THE GEOSTRATEGIC IMPLICATIONS OF INDIA'S SPACE PROGRAM

Dinshaw Mistry

In August 1999, India announced a draft nuclear doctrine that declared that its nuclear forces would be based on "a triad of aircraft, mobile land-based missiles, and sea-based assets," and that "space-based and other assets shall be created to provide early warning, communications, [and] damage/detonation assessment" for this force.[1] The draft doctrine was not official government policy; it primarily represented the thinking of technical and political elites who influence Delhi's nuclear decision making to varying degrees. Nevertheless, although the government of India ultimately distanced itself from the document, Delhi has still been pursuing many of the doctrine's technical parameters. And while it may take India several years to build and deploy a robust nuclear arsenal, many of the technologies required for such a force are already becoming available through the country's space program.

India's space program undertakes two major activities–it builds satellites used for remote-sensing, meteorology, and communications and constructs the rockets to launch its satellites. These space assets have found both civilian and military applications. In the 1970s and 1980s, India's first satellite launch vehicle, the SLV-3, was powerful enough only to launch a light payload (typically, a scientific satellite) to 300–450-km altitude low earth orbit (LEO). Such light-weight low-orbit satellites did not have significant military or commercial capabilities. However, the SLV-3 could still be used as an intermediate range ballistic missile.

Dinshaw Mistry is Fellow at the Belfer Center for Science and International Affairs, Kennedy School of Government, Harvard University, Cambridge, Mass.

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[1] "Draft Report of National Security Advisory Board on Indian Nuclear Doctrine," August 17, 1999, on the Embassy of India in the U.S. home page, at <http://www.indianembassy.org/policy/CTBT/nuclear_doctrine_aug_17_1999.html>.

In the 1990s, India developed more powerful launch vehicles to launch heavier satellites into the optimal higher altitude orbits. These advanced satellites were designed (and have been primarily used) for economic applications, but they also offer potential military spin-offs. The Polar Satellite Launch Vehicle (PSLV) enables the Indian Space Research Organization (ISRO) to place its medium-weight remote-sensing satellites into the optimal 800–900-km altitude orbit. The PSLV's successor, the Geostationary Satellite Launch Vehicle (GSLV), permits ISRO to launch heavy-weight communications satellites to the necessary 36,000-km altitude GEO. These space assets provide New Delhi with a satellite-based reconnaissance and communications capability. Such advancing space capabilities, combined with the modernization of India's conventional forces and the development of its nuclear forces, could significantly influence the strategic relationship between India and its traditional rivals, Pakistan and China, and thereby have broader security implications for the Asia-Pacific region.

This article critically examines the geostrategic implications of India's space program.[2] The article first reviews the history of India's space program, the development of India's satellite launch vehicles and missiles, technological obstacles to these projects due to international arms control embargoes, and India's satellites. It then examines how broader political developments have historically influenced India's space program, which suggests that recent political developments–such as India's seeking of a nuclear arsenal–could lead to greater strategic uses for its space assets. Accordingly, the article next analyzes how India's space assets may be used as nuclear delivery systems and for reconnaissance and command and control, and discusses the strategic utility of such applications. It finally discusses issues of organization, manpower, and costs that may constrain the scope of India's space activities, and concludes with an overall assessment of India's space capabilities.

The History of India’s Space Program

India's space program has passed through two stages of development. The first stage began in the 1960s and involved setting up an administrative framework and gaining experience with elementary rocket operations such as

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[2] Other aspects of India's space program, such as its economic development applications and commercial uses, are only briefly alluded to in this article and examined in greater detail in Dinshaw Mistry, “Technology for Defense and Development: India's Space Program” in *India's Nuclear Security*, eds. Amit Gupta and Raju Thomas (Boulder, Colo.: Lynne Rienner, 2000), pp. 201–20. It should also be clarified that the credibility of sources used in this article–such as trade journals, newspapers, and official publications–varies considerably; therefore, technical details in this article may not be precisely accurate but are still sufficient to make broad technological and strategic assessments.

sounding rockets, which carry light payloads such as scientific experiments into and beyond the atmosphere (to 100–300-km altitudes).[3] Initial low-tech space operations commenced in the early 1960s, ISRO was formed to coordinate these activities in 1969, and the Indian Department of Space (DoS) was established in 1972. ISRO is part of the DoS. Coordination between ISRO and other space-related agencies (such as the national remote sensing agency that uses ISRO satellite data) is politically carried out through the Indian Space Commission (ISC), which reports to the Prime Minister's Office. The ISC director is also the head of the DoS and the chairperson of ISRO. The ISC formulates Indian space policy, and the DoS executes ISC policy through ISRO.

ISRO's first chairman, Vikram Sarabhai, planned the gradual evolutionary development of the Indian space program. In 1970, Sarabhai noted that

> in a 10-year time frame, one must acquire the capability not only of building telecommunication satellites such as INSAT-1 but also of launching them into synchronous orbit. . . . [T]o begin with, we have set as a goal the development of a satellite launcher of the Scout type. . . . [O]nce the basic systems have been developed for this, and experience acquired in operating them, it is estimated that a five-year period from 1975 to 1980 should be adequate for the second stage of development of larger boosters.[4]

The Indian space program has lagged more than a decade behind Sarabhai's intended schedule.

The latter phase of the first stage of India's space program focused on mainly experimental, low-capability projects that allowed Indian scientists to gain experience in the construction and operation of satellites and launchers. In this phase, ISRO built (with foreign assistance) the Bhaskara earth observation satellites and the APPLE (Ariane Payload Experiment) communication satellite. From 1979 to 1983, it also conducted four tests of its indigenously built SLV-3 rocket (that was designed similar to the U.S. Scout rocket).

