

Terriers rescue attempt from McMurdo ground station

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This report describes the Terriers rescue attempt from McMurdo ground station (MGS) that took place from December 15th through December 24th 1999. The purpose of using MGS was to take advantage of the high albedo of the Antarctic ice near the winter solstice. It was hoped that the reflected sunlight off the snow and ice over the large Antarctic continent would be sufficient to illuminate the Terriers' solar panel and allow the satellite to power up.

1 Satellite description

The Terriers satellite was launched into a polar sun synchronous orbit in May of 1999. The telemetry link was established for the second and third (the first one was low on the horizon and we didn't get a link) passes over the ground station at Boston University. House keeping data collected during these passes indicated that the battery voltage was decreasing and that soon the satellite would be out of power, if it did not point the solar panel towards the sun. Contact has not been established with the satellite since.

Analysis of the housekeeping data indicated that the satellite attitude control system (ACS) had spun up the satellite properly, but was not slewing the spin vector (normal to the solar panel) towards the sun. Examination of satellite ground test data along with satellite simulations concluded that the cause of the problem was that the Y axis magnetic torque coil polarity was reversed. Initial ground measurements from NORAD, indicated that the satellite had indeed spun up and that the solar panel was oriented away from the sun. Later measurements indicated that the satellite was spinning down at a linear rate. This linear spin down rate would most likely be caused by Mu metal in one of the instruments also by the cadmium and nickle in the batteries acting on the Earth's magnetic field.

Simulations show that with the satellite powered down for long periods of time, the satellite will eventually enter a tumble that is not periodic to the orbital rotation period. The primary torques operating on the satellite are due to the Earth's magnetic field, acting on the soft Mu metal and on any permanent magnetic dipole moments on the satellite, and the Earth's gravity gradient torque. The gravity gradient torque taken alone, would allow the satellite to enter a stable Thompson spinner mode with the satellite body making one revolution per orbit (i.e. +Y solar panel normal vector pointed to the orbit normal and the satellite +Z or -Z axis always pointed nadir). The Earth's magnetic field operating on the Mu metal and and permanent dipole in the satellite produce body torques that are periodic at twice the orbital frequency. Taken together, however, these disturbance torques cause a somewhat chaotic satellite motion that is aperiodic with the orbital period. It is difficult to predict the actual tumble of the satellite due to the level of uncertainty of the magnitude of the Mu metal and dipole effects and also due to uncertainty of the second order external torques (such as aero drag and solar pressure). However, it is highly *unlikely* that the satellite attitude is fixed in inertial space.

2 MGS pass geometry

Near the solstice time period, the distribution of ice in Antarctica is nearly symmetric about the pole and extends nearly to the Antarctic circle. This symmetry, combined with the sun synchronous orbit of the satellite presents a constant ice albedo effect to the satellite for all passes. The only variable from orbit to orbit is the relative location of MGS. This can be seen in the Figure 1. The MGS locations for orbit numbers 3189 through 3192 and 3203 are shown. Many other orbits and orientations were also tracked. The orbits with MGS nearest the orbit plane provide the highest elevation angles and longest passes. Table 1 shows the azimuth, elevation and time for the rising, maximum elevation and setting of the satellite as seen from MGS vs. orbit number.

Table 1: Passes covered at MGS.

