6	4.563	-25.630	866.0	99.2	0.007	0.047
495	322	7	31	52.3	918.6	-0.308	-19.691	368.7	65.1	0.004	0.081
496	322	7	32	1.3	984.8	-0.643	-23.812	392.1	65.0	0.001	0.052
497	322	7	32	8.3	1088.6	-1.126	-19.409	367.0	65.0	0.005	0.087
498	322	7	33	41.3	995.7	-0.636	-20.032	388.7	65.0	0.002	0.076
499	322	7	35	10.1	2296.8	-2.408	-17.023	1893.5	86.4	0.170	0.139

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
500	322	7	35	12.5	1597.1	5.849	-19.356	508.0	98.4	0.033	0.090
501	322	7	35	16.3	1061.2	-0.966	-20.435	368.8	65.0	0.004	0.071
502	322	7	36	7.0	1057.2	-0.986	-21.244	345.5	65.1	0.002	0.064
503	322	7	36	39.3	1406.6	5.155	-24.147	767.5	98.3	0.005	0.051
504	322	7	37	4.0	1569.4	-3.303	-21.957	1305.4	75.3	0.010	0.059
505	322	7	37	33.3	1023.2	-1.654	-26.375	640.1	98.7	0.001	0.046
506	322	7	37	58.3	1007.5	-0.645	-14.763	427.5	65.0	0.005	0.189
507	322	7	38	12.3	1150.4	3.948	-19.254	899.2	99.1	0.018	0.093
508	322	7	38	41.3	1810.6	5.190	-22.177	867.4	99.5	0.004	0.058
509	322	7	39	24.5	1200.4	4.270	-24.194	876.1	99.2	0.018	0.051
510	322	7	39	26.3	1212.1	-1.764	-23.580	300.0	65.0	0.003	0.053
511	322	7	39	57.3	1152.7	-1.428	-22.702	353.6	65.0	0.003	0.056
512	322	7	39	59.3	1140.3	-1.332	-28.292	356.4	65.0	0.002	0.043
513	322	7	42	5.3	1284.1	-2.071	-29.253	300.0	65.0	0.005	0.041
514	322	7	42	22.3	1243.4	5.002	-27.195	755.3	98.9	0.013	0.045
515	322	7	42	56.3	1834.4	5.555	-18.146	668.2	98.6	0.033	0.114
516	322	7	43	14.9	1264.7	-3.081	-26.679	1009.6	83.0	0.004	0.046
517	322	7	43	17.5	1918.6	4.136	-19.562	1403.0	101.9	0.009	0.083
518	322	7	43	19.3	1376.0	4.832	-27.117	846.2	99.0	0.014	0.045
519	322	7	43	46.3	1190.7	-1.710	-22.308	277.7	65.1	0.009	0.057
520	322	7	44	16.4	1189.9	-3.166	-28.176	939.6	82.8	0.002	0.043
521	322	7	44	17.5	2336.3	4.914	-19.368	825.9			0.089
522	322	7	44	20.3	1262.6	-1.950	-23.170	324.4	65.0	0.007	0.054
523	322	7	45	10.2	2088.5	-4.445	-18.872	1523.6	69.2	0.057	0.100
524	322	7	45	16.3	1250.9	5.300	-29.457	692.2	99.0	0.010	0.041
525	322	7	46	16.3	1226.4	-1.876	-24.158	273.5	65.1	0.001	0.051
526	322	7	46	35.3	1236.6	-1.842	-21.139	319.1	65.0	0.001	0.065
527	322	7	46	39.3	1337.6	-2.264	-23.029	336.2	65.0	0.013	0.055
528	322	7	47	49.3	1106.5	-1.122	-19.669	386.7	65.1	0.006	0.081
529	322	7	48	20.0	1028.3	5.459	-25.827	588.3	98.9	0.020	0.047
530	322	7	48	48.3	1167.4	-1.372	-20.259	385.8	65.1	0.003	0.073
531	322	7	48	54.3	1108.3	-1.121	-23.242	370.5	65.1	0.004	0.054
532	322	7	49	2.3	1179.1	-1.500	-23.107	354.0	65.1	0.012	0.054
533	322	7	49	6.3	1253.8	-1.917	-22.912	327.0	65.0	0.004	0.055
534	322	7	49	30.3	1118.6	-1.182	-19.376	374.4	65.1	0.007	0.089
535	322	7	49	41.3	1209.6	-1.516	-24.978	395.2	65.0	0.002	0.049
536	322	7	49	56.3	1324.9	-2.181	-17.465	329.6	65.1	0.009	0.126
537	322	7	50	3.3	1306.1	-2.180	-22.405	304.6	65.0	0.002	0.057
538	322	7	50	17.3	1684.0	2.631	-23.207	911.1	83.0	0.018	0.054
539	322	7	50	18.3	1231.0	4.687	-28.501	790.3	98.8	0.030	0.043
540	322	7	51	50.3	1351.1	-2.475	-21.971	255.6	65.0	0.004	0.059
541	322	7	51	51.5	995.9	4.583	-22.741	704.7	99.0	0.016	0.056
542	322	7	52	11.3	1330.0	-0.544	-26.514	921.7	65.0	0.003	0.046

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
543	322	7	52	14.3	1596.5	5.007	-23.717	873.1	99.2	0.017	0.052
544	322	7	52	21.3	1309.8	4.971	-27.960	789.2	98.9	0.011	0.044
545	322	7	52	43.3	1185.7	-1.498	-19.248	375.7	65.1	0.005	0.093
546	322	7	52	54.3	1419.0	5.819	-27.427	575.7	98.7	0.024	0.044
547	322	7	53	15.3	2417.8	4.920	-19.342	804.2	99.1	0.009	0.090
548	322	7	53	58.5	2009.4	5.164	-19.220	793.2	98.9	0.009	0.094
549	322	7	54	4.3	1101.6	4.935	-29.082	710.5	99.0	0.016	0.041
550	322	7	54	35.3	1272.4	-1.890	-20.188	372.2	65.0	0.005	0.074
551	322	7	56	0.3	1208.0	4.998	-19.364	740.6	98.9	0.017	0.089
552	322	7	56	28.3	2095.1	4.741	-20.024	1007.3	99.1	0.033	0.076
553	322	7	58	50.3	1170.3	5.060	-21.203	721.2	99.1	0.007	0.064
554	322	8	0	19.5	1222.2	-1.113	-29.133	836.3	100.9	0.012	0.041
555	322	8	0	19.3	1288.3	-2.021	-23.259	345.2	65.0	0.005	0.054
556	322	8	1	26.0	1411.2	5.899	-20.610	540.6	98.6	0.023	0.069
557	322	8	2	54.0	1677.7	5.149	-24.679	838.0	99.2	0.012	0.050
558	322	8	3	7.3	874.8	4.840	-24.879	599.0	98.9	0.022	0.049
559	322	8	3	23.3	1357.4	-2.160	-15.876	399.2	65.0	0.002	0.162
560	322	8	3	35.3	1237.1	-1.728	-20.209	364.8	65.1	0.005	0.074
561	322	8	4	10.3	1510.5	5.776	-23.324	590.6	98.8	0.019	0.053
562	322	8	4	27.5	1711.2	5.052	-23.740	874.6	99.3	0.021	0.052
563	322	8	4	30.3	1216.3	-1.490	-19.149	428.4	65.0	0.005	0.096
564	322	8	5	20.3	1349.7	-2.215	-21.300	357.1	65.0	0.003	0.063
565	322	8	6	39.3	1263.5	-1.787	-22.269	376.7	65.0	0.004	0.058
566	322	8	7	8.3	1371.6	-2.434	-22.733	305.4	65.0	0.003	0.056
567	322	8	7	28.3	1183.9	-1.224	-21.934	884.3	98.7	0.075	0.059
568	322	8	7	52.3	1311.6	-1.996	-21.023	388.5	65.1	0.006	0.065
569	322	8	7	53.3	1258.5	-1.339	-22.748	445.7	99.7	0.008	0.056
570	322	8	8	26.3	1656.2	3.710	-18.771	1327.2	102.0	0.006	0.101
571	322	8	9	13.3	1363.1	-2.294	-20.169	331.2	65.0	0.003	0.074
572	322	8	9	52.3	1387.1	-2.431	-19.994	333.8	65.0	0.003	0.077
573	322	8	10	29.3	1135.0	4.920	-30.619	730.8	99.2	0.009	0.039
574	322	8	10	41.3	1284.6	-1.843	-16.593	409.7	65.1	0.004	0.149
575	322	8	10	57.3	1293.1	-1.919	-22.006	378.6	65.1	0.005	0.059
576	322	8	10	59.3	1307.7	-1.869	-25.849	423.4	65.1	0.014	0.047
577	322	8	12	13.0	1155.6	5.005	-21.193	718.1	99.1	0.020	0.064
578	322	8	13	33.0	2262.6	-3.475	-19.334	1894.4	63.8	0.091	0.091
579	322	8	13	54.3	1152.5	4.253	-19.642	861.7	99.4	0.006	0.082
580	322	8	14	51.3	2394.1	-4.350	-17.283	1191.0	64.6	0.079	0.133
581	322	8	15	14.0	2229.5	5.048	-17.393	808.3	99.2	0.018	0.130
582	322	8	16	41.3	1361.0	-2.206	-21.199	380.5	65.1	0.005	0.064
583	322	8	17	8.3	806.0	4.733	-23.896	574.9	98.8	0.023	0.052
584	322	8	17	32.3	1425.5	-2.509	-20.892	356.2	65.1	0.004	0.067
585	322	8	18	15.0	1642.0	5.139	-19.971	868.3	99.4	0.004	0.077

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
586	322	8	18	17.3	2219.9	4.272	-19.077	1539.9	99.3	0.063	0.097
587	322	8	18	30.3	1482.4	5.497	-18.649	674.5	99.0	0.016	0.103
588	322	8	18	56.0	1204.3	5.918	-26.952	530.4	98.7	0.023	0.045
589	322	8	19	49.3	2264.9	5.193	-16.888	645.1	98.6	0.026	0.142
590	322	8	20	56.3	913.2	4.868	-19.263	615.2	97.7	0.002	0.093
591	322	8	21	10.3	1491.9	-2.897	-21.754	320.5	65.1	0.003	0.060
592	322	8	22	47.5	2096.6	5.206	-18.276	759.9	99.1	0.018	0.111
593	322	8	22	55.3	1086.5	-0.912	-19.671	438.7	65.1	0.005	0.081
594	322	8	25	13.3	1560.4	-3.090	-20.477	361.7	65.0	0.001	0.071
595	322	8	26	21.3	1413.7	-2.416	-19.235	388.0	65.0	0.004	0.093
596	322	8	28	21.0	1535.6	-2.964	-22.265	359.8	65.1	0.002	0.058
597	322	8	28	34.3	1381.7	-6.498	-26.706	499.5	62.2	0.069	0.046
598	322	8	28	52.0	2001.2	5.108	-18.136	870.5	99.3	0.013	0.114
599	322	8	29	45.3	2415.6	4.312	-20.767	1545.8	102.5	0.016	0.068
600	322	8	30	27.3	1445.3	-1.688	-19.493	783.3	97.5	0.043	0.084
601	322	8	31	1.3	1601.7	-3.283	-20.860	362.5	65.1	0.003	0.067
602	322	8	31	33.3	1174.5	5.151	-17.613	656.7	97.7	0.014	0.123
603	322	8	33	55.3	1363.4	-2.419	-19.248	369.6	64.7	0.002	0.093
604	322	8	33	59.3	1578.3	-3.248	-21.412	342.2	65.0	0.005	0.063
605	322	8	34	36.3	1496.6	5.767	-20.074	577.6	98.8	0.025	0.076
606	322	8	35	4.3	1681.7	5.534	-23.727	661.4	98.9	0.000	0.052
607	322	8	35	36.3	1648.3	-3.585	-17.689	313.4	65.1	0.002	0.121
608	322	8	35	38.3	1603.2	-1.241	-21.199	606.9	98.3	0.005	0.064
609	322	8	37	0.5	1070.8	-1.700	-19.939	755.2	97.6	0.045	0.077
610	322	8	37	6.3	1515.5	-2.835	-19.363	393.1	65.0	0.005	0.089
611	322	8	38	2.3	1579.1	-3.220	-19.666	347.2	65.1	0.001	0.081
612	322	8	38	14.3	1459.5	-2.597	-20.840	377.9	65.1	0.002	0.067
613	322	8	38	37.3	1674.4	-3.692	-19.263	307.4	65.0	0.006	0.093
614	322	8	38	47.3	1496.6	4.982	-19.658	858.3	99.3	0.012	0.081
615	322	8	40	25.3	1509.6	-2.838	-22.155	386.3	65.0	0.007	0.058
616	322	8	40	25.5	2410.8	4.446	-18.559	1484.8	101.6	0.006	0.105
617	322	8	41	55.0	1881.4	5.214	-19.219	847.9	99.5	0.008	0.094
618	322	8	42	41.3	1613.3	-3.372	-19.611	362.4	65.0	0.001	0.082
619	322	8	43	18.3	1590.8	-3.227	-21.243	365.1	65.0	0.002	0.064
620	322	8	44	18.3	1640.0	-3.490	-19.110	342.8	65.0	0.004	0.097
621	322	8	44	49.2	1144.3	-1.251	-21.117	933.7	97.4	0.023	0.065
622	322	8	47	9.0	2173.0	5.242	-18.805	686.0			0.101
623	322	8	50	45.3	1302.4	5.999	-19.376	515.7	98.8	0.023	0.089
624	322	8	50	45.5	2167.4	4.996	-18.557	880.8	99.2	0.020	0.105
625	322	8	51	34.3	1665.6	-3.584	-21.713	348.7	65.0	0.006	0.061
626	322	8	52	32.3	1666.1	-3.587	-20.860	353.3	64.9	0.011	0.067
627	322	8	52	44.3	1588.9	5.451	-19.637	707.4	99.1	0.017	0.082
628	322	8	53	22.0	1603.7	5.514	-18.431	614.7	97.7	0.003	0.108

