Are MIRVs and Satellite Integration and Dispensation Mutually Inclusive?

An Analysis of India’s Capabilities

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Despite some differences, integration of satellites and their orbital dispensation, and integration of multiple warheads and their delivery vehicles are often treated as though they are identical processes. This paper first briefly looks at the extent to which satellite integration and dispensing capabilities assisted in the development of Multiple Independently Targetable Re-entry Vehicle (MIRV) technology in the United States. It then will demonstrate that concerns about India-U.S. civilian space cooperation leading to India’s development of a MIRV capability are misguided. India already possesses incipient capabilities to MIRV its missiles, but this does not mean that it can immediately secure a full-fledged MIRV capability, because there are a range of conditions that would affect its development of MIRV technology. As a cautionary note, the detailed effort here is intended to outline what India is potentially capable of doing; therefore the following analysis should not be construed as meaning that India will or should do the things laid out.

There are five key technologies that are vital for the development of MIRV technology. These are: rocket engines that are restartable, vernier rockets or engines, inertial guidance technology that has high reliability and precision, re-entry vehicles that are highly accurate, and high efficiency miniaturized warheads.[1] A MIRV “bus” is a receptacle that carries the re-entry vehicles, which carry the warhead, and the guidance and control systems are built into the upper stage of the missile.[2] The bus is maneuverable, makes efficient on-orbit trajectory shifts, and releases each re-entry vehicle in sequence.[3] To attain these fine adjustments and movement, vernier rockets or engines are used to draw the bus away from the rapidly dropping re-entry vehicles.[4]

The defining feature of MIRVed missiles is their capability to deliver multiple warheads along separate trajectories.[5] MIRVs provide targeting flexibility, whether it is against a single target or against multiple targets. They can be used to target several areas, provided they are within the ambit of separation generated by the MIRVs, in effect within its footprint.[6]

In the United States during the 1960s, the direct conceptual and technological forerunner to the MIRV system was the Titan III Tran-stage, a Post Boost Control System (PBCS) or “bus” that was developed for delivering multiple satellite payloads into orbit.[7] The Transtage represented a true “bus,” but it did not proffer any tangible benefits in achieving the accuracy necessary for delivering multiple warheads.[8] The Transtage demonstrated how stopping and restarting its hypergolic (liquid propellants) engine and its capacity to shift orbit to emplace satellites on different orbital trajectories could assist in the realization of a MIRV capability.[9]

As a declassified Department of Defense (DOD) document reveals, MIRV development can be traced as such: “Fallout gained from several space programs, not all associated with military space applications, was a series of developments directly adaptable to the realization of maneuverable platforms for ICBM use.”[10]

Given the dual-use nature of space technology, what can one make of the claims that increased civilian space cooperation between the United States and India will result in transfer of technology that may bring integration and delivery capabilities warheads into India’s arsenal? The National Aeronautics and Space Administration (NASA) is poised to send two instruments aboard India’s Polar Satellite Launch Vehicle (PSLV) in 2008. Raising concerns about India-U.S. civilian space cooperation, one analyst, Jennifer Kline, reached the suggestive conclusion that technical “know-how” about satellite integration capabilities will enable India to MIRV its ballistic missiles:

> While there is little concern that the inclusion of the M3 and Mini-SAR on the Chandrayaan-I will result in a technology transfer of any great significance, there remain lingering apprehensions among some Washington-based missile experts about the potential transfer of “tacit knowledge” skills in the form of payload integration assistance for the lunar mission that might later be exploited for military functions. The principal concern is that if U.S. system integration specialists work with Indian engineers to demonstrate the best method for integrating payloads into space vehicles, then critical tacit knowledge skills that can only be learned by "doing" will transfer into the hands of the Indian engineers. This know-how is also relevant to certain military activities, such as integrating multiple nuclear warhead payloads into inter-continental ballistic missiles (ICBMs). In the late 1990s, a major controversy erupted when two U.S. firms, Loral and Hughes Aircraft, were found to have transferred tacit knowledge of this kind to China during discussions aimed at overcoming technical obstacles to the successful launch of their satellites on Chinese space launch vehicles. Similarly, any U.S. assistance in preparing the Indian lunar mission with regard to automated deployment structures in space could conceivably help India develop penetration aids for its ballistic missiles, which might reduce the effectiveness of U.S. missile defense systems. Indeed, the possibility that transferred U.S. technology might be utilized for improving Indian ICBMs or for expanding Indian capacity to construct ICBMs remains a major source of controversy in the U.S.-India space cooperation deal.[11]

This point is often regurgitated and incidentally became one reason for suspending American commercial satellite launches from Chinese space launch vehicles in the late 1990s. Just as there was no substantive reason for suspending cooperation with China then, there is nothing to be concerned about current or expanded India-U.S. space cooperation either.

