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POLICY ANALYSIS: SPACE PROGRAMMES of JAPAN AND INDIA

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ABSTRACT

Today, increasing number of counties in the Asia Pacific region is using outer space with various purposes. Many countries are also aspiring to acquire indigenous capability for space activities. Moreover, increasing private/commercial activities are seen in this region, which is creating competition in the market for technology, applications and services. Security needs are also major drivers of space activity in many countries.

Under the umbrella of Space Policy and Law Network in Asia Pacific (SPLANAP), University of Tokyo (Japan) and National Institute of Advanced Studies (India) have taken up a joint study to research and prepare a report on space policies of the Asia Pacific region, especially including Japan, India and many other space faring nations in this region. As the first step of this joint project, the team has undertaken a comparative analysis of space policies in Japan and India. Japan and India are leading space faring countries in this region.

In Japan, promoting advanced technology innovation and scientific research has been the major policy objective. In addition, space utilization, as well as industrialization of space are also primary drivers for the space policy objectives since the enactment of Basic Space Law in 2008. In this regard, Japan has faced policy challenges regarding how to promote space utilization and industrialization and how to coordinate policies and goals of various stakeholders. There is a compelling need for a new thinking for space strategy based on the recent changes in Japan's space policy.

On the other hand, India has long history in "space for national development" and has actively used space systems like communication satellite and remote sensing satellite to meet various social needs, which include disaster monitoring, natural resources management, tele-education, tele-medicine, national communication, navigation services and so on. India has also developed some mechanism for policy coordinating between space agency and user organization. In recent years, India has also actively pursued space exploration program, including ambition for human space flight. In a recent study by NIAS, a clear need for a comprehensive national space policy in India has been established.

In this context, this paper presents the results of the comparison of space policies and governances in Japan and India and examine commonalities/differences, characteristic, relative strengths/challenges. This comparative analysis contributes to clearly identifying policy challenges faced by the both nations and getting clue to resolving those challenges.

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I. INTRODUCTION

Outer Space has been a source of curiosity and inspiration for human kind since time immemorial. Since the launch of Sputnik, more than 50 years ago, the roles and meaning of space for humanity had been widely diversifying. What started as a competition for military superiority between the two super powers then is transformed today into multi-dimensional endeavors of large number of actors, both from the governments and private sector, impacting the social, economic, and scientific and security dimensions of global human society. Space has become a part of daily life for a majority of the citizens of the globe.

In the Asia Pacific region, space activity is prevalent in almost 41 nations of the region with a wide range of national and regional applications. It is also clear increasing numbers of the Asia Pacific countries are using operational space activities – satellite communications, earth observation imaging and navigation applications. Security needs are also major drivers of space activity in many countries; spin-offs from militarily developed technology bring in substantial funds for space programmes – which ultimately benefit civilian space.

Policies and legal regimes could be profound and national-regional- and global cooperation in space is required. Space Governance is also be a major factor to address and would voluntary codes of conduct be more suited one has to see. The threats of space militarization also will impact policy definition even as use of space for human security and anti-Earth activities will increase in a cooperative manner.

University of Tokyo and NIAS are presently engaged in a joint research (under the Space Policy and Law Network in Asia Pacific (SPLANAP) banner) on the current and projected space policies and programmes of the Asia Pacific region – specifically including Japan, India, China and many up-coming and rising spacefaring countries in the region. Such a policy-analysis study could identify key issues of national policies and build a case for a comprehensive "AP Regional Space Policy" - addressing the long-term strategy of cooperation and policy development. Some of the key area for the policy research would be to address regional cooperation and applications – especially in the context of maritime security; space governance; industry collaboration; earth observation Applications; satellite communications for education and health; disaster management; manned space exploration; assessing role of space for improvement in quality of life and many other areas.

To begin with the study has analyzed the space programmes and policy perspectives of Japan and India. In future it is intended to expand this analysis to include the space policies of other nations – China, Thailand, Korea, Vietnam, Indonesia, Malaysia etc. and academically develop an over-arching framework for a regional space policy cooperation.

This paper presents the results of the comparison of space programmes and activities in Japan and India and examine commonalities/differences, characteristics and relative strengths/challenges.

II. JAPAN'S SPACE POLICY AND GOVERNANCE

II.I Historical Overview of Japan's Space Policy

While Japan has a long history of space activities since 1950s[1], it was not until 2008 that the Basic Space Law was established.[2] Japan has made various achievements in space activities so far. However, it is often said that Japan had lacked a comprehensive space strategy until the enactment of the Basic Space Law[3]. Indeed, Japan had considered space activities as a part of science and technology policy and had largely focused on technological development to catch up advanced spacefaring nations. The Basic Space Law, therefore, is often considered as a turning point of Japan's space policy.[4]

Japan's space effort was started in 1950s by a scientific group led by Professor Hideo Itokawa of the University of Tokyo. He started to develop a very small "pencil" rocket in 1955. His team also successfully launched a solid-propellant sounding rocket, *K*-6, in 1958 as a Japan's contribution to International Geophysical Year (IGY). Professor Itokawa and his team had a strong desire to develop autonomous space technology by own effort[5].

Professor Itokawa's team evolved into the University of Tokyo's Institute of Space and Aeronautical Science (ISAS) in 1964. [6] As a university-based scientific and technological research institute, ISAS continued to independently develop solid-propellant rocket and scientific satellite. In 1970, ISAS successfully launched the Japan's first satellite, *Ohsumi*, with L-4S rockets developed by them. This achievement made Japan the forth nation to launch a satellite by its own effort. Since then, ISAS has played a leading role in Japan's space science efforts by sending more than 30 spacecraft to earth orbit and beyond[7].