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
629	322	8	53	39.3	2051.7	4.183	-20.585	1459.1	101.7	0.011	0.069
630	322	8	55	1.3	1736.6	-5.971	-24.606	806.5	65.1	0.002	0.050
631	322	8	56	4.3	1704.3	-3.861	-20.886	316.2	64.9	0.007	0.067
632	322	8	56	51.5	1658.4	-1.462	-19.015	780.7	97.5	0.041	0.098
633	322	8	57	7.3	1349.4	-1.530	-19.966	1026.0	97.1	0.018	0.077
634	322	8	58	4.3	1599.1	-5.843	-26.609	805.5	65.0	0.002	0.046
635	322	8	58	34.3	1556.0	5.323	-19.371	751.8	98.5	0.037	0.089
636	322	8	58	46.3	2123.5	0.054	-18.185	1614.3	64.6	0.269	0.114
637	322	8	58	51.3	1782.9	5.669	-19.421	720.6	99.7	0.033	0.086
638	322	8	58	51.2	2379.3	-3.939	-18.536	631.1	82.3	0.013	0.105
639	322	8	59	3.3	1580.0	-5.823	-25.013	805.4	64.9	0.002	0.049
640	322	8	59	17.3	1657.0	5.620	-18.556	622.8	99.0	0.017	0.105
641	322	8	59	43.3	1558.7	-5.797	-26.411	805.6	65.0	0.003	0.046
642	322	8	59	49.3	1684.1	-5.922	-25.749	810.6	65.0	0.001	0.047
643	322	9	0	18.3	1732.8	-3.846	-19.822	356.4	65.0	0.006	0.079
644	322	9	0	57.3	1513.2	5.947	-23.164	510.6	98.8	0.025	0.054
645	322	9	1	2.3	1645.2	-5.895	-25.812	807.6	65.0	0.001	0.047
646	322	9	3	21.3	1266.2	4.680	-22.947	852.3	99.4	0.007	0.055
647	322	9	3	44.3	2006.8	0.342	-21.383	1249.6	72.4	0.078	0.063
648	322	9	3	50.5	1230.3	-5.138	-25.035	805.8	65.0	0.002	0.049
649	322	9	3	51.4	2046.4	-3.767	-19.022	1061.8	82.6	0.027	0.098
650	322	9	3	55.3	1346.1	5.381	-20.536	737.9	98.8	0.042	0.070
651	322	9	4	20.5	1256.6	-5.220	-26.315	805.4	65.0	0.000	0.046
652	322	9	4	49.5	1192.7	-5.023	-26.641	804.9	65.1	0.002	0.046
653	322	9	5	13.3	1769.0	-3.928	-17.456	389.4	65.0	0.006	0.126
654	322	9	5	25.3	1616.7	-3.278	-19.390	369.3	65.1	0.001	0.088
655	322	9	5	34.3	1739.9	-3.853	-18.594	367.7	65.0	0.001	0.104
656	322	9	5	45.4	1089.1	-4.596	-26.999	804.5			0.045
657	322	9	5	45.4	1089.6	-4.602	-25.211	804.2	64.9	0.002	0.048
658	322	9	6	1.5	1034.5	-4.287	-26.146	804.7	65.0	0.002	0.047
659	322	9	6	16.5	958.9	-3.722	-26.711	804.0	65.0	0.002	0.045
660	322	9	6	24.3	722.0	-4.604	-18.479	394.6	56.9	0.251	0.107
661	322	9	6	51.3	1977.4	5.215	-12.568	647.1	97.8	0.023	0.246
662	322	9	8	34.3	1618.5	-3.304	-20.769	395.4	64.9	0.005	0.068
663	322	9	9	35.5	1531.8	-3.774	-25.428	995.2	83.1	0.008	0.048
664	322	9	9	50.0	1909.9	5.331	-21.080	614.5	97.6	0.002	0.065
665	322	9	10	46.3	834.9	5.040	-22.942	559.3	99.0	0.021	0.055
666	322	9	12	9.3	1635.4	-2.397	-22.926	1190.7	90.3	0.016	0.055
667	322	9	14	21.3	1762.8	-3.946	-23.521	371.9	65.0	0.001	0.053
668	322	9	14	22.3	1352.7	5.412	-20.318	682.9	99.1	0.019	0.072
669	322	9	14	33.3	2354.5	5.226	-17.603	599.0			0.123
670	322	9	16	25.5	1636.1	5.228	-19.604	798.6	98.5	0.035	0.082
671	322	9	18	7.0	1460.4	5.867	-25.442	549.8	99.0	0.022	0.048

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
672	322	9	19	24.3	1396.4	5.839	-21.309	565.8	99.0	0.021	0.063
673	322	9	20	5.3	925.6	-3.969	-25.600	753.0	70.7	0.007	0.048
674	322	9	21	37.0	1757.8	-3.850	-21.042	386.8	65.1	0.002	0.065
675	322	9	22	36.3	2212.5	-2.752	-16.614	1784.4	82.1	0.032	0.149
676	322	9	23	3.0	1777.2	-3.950	-19.524	374.5	65.1	0.001	0.084
677	322	9	24	7.3	1835.4	-4.195	-18.444	391.7	65.1	0.005	0.108
678	322	9	24	27.3	2226.8	5.126	-19.131	756.4	98.9	0.010	0.096
679	322	9	25	3.3	2176.0	5.339	-18.463	614.4	98.7	0.021	0.107
680	322	9	29	38.0	1145.7	4.254	-26.772	861.7	99.7	0.005	0.045
681	322	9	31	20.0	1450.2	5.602	-18.941	627.4	99.5	0.043	0.099
682	322	9	33	12.0	1375.9	5.799	-24.054	568.3	98.8	0.025	0.051
683	322	9	33	23.3	1157.7	2.560	-16.893	878.6	81.2	0.002	0.142
684	322	9	34	45.3	1763.5	5.788	-20.119	554.9	98.7	0.023	0.075
685	322	9	35	50.0	2262.5	5.153	-19.950	766.5	99.5	0.008	0.077
686	322	9	36	51.3	1407.5	5.891	-17.458	557.2	99.1	0.022	0.126
687	322	9	37	16.3	1954.1	-4.667	-15.984	400.9	65.0	0.006	0.160
688	322	9	37	42.3	1209.7	2.636	-23.471	882.8	81.2	0.001	0.053
689	322	9	37	47.3	1823.9	5.844	-18.755	484.3	98.7	0.032	0.101
690	322	9	38	39.3	1577.7	5.317	-19.969	752.6	98.9	0.008	0.077
691	322	9	38	54.3	1845.8	-4.138	-17.475	428.9	65.0	0.002	0.125
692	322	9	40	12.2	1382.5	-3.153	-22.113	768.2	89.4	0.018	0.058
693	322	9	40	17.3	1879.8	-4.449	-20.609	378.7	65.0	0.010	0.069
694	322	9	40	49.3	1279.3	5.427	-18.697	665.9	99.3	0.017	0.102
695	322	9	42	32.0	1423.3	5.368	-24.122	719.9	99.3	0.018	0.051
696	322	9	43	10.0	1422.4	5.678	-25.775	617.0	99.1	0.019	0.047
697	322	9	44	17.3	1429.7	5.017	-27.294	861.6	99.7	0.005	0.044
698	322	9	44	59.3	1218.4	4.534	-20.464	858.3	99.7	0.007	0.071
699	322	9	45	0.5	1899.6	-4.412	-17.138	411.0	65.0	0.002	0.137
700	322	9	45	53.3	1672.5	-3.318	-19.399	446.4	65.1	0.008	0.087
701	322	9	46	24.0	1359.0	4.840	-20.104	858.2	99.6	0.014	0.075
702	322	9	47	34.3	1925.7	-2.647	-21.34	1075.0	90.4	0.022	0.063
703	322	9	48	46.3	2012.5	-1.153	-19.266	1506.8	97.9	0.049	0.093
704	322	9	49	34.3	1700.8	-2.922	-20.438	1341.8	82.6	0.030	0.071
705	322	9	51	6.0	1627.3	5.931	-22.733	521.6			0.056
706	322	9	51	8.3	967.7	-3.842	-25.106	702.3	81.3	0.002	0.049
707	322	9	51	42.0	1925.8	5.499	-20.191	678.4	99.4	0.010	0.074
708	322	9	52	10.3	2034.1	1.740	-19.851	600.9	82.1	0.008	0.078
709	322	9	54	50.3	1455.3	4.777	-21.955	910.5	99.7	0.032	0.059
710	322	10	0	18.3	1939.6	-4.548	-16.647	425.6	65.0	0.003	0.148
711	322	10	0	31.3	861.1	5.185	-32.160	556.2	99.1	0.020	0.037
712	322	10	1	54.3	1945.5	5.617	-17.638	556.8	99.2	0.022	0.122
713	322	10	2	40.3	1504.5	5.419	-22.039	745.8	99.1	0.009	0.059
714	322	10	3	45.3	1749.6	-5.225	-19.513	1131.4	62.3	0.366	0.084

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
715	322	10	4	4.3	1870.9	2.212	-19.351	974.2	82.4	0.006	0.090
716	322	10	4	34.5	974.8	-2.248	-20.210	489.1	96.9	0.041	0.074
717	322	10	5	30.0	1779.1	-2.335	-22.477	958.7	64.9	0.024	0.057
718	322	10	6	26.3	2073.8	5.205	-17.989	868.0	99.8	0.006	0.116
719	322	10	7	53.3	1402.4	5.951	-27.022	521.5			0.045
720	322	10	9	20.3	1838.0	5.241	-21.780	860.0	99.7	0.008	0.060
721	322	10	10	38.5	1846.4	5.519	-21.366	664.2	99.0	0.024	0.063
722	322	10	10	40.3	1524.3	5.945	-22.707	523.4	99.1	0.023	0.056
723	322	10	10	59.3	2088.3	-0.066	-16.406	1534.6	102.8	0.059	0.153
724	322	10	14	44.3	1193.8	6.049	-27.803	492.2	98.8	0.025	0.044
725	322	10	15	54.3	935.3	5.704	-25.681	527.6	99.1	0.027	0.047
726	322	10	16	6.3	1818.9	5.547	-19.603	685.4	99.3	0.012	0.082
727	322	10	16	27.0	1113.1	4.335	-23.869	816.7	99.6	0.012	0.052
728	322	10	18	12.3	1690.5	-1.545	-22.168	1026.7	97.3	0.026	0.058
729	322	10	19	15.3	2075.1	4.982	-14.083	776.2	98.4	0.034	0.207
730	322	10	19	56.3	1348.1	6.166	-19.77	443.5	98.5	0.033	0.080
731	322	10	20	20.0	2006.6	5.603	-21.391	516.3	98.5	0.024	0.063
732	322	10	21	34.3	1347.9	-1.518	-26.050	628.9	98.6	0.003	0.047
733	322	10	23	48.3	815.6	5.060	-19.998	561.0	98.8	0.022	0.077
734	322	10	25	6.3	1343.4	6.065	-25.365	475.0	98.9	0.022	0.048
735	322	10	26	17.3	1656.1	5.208	-22.790	849.4	99.8	0.011	0.055
736	322	10	28	7.0	1706.3	5.224	-21.899	852.2	99.7	0.007	0.060
737	322	10	28	33.3	1344.7	6.041	-23.363	507.4	99.1	0.020	0.053
738	322	10	28	35.3	1700.4	-2.554	-19.804	1307.2	88.2	0.005	0.079
739	322	10	29	57.0	1677.8	4.213	-19.585	1093.4	98.7	0.154	0.083
740	322	10	30	15.3	1844.9	5.796	-19.749	526.5	99.1	0.021	0.080
741	322	10	31	58.3	1031.5	4.840	-18.690	685.3	98.1	0.000	0.102
742	322	10	32	9.3	1531.2	5.126	-19.127	830.5	99.6	0.010	0.096
743	322	10	36	10.3	1793.9	0.582	-19.384	593.2	75.7	0.009	0.088
744	322	10	41	10.3	1466.8	-1.520	-21.056	794.4	97.9	0.037	0.065
745	322	10	43	3.0	1109.1	-1.828	-27.466	741.0	97.2	0.016	0.044
746	322	10	43	32.3	1134.8	5.858	-21.603	565.2	99.1	0.032	0.061
747	322	10	44	27.3	1777.7	-4.675	-18.126	524.8	83.7	0.299	0.114
748	322	10	45	49.0	2172.7	5.141	-21.262	854.7			0.064
749	322	10	50	46.3	1951.1	1.757	-18.809	1544.6	82.0	0.021	0.101
750	322	10	50	57.3	1105.2	4.479	-22.923	719.1	95.1	0.024	0.055
751	322	10	53	30.3	1520.0	5.367	-19.378	743.7	99.5	0.018	0.089
752	322	10	53	40.3	1182.7	5.595	-21.282	537.2	97.3	0.025	0.063
753	322	10	58	12.0	1485.6	0.394	-19.313	464.5	104.8	0.027	0.092
754	322	11	2	28.3	1182.7	0.479	-22.926	958.6	67.0	0.008	0.055
755	322	11	3	58.3	685.3	5.178	-32.974	468.5			0.036
756	322	11	4	30.3	1034.2	5.466	-20.208	590.8	98.9	0.016	0.074
757	322	11	4	57.3	824.9	5.320	-18.822	502.4	98.0	0.018	0.101