A brief retrospective would help clarify some issues. In 1998, controversy erupted in the United States over the telecom giant Motorola’s alleged transfer to China of the Iridium Smart Dispenser. Motorola’s Smart Dispenser releases multiple satellites into orbit, which some alleged enabled the Chinese to develop a MIRV capability.[12] But as the House Select Subcommittee report on China’s space and missile forces, also known as the Cox report, noted in 1998, “The PRC [People’s Republic of China, or China] has demonstrated all of the techniques that are required for developing a MIRV bus, and that the PRC could develop a MIRV dispensing platform within a short period of time after making a decision to proceed.”[13] This statement is reinforced by two additional facts. As early as 1981, China had dispensed three satellites from a single platform which gave “it an incipient multiple-warhead capability.”[14] Secondly, Motorola did not transfer design information of the Iridium dispenser; instead, the company laid out specific technological parameters based on which Chinese engineers developed through indigenous effort a satellite dispenser to Motorola's needs.[15] The obvious conclusion one immediately derives is that China already wielded the technological precursors for the development of a MIRV capability and no real net technology transfer actually accrued to China's MIRV development program.

As China expert Michael Swaine noted in 1998, "Among those who look at Chinese military capabilities, there's a fairly strong degree of skepticism about the extent to which China's relationship with U.S. commercial satellite makers has resulted in significant advances in its long-range military missile capabilities."[16]

This applies to India as well. The technical fallacy is that the two NASA instruments will be fixed to one of the satellites. As Subrata Ghoshroy, a former analyst with the Government Accountability Office (GAO), has pointed out:

> This type of concern is not new. Both India and China are manufacturing and launching satellites. So the basic integration and dispensing capabilities are there. In my opinion, detailed knowledge of the payloads would be difficult to obtain by ISRO engineers from simply launching something on the ISRO platform. The two NASA payloads for the Chandrayaan mission will be bolted to the satellite, not dispensed from it. It seems totally far fetched that such a mission would generate any information relevant to a MIRV design.[17]

Thus the concern that NASA's engineers might transfer "tacit" knowledge in efforts to mate two lunar instruments with India's PSLV, which would enable India's space engineers to learn warhead-missile integration techniques, does not stand the test of technical evidence.

In the analysis to follow, we will explore why more substantive issues would help qualify the syllogistic and misleading argument that satellite integration would automatically lead to a MIRV capability.

Some media reports suggest India's Defence Research and Development Organization (DRDO) has already initiated tentative efforts to develop a MIRV capability for India's Agni-III intermediate range ballistic missiles. Note that the launch of India's *Chandrayaan* moon mission that would carry two of NASA's instruments isn't scheduled until June or July of this year.[18] This would pretty much refute the allegation that Indian engineers would spin off information from its civilian space sector to its missile program. Nevertheless, even if one were to dismiss this position as unverifiable and assert that the DRDO's quest to develop MIRVs could still in some way be assisted through American transfers in the realm of civilian space cooperation, it does not square with the fact that several countries have launched their instruments and satellites from Indian boosters and that India has had the capacity to integrate and dispense multiple satellite payloads since 1999. The European Space Agency (ESA) is launching its own instruments aboard the same Indian Space Launch Vehicle (SLV) that would host NASA's M3 and Mini-SAR instruments. Additionally, in 1999, the Indian Space Research Organization (ISRO) launched three satellite payloads, the IRS-P4, and two foreign microsatellites (the Korean KITSAT-3 and Germany's TUBSAT) simultaneously on a single PSLV rocket.[19] In May 2005, India launched the Cartosat-1 and Hamsat satellites from another version of the