Action	Time	Az	El	Orbit	Action	Time	Az	El	Orbit
AOS Horizon	1999 350 01:00:13	132.275	0.045	3189	AOS Horizon	1999 352 00:48:16	134.353	0.017	3219
AOS Mask	1999 350 01:00:13	132.275	0.045	3189	AOS Mask	1999 352 00:48:16	134.353	0.017	3219
PCA	1999 350 01:06:28	210.384	77.571	3189	PCA	1999 352 00:54:31	204.691	81.859	3219
LOS Mask	1999 350 01:12:46	304.567	0.027	3189	LOS Mask	1999 352 01:00:50	308.361	0.032	3219
LOS Horizon	1999 350 01:12:46	304.567	0.027	3189	LOS Horizon	1999 352 01:00:50	308.361	0.032	3219
AOS Horizon	1999 350 02:34:48	113.919	0.049	3190	AOS Horizon	1999 352 02:22:53	116.471	0.039	3220
AOS Mask	1999 350 02:34:48	113.919	0.049	3190	AOS Mask	1999 352 02:22:53	116.471	0.039	3220
PCA	1999 350 02:41:03	197.222	55.992	3190	PCA	1999 352 02:29:08	199.729	57.524	3220
LOS Mask	1999 350 02:47:14	276.741	0.031	3190	LOS Mask	1999 352 02:35:20	280.077	0.020	3220
LOS Horizon	1999 350 02:47:14	276.741	0.031	3190	LOS Horizon	1999 352 02:35:20	280.077	0.020	3220
AOS Horizon	1999 350 04:09:12	91.467	0.017	3191	AOS Horizon	1999 352 03:57:18	94.563	0.015	3221
AOS Mask	1999 350 04:09:12	91.467	0.017	3191	AOS Mask	1999 352 03:57:18	94.563	0.015	3221
PCA	1999 350 04:15:27	174.424	53.382	3191	PCA	1999 352 04:03:33	177.616	52.822	3221
LOS Mask	1999 350 04:21:37	252.915	0.045	3191	LOS Mask	1999 352 04:09:43	255.721	0.019	3221
LOS Horizon	1999 350 04:21:37	252.915	0.045	3191	LOS Horizon	1999 352 04:09:43	255.721	0.019	3221
AOS Horizon	1999 350 05:43:37	64.891	0.035	3192	AOS Horizon	1999 352 05:31:42	68.489	0.025	3222
AOS Mask	1999 350 05:43:37	64.891	0.035	3192	AOS Mask	1999 352 05:31:42	68.489	0.025	3222
PCA	1999 350 05:49:52	148.480	68.021	3192	PCA	1999 352 05:37:57	152.266	64.959	3222
LOS Mask	1999 350 05:56:08	233.289	0.043	3192	LOS Mask	1999 352 05:44:12	235.569	0.043	3222
LOS Horizon	1999 350 05:56:08	233.289	0.043	3192	LOS Horizon	1999 352 05:44:12	235.569	0.043	3222
AOS Horizon	1999 350 07:18:17	34.794	0.006	3193	AOS Horizon	1999 352 07:06:20	38.782	0.048	3223
AOS Mask	1999 350 07:18:17	34.794	0.006	3193	AOS Mask	1999 352 07:06:20	38.782	0.048	3223
PCA	1999 350 07:24:32	313.142	75.116	3193	PCA	1999 352 07:12:35	316.095	80.662	3223
LOS Mask	1999 350 07:30:53	217.271	0.007	3193	LOS Mask	1999 352 07:18:55	219.147	0.013	3223
LOS Horizon	1999 350 07:30:53	217.271	0.007	3193	LOS Horizon	1999 352 07:18:55	219.147	0.013	3223
AOS Horizon	1999 350 23:19:25	148.210	0.032	3203	AOS Horizon	1999 352 23:07:26	149.923	0.045	3233
AOS Mask	1999 350 23:19:25	148.210	0.032	3203	AOS Mask	1999 352 23:07:26	149.923	0.045	3233
PCA	1999 350 23:25:40	65.705	58.985	3203	PCA	1999 352 23:13:41	66.917	54.222	3233
LOS Mask	1999 350 23:31:57	337.710	0.024	3203	LOS Mask	1999 352 23:19:56	341.880	0.028	3233
LOS Horizon	1999 350 23:31:57	337.710	0.024	3203	LOS Horizon	1999 352 23:19:56	341.880	0.028	3233