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
758	322	11	8	4.3	1434.7	-2.909	-24.065	839.5	90.3	0.004	0.051
759	322	11	8	31.3	1118.6	5.935	-18.818	536.0	99.2	0.029	0.101
760	322	11	8	45.3	1407.2	6.057	-25.881	498.3	99.1	0.023	0.047
761	322	11	8	50.3	2163.7	5.599	-18.233	525.1	98.9	0.032	0.112
762	322	11	10	58.0	1558.4	-1.983	-19.392	1303.3	90.0	0.005	0.088
763	322	11	11	52.3	2053.0	-2.908	-19.382	1641.0	82.6	0.027	0.088
764	322	11	12	7.3	1222.6	6.035	-20.778	494.8	99.2	0.026	0.067
765	322	11	12	25.3	1915.8	-2.578	-23.082	1354.0	88.4	0.006	0.054
766	322	11	13	11.3	1959.8	1.897	-17.588	1482.8	82.2	0.014	0.123
767	322	11	14	7.3	1567.9	-2.101	-23.318	1284.5	90.0	0.006	0.054
768	322	11	14	52.0	2258.4	5.152	-17.724	752.1	100.0	0.038	0.120
769	322	11	18	50.3	1988.1	0.640	-19.305	1500.5	73.7	0.003	0.092
770	322	11	19	24.3	1501.0	5.808	-26.901	586.3	99.2	0.014	0.045
771	322	11	19	52.0	1648.0	5.442	-22.312	633.9	97.7	0.022	0.057
772	322	11	20	0.3	1300.1	5.837	-19.826	576.8	98.9	0.021	0.079
773	322	11	22	2.3	1261.8	-1.506	-19.282	459.1	65.5	0.018	0.092
774	322	11	24	27.3	1254.7	-1.587	-19.933	842.5	97.9	0.020	0.077
775	322	11	24	41.3	912.6	-0.130	-19.869	397.2	65.4	0.016	0.078
776	322	11	25	12.3	1612.7	-5.958	-21.288	678.4	62.2	0.445	0.063
777	322	11	28	41.3	1931.1	5.434		708.0	99.6	0.016	
778	322	11	30	12.3	1221.3	4.689		824.4	99.9	0.014	
779	322	11	30	48.3	1859.9	-2.434		1302.5	99.1	0.031	
780	-8000	11	31	5.3	1103.5	5.569		619.2			
781	322	11	33	28.3	1558.7	-1.740		818.9	65.1	0.005	
782	322	11	36	42.3	1515.7	-2.539		893.6	62.3	0.272	
783	322	11	37	51.3	1887.6	5.279		621.4	97.8	0.028	
784	322	11	39	26.3	1627.4	6.072		440.9	99.5	0.033	
785	322	11	39	49.3	1018.0	-1.502		697.7	98.1	0.049	
786	322	11	40	17.3	1916.2	-2.428		1281.9	90.1	0.005	
787	322	11	40	55.3	1452.0	-0.785		1153.8	99.4	0.068	
788	322	11	42	8.0	1285.4	6.156		473.8	99.1	0.024	
789	322	11	43	4.3	665.6	-0.922		536.2	99.6	0.003	
790	322	11	44	55.3	1889.5	5.599		604.8	98.9	0.024	
791	322	11	45	37.3	1757.5	-2.347		1289.9	90.2	0.004	
792	322	11	48	52.0	1209.2	-1.858		622.8	97.1	0.030	
793	322	11	49	18.3	921.6	5.607		520.8	98.9	0.018	
794	322	11	49	51.5	2460.5	-0.321		1510.3	98.5	0.054	
795	-8000	11	49	56.3	2152.6	5.230		744.1			
796	322	11	53	27.3	980.3	5.790		517.6	99.0	0.023	
797	322	11	56	46.3	1614.6	5.631		620.0	99.4	0.026	
798	322	11	57	4.3	1362.5	5.944		511.5	98.9	0.015	
799	322	12	2	49.0	1506.4	-1.491		834.1	98.1	0.029	
800	322	12	3	32.3	1426.2	5.731		708.1	102.4	0.008	

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
801	322	12	3	38.3	1304.2	-1.565		841.8	98.0	0.029	
802	322	12	6	46.0	1624.2	5.218		817.9	99.0	0.001	
803	322	12	7	44.3	1571.2	5.353		747.6	99.7	0.022	
804	322	12	11	48.3	1047.3	-7.097		277.2	65.0	0.001	
805	322	12	20	34.3	2402.8	2.953		1130.7	90.0	0.013	
806	322	12	20	53.3	1798.9	-7.076		331.9	65.0	0.004	
807	322	12	21	40.2	1052.4	-7.034		295.9	100.0	0.016	
808	-8000	12	21	28.3	1293.3	4.987		797.9			
809	322	12	22	42.3	1549.7	-7.085		329.8	65.0	0.002	
810	322	12	23	1.5	1754.9	-7.057		345.7	65.0	0.004	
811	322	12	23	3.3	1334.1	0.704		842.2	71.0	0.002	
812	322	12	24	35.3	1396.5	-7.080		322.6	65.0	0.004	
813	322	12	24	56.3	686.7	-6.833		262.1	65.1	0.003	
814	322	12	25	32.3	1340.7	-7.192		268.2	64.9	0.003	
815	322	12	25	52.0	1678.1	-7.121		316.9	65.0	0.001	
816	322	12	25	52.5	1137.2	-1.520		868.4	98.3	0.028	
817	322	12	26	5.5	1359.4	-1.858		530.9	97.2	0.005	
818	322	12	27	10.3	1749.4	-0.996		1124.0	99.7	0.030	
819	322	12	27	27.0	1844.6	-1.131		551.4	97.1	0.033	
820	322	12	27	46.3	1548.8	-7.209		271.6	65.1	0.001	
821	322	12	27	49.3	2254.8	-3.994		1622.5	74.5	0.025	
822	322	12	29	24.3	851.1	-1.434		609.2	65.0	0.003	
823	322	12	29	55.3	1753.7	-7.075		342.6	65.1	0.001	
824	322	12	30	24.3	825.0	-6.851		298.6	99.4	0.061	
825	-8000	12	30	48.3	1429.6	-1.053		973.3			
826	322	12	36	9.3	776.7	-3.628		507.0	56.8	0.173	
827	322	12	36	10.3	1773.0	-7.003		374.2	65.1	0.003	
828	322	12	36	59.3	1251.4	-1.539		934.5	98.3	0.027	
829	322	12	38	29.3	1122.1	-6.841		370.1	65.0	0.002	
830	322	12	38	53.3	681.9	-6.098		371.4	65.0	0.001	
831	322	12	39	0.3	1303.6	-4.918		585.0	81.2	0.002	
832	322	12	39	42.5	1386.6	-7.019		347.7	65.1	0.003	
833	322	12	39	48.3	792.2	5.937		417.3	99.2	0.022	
834	322	12	40	7.3	874.5	-6.732		337.8	65.0	0.001	
835	322	12	41	0.0	656.7	-2.382		403.7	56.9	0.250	
836	322	12	41	22.3	1289.2	-1.536		871.0	98.1	0.016	
837	322	12	42	40.0	1595.4	-6.936		400.0	65.1	0.003	
838	322	12	42	59.5	1337.3	-6.939		373.9	65.0	0.002	
839	322	12	43	19.3	849.1	-6.664		343.2	64.9	0.000	
840	322	12	43	20.3	1226.8	-1.545		868.8	98.4	0.027	
841	322	12	45	13.3	1853.5	-7.043		362.1	65.1	0.001	
842	-8000	12	45	21.2	1261.2	-2.000		541.9			
843	-8000	12	45	23.0	1451.5	-4.715		1010.5			

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
844	322	12	46	38.9	1583.2	-4.026		910.5	83.0	0.002	
845	322	12	46	48.3	1389.5	5.929		521.4	99.0	0.016	
846	322	12	47	5.3	1582.2	0.894		1312.9	62.6	0.355	
847	322	12	47	41.3	1146.4	-3.602		945.4	57.0	0.308	
848	322	12	48	40.3	1407.8	5.206		782.8	99.9	0.013	
849	322	12	49	1.3	1127.2	-6.898		355.8	65.1	0.002	
850	322	12	49	14.3	986.7	5.350		563.2	98.8	0.020	
851	322	12	50	6.0	1593.4	-0.802		1308.6	101.5	0.001	
852	322	12	50	38.2	2467.6	-1.068		2092.4	64.8	0.042	
853	322	12	50	39.6	1644.9	-1.307		833.7	98.3	0.031	
854	322	12	50	44.3	753.8	-2.632		500.1	57.0	0.257	
855	322	12	50	48.3	1257.0	-6.904		375.1	65.0	0.001	
856	322	12	51	38.3	1468.5	-1.363		842.0	98.1	0.030	
857	322	12	52	45.5	1220.1	-1.524		868.5	98.5	0.035	
858	322	12	53	48.3	1875.8	-1.261		460.3	96.6	0.014	
859	322	12	54	18.3	546.3	-5.125		386.9	65.0	0.003	
860	322	12	54	35.4	1355.9	-1.549		872.0	98.3	0.020	
861	322	12	54	40.3	1283.7	6.088		439.0	98.8	0.005	
862	322	12	54	41.0	860.9	-1.674		589.2	97.3	0.033	
863	322	12	55	0.0	735.4	-6.189		384.3	65.0	0.000	
864	322	12	55	9.0	1143.8	-6.836		373.9	65.3	0.003	
865	322	12	56	56.3	1507.2	-1.694		455.9	97.2	0.045	
866	322	12	58	51.3	1306.7	-1.332		915.8	98.2	0.023	
867	322	13	0	59.3	1512.2	-1.537		939.8	98.4	0.029	
868	322	13	1	14.3	1641.2	-3.183		395.6	65.4	0.016	
869	-8000	13	4	44.3	1273.4	5.180		741.0			
870	-8000	13	5	6.3	1465.1	-1.539		1006.3			
871	322	13	6	18.3	1251.8	-1.556		872.9	98.4	0.025	
872	322	13	7	30.3	1121.1	5.640		579.9	99.7	0.023	
873	322	13	8	2.3	1454.7	-1.552		804.5	97.8	0.018	
874	322	13	14	5.5	1147.1	-2.048		498.2	97.4	0.042	
875	322	13	14	13.3	1238.9	-2.012		500.9	97.4	0.041	
876	322	13	14	56.0	1672.6	-1.223		809.7	98.3	0.032	
877	322	13	16	47.0	1492.8	5.291		778.7	99.1	0.003	
878	322	13	17	8.3	1824.9	-1.040		871.8	98.2	0.023	
879	322	13	22	48.5	1685.6	-1.146		912.8	98.2	0.025	
880	322	13	22	52.3	1496.2	3.801		1119.2	95.6	0.029	
881	322	13	23	18.3	1758.9	2.478		983.6	83.1	0.006	
882	322	13	25	26.0	1620.4	5.683		609.3	99.0	0.017	
883	322	13	26	18.0	1338.7	-1.285		968.7	98.1	0.023	
884	322	13	28	17.3	1530.7	-1.367		665.5	98.4	0.055	
885	322	13	28	36.3	2499.6	4.553		1467.9	101.7	0.023	
886	322	13	28	39.3	1355.0	-1.522	-29.999	884.0	98.2	0.014	0.040