During 1960s, Japan also formed its space policy and organizations. In 1960, National Space Activities Council (NSAC) was set up within Prime Minister's Office as an advisory body for space activities and replaced by Space Activities Commission (SAC) in 1968. In mid 1960s, Japan recognized the significance of space applications for society, such as communication, broadcasting, and weather monitoring. Therefore, Japan needed to develop a space launch vehicle capable of sending application satellites to geostationary orbit.

To this end, apart from the efforts by ISAS, Japan established the National Space Development Agency

(NASDA) in 1969 with the aim to develop liquid-fueled space launch vehicle and application satellites. Unlike ISAS, NASDA carried out this effort with the technological assistance from the United States. Based on the 1969 Exchange of Note with the United States and its revisions (1976 and 1980), NASDA developed N-I, N-II, and H-I rockets (ancestors of H-IIA and H-IIB rockets) based on the U.S. Thor-Delta rocket technology[8].

In parallel, NASDA also made efforts to develop application satellites (communication satellite, broadcasting satellite, and weather forecasting satellite) with the assistance of the United States during 1970s-80s. These efforts were also carried out though close cooperation among NASDA, user organizations, and space industry. For example, NASDA closely cooperated with Nippon Telegram and Telephone Public Corporation (NTT) and KDD and Mitsubishi Electronics in order to develop communication satellite series. Similarly, NASDA also developed broadcasting satellites by teaming up with Japanese Broadcasting Corporation (NHK) and Toshiba. Meteorological satellites were also developed through the cooperation among NASDA, the Meteorological Agency, and Nippon Electronic Corporation (NEC). In 1978, SAC issued a fifteen-year space strategy entitled "the Outlines of Space Development Policy." With an eye on the significance of "adequately and effectively meeting various social needs," this document set forth a goal of promoting space applications in such areas as communication, broadcasting, and weather forecasting etc.[9]

In 1990s, however, Japan's space policy faced serious challenges. In the situation that trade friction between the United States and Japan was getting serious, the United States criticized Japan's unfair satellite procurement protocol as industrial protection policy. As mentioned above, NASDA had closely cooperated with Japan's space industry to develop and build application satellites during 1970-80s. Responding this strong criticism by the United States, Japanese government decided to open its government procurement market for non-R&D satellite to international tender. This so-called the 1990 U.S.-Japan Satellite Procurement Agreement had a serious impact on Japan's space policy because international competitiveness of Japan's satellite industry was still insufficient to fully compete with U.S. satellite industry. In consequence, Japanese government needed to procure most of non-R&D satellites from the U.S. companies. On the other hand, NASDA and Japan's space industry came to focus on the development of R&D satellites[11].

Moreover, Japan's space policy had long been independent from military and security objectives. In 1969, the Diet adapted a resolution concerning "space development for exclusively peaceful purposes." Because of its peaceful constitution, Japan uniquely interpreted "peaceful purposes" as "non-military," rather than "non-aggressive," and prohibited the SDF from using, owning and operating space.[12] Therefore, unlike other spacefaring nations, Japan's space industry did not benefit from security needs. This was also the reason why Japan's space policy came to focus on government-funded "non-military" R&D program, as well as space science and exploration missions, since 1990s.

At that time, however, security environment in East Asia was becoming uneasy. In particular, North Korea's missile program was recognized as a major security concern in Japan. In this situation, North Korea launched *Taepodong* missile in August 1998, which flew over the Japanese territory. This event shocked Japanese politician and citizens, and had them recognized the need to have "its own eye" to monitor North Korea's missile program. Responding to the crisis, Japanese government immediately decided to introduce Information Gathering Satellite (IGS) in December 1998.[13] Under the principle of "peaceful" space activities set forth by the 1969 Diet Resolution, however, the Japan Defense Agency and SDF were not able to operate IGS as a military reconnaissance satellite system. Therefore, IGS was introduced as a multi-purposes crisis management satellite system, which can be widely used for both security and civil purposes. It was also decided that Cabinet Office, rather than Japan Defense Agency, maintains and operates IGS by establishing Cabinet Satellite Intelligence Center (CSICE).

In early 2000s, there was a major transformation of Japan's space policy governance. In 2001, as a part of administrative reforms, Science and Technology Agency (STA) exercising jurisdiction over NASDA and the Ministry of Education overseeing ISAS were merged to become the Ministry of Education, Culture, Sports, Science and Technology (MEXT). In consequence, Japan's two space organizations, NASDA and ISAS, were also consolidated into a new space agency, Japan Aerospace Exploration Agency (JAXA), in 2003. This administrative reform also transformed Japan's space policy making. SAC, which had played a central role in Japan's overall space policy making since 1968, was placed under MEXT in 2001. This movement reduced the role of SAC only to the supervision of JAXA's activities. Instead, Council for Science and Technology Policy

(CSTP) chaired by the prime minister was organized to oversee and formulate Japan's overall science and technology policy, including space policy, at the top level[14].

JAXA continued to focus on the R&D space programs, as well as space science and exploration mission including the contribution to International Space Station (ISS) programs, largely from the perspective of Japan's science and technology policy. The development of new technologies (R&D) itself became the main goal of Japan's space policy without any scenario of using them for Japan's society. On the other hand, Japan's space industry (satellite manufacturing and space launch services) has been reliant on government-funded R&D space program. About 90% of demands for Japan's space industry come from government because of its insufficient international competitiveness. During the period, Japan recognized the need to alter the situation: needs for promoting space application for both in the civil and security fields and strengthening international competitiveness of Japan's space industry.