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[3] Gary Milhollin, “India's Missiles–With a Little Help from Our Friends,” *Bulletin of the Atomic Scientists* (*BAS*), November 1989, pp. 31–35. Less powerful rockets can only launch light satellites into LEOs of 100–300-km altitude; they cannot reach higher altitudes. More powerful rockets are required to launch heavy (earth observation and communications) satellites into higher orbits. Such satellites are typically heavier because they carry many or more sophisticated cameras and sensors for earth observation, or many transponders (electronic devices) for radio and television communications. Higher orbits are also more useful for such applications–a 36,000-km altitude geostationary earth orbit (GEO) where a satellite can be parked in a fixed location above the earth is optimal for communications satellites.

[4] Vikram Sarabhai, *Science Policy and National Development*, ed. Kamla Chowdhry (Delhi: Macmillan, 1974), p. 61.

The second stage of India's space program commenced in the mid-1980s and focused on larger, more powerful, and mission-specific systems. This stage involved building the PSLV, which was used to launch the Indian Remote Sensing (IRS) satellite, and the PSLV's successor, the GSLV, which was used to to launch the Indian National Satellite (INSAT), a meteorology and telecommunications platform. With the PSLV commencing operational launches in 1997 after three prior demonstration flights and the GSLV making its first flight in 2001, India's space program has emerged from its developing stages and joined the ranks of the world's five most advanced space agencies through the development of such GEO capability.

Satellite Launch Vehicles

ISRO has built two generations of launch vehicles–the less powerful SLV-3 and its upgrade, the ASLV, and the more powerful PSLV and its upgrade, the GSLV. These programs achieve some efficiency and economy of scale because each new launcher utilizes some of the guidance and rocket propulsion systems from prior launchers (see Table 1). For example, the SLV-3 had a single nine-ton solid fuel engine and was powerful enough to launch a 35-kg payload to a 300-km altitude LEO. Three such engines power the ASLV, enabling it to place a 100-kg payload in a 450-km altitude LEO. The same nine-ton solid fuel propulsion systems are also used in the Agni missile and as Peripheral strap-on boosters in the PSLV.

The PSLV and GSLV utilize two major indigenously built propulsion systems–a 130-ton solid fuel engine, and a 37–40-ton liquid fuel engine (whose design is based on the Viking engine of the European Space Agency [ESA] used in the Ariane launch vehicle). They allow the PSLV to launch a 1,200-kg payload (the IRS satellite) to a 800–900-km altitude polar orbit. The same systems are used on the GSLV and supplemented with a 12-ton cryogenic engine, which enables the GSLV to carry a heavier 2,500-kg payload (an INSAT-2 class satellite) to a higher 36,000-km GEO.

The first batch of GSLVs use Russian-supplied cryogenic engines. Later GSLVs will use indigenously built and more powerful cryogenic engines that can launch heavier 3,500-kg satellites; these satellites would carry a larger number of transponders and facilitate a greater volume of communications. ISRO's first ground test of its indigenous cryogenic engine failed in February 2000. ISRO expected to build an operational cryogenic engine by 2003. ISRO also plans to use a 200-ton solid fuel engine and a 20-ton cryogenic engine for future more powerful GSLVs that would have greater payload capabilities.

India's satellite launch vehicle program, though maturing, has not escaped failures–only five out of eight (62%) SLV-3 and ASLV launches were successful, while four out of five (80%) of PSLV launches have been successful.

TABLE 1 *India's Satellite Launch Vehicles and Missiles*

Launch Vehicle	*Date*	*Height (m)*	*Weight (tons)*	*Altitude (km)*	*Range (km)*	*Payload (satellite) (kg)*	*Propulsion (stage, wt in tons, fuel)*
SLV-3	August 1979,* July 1980, May 1981, April 1983	23	18	LEO: 300	(1,500)	35 (Rohini)	*stage 1*: one 9-ton SF engine
ASLV	March 1987,* July 1988,* May 1992, April 1994	23	41	LEO: 450	–	100 (SROSS)	*stage 1*: three 9-ton SF engines
PSLV	September 1993,* October 1994, March 1996, October 1997, May 1999, October 2001	44	275	800–900	–	1,000 (IRS)	*stage 1*: one 130-ton SF engine and six nine-ton SF engines *stage 2*: one 37-ton LF engine
				GEO		450	
GSLV	April 2001	51	402	GEO	–	2,500 (INSAT-class or GSAT)	*stage 1*: one 130-ton SF engine and four 37-ton LF engines *stage 2*: one 37-ton LF engine *stage 3*: one 12-ton Cr engine
Prithvi	March 1988 (17 tests until 2000)	8	4	–	150 250	1,000 250	one 3-ton LF engine
Agni-1	May 1989, July 1992,* February 1994	21	16	–	1,500	1,000	one 9-ton SF engine and one 3-ton LF engines
Agni-2	April 1999, January 2001	21	16	–	2,000	1,000	one 9-ton SF engine and one 4-ton SF engine

SOURCE: Data compiled by author from ISRO data and *Jane's Space Directory* (Alexandria, Virginia: Jane's Information Group, 1999–2000).

NOTES: SF = solid fuel; LF = liquid fuel; Cr = cryogenic fuel.

*Mission failure.

The first SLV-3 launch (August 1979), the first (March 1987) and second (July 1988) ASLV launches, and the first PSLV launch (September 1993) failed. In most of these cases, the hardware and major propulsion systems performed well. The failures occurred because of software problems such as the delayed ignition of stages, disturbances during the separation of stages, and the inability of the guidance and control systems to correct for trajectory deviations resulting from these disturbances. Other partial failures occurred in the fourth PSLV launch in September 1997. During this launch, the rocket reached the required altitude but did not precisely place the satellite into the correct orbit. Moreover, the initial GSLV launch attempt in March 2001 was aborted one second before lift-off (though this feat successfully validated the performance of the safety systems). The first GSLV flight in April 2001 was successful but left the satellite just short of its precise orbit.