AOS Horizon	1999 351 00:54:15	133.320	0.043	3204	AOS Horizon	1999 353 00:42:17	135.375	0.017	3234
AOS Mask	1999 351 00:54:15	133.320	0.043	3204	AOS Mask	1999 353 00:42:17	135.375	0.017	3234
PCA	1999 351 01:00:30	209.497	79.728	3204	PCA	1999 353 00:48:32	198.745	84.085	3234
LOS Mask	1999 351 01:06:48	306.456	0.043	3204	LOS Mask	1999 353 00:54:51	310.281	0.046	3234
LOS Horizon	1999 351 01:06:48	306.456	0.043	3204	LOS Horizon	1999 353 00:54:51	310.281	0.046	3234
AOS Horizon	1999 351 02:28:50	115.190	0.006	3205	AOS Horizon	1999 353 02:16:55	117.729	0.047	3235
AOS Mask	1999 351 02:28:50	115.190	0.006	3205	AOS Mask	1999 353 02:16:55	117.729	0.047	3235
PCA	1999 351 02:35:05	197.592	56.728	3205	PCA	1999 353 02:23:10	201.254	58.407	3235
LOS Mask	1999 351 02:41:17	278.396	0.037	3205	LOS Mask	1999 353 02:29:22	281.768	0.031	3235
LOS Horizon	1999 351 02:41:17	278.396	0.037	3205	LOS Horizon	1999 353 02:29:22	281.768	0.031	3235
AOS Horizon	1999 351 04:03:15	93.019	0.005	3206	AOS Horizon	1999 353 03:51:21	96.102	0.050	3236
AOS Mask	1999 351 04:03:15	93.019	0.005	3206	AOS Mask	1999 353 03:51:21	96.102	0.050	3236
PCA	1999 351 04:09:30	175.790	53.074	3206	PCA	1999 353 03:57:36	179.896	52.621	3236
LOS Mask	1999 351 04:15:40	254.304	0.042	3206	LOS Mask	1999 353 04:03:45	257.145	0.027	3236
LOS Horizon	1999 351 04:15:40	254.304	0.042	3206	LOS Horizon	1999 353 04:03:45	257.145	0.027	3236
AOS Horizon	1999 351 05:37:40	66.699	0.045	3207	AOS Horizon	1999 353 05:25:44	70.270	0.025	3237
AOS Mask	1999 351 05:37:40	66.699	0.045	3207	AOS Mask	1999 353 05:25:44	70.270	0.025	3237
PCA	1999 351 05:43:55	150.948	66.441	3207	PCA	1999 353 05:31:59	154.221	63.572	3237
LOS Mask	1999 351 05:50:11	234.429	0.001	3207	LOS Mask	1999 353 05:38:14	236.740	0.013	3237
LOS Horizon	1999 351 05:50:11	234.429	0.001	3207	LOS Horizon	1999 353 05:38:14	236.740	0.013	3237
AOS Horizon	1999 351 07:12:19	36.788	0.044	3208	AOS Horizon	1999 353 07:00:20	40.773	0.018	3238
AOS Mask	1999 351 07:12:19	36.788	0.044	3208	AOS Mask	1999 353 07:00:20	40.773	0.018	3238
PCA	1999 351 07:18:34	313.473	77.915	3208	PCA	1999 353 07:06:35	323.820	83.292	3238
LOS Mask	1999 351 07:24:54	218.205	0.020	3208	LOS Mask	1999 353 07:12:55	220.106	0.038	3238
LOS Horizon	1999 351 07:24:54	218.205	0.020	3208	LOS Horizon	1999 353 07:12:55	220.106	0.038	3238
AOS Horizon	1999 351 23:13:26	149.064	0.051	3218	AOS Horizon	1999 353 23:01:25	150.790	0.014	3248
AOS Mask	1999 351 23:13:26	149.064	0.051	3218	AOS Mask	1999 353 23:01:25	150.790	0.014	3248
PCA	1999 351 23:19:41	65.970	56.571	3218	PCA	1999 353 23:07:40	68.394	51.950	3248
LOS Mask	1999 351 23:25:57	339.784	0.016	3218	LOS Mask	1999 353 23:13:55	343.971	0.010	3248
LOS Horizon	1999 351 23:25:57	339.784	0.016	3218	LOS Horizon	1999 353 23:13:55	343.971	0.010	3248