II.II Policy Changes after the Basic Space Law in 2008

The Basic Space Law was passed by the Diet in May 2008. This law set some new objectives of Japan' space activities: (1) improving the everyday life of Japanese citizens, (2) strengthening national and international security, (3) encouraging Japan's space industry, (4) promoting international space cooperation and space diplomacy, (5) Advancing science and technology. With these objectives of space activities in mind, the Basic Space Law aims to strategically and comprehensively carry out Japan's space activities

Under the Basic Space Law, Japanese government formulated the Basic Plan on Space Policy in 2009 and has so far revised twice in 2013 and 2015. The latest version of the plan, decided in January 2015, sets forth some objectives of Japan's space activities: (1) ensuring space security, (2) promoting practical use of space in civil areas, and (3) strengthening industrial base, as well as science and technology, regarding space activities.[15]

First, security space is now becoming an important space policy objective in Japan. [16] The article III of the Basic Space Law stipulates that "space use and exploitation shall be carried out…. to maintain peace and security in our homeland and the world."[17] This redefines the principle of "peaceful purpose" as "non-aggressive," not "non-military," and allows the Ministry of Defense (MoD) and SDF to use, own, and operate space systems for security and defense purposes in accordance with Outer Space Treaty in 1967 as well as Japan's pacifist constitution[18].

The 2015 Basic Plan on Space Policy places more emphasis on the use of space for security purposes than ever before. It stresses the need to strengthen Japan's security capability by actively using space systems for communication, information gathering, positioning, and navigation. For example, QZSS is now expected to contribute not only to the civil area but also to the security field.[19] MoD is now willing to procure X-band Defense Communication Satellite through Private Finance Initiative (PFI).[20] Japan also seeks to improve ISR capability by strengthening space-based information gathering systems like IGS and other remote sensing satellites.[21]

Second, the promotion of space utilization in public and private sectors is also a major space policy objective in Japan. The Basic Space Law re-focuses on the promotion of space utilization in the civil area after a long interval. The 2015 Basic Plan on Space Policy seeks to facilitate the use of space systems for communication, broadcasting, remote sensing, and positioning as critical social infrastructures. These space assets are expected to contribute to resolving global issues such as disaster management and climate change. According to the 2015 Basic Plan on Space Plan, Japan seeks to create seven-satellite constellation of QZSS and to start its operation by 2023.[23] Weather forecasting satellite (*Himawari*) and environmental monitoring satellites (GOSAT series and GCOM series) are also expected to be launched in the near future. Japan also plans to conduct research and development for advanced communication satellite and remote sensing technology (Advanced Optical Satellite / Advanced Radar Satellite).

Besides, the 2015 Basic Plan on Space Policy also aims at creating new industry and services by using diverse information derived from space (satellite imagery and positioning data, etc.).[24] Space-based information has potential for creating new values in various fields such as agriculture, fishery industry, maritime safety and management, personal navigation, and so on. Micro/small satellite also has a great potential to create new businesses and services. Creating new space-based businesses will contribute to improvement of everyday life of people, economic growth, creation of new job, and development industry.

Third, Japan's space policy also aims at the promotion of space industry. Space industrial base, as well as science and technology, has been recognized as the foundation of Japan's independent space capabilities. The Basic Plan on Space Policy, therefore, directs the government to maintain and strengthen the international competitiveness of Japan's space industry.[25]

Because Japan's satellite industries was mostly reliant on government-funded R&D space programs, they had little experience in obtaining the order for satellites in private and global markets. In this situation, Japan's satellite industry had little opportunity to improve its international competitiveness and cost effectiveness. Now, Japanese government tries to change the situation by supporting commercial space activities in private sector. For example, the MoD will procure its own X-band Defense Communication Satellites by means of Private Finance Initiative (PFI). The Basic Plan on Space Policy also urged the government to promote diplomatic efforts to support the overseas development of Japan's space industry and the creation of new market abroad.[26] For example, a Japanese satellite company received an order for two remote sensing satellites from Vietnam though the Official Development Assistance (ODA).

In addition, Japan also tries to facilitate the commercialization of space launch services. Japan entered into the business when the Mitsubishi Heavy Industry (MHI) and JAXA successfully launched H-IIA rocket loaded with Korean satellite, *KOMSAT-3*, in May 2012. Since then, MHI has received orders for commercial space launch services from Canada in 2013 and UAE (Dubai) in 2015, as well as from a Japanese satellite communication company (SKY Perfect JSAT Corporation) in 2014. Japan seeks to accelerate this trend by developing a more cost effective, new space transportation vehicle, H-3 rocket in the future. Japanese government also intends to support and facilitate the efforts in private sector to start new business by consolidating the legal system and policy framework such as Space Activities Act and Satellite Remote Sensing Act (data policy)[27].

As Japan's policy has been emphasizing on space application in the civil and security areas and industrial promotion, "realizing social value (for example, contribution to national security and the improvement of international competitiveness of Japan's space industry, etc.)" become an important factor in overall space policy making.[29] The 2015 Basic Plan on Space Policy states that it should be carefully considered from a comprehensive perspective of global trends, cost effectiveness, and expected social benefits whether Japan should participate in the future international space exploration program.[30] Now, Japan's efforts in space science and exploration need to find the adequate mix of rationales in other areas like industrial interests and diplomatic gains in order to justify the programs.