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
887	322	13	30	1.3	1462.2	-5.346	-21.846	883.8	66.7	0.004	0.060
888	322	13	35	47.3	1952.4	5.834	-19.700	497.8	99.1	0.039	0.081
889	322	13	36	14.3	620.4	-1.449	-19.819	434.6	56.8	0.223	0.079
890	322	13	37	19.3	1551.8	-1.378	-21.371	891.3	98.1	0.010	0.063
891	322	13	37	41.3	1277.0	-1.330	-19.783	765.1	98.4	0.062	0.079
892	322	13	39	50.3	903.0	6.116	-22.133	423.6	99.3	0.022	0.058
893	322	13	40	33.3	1507.6	-2.980	-19.630	1209.0	82.5	0.002	0.082
894	322	13	41	55.3	2090.8	-0.627	-18.060	833.2	98.3	0.028	0.115
895	322	13	42	10.3	1662.6	-1.058	-19.537	888.0	99.8	0.070	0.084
896	322	13	43	40.3	1296.1	-1.781	-19.453	660.5	97.1	0.026	0.085
897	322	13	46	31.0	1607.8	-1.498	-19.720	494.5	97.4	0.038	0.080
898	322	13	51	6.0	1474.3	0.190	-25.491	734.3	70.9	0.004	0.048
899	322	13	51	19.3	1438.7	-1.570	-19.937	791.3	98.3	0.038	0.077
900	322	13	57	24.0	1424.9	5.482	-20.950	709.5	100.2	0.018	0.066
901	322	13	58	48.3	1508.0	-0.892	-20.267	712.0	99.8	0.057	0.073
902	322	13	59	17.3	1106.6	-6.662	-32.944	428.6	65.2	0.005	0.036
903	322	13	59	45.3	1090.2	-1.209	-29.559	888.3	98.3	0.009	0.041
904	322	14	1	39.3	1788.7	5.657	-21.505	606.8	99.6	0.030	0.062
905	322	14	2	57.3	1612.9	-1.303	-19.761	706.5	98.6	0.055	0.080
906	322	14	3	24.3	1806.2	-0.841	-19.609	1052.0	99.6	0.007	0.082
907	322	14	8	42.3	1842.8	-6.990	-20.062	410.0	65.1	0.006	0.076
908	322	14	8	46.3	1836.6	-3.281	-18.252	1340.1	82.5	0.003	0.112
909	322	14	9	2.3	1422.0	-2.827	-17.442	472.6	63.9	0.103	0.127
910	322	14	11	12.0	1382.1	-1.410	-21.836	859.2	98.4	0.023	0.060
911	322	14	18	14.3	2040.0	4.374	-21.872	1364.0	100.8	0.035	0.060
912	322	14	18	56.3	1918.3	5.795	-22.327	538.5	99.2	0.037	0.057
913	322	14	19	7.3	1744.8	-1.354	-18.728	1288.3	98.8	0.049	0.102
914	322	14	19	33.3	1185.7	-1.397	-22.942	916.3	98.7	0.021	0.055
915	322	14	22	24.5	1167.3	-1.064	-20.246	900.9	99.9	0.061	0.073
916	322	14	22	29.3	2202.9	-4.097	-17.220	1530.0	73.4	0.005	0.135
917	322	14	22	45.2	2034.9	-0.848	-19.249	1599.9	101.3	0.029	0.093
918	322	14	22	52.3	1353.9	5.788	-20.963	550.8	99.1	0.018	0.066
919	322	14	23	13.3	1533.8	-1.356	-23.002	902.2	98.2	0.010	0.055
920	322	14	24	32.0	1868.7	5.962	-20.770	437.7	99.5	0.023	0.068
921	322	14	24	50.3	1197.8	-1.452	-22.808	945.3	98.7	0.022	0.055
922	322	14	25	40.3	1511.1	-3.644	-25.913	1028.5	82.7	0.008	0.047
923	322	14	26	14.3	1072.6	-1.015	-38.553	770.7	62.3	0.089	0.029
924	322	14	27	19.3	1001.3	0.070	-22.669	627.0	65.7	0.002	0.056
925	322	14	27	42.3	1156.5	-1.352	-21.085	893.4	98.3	0.009	0.065
926	322	14	29	49.3	1325.2	6.086	-20.412	505.5	99.8	0.024	0.071
927	322	14	31	5.3	1534.2	-2.071	-22.040	1295.2	83.1	0.107	0.059
928	322	14	34	57.3	1138.9	6.028	-22.730	500.1	99.7	0.022	0.056
929	322	14	36	21.3	690.5	-4.845	-19.349	252.8	57.2	0.020	0.090

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
930	322	14	38	59.0	1354.7	4.435	-25.676	969.1	102.7	0.046	0.047
931	322	14	39	37.3	1226.3	5.779	-18.462	539.9	98.2	0.004	0.107
932	322	14	41	54.3	1266.1	5.864	-19.363	486.7	97.7	0.002	0.089
933	322	14	44	24.0	1794.6	5.139	-22.343	638.8	95.5	0.028	0.057
934	322	14	44	26.3	1723.5	5.940	-21.253	377.6	98.6	0.004	0.064
935	322	14	47	10.5	1402.9	-6.949	-21.078	388.0	65.2	0.005	0.065
936	322	14	52	1.3	1184.5	-1.411	-19.425	893.9	98.3	0.007	0.086
937	322	14	53	48.3	1234.3	3.058	-19.35	613.8	81.2	0.004	0.090
938	322	14	58	55.3	1917.7	5.768	-21.256	401.3	98.8	0.010	0.064
939	322	14	58	56.3	2084.5	5.618	-19.960	545.8	99.2	0.028	0.077
940	322	15	0	58.3	1853.7	3.736	-21.905	776.9	89.4	0.006	0.060
941	322	15	1	25.3	720.2	-1.395	-28.435	563.3	97.9	0.028	0.043
942	322	15	5	16.3	1522.9	-1.434	-20.483	736.5	98.1	0.023	0.070
943	322	15	8	6.5	1138.1	-1.134	-19.487	943.5	98.4	0.008	0.085
944	322	15	8	11.3	1904.0	-0.530	-19.222	1457.6	102.0	0.005	0.094
945	322	15	9	33.5	1783.4	-0.809	-20.429	1049.3	100.0	0.001	0.071
946	322	15	9	39.3	1520.7	4.765	-20.010	1032.8	102.1	0.017	0.076
947	322	15	9	54.3	1320.7	-1.343	-17.715	942.0	98.4	0.018	0.121
948	322	15	12	6.3	1603.4	-4.732	-24.973	688.3	81.2	0.001	0.049
949	322	15	12	38.3	1675.2	-0.962	-18.836	1045.3	100.4	0.019	0.100
950	322	15	13	1.3	862.9	-1.720	-26.129	567.9	97.7	0.031	0.047
951	322	15	15	0.3	1580.2	-1.443	-18.645	633.4	97.7	0.022	0.103
952	322	15	15	31.3	2076.5	-0.893	-18.238	1034.9	99.0	0.065	0.112
953	322	15	16	18.0	2117.6	0.097	-18.288	1040.7	101.3	0.021	0.111
954	322	15	17	46.3	896.5	-4.401	-24.622	640.1	57.0	0.313	0.050
955	322	15	18	17.3	1182.1	0.556	-26.309	571.0	70.0	0.002	0.046
956	322	15	19	6.0	1151.1	-3.487	-28.048	977.7	64.6	0.006	0.043
957	322	15	20	20.0	1025.6	-1.214	-22.042	827.6	98.3	0.011	0.059
958	322	15	26	36.0	1946.0	-0.924	-17.945	973.7	98.7	0.025	0.117
959	322	15	26	57.3	1505.6	-1.315	-19.518	957.0	98.5	0.015	0.084
960	322	15	29	40.3	1479.4	2.805	-23.119	876.9	82.8	0.007	0.054
961	322	15	31	26.0	881.4	-1.600	-19.584	652.3	98.0	0.024	0.083
962	322	15	33	20.3	1507.2	-1.345	-19.345	711.8	98.1	0.028	0.090
963	322	15	33	54.3	1541.0	-1.290	-22.421	927.5	98.5	0.016	0.057
964	322	15	35	33.3	1821.4	5.360	-22.075	778.0	99.1	0.005	0.059
965	322	15	35	46.0	1330.3	-1.474	-20.486	866.0	98.7	0.015	0.070
966	322	15	35	58.3	1602.6	-1.319	-19.124	611.0	97.6	0.029	0.096
967	322	15	36	34.5	1412.1	-1.660	-24.320	633.6	97.9	0.026	0.050
968	322	15	36	41.3	1503.9	-1.585	-18.869	844.1	97.5	0.018	0.100
969	322	15	37	41.3	1193.8	3.113	-26.630	767.0	83.0	0.003	0.046
970	322	15	38	54.3	1740.2	-1.171	-17.414	660.4	97.5	0.031	0.129
971	322	15	39	26.3	721.6	-1.471	-20.328	539.8	97.9	0.034	0.072
972	322	15	41	38.3	1776.4	4.220	-18.353	1321.3	102.0	0.019	0.110

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
973	322	15	42	36.3	913.7	0.767	-20.832	478.7	68.1	0.005	0.067
974	322	15	43	3.5	1365.4	-1.755	-21.714	542.8	97.8	0.025	0.061
975	322	15	45	35.3	1923.6	-3.457	-19.233	790.7	65.0	0.019	0.094
976	322	15	48	51.0	1925.3	-0.508	-17.799	1335.5	101.7	0.010	0.119
977	322	15	52	38.0	1664.2	5.296	-20.403	1059.2	99.9	0.123	0.071
978	322	15	52	55.0	961.7	5.868	-23.640	472.0	99.3	0.016	0.052
979	322	15	53	10.3	1257.4	-1.343	-24.161	916.7	97.9	0.037	0.051
980	322	15	53	36.3	1102.6	-1.329	-18.739	850.6	98.9	0.020	0.102
981	322	15	56	4.3	1196.7	-1.414	-23.698	861.5	98.7	0.013	0.052
982	322	15	58	3.3	1987.4	-0.987	-19.650	1031.5	98.5	0.029	0.082
983	322	15	58	27.3	1287.3	2.928	-26.462	692.7	81.3	0.004	0.046
984	322	15	58	38.4	1819.1	-0.981	-20.208	956.0	98.6	0.011	0.074
985	322	15	58	47.0	1804.6	2.021	-20.832	1455.5	82.6	0.003	0.067
986	322	15	58	55.0	1773.7	-1.058	-20.217	811.2	98.4	0.015	0.074
987	322	15	59	9.3	1177.0	4.238	-22.477	864.2	96.7	0.020	0.057
988	322	16	0	37.3	1659.1	-0.303	-18.230	417.8	101.1	0.012	0.112
989	322	16	1	20.3	1148.3	-1.151	-20.665	925.7	98.6	0.013	0.068
990	322	16	3	58.3	2021.6	3.151	-18.262	1478.0	85.8	0.220	0.112
991	322	16	4	45.0	1900.0	3.978	-19.941	1197.3	97.1	0.048	0.077
992	322	16	13	48.3	1724.3	-1.320	-17.159	1043.0	98.2	0.028	0.136
993	322	16	14	57.0	1408.7	-1.443	-27.719	875.2	98.5	0.013	0.044
994	322	16	17	19.3	1842.3	-0.918	-17.980	938.6	98.5	0.015	0.116
995	322	16	17	50.3	1129.5	-1.691	-17.874	649.0	97.7	0.030	0.118
996	322	16	20	7.3	1187.1	-1.834	-18.479	601.3	97.5	0.000	0.107
997	322	16	21	25.3	2205.3	-0.327	-18.09	925.1	98.4	0.017	0.115
998	322	16	23	32.3	1171.5	-1.299	-23.583	844.6	98.8	0.021	0.053
999	322	16	27	23.3	1291.0	2.914	-29.791	886.9	83.1	0.003	0.040
1000	322	16	29	44.5	1181.8	-1.391	-25.935	716.9	98.9	0.052	0.047
1001	322	16	30	42.3	1359.5	-1.106	-23.487	846.3	98.8	0.059	0.053
1002	322	16	33	2.3	1636.5	-1.119	-20.159	916.3	98.6	0.013	0.074
1003	322	16	34	26.0	1266.7	0.210	-22.405	1002.6	65.8	0.011	0.057
1004	322	16	36	36.5	978.0	-1.752	-19.772	682.3	98.2	0.025	0.080
1005	322	16	36	51.0	2191.5	-0.438	-16.857	945.3	98.5	0.015	0.143
1006	322	16	37	22.5	1366.4	-1.417	-21.046	785.1	99.2	0.015	0.065
1007	322	16	37	26.3	2227.6	-0.314	-17.601	938.0	98.6	0.013	0.123
1008	322	16	37	41.3	1152.8	-1.722	-20.887	693.4	98.1	0.002	0.067
1009	322	16	39	20.3	1822.8	6.170	-20.953	434.2	100.0	0.029	0.066
1010	322	16	39	27.0	1429.2	-1.306	-19.606	950.1	98.6	0.016	0.082
1011	322	16	40	39.5	1758.4	-1.049	-19.937	900.2	98.9	0.020	0.077
1012	322	16	42	21.0	1609.6	4.314	-25.428	1156.8	100.7	0.003	0.048
1013	322	16	43	47.3	1282.4	-1.525	-24.209	818.3	98.6	0.011	0.051
1014	322	16	44	43.0	1400.9	-1.319	-21.516	991.6	98.7	0.015	0.062
1015	322	16	48	11.3	1095.0	-1.837	-31.427	661.9	98.3	0.027	0.038

