Evaluation of the Opportunity to Launch Prowler on STS 38

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Abstract

Space shuttle Atlantis was launched on STS 38, a classified DoD mission, in November 1990. It was officially acknowledged to have deployed a single satellite, later identified by researchers as SDS 2-2, a geosynchronous NRO communications relay. The deployment of a second satellite has since leaked out: an optically stealthy, geosynchronous satellite inspector, named Prowler. A retrospective analysis confirms that STS 38 had the opportunity to launch Prowler.

Atlantis could easily have launched the combined mass of both satellites and accommodated them within its payload bay. The orbital and observational history of STS 38 reveals the time of both payload deployments, and narrows the time of the PKM firings to a roughly half day period.

Prowler was at risk of detection by the Soviet Union's space surveillance and SIGINT systems, from deployment until arrival at its initial location in GEO. Taking into account likely detection avoidance measures narrows the time of its PKM firing to three revolutions.

Evidence of deception consistent with providing cover for Prowler is found in the shuttle's non-standard payload separation manoeuvres after both satellite deployments, and the apparent timing of Prowler's deployment to avoid detection by the SIGINT facility at Lourdes, Cuba.

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Acknowledgements

Thank you Jonathan McDowell, for building and maintaining your unique record of launch dates and times, satellite catalogue, and archive of historical TLEs, which were referred to countless times throughout this study.

Thank you Allen Thomson for helpful suggestions and encouragement.

1. Summary

Space shuttle Atlantis was launched on STS 38, a classified DoD mission, in November 1990. It was officially acknowledged to have deployed a single payload, and the public observed a single payload - orbiting in formation with Atlantis - eventually identified as SDS 2-2, a geosynchronous communications relay belonging to the National Reconnaissance Office.

The story that STS 38 had also launched Prowler began to leak out to the public in 1999. It was an experimental and highly classified geosynchronous satellite inspector, with stealth capability. A recent report identified a GEO object discovered in 1998 as Prowler. Its optical and orbital characteristics correlate strongly, but circumstantially, with the Prowler story. The report also made public the revelation that Prowler was built on the HS-376 satellite bus.

Very little of the Prowler story has been revealed – none of it officially – so there is room for doubt, and a desire to learn more, which is the motivation for this report.

Whether STS 38 had the opportunity to orbit Prowler has been evaluated with respect to the following questions. Could the shuttle have lifted the extra mass? Would it have fit in its payload bay? Is there evidence of both satellite deployments in the orbital and observational history of STS 38? Was Prowler at risk of detection by the Soviet Union, and how could it have been avoided? Is there evidence of detection avoidance or other forms of deception, consistent with the Prowler story?

There is now sufficient information about SDS 2-2 and Prowler to conclude that Atlantis could easily have launched their combined mass, and accommodated both within its payload bay.

STS 38 provided cover for Prowler by means of a performance staged to enable the Soviets to readily detect SDS 2-2, while remaining unaware of Prowler. Whether they were deceived is unknown, but the general public certainly was. Only after its existence leaked out, was there reason to revisit the facts surrounding STS 38, to see what might have been overlooked.

The orbital and observational history of STS 38 reveals evidence of both satellite deployments, which differed significantly from standard practice, to help conceal Prowler. Atlantis deployed SDS 2-2 about 7 hours after launch, and separated from it by raising its orbit slightly, with delta-V less then one tenth normal for the size of SDS 2-2's perigee-kick motor (PKM). In another departure from normal, the satellite lingered in LEO, instead of firing its PKM at the next node.

Atlantis deployed Prowler nearly 22 hours after it deployed SDS 2-2, and separated from it with an unusual manoeuvre, that lowered its orbit instead of raising it. It also happenned to arrest the separation from the SDS - by then more than 250 km ahead of Atlantis – and initiate a very gradual overtaking, perhaps to create the impression of a rough station-keeping manoeuvre, to keep Soviet attention focussed on the SDS.

The orbit manoeuvres and visual observations narrow the time of Prowler's PKM firing to the 12 hour period following its deployment. SDS 2-2's PKM firing occurred within a 16.5 hour period that overlapped that of Prowler.

Prowler was at risk of detection by the Soviet Union's space surveillance and SIGINT systems, from deployment until arrival at its initial location in GEO. Likely detection avoidance measures have been taken into consideration to gain insight into the timing of its deployment, and further narrow the time of its PKM firing. Several optical and radar sites could have detected Prowler,

which could have been avoided by scheduling its deployment and PKM firing to occur when beyond their horizon.

The SIGINT site at Lourdes, Cuba, might have been able to detect Prowler, which could have been avoided while in LEO by scheduling the deployment and PKM firing to occur outside the ten hour daily period when the orbital plane was above the horizon. The GTO and initial GEO orbit would have been within range of Lourdes; however, detection might have been avoided using one of several methods listed in Section 7.3.

Immediately preceding Prowler's deployment, Atlantis and the already deployed SDS 2-2 made seven consecutive passes of Lourdes. Their radio transmissions should have been readily detected on most of them, and they could have been seen visually on one (weather permitting), enabling accurate determination of their orbits, and firmly establishing in the minds of Soviet analysts that they had tracked *the* payload of STS 38.

Atlantis deployed Prowler a few minutes after the last of the Lourdes passes, which suggests great caution to avoid detection, and a well-timed performance staged for the Soviets.

Avoiding detection by the Soviet radar and optical space surveillance system constrained Prowler's PKM firing to the three consecutive descending nodes beginning at MET 1:09:18 (d:hh:mm), resulting in first apogee between 40 W and 86 W. Check-out and testing likely was performed at a location co-longitudinal with the continental U.S.A. - within sight of its operators, and at least as importantly, out of sight of Russia.