Action	Time	Az	El	Orbit	Action	Time	Az	El	Orbit
AOS Horizon	1999 354 00:36:18	136.384	0.043	3249	AOS Horizon	1999 355 06:48:20	44.719	0.009	3268
AOS Mask	1999 354 00:36:18	136.384	0.043	3249	AOS Mask	1999 355 06:48:20	44.719	0.009	3268
PCA	1999 354 00:42:33	188.731	86.418	3249	PCA	1999 355 06:54:35	6.081	88.105	3268
LOS Mask	1999 354 00:48:52	312.215	0.031	3249	LOS Mask	1999 355 07:00:55	222.052	0.030	3268
LOS Horizon	1999 354 00:48:52	312.215	0.031	3249	LOS Horizon	1999 355 07:00:55	222.052	0.030	3268
AOS Horizon	1999 354 02:10:56	118.964	0.030	3250	AOS Horizon	1999 355 08:23:21	12.702	0.019	3269
AOS Mask	1999 354 02:10:56	118.964	0.030	3250	AOS Mask	1999 355 08:23:21	12.702	0.019	3269
PCA	1999 354 02:17:11	202.107	59.381	3250	PCA	1999 355 08:29:36	288.534	48.548	3269
LOS Mask	1999 354 02:23:24	283.484	0.018	3250	LOS Mask	1999 355 08:35:49	207.891	0.021	3269
LOS Horizon	1999 354 02:23:24	283.484	0.018	3250	LOS Horizon	1999 355 08:35:49	207.891	0.021	3269
AOS Horizon	1999 354 03:45:22	97.595	0.006	3251	AOS Horizon	1999 355 22:49:23	152.462	0.031	3278
AOS Mask	1999 354 03:45:22	97.595	0.006	3251	AOS Mask	1999 355 22:49:23	152.462	0.031	3278
PCA	1999 354 03:51:37	180.566	52.525	3251	PCA	1999 355 22:55:38	69.879	47.672	3278
LOS Mask	1999 354 03:57:47	258.597	0.013	3251	LOS Mask	1999 355 23:01:50	348.221	0.034	3278
LOS Horizon	1999 354 03:57:47	258.597	0.013	3251	LOS Horizon	1999 355 23:01:50	348.221	0.034	3278
AOS Horizon	1999 354 05:19:46	72.043	0.045	3252	AOS Horizon	1999 356 00:24:17	138.372	0.021	3279
AOS Mask	1999 354 05:19:46	72.043	0.045	3252	AOS Mask	1999 356 00:24:17	138.372	0.021	3279
PCA	1999 354 05:26:01	156.714	62.272	3252	PCA	1999 356 00:30:32	94.811	86.605	3279
LOS Mask	1999 354 05:32:15	237.922	0.016	3252	LOS Mask	1999 356 00:36:52	316.127	0.021	3279
LOS Horizon	1999 354 05:32:15	237.922	0.016	3252	LOS Horizon	1999 356 00:36:52	316.127	0.021	3279
AOS Horizon	1999 354 06:54:20	42.752	0.004	3253	AOS Horizon	1999 356 01:58:57	121.398	0.022	3280
AOS Mask	1999 354 06:54:20	42.752	0.004	3253	AOS Mask	1999 356 01:58:57	121.398	0.022	3280
PCA	1999 354 07:00:35	335.548	85.835	3253	PCA	1999 356 02:05:12	204.333	61.587	3280
LOS Mask	1999 354 07:06:55	221.074	0.044	3253	LOS Mask	1999 356 02:11:26	286.961	0.022	3280
LOS Horizon	1999 354 07:06:55	221.074	0.044	3253	LOS Horizon	1999 356 02:11:26	286.961	0.022	3280
AOS Horizon	1999 354 08:29:23	10.589	0.000	3254	AOS Horizon	1999 356 03:33:25	100.581	0.041	3281
AOS Mask	1999 354 08:29:23	10.589	0.000	3254	AOS Mask	1999 356 03:33:25	100.581	0.041	3281
PCA	1999 354 08:35:38	287.029	46.506	3254	PCA	1999 356 03:39:40	184.333	52.466	3281
LOS Mask	1999 354 08:41:50	207.064	0.031	3254	LOS Mask	1999 356 03:45:49	261.544	0.025	3281
LOS Horizon	1999 354 08:41:50	207.064	0.031	3254	LOS Horizon	1999 356 03:45:49	261.544	0.025	3281
AOS Horizon	1999 354 22:55:24	151.637	0.009	3263	AOS Horizon	1999 356 05:07:48	75.541	0.047	3282
AOS Mask	1999 354 22:55:24	151.637	0.009	3263	AOS Mask	1999 356 05:07:48	75.541	0.047	3282
PCA	1999 354 23:01:39	69.346	49.769	3263	PCA	1999 356 05:14:03	160.343	59.951	3282
LOS Mask	1999 354 23:07:53	346.084	0.012	3263	LOS Mask	1999 356 05:20:16	240.341	0.012	3282
LOS Horizon	1999 354 23:07:53	346.084	0.012	3263	LOS Horizon	1999 356 05:20:16	240.341	0.012	3282
AOS Horizon	1999 355 00:30:18	137.382	0.045	3264	AOS Horizon	1999 356 06:42:20	46.676	0.031	3283
AOS Mask	1999 355 00:30:18	137.382	0.045	3264	AOS Mask	1999 356 06:42:20	46.676	0.031	3283
PCA	1999 355 00:36:33	145.065	87.857	3264	PCA	1999 356 06:48:35	98.844	88.192	3283
LOS Mask	1999 355 00:42:52	314.165	0.040	3264	LOS Mask	1999 356 06:54:54	223.046	0.048	3283
LOS Horizon	1999 355 00:42:52	314.165	0.040	3264	LOS Horizon	1999 356 06:54:54	223.046	0.048	3283
AOS Horizon	1999 355 02:04:57	120.191	0.039	3265	AOS Horizon	1999 356 08:17:18	14.832	0.002	3284
AOS Mask	1999 355 02:04:57	120.191	0.039	3265	AOS Mask	1999 356 08:17:18	14.832	0.002	3284
PCA	1999 355 02:11:12	203.586	60.437	3265	PCA	1999 356 08:23:33	290.689	50.693	3284
LOS Mask	1999 355 02:17:25	285.210	0.032	3265	LOS Mask	1999 356 08:29:47	208.745	0.041	3284
LOS Horizon	1999 355 02:17:25	285.210	0.032	3265	LOS Horizon	1999 356 08:29:47	208.745	0.041	3284
AOS Horizon	1999 355 03:39:24	99.101	0.037	3266	AOS Horizon	1999 356 22:43:21	153.296	0.027	3293
AOS Mask	1999 355 03:39:24	99.101	0.037	3266	AOS Mask	1999 356 22:43:21	153.296	0.027	3293
PCA	1999 355 03:45:39	182.732	52.457	3266	PCA	1999 356 22:49:36	70.896	45.659	3293
LOS Mask	1999 355 03:51:48	260.057	0.030	3266	LOS Mask	1999 356 22:55:47	350.349	0.025	3293
LOS Horizon	1999 355 03:51:48	260.057	0.030	3266	LOS Horizon	1999 356 22:55:47	350.349	0.025	3293
AOS Horizon	1999 355 05:13:47	73.796	0.036	3267	AOS Horizon	1999 357 00:18:16	139.349	0.024	3294
AOS Mask	1999 355 05:13:47	73.796	0.036	3267	AOS Mask	1999 357 00:18:16	139.349	0.024	3294
PCA	1999 355 05:20:02	158.259	61.071	3267	PCA	1999 357 00:24:31	75.183	84.432	3294
LOS Mask	1999 355 05:26:15	239.114	0.049	3267	LOS Mask	1999 357 00:30:51	318.105	0.025	3294
LOS Horizon	1999 355 05:26:15	239.114	0.049	3267	LOS Horizon	1999 357 00:30:51	318.105	0.025	3294