PSLV. In January 2007, ISRO went one step further, simultaneously launching the satellites, India's CARTOSAT-2, Indonesia's LAPAN-TUBSAT and Argentina's PEHUENSAT-1 and the Space Recovery Experiment-1 (SRE-1) Capsule.[20] In April 2007, India registered its first successful commercial launch on a PSLV C8 – the 352-kilogram Italian satellite AGILE along with a non-commercial 185-kilogram craft known as the Advanced Avionics Module (AAM) in order to "test advanced launch vehicle avionics systems like mission computers, navigation and telemetry systems."[21] As recently as Jan. 28, 2008, the C10 version of the PSLV launched an Israeli spy satellite.[22]

ISRO's multiple satellite launches in January 2007 did represent a key milestone in India's space program. Engineers from ISRO used a four stage PSLV C7. For this launch, India also developed the Dual Launch Adapter (DLA) to launch and dispense four satellites.[23] The Iridium satellite dispenser that triggered paranoia about technology transfer to China in the United States is similar to the DLA. The DLA launched two 500-650 kilogram spacecraft – the Cartosat 2 and the Space Recovery Capsule - and two other smaller satellites.

The fourth or final stage of the PSLV C7 is essentially the equivalent of the Post Boost Control System (PBCS) or the Tran- stage bus that the United States used for multiple satellite launches in the 1960s. To that extent, the PBCS and the PSLV's final stage are a maneuvering platform. Note that the PSLV fourth stage engine is restartable,[24] just as the PBCS had a restart capability. In the PSLV's case, the fourth stage employs a 7.5-kilonewton pressure fed bi-propellant liquid engine with an impulse of 305 per second guiding the satellite payload to achieve orbital injection.[25] Yet for upper stage technology, propulsive energy alone does not count in optimizing and calibrating injection accuracy. Rather, the key determinants are navigation sensors, the quality of navigation software, and the efficiency of the guidance and control system.[26] The PSLV's fourth stage in the January 2007 launch executed a complex set of maneuvers to place its payload precisely into their designated orbit. As ISRO scientists in one paper recently noted, "The orbital injection accuracies for the PSLV and GSLV…have been excellent."[27] This has been achieved through the consistent qualitative improvement in the Redundant Strap Down Inertial Navigation System (RESINS) which uses indigenously developed Dynamically Tuned Gyros (DTG) and Servo Accelerometers (SA).[28] The SAs are high accuracy devices that enable precise payload injections.

In addition, the half-ton Space Recovery Experiment (SRE) capsule that India launched and recovered validated "(1) light weight reusable thermal protection system, (2) aero-thermal structure design/analysis, (3) hypersonic aerothermodynamics, (4) navigation, guidance and control of re-entry vehicle, (5) deceleration systems, (6) floating systems and recovery systems/operation, and (7) management of communication blackout."[29] The SRE was de-orbited after 12 days in space, during which time it conducted microgravity experimentation, provided valuable data on reusable launch vehicles, and helped scientists understand the requirements for India's manned moon mission. Indian space managers recovered the capsule 165 kilometers off the southeast coast of India.

The successful recovery of the SRE certainly indicates the validation of at least a nascent re-entry vehicle capability pivotal to MIRV development. The SRE design seems to share some technical features to a few re-entry vehicles tested and used by the United States over the years. The SRE is a sphere-cone-flare design similar to the Atlas Mk 3 RV launched in 1960 and the Titan II ICBM's Mk 6 RV deployed in 1960.[30] In addition, the SRE-1 demonstrated a hypersonic capability and onboard guidance and control sub-systems similar to what the United States validated when it first tested its hypersonic re-entry vehicle known as the Maneuvering Ballistic Re-entry Vehicle (MBRV) in the 1960s.[31] The MBRV served as an important building block for the Minuteman III MIRV system.[32] Notably, the SRE-1 also validated a Kalman Filter which provides sensory information such as position and speed of a moving or static object.[33] Thus to that degree, SRE-1 is consequential if applied and developed further for military purposes.

Finally, in 2001 vernier engines that control and regulate vehicular oscillations, a critical technology for the development of a MIRV capability, were used in the upper stage of the first developmental flight of ISRO's Geosynchronous Launch Vehicle (GSLV) which placed a two-ton payload in Geo Transfer Orbit (GTO).[34] The Inertial System's Unit (ISU) of ISRO is responsible for the research and development of advanced upper stage technologies related to guidance, navigation, restart capability and positional changes in space particularly for Geosynchronous launches.[35] Currently, ISRO is working on the development of optical gyros and high efficiency accelerometers.[36]

All these developments occurred long before the scheduled launch of NASA's instruments. India already has critical enabling technology necessary for the research and development of a MIRV capability that have been validated through a series of successful satellite launches. Thus any technological accoutrements that can potentially arise from current or expanded U.S.-India civilian space cooperation are, at best, tangential.