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1016	322	16	52	38.3	1291.7	-1.484	-18.523	837.7	98.5	0.013	0.106
1017	322	16	52	58.3	1935.0	5.620	-21.769	520.1	99.4	0.023	0.060
1018	322	16	53	57.3	1782.8	4.422	-20.376	1076.7	98.7	0.083	0.072
1019	322	16	55	3.3	1684.8	0.917	-20.501	755.1	75.8	0.008	0.070
1020	322	17	0	36.3	1126.1	-1.740	-22.618	708.4	97.6	0.022	0.056
1021	322	17	2	47.3	1444.2	-1.524	-19.704	712.4	98.0	0.007	0.081
1022	322	17	6	36.0	1858.4	-1.070	-19.990	1317.0	99.5	0.034	0.077
1023	322	17	6	56.3	1310.1	-2.094	-23.567	668.6	62.4	0.085	0.053
1024	322	17	12	2.5	1475.5	-1.367	-20.126	1039.3	99.1	0.018	0.075
1025	322	17	12	9.3	1856.3	5.606	-19.136	901.6	102.4	0.024	0.096
1026	322	17	12	44.0	1354.4	4.072	-23.164	1038.0	100.7	0.006	0.054
1027	322	17	13	46.3	2418.2	-3.417	-18.798	1353.2	82.9	0.009	0.101
1028	322	17	15	36.0	1313.9	-1.484	-24.523	763.4	98.3	0.013	0.050
1029	322	17	17	51.3	2130.1	-0.443	-19.423	856.6	98.7	0.012	0.086
1030	322	17	20	37.0	1225.7	-1.441	-19.158	848.6	98.8	0.013	0.095
1031	322	17	22	38.0	1170.4	-1.306	-29.992	882.3	99.0	0.007	0.040
1032	322	17	23	57.3	1330.8	-1.727	-17.166	853.8	98.4	0.050	0.136
1033	322	17	25	5.3	1432.3	-1.100	-19.347	1032.8	100.0	0.000	0.090
1034	322	17	28	20.3	1562.9	-1.304	-21.403	843.7	98.5	0.009	0.063
1035	322	17	29	45.3	914.1	-1.154	-21.048	758.5	98.5	0.011	0.065
1036	322	17	31	9.3	1331.4	-1.377	-26.620	860.5	99.0	0.013	0.046
1037	322	17	31	41.3	1206.5	-1.392	-20.349	850.5	98.7	0.009	0.072
1038	322	17	32	58.2	1260.6	-1.737	-30.215	648.7	97.7	0.024	0.040
1039	322	17	33	25.3	1390.4	2.884	-20.681	872.1	83.0	0.005	0.068
1040	322	17	36	7.3	1527.5	-5.663	-23.065	794.2	70.9	0.016	0.054
1041	322	17	36	12.3	1495.9	-3.703	-16.335	997.8	82.9	0.004	0.154
1042	322	17	36	35.0	1213.8	-1.350	-22.149	859.6	99.1	0.015	0.058
1043	322	17	39	32.3	1822.5	3.485	-19.885	1464.2	102.4	0.074	0.078
1044	322	17	39	37.3	1916.2	-0.835	-19.293	847.1	98.6	0.011	0.092
1045	322	17	40	13.3	1333.9	2.729	-21.959	947.1	82.5	0.001	0.059
1046	322	17	41	3.3	1263.6	6.002	-21.554	611.1	101.1	0.156	0.062
1047	322	17	42	30.5	1209.8	-1.349	-19.664	873.6	98.9	0.007	0.081
1048	322	17	42	32.0	1251.0	-1.293	-26.478	1020.1	98.6	0.023	0.046
1049	322	17	43	39.0	1702.2	-5.189	-23.256	927.9	63.4	0.058	0.054
1050	322	17	44	15.2	1415.7	-1.337	-19.890	864.2	99.0	0.012	0.078
1051	322	17	47	14.5	2136.8	5.102	-21.769	824.9	99.0	0.003	0.060
1052	322	17	48	58.0	1502.9	-1.073	-24.634	750.7	99.1	0.047	0.050
1053	322	17	50	47.3	1153.7	-1.290	-27.665	878.9	98.8	0.008	0.044
1054	322	17	51	40.3	1396.6	5.614	-23.253	510.2	96.1	0.046	0.054
1055	322	17	54	41.3	869.9	-1.895	-31.634	437.8	98.4	0.006	0.038
1056	322	17	55	56.0	1546.3	-6.266	-18.585	622.8	63.9	0.104	0.104
1057	322	17	56	7.4	1200.3	-1.537	-27.214	742.8	98.5	0.011	0.045
1058	322	17	56	9.3	1229.1	2.770	-22.261	893.2	82.6	0.003	0.058

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1059	322	17	56	44.3	1199.9	-1.385	-23.586	856.2	99.1	0.016	0.053
1060	322	18	0	33.0	1117.8	-1.390	-18.113	846.3	98.8	0.003	0.115
1061	322	18	0	59.3	1424.7	-1.425	-20.501	737.0	98.6	0.015	0.070
1062	322	18	2	5.0	979.7	-1.105	-19.443	815.9	98.7	0.005	0.085
1063	322	18	2	31.3	1715.2	-1.075	-21.031	865.5	99.0	0.013	0.065
1064	322	18	5	18.0	1195.8	-1.457	-18.543	836.7	98.8	0.003	0.105
1065	322	18	7	7.4	1133.1	-1.264	-29.830	865.0	99.1	0.007	0.040
1066	322	18	7	7.5	1111.0	-1.284	-21.948	866.5	99.3	0.017	0.059
1067	322	18	7	8.3	1623.7	-1.216	-19.850	856.7	98.8	0.011	0.078
1068	322	18	9	55.4	1110.2	-1.191	-24.346	898.3	98.9	0.008	0.050
1069	322	18	9	58.0	2260.8	1.701	-18.558	1369.1	82.2	0.012	0.105
1070	322	18	10	7.3	1233.8	-1.395	-25.707	871.8	98.9	0.007	0.047
1071	322	18	12	26.3	1264.9	-1.479	-19.254	760.7	98.7	0.014	0.093
1072	322	18	12	57.5	1255.0	-1.346	-19.898	875.2	99.0	0.012	0.078
1073	322	18	12	59.3	1088.3	-1.261	-24.566	861.1	99.1	0.010	0.050
1074	322	18	13	54.3	1946.9	-3.633	-19.875	1515.2	73.8	0.005	0.078
1075	322	18	15	48.3	1757.7	-1.050	-19.244	838.2	98.7	0.010	0.093
1076	322	18	16	7.2	1869.4	-3.609	-18.447	1253.5	82.3	0.012	0.108
1077	322	18	16	11.3	1262.0	4.353	-28.387	911.0	99.0	0.004	0.043
1078	322	18	16	38.0	1661.6	-1.048	-19.451	890.0	98.9	0.015	0.085
1079	322	18	18	34.2	1984.4	-0.787	-19.318	790.6	98.4	0.025	0.091
1080	322	18	18	45.3	1580.2	-1.225	-20.015	878.9	98.9	0.007	0.076
1081	322	18	20	12.3	1150.3	-1.321	-27.796	862.7	98.9	0.007	0.044
1082	322	18	20	30.3	1382.5	-1.334	-24.441	865.7	99.2	0.012	0.050
1083	322	18	24	13.0	1146.5	-1.303	-20.984	866.6	99.1	0.007	0.066
1084	322	18	26	22.5	1291.5	-1.513	-20.245	772.3	98.8	0.012	0.073
1085	322	18	26	51.3	1009.6	-1.768	-19.974	653.9	98.5	0.027	0.077
1086	322	18	28	11.3	1776.1	-0.929	-19.130	862.6	99.1	0.016	0.096
1087	322	18	28	23.3	1128.9	2.795	-22.912	865.7	83.0	0.001	0.055
1088	322	18	28	44.3	1403.8	-1.473	-18.780	962.8	98.7	0.025	0.101
1089	322	18	32	8.3	1385.8	-1.379	-18.879	813.1	98.9	0.008	0.100
1090	322	18	32	51.3	1543.3	-1.224	-19.698	895.5	98.9	0.007	0.081
1091	322	18	35	15.5	1811.9	-0.920	-19.143	876.7	99.2	0.017	0.096
1092	322	18	35	36.5	1711.5	-1.081	-20.129	865.0	99.1	0.012	0.075
1093	322	18	35	45.5	1756.3	-1.085	-18.840	1181.4	99.6	0.027	0.100
1094	322	18	35	55.3	1837.8	-0.906	-19.011	856.0	98.9	0.010	0.098
1095	322	18	36	46.3	1374.3	-1.370	-18.037	864.0	99.0	0.008	0.116
1096	322	18	37	35.0	1835.7	-0.873	-19.103	885.1	98.8	0.016	0.097
1097	322	18	38	18.5	965.6	-1.328	-19.726	723.8	98.7	0.013	0.080
1098	322	18	38	29.3	1129.7	-1.637	-25.211	814.6	98.6	0.032	0.048
1099	322	18	39	17.3	1824.6	-0.882	-19.994	888.7	98.8	0.006	0.077
1100	322	18	40	17.3	1597.2	-1.190	-22.969	775.8	98.6	0.010	0.055
1101	322	18	40	57.3	1408.9	4.179	-21.465	971.5	97.5	0.043	0.062

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1102	322	18	41	14.3	1304.2	-1.645	-24.61	745.2	98.3	0.012	0.050
1103	322	18	43	11.3	1428.2	-1.285	-20.516	878.4	98.9	0.004	0.070
1104	322	18	43	25.3	786.6	-3.426	-18.311	506.2	57.0	0.318	0.111
1105	322	18	46	2.5	1978.0	0.149	-17.421	904.1	102.4	0.003	0.129
1106	322	18	46	29.3	1391.3	-1.408	-14.125	867.5	98.9	0.000	0.206
1107	322	18	47	14.3	1914.4	-1.127	-19.367	1015.7	98.5	0.043	0.089
1108	322	18	47	37.3	1623.0	-1.211	-20.812	813.4	98.8	0.010	0.067
1109	322	18	49	34.3	1779.4	-0.980	-19.358	875.4	98.8	0.006	0.090
1110	322	18	50	11.5	923.5	-1.128	-26.519	746.6	98.8	0.013	0.046
1111	322	18	50	39.3	1871.5	-1.069	-19.075	711.9	97.6	0.027	0.097
1112	322	18	51	2.3	1096.6	-1.031	-19.325	915.6	99.1	0.010	0.091
1113	322	18	51	22.3	1179.5	-1.531	-25.133	713.2	98.6	0.016	0.049
1114	322	18	53	37.3	1010.7	-1.314	-21.280	772.6	98.8	0.009	0.063
1115	322	18	54	22.5	997.5	-1.188	-25.346	798.2	98.8	0.005	0.048
1116	322	18	54	33.4	1150.2	-1.338	-25.070	863.3	99.3	0.010	0.049
1117	322	18	55	3.3	1576.8	-1.297	-19.354	557.0	98.3	0.027	0.090
1118	322	18	55	6.3	931.6	-1.172	-26.441	773.4	98.9	0.009	0.046
1119	322	18	56	25.1	1754.0	-0.228	-20.590	880.3			0.069
1120	322	18	57	12.3	1349.1	-1.322	-26.970	854.0	98.8	0.005	0.045
1121	322	18	58	40.5	1310.1	-1.641	-20.976	639.0	97.6	0.013	0.066
1122	322	18	59	9.3	1513.7	-1.255	-18.354	876.1	99.0	0.005	0.110
1123	322	19	0	42.2	1347.8	-1.027	-19.743	1063.7	100.2	0.004	0.080
1124	322	19	0	53.3	1471.3	-1.256	-21.903	902.4	99.1	0.007	0.060
1125	322	19	2	26.3	1284.4	-1.392	-23.505	852.9	99.1	0.007	0.053
1126	322	19	5	22.3	1241.3	-1.578	-20.084	595.9	98.8	0.036	0.075
1127	322	19	7	51.3	1760.3	-1.145	-19.279	1042.3	98.8	0.029	0.092
1128	322	19	8	23.3	1329.1	4.399	-28.746	958.9	100.2	0.004	0.043
1129	322	19	10	14.2	2014.2	-0.692	-17.592	961.4	98.7	0.017	0.123
1130	322	19	10	20.3	726.4	-1.496	-32.996	538.6	57.0	0.269	0.036
1131	322	19	13	0.0	1177.7	0.237	-30.606	919.2	65.8	0.010	0.039
1132	322	19	14	23.3	1291.9	-1.623	-27.665	705.6	98.7	0.028	0.044
1133	322	19	15	11.3	1279.4	-1.288	-22.144	902.3			0.058
1134	322	19	15	46.3	2218.3	4.481	-19.357	983.7	97.5	0.047	0.090
1135	322	19	15	53.3	1266.0	-1.340	-27.338	864.9	99.3	0.006	0.044
1136	322	19	16	22.5	1468.8	-1.331	-19.225	844.7	99.0	0.007	0.094
1137	322	19	17	43.3	1955.6	-0.708	-19.701	860.5	98.8	0.007	0.081
1138	322	19	17	48.3	927.8	-1.398	-29.013	723.5	99.0	0.020	0.041
1139	322	19	18	39.0	1612.9	-6.064	-17.659	766.4	65.0	0.018	0.122
1140	322	19	19	18.3	1380.4	-5.744	-17.880	765.0	65.0	0.019	0.118
1141	322	19	20	21.3	1072.4	-1.231	-29.875	857.3	99.0	0.002	0.040
1142	322	19	21	24.3	2472.2	3.395	-18.784	1713.0	98.8	0.060	0.101
1143	322	19	21	49.3	1706.9	5.231	-22.899	783.7	98.6	0.002	0.055
1144	322	19	22	27.3	1744.0	-1.013	-17.697	892.3	98.9	0.008	0.121
1145	322	19	23	7.3	1807.3	4.022	-21.513	1187.2	98.1	0.049	0.062