II.III Space Policy Governance of Japan

Since the establishment of the Basic Space Law, Japan has again experienced a major transformation of space policy governance. The Basic Space Law mandated the establishment of Strategic Headquarters for Space Policy as a top-level space policy decision-making body[31]. Chaired by the prime minister, it consists of all ministers. Its objective and role is to comprehensively and strategically promote space activities at the top level of the whole government.

In 2012, Japanese government also set up the Office of National Space Policy (ONSP) under the Cabinet Office (CO). The role of ONSP is to effectively coordinate Japan's overall space policy among various ministers and to make plans for space programs and budget from a comprehensive perspective. Also, the Committee on National Space Policy was established in 2012 within CO as a space policy advisory group consisting of seven experts from outside of the government. Now, the center of Japan's overall space policy formulation and coordination is at CO.

The role of JAXA was also expanded. In line with the principles of the Basic Space Law, the Law concerning JAXA was amended in 2012. One of major changes was to enable JAXA to work as a core implementation agency to provide necessary technical supports to overall Japan's space activities, including defense related activities. JAXA is now also expected to provide private sector with necessary supports for industrial promotion. Therefore, competent ministers exercising jurisdiction over JAXA were newly added in 2012. In addition to the ministers of MEXT and the Ministry of Internal Affairs and Communication (MIC), which have been supervising JAXA, the prime minister and the minister of Ministry of Economy, Trade, and Industry (METI) became a competent minister of JAXA in 2012 to promote space application and to support commercial space activities.

Recently, as the importance of space activities as diplomatic tools grow, the role of the Ministry of Foreign Affairs (MoFA) is also expanding. In 2012, MoFA created a new office, Space Policy Division, under the Foreign Policy Bureau. Its purpose is to play more active roles in international society though international space cooperation and space diplomacy[32].

Now, various ministries and agencies become involved in Japan's space policy. All ministries are also expected to be potential user of space. In security field, the role of MOD will also be more and more increasing in Japan's space activities. Japan's space policy governance structure is becoming very comprehensive and complex. Therefore, effective coordination of space policy among these various stakeholders is very important.

II.IV Achievement Metrics

As of 2015, there are many accomplishments in space activities in Japan.

- Japan has so far implemented 100 space launch missions, of which 88 missions are successfully accomplished.
- Japan has independent space access though some space transportation systems, including both liquid-fueled system (H-IIA) and solid propellant rocket (Epsilon). Japan decided to develop indigenous space transportation system, H-II, in 1984 by using only domestically developed technology. Japan is now planning to develop next-generation core space transportation system, H-3.
- Japan has cutting-edge satellite capabilities which includes remote sensing, weather monitoring, environmental monitoring, ocean observation, positioning, communications, and scientific spacecraft. However, their international competitiveness in market at home and abroad is relatively weak.
- In 1984, Japan decided to participate in U.S. Space Station. Later, Japan has participated in International Space Station as the only nation from Asia and contributed to the program.by developing Japanese Experimental Module (JEM), *Kibo*, of ISS. Japan also has developed and launched resupply vehicle, H-II Transfer Vehicle (HTV). 9 Japanese astronauts have so far traveled to space 17 times in total.
- Japan has been credited with various achievements in space science and exploration, including asteroid exploration by *Hayabusa* and unmanned moon exploration by *Kaguya*.
- Japan took an initiative to establish APRSAF and has played a leading role in regional space cooperation effort.

II.V Looking Ahead

The 2015 Basic Plan on Space Policy sets forth the future plans for next 10 years (2015-2024). The plan places more emphasis on space applications in the both civil and security areas. Security is now given high priority of space policy.

In the security area, the future plans include: increasing number of Information Gathering Satellite (IGS), Improving Space Situational Awareness (SSA) and Maritime Domain Awareness (MDA), introducing X-Band Defense Communication Satellites. Japan also examines the possibility of using QZSS, small satellites, dual-use satellite, and commercial satellite for security purposes.

In the civil arena, many missions are expected to be conducted within next 10 years, which include: the completion and operation of seven-satellite constellation of QZSS, the development of Advanced Optical Satellite and Advanced Radar Satellite, the launch and operation of *Himawari* 8 and 9 (meteorological satellites), environment monitoring satellites such as GOSAT-2 & 3 (greenhouse gases monitoring) and GCOM-C (clime change monitoring). Japan also conducts R&D for next-generations satellite communication.

The 2015 Basic Plan on Space Policy also plans to create and operate seven-satellite constellation of QZSS until 2023. Under the current policy, QZSS is expected to be used not only for the civil area but also for the security needs.

Creating new space-based businesses and strengthening existing industrial capability are also very important goal of Japan's space policy. To this end, Japan will establish Space Activities Act and Satellite Remote Sensing Act in 2016.

Space science and exploration, including human spaceflight program, are also important elements for the future of Japan's space activities. How to strike a balance between space application (including security) and space science & exploration? This is one of the space policy challenges Japan is now facing toward the future.

III. INDIA'S SPACE PROGRAMME AND GOVERNANCE

Indian space activities originated from purely scientific interests of a large scientific community in 1960s with the sounding rocket launch experiments. The early space efforts owe much to the vision given by Dr. Vikram Sarabhai - "……to be second to none in the application of advanced technologies to the real problems of man and society". This extraordinary vision was based on realism and pragmatism and with deep insights into the then socio economic context of the country. Soon, by late 1960s, India had accreted a programmatic concept of basic experiments on the technology and user-development front to found a "end-to-end" systems concept that was very critical for space systems. The mantra of self-reliance that Dr Sarabhai gave became the life current that enabled space program to overcome numerous challenges in learning and experimenting with new technologies.