The deception continued after STS 38, in USSTRATCOM's satellite catalogue, which acknowledged only the SDS, officially named USA 67, and attributed both PKMs to it, implying a two-stage rocket of some kind. In the event that both PKMs were discovered in GTO and correlated with STS 38, their orbits would have appeared, at least superficially, to belong to a two stage PKM. For their orbital planes to have appeared related, the PKM firings must have been separated by no more than two or three revolutions.

2. Introduction

This report evaluates the opportunity for STS 38 to have orbited Prowler.

Sections 3 and 4 respectively describe STS 38 and the emergence of the story of Prowler.

Section 5 evaluates the capability of the shuttle to orbit the mass and volume of both satellites and their supporting hardware. Section 6 analyzes the shuttle's orbital manoeuvres and visual observations by the public, revealing evidence of both satellite deployments, and narrowing the time of their PKM firings.

Section 7 describes the radar, optical and SIGINT detection risks faced by Prowler, and how they could have been avoided. Section 8 considers detection avoidance in LEO and GTO/GEO, to gain insight into the time of deployment, and further narrow the probable time of PKM firing.

Section 9 describes the deceptive cataloguing of the SDS 2-2 and Prowler PKMs, and the characteristics of their orbits that would have facilitated the deception, in the event of discovery.

Section 10 states the conclusions, and offers suggestions for additional research.

3. STS 38

Space shuttle mission STS 38 was launched on November 15, 1990, from Cape Canaveral, on a highly classified dedicated DoD mission. Its crew consisted of Richard O. Covey, Commander, Frank L. Culbertson, Jr., Pilot, and Mission Specialists Robert C. Springer, Carl J. Meade, and Charles D. Gemar. It was to have landed after 4 days at Edwards AFB in California; however, bad weather forced a one day delay, and diversion to the Kennedy Space Center, in Florida.

Prior to the launch, Aviation Week & Space Technology identified the payload as a satellite called AFP-658 (Air Force Project 658), with a "gross weight of 22,000 lbs," carrying "digital cameras and other sensors, which will focus on the Persian Gulf region to provide both strategic and tactical reconnaissance information for Desert Shield air and ground commanders there." It would also "carry an upper stage to lift its orbit about 400 NM from the shuttle's."[1]

In an effort to gather information regarding the expected satellite deployment, the author of the present report encouraged and supported visual observations of STS 38 by the public.[2] Observers in Florida, Texas[3] and Arizona[4], reported a bright, reddish satellite, flashing about once per second, orbiting in formation with Atlantis. As expected, it soon manoeuvred and the observers lost track of it. Subsequent searches did not reveal the LEO (low Earth orbit) imagery intelligence satellite predicted by AV Week, and its existence has long since been discounted.

The satellite seen in formation with Atlantis was eventually determined to have been SDS 2-2 (aka SDS B-2 and Quasar B-2), the second of a new generation of National Reconnaissance Office (NRO) communications relay.[5]

4. Prowler Emerges

The earliest public reference to Prowler appears to have been in 1999, on a web site oriented to applied science and technology policy, which described it as "geosynchronous SIGINT," and having been "said to include low-observable features". Nearly all of the remaining description was at variance with subsequent leaks, and is considered incorrect. The launch vehicle and date of launch were not reported.[6]

A 2004 news report on a controversial U.S. stealth satellite program revealed that an unacknowledged second satellite had been launched on STS 38: "an experimental and highly classified satellite called 'Prowler'," that had "stealthily maneuvered close to Russian and presumably other nations' communications satellites" in geosynchronous orbit.[7]

A 2008 article on the hidden meaning in military patches reported a second crew patch of STS 38, that appeared to hint at the unusual secrecy of their mission.[8]

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[1] Edward H. Kolcum, "Next Shuttle Flight to Carry Sensors for Providing Intelligence on Persian Gulf," *Aviation Week & Space Technology*, October 22, 1990, pg. 29.
[2] Ted Molczan, "STS 38 Visual Observation Guide," *sci.space*, 13 Nov 90 13:12:28 GMT.
[3] Ted Molczan, "USA 38 Payload Observed," *sci.space*, 17 Nov 90 04:21:37 GMT.
[4] Private e-mail correspondence with an astronomer. Nov 17-19, 1990.
[5] Dwayne A. Day, "Out of The Shadows: The Shuttle's Secret Payloads," *Spaceflight*, Vol. 41, Feb 1999.
[6] Data found in the public web archive, web.archive.org, indicates that the Federation of American Scientists added its web page on Prowler to www.fas.org sometime after April 29, 1999 and before Oct 12, 1999. The content creator listed at the time was John Pike.
[7] Robert Windrem, "What is America's Top-Secret Spy Program?," *NBC News*, Dec 9, 2004.
[8] Roger Guillemette and Dwayne A. Day, "Space Age Hieroglyphs," *The Space Review*, Aug. 25, 2008.

The author of the present report recently reported the identification of a GEO object discovered by hobbyists in 1998 as Prowler, and made public the revelation that it was built on the HS-376 satellite bus. The optical and orbital characteristics of the GEO object were found to correlate strongly, but circumstantially, with the Prowler story.[9]

Very little of the Prowler story has been revealed – none of it officially – so there is room for doubt, and a desire to learn more, which is the motivation for this report.

5. Evaluation of Shuttle Capability to Orbit SDS 2-2 and Prowler

For SDS 2-2 and Prowler to have been launched on STS 38, Atlantis must have been able to orbit their combined mass and accommodate both within its payload bay.