But does placing multiple satellites in orbit require the same level of precision as delivering MIRVs? John Pike of GlobalSecurity.org explained in 1998:

> Satellite operators generally set standards for launch vehicles, placing their satellites into some proximity of the destination orbit. But the margin for error in the real world is normally many miles. And since satellites always carry their own maneuvering propellant, it's left to the satellite rather than the launcher to reach the ultimate destination. And in the case of deploying multiple satellites, this deployment can take place over a period of hours or days rather than the minutes found in the case of a multiple warhead missile. The warheads carried on missiles have no such supplementary guidance or propulsion capability, and rely entirely on the missile and equality of the re-entry vehicle body to reach their terrestrial destination.[37]

The answer is no, delivering satellites on orbit does not require the same accuracy that is needed in a MIRV, but Pike's statement is still conditional. There is a definitional issue of accuracy. In India's case, the demands on accuracy are contingent, in that missile accuracy is not completely geared to striking military targets, necessitating extensive testing to achieve high levels of precision. There are differences between the needs of India, China and the United States when it comes to missile precision. During the Cold War, accuracy through counterforce attacks was a premium for the United States. The objective was to fight and win a nuclear war with the Soviet Union.[38] But India's nuclear doctrine represents a significant departure from Cold War thinking because it implicitly emphasizes countervalue targeting as a retributive measure, obviating the need to optimize accuracy through precision nuclear attacks against the adversary's retaliatory forces. In fact, speaking in the context of China's targeting posture, Pike himself maintains it makes little difference where exactly ground zero is for Chinese missiles, if their target is another country's city.[39] This point applies equally in India's case. As one influential member of India's nuclear policymaking establishment noted, India's nuclear doctrine and force posture rejects the "spurious doctrines of counterforce."[40] To that extent, accuracy is unlikely to be the definitive or stringent criterion for India, since it has the luxury of settling for moderate accuracy as opposed to high accuracy, and eases some technical strictures or precision necessary under a counterforce doctrine. Technology in this instance is likely to interact with doctrine.

But there is another conditional issue with Pike's statement. A multiple satellite ejection does not necessarily have to occur over a period of hours and days: the process can happen in the space of a few minutes. In fact, the 2007 launch discussed above ejected all satellites within a few minutes.[41] Nevertheless, even if this analysis has shown India's mastery of the techniques of multiple satellite dispensation, the conversion of that into a credible MIRV capability requires more exacting standards, because there are other conditional variables.

Three hurdles will confront India's MIRV efforts: warhead miniaturization, warhead guidance and re-entry technology. The challenge for India is not per se about weapon yield if the objective is merely to develop simple fission-based warheads of 5-20 kiloton yield, which it can do. The real problem lies in sufficiently miniaturizing and making the warheads light so as to enable their successful integration into a MIRV platform. MIRV design and development in the United States benefited from significant parallel advances in electronics that enabled warhead miniaturization and substantial qualitative progress in yield-to-weight ratios. If high yield does not count, then weight and compactness (size and dimensions) certainly do. In the case of simple fission devices, it is reasonable to assume that India's nuclear scientists since the 1998 nuclear tests have made some progress in fabricating new weapons designs or made improvements on older ones.[42] Whether these designs are small and light enough to be compatible with a MIRV configuration is unknown, but MIRVed ballistic missiles are finely balanced projectiles. As Greenwood notes, "The entire package must be made small enough and light enough to meet the severe volume and weight constraints of the missile's overall design."[43] In India's case, reducing size and weight could compromise the yield of even 15- to 20-kiloton warheads. Indian missile engineers and nuclear scientists working in concert will have to harmonize these three demands. If not, they may have to settle for 5- to 10-kiloton yields to develop compact and lighter warheads. Whether India's strategic and military elites are prepared to do that is open to conjecture.

On the other hand, if the quest is to achieve higher thermonuclear yields without compromising the imperatives of lower weight and size, the challenge is substantially greater. With only six nuclear tests under its belt, it is difficult to imagine that India can overcome all these challenges without sacrificing something and it applies particularly to high yield weapons.[44] One account maintains that it is possible that India can build thermonuclear weapons, but the thermonuclear test that Indian scientists claimed they conducted in 1998 might not have yielded the desired result.[45] Therefore, India's nuclear warhead integration capacity is not linked to its satellite integration capabilities. India’s capacity to do the latter is emphatically unquestionable, but is not necessarily certain in the former.