Action	Time	Az	El	Orbit	Action	Time	Az	El	Orbit
AOS Horizon	1999 357 01:52:57	122.596	0.031	3295	AOS Horizon	1999 359 01:40:55	124.942	0.026	3325
AOS Mask	1999 357 01:52:57	122.596	0.031	3295	AOS Mask	1999 359 01:40:55	124.942	0.026	3325
PCA	1999 357 01:59:12	205.758	62.827	3295	PCA	1999 359 01:47:10	207.719	65.600	3325
LOS Mask	1999 357 02:05:26	288.722	0.039	3295	LOS Mask	1999 359 01:53:25	292.305	0.048	3325
LOS Horizon	1999 357 02:05:26	288.722	0.039	3295	LOS Horizon	1999 359 01:53:25	292.305	0.048	3325
AOS Horizon	1999 357 03:27:25	102.035	0.019	3296	AOS Horizon	1999 359 03:15:25	104.922	0.048	3326
AOS Mask	1999 357 03:27:25	102.035	0.019	3296	AOS Mask	1999 359 03:15:25	104.922	0.048	3326
PCA	1999 357 03:33:40	185.372	52.556	3296	PCA	1999 359 03:21:40	188.874	52.892	3326
LOS Mask	1999 357 03:39:49	263.040	0.050	3296	LOS Mask	1999 359 03:27:49	266.114	0.036	3326
LOS Horizon	1999 357 03:39:49	263.040	0.050	3296	LOS Horizon	1999 359 03:27:49	266.114	0.036	3326
AOS Horizon	1999 357 05:01:48	77.264	0.029	3297	AOS Horizon	1999 359 04:49:47	80.671	0.006	3327
AOS Mask	1999 357 05:01:48	77.264	0.029	3297	AOS Mask	1999 359 04:49:47	80.671	0.006	3327
PCA	1999 357 05:08:03	161.606	58.932	3297	PCA	1999 359 04:56:02	164.458	57.139	3327
LOS Mask	1999 357 05:14:16	241.578	0.007	3297	LOS Mask	1999 359 05:02:14	244.094	0.039	3327
LOS Horizon	1999 357 05:14:16	241.578	0.007	3297	LOS Horizon	1999 359 05:02:14	244.094	0.039	3327
AOS Horizon	1999 357 06:36:19	48.626	0.019	3298	AOS Horizon	1999 359 06:24:17	52.494	0.050	3328
AOS Mask	1999 357 06:36:19	48.626	0.019	3298	AOS Mask	1999 359 06:24:17	52.494	0.050	3328
PCA	1999 357 06:42:34	120.840	85.843	3298	PCA	1999 359 06:30:32	136.970	81.142	3328
LOS Mask	1999 357 06:48:53	224.053	0.047	3298	LOS Mask	1999 359 06:36:50	226.108	0.037	3328
LOS Horizon	1999 357 06:48:53	224.053	0.047	3298	LOS Horizon	1999 359 06:36:50	226.108	0.037	3328
AOS Horizon	1999 357 08:11:16	16.920	0.050	3299	AOS Horizon	1999 359 07:59:09	21.137	0.039	3329
AOS Mask	1999 357 08:11:16	16.920	0.050	3299	AOS Mask	1999 359 07:59:09	21.137	0.039	3329
PCA	1999 357 08:17:31	291.552	52.913	3299	PCA	1999 359 08:05:24	295.408	57.653	3329
LOS Mask	1999 357 08:23:45	209.595	0.043	3299	LOS Mask	1999 359 08:11:40	211.318	0.038	3329
LOS Horizon	1999 357 08:23:45	209.595	0.043	3299	LOS Horizon	1999 359 08:11:40	211.318	0.038	3329
AOS Horizon	1999 358 00:12:14	140.319	0.002	3309	AOS Horizon	1999 360 00:00:10	142.216	0.038	3339
AOS Mask	1999 358 00:12:14	140.319	0.002	3309	AOS Mask	1999 360 00:00:10	142.216	0.038	3339
PCA	1999 358 00:18:29	70.199	81.782	3309	PCA	1999 360 00:06:25	62.658	76.539	3339
LOS Mask	1999 358 00:24:50	320.093	0.000	3309	LOS Mask	1999 360 00:12:45	324.119	0.018	3339
LOS Horizon	1999 358 00:24:50	320.093	0.000	3309	LOS Horizon	1999 360 00:12:45	324.119	0.018	3339