5.1 Mass and Length of SDS 2-2

It is generally accepted that SDS 2-2 was a second generation NRO communications relay. They employed a single stage perigee-kick motor (PKM) to raise their apogee to a fraction of their operational altitude, and used their integral liquid apogee motor (LAM) to perform all remaining manoeuvres to reach geosynchronous or Molniya orbit.

The author's ongoing study of the SDS 2 series (to be published when complete) reveals that SDS 2-2 employed an Orbus 21S PKM, with fuel probably off-loaded to 50 percent of its maximum load, which would have raised the apogee to approximately 11,000 km.

The payload-separated mass would have been about 5,900 kg, which the subsequent LAM manoeuvres would have reduced to about 2,560 kg upon entering the initial GEO orbit, similar to that of the HS-389 based Intelsat VI spacecraft, to which SDS 2 is similar.

The total SDS-related mass carried to orbit by the shuttle was about 12,700 kg, as broken down by major components below.

SDS 2-2 Shuttle Payload	Mass - kg
SDS 2-2 satellite	5,900
Orbus 21S PKM (50% of max fuel load)	5,500
Airborne Support Equipment	1,300
Total	12,700

The total length of the spacecraft and PKM was about 8.3 m,[10] mounted horizontally in the payload bay,[11] similar to Intelsat VI.

[9] Ted Molczan, "Unknown GEO Object 2000-653A / 90007 Identified as Prowler," Jan. 21, 2011.

[10] L. R. Dest, J-P. Bouchez, V. R. Serafini, M. Schavietello, and K. J. Volkert, "Intelsat VI Spacecraft Bus Design," *Comsat Technical Review*, Vol. 21, No.1, Spring 1991. Intelsat VI had been designed for launch by Ariane and Shuttle, but in the aftermath of the loss of Challenger in 1986, the Shuttle was replaced by Commercial Titan III. Table 1 on p. 9 states the length for launch on Titan, including PKM: 8.284 m.

[11] "Hughes Outlines Intelsat VI," *Flight International*, 17 April 1982, p.980. Drawing depicts spacecraft in cradle, mounted horizontally in payload bay. Caption states "Ejection of the satellite will be by a simple spring and two-pivot release system, which imparts both spin and a sideways push."

5.2 Mass and Length of Prowler

A source who learned in the mid-1990s that Prowler had been launched on the shuttle and that it was based upon the HS-376 bus informed me of those facts; therefore, Prowler's PKM almost certainly is a PAM-D (Payload Assist Module), as was the case for all fifteen HS-376 communications satellites launched on the shuttle. The typical mass carried to orbit by the shuttle was about 4,500 kg, as broken down by major components below.

Prowler Shuttle Payload	Mass - kg
Prowler satellite	1,300
PAM-D PKM	2,100
Airborne Support Equipment	1,100
Total	4,500

HS-376 spacecraft were mounted vertically in the payload bay atop the PAM-D, within a 2.4 m long cradle.[12]

5.3 Shuttle Performance Sufficient to Orbit Both Satellites

The combined mass of both satellites, their PKMs, and airborne support equipment (ASE) was 17,200 kg, well within the capability of the Shuttle at the time. For example, in 1989, on STS 30, Atlantis carried Magellan into a similar orbit; total mass of spacecraft, Inertial Upper Stage (IUS) and Airborne Support Equipment was 20,751 kg, per the mission press kit.

The combined length of both satellites, about 10.7 m, would have fit within the Shuttle's 18.3 m long payload bay.

6. Orbital and Observational Evidence of Both Satellite Deployments

Analysis of the shuttle's orbital manoeuvres and visual observations by the public, reveals evidence of both satellite deployments, and narrows the time of their PKM firings.

The timeline of significant orbital events and visual observations discussed in this section is summarized in Table 1 on page 6.

The official orbital history of STS 38 consists of "2-line" element (TLE) sets, available in the respective public archives of Jonathan McDowell and T.S. Kelso:

http://www.planet4589.org/space/elements/20900/S20935

http://celestrak.com/NORAD/archives/STS/sts-38.txt

Except where noted, Atlantis TLEs used in this report were obtained from one of the above two web pages, or from personally archived printed reports, received in 1990 from the Orbital Information Group of NASA's Goddard Space Flight Center.

[12] A NASA web page on the Payload Assist Module, describes the cradle length as "93 inches static", which is about 2.4 m. <http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/carriers.html#pam-d>