In addition to these complex tradeoffs, there is an important secondary challenge. The guidance and control mechanism has to be a high memory computer repository that can sort out guidance equations for every single vehicle, preserve target data, and avert movements during free-fall injurious to vehicular stability.[46] Vernier rockets are crucial in this exercise, as are other inertial systems such as accelerometers and gyroscopes. India’s advances in these areas are reasonable and do not represent an acute challenge, but improvements will be necessary to fit the demands of a MIRV capability.

A crucial final challenge ties into Pike’s statement noted above, which is the essential difference between dispensing multiple satellites and delivering multiple warheads. The distinction is self-evident: satellites do not immediately return to earth, while re-entry vehicles do. Re-entry technology will remain a demanding technological challenge for India’s missile engineers.

Designing the re-entry vehicles deployed in the U.S. arsenal required a substantial investment in research and development. The real challenge as Greenwood points out was in making the vehicles slimmer to withstand excess aerodynamic pressures in order to optimize high “ballistic coefficients,” and ease rapid re-entry, stabilize gyrations during the vehicle’s steep descent through the atmosphere to offset yaw, and ensure that the high quality heat deflecting ablative material is light (typically high grade carbon composites) and is evenly distributed across the vehicle.[47] All these performance characteristics have to be met while simultaneously protecting the vehicle in the re-entry phase.[48]

Even if one accepted the assumption that high accuracy and yield are inconsequential for India, at a minimum guidance and particularly re-entry would remain inescapable challenges. As Theodore Von Karman pointed out, “Reentry is…perhaps the most difficult problem one can imagine.”[49] To that extent, Indian missile engineers would confront difficult technical hurdles in MIRVing the latest variant of the AGNI-III Medium Range Ballistic Missile (MRBM) and potentially other Indian missiles in the future. Despite the declared intention to develop MIRVs, it is still unclear whether India’s missiles will be tipped with MIRVs or Multiple Re-entry Vehicles (MRVs). If it is the latter, then it does not represent a significant advance in capabilities, because MRV-tipped missiles are relatively crude devices and release their warheads unguided to their target in clusters of two or three.[50] There is evidence to suggest that India is working on militarily usable re-entry systems or critical materials and technologies related to that end through either collaborative projects with other countries and through indigenous effort.[51]

There are similar underlying principles between MIRVs and satellite integration and dispensation. There also exists an immutable interchangeability of some technologies for the development of both, but the objectives for which they are developed are vastly different and therefore the technical demands are also different. That is where the crucial distinction lies.

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[1] Ted Greenwood, “Appendix B: The Technical Precursors of the MIRV Bus,” *Making the MIRV: A Study of Defense Decision Making*, (Lanham: MD, University Press of America, 1988), p. 167. See also “Introduction,” *The Origins of MIRV,* SIPRI Research Report No. 9, Stockholm International Peace Research Institute, August, 1973, p. 7.

[2] Greenwood, “Overview,” p. 2.

[3] Ibid, p. 2.

[4] Ibid.

[5] Ibid, p. 1.

[6] Ibid.

[7] Greenwood, “Appendix B,” p. 168.

[8] Ibid.

[9] Ibid.

[10] “MIRV: A Brief History of Minuteman and Multiple Reentry Vehicles,” Daniel Buchonnet, Lawrence Livermore Laboratory, February 1976, p. 45, http://www.gwu.edu/~nsarchiv/nsa/NC/mirv/mirv1_51.html.

[11] Kline may cite that her piece appeared prior to the January 2007 launch, but even then her position is not tenable, because at the least she could have noted ISRO’s plans for the January 2007 launch. Sokolski and Speier’s articles appeared after the January 2007 launch. Their arguments can be dismissed as baseless. For information on ISRO’S plans that culminated in the January 2007 launch, see “Space Transportation,” *Indian Space Research Organization: ISRO,* http://www.isro.org/rep2006/Space%20Transportation.htm, accessed on March 16, 2008; Jennifer Kline, “U.S.-India Space Cooperation Reaches New Heights, Despite Lingering Proliferation Concerns,” *WMD Insights,* James Martin Center for Nonproliferation Studies, July 20, 2006, http://cns.miis.edu/pubs/other/kline_060720.htm; Henry Sokolski, “Negotiating the Obstacles to U.S.-Indian Strategic Cooperation,” *Gauging U.S.-India Strategic Cooperation,* Henry Sokolski (ed.), March 2007, p. 10, http://www.npec-web.org/Books/20070300-NPEC-GaugingUS-IndiaStratCoop.pdf; and Richard Speier, “U.S. Satellite and Space Launch Cooperation and India’s Intercontinental Ballistic Missile Program,” in the same volume, p. 201-2.

