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Orbital Phasings of Soviet Ocean Surveillance Satellites

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Since 1974 two types of Soviet ocean surveillance satellites in groups of two or three have been periodically conducting missions with peculiar characteristics. Pairs of satellites of a common class perform numerous small orbital maneuvers during their short operational lifetimes to maintain specific temporal separations. The orbital planes of satellites of different classes are found to be phased with respect to each other. An explanation for these intra- and interphasings of Soviet ocean surveillance satellites is the desire to promote overflight of ocean areas by two or more satellites in less than an hour.

Introduction

WITH the fiery re-entry of Kosmos 954 over the Canadian tundra in early 1978, the previously low-profile Soviet ocean surveillance program acquired a plethora of undesired publicity in the popular press.[1-5] Despite the fact that orbital flights had begun at least 10 years earlier, only a few people outside of military intelligence circles paid the relatively short-lived satellites much heed.[6] The realization that the majority of these satellites carried potentially hazardous radioactive materials finally awakened the general public to their presence.

In actuality, it is known that there exist two types of Soviet ocean surveillance satellites whose missions are to gather electronic intelligence (ELINT) about the deployment of U.S. and Allied naval forces.[7-9] Phase I of the program began in the final days of 1967 with the launching of the first of the 19 class I satellites. From an altitude of 250-260 km these spacecraft are reported to carry nuclear-powered radar designed to search out ships on the high seas, to distinguish the class of the subject vessels, and to estimate their direction and speed. Seven years later, a complementary program of ocean surveillance satellites, class II, was implemented with the orbiting of Kosmos 699.† This species of spacecraft which is apparently powered by solar arrays circles the Earth at a higher altitude of 430-440 km and reportedly detects foreign vessels by patiently listening for tell-tale electromagnetic radiations, perhaps including ship-to-ship and ship-to-shore communications and emanations of ship-borne radars. Identification and determination of bearing and speed are again probable objectives.

The purpose of this study was to discern the rationale of the observed satellite formations and to determine if any phasing existed between class I and class I satellites. No attempt was made to examine the possible mechanisms by which these spacecraft perform their missions.

Pairings of Class I and Class II Satellites

Between 1967 and 1973 seven of the radar-type surveillance (class I) satellites were orbited at intervals of 6-30 months. The uniqueness of these satellites appeared in their remaining in a low (250-260 km) altitude orbit for 1-45 days before apparently breaking apart and propelling one section up to an orbital altitude of between 900 and 1050 km. The ultimate demise of Kosmos 954 confirmed speculation that this maneuver was designed to transport the satellite's radioactive power supply to a storage orbit at an orbital altitude from which natural decay requires several hundred years. Therefore, the Soviets could avert the consequences of an accidental re-entry over populous areas and could defer retrieval to a time in the distant future. A series of malfunctions in the Kosmos 954 spacecraft prevented this final maneuver and resulted in its unscheduled impact on Canadian territory.

In 1974 a new twist was added to the fledgling program when on May 15 Kosmos 651 was placed into the now standard low Earth orbit. Only two days later a second spacecraft, Kosmos 654, was inserted into a similar orbit in virtually the same orbital plane. It was quickly determined that Kosmos 654 led Kosmos 651 by approximately 25 min and that both satellites were performing small orbital corrections to maintain this time separation.

The following year a second pair of spacecraft, Kosmos 723 and 724, was orbited in a span of just five days. This time the initial interval between nodal crossings was slightly greater than 27 min and the orbital planes were separated by 23 deg. Within a week of its launch Kosmos 723 exhibited the unusual characteristic (for a class I satellite) of gradually increasing its orbital period each day. Thus, the time separation between Kosmos 723 and 724 continually decreased until the simultaneous operations ceased when Kosmos 723 was moved to the higher altitude storage orbit six weeks after launch.

In late 1975 another of the radar-type satellites, Kosmos 785, was placed into a low circular orbit. Before a second satellite could be launched, Kosmos 785 apparently malfunctioned and within a day split apart, sending its radioactive power supply to the higher storage orbit. During the next two years two more pairs were operated: Kosmos 860 and 861 in 1976 and Kosmos 952 and 954 in 1977. In both cases the satellites were nearly coplanar; but whereas Kosmos 952 and 954 followed the lead of Kosmos 651 and 654 with a nearly 26 min spacing, Kosmos 860 and 861 maintained a separation of close to 38 min.

As an apparent result of international protests and spacecraft requalification, a hiatus in this portion of the ocean surveillance program followed the re-entry and breakup of Kosmos 954. After 2½ years flights resumed in 1980 with the launch of Kosmos 1176 in late April as tensions and activity in the Persian Gulf region rose. More recently, in the spring of 1981 a fifth pair of class I satellites, Kosmos 1249 and 1266, was placed in roughly the same orbital plane with a time phasing of 26 min.

In 1979 the passive ELINT satellites of the Kosmos 699 class (class II) also began flying in pairs: Kosmos 1094 and

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†The Military Posture statement for fiscal year 1980 from the U.S. Joints Chiefs of Staff provides military acronyms for these two types of satellite systems. The class I type satellite is referred to as a RORSAT (Radar Ocean Reconnaissance Satellite), and the class II type is referred to as an EORSAT (ELINT Ocean Reconnaissance Satellite).

1096 in 1979, Kosmos 1167 and 1220 in 1980-81, and Kosmos 1220 and 1260 in 1981. It now appears that a change from solo to dual flights is a natural evolution of these ocean surveillance programs, perhaps indicating the transition from a testing to an operational status. Kosmos 1094 and 1096 were virtually coplanar and initially crossed the equator almost 24 min apart, whereas the planes of Kosmos 1167 and 1220 were initially separated by slightly more than 2½ deg with their ascending nodes approximately 36 min apart. Kosmos 1260, which was apparently launched as a replacement for Kosmos 1167, entered an orbital plane only ½ deg from that of Kosmos 1220, but was 45 min behind Kosmos 1220.

Phasings Explained

The eight pairs of ocean surveillance spacecraft flown between 1974 and 1981 have, with varying degrees of success, maintained very specific time phasings with frequent orbital maneuvers. Moreover, these temporal separations have not been identical, but have ranged 23-45 min. To realize the significance and nonarbitrary nature of these values, it is necessary to consider a peculiar characteristic of these satellite orbits.

Although spacecraft instrument specifications and capabilities as well as desired geographical coverage help model the orbital parameters of any satellite, for many Soviet satellite programs orbital track repetition appears to be a major consideration in selecting the final satellite altitude and inclination.[7,10] By flying at mean altitudes of near 260 and 435 km at an inclination of 65 deg, these active and passive ELINT spacecraft repeat their fixed ground tracks every seven and four days, respectively. That is to say that after accounting for Earth rotation and for precession of the line of nodes there exist only 111 nominal ascending nodes for the class I satellites and only 61 ascending nodes for the class II satellites.

Illustrative of the precision with which the Soviets attempt to maintain these specific nodes is the year-long flight of Kosmos 1167. The ascending node of Kosmos 1167's 12th revolution was arbitrarily chosen as the reference point. Every 61 revolutions thereafter the longitude of Kosmos 1167's ascending node was calculated (Fig. 1). The satellite exhibited a high degree of accuracy maintaining a nominal ascending node of 113.53 °E, with the exception of a short period in the fall of 1980 which will be addressed later in this paper.

To enable two class I satellites to traverse the same set of ground tracks, their ascending nodes must be separated by an angle Θ equal to an integer multiple n of 360 divided by 111 or 3.24 deg of longitude. For truly coplanar satellites the time phasing must be multiples of approximately 12.9 min, e.g. Kosmos 952 and 954 were separated by 25.8 min (Table 1). A graph has been constructed which illustrates the potential time phasings for any pair of class I satellites, given the separation of their orbital planes (Fig. 2). The Kosmos 723 and 724 duo represents the ocean surveillance team to date with the largest planar separation. Additionally, Kosmos 723 and 724 are the only pair in which the satellite with the more westerly ground track possesses the earlier ascending node. However, Fig. 2 verifies the appropriateness of the observed time phasing of this pair.

Similar analysis permitted the construction of Fig. 3 for the Soviet class II ocean surveillance satellites. Nodal crossing intervals in this group must be integer multiples of 5.90 deg longitude (360 divided by 61), which implies phasing coplanar

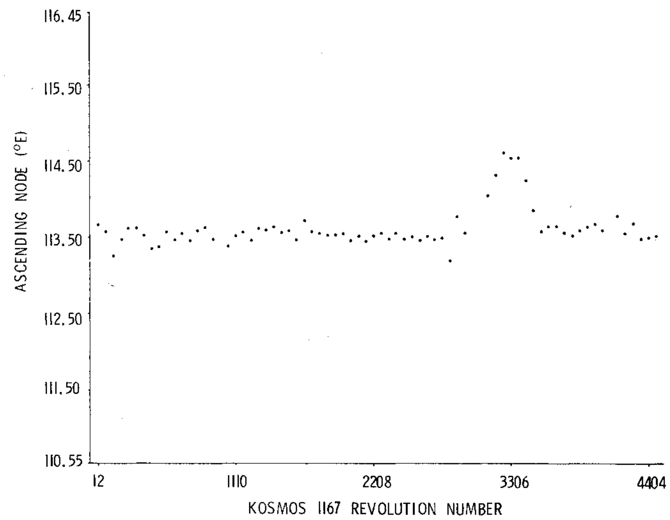

Fig. 1 Kosmos 1167 returned to the same ascending node every 61 revolutions.

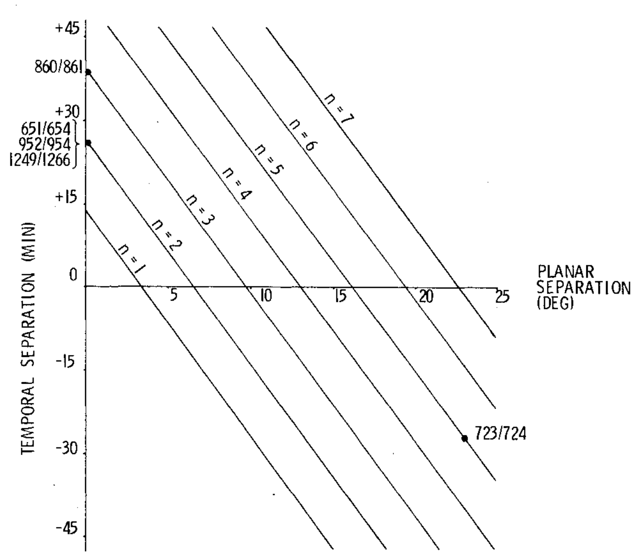

Fig. 2 Class I satellite phasing relationships (diagonal lines represent permissible ascending nodes between successive orbital ground tracks).

Table 1 Soviet ocean surveillance pair phasings

System	Year	Satellite pair	n	Initial planar separation, deg	Initial time phasing, min
Class I	1974	K651/K654	2	0.03	25.4
	1975	K723/K724	5	23.19	−27.5
	1976	K860/K861	3	0.11	38.1
	1977	K952/K954	2	0.08	25.8
	1981	K1249/K1266	2	0.05	25.9
Class II	1979	K1094/K1096	1	0.00	23.8
	1980	K1167/K1220	2	2.62	36.3
	1981	K1220/K1260	2	0.52	44.9

satellites by multiples of 23.5 min. Although the Kosmos 1167 and 1220 pair exhibited $n=2$, the 2.6 deg separation of their orbital planes necessitated a time phasing significantly lower than if they had shared the same orbital plane.

Figure 4 documents the tight control Soviet program directors exerted on this temporal separation during the class II flights of Kosmos 1167 and 1220 in late 1980 and early 1981. Although a gradual decrease is apparent in the time separation of nodal crossings, this is precisely accounted for by the fact that Kosmos 1220 was experiencing a slightly smaller (~99.9%) precession rate than Kosmos 1167 due to its greater inclination, i.e., almost 0.03 deg. This results in a gradual increase in the angular separation of orbital planes, necessitating a small continual decrease in temporal separation (Fig. 3). Similar evidence of rigid temporal separations has been found for other class I and class II satellite pairs.

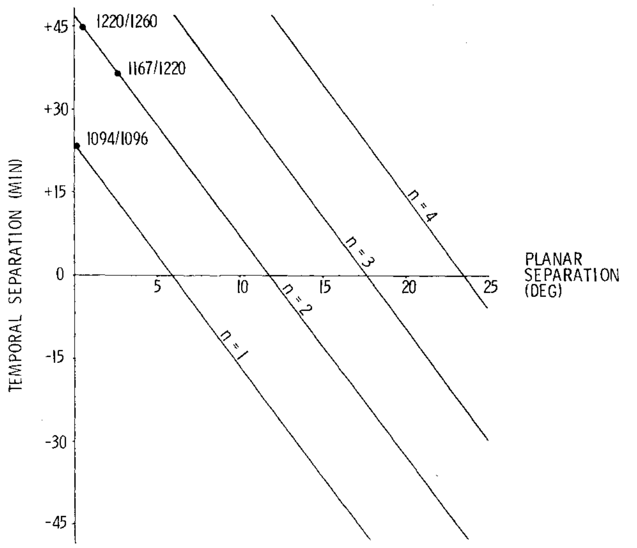

Fig. 3 Class II satellite phasing relationships (diagonal lines represent permissible ascending nodes between successive orbital ground tracks).

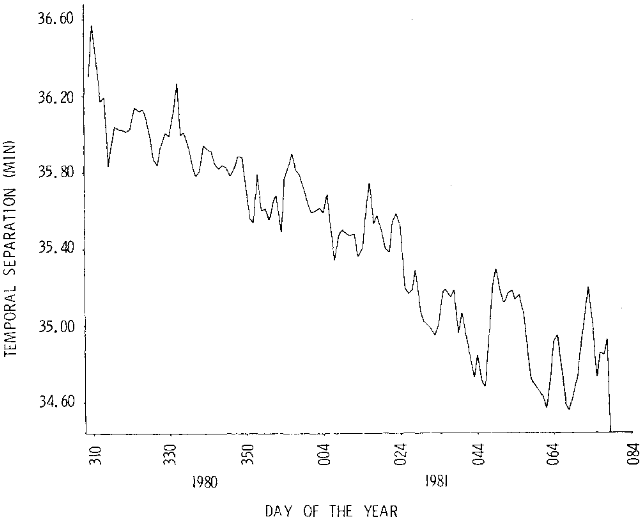

Fig. 4 Time phasing of Kosmos 1167 and 1220 decreased due to mismatch of the nodal precession rates.

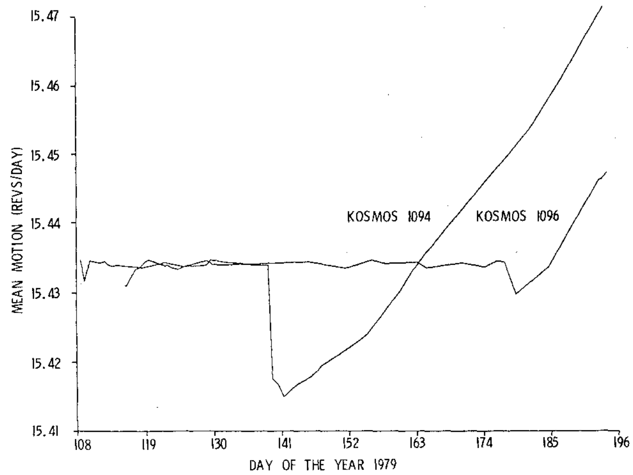

Fig. 5 Joint operations between Kosmos 1094 and 1096 appear to have ceased when Kosmos 1094 began natural decay on May 21, 1979.

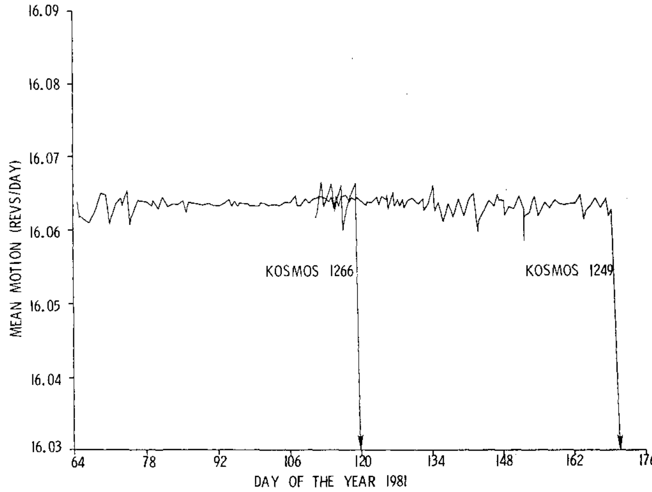

Fig. 6 Low-orbit operation of Kosmos 1249 and 1266.

Table 2 Cooperative active and passive ocean surveillance satellites

Year	Class II satellites	Class I satellites	Initial planar separation, deg	Possible period of joint operations (days)
1975	K699	K723/K724	Not applicable	—
1975	K777	K785	143	—
1976	K838	K860/K861	142	Oct. 17-Nov. 14 (28)
1976	K868	K861	132	Nov. 26-Dec. 20 (24)
1977	K937	K952/K954	150	Sept. 16-Nov. 1 (46)
1980	K1167	K1176	146	April 29-Sept. 10 (134)
1981	K1167 K1220 K1260	K1249/K1266	147	March 5-June 19 (106)

Class I and Class II Interphasings

The pattern of launches of the Soviet passive and active ELINT ocean surveillance satellites suggests the possibility of an effort to conduct some mode of simultaneous operations utilizing the two different reconnaissance techniques.[9,11] To date 10 of the class II satellites have been successfully orbited. Of these, seven have preceded one or two class I launches, one was orbited shortly after a pair of class I satellites, and the remaining two flew a joint mission during the brief class I flight hiatus. Thus, investigations were conducted to determine if any consistent orbital relationship between the two satellite classes existed.

The first step was to isolate the possible periods of joint operations. By analyzing the mean motion time histories of class I and class II satellites, an estimate of their operational lifetimes was made (Figs. 5 and 6). In the case of the former, radar operations must certainly cease when the spacecraft is dismembered and the nuclear power supply is raised to the storage orbit. On the other hand, the class II satellites may be considered dead or at least in a reduced mission capacity when the characteristic small orbital maneuvers cease and natural orbital decay begins. Thus the possible period of joint operations between class I and class II satellites was established (Table 2). No joint operations are attributed to the first two class I and class II constellations since in the case of Kosmos 699 the satellite had already begun natural decay before the launches of Kosmos 723 and 724[7] and in the case of Kosmos 777 and 785 the latter spacecraft apparently malfunctioned immediately and was placed in a storage orbit after only 10 revolutions. Kosmos 868 appears to have been a replacement for Kosmos 838 since its launch came shortly after Kosmos 838 entered a regime of natural orbital decay and while Kosmos 861 was still active.

Further analysis of the 1980 Soviet ocean surveillance satellites' mean motion time histories also suggested a connection between the class I and class II satellites. The class I satellite Kosmos 1176 was launched 46 days after the class II satellite Kosmos 1167 and remained in its low operational orbit for a record 134 days. Shortly after the transfer of Kosmos 1176's nuclear power supply to a storage orbit, Kosmos 1167 ceased its normal micromaneuvers and exhibited first anomalously high and then low values of mean motion (Fig. 7). However, a return to its characteristic behavior was seen just prior to the launch of another class II satellite, Kosmos 1220. Although the reason for the higher than normal mean motion is unknown, the abrupt change to a lower than normal mean motion was necessary to bring Kosmos 1167 back to its usual ground track, i.e., ascending nodes (Fig. 1).

The implication is that strict adherence to its predetermined ground track is essential when operating in conjunction with another satellite. A very similar increase in the mean motion of Kosmos 1260 has just been observed (June 27, 1981) following the end of the operational life of the class I satellite Kosmos 1249 on June 19, 1981.

Although both types of spacecraft travel in circular orbits at inclinations of 65 deg, the higher altitude of the class II satellites results in a roughly 3½ min difference in orbital periods and hence prevents a close coupling of satellite motions of the two spacecraft types. However, an examination of the relative positions of the orbital planes of the class I and class II satellites revealed an unexpected correlation. Whenever a class I-class II constellation was formed, the right ascension of the class II satellite was always 132-150 deg greater (i.e., orbital plane more easterly) than that of the class I satellite(s) (Table 2). This consistency precludes random chance. Due to the smaller nodal precession rate of the class II satellite, the net separation rate of the orbital planes amounts to only ⅓ deg per day. Thus after the 46 days of joint operations between Kosmos 937 and Kosmos 952/954 the orbital planes had expanded only an additional 15 deg (Fig. 8).

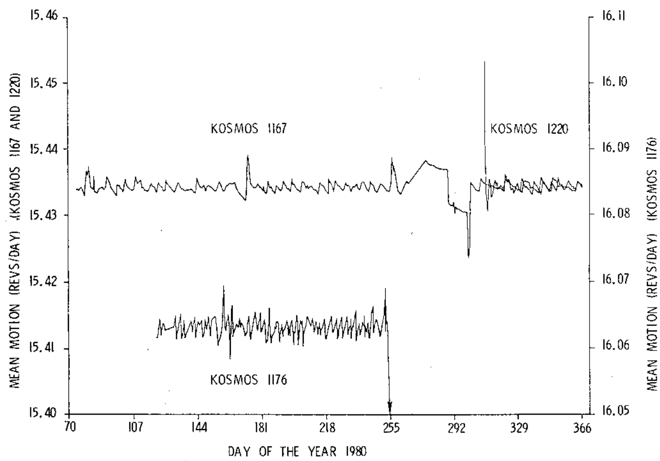

Fig. 7 Kosmos 1167 underwent anomalous behavior between flights of Kosmos 1176 and 1220.

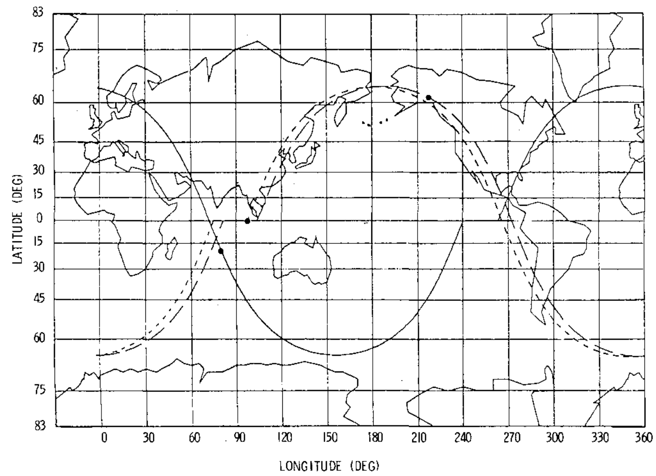

Fig. 8 The Kosmos 937 (solid line), Kosmos 952 (short dashes), and Kosmos 954 (long dashes) constellation at 0721 GMT on Sept. 26, 1977.

Conclusions

The operation of Soviet ocean surveillance satellites in pairs of the same class appears to be highly dependent upon maintaining a common set of ground tracks. Since the satellites have been separated in time by no more than 45 min and since their adjoining ground tracks are closely spaced, a significant probability exists that both satellites will be able to detect the same naval vessels in the vicinity of their ground tracks. Just as a ground observer requires the sightings of several navigation satellites to accurately pinpoint his position, multiple passes of ELINT satellites may be required to determine the location of an object on the Earth. However, in this case the object of interest is mobile, presenting accuracy and correlation problems if sightings are more than a few hours apart. Data from a pair of satellites which are displaced both in space and time will improve the accuracy of location of the relatively slow-moving ocean craft as well as provide information on speed and bearing.

Employment of both classes of satellites further enhances detection probability, e.g., at times a ship may attempt radio/radar silence to avoid class II satellites or weather and sea conditions may degrade the effectiveness of class I satellites. However, since the two satellite classes possess different orbital periods due to their different altitudes (probably a tradeoff between radar power limitations of the class I satellites and a larger field of view for the class II satellites), another technique to insure passage over a common ocean area within a short time interval has been adopted.

By insuring that the orbital plane of the class II satellite leads the orbital plane of the class I satellite by 132-150 deg, the Soviets have carefully positioned the nominal intersection of the ascending class II satellite ground track and the descending class I satellite ground track between 22° and 38°N latitude. Thus both types of satellite will always pass over the same ocean region at these latitudes within less than an hour of one another. Also possible are more prolonged sequential overflights at slightly lower latitudes. For example, Kosmos 937, 952, and 954 all passed just to the west of the Panama Canal on Sept. 26, 1977 at intervals of approximately 60 and 30 min.

Fixes from all three satellites will refine even further the location accuracy and determination of speed and bearing of the ship. The complementary information of the electromagnetic emanations picked up by the class II satellite and the sizing estimate derived by the class I satellite may aid in the identification of the vessel type.

Due to the varying time difference of nodal crossings of the class I and class II satellites, the latitude range of intersections actually extends several degrees above and below the 22-38°N latitude band. In addition, as the orbital planes separate at the ⅓ per day rate, the intersection latitude gradually drifts southward. Therefore, during the expected period of joint operations, the sea lanes and ports most vital to U.S. and Allied naval forces receive prime coverage.

The marked improvement in longevity exhibited by the 1980 class I and class II satellites indicates a renewed emphasis on strategic ocean reconnaissance concurrent with the expansion of the Soviet Navy's projection of power. Operations in early 1981 indicate that a constellation of two class I and two class II satellites may soon appear as the standard Soviet ocean surveillance network.

Acknowledgments

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