Table 1: STS 38 Orbital Event and Observation Timeline

Date	UTC hh:mm	Day of Year ddd.ddddd	MET d:hh:mm	Event
1990 Nov 15	23:48	319.99167	0:00:00	Lift-off.
1990 Nov 16	00:28	320.01944	0:00:40	Atlantis entered initial orbit: 223.5 x 224.9 km.
1990 Nov 16	01:00	320.04175	0:01:12	Epoch of TLE: 222.4 X 223.8 km.
1990 Nov 16	01:21	320.05625	0:01:33	Atlantis observed from Austin, Texas, by Mike McCants, a highly experienced observer. Pass entered eclipse 10 deg in west; poor phase angle.
1990 Nov 16	03:13	320.13403	0:03:25	Atlantis raised apogee to 272 km.
1990 Nov 16	04:48	320.20017	0:05:00	Epoch of TLE: 223.1 X 271.6 km.
1990 Nov 16	05:29	320.22847	0:05:41	Atlantis raised perigee to circularize orbit at 269.1 X 273.3 km.
1990 Nov 16	06:56	320.28889	0:07:08	Approximate time of SDS 2-2 deployment. Estimated orbit 269.1 X 273.3 km.
1990 Nov 16	07:16	320.30278	0:07:28	Approximate time of Atlantis' 0.6 m/s manoeuvre to separate from SDS 2-2. Manoeuvre less than 10 percent of normal for a PKM the size of SDS 2-2's.
1990 Nov 16	09:48	320.40851	0:10:00	Epoch of TLE: 270.9 X 273.7 km.
1990 Nov 16	17:33	320.73142	0:17:45	Epoch of TLE: 270.5 X 273.9 km.
1990 Nov 16	18:54	320.78750	0:19:06	Shuttle raised orbit ~0.85 km, at ascending node near 101.3 W. Perhaps intended to optimize orbit for the later Prowler deployment.
1990 Nov 16	23:22	320.97399	0:23:44	Epoch of TLE: 271.9 X 274.2 km.
1990 Nov 16	23:46	320.99028	0:23:58	Tampa, Florida area observation of Atlantis, trailing what obviously was one of its payloads, by 24.1 seconds in time (range ~180 km). Payload described as having a colour in the red end of the spectrum - rapidly varying from reddish to golden to yellow white. Payload brightness was magnitude zero, with a small regular variation, over a period of roughly 1 s. Payload eventually identified as SDS 2-2, based on its ~30 RPM rotation and reddish hue – identical to three others that have been observed in LEO parking orbit. It could not have been Prowler, which would have rotated at 50 to 55 RPM, like other HS-376 satellites.

Table 1: STS 38 Orbital Event and Observation Timeline, cont.

Date	UTC hh:mm	Day of Year ddd.ddddd	MET d:hh:mm	Event
1990 Nov 17	01:14	321.05139	1:01:26	An experienced observer in Tucson, Arizona observed Atlantis and SDS 2-2. The SDS was fainter than Atlantis by about 2.5 magnitudes, tumbling or spin stabilized with a period of about 1.5 seconds. It appeared ahead of the shuttle by about 20 degrees and was "reddish - yellow." Separation between spacecraft was about the same as reported from Florida on the previous revolution.
1990 Nov 17	01:15	321.05208	1:01:27	Mike McCants observed SDS 2-2 from Austin, Texas for about 10 s, followed by Atlantis, through a hole in the clouds. Last reported sighting of SDS 2-2.
1990 Nov 17	01:37	321.06736	1:01:49	Earliest possible descending node of SDS 2-2 PKM firing.
1990 Nov 17	04:37	321.19236	1:04:49	Approximate time of Prowler deployment. Descending node, 70.5 W.
1990 Nov 17	04:56	321.20556	1:05:08	Approximate time of Atlantis' 2.2 m/s manoeuvre to lower orbit to separate from Prowler. A normal separation manoeuvre would have raised the orbit.
1990 Nov 17	04:58	321.20712	1:05:10	Epoch of first TLE after separation from Prowler: 264.2 X 274.2 km.
1990 Nov 17	06:07	321.25486	1:06:19	Earliest possible Prowler PKM firing, descending node near 93.2 W.
1990 Nov 17	18:03	321.75208	1:18:15	Last possible PKM firing descending node, before first satellite non-sighting.
1990 Nov 17	18:21	321.76458	1:18:33	Atlantis observed from Australia by a highly experienced observer. Nothing else seen -15 min to +5 min. Twilight conditions; able to see to mag 4. Satellites must have fired their PKMs sometime before this observation, else they would have been seen.
1990 Nov 17	21:12	321.88333	1:21:24	Atlantis exited the satellite deployment orbit by lowering perigee to 226 km.
1990 Nov 17	23:41	321.98681	1:23:53	Atlantis seen by three observers from different locations in Florida, on a high elevation pass. No satellites seen.
1990 Nov 19	21:48	323.90833	3:22:00	Planned landing at Edwards AFB; both attempts waved off due to high wind.
1990 Nov 20	21:43	324.90486	4:21:55	Atlantis landed at KSC, on runway 33.

6.1 Description of Standard Payload Separation Manoeuvres

The manoeuvres of STS 38 are best understood in the context of standard operating procedure, as revealed in mission press-kits, and through analysis of published orbital data. GEO payloads were deployed at the node (equator crossing) opposite that of the planned PKM firing, and the shuttle manoeuvred 15–20 min later to create sufficient separation 30 min later at PKM firing, to avoid damage to its windows and thermal protection system due to plume impingement. The larger the PKM, the greater the required separation.

The PKM employed for SDS 2-2 was the Orbus 21S - a spin-stabilized version of the first stage motor of the Inertial Upper Stage (IUS). For the IUS, the standard separation delta-V was about 9.5 m/s, which put the shuttle about 80 km behind, and 30 km above the PKM at firing.

Since Prowler was based on the HS-376 bus, it probably employed the PAM-D, as explained in Section 5.2. The standard separation delta-V was about 3.4 m/s, which put the shuttle about 20 km behind, and 10 km above the PKM at firing.

6.2 Atlantis Raises Orbit to Payload Deployment Altitude

Forty minutes after launch, Atlantis entered a 223.5 x 224.9 km orbit. At Mission Elapsed Time (MET) 0:03:25 (d:hh:mm) it made the first of two manoeuvres to reach the payload deployment altitude, raising its apogee to 272 km, documented by an official TLE with epoch at MET 0:05:00:

```
1 20935U 90 97  A 90320.20017361  .00320873  40597-4  25599-3 0    39
2 20935  28.4683 242.1896 0037834 196.9133   7.8577 16.11416272    39
```

There is no official TLE that records the orbit immediately after circularization. By the epoch of the next official TLE, at MET 0:10:00, Atlantis had deployed SDS 2-2 and separated from it, resulting in an approximately 270.9 X 273.7 km orbit:

```
1 20935U 90 97  A 90320.40850694  .00161290  68898-5  25599-3 0    47
2 20935  28.4646 240.6373 0006560 286.7334  43.3613 16.02355418    67
```

The intersection of the above TLEs reveals the apogee of circularization as MET 0:05:41.