III.I Indian Space Governance Structure

The structure of Indian space activities has been founded on principles of efficiency, flexibility and autonomy and the organisation structure is driven by a mission-orientation. Right from 1970s, when Indian space accreted under Indian Space Research organisation (ISRO), high-level of political, administrative and public support has been forth-coming to a very-high-level. With the determined thrust to scientific temper and developing indigenous scientific capabilities, the Indian government founded the space governance structure in ISRO and brought together a team of professionals of high-level competence and commitment – Prof Satish Dhawan was given this role and from 1970s started the Indian saga of space.

Indian space activities is directly under the Prime Minister of India – thereby giving space activities the high-level authority and over-arching governing umbrella of the whole Indian government in support. This "high-positioning" brings tremendous flexibility and autonomy but poses a very high-level of accountability for results and delivery. To illustrate, just on September 7, 2015, Prime Minister of India conducted a review where how governance activities can effectively use space products and the future space utilisation was discussed – thereby bringing the highest focus for space utilisation amongst ministries and users.

An apex Space Commission, comprising of the Chairman of ISRO and top administrative officers of Indian government and technical experts, has been given programmatic and financial autonomy to plan, oversee and implement India's space programme. The Space Commission also brings in the necessary inter-ministerial interfaces required for the use of space within government ministries and user agencies.

Indian government has also established inter-ministerial user groups to coordinate satellite communications programmes; remote sensing programmes and space science and education activities. These interfaces help in defining user and national needs but also in addressing efficiency of available space inputs.

ISRO is organised into various competence centres that address specific areas of space technology – satellite design/manufacture; rocket development; mission operations; launch complex; space applications; remote sensing applications; education and training; space science etc. Antrix Corporation is a wholly-owned commercial and marketing arm of ISRO. About 16,000 people are employed by ISRO and its sub-units.

Various industries collaborate with ISRO – mainly as sub-contractors; universities and research institutions undertake R&D in space; ministries and state governments have space cells to address specific needs. This, itself brings in another 5-6000 people into the space-umbrella.

Thus, over the years, a wide network of laboratories, programmes, human resources, industrial capabilities, research programmes and global outreach has been enabled successfully.

III.II Indian Space Programme and Policy Perspectives

(Much of the material below is extracted from a paper presented at 65th International Astronautical Congress, Toronto, Canada - FUTURE INDIAN SPACE - RENEWING POLICY DIMENSIONS (IAC-14.E3.2.7)[34]

From a policy analysis, the Indian space program evolution can be broadly categorized under three distinct phases:

- The proof of concept demonstrations of the use of the vantage point of Space for addressing the country's developmental needs and these were exemplified by the Satellite Instructional Television Experiment (SITE), the Satellite Telecommunications Experimental Project (STEP), and use of Landsat satellite data for natural resource management applications. The space segment was procured with international cooperation. By early 1970s, India was on its way to develop its first satellite – Aryabhata and started the "grand plan" of an indigenous end-to-end space technology development capability.

- The experimental phase saw the development of an end-to-end experience in the realization of space systems - experimental earth observation satellites like Bhaskara I and Bhaskara II; India's first experimental geostationary satellite APPLE and the initial space launch vehicles such as SLV-3 and ASLV characterise this phase. It facilitated competence building at the core level. Thus, by late 1970s and in 1980s, India invested considerably in building laboratories and facilities and also initiated a 3-pronged programme – Indian communication satellites in INSAT; Indian EO satellites in IRS and Indian launch vehicle programme through the Polar and Geo-synchronous launch vehicles.
- The operational phase was then taken up with an understanding of and analyzing the complex interplay of - evaluation of alternate approaches to arrive at the most optimal solutions; decide on exercising buy or build options parallel indigenous development plan to achieve self-reliance goals. This phase resulted in establishment of National Systems such as (i) Indian National Satellites (INSATs) / GSATs for communications, broadcasting and weather observations (ii) Indian Remote Sensing Satellite Series and (iii) Polar satellite Launch Vehicle, PSLV - all examples of operational space systems that have to meet stringent operational service performance criteria.

By early 2000, India had achieved a technological maturity of space systems and utilisation and this challenged it to envision missions to far-away Moon and thus came about Chandrayaan-1 – which originally started (in 2000) from a simple question "Can we go to the Moon?". Soon by 2002, India also started planning for its own Positioning Satellites systems in Indian Regional Navigational Satellite System (IRNSS).

Yet another aspect that emerged in mid 1990s and early 2000s was forays of Indian space products into the global market place – through Antrix Corporation which marketed Indian space capabilities globally and thereby capitalizing revenue models for Indian space. Most of the developments and manufacturing were organised into various units of about 16000 strong Indian Space Research Organisation (ISRO) with contract-mode industry-interfaces – which helped in the overall development process for ISRO.

Towards 2010s, India had challenges to comprehend because of failures of GSLV – even as PSLV emerged as a reliable launch vehicle for 2t class spacecraft and the work-horse for ISRO. But the successive failures of GSLV have posed tremendous challenges which are being systematically overcome in recent times. Yet another challenge that faced India was the gap in satellite communication transponders that started stifling the service segment of DTH, social broadcasting, data communications – and more so in terms of slowing down technology development in newer areas (like Ka-band and large class satellites etc).