AOS Horizon	1999 358 01:46:56	123.773	0.015	3310	AOS Horizon	1999 360 01:34:53	126.093	0.011	3340
AOS Mask	1999 358 01:46:56	123.773	0.015	3310	AOS Mask	1999 360 01:34:53	126.093	0.011	3340
PCA	1999 358 01:53:11	206.367	64.163	3310	PCA	1999 360 01:41:08	208.129	67.131	3340
LOS Mask	1999 358 01:59:26	290.508	0.030	3310	LOS Mask	1999 360 01:47:24	294.124	0.041	3340
LOS Horizon	1999 358 01:59:26	290.508	0.030	3310	LOS Horizon	1999 360 01:47:24	294.124	0.041	3340
AOS Horizon	1999 358 03:21:25	103.482	0.021	3311	AOS Horizon	1999 360 03:09:24	106.337	0.048	3341
AOS Mask	1999 358 03:21:25	103.482	0.021	3311	AOS Mask	1999 360 03:09:24	106.337	0.048	3341
PCA	1999 358 03:27:40	186.883	52.697	3311	PCA	1999 360 03:15:39	190.309	53.169	3341
LOS Mask	1999 358 03:33:50	264.582	0.003	3311	LOS Mask	1999 360 03:21:48	267.674	0.048	3341
LOS Horizon	1999 358 03:33:50	264.582	0.003	3311	LOS Horizon	1999 360 03:21:48	267.674	0.048	3341
AOS Horizon	1999 358 04:55:48	78.979	0.032	3312	AOS Horizon	1999 360 04:43:46	82.355	0.002	3342
AOS Mask	1999 358 04:55:48	78.979	0.032	3312	AOS Mask	1999 360 04:43:46	82.355	0.002	3342
PCA	1999 358 05:02:03	163.400	57.987	3312	PCA	1999 360 04:50:01	166.031	56.360	3342
LOS Mask	1999 358 05:08:15	242.824	0.033	3312	LOS Mask	1999 360 04:56:13	245.389	0.025	3342
LOS Horizon	1999 358 05:08:15	242.824	0.033	3312	LOS Horizon	1999 360 04:56:13	245.389	0.025	3342
AOS Horizon	1999 358 06:30:18	50.565	0.026	3313	AOS Horizon	1999 360 06:18:15	54.413	0.042	3343
AOS Mask	1999 358 06:30:18	50.565	0.026	3313	AOS Mask	1999 360 06:18:15	54.413	0.042	3343
PCA	1999 358 06:36:33	130.110	83.469	3313	PCA	1999 360 06:24:30	139.077	78.859	3343
LOS Mask	1999 358 06:42:52	225.073	0.026	3313	LOS Mask	1999 360 06:30:48	227.158	0.028	3343
LOS Horizon	1999 358 06:42:52	225.073	0.026	3313	LOS Horizon	1999 360 06:30:48	227.158	0.028	3343
AOS Horizon	1999 358 08:05:12	19.049	0.012	3314	AOS Horizon	1999 360 07:53:05	23.236	0.031	3344
AOS Mask	1999 358 08:05:12	19.049	0.012	3314	AOS Mask	1999 360 07:53:05	23.236	0.031	3344
PCA	1999 358 08:11:27	294.202	55.245	3314	PCA	1999 360 07:59:20	297.464	60.149	3344
LOS Mask	1999 358 08:17:43	210.444	0.025	3314	LOS Mask	1999 360 08:05:37	212.192	0.033	3344
LOS Horizon	1999 358 08:17:43	210.444	0.025	3314	LOS Horizon	1999 360 08:05:37	212.192	0.033	3344
AOS Horizon	1999 359 00:06:12	141.276	0.007	3324	AOS Horizon	1999 360 23:54:07	143.151	0.044	3354
AOS Mask	1999 359 00:06:12	141.276	0.007	3324	AOS Mask	1999 360 23:54:07	143.151	0.044	3354
PCA	1999 359 00:12:27	66.228	79.162	3324	PCA	1999 361 00:00:22	61.986	73.806	3354
LOS Mask	1999 359 00:18:47	322.106	0.050	3324	LOS Mask	1999 361 00:06:42	326.148	0.009	3354
LOS Horizon	1999 359 00:18:47	322.106	0.050	3324	LOS Horizon	1999 361 00:06:42	326.148	0.009	3354