6.3 SDS 2-2 Deployed

Atlantis' orbit at the time of circularization was estimated by assuming that the elements were substantially the same as those of SDS 2-2, which was observed from near Tampa, Florida at MET 0:23:58, leading Atlantis by 24.1 s (range about 180 km). Assuming identical rates of decay, an approximately 269.1 X 273.3 km orbit accounts for the observed separation:

```
Atlantis at entry into payload deployment orbit (estimate)
1 20935U 90097A   90320.22834492  .00164353  00000-0  25599-3 0    00
2 20935  28.4683 241.9726 0008500 273.4484  95.0700 16.02732000    00
```

Analysis of the preceding two TLEs, reveals the time of separation to have been about MET 0:07:28. Its magnitude - about 0.6 m/s - was less than ten percent of the 9.5 m/s that followed IUS deployments, the first stage of which employed the same motor used as SDS 2-2's PKM.

SDS 2-2 was deployed about 20 min earlier, near MET 0:07:08, at the ascending node at 82.4 E. The approximate elements of SDS 2-2 result from propagating the above Atlantis TLE to that point, and changing the designations; dimensions were 269.1 X 273.3 km:

```
SDS 2-2 at time of deployment (estimate)
1 20963U 90097B   90320.28913194  .00164528  00000-0  25599-3 0    08
2 20963  28.4683 241.5102 0008486 274.2130  85.8011 16.02750000    07
```

6.4 Prowler Deployed

An approximately 0.5 m/s orbit manoeuvre at MET 0:19:06, at the ascending node near 101.3 deg W, raised Atlantis' orbit about 0.85 km, to 271.9 X 274.2 km, perhaps to optimize it for Prowler's eventual deployment and PKM firing, which probably occurred at a descending node. The orbit is documented by the official TLE of epoch at MET 0:23:44:

```
1 20935U 90 97  A 90320.97399137  .00158486  66265-5  25599-3 0    60
2 20935  28.4661 236.3333 0006164 284.9281  73.9171 16.02067102   162
```

It should be noted that this could not have been the primary manoeuvre to separate from SDS 2-2, because it accounted for only a small fraction of the distance between them when they were observed at MET 0:23:58.

At approximately MET 1:05:10, Atlantis manoeuvred to lower its orbit to 264.3 X 274.2 km, apparently to separate from Prowler, as documented by this contemporaneous TLE:

```
1 20935U 90 97  A 90321.20711805  .00172130  83592-5  25599-3 0    72
2 20935  28.4660 234.5683 0006699 345.9240 280.3921 16.03444325   192
```

This manoeuvre differed from those of typical PAM-D deployments, in that it lowered the orbit instead of raising it, and was two thirds their magnitude - about 2.2 m/s vs. 3.4 m/s.

It is interesting to note that by the time of this manoeuvre, SDS 2-2's mean motion was about 16.03 rev/d, and it led Atlantis by more than 250 km. The manoeuvre arrested the separation and caused a very gradual overtaking, which might have been interpreted by analysts unaware of Prowler, as a sort of station-keeping manoeuvre – albeit at a distance much greater than normally considered station-keeping. Combined with the atypical characteristics for a separation manoeuvre, this could have helped maintain Prowler's cover, by keeping Soviet attention focussed on the SDS.

Based on typical satellite deployments, Prowler would have been deployed 15 to 20 min prior to the separation manoeuvre, probably at the descending node at MET 1:04:49, near 70.5 W. The following Prowler elements result from propagating Atlantis' elements at epoch 90320.97399137 to that point, and changing the designations to those adopted recently by hobbyists;[13] orbit dimensions were 271.6 x 274.2 km:

```
Prowler at time of deployment (estimate)
1 90007U 90097E   90321.19218750  .00158268  00000-0  25599-3 0    05
2 90007  28.4661 234.6749 0006141 287.5489 252.3505 16.02136000    06
```

The earliest node at which Prowler's PKM firing could have occurred, was the descending node near MET 1:06:19, by which time it trailed Atlantis by about 33 km.

[13] USSTRATCOM's satellite catalogue contains four STS 38-related entries, corresponding to Atlantis, SDS 2-2 and both PKMs, but not Prowler; therefore, hobbyists have assigned it the next available COSPAR designation, 1990-097E. They continue to use their 90007 catalogue number, in the absence of an official one.

6.5 Payload Non-Sighting Defines Latest Time of PKM Firings

SDS 2-2 was last observed at MET 1:01:27, from Austin, Texas, and Tucson, Arizona. The next reported visual observation of STS 38 was at MET 1:18:33, from Australia. The period of observation was from 15 min before the pass of Atlantis, to 5 min after, during which only Atlantis was seen. This was the first non-sighting of SDS 2-2 and Prowler - a strong indication that they had already fired their PKMs to leave LEO.

The orbit manoeuvres and visual observations narrow the time of SDS 2-2's PKM firing to the descending nodes from MET 1:01:49 to 1:18:15, and Prowler's from MET 1:06:19 to 1:18:15.

Since Prowler was launched under the cover of SDS 2-2, its deployment and PKM firing probably were timed to minimize the risk of detection by Soviet space surveillance and SIGINT systems, as discussed in the following sections.

7. Prowler Detection Risk and Avoidance Measures

This section describes Prowler's optical, radar and SIGINT detection risks, and how they could have been avoided.