In 2011, ISRO took upon a new challenge of a foray to Mars in the 2013 orbit-window for Mars. The Mars Orbiter Mission (MOM) was successfully launched in November, 2013 and manoeuvred to enter into Mars orbit and conducted its experiments of imaging and measurements. But more significantly, MOM established the fact that India can successfully undertake long-duration planetary missions and had gained the basis experience in this regard.

In 2015, ISRO successfully launched the indigenous GSLV and placed GSAT-6 satellite in orbit and established its capability to design, develop and operationalise geo-synchronous launch capability and access GTO orbits with heavy satellites.

Thus, one can see that over the past 50 years, India has made significant progress in space technology – achieving projects, missions, programmes and developing new applications.

III.II.I Policies for Satcom and Remote Sensing Data

Towards end of 1990s, India had a mature satellite communications programme through its INSAT system and a remote sensing satellite through its IRS. Much of the space development and utilisation was pushed by ISRO with a visionary drive that envisaged a foundation of national-anchoring for Indian space but a growth in commercial and privatisation activities – for it was envisaged that it would be just impossible for ISRO to take up efforts to meet the growing demands that would emanate from 2000s and ahead. Thus, ISRO took up considerable think-tank activities to have a 2-pronged strategy of protecting national space interests and at same time preparing for large-scale commercial demands.

It was during these times that the Satellite Communication (Satcom) Policy was taken up and adopted by Indian government in 1999 and the

Remote Sensing Data Policy (RSDP) was taken up and adopted by Indian government in 2001.

Satcom Policy[35]

The SATCOM Policy was adopted by India in 1999 but its evolution started from 1997 time-frame. The Satcom Policy-1999 was based on then technical developments in satellite technology as well as in the associated/alternate communications technologies and the aim was to develop a vibrant satellite communications regime for India that catered to national and commercial needs.

The main goals of the Satcom Policy-1999 were as follows:

- build national capabilities in satellite communications by way of a healthy and thriving communications satellite, ground equipment and satellite communications service industry AND sustained utilisation of Indian space capabilities - satellites, launch vehicles and ground equipment design
- Make available INSAT systems for social-applications development and ensuring that INSAT system benefits a larger segment of the economy and population
- Encourage and promote privatisation of satellite communications in India by way of encouraging private sector investment in space industry and also attracting foreign investments

Some of the innovative aspects of the Satcom policy-1999 were to change the paradigm at that time and included:

- authorizing capacity of Indian National satellites (INSAT) to be leased to non-government (Indian and foreign) parties on commercial terms. This was essential so that commercial services could ride on INSAT – envisaged to spur the DTH and VSAT market in India to a large extent.
- allow Indian parties to provide services including TV up-linking through Indian satellites – thereby to open up a variety of TV channels in India.
- co-ordinate and register satellite systems and networks by and for Indian private parties. The intent was clearly stated but this has not happened till now.
- satellites for government use to be made available by Department Of Space. However, there have been severe shortages in transponders available from DOS for social applications and thus impacting educational satellite services, tele-medicine services through satellites, state development communications and e-governance services. Gap in demand-supply – growing demand for satellite capacity is a challenge
- DTH preference on Indian Satellite Systems
- The operations from Indian soil using foreign satellites under certain conditions

It was envisaged in 1999 that Satcom Policy would ultimately bring great benefit to India by way of big boost for DTH business, VSAT services, robust connectivity for education outreach across the country, reliable telemedicine connectivity, increased capacity leasing and a great growth in Indian ground equipment manufacturing. It was also envisaged that ultimately the Satcom policy-1999 should help position Indian Satellite Systems, both from public and private sectors including JVs for communication satellite ventures and also bring in a variety of new value-added services.

The corner stone of the SATCOM Policy[36] was the preference to be given to Indian Satellite Systems (ISS) while giving service licenses – thereby ensuring "protective cover" for INSAT and other Indian registered private sector satellites for Indian services against any "market on-slaught" from global commercial systems. However, the pragmatism of the Satcom Policy is that it does not in any way prohibit the use of foreign satellite systems – which, after a due process, can be treated on par with ISS for service licensing in India. This has not happened – mainly due to deficiencies of appropriate procedures in implementation.

The Satcom policy is silent on orbit-spectrum situation for Indian interests including needs of private satellite systems. There is a problem that there are not many such slots available globally for use and coordination has become complex and inordinately time consuming. Unfortunately, even as of 2014, additional orbit-spectrum resources for expansion of much needed infrastructures are eluding solution.

Remote Sensing Data Policy[37]

The Remote Sensing Data Policy (RSDP) defines the Indian regulations for acquisition, dissemination of satellite images in India - earlier, RSDP-2001 and now RSDP-2011[38] governs how satellite images are to be acquired and distributed – allowing upto 1m images to be openly dissemination to users. The RSDP embeds the concept of "regulation" to address the dissemination for 1m images.

Thus, the RSDP-2001 provided the earliest "framework" for a comprehensive imaging policy –

for the first time remote sensing was identified as a "public good" and the concept of national commitment to continued imaging programme through IRS was included. The RSDP introduced the concept of "one-window" access to any image (Indian or foreign satellite) - which today appears to be against "free market" concept. Another concept that RSDP-2001 started was of "regulatory use-determination" (mainly to stave off the hard-block of private sector access to 5.8m images "could become a security concern") whereby images upto 5.8m would be "available on non-discriminatory basis" but images better than 5.8m would be "regulated" for private sector users on case-by-case basis. The RSDP-2001 carried yet another major aspect – images would be screened to obliterate some geographic regions (then called Vital Areas/Vital points) so that such "map-erasing" methods also are applied to images. The RSDP also required foreign satellite images TO BE routed through the national agency – National Remote Sensing Centre (then Agency), NRSC.