Ballistic Missiles

India's missile program partially overlaps with, while being partly distinct from, India's space program. In July 1983, New Delhi embarked upon an Integrated Guided Missile Development Program (IGMDP). The IGMDP was initially allocated a budget of Rs. 380 crore ($130 million) and by 1994 had received over Rs. 780 crore ($275 million).[5] It was pursued through India's Defense Research and Development Laboratory (DRDL) at Hyderabad in South India. DRDL is part of a larger military research and development (R&D) apparatus, the Defense Research and Development Organization (DRDO). The outlays for Department of Atomic Energy (DAE), DRDO, and ISRO were Rs. 1,537 crore ($390 million), Rs. 2,786 crore ($700 million), and Rs. 1,755 crore ($430 million), respectively, in the 1999–2000 budget.

The goal of the IGMDP was to build five missiles–an anti-tank missile, two surface-to-air missiles, and the 150–250 km-range Prithvi and the 1,500–2,500-km range Agni missiles. The latter two systems form the backbone of India's missile forces. Besides the IGMDP, DRDO has other military projects such as the Light Combat Aircraft (LCA) and the Main Battle Tank (MBT) and has developed systems such as radars, sonars, simulators, materials and composites, and parallel processing computers.

Produced by Bharat Dynamics Limited, the Prithvi missile has a propulsion system derived from the SA-2 missile of 1960s vintage. Eighteen Prithvi tests (and a failed test from a naval platform) were conducted between 1988 and 2001. Fourteen of these were of the SS-150, the 150-km range

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[5] Tim McCarthy, "India: Emerging Missile Power" in *The International Missile Bazaar: The New Suppliers' Network*, eds. William Potter and Harlan W. Jencks (Boulder, Colo.: Westview Press, 1994) p. 202; and Waheguru Pal Singh Sidhu, *Enhancing Indo-U.S. Strategic Cooperation*, Adelphi Paper No. 313 (September 1997), p. 25.

version of the missile; they took place from 1988 to 1994. Subsequent tests were held of the SS-250 variant, which can travel 250-km but with a reduced payload. All Prithvi tests were reported to be successful, except for the sixth during which the missile broke up in flight. The first six tests (1988–92) were from the SHAR center and subsequent ones (May 1992 onward) were from the Chandipur range. Test numbers 8 to 10 were from mobile launchers, and the tenth test in June 1993 was the first from a production batch.

User trials for the Indian army took place in June 1994. That year the army placed an order for 75 SS-150s and the Indian air force sought 25 SS-250s. By the end of that June, India's 333rd Missile Group in Secundrabad (in South India) had acquired six missiles.[6] A few Prithvi missiles were transferred to Jalandher close to the border with Pakistan in May–June 1997, but these were moved back to Secundrabad.[7] The Prithvi is distinct from ISRO's sounding rockets, which theoretically could have been converted into short-range ballistic missiles. Thus, in terms of short-range missiles, ISRO and DRDO have pursued different rocket programs.

The Agni missile is more directly derived from the Indian space program's SLV-3. In ISRO's early years when it was headed by Vikram Sarabhai and Satish Dhawan, the organization opposed military applications for its dual-use projects such as the SLV-3. Eventually, however, the DRDO-based missile program borrowed human resources and technology from ISRO. Missile scientist Abdul Kalam, who headed the SLV-3 project at ISRO, moved to DRDO to direct India's missile program. While only about a dozen scientists accompanied Kalam from ISRO to DRDO, key DRDO projects nevertheless benefited from prior ISRO projects. Kalam designed the Agni-1 missile using the SLV-3's solid-fuel first stage and a liquid-fuel (Prithvi-missile-derived) second stage. The Agni-1 flew three times–in 1989, 1992, and 1994–to a maximum range of 1,400 km.

Agni missile tests (but not R&D) were temporarily frozen thereafter; on December 5, 1996, New Delhi announced the suspension of the Agni program. That year an October Indian defense ministry report recommended that the Agni be suspended. Citing this report, an Indian parliamentary committee stated that because the objectives of the Agni technology demonstration project had been met, the project was being terminated. The committee added that the decision to develop a missile system from Agni technology

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[6] Greg Gerardi, "India's 333rd Prithvi Missile Group," *Jane's Intelligence Review*, August 1995, pp. 361–64.

[7] R. Jeffrey Smith, "India Moves Missiles Near Pakistani Border," *Washington Post*, June 3, 1997; and Andrew Koch and Waheguru Pal Singh Sidhu, "Subcontinental Missiles," *BAS*, July/August 1998.

could be taken at an appropriate time consistent with the prevailing threat perception.[8]

The missile program revived after India's 1998 nuclear tests and the accompanying political decision to develop a more capable nuclear arsenal. India tested the rail-mobile Agni-2 missile to a range of 2,000 km in April 1999 and tested it again in January 2001 "in its final operational configuration." The Agni-2 has a solid fuel second stage built by ISRO.

MTCR Technology Embargoes

The Missile Technology Control Regime (MTCR) is a key international instrument aiming to halt the spread of ballistic missiles by denying states the necessary foreign technical assistance for rocket development. Influenced by the MTCR's technology barriers and political-economic pressures, Argentina, Brazil, South Africa, Taiwan, South Korea, and Egypt curbed their missile activity, while in the decade after the MTCR came into force Syria, Iraq, and Libya saw their missile development efforts fail. However, the MTCR was unable to prevent tests of 1,000–1,500-km range missiles by North Korea, Pakistan, and Iran in 1998.

India's space program had initially benefited from foreign technology transfers. For example, in the early 1970s Germany's space agency transferred technologies relevant to propulsion and guidance systems, flight controls, material science, and wind tunnels. In the 1960s, foreign sounding rockets were launched from the Thumba range in South India, while the design of the U.S. Scout rocket was taken as the model for the SLV-3. Despite such links with foreign suppliers, India's space activity nonetheless did not come to a halt when foreign assistance was restricted by the MTCR. ISRO and Indian industry indigenously developed many space and missile technologies after being denied their import. These included shell catalysts for rocket fuel, magnesium plates for the Prithvi, radiation-hardened integrated circuits for satellites, and maraging steel for rocket motor casings. This indigenous construction typically took five years and resulted in an approximately 10% increase in expenditures. These obstacles of time and money were significant in the short-term, but because ISRO was not operating under rigid time-constraints, the slow pace of indigenous production did not hurt ISRO projects.[9] The highly publicized imposition of U.S. nonproliferation sanctions in 1992–94 against ISRO and a Russian firm, Glavkosmos, for the latter's supplying of cryogenic engines to the former did not significantly

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[8] Reuters, December 5, 1996.