[12] “PRC Missile and Space Forces,” Chapter 4, *House Report 105-851: Report* http://www.access.gpo.gov/congress/house/hr105851/VI-09-Chap4.pdf, p. 196.

[13] Ibid.

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[14] "Nuclear Warhead Modernization: Multiple Reentry Vehicle (MRV)/Multiple Independently Targetable Reentry (MIRV) Modernization/Warhead Miniaturization," James Martin Center for Nonproliferation Studies, June 1998, http://cns.miis.edu/research/china/coxrep/wwhmdat.htm.

[15] "PRC Missile and Space Forces," Ibid. The independent technical expert to the subcommittee is believed to have confirmed the non-transfer of design information.

[16] Quoted in Bradley Graham, "Chinese Missile Gain Questioned by Experts," *Washington Post*, May 31, 1998. Nevertheless, there were flaws inherent in the Cox Committee report because it was ultimately an exercise in inferential and speculative analysis. For a critique of the report, see Alastair Iain Johnston, W.K.H. Panofsky, Marco Di Capua, and Lewis R. Franklin, "Executive Summary, in M.M. May (ed.), *The Cox Committee Report: An Assessment*, December 1999, p. 9-19.

[17] Email correspondence with author, Feb. 28, 2008.

[18] Ajai Shukla, "Agni Missile to Get Multiple Warheads," *Business Standard*, Jan. 28, 2008, http://www.businessstandard.com/common/news_article.php?leftnm=10&bKeyFlag=BO&autono=311852. The reporter who filed this report spoke to the author and confirmed that India indeed is going to MIRV the Agni-III MRBM.

[19] "Milestones," ISRO, http://www.isro.org/rep2002/Links/Milestones.htm, accessed March 7, 2008.

[20] S.C. Gupta, B.N. Suresh and K. Sivan, "Evolution of Indian Launch Vehicle Technologies," *Current Science*, Vol. 93, No. 12, Dec. 25, 2007, p. 1709.

[21] "PSLV Successfully Launches Italian Satellite," *Indian Space Research Organization: ISRO*, April 23, 2007, http://www.isro.org/pressrelease/Apr23_2007.htm.

[22] See P.R. Kumaraswamy, "With Israel, Is Sky the Limit, *Newindpress.com*, Jan. 28, 2008, http://www.newindpress.com/NewsItems.asp?ID=IEM20080128212239.

[23] T.S. Subramanian, "After Runaway Success, a Major Technological Task Begins for ISRO," *The Hindu*, Jan. 11, 2007, http://www.hindu.com/2007/01/11/stories/2007011104251300.htm.

[24] India first tested the fourth stage of the PSLV in September 1989 at the liquid propulsion test facility at Mahendragiri in Southern India. See R.L.N Sarma, "India's Space Program," Volume 3(5) March-April, 2001, http://www.bharat-rakshak.com/MONITOR/ISSUE3-5/sarma.html.

[25] Gupta et al, p. 1708.

[26] Ibid.

[27] Ibid, p. 1709.

[28] Ibid.

[29] Ibid.

[30] See "Space Transportation," *Indian Space Research Organization: ISRO*, http://www.isro.org/rep2006/Space%20Transportation.htm, accessed on March 20, 2008; and "GE-Reentry

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Systems," *American Institute of Aeronautics and Astronautics: Historic Aerospace Site,*: http://www.aiaa.org/Participate/Uploads/07-0634GEReentry.pdf, p. 4-7, accessed on March 10, 2008.

[31] "GE-Reentry Systems," Ibid.

[32] Ibid.

[33] Gupta et al, p. 1709. See also the specific definition and uses of Kalman Filter, in "Space and Electronic Warfare: Terms," p. 78 and 188, http://www.rtna.ac.th/article/Space%20&%20Electronic%20Warfare%20Lexicon.pdccessed March, 21, 2008.