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1146	322	19	23	40.0	2130.9	4.685	-18.782	908.3	97.4	0.038	0.101
1147	322	19	24	36.0	1737.3	-1.001	-19.636	716.7	98.7	0.016	0.082
1148	322	19	25	1.5	2026.0	-0.585	-18.141	909.9	99.0	0.005	0.114
1149	322	19	25	7.5	1836.1	-0.914	-18.390	905.4	98.8	0.010	0.109
1150	322	19	25	16.3	1342.5	-1.328	-18.961	887.4	99.2	0.009	0.099
1151	322	19	25	48.3	920.1	-1.241	-23.929	741.8	98.8	0.009	0.052
1152	322	19	26	6.3	1167.5	-1.270	-22.131	906.6	99.1	0.009	0.058
1153	322	19	33	9.0	1979.5	-3.347	-21.241	898.3	64.8	0.005	0.064
1154	322	19	34	48.3	1291.7	2.599	-25.179	1004.1	83.0	0.004	0.048
1155	322	19	34	57.3	1322.5	-1.463	-19.383	721.5	98.8	0.013	0.088
1156	322	19	38	58.2	2010.7	-0.522	-18.564	555.5	98.4	0.028	0.105
1157	322	19	40	36.1	1578.5	4.429	-21.047	612.4			0.065
1158	322	19	42	31.3	1232.6	4.840	-24.331	783.3	97.6	0.037	0.050
1159	322	19	42	55.3	2149.7	-0.315	-19.505	890.8	99.0	0.003	0.084
1160	322	19	43	34.3	835.3	-3.767	-25.004	541.7	57.0	0.317	0.049
1161	322	19	43	42.0	1775.4	-0.562	-20.258	1105.1	100.3	0.050	0.073
1162	322	19	45	2.3	1268.8	-1.469	-20.367	869.9	99.0	0.002	0.072
1163	322	19	46	2.3	1678.7	-1.145	-18.868	778.3	98.9	0.009	0.100
1164	322	19	48	3.2	1471.8	-1.235	-20.153	924.7	98.9	0.012	0.075
1165	322	19	48	8.3	1200.7	-1.666	-25.039	555.4	98.4	0.024	0.049
1166	322	19	48	47.3	1136.3	5.245	-21.524	663.5	98.7	0.002	0.062
1167	322	19	49	21.3	2015.5	-0.656	-17.913	882.6	98.8	0.004	0.117
1168	322	19	50	5.0	1227.4	-1.344	-21.228	834.8	99.2	0.007	0.064
1169	322	19	52	1.2	1427.1	-1.397	-24.407	813.2	98.7	0.003	0.050
1170	322	19	52	9.3	1089.5	-1.201	-21.380	879.1	99.1	0.002	0.063
1171	322	19	53	43.3	1882.1	2.230	-20.512	916.3	82.4	0.005	0.070
1172	322	19	57	5.0	1798.6	-0.908	-17.315	913.8	99.1	0.010	0.133
1173	322	19	57	55.3	1066.9	-4.118	-14.701	765.2	81.7	0.069	0.192
1174	322	19	57	54.5	1300.7	-1.540	-30.117	764.2	98.6	0.003	0.040
1175	322	19	59	36.2	1062.0	-1.112	-27.719	807.3	98.6	0.040	0.044
1176	322	20	3	6.3	1971.8	-0.549	-15.939	1547.8	101.5	0.020	0.161
1177	322	20	3	47.5	1649.8	-1.104	-19.981	922.6			0.077
1178	322	20	3	47.0	1396.1	-0.707	-24.245	971.8	65.0	0.002	0.051
1179	322	20	4	22.3	945.9	-1.251	-19.532	768.0	98.8	0.011	0.084
1180	322	20	5	48.3	1575.4	-4.287	-19.977	886.8	81.2	0.001	0.077
1181	322	20	7	18.3	1781.0	-0.936	-18.587	914.1	99.0	0.008	0.104
1182	322	20	8	10.3	806.2	-4.371	-20.051	529.7	56.9	0.317	0.076
1183	322	20	11	8.3	1774.1	-0.953	-17.815	885.8	99.1	0.003	0.119
1184	322	20	12	21.4	1851.4	-0.832	-19.665	921.2	99.2	0.006	0.081
1185	322	20	12	27.2	1182.9	-1.297	-21.223	863.6	99.3	0.005	0.064
1186	322	20	12	33.3	803.7	-4.439	-26.924	532.0	56.9	0.315	0.045
1187	322	20	12	53.3	1972.6	-0.535	-17.801	865.1	99.4	0.010	0.119
1188	322	20	14	36.5	1420.3	-1.184	-21.323	936.8	99.0	0.015	0.063
1189	322	20	15	11.1	1126.3	-1.439	-21.703	819.9	99.1	0.003	0.061

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1190	322	20	15	18.3	1447.7	-1.267	-18.621	871.3	99.6	0.012	0.103
1191	322	20	15	18.5	1097.1	-1.372	-30.334	821.7	99.0	0.008	0.039
1192	322	20	15	52.3	1552.1	5.502	-20.858	725.1	98.9	0.024	0.067
1193	322	20	15	59.3	1212.1	4.501	-31.766	848.5	97.6	0.019	0.037
1194	322	20	16	45.0	2093.2	-0.400	-18.478	894.6	99.2	0.006	0.107
1195	322	20	17	41.3	1082.8	-1.443	-18.435	838.5	98.7	0.017	0.108
1196	322	20	19	18.3	1266.3	-1.414	-21.481	858.0	99.0	0.007	0.062
1197	322	20	20	16.3	1934.2	-0.781	-19.564	1147.5	99.1	0.041	0.083
1198	322	20	21	34.0	1642.9	-3.796	-23.490	1061.0	82.9	0.014	0.053
1199	322	20	22	45.0	1469.9	-1.141	-21.116	908.1	99.3	0.012	0.065
1200	322	20	23	17.3	2165.9	5.007	-18.699	1002.2	100.0	0.003	0.102
1201	322	20	23	22.3	1192.4	-1.437	-21.567	642.5	98.8	0.043	0.062
1202	322	20	25	1.3	1054.7	-1.493	-19.210	780.0	98.2	0.000	0.094
1203	322	20	25	31.3	2039.3	-3.859	-17.397	1512.4	73.6	0.005	0.130
1204	322	20	26	31.0	1197.2	-1.691	-23.819	701.6	98.4	0.021	0.052
1205	322	20	28	22.3	1567.9	-3.075	-24.227	776.4	64.0	0.182	0.051
1206	322	20	28	38.5	986.8	-1.431	-24.480	738.8	98.8	0.002	0.050
1207	322	20	28	42.0	1683.9	5.236	-20.185	777.4	97.7	0.036	0.074
1208	322	20	30	0.2	1680.7	-1.073	-22.608	909.4	99.1	0.007	0.056
1209	322	20	30	12.5	1307.0	-1.436	-20.001	820.9	99.0	0.008	0.076
1210	322	20	30	36.2	2054.5	-0.525	-19.030	833.7	99.1	0.010	0.098
1211	322	20	32	31.5	1152.3	-1.382	-20.246	836.6	99.1	0.006	0.073
1212	322	20	32	47.3	1412.5	2.648	-23.815	806.6	81.3	0.005	0.052
1213	322	20	33	11.0	1267.2	-1.641	-26.417	800.9	98.1	0.003	0.046
1214	322	20	33	24.3	1604.7	-1.108	-23.835	678.7	98.8	0.019	0.052
1215	322	20	33	53.3	942.3	-1.352	-20.403	726.5	98.9	0.011	0.071
1216	322	20	34	16.0	1552.5	-1.237	-19.602	748.4	99.1	0.018	0.082
1217	322	20	34	51.3	1485.3	-1.435	-20.732	764.7	98.8	0.009	0.068
1218	322	20	35	20.5	1113.1	-1.463	-17.507	805.0	99.0	0.010	0.125
1219	322	20	37	12.3	1260.3	-1.570	-23.315	785.4	98.2	0.002	0.054
1220	322	20	39	30.3	1282.4	-4.413	-19.964	689.3	81.8	0.033	0.077
1221	322	20	40	45.3	2000.2	-3.347	-13.754	1345.1	82.4	0.022	0.214
1222	322	20	41	7.3	1461.8	-1.345	-17.409	735.2	98.9	0.012	0.129
1223	322	20	41	42.3	1758.8	-0.963	-20.053	862.0	99.4	0.013	0.076
1224	322	20	43	6.3	1045.6	-1.325	-19.857	815.0	99.1	0.008	0.078
1225	322	20	43	49.3	2033.5	-0.674	-16.168	994.9	99.0	0.020	0.157
1226	322	20	44	11.5	960.8	-1.488	-19.645	681.0	98.9	0.012	0.082
1227	322	20	44	16.3	1017.3	-1.258	-22.329	812.7	99.1	0.008	0.057
1228	322	20	46	40.0	1610.1	-6.579	-24.264	612.9	63.0	0.096	0.051
1229	322	20	47	30.3	1755.4	-0.912	-19.755	864.9	99.4	0.007	0.080
1230	322	20	48	40.2	1796.4	-0.984	-21.060	818.3	98.9	0.007	0.065
1231	322	20	48	51.3	1278.9	-1.292	-21.733	869.9	99.5	0.005	0.061
1232	322	20	49	8.2	1504.4	-1.139	-18.213	922.1	99.4	0.015	0.113
1233	322	20	49	17.3	1442.1	-5.595	-21.788	641.7	75.7	0.010	0.060

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1234	322	20	50	54.5	1848.1	-0.883	-18.975	952.0	99.1	0.013	0.099
1235	322	20	51	1.0	1433.0	-1.523	-19.791	786.4	98.2	0.001	0.079
1236	322	20	51	20.4	1208.8	-1.369	-29.843	720.4	98.8	0.041	0.040
1237	322	20	51	22.5	1747.1	-1.008	-20.502	822.7	99.2	0.006	0.070
1238	322	20	51	36.3	2156.1	4.832	-18.530	1186.1	98.7	0.061	0.106
1239	322	20	52	52.0	1385.9	0.993	-21.372	1091.8	64.9	0.249	0.063
1240	322	20	53	2.3	1175.1	-1.447	-18.801	773.2	99.0	0.006	0.101
1241	322	20	53	30.1	1028.3	-1.316	-23.153	782.7	99.2	0.007	0.054
1242	322	20	53	33.2	1495.1	-1.317	-19.898	681.4	98.9	0.018	0.078
1243	322	20	53	41.3	1328.9	-1.722	-15.649	697.6	98.3	0.033	0.166
1244	322	20	54	33.3	2345.6	1.310	-16.958	925.9	82.6	0.009	0.141
1245	322	20	56	40.3	1427.8	-1.344	-22.928	795.8	99.0	0.009	0.055
1246	322	20	57	47.3	1354.3	-1.371	-18.981	630.3	98.9	0.028	0.099
1247	322	20	58	1.3	1090.4	-7.923	-30.713	322.9	62.3	0.323	0.039
1248	322	21	0	26.3	1453.0	-1.306	-22.717	674.3	98.8	0.019	0.056
1249	322	21	1	14.3	1092.1	-1.336	-26.546	765.1	99.2	0.010	0.046
1250	322	21	1	32.0	1214.5	-1.358	-20.533	880.3	98.6	0.036	0.070
1251	322	21	2	31.5	1283.9	-1.416	-22.504	831.5	99.1	0.005	0.057
1252	322	21	2	41.5	1069.3	-1.541	-22.999	717.4	99.0	0.011	0.055
1253	322	21	3	6.3	2356.0	4.958	-18.257	1027.5	98.4	0.066	0.112
1254	322	21	4	15.3	1586.6	-1.200	-20.856	689.2	99.0	0.015	0.067
1255	322	21	4	35.3	2013.7	-0.676	-18.058	965.2	99.1	0.016	0.115
1256	322	21	5	55.5	1668.1	-2.611	-20.738	1406.6	83.4	0.009	0.068
1257	322	21	6	2.3	1931.6	-1.035	-18.764	1132.6	98.9	0.055	0.101
1258	322	21	7	6.3	1062.1	-1.474	-23.119	739.3	99.0	0.010	0.054
1259	322	21	8	5.3	1422.6	-1.331	-25.630	671.6	98.9	0.018	0.047
1260	322	21	8	5.5	1148.1	-0.944	-19.638	868.9	99.6	0.047	0.082
1261	322	21	8	22.3	1396.7	2.738	-26.315	974.4	82.9	0.004	0.046
1262	322	21	9	19.5	1139.5	-1.798	-20.986	505.9			0.066
1263	322	21	9	24.3	1365.4	-1.374	-19.228	871.5	99.4	0.003	0.094
1264	322	21	12	11.3	1041.3	-1.218	-32.217	831.7	99.5	0.010	0.037
1265	322	21	12	53.3	1551.0	3.681	-22.848	1167.3	99.4	0.071	0.055
1266	322	21	15	15.4	1430.6	-1.391	-19.683	1123.1	99.0	0.061	0.081
1267	322	21	16	25.3	1733.4	2.523	-24.535	939.1	82.9	0.004	0.050
1268	322	21	17	42.3	1994.2	4.594	-21.305	1337.2	99.0	0.088	0.063
1269	322	21	18	8.3	1205.1	-1.488	-22.393	766.7	99.2	0.008	0.057
1270	322	21	18	27.5	1019.1	-1.467	-34.440	726.8			0.034
1271	322	21	18	57.3	1798.0	-0.885	-16.802	848.9	99.2	0.003	0.144
1272	322	21	19	14.3	1863.1	3.891	-21.635	1396.1			0.061
1273	322	21	19	46.3	847.7	-1.260	-28.559	674.0	99.0	0.013	0.043
1274	322	21	23	1.3	1385.6	-0.837	-24.353	762.8	66.0	0.023	0.050
1275	322	21	23	12.0	1422.3	-1.380	-21.535	779.8	99.0	0.008	0.062
1276	322	21	23	29.0	1629.8	1.198	-19.760	875.6	75.8	0.014	0.080
1277	322	21	24	40.5	724.5	-1.336	-20.492	566.8	98.9	0.031	0.070