7.1 Optical

Prowler reportedly was optically stealthy to avoid detection while operating in GEO, within sight of the Soviet optical space surveillance system. The exact mechanism used is not known, but it probably could not have been passive, given that its HS-376 bus was a cylinder, covered with solar cells, that rotated at 55 RPM. An active stealth system would have required a stable mounting point, which could only have been provided by the satellite's de-spun platform.

Assuming Prowler operated like HS-376 communications satellites, then from its deployment by the shuttle until its arrival at its initial orbital slot – which could have taken anywhere from a few days to a few weeks - its spun and de-spun sections would have been locked together and spinning at 55 RPM, preventing operation of a stealth system. During this period, Prowler could only have avoided detection by staying below the horizon of Soviet optical space surveillance sites at times when the spacecraft would be illuminated by the sun against a dark sky.

An early 1990s study of the Russian Space Surveillance System (SSS) reported at least 21 optical or electro-optical facilities at 14 geographic locations in seven countries that had been part of the USSR: five in Russia, four in Ukraine, and one each in Armenia, Georgia, Kazakhstan, Tajikistan and Turkmenistan. Nine of the sites were at least partly supported by the Russian Academy of Sciences (RAS), which was reported to have "operated additional equipment at sites in Bolivia, Chile, Ecuador, and Egypt."[14]

Two sites on Soviet territory were sufficiently southerly to have seen Prowler in its low inclination deployment orbit: Ashkhabad, Turkmenistan (37.9 N, 57.9 E) and Dushanbe, Tajikistan (38.5 N, 68.7 E); at both sites, the orbit would have culminated as high as 9 deg elevation. Assuming the sites had an unobstructed view that low, they could have detected Prowler under favourable illumination conditions.

[14] David M. Rodvold and Nicholas L. Johnson (Kaman Sciences Corporation), "The Russian Space Surveillance System: Characteristics and Comparisons with the US SSN," *Proceedings of The 1994 Space Surveillance Workshop, MIT Lincoln Laboratory*.

Objects at the altitude of Prowler's GTO and GEO orbit were visible to all of the sites on Soviet territory, but since they ranged in longitude between Simeiz, Ukraine (44.42 N, 34.00 E) and Yuzhno-Sakhalinsk, Russia (47 N, 143 E), the detection risk was limited to approximately 30 W longitude, eastward through 150 W – roughly the eastern hemisphere. Detection could have been avoided by placing first apogee over the western hemisphere, between 30 W and 150 W longitude.

The aforementioned three South American and one Egyptian site were in a geographical position to have posed a detection risk to Prowler; however, they were mentioned only in passing; and among the deficiencies of the SSS listed in the summary of the cited study, was the "invisibility of most of the Western Hemisphere portion of the GEO arc"; therefore, it is doubtful that they contributed significantly to the SSS or to the detection risk for Prowler.

7.2 Radar

It would have been difficult to make Prowler stealthy against radar, because its outer surface would have been covered with solar cells; however, radar stealth probably was not considered necessary, since the spacecraft was designed to operate in GEO, well beyond the effective range of space surveillance radars.

The low inclination and altitude of Prowler's LEO deployment orbit put it out of range of most Soviet space surveillance radars, but there was a risk of detection by its southernmost radar, located at Qabala, Azerbaijan (40.87 N, 47.81 E), with azimuth range from about 110 to 220 degrees[15] and elevation range from 2 to 45 degrees.[16]

7.3 SIGINT

Once in GEO, Prowler's de-spun section would have provided a stable platform for a high-gain directional antenna to narrowly beam its signal to ground stations, perhaps employing inter-satellite links, with a low risk of detection; however, in LEO and GTO, it probably would have been limited to using an omnidirectional antenna, which would have required a different strategy to avoid detection. Possible methods include maintaining radio silence when within range of SIGINT sites, using a frequency unknown to the Soviets, or using LPI/LPD (low-probability of interception/detection) technology.

The greatest land-based SIGINT detection risk probably was posed by the facility at Lourdes, Cuba (23.00 N, 82.48 W), which was staffed by more than 2,000 Soviet personnel, to monitor "US military, space, and domestic communications."[17] (Cuba also seems like a good location for radar and optical space surveillance, but intensive web searches did not turn up evidence of such activities.)

SIGINT and satellite/missile tracking ships also posed a risk of detection, but insufficient information was available to make an assessment.

The following section considers detection avoidance in LEO and GTO/GEO, to gain insight into the time of Prowler's deployment, and further narrow the probable time of its PKM firing.

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[15] The U.S. Congressional Budget Office, "Options for Deploying Missile Defenses in Europe," Feb 2009.
[16] Andrey Ordach, press secretary of the Russian Embassy, in a 2007 presentation that proposed a combined centre for missile launches and data analysis, which would have included Qabala (slide 22). < http://www.csotan.org/ao/AO28/ambarus.pps>
[17] US Government, "Soviet Military Power: An Assessment of the Threat 1988", p.29.

8. Detection Avoidance Constraints on Prowler Deployment and PKM Firing

This section applies the information on detection risk and avoidance presented in Section 7, in an effort to gain insight into the timing of Prowler's deployment, and further constrain the window of opportunity for its PKM firing, developed in Section 6. The LEO and GTO/Initial GEO phases are analysed separately, since they involve different detection risks.