[9] A. Baskaran, "Different Stages of Technological Capabilities and the Effectiveness of Export Controls: The Case of India's Space and Missile Programs" (paper presented at the 9th International Summer Symposium on Science and World Affairs, Ithaca, New York, July 1997).

affect ISRO activity. Eventually, ISRO acquired cryogenic engines from Russia (albeit without the technology). Thus, while for the time being the MTCR has delayed and increased the costs of ISRO projects, it has not halted any project.

Satellites

India's satellite program has achieved quicker and greater success than the country's satellite launch vehicle program. The first Indian satellites–Aryabhatta, Bhaskara, and Rohini–enabled Indian scientists to gain experience in satellite operations and were stepping stones toward developing more capable satellites (see Table 2). The 1,100-kg INSAT-1 series was constructed in the U.S. by Ford Aerospace. These satellites carried communications transponders and meteorological sensors. The 2,000–2,500-kg INSAT-2 satellites were indigenously built by ISRO; they had a greater number of and more powerful transponders than INSAT-1. Their low-power C-band transponders typically support a few hundred phone lines each, while higher power transponders in the extended-C, S, and Ku bands each support a television channel or high volume data and mobile communications. INSAT-2 meteorological sensors provide seven-minute repetitive coverage (useful for tracking and relaying information on rapidly changing weather conditions), which is better than the 30-minute INSAT-1 time frame.

The INSAT satellites have been well utilized in setting up a national telecommunications infrastructure. For example, INSAT-1B extended television coverage to over 75% of India's population and subsequent INSATs brought most of India under television coverage. The INSAT-2 satellites provide telephone links to remote areas; data transmission for organizations such as the National Stock Exchange; mobile satellite service communications for private operators, railways, and road transporters; and broadcast satellite services used by India's state-owned television agency and commercial television channels.

The GSATs are smaller satellites launched on the initial GSLVs. The GSATs are intended for low-cost experiments and demonstrations of technologies such as digital audio, data and video broadcasting, Internet services, and wide-band multimedia signals. GSAT-1 weighed 1,540 kg and carried two S-band transponders, a high-power C-band transponder, and two C-band transponders.

The first of the INSAT-3 satellites, INSAT-3B, was launched in March 2000. It provides fixed as well as mobile satellite services and replaced INSAT-2D. INSAT-3A is a multipurpose communication and meteorological satellite that carries a meteorological data relay transponder and a search and rescue transponder. INSAT-3C is intended to be a communication satellite

TABLE 2 *India's Satellites*

Satellite	*Date (mo-yr)*	*Launch Vehicle*	*Weight (kg)*	*Altitude (km)*	*Function*	*Sensors/Capability*
Aryabhatta	April 1975	SL-8 (Soviet)	360	590	Scientific	Resolution: 1,000-meter
Bhaskara-1	June 1979	SL-8 (Soviet)	440	530	Earth-observation	Resolution: 1,000-meter
Bhaskara-2	November 1981	SL-8 (Soviet)	440	530	Earth-observation	Resolution: 1,000-meter
Apple	June 1981	Ariane (ESA)	670	GEO	Telecom	Resolution: 1,000-meter
INSAT-1-A	April 1982, August 1983	Delta (U.S.)	1,100	GEO	Telecom & meteorology	Transponders: 12 C-band and 2 S-band
-B, -C, -D	July 1988, June 1990	Challenger (U.S.), Ariane, Delta				Transponders: 12 C-band and 2 S-band
INSAT-2-A	May 1992	Ariane	1,900–2,100	GEO	Telecom & meteorology	18 C-band and 2 S-band
-B, -C	March 1993, December 1995					18 C-band and 2 S-band
-D, -E	June 1997, April 1999					18 C-band, 3 S-band, and 3 Ku-band
INSAT 3-B	March 2000	Ariane	2,100	GEO		12 C-band, 3 Ku-band, 1 S-band
GSAT	1999–2000	GSLV	1500+	GEO	Telecom (education)	3 C-band and 2 S-band
IRS 1-A	March 1988	Vostok (Russia)	1,000	800–900	Remote sensing	72-meter and 36-meter
-B	August 1991	Vostok (Russia)				72-meter and 36-meter
P2	October 1994	PSLV-D2 (India)				36-meter
-C	December 1995	Molniya (Russia)				23-meter and 6-meter
P3	March 1996	PSLV-D3				WiFS (180-meter)
-D	September 1997	PSLV-C1				23-meter and 6-meter
P4	May 1999	PSLV-C2				WiFS, 10-meter, 2-meter
	October 2001					
P5, -P6		PSLV-C4, -C5				

SOURCE: Ibid., Table 1.

similar to INSAT-3A, while INSAT-3D will be primarily configured as a meteorological satellite.

The IRS program removed New Delhi's dependence on satellite images from the U.S.'s Landsat and the multinational SPOT (Satellite Pour l'Observation de la Terre) satellites. IRS-1A was launched in March 1988, IRS-1B in August 1991, and IRS-1C in December 1995, on Russian launch vehicles. IRS-1D (September 1997) and the IRS-P series are launched on India's PSLV. IRS-1A and -1B sensors had a resolution of 72-meter multispectral (in the visible and near-infrared band) and 36-meter panchromatic. Multispectral sensors acquire a separate image for each wavelength band of light; they provide good overall detection since multiple images of the same object can be compared in order to accurately determine data. Panchromatic sensors acquire a single image of the viewed area by collecting light over a wide wavelength band; consequently, objects may not be accurately identified.