It is clear that in RSDP-2001 was adopted when Indian imaging corresponded to 5.8m and the availability of Indian 2.5m or 1m was in still in "planning stage" – while 1m images from IKONOS, in 2000, made way into the image market, including in India. Thus, even though the RSDP clearly emanated from the competitive challenge of US 1m images against the Indian 5.8m IRS system in the Indian market – it was certainly a protective regime for IRS till it could also match with commercial 1m image availability from IRS systems (which happened only in 2006).

But there was a major path-way crafted in RSDP-2001 in the concept of "licensing" RS satellites and RS data acquisition/distribution in India – creating that "window-opening" for future Indian private RS satellites and Indian private agencies to acquire/distribute any satellite images in India. Such privatisation was envisaged even way back in late 1990s and was embedded into RSDP-2001. However, till 2014 no such licensing application has been encouraged and NRSC has continued to be the single "monopolistic" data provider. However, of late market-talk indicates few private players considering licensing applications for acquiring or distributing foreign satellite images in India – though the stage of private Indian RS satellites is still far away.

By 2005-06, India also launched 2.5m and 1m images but by then the larger proliferation of 1m images from US commercial satellites had also happened. Thus, the 5.8m thresh-hold of RSDP-2001 as "regime for non-discriminatory access" was found detrimental to Indian cause/users and was soon rendered irrelevant. Therefore, in RSDP-2011 a lower bar for "non-discriminatory access" to 1m was promulgated – but then fully retaining all other aspects of RSDP-2001.

The impact of RSDP has not been quite as envisaged – neither did the "protective regime" in early 2000s help stave the challenge of foreign 1m images because US 1m images became widely popular as against 5.8m/2.5m images and very limited 1m images from IRS systems; NOR did it help develop and position Indian private RS systems for satellites and distribution. With NRSC the "sole agency" for distributing images, it has become further monopolistic as it adopts IRS-centricity and pushes 2.5m and limited 1m images – thereby denying Indian users 0.3m level images for national development. At the same time, Indian is unable to match the resolution quality of US commercial systems (that have reached 0.3m level in global market) and has plans for a 0.5m imaging IRS in 2017 time-frame. Policy reforms distinguishing government procurement markets that combine multiple objectives and the private markets need to be considered, balancing the benefit from open competitive systems.

III.III Indian Space Achievement Metrics

As of 2015, here are some metrics of the past 40 years and over the past 8 Five Year Plans (1974-2015):

- A cumulative budget of about INR 930 billion has been formally allocated in 40 years of eight 5-yr plans by Indian government.
- As against the committed allocations, the actual utilisation has been INR 543 billion.
- Approval for 200 missions has been accorded by Indian government but 124 missions have been accomplished - out of which 14 missions have been failures.
- Independent access to space through a reliable and operational PSLV launch vehicle and a proven operational indigenous Geostationary launch vehicle, GSLV incorporating an indigenously developed cryogenic upper stage
- World class satellite capability that cover a wide variety of applications satellites – INSAT, IRS and IRNSS for telecommunications, broadcasting, weather observations, remote sensing and

navigation and scientific spacecraft including orbiters to the Moon and Mars.

- Wide use of INSAT communications systems have resulted in the wide outreach of TV signals (from early 1980s onwards) to almost whole of the country and growth of large-scale DTH and VSAT data communication business.

- The availability of low-priced and easily available IRS images (from about 20 IRS missions) and a great thrust to use of images and geographical information techniques proliferated IRS data into many governance and national building activities – by way of inventory and maps of natural resources, critical support to disaster management activities and environmental monitoring.

- Weather and ocean services modelling have derived a great boost from the availability of INSAT and Oceansat images/data on a variety of ocean and atmospheric data – thus consolidating the scientific services of meteorological department and Earth Sciences.

- Forays in planetary missions have been made through Chandrayaan-1 and MOM-1 to establish the technological capability of Indian space to undertake far-reaching planetary exploration and also undertaking advanced scientific studies.

- Unique missions for astronomical observations – Astrosat and operational Positioning Services – through IRNSS constellation have been planned but are yet to be launched or fructify.

- Global commercial operations of Indian space in 52 commercial/foreign satellites on its PSLV; sale of IRS images and value-addition services and, more lucratively, transponder lease business in India are estimated to have resulted in revenue earnings of about INR 100 billion over the past 20 years, although only a part of the capacity created was available to the commercial activity. It must be noted that this estimated revenue earnings includes an after-tax profitability of anywhere between 10-14% - thereby, meaning that the net-earnings were well over INR ten billion in profits for the commercial activities undertaken.

<u>III.IV Looking Ahead</u>

India does not have a formal National Space Policy that has been legislated or formalised into a public-domain document. Indian space is still guided by Vikram Sarabhai vision of "……applications to the real problems of man and society" – which still serves as a national space policy tenet and has been guiding the developments over past 44 years. The programmatic definitions of Indian Space are made in the Five Year Plans of the Indian Government.

Presently, in the 12th Five Year Plan (2012-2017)[39], Indian Government has allocated INR 39 billion and has approved 58 missions over the 5 years period. The plan also makes forays into heavy communications satellites, advanced EO and weather satellites, achieving operational status of geo-orbit launch systems, advanced missions for exploration of Mars, lander on Moon and IRNSS constellation and studies for human space-flight programme.