[34] "Space Transportation," Ibid.

[35] "India, Satellite Guidance, Navigation and Control Components," Bill Sweetman (ed.,) *Jane's Space Directory 2006-2007,* Twenty-Second Edition (Cambridge University Press: Coulsdon, 2006) p. 193.

[36] Gupta et al, p. 1709.

[37] See John Pike's Congressional Testimony in "Commercial Space Launches and Foreign ICBMs," May 21, 1998, http://www.fas.org/spp/starwars/congress/1998_h/s980521t.htm, p. 69-70.

[38] Freedman in this superb account describes how counterforce stemmed from early concepts in limited war, airpower and bureaucratic pressures from the United States Air Force. See Lawrence Freedman, *The Evolution of Nuclear Strategy,* (Palgrave Macmillan: Basingtoke), Third Edition 2003, p. 121-123.

[39] Pike, ibid. Since Pike's statement, which was made in 1998 in the heat of the Cox Committee's investigation, some strategists have noted that China may be shifting its nuclear posture from "minimum deterrence" to a posture of "limited deterrence" that necessitates the formulation of an expanded war fighting role for its nuclear forces. This may be more a response to United States' pursuit of theater and national missile defenses. But China still pursues a combination of no-first use, a countervalue and retaliation-only policy. As Gill, Mulvenon and Stokes note, "By itself, however, the modernization of Chinese nuclear C4I does not automatically imply that the force is transitioning to a flexible response, counterforce footing. The changes might signal desire for eventual launch under attack (LUA) capability, but the current inventory of missiles and the next generation of replacements are not capable of the reaction times necessary for such a capability. Instead, it is more likely that the C4I modernization program is meant to improve the credibility of China's minimal deterrent posture in the short- to medium-term." See, Bates Gill, James Mulvenon and Mark Stokes, "The Chinese Second Artillery Corps: Transition to Credible Deterrence," RAND, 2002, http://www.rand.org/pubs/conf_proceedings/CF182/CF182.ch11.pdf, p. 547.

[40] This comment was made by K. Subrahmanyam, an influential advocate of minimum deterrence in India. Cited in George Perkovich, *India's Nuclear Bomb: The Impact on Global Proliferation* (Berkeley: University of California), 2001, p. 327. Although slightly dated, for an elaborate enunciation of the political tenets of India's nuclear doctrine and strategy, see K. Subrahmanyam, "Nuclear Force Design and Minimum Deterrence Strategy for India," in Bharat Karnad (ed.), *Future Imperiled: India's Security in the 1990s,* (Viking, Penguin Books: New Delhi), 1994, p. 176-191. See also for a superb interpretation of India's nuclear doctrine, Ashley J. Tellis, "India's Emerging Nuclear Doctrine: Exemplifying the Lessons of the Nuclear Revolution," *The National Bureau of Asian Research, NBR,* Volume 12, Number 2, May 2001, p. 17-25, http://www.nbr.org/publications/analysis/pdf/vol12no2.pdf.

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[41] See an elaborate description of the separation process in “PSLV Successfully Launches Four Satellites,” *Indian Space Research Organization: ISRO*, Jan. 10, 2007, http://www.isro.org/pressrelease/Jan10_2007a.ht.

[42] There is no reason to believe that India’s nuclear scientists do not have the capacity to build fission devices. See George Perkovich, *India’s Nuclear Bomb*, p. 375.

[43] Greenwood, “Overview,” p. 3.

[44] Bharat Karnad, a vociferous hardliner, has repeatedly made the case for “hot” testing to validate India’s thermonuclear weapons capability. See Bharat Karnad, “Nuclear Test is a Must,” *Hindustan Times*, Feb. 29, 2008.

[45] George Perkovich, *India’s Nuclear Bomb*, p. 427-33.

[46] Greenwood, “Overview,” p. 3.

[47] Ibid.

[48] Ibid.

[49] “GE-Reentry Systems,” p. 4.

[50] See “Busload of Megatons,” *Time,* June 27, 1969, http://www.time.com/time/magazine/article/0,9171,900911,00.html.

[51] “India Eyes Hyper-cruise,” *Aviation Week and Space Technology*, November 5, 2007. See also, Sharad Joshi, “India and Pakistan Missile Race Surges On,” James Martin Center for Nonproliferation, October 2007, http://cns.miis.edu/pubs/other/wmdi071008d.htm.