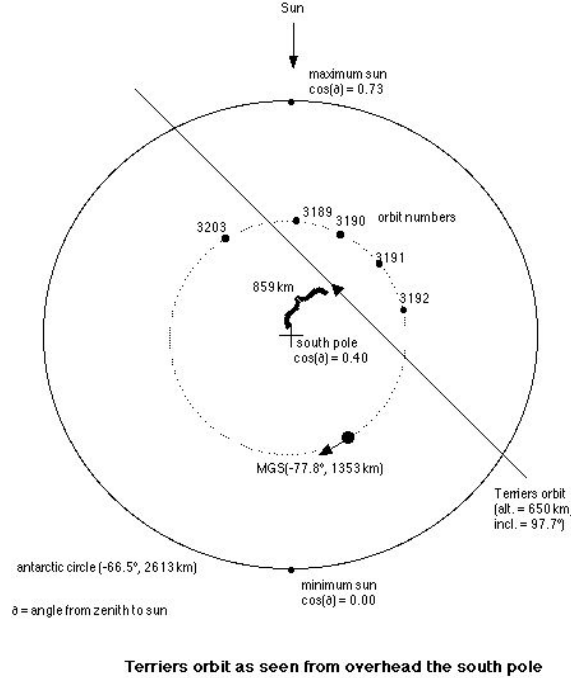


Figure 1: The TERRIERS pass geometry from MGS.

2.1 Panel illumination vs. orbit position

The albedo from the ice can be very high for certain angles at certain wavelengths. For a Lambert surface, numbers between 0.6 to 0.7 are typically used as an average over all angles. A Lambert surface is one in which the intensity of the reflected light per unit solid angle is a function only of the angle between the unit normal vector to the surface and the vector to the sun. A numerical integration, assuming the ice is a Lambert surface with 100% albedo and assuming that the ice is continuous out to the Antarctic circle (very optimistic), was carried out for the Terriers orbit assuming that the panel was pointed downward (see Figure 2) (best case) and that the panel was pointed orbit normal (see Figure 3) (more likely case). The Y axis is the fraction of full normal sun at 1 AU (1 AM0). The X axis is the phase of the orbit in the orbit plane in radians from the South to North equatorial crossing. The peak illumination for the downward case results in the panel seeing about 0.45 AM0. The more likely case of the panel being pointed to the orbit normal, results in a peak illumination of about 0.13 AM0. Both peaks occur when the satellite is slightly ahead of its closest approach to the pole (even though the satellite is in view of the greatest amount of the ice when closest to the pole, the ice further north, towards the sun, is brighter due to the sun being at a higher elevation angle there).