IRS-1C and -1D cameras have a better resolution of 23-meter multispectral and six-meter panchromatic. The IRS-P series are quick-turnaround low cost versions of the IRS-1 satellites, costing approximately $15 million (far less than the $50 million IRS-1 series).[10] IRS-P3 carried a Wide Field Sensor (WiFS) of 180-meter resolution to monitor vegetation. IRS-P4 is an ocean satellite launched on PSLV-C2. IRS-P5 (Cartosat-1) will provide two-meter panchromatic images, while Cartosat-2 (to be launched in 2003–04) will have a one-meter resolution. IRS-P6 (Resourcesat) will have the same configuration as IRS-1D and be used for agricultural applications, while IRS-P7 (Oceansat) will have fishing applications, and IRS-P8 and -P9 are intended for atmospheric and environmental studies.

The IRS satellites form the nucleus of the Indian Natural Resource Management program. Regional Remote Sensing Service Centers (RRSSCs) in five Indian cities and Remote Sensing Application Centers in 20 Indian states have used IRS images for a wide range of economic applications. These include environmental monitoring, analyzing soil erosion and the impact of soil conservation measures, forestry management, determining land cover for wildlife sanctuaries, delineating ground water potential zones, flood inundation mapping, drought monitoring, estimating crop acreage and deriving agricultural production estimates, fisheries monitoring, mining and geological applications such as surveying metal and mineral deposits, and urban planning.[11]

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[10] Michael Mecham, “Cost-Conscious Indians Find Profits in Imaging Satellites,” *Aviation Week and Space Technology*, August 12, 1996, p. 59.

[11] “Remote Sensing Tech Being Widely Used All Over India,” *Deccan Herald,* October 3, 1997.

Political-Economic Influences and Objectives

When it was first conceived in the 1960s, India's space program was intended to play a significant role in a broader national policy of planned socioeconomic development. At the time, technological advances promised to enable countries to leapfrog over traditional stages of development and make a quick transition to an industrial and post-industrial society. Therefore, satellite communications, educational television programs, meteorology, and natural resource survey and management were, and continue to be, priority areas for the Indian space program. India's space program has also been guided by strong political motivations. It was intended to symbolize India's high-technology achievements and enhance New Delhi's international status, especially among the non-aligned group of nations. The Indian space program also caters to a domestic constituency–successful satellite deployments and launches are national morale boosters.

Following the 1971 war with Pakistan and New Delhi's emerging perceptions of a U.S.-Pakistan-China convergence in that war, India's space program was sharply upgraded in mid-1972. ISRO was separated from the Atomic Energy Commission and placed under the DoS, which was set up in 1972 and assigned rigid schedules for meeting technical and applied objectives. In July 1974 (soon after India's nuclear test that May), ISRO director Satish Dhawan stated before a parliamentary committee that India had the ability to produce medium-range missiles with locally developed solid fuels and guidance systems.[12] Dhawan was referring to the SLV-3, which was actually still five years from its first flight.

In the mid-1980s, a significant military spin-off from India's space program emerged when the SLV-3's first stage was used in the Agni missile. The PSLV and its successor, the GSLV, are better suited for commercial rather than military applications. The commercial aspect of India's space program became prominent in the 1990s, when, influenced by India's economic liberalization program, ISRO's goals widened to offer its space services on the international market. ISRO set up the Antrix corporation in 1992 to market its services. ISRO gained limited revenue from the sale of IRS images (valued at $5 million in 1998 and estimated to be $10–$20 million subsequently) and the lease of 11 C-band transponders on INSAT-2E to Intelsat ($100 million for 10 years). Future revenue from any satellite launches (such as $25 million for a PSLV launch or more for a GSLV launch) would also be limited because of ISRO's low launch rate of one or two launches annually. Such revenue would not be sufficient to recover the

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[12] Dieter Braun, "Wie friedlich ist Neu-Delhi's Atom-programm?" [How peaceful is New Delhi's atomic program?] *Europa-Archive*, September 25, 1974, p. 626.

several hundred million dollars development cost of the PSLV and GSLV program.

Writing in 1986, Raju Thomas noted that ultimately

> India's intentions may be judged simply from the level of technological capabilities, whether for development or defense purposes. Does the technology achieved in the civilian nuclear and space program provide India with credible nuclear weapons and delivery systems? The answer to this question is yes–if not now, then at least in the near future?[13]

India's space program subsequently provided an intermediate range nuclear delivery system–the Agni missile. In addition, India's satellites and satellite launch vehicles have several potential military and strategic applications.

Nuclear Weapon Delivery Systems

India's first satellite launch vehicle, the SLV-3, was modified into the Agni missile. Despite being more powerful than the SLV-3, India's subsequent satellite launchers, the ASLV and PSLV, have not found direct applications as ballistic missiles. The Agni is relatively light and therefore transportable; it provides for an ideal mobile intermediate-range ballistic missile system. The Agni-1 and Agni-2 give New Delhi a minimum deterrent but cannot strike China's most important cities, Beijing and Shanghai, which are 2,500 km away from insecure launch sites in Northeast India.

The ASLV and PSLV theoretically have a 4,000-km and 8,000-km range, respectively, and would bring China's heartland within range when launched from secure launch sites in East and Central India. Yet it would be difficult to deploy the ASLV and PSLV as mobile, truck- or rail-mounted missiles because of their strap-on boosters (which greatly increase the effective diameter of these systems and make it hard to deploy them on mobile launch units). Moreover, the PSLV is extremely heavy and inefficient in terms of weight-to-payload ratio. Any missile with the PSLV's first and second stage boosters would weigh some 170 tons, while most intercontinental ballistic missiles of capabilities similar to the PSLV weigh less than 100 tons. Therefore, instead of utilizing the complete PSLV as a missile, DRDO may use portions of the PSLV in a 3,000–5,000-km range Agni-3.