8.1 LEO Detection Avoidance

Table 2 lists the detection risks faced by Prowler while in its LEO parking orbit (estimated TLE below), which was introduced in Section 6.4:

```
1 90007U 90097E   90321.19218750  .00158268  00000-0  25599-3 0    05
2 90007  28.4661 234.6749 0006141 287.5489 252.3505 16.02136000    06
```

To provide context, the period evaluated includes the 9.5 hours prior to Prowler's deployment, from MET 0:19:13 through 1:04:43, during which Atlantis and the already deployed SDS 2-2 made seven consecutive passes of the Lourdes, Cuba SIGINT site, most at elevations which would have enabled easy reception of their radio transmissions; one soon after twilight, enabling optical detection.

Table 2: Timeline of Prowler Detection Risks in LEO Deployment Orbit

	UTC	MET		Max EL	Dur	Potential Detection Risk		
Date	**hh:mm**	**d:hh:mm**	**Site**	**deg**	**min**	**Radar**	**SIGINT**	**Optical**
1990 Nov 16	19:01	0:19:13	Lourdes	7	5		X	
1990 Nov 16	20:36	0:20:48	Lourdes	51	8		X	
1990 Nov 16	22:11	0:22:23	Lourdes	29	7		X	
1990 Nov 16	23:46	0:23:58	Lourdes	20	7		X	X
1990 Nov 17	01:15	1:01:27	Atlantis and SDS 2-2 last seen; Prowler not deployed yet.					
1990 Nov 17	01:21	1:01:33	Lourdes	41	8		X	
1990 Nov 17	02:56	1:03:08	Lourdes	27	7		X	
1990 Nov 17	04:31	1:04:43	Lourdes	3	3		X	
1990 Nov 17	04:34	1:04:46	Atlantis passed below horizon of Lourdes.					
1990 Nov 17	04:37	1:04:49	Approximate time of Prowler deployment.					
1990 Nov 17	13:09	1:13:21	Qabala	3	3	X		
1990 Nov 17	13:11	1:13:23	Dushanbe	9	2			X
1990 Nov 17	14:43	1:14:55	Qabala	5	5	X		
1990 Nov 17	14:44	1:14:56	Ashkhabad	8	1			X
1990 Nov 17	16:17	1:16:29	Qabala	2	2	X		
1990 Nov 17	18:21	1:18:33	Only Atlantis seen; therefore, both PKMs had been fired.					
1990 Nov 17	18:58	1:19:10	Lourdes	13	6		X	

SDS 2-2 and its PKM probably transmitted strong S-band beacons on standard NASA/USAF SGLS (Space Ground Link System) channels, that would have been readily detectable by Lourdes, which along with a possible optical sighting, would have convinced Soviet analysts that they had tracked *the* payload of STS 38.

At MET 1:04:46, Atlantis and SDS 2-2 passed out of range of Lourdes after the seventh and final pass of the series. A few minutes later, Atlantis deployed Prowler. About 20 minutes later, near MET 1:05:10, Atlantis manoeuvred to separate from Prowler.

That Atlantis deployed Prowler only after the Lourdes passes, suggests great caution to avoid detection, and a well-timed performance staged for the Soviets. Assuming Prowler could have maintained radio silence or employed LPI/LPD transmissions, it is unclear what detection risk might have been perceived, apart from the potential optical/visual detection on the fourth pass, nearly five hours prior to the deployment. It may simply reflect an abundance of caution - an acknowledgment of the limitations of the available intelligence on the capability of Lourdes.

It would be more than 8 hours before Prowler's next detection risk, at MET 1:13:21, when it would have risen 3 deg above the horizon of the Qabala radar, followed within two minutes by a 9 deg twilight pass of the Dushanbe optical site. Whether it could have been detected on such marginal passes seems moot, since it had several ideal PKM firing opportunities before then.

8.2 GTO and Initial GEO Detection Avoidance

Table 3 lists Prowler's approximate longitude of first apogee for the nine descending nodes within the period of its PKM firing determined in Section 6.5. The longitudes are uncertain by at least several degrees, due to uncertainty in the apogee of the GTO.[18]

Table 3: Prowler PKM Firing Opportunities

Date	UTC	MET	DOY	Descending Node		Prowler First Apogee
				Long	RAAN	Approx Long
1990 Nov 17	06:06:26	1:06:18:11	321.25446759	93.46 W	234.20	6 E
1990 Nov 17	07:36:07	1:07:47:52	321.31674769	116.42 W	233.73	17 W
1990 Nov 17	09:05:48	1:09:17:33	321.37902778	139.39 W	233.22	40 W
1990 Nov 17	10:35:29	1:10:47:14	321.44130787	162.34 W	232.78	63 W
1990 Nov 17	12:05:10	1:12:16:55	321.50358796	174.71 E	232.31	86 W
1990 Nov 17	13:34:51	1:13:36:36	321.56586806	151.76 E	231.83	109 W
1990 Nov 17	15:04:32	1:15:06:17	321.62814815	128.81 E	231.36	132 W
1990 Nov 17	16:34:13	1:16:45:58	321.69042824	105.87 E	230.89	155 W
1990 Nov 17	18:03:54	1:18:05:39	321.75270833	82.94 E	230.41	178 W

The descending node near MET 1:09:18 (d:hh:mm), at 139.39 W, was the first of five that would have put the GTO and first apogee in the detection avoidance zone between 30 W and 150 W, beyond the range of the westernmost and easternmost optical space surveillance sites on

[18] The longitudes are based on a GTO of apogee 36,500 km - the median of the 13 shuttle-launched HS-376 communications satellites that reached GTO (two others failed to do so, due to PKM failures).

Soviet territory, respectively Simeiz, Ukraine and Yuzhno-Sakhalinsk, Russia, identified in Section 7.1.