3 Terriers power system and boot requirements

Design flaws in the Terriers power system make recovering the satellite (with dead batteries) from the Antarctic albedo difficult. Measurements performed on a satellite engineering model after launch indicate that with dead batteries, about 35% to 85% (depending on the bootup state of the satellite) of full sunlight on the panel is needed to get the satellite to boot up. In addition, the power system can get in a stuck state such that when illumination is applied to the solar panel, it might not boot up at all. How the satellite on orbit will respond to sunlight on the panel with dead batteries, depends on the state of the power system (i.e. main relay switch) when the satellite initially ran out of battery power, which is unknown. (Tests on

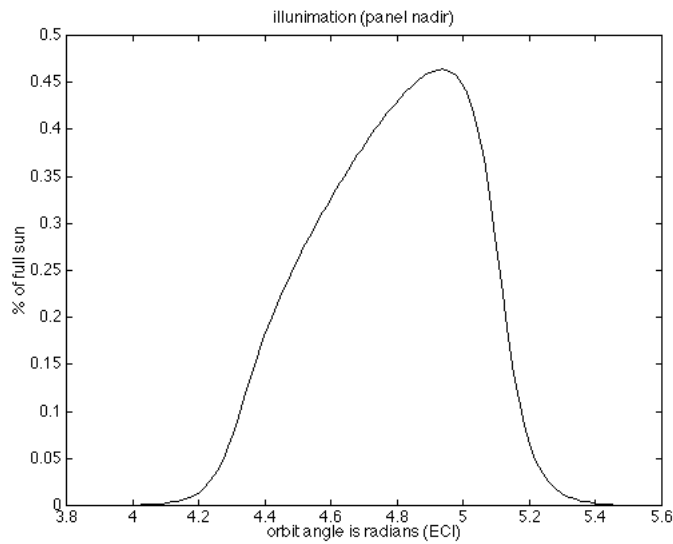


Figure 2: Percentage of a full sun on a nadir pointing TERRIERS array for a Lambertian surface out to the Antarctic circle.

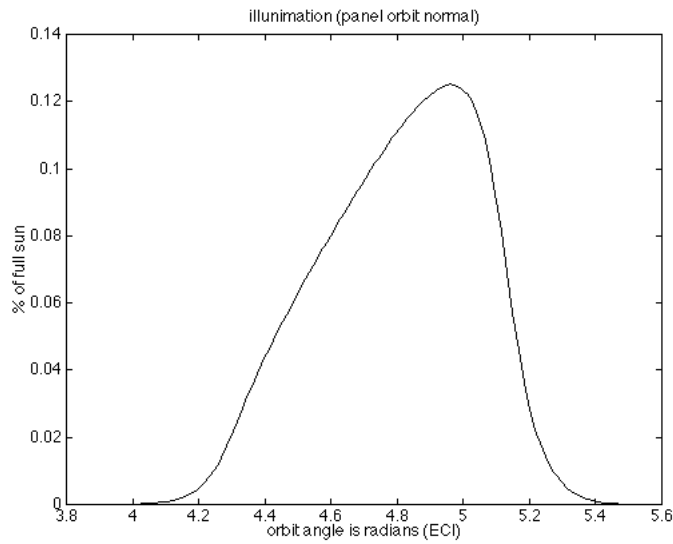


Figure 3: Percentage of a full sun on a nadir pointing TERRIERS array for a Lambertian surface out to the Antarctic circle.

the satellite engineering model indicate that the main relay switch should have remained open. However, if the satellite has been seeing the sun for the past 5 months, then every time the power goes down there is a chance it will end up in the “bad” state.) The albedo effect alone for the best case (panel pointed nadir) might provide enough power for the satellite to boot. Even though it is unlikely that the satellite would maintain this attitude over the entire orbit, it is somewhat likely that the satellite would find itself with its panel pointed nadir when near the south pole for some passes, if it were slowly tumbling. It is also possible for the panel to be oriented at an angle where it sees some direct sunlight and that this sunlight combined with the albedo effect is enough to provide the needed illumination on the panel for the satellite to boot up.