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1278	322	21	24	46.2	857.9	-1.313	-21.335	645.1	98.7	0.022	0.063
1279	322	21	24	58.3	2006.7	3.967	-19.850	1389.6	98.3	0.044	0.078
1280	322	21	25	2.0	2250.7	-0.149	-18.561	935.3	99.2	0.013	0.105
1281	322	21	25	24.3	833.6	-3.105	-28.577	580.8	56.8	0.263	0.042
1282	322	21	25	35.3	1932.0	-0.865	-17.244	838.6	98.5	0.017	0.134
1283	322	21	25	56.3	1991.4	-0.835	-18.228	853.2	98.4	0.017	0.113
1284	322	21	28	44.3	1600.2	-1.200	-21.405	836.8	99.1	0.007	0.063
1285	322	21	30	23.3	2019.6	-0.752	-19.036	847.3	98.5	0.014	0.098
1286	322	21	30	48.5	1139.9	-1.558	-30.156	651.0	98.6	0.023	0.040
1287	322	21	30	51.3	897.9	-1.382	-20.351	700.7	99.0	0.012	0.072
1288	322	21	31	40.3	1403.7	-1.292	-22.405	869.6	99.4	0.002	0.057
1289	322	21	32	11.3	1269.1	-1.441	-26.783	916.6	98.5	0.037	0.045
1290	322	21	32	51.3	2201.7	-0.898	-17.867	1761.1	100.8	0.051	0.118
1291	322	21	33	42.3	1076.7	5.519	-21.431	587.4	96.7	0.041	0.062
1292	322	21	36	31.3	1320.4	-1.203	-22.455	1074.6	99.2	0.036	0.057
1293	322	21	36	52.7	1723.6	-0.980	-19.486	760.8	99.1	0.009	0.085
1294	322	21	36	59.3	1423.2	-1.534	-21.684	826.3	99.1	0.035	0.061
1295	322	21	39	7.3	952.4	5.049	-44.082	618.2	96.7	0.032	0.023
1296	322	21	39	15.5	1348.7	-1.225	-18.458	987.9	99.4	0.020	0.107
1297	322	21	39	43.0	966.5	-1.184	-30.935	790.8	99.2	0.007	0.039
1298	322	21	42	49.0	2118.1	-0.520	-17.188	853.7	98.7	0.020	0.136
1299	322	21	44	9.3	1507.7	-1.278	-19.350	576.3	99.3	0.048	0.090
1300	322	21	45	15.1	670.1	-1.261	-18.117	556.0	97.7	0.013	0.115
1301	322	21	45	47.3	1493.4	-0.848	-19.091	919.5	99.4	0.070	0.097
1302	322	21	48	15.0	1034.0	0.614	-29.888	822.2	63.0	0.133	0.040
1303	322	21	48	40.3	1454.3	-1.347	-17.486	629.1	98.8	0.016	0.125
1304	322	21	48	45.3	808.2	-1.309	-19.461	624.2	99.0	0.016	0.085
1305	322	21	51	36.5	1244.5	-1.597	-21.966	669.6	98.5	0.020	0.059
1306	322	21	51	44.3	885.8	-1.524	-19.216	615.6	98.9	0.017	0.094
1307	322	21	53	18.3	1174.3	5.347	-28.115	609.8	97.0	0.034	0.043
1308	322	21	53	24.3	1332.1	5.044	-19.735	839.3	99.4	0.067	0.080
1309	322	21	56	40.3	1055.5	-1.191	-27.511	820.9	99.9	0.016	0.044
1310	322	21	57	8.3	1688.1	-1.038	-18.444	743.5	99.1	0.010	0.108
1311	322	21	58	30.3	1361.0	-1.412	-18.993	687.5	99.0	0.013	0.098
1312	322	21	59	3.5	1771.4	-0.930	-19.995	606.1	98.8	0.027	0.077
1313	322	21	59	43.3	1894.0	-0.701	-18.254	805.8	99.3	0.010	0.112
1314	322	22	0	9.3	1918.4	-0.791	-18.237	936.9	98.5	0.044	0.112
1315	322	22	1	36.3	1350.9	-1.247	-25.057	902.0	99.6	0.009	0.049
1316	322	22	1	52.5	895.3	-1.818	-19.564	600.8	97.8	0.002	0.083
1317	322	22	2	4.3	1338.4	2.812	-24.934	704.0	81.2	0.004	0.049
1318	322	22	2	9.3	1716.8	-0.961	-23.786	671.9	98.8	0.022	0.052
1319	322	22	3	5.2	1688.3	-1.006	-19.342	722.1	99.0	0.011	0.090
1320	322	22	5	14.5	1250.3	-1.514	-24.111	729.9	99.1	0.016	0.051
1321	322	22	6	3.3	1584.8	-1.192	-24.484	760.6	98.8	0.008	0.050

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1322	322	22	7	54.0	1770.8	2.401	-20.236	962.9	82.6	0.004	0.073
1323	322	22	9	9.5	1587.1	-4.693	-17.869	699.8	81.2	0.004	0.118
1324	322	22	9	9.1	1978.6	-0.681	-17.772	854.8	99.1	0.014	0.120
1325	322	22	9	19.5	1517.7	-4.064	-24.926	886.9	82.8	0.003	0.049
1326	322	22	9	27.5	1152.6	-1.565	-19.441	635.8	99.0	0.015	0.085
1327	322	22	9	32.0	973.3	-1.233	-27.967	774.9	99.3	0.007	0.043
1328	322	22	10	3.5	1231.9	-1.337	-18.664	828.9	99.6	0.007	0.103
1329	322	22	10	37.5	1934.6	-0.658	-19.130	703.4	99.0	0.012	0.096
1330	322	22	10	45.0	2426.7	0.257	-18.250	774.6	99.0	0.016	0.112
1331	322	22	11	26.3	1578.1	-1.062	-19.345	669.4	98.9	0.022	0.090
1332	322	22	13	32.0	1492.8	2.634	-25.817	845.7	81.7	0.020	0.047
1333	322	22	14	54.3	1247.6	-1.462	-19.954	744.5	99.1	0.004	0.077
1334	322	22	15	27.3	1713.6	2.238	-20.927	1271.6	82.5	0.008	0.066
1335	322	22	16	57.3	2251.8	0.040	-17.476	943.7	99.5	0.028	0.125
1336	322	22	18	6.0	1388.6	-1.441	-26.146	488.1	98.8	0.033	0.047
1337	322	22	19	5.3	1495.8	-1.106	-19.333	888.8	99.6	0.008	0.091
1338	322	22	19	52.0	1494.3	4.905	-23.872	857.9	98.2	0.027	0.052
1339	322	22	21	44.0	1404.3	-1.424	-25.403	529.3	98.6	0.028	0.048
1340	322	22	23	15.3	1676.3	-1.000	-19.369	659.0	98.9	0.014	0.089
1341	322	22	24	36.5	1419.6	-1.369	-25.147	717.4	99.0	0.012	0.048
1342	322	22	24	52.0	1910.6	4.041	-18.978	1258.6	98.5	0.040	0.099
1343	322	22	29	15.3	1108.0	4.153	-26.135	836.3	98.2	0.030	0.047
1344	322	22	31	25.3	1659.9	-1.090	-20.577	776.1	99.1	0.018	0.069
1345	322	22	33	25.3	1597.2	5.625	-23.981	620.0	97.5	0.033	0.051
1346	322	22	34	27.3	1680.0	3.912	-19.319	1184.9	98.3	0.038	0.091
1347	322	22	35	8.0	1600.7	2.678	-21.133	984.9	83.0	0.003	0.065
1348	322	22	38	6.3	1462.9	-1.244	-23.074	811.4	99.2	0.008	0.054
1349	322	22	39	14.3	1495.0	-1.501	-19.882	604.9	97.8	0.021	0.078
1350	322	22	40	2.3	1785.4	4.640	-18.355	1006.3	98.0	0.016	0.110
1351	322	22	40	15.3	1886.5	2.366	-17.763	919.8	82.9	0.015	0.120
1352	322	22	41	48.5	1824.1	-0.835	-16.968	753.2	99.1	0.019	0.141
1353	322	22	41	50.0	1675.4	-0.995	-17.064	644.3	99.0	0.022	0.138
1354	322	22	42	46.3	1162.3	4.850	-25.285	723.6	97.8	0.040	0.048
1355	322	22	43	0.3	1311.0	0.040	-23.842	1024.0	66.3	0.006	0.052
1356	322	22	44	7.3	1359.0	-1.499	-23.493	696.1	99.1	0.026	0.053
1357	322	22	44	35.3	1309.9	5.084	-24.507	744.7	97.5	0.006	0.050
1358	322	22	44	48.0	1507.4	-1.245	-22.017	748.9	99.3	0.012	0.059
1359	322	22	45	23.0	1118.3	4.221	-30.559	830.6	98.3	0.032	0.039
1360	322	22	45	32.3	2103.2	4.077	-18.249	1410.8	98.6	0.035	0.112
1361	322	22	45	34.3	1125.9	-1.559	-24.744	682.7	99.2	0.018	0.049
1362	322	22	45	48.3	1709.2	4.819	-20.318	1022.2	99.9	0.006	0.072
1363	322	22	46	58.3	1991.6	4.023	-19.331	1421.2	98.8	0.042	0.091
1364	322	22	48	20.3	1564.3	-1.188	-17.561	809.8	99.2	0.006	0.124
1365	322	22	48	46.3	2192.1	-0.309	-20.514	1553.2	101.9	0.005	0.070

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1366	322	22	51	21.0	1007.3	-1.267	-25.327	788.6	99.4	0.010	0.048
1367	322	22	51	47.3	1439.5	-3.860	-17.430	943.4	82.5	0.001	0.128
1368	322	22	52	2.5	1648.7	-1.003	-19.738	837.6	99.7	0.010	0.080
1369	322	22	52	13.3	1398.2	-1.400	-27.331	722.7	99.3	0.021	0.044
1370	322	22	52	49.3	2262.4	4.933	-19.222	825.0	97.8	0.025	0.094
1371	322	22	53	7.5	1834.8	-4.100	-20.602	937.9	82.5	0.002	0.069
1372	322	22	53	9.3	1768.9	5.006	-23.280	868.8	98.0	0.013	0.054
1373	322	22	54	16.3	2099.6	-0.323	-17.358	713.6	99.0	0.011	0.132
1374	322	22	55	41.0	1972.5	5.035	-18.252	711.3	97.4	0.024	0.112
1375	322	22	58	19.3	1280.3	4.563	-29.145	877.6	97.8	0.008	0.041
1376	322	22	58	32.3	1738.4	-0.950	-18.449	828.1	99.4	0.007	0.107
1377	322	23	1	58.0	1567.0	4.364	-23.399	1023.0	98.2	0.025	0.053
1378	322	23	2	32.3	1451.6	-1.358	-25.389	604.0	99.0	0.022	0.048
1379	322	23	2	46.3	1620.5	3.054	-23.233	1270.6	89.9	0.007	0.054
1380	322	23	3	36.3	1327.0	-1.316	-24.342	743.6	99.5	0.005	0.050
1381	322	23	4	16.3	2044.3	-0.522	-19.665	894.4	98.7	0.035	0.081
1382	322	23	5	30.3	1883.4	5.144	-23.749	822.9	98.1	0.030	0.052
1383	322	23	5	31.5	1066.5	-1.564	-28.924	594.0	99.1	0.018	0.042
1384	322	23	5	32.3	1048.0	-5.551	-31.461	627.7	71.0	0.016	0.038
1385	322	23	5	46.6	1291.3	4.949	-29.089	770.4	98.3	0.050	0.041
1386	322	23	6	3.0	1507.6	-1.342	-19.868	620.9	98.4	0.022	0.078
1387	322	23	7	54.5	1309.6	4.303	-26.429	929.6	98.2	0.017	0.046
1388	322	23	8	8.3	1557.4	-1.162	-21.938	595.3	98.9	0.020	0.059
1389	322	23	9	47.5	2037.6	-0.361	-17.949	660.8	99.0	0.015	0.117
1390	322	23	9	55.3	2115.2	-0.231	-18.715	767.8	99.5	0.025	0.102
1391	322	23	10	55.0	1510.2	-3.887	-21.458	940.8	82.6	0.002	0.062
1392	322	23	11	25.3	788.3	-1.299	-25.179	591.7	99.1	0.019	0.048
1393	322	23	11	44.3	1600.8	3.000	-24.715	1269.2	89.9	0.007	0.049
1394	322	23	11	51.3	2017.1	4.046	-19.134	1388.4	98.8	0.035	0.096
1395	322	23	14	50.3	1785.2	5.077	-22.824	849.6	98.2	0.024	0.055
1396	322	23	15	4.5	1975.3	-0.781	-15.623	611.4	97.7	0.022	0.167
1397	322	23	15	11.0	1565.5	4.843	-25.360	897.3	98.1	0.017	0.048
1398	322	23	15	38.3	1862.6	-0.546	-18.558	1322.2	102.3	0.011	0.105
1399	322	23	16	6.3	1454.7	-1.253	-18.879	649.3	98.9	0.023	0.100
1400	322	23	16	32.5	1322.1	-1.301	-21.817	817.8	100.0	0.050	0.060
1401	322	23	18	34.5	1738.5	-3.029	-22.487	1488.7	73.7	0.003	0.057
1402	322	23	18	34.3	1837.6	3.260	-17.455	1275.7	90.2	0.003	0.127
1403	322	23	18	49.3	1105.5	4.597	-29.999	786.8	98.2	0.026	0.040
1404	322	23	18	50.3	1381.7	-1.419	-27.902	570.5	99.1	0.006	0.044
1405	322	23	19	8.3	2008.3	4.663	-21.472	1012.2	98.3	0.032	0.062
1406	322	23	19	39.3	1849.5	3.675	-19.185	1348.6	98.9	0.049	0.095
1407	322	23	20	25.3	1136.7	-1.384	-26.514	849.0	98.6	0.035	0.046
1408	322	23	21	34.3	1518.7	-2.079	-15.570	688.4	65.0	0.013	0.169
1409	322	23	21	55.2	971.4	-1.600	-18.863	561.5	99.0	0.022	0.100