DRDO was considering two options to increase the Agni-3's range to 5,000 km. One option would utilize a solid booster of 1.8-meter diameter with 36 tons of propellant fuel (the PSLV utilizes a 36-ton liquid fuel booster), while the second option would add a third stage to the Agni-2, though stage separation is a complicated process. In September 2000, De-

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[13] Raju Thomas, "India's Nuclear and Space Programs," *World Politics* 38:2 (January 1986), p. 340.

fense Minister George Fernandes informed India's Defense Consultative Committee that the Agni-3 missile had almost completed the development stage and was ready for testing sooner than expected.[14]

Reconnaissance

The IRS satellites are primarily used for civilian applications. The present IRS system offers only a moderate military reconnaissance capability, with the drawbacks of poor resolution and limited frequency of coverage. The LISS-3 cameras on IRS-1C have a 23-meter resolution in the visible and near-infrared band, permitting the detection of large military installations. The PAN camera on IRS-1C has a resolution of six-meter panchromatic, which can broadly detect surface ships, aircraft, tank formations, and ballistic missile units, but may not precisely identify these objects.

Two important shortcomings of the IRS satellites should be noted. First, the visible and near-infrared cameras do not permit viewing through cloud cover and dense foliage. Second, the IRS satellites are unable to provide round-the-clock monitoring. The 23-meter resolution LISS-3 camera on IRS-1C has a 24-day repeat cycle (i.e., it revisits a given location every 24 days). The six-meter resolution PAN camera has a 40-day repeat cycle, though the camera can be swiveled to yield a five-to-seven-day repeat cycle.[15] These shortcomings in repeat cycles are likely to persist even with the advent of new IRS satellites; for example, a combination of two satellites, each with a five-to-seven-day repeat cycle, would together provide only a two-to-three-day repeat cycle. Thus the IRS system could not provide daily or hourly updates of a battlefield situation to military command centers.

These drawbacks can be overcome on an ad hoc basis by changing the IRS orbit to yield a shorter repeat cycle. ISRO could also increase the resolution from its satellites by moving them to a lower orbit. From their 800-km altitude orbit, the LISS-3 and PAN sensors have a 23-meter and six-meter resolution, respectively. When placed at a lower altitude (typically a 300-km altitude orbit), they would generate militarily useful eight-meter multispectral and two-meter panchromatic images, respectively. The above adjustments in satellite orbit would expend fuel and decrease the satellite's life-cycle, and are not known to have been attempted. Finally, the Indian military could build a series of dedicated military reconnaissance satellites from existing

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[14] "3000-km Agni-III Ready; N-Restraint Can Go, Warns India," *Deccan Chronicle*, September 23, 2000.

[15] Repeat cycles are inversely proportional to the swath width of a camera. The repeat cycle for IRS-1C's 23-meter resolution, 140-km-swath width LISS-3 camera is 24 days; repeat cycles for 180-meter resolution images are five days for IRS-1C's 770-km swath width sensor, and three days for IRS-P3 sensors. The six-meter resolution PAN sensor has a 70-km swath width, yielding a 40-day repeat cycle.

IRS technology. This option becomes feasible because only small incremental costs would be involved in using the IRS infrastructure and a proven launch vehicle (the PSLV) to construct and deploy a dedicated military reconnaissance satellite system. Thus, Delhi's defense bureaucracy experimented with the concept in October 2001 when the PSLV launched a 1,108 kg Technology Experiment Satellite (TES) to a 568 km orbit; its one-meter resolution panchromatic camera with a two-to-three-day repeat cycle provided useful reconnaissance capabilities.[16]

Command, Control, and Communications

India's communications satellites have some military capabilities but have not had specifically designated military functions. The INSATs can be used for multiple access digital data transmission, teleconferencing, and remote area emergency communications, features that would be well-utilized in a command and control network and for search and rescue. However, the INSATs are not optimal for military operation because of their inappropriate frequency range. The C, S, and K band transponders on INSAT-2 operate primarily in the UHF and low SHF range, which is typical for civilian communication satellites; these frequencies can easily be jammed (to overcome this limitation, the TES may have carried a beam-steering antenna that would prevent eavesdropping on communication).[17] Dedicated military communications satellites operate in the high SHF or EHF range that is less susceptible to jamming. A second limitation with the INSATs is their limited transponder capacity. Moreover, the fixed number of transponders on the INSATs were intended, and have in fact been leased, for civilian and commercial use and are in short-supply, leaving few available for India's military. The failure of INSAT-2D added to the shortage of transponders and caused ISRO to lease first Arabsat 1-C in 1997 and then three C-band transponders from Thailand in 2000.

These limitations can be temporarily corrected by using some civilian transponders for military purposes. Further, with the launch of new satellites, ISRO could have 135 transponders by 2002 (compared with 67 transponders in 1998), including more Ku-band transponders (that allow a higher volume of communications than C-band transponders), which could give New Delhi a few more transponders for military use. New Delhi could also build dedicated communication satellites, a project that is technically and financially viable because its costs are lowered by using existing INSAT infrastructure. The PSLV can launch 500-kg communications satellites (which would carry only a few transponders and facilitate a small volume of communication) into

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16. *Deccan Herald*, October 23, 2001.
17. The *Hindu*, October 23, 2001.

GEO. The GSLV would give New Delhi a launch vehicle for any heavier and more powerful military communications satellites. Finally, the extent of the Indian military's ground-based institutional arrangements that enable the integration of satellite information with tactical and strategic planning are unclear–they are probably still in a rudimentary phase, but they could be further advanced as India develops its nuclear forces.

The Strategic Utility of India’s Space Assets

In the middle term, India could build either a modest or an expanded nuclear and space force. A modest force would comprise 100 to 150 nuclear weapons delivered by Jaguar, Su-30, and Mirage-2000 aircraft as well as medium-range missiles. In 1996–98, India entered a $1.8 billion deal for 40–50 Russian Su-30MKI strike aircraft to be delivered by 2003. It subsequently signed a $3 billion deal for 140 more Su-30s to be produced under license in India over 15 years. These aircraft carry a several ton payload to a 5,000-km range with one flight refueling. In September 2000 India's government approved a Rs. 15 billion ($300 million) deal for 10 Mirage-2000 aircraft.