Looking ahead, ISROs direction seems to be undertake the missions that have been approved and planned in 12th FY Plan and further recently articulated by Chairman, ISRO towards "…..developing heavy lift launchers, reusable launch vehicles, cryogenic engines for low cost access to space and use of composite materials for space applications" AND ".. aim is to be future-ready to maintain an edge in technology .. and enhance them"[40]

At various times, ISRO has also publicly acknowledged to develop industrial capability and involve Indian industries for its national and global programmes. The shortage of communication transponders and easy availability of remote sensing images have triggered many industries to look at private-sector space activities – but these are yet to take off in a major way mainly due to lack of policies that can enable a national space eco-system with industry and commercial activities.

The challenge is also in future activities of human space-flight programme – not just technologically but also from investment and sustenance point of view. Public acceptance of such programmes can be forth-coming but the technological aspects along with organizational structures are yet to be defined and fructified – though study level activities have been just funded.

Within India, the need is felt for a holistic National Space Policy – basically looking far ahead and creating a roadmap that will look 30-50 years ahead but also knit and integrate the various elements into efficiently-performing assets for Indian capability.

IV. SIMILARITIES AND UNIQUENESS – JAPAN AND INDIA SPACE ACTIVITIES

It is not our intent to critically analyse and examine the space programmes of Japan and India. Such a critical analysis has to be subject of a long-standing research project and spread over time and interactions – something we have not been able to do as of now.

However, in our research we have observed similarities and individual uniqueness that characterise both space programmes and it is our intention to document these observations. We hope this will help various researchers to understand the evolution of space programmes and also help many researchers in Asia Pacific region (and the world) to look at development of space programmes.

We also hope that this research can contribute to possible areas of cooperation between Japan and India in the field of space – especially because similarities are many and uniqueness can be leverages by one another.

Some of the salient points to mention are:

- Both Japan and India have a long heritage of space activities – almost starting off at same time-periods in very early 1960s
- Inspiring individuals gave the starting leadership and vision- setting – Prof Hideo Itokowa in Japan and Dr Vikram Sarabhai (and later by Prof Satish Dhawan) for India. In both programmes the beginnings were in sounding rockets for atmosphere research.
- Strong political support were forthcoming to both programmes – in both countries the Prime Minister themselves have provided political and programmatic leadership.
- Formation of national space agency – with sub-units for various space elements is common to Japan and India – NASDA/JAXA in Japan and ISRO in India.
- Clear separation between civil and defence purposes in Japan and India. But recently there is increasing interconnection between civil and security needs in Japan.
- Autonomy and flexibility has been the hallmark through very high-level space council/commission that have provided the programmatic and financial directions.
- Both programmes have justification of national capability and national development. Here we see, India more thrusted to national development and governance activities. Japan has a greater technological drive in successful manner.
- Both programmes have operational capability to access space through their own indigenous launchers – Japan has manufacturing and operational cryogenic capability and India is in process of operational capability and operational satellite manufacturing capability for communications, remote sensing; positioning, planetary missions etc.
- India has a great outreach in space applications for societal development and addressing national development – natural resources management and mapping/inventory, disaster management, education, health, TV broadcasting, voice/data connectivity, meteorology and climate; environment monitoring, security and many other areas. Japan had main aims for space applications in meteorology, broadcasting and communication. Recently emphasis move toward climate/ environmental monitoring, disaster management, and security. Japan restructured the space governance mechanism beginning with the administrative reform in 2001 and finishing with the establishment of Office of National Space Policy (ONSP) under the Cabinet Office (CO) and the Committee on National Space Policy in 2012.
- Japan government has adopted a Basic Space Law in 2008 and set Basic Space Plan which was recently modified in 2015 – which defines the national direction for space. India is yet to have a formal national space policy but is directional by 5-year approved goals and programmes of Indian government. In our assessment, we see tremendous activities for a holistic space policy being undertaken in both countries – involving many agencies/researchers.
- Privatisation of space is yet to develop in both nations – in terms of private investment and development and ownership of space assets. The eco-system for such a development is yet to evolve. However, major industries in both nations are involved in the national space activity through ISRO and JAXA, respectively. In Japan, industries develop whole systems – total satellite development or launch development and so on – this is yet to be seen in India where industries are still in sub-system mode.
- International Cooperation is the hallmark of both space programmes – through active bi-lateral, multi-lateral and opportunity cooperation. Japan is well dove-tailed into international space mission – International Space Station; ESCAP; APRSAF; GEO mission contributions and global planetary science mission profiles.

- Indian space activities are extremely cost-effective and are successful with least investments.

V. CONCLUSION

Japan and India have an operational space programme spawning >50 years of development. With vision and determination, both programmes have matured into success at various levels and are playing a major role in the AP region. Right now, both programmes are working to define the future course and long-term strategy and adapting to the global scenario of space development.

Policy definition is in the regime of both national – Japan is further evolving the Basic Space Law and Indian is working for a space policy too. With large mission profiling ahead of both nations in next 10-20 years, it is only through good and pragmatic policies that both nations can sustain their forward march and also contribute to humanity for improving society and developing its people.

Japan and India are major nations in AP region and together can play a major role in regional space – in terms of complementing and supplementing space capabilities for the societal and commercial development of space in AP region. They have tremendous capability to "pool" and cooperate to reach space products to many nations in the region – through bi-lateral cooperation and multi-