Table D-3. Detection list Cobra Dane radar observed during the 2008 campaign - cont.

	Epoch				Slant Range	Range Rate	Radar Cross Section	Altitude	Inclination	Eccentricity	Characteristic Length
NO.	doy	hr	min	sec	(km)	(km/sec)	(dBsm)	(km)	(deg)		(m)
1410	322	23	23	15.3	1905.5	4.205	-19.739	1204.7	98.6	0.033	0.080
1411	322	23	23	43.5	1367.8	-1.312	-19.520	573.8	99.3	0.032	0.084
1412	322	23	23	52.0	1722.6	3.648	-19.999	1362.9	98.6	0.037	0.077
1413	322	23	24	8.3	1660.0	3.098	-21.978	1272.9	89.9	0.007	0.059
1414	322	23	24	32.0	1590.2	4.843	-23.558	905.4	98.0	0.014	0.053
1415	322	23	24	34.3	1611.9	4.438	-20.648	1022.7	98.3	0.024	0.069
1416	322	23	26	3.0	1802.2	-0.809	-19.654	843.4	99.7	0.012	0.082
1417	322	23	26	29.3	1913.3	5.372	-19.126	873.5	99.4	0.056	0.096
1418	322	23	26	50.3	1411.1	-1.273	-19.558	827.7	99.6	0.004	0.083
1419	322	23	28	58.0	1876.3	5.027	-19.314	873.7	98.1	0.013	0.092
1420	322	23	29	51.3	1110.6	-1.341	-34.471	776.7	99.7	0.007	0.034
1421	322	23	31	51.5	704.2	-1.097	-29.999	546.3	99.1	0.020	0.040
1422	322	23	33	22.0	1184.6	4.345	-28.284	863.6	98.1	0.009	0.043
1423	322	23	36	25.5	2393.0	-0.486	-17.493	1885.4	103.6	0.061	0.125
1424	322	23	36	48.3	1901.3	3.789	-23.029	619.9	89.3	0.015	0.055
1425	322	23	37	34.0	1901.2	-0.580	-18.674	1240.4	100.7	0.058	0.103
1426	322	23	39	5.5	1219.9	-1.488	-22.098	623.1	99.0	0.021	0.059
1427	322	23	40	48.0	1241.4	5.195	-19.401	693.3	97.9	0.035	0.087
1428	322	23	42	5.0	1462.3	-1.335	-18.273	537.7	99.0	0.022	0.112
1429	322	23	42	37.3	1371.9	-1.353	-20.290	773.9	99.5	0.013	0.073
1430	322	23	43	0.3	1200.4	2.904	-21.616	738.3	81.2	0.006	0.061
1431	322	23	43	24.3	1385.4	-5.367	-20.229	819.1	70.0	0.006	0.074
1432	322	23	43	37.3	1947.5	3.256	-22.840	1271.4	90.1	0.003	0.055
1433	322	23	43	39.9	1417.0	-1.155	-19.325	691.4	100.0	0.022	0.091
1434	322	23	43	44.4	1141.3	-1.264	-24.777	828.2	99.0	0.013	0.049
1435	322	23	43	46.3	1295.7	2.795	-27.069	758.9	81.3	0.004	0.045
1436	322	23	43	50.3	1559.9	5.068	-22.885	821.5	98.0	0.019	0.055
1437	322	23	44	6.0	2237.4	4.393	-19.525	1161.0	98.1	0.027	0.084
1438	322	23	44	13.5	1751.2	-0.710	-16.715	1437.7	101.6	0.002	0.146
1439	322	23	44	25.3	1555.9	2.688	-18.329	754.8	83.8	0.298	0.110
1440	322	23	46	9.3	2350.3	4.842	-17.446	706.1	97.8	0.019	0.127
1441	322	23	47	41.3	1863.1	4.850	-22.926	1057.2	100.0	0.003	0.055
1442	322	23	47	53.3	1359.6	-1.364	-20.296	663.0	98.9	0.020	0.073
1443	322	23	48	44.3	779.2	-1.343	-31.098	557.7	99.1	0.023	0.038
1444	322	23	49	41.5	1269.1	-1.398	-24.445	725.4	99.3	0.013	0.050
1445	322	23	49	46.0	1670.7	6.059	-18.450	525.1	101.2	0.023	0.107
1446	322	23	52	37.3	1125.2	-1.470	-20.381	625.2	99.3	0.018	0.072
1447	322	23	53	12.3	1156.9	-1.587	-28.323	558.8	99.0	0.024	0.043
1448	322	23	56	10.3	1218.4	4.446	-21.348	864.4	98.2	0.009	0.063
1449	322	23	56	25.3	1325.1	-1.425	-23.193	777.0	99.4	0.011	0.054
1450	322	23	57	7.3	1374.3	5.757	-20.942	587.5	98.4	0.019	0.066
1451	322	23	58	39.3	1988.7	4.640	-19.935	1245.6	99.3	0.044	0.077
1452	322	23	59	15.3	1937.2	5.996		489.2	99.7	0.057	

Appendix E

NASA's Size Estimation Model

Physical size is estimated from radar cross section (RCS) using NASA's Size Estimation Model (SEM). Debris objects were selected from two hypervelocity impacts of simulated satellites. Some artificial debris-like objects were also included in the sample to better represent the postulated orbital debris environment. This included a printed circuit board and a piece of solid rocket motor aluminum oxide (Al_2O_3) slag. The RCS values of these 39 debris objects were measured at a controlled RCS radar range operated by the System Planning Corporation. The RCSs of these objects were measured over 4 radar frequency bands (2.5647-3.9111 GHz, 4.116-7.986 GHz, 8.1544-12.7684 GHz, and 12.924-17.538 GHz) with 8 steps in the band of the lowest frequency and 16 steps in the band for the other three, and with hundreds of source-object orientations. These frequencies, S-, C-, X-, and Ku-band, respectively, were chosen since they represent radar frequencies often used for orbital debris observations.

The characteristic length of an object is defined as the average of the largest dimensions for an object measured along three orthogonal axes. The first axis was chosen to coincide with the largest dimension, the second axis to coincide with the largest dimension in a plane orthogonal to the first axis, and the third axis to be orthogonal to the first two axes. In this report, the characteristic length of an object is often referred to as size or diameter.

Consistent with Maxwell's equations of electromagnetics, radar data from different wavelengths can be compared by normalizing the size by the wavelength of the measuring frequency and the RCS by the wavelength squared. This results in a size parameter x = size/wavelength and an RCS parameter z = RCS/wavelength^2. Figure E-1 shows the relationship between the measured RCS parameter and the object's physical size parameter. Each of the 2072 points on this plot is a weighted average for a single object over hundreds of different orientations at a single frequency. The data were weighted to account for nonuniform sampling of the object orientations as the data were collected.

From this plot, a scaling curve (smooth solid line) was developed, which represents the mean of the measured RCS for each size/wavelength. For debris sizes much smaller or larger than the radar wavelength, the scaling curve approaches the Rayleigh or optics region curves, as expected. Between the Rayleigh and optics region curves is the Mie resonance region that results in an enhanced RCS measurement, on average, for a given size. In the resonance region, the scaling curve deviates from the optical curve (not shown) such that for a given RCS, the object is smaller in characteristic length than it would have been

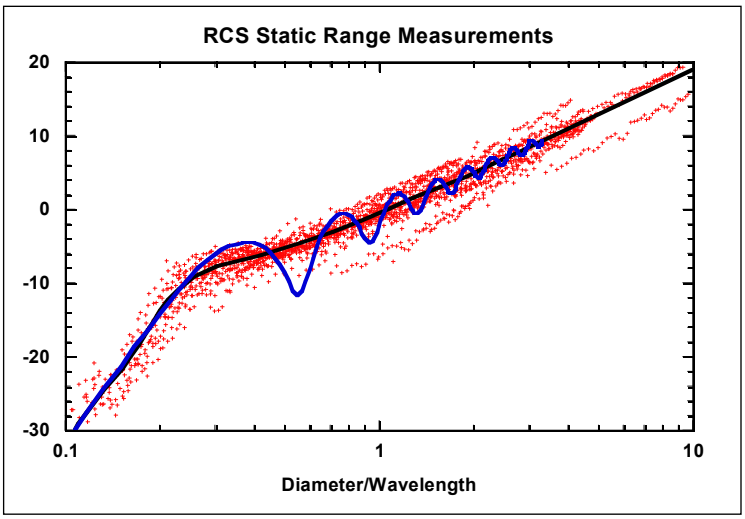

Figure E-1. Results of RCS-to-Physical size measurements on 39 "representative" debris objects over the frequency range 2.0 - 18 GHz (15 - 1.67 cm wavelength). Each point represents an average RCS for a single object measured at a single frequency over many orientations. The oscillating line is the radar cross section for a spherical conductor while the smooth line is the polynomial fit to the data.

interpreted to be by using the optical approximation. The scaling curve may be expressed as:

$x = \sqrt{\frac{4z}{\pi}}$, for $z > 5$, Optical Regime

$x = \sqrt[6]{\frac{4z}{9\pi^5}}$, for $z < 0.03$, Rayleigh Regime

$x = g(z)$, in between, Mie Resonance Regime

where z = RCS/λ, x = diameter/λ, and λ is wavelength. In the above equations, the quantity z is assumed to not be expressed in dB. The smooth function g(z) is expressed by 23 points in Table E-1.

Table E-1. The NASA SEM curve x=g(z) in the Mie resonance region.

x=diameter/λ	z=RCS/λ²
0.10997	0.001220
0.11685	0.001735
0.12444	0.002468
0.13302	0.003511
0.14256	0.004993
0.15256	0.007102
0.16220	0.01010
0.17138	0.01437
0.18039	0.02044
0.18982	0.02907
0.20014	0.04135
0.21237	0.05881
0.22902	0.08365
0.25574	0.1190
0.30537	0.1692
0.42028	0.2407
0.56287	0.3424
0.71108	0.4870
0.86714	0.6927
1.0529	0.9852
1.2790	1.401
1.5661	1.993
1.8975	2.835

Note that most of the debris for Haystack is in the Rayleigh region, which allows size estimates that are relatively insensitive to errors in the RCS measurements.

For comparison, the oscillating RCS-to-size curve for a spherical conductor is shown in the figure. The NASA SEM is not applicable to estimate sizes of spherical conductors (such as NaK droplets) in the Mie Resonance region. The oscillations result from constructive and destructive interference of electromagnetically induced waves on the surface of the conducting sphere.

The size-to-RCS curve for a spherical conductor is expressed theoretically as:

$$z = \frac{1}{\pi}\left|\sum_{n=1}^{\infty}(-1)^n\left(n+\frac{1}{2}\right)(b_n - a_n)\right|^2$$

where the coefficients a_n and b_n are

$$a_n = \frac{j_n(2\pi x)}{h_n^{(2)}(2\pi x)}$$

$$b_n = \frac{2\pi x \cdot j_{n-1}(2\pi x) - n \cdot j_n(2\pi x)}{2\pi x \cdot h_{n-1}^{(2)}(2\pi x) - n \cdot h_n^{(2)}(2\pi x)}$$

where $h_n^{(2)}(x) = j_n(x) - i \cdot y_n(x)$, in which $j_n(x)$ and $y_n(x)$ are the spherical Bessel functions of the first and second kinds, respectively.