India's missile arsenal could include 100 or more 150–250-km range Prithvi missiles (only some of these may be nuclear-armed), several tens of the 2,000-km range Agni-2 (India had built a few of these missiles by 2001), and the more powerful 3,700-km range Agni-3. During the 1990s, India launched one PSLV annually; each had six of the nine-ton solid-fuel boosters used in the Agni missiles. One report notes that India had 10 Agni-1 missiles and two Agni-2 prototypes in 2000, and that if required, DRDO and the Bharat Dynamics Limited could build 18 Agni-2s a year.

India's August 1999 draft nuclear doctrine outlines a more extensive force. To this end, India's BJP-led government (influenced by pronuclear bureaucratic groups) may be willing to allocate considerable economic resources. A low level estimate is that India could spend Rs. 700 billion ($15 billion) over a 30-year period to build a triad with 400 nuclear weapons, which translates into annual expenditures of $500 million, compared against India's $10 billion defense budget and $350 billion GNP. An expanded Indian nuclear force could comprise 300 to 500 nuclear weapons including thermonuclear devices, deployed on land-based intermediate and long-range ballistic missiles and sea-launched ballistic and cruise missiles. India also seeks nuclear-powered submarines through its Advanced Technology Vehicle (ATV) project, though this could take at least a decade to build.

New Delhi's space assets would enhance its nuclear force. India's defense bureaucracy has already experimented with IRS images for reconnaissance purposes. For example, in 1996, New Delhi's Ministry of Defense may have temporarily blocked the use of IRS-1C by the Indian Environment Ministry, Agriculture Ministry, and other government agencies to monitor ballistic missiles near India's borders. In 1997, the Indian Air Force's "Airpower Doctrine" aspired to use space assets for surveillance and battle management.

The Kargil military operations of summer 1999 accelerated New Delhi's efforts to use its PSLV-launched satellites for military reconnaissance. India's military sought to use the forthcoming two-meter resolution Cartosat-1 and one-meter resolution Cartosat-2 for such purposes. By 2000, the air force was conceptualizing various doctrines and schemes for the establishment of an aerospace command and the military use of space, and a parliamentary committee also endorsed the idea. Under its proposed nuclear air and space command, the air force seeks to control both the Agni missiles and strategic surveillance resources. These nuclear, missile, and space capabilities would affect the calculations of regional security planners on both conventional and nuclear issues.

India's satellites are presently unable to maintain round-the-clock coverage of Pakistan's military activities–they failed to detect military intrusions in the Kargil sector of Kashmir in 1999–but permit New Delhi to acquire a database of Pakistani targets. If New Delhi acquires dedicated military reconnaissance satellites that provide daily coverage of Pakistan's military installations, it would obtain a better counterforce capability versus Pakistan (counterforce is the targeting of the opponent's military nuclear forces–because such targets may be numerous, hidden, and well-protected, counterforce missions can be more complicated).

India may not have sufficient resources to build a large military capability required for counterforce missions. Yet, Pakistan's nuclear arsenal is itself small and concentrated at a few locations, and India's limited capabilities are therefore sufficient for a first-strike mission against these few crucial targets. Ultimately, deterrence rests on both perceptions and capabilities–and therefore, even if it does not intend to launch a first strike (indeed, New Delhi would need to have extraordinary confidence in its forces to consider a counterforce mission), New Delhi still has the capabilities to undertake a first strike against Islamabad's nuclear assets and delivery systems. This considerably weakens Pakistan's deterrent, or at least increases Islamabad's perceptions that its deterrent is vulnerable. This in turn makes Islamabad more likely to preemptively move its missiles (movements that may appear threatening to India) or consider a preemptive first strike of its own in any crisis. These factors decrease the stability of deterrence in the subcontinent.

India's Agni-2 and Agni-3 and its advanced strike aircraft such as the Su-30 also provide New Delhi with countervalue capabilities against China. Countervalue is defined here as the targeting of the opponent's cities and population centers that offer large and easily located targets. India would still take several years to develop a modest-sized missile-based nuclear deterrent against China. However, India's satellite reconnaissance systems enable New Delhi to counter Chinese conventional threats in the short-term. India's satellite intelligence capabilities give its military planners invaluable tactical and strategic information on Chinese military forces in Tibet. The existing IRS satellites and a future series of dedicated military satellites could give India's armed forces sufficient early warning about the movement of Chinese military forces from central China toward Tibet and India, thus facilitating the timely deployment of Indian conventional forces to counter such Chinese military deployments.

With the maturation of India's satellite-based reconnaissance and communications capabilities, Pakistan's nuclear deterrent against India would become somewhat vulnerable to an Indian first strike and New Delhi could also more effectively counter a Chinese conventional military threat. The China-Pakistan strategic balance versus India could then be altered. Beijing will have less reliance on the ability of Islamabad's nuclear deterrent to securely balance Delhi, and Islamabad would have less confidence in Beijing's ability to counter Delhi. The U.S. and Southeast Asian nations could also more seriously consider balancing any future emerging Chinese threat with India's increasing nuclear and conventional capabilities that are enhanced by its reconnaissance and communications satellites.

Costs, Manpower, and Organizational Structure

India's space expenditures have increased gradually from an annual average of approximately \$70 million between 1965–79 to \$85 million in 1979–80, \$230 million in 1985–86, \$300 million in 1995–96, and \$350–\$400 million in 1999–2000.[18] ISRO employs over 15,000 scientific and technical personnel. In addition, some 500 public and private sector firms, national laboratories, and academic institutions undertake research or build components for ISRO; half the ISRO budget is outsourced to these subcontractors.[19]

Approximately 45% of the ISRO budget is used for operational satellites and 35%–40% for launch vehicles, with the remainder used for space applications at regional space centers and for administrative costs. In general, the development of more advanced systems–such as heavy propulsion systems for the PSLV and GLSV and more advanced satellites–in larger quantities, plus the construction of a second launch pad in the coming years, accounts

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[18] ISRO notes that "[t]he total cumulative expenditure on space research until the end of the Eighth Plan period (from inception in 1962–63 to 1996–97) is Rs. 7,431.67 crores"; this is Rs. 74 billion for 35 years or Rs. 1.6 billion/year, but exchange rate fluctuations and inflation affect comparing data across years. See the ISRO website, at <www.isro.org> and <http://www.isro.org/performance_budget.htm>.