Recalling from Section 8.1, that in its LEO parking orbit Prowler was at risk of radar and optical detection near MET 1:13:21, the latest possible PKM firing arguably would have been constrained to the descending node near MET 1:12:17.

Applying both sets of constraints narrows the probable time of the PKM firing to the three consecutive descending nodes beginning at MET 1:09:18, resulting in respective first apogee at approximately 40 W, 63 W and 86 W.

Prowler's initial geosynchronous longitude is unknown, but check-out and testing of the experimental spacecraft ideally would have been accomplished over the western hemisphere, co-longitudinal with the continental U.S.A., within direct sight of its operators, and at least as importantly, out of sight of Soviet territory.

9. Deception in Satellite Catalogue

9.1 PKMs Falsely Attributed to One Satellite

USSTRATCOM's official satellite catalogue falsely attributes the rocket bodies of STS 38 to its one acknowledged payload, USA 67, which is known to be SDS 2-2. Below are the official designations and their actual identity:

COSPAR	SSN	Official Name	Actual Identity
1990-097C	20964	USA 67 R/B (1)	SDS 2-2 PKM (Orbus 21S)
1990-097D	20965	USA 67 R/B (2)	Prowler PKM (PAM-D)

The actual identity of 1990-097C arises from research into the SDS 2 spacecraft, which jettisoned only one rocket body - a PKM - as discussed in Section 5.1. Therefore, 1990-097D must belong to Prowler, and given the revelation that its bus is the HS-376, it must be its PKM - almost certainly a PAM-D (Payload Assist Module), as was the case for all fifteen HS-376 communications satellites launched on the shuttle.

The official cataloguing of the rocket bodies had long been a source of confusion and speculation. Since both were attributed to one payload, there was speculation that they belonged to an Inertial Upper Stage (IUS) - a large two-stage rocket that had flown on ten previous shuttle missions, and launched civilian and military satellites to GEO, and interplanetary probes. On GEO missions, the first stage functioned as the PKM, and the second stage as the AKM (apogee kick motor). However, the catalogue clearly identifies the rocket bodies of those launches as IUS, but does not identify the model of those of STS 38.

It could be argued that since the stealthy Prowler's launch has not been acknowledged in the satellite catalogue, less suspicion would have been aroused had its rocket body also not been catalogued. But since the rocket probably was not stealthy, it might eventually have been discovered, and if both rocket bodies had been found and traced to STS 38, then having acknowledged only one of them in the catalogue would have aroused even greater suspicion.

9.2 PKM Orbits Enhanced Deception

In the event both PKMs were discovered in GTO, the deception might have been facilitated by their orbits, as approximated below, which could be interpreted, at least superficially, as two-stages belonging to a single satellite, consistent with how USSTRATCOM catalogued them.

Orbit	Inc deg	Perigee km	Apogee km
LEO parking	28.5	270	270
SDS 2-2 PKM	~27.0	270	~11,000
Prowler PKM	~25.0	270	≥36,000

For the orbital deception to have withstood professional scrutiny, their planes must have been in reasonably close proximity when propagated back to the time of STS 38. Assuming SDS 2-2 fired its PKM first, the difference between the rate of precession of its plane and that of the parking orbit would have been nearly 0.4 deg per revolution of the latter, which probably would have limited the interval between the two firings to two or three revolutions.

An actual two stage PKM could only have fired its second stage at the perigee of its first stage, in this case at intervals of about 219 min, which could have been approximated by firing Prowler's PKM two parking orbit revolutions later - about 180 min.

Realistic initial planar and temporal spacing would have diminished in importance, the longer the discovery after launch, due to the inherent inability to precisely model the long term effects of orbital perturbations, especially due to drag and radiation pressure. Among the deficiencies of the Russian space surveillance system reported in the study cited in section 7.1, was the "the tracking of low inclination orbits and highly elliptical orbits," which raises doubts that the PKMs would have been discovered quickly.

10.0 Conclusions

Atlantis had sufficient payload performance and space in its payload bay to orbit Prowler.

SDS 2-2 was deployed near MET 0:07:08 (d:hh:mm), and Prowler near MET 1:04:49.

Orbit manoeuvres and visual observations narrow the time of SDS 2-2's PKM firing to the descending nodes from MET 1:01:49 to 1:18:15, and Prowler's from MET 1:06:19 to 1:18:15.

Avoiding detection by the Soviet radar and optical space surveillance system constrained Prowler's PKM firing to the three consecutive descending nodes beginning at MET 1:09:18, resulting in first apogee between 40 W and 86 W. Check out and testing likely was performed at a location co-longitudinal with the continental U.S.A.

Evidence of deception consistent with providing cover for Prowler is found in the shuttle's non-standard payload separation manoeuvres after both satellite deployments, and the apparent timing of Prowler's deployment to avoid detection by the SIGINT facility at Lourdes, Cuba.

Considerable scope for investigation remains, beginning with the following questions inadequately addressed by this report:

What was the risk of detection by Soviet SIGINT and satellite/missile tracking ships?

What was Prowler's probable SIGINT detection avoidance strategy/technology?

What, if any, detection risks did Lourdes pose, other than SIGINT?

Detailed knowledge of shuttle operations and any operational constraints that may have been imposed by the design of the satellite buses of Prowler (HS-376) and SDS 2-2 (HS-389), could provide useful insights into the timing of the payload deployments and the unusual separation manoeuvres, and enable a better overall assessment of feasibility.

Contingency plans to maintain Prowler's cover in the event of delays or failures of key elements of the plan, would be of interest, as would a detailed evaluation of the timing and results of the PKM firing manoeuvres that would have left them in orbits that most resembled both stages of a two-stage PKM.