[19] Nicholas Johnson and David Rodvold, *Europe and Asia in Space, 1993–94* (Kirtland, N.M.: USAF Phillips Laboratory, 1994), p. 10.

TABLE 3 *A Comparative Study of Eight Space Programs*

Country	*No. of Launches*		*First Launch*		*First Use of Cryogenic Technology*	*Space Expenditures (1990–95 avg, in US$ millions)*	*Estimated % of GDP*
	1957–1988	*1989–2000*	*LEO*	*GEO*			
U.S.	890	336	1958	1967	1966	25,000	0.5
Russia & CIS	2,107	542	1957	1967	–	–	–
China	23	46	1970	1984	1984	1,000	0.25
Japan	36	20	1970	1975	1986	2,100	0.05
India	5	8	1980	2001	2001	260	0.08
Israel	1	3	1988	–	–	20	0.03
Brazil	–	2	1997	–	–	70	0.02

SOURCES: Data compiled by author from Andrew Wilson, ed., *Jane's Space Directory, 1995–96* (Alexandria, Virginia: Jane's Information Group, 1996).

NOTES: Russia's space expenditures have declined from Cold War levels of $6 billion to post-Cold War levels of $1 billion. In recent years, there were 82 launches in 2000 (including 28 U.S. and 37 Russian or Commonwealth of Independent States [CIS]), 78 launches in 1999 (including 31 U.S. and 28 CIS), and 81 launches in 1998 (including 36 U.S. and 25 CIS). Zenit/Sealaunch is counted as CIS.

for the steady increase in space budgets. For example, Cartosat-1 was reported to cost Rs. 250 crore ($50–$60 million), a figure that could include the launch cost. The entire GSLV project could cost Rs. 1,500 crores ($300 million), which includes Rs. 450 crores for the first three GSLV flights, Rs. 500 crores for acquiring seven cryogenic engines from Russia, about Rs. 200 crores on infrastructure development, and the balance on technology development.

Like the space programs of other countries, ISRO relies heavily on government funding and therefore remains under constant pressure to secure political support. India's political leaders including the prime minister are regularly invited to space launches to secure their endorsement for ISRO activities; they routinely oblige, especially because of the prestige associated with the Indian space program. At the same time, expenditures on science and technology endeavors are called into question.

The Indian space program is not as strong as those of the world's major space powers, especially in terms of its launch rate and quantity and volume of services, and to a lesser extent in terms of quality (see Table 3). It also lags 10 to 15 years or one technological generation behind the space programs of Japan, China, and the ESA, and about 20 years or two technological generations behind the U.S. and Russian space programs. However, in terms of output per unit expenditure, the Indian space program compares favorably with other space programs; it has provided modest socioeconomic, political, military, and commercial benefits without consuming a large amount of New Delhi's financial resources.

Assessment

India's space assets were developed for economic purposes but have found some (and offer the potential for further) military applications. In purely economic terms, India's space infrastructure cost a few billion dollars over a period of several decades (India's space budgets totaled Rs. 74 billion from 1962 to 1997), but this infrastructure did not provide immediate tangible economic or military benefits. It was only after this initial investment that India's more advanced space assets found modest economic and military applications in the 1990s. India could well have purchased such space services commercially on the international market at prices only marginally more expensive than indigenous services. Thus, in purely economic terms, India's space assets have cost more than the revenues they have generated. On the other hand, locally supplied space services do not have to be paid in foreign currency; this saving of foreign exchange is one economic benefit from an indigenous space program.

A second set of benefits from indigenously developed space assets is political in nature. First, space assets provide international prestige and have foreign policy spin-offs. ISRO can offer PSLV, IRS, and INSAT services to other states, thereby reinforcing New Delhi's political and economic ties with these nations. Second, by acquiring technological autonomy over its space assets, New Delhi can use them not only for economic purposes but also for military missions. The IRS-PSLV and INSAT-GSLV projects demonstrate ISRO's ability to both build and launch militarily useful and strategically significant reconnaissance and communications satellites. This could greatly enhance New Delhi's power projection and force multiplication capability in the Indian Ocean and Asia-Pacific regions, thereby affecting the strategic balance in these regions.

While several states or firms have national and commercial satellites, ISRO is among a small group of about 10 space agencies that have a significant satellite launch capacity. Over a dozen countries–including an Arab state consortium, Argentina, Brazil, Egypt, Indonesia, Mexico, Norway, Singapore, Spain, Sweden, Thailand, and Turkey–have purchased or indigenously developed communication satellites. Earth observation satellites (civilian and military) are presently operated by the U.S., Russia, Europe (ESA and France), China, Japan, and India; Canada operates a radar imaging satellite; while Israel has launched short-duration reconnaissance satellites. Other nations purchase remote sensing data commercially on the international market. Besides the eight space agencies shown in Table 3, a few other states–North Korea, Iran, Argentina, Spain, and South Korea–are seeking (and have developed some of the infrastructure for) a satellite-launch capability, but this will be initially restricted to light payload LEO.

The somewhat limited capabilities of India's space assets compared to those of the world's major space-faring agencies restrict New Delhi's performance and international competitiveness but do not significantly detract from its modest economic, political, and military utility. India's space assets are now sufficiently advanced to enhance its nuclear deterrent and strategic capabilities. These technological advancements could well coincide with, and further facilitate, India's emergence as a major player in the Asia-Pacific by the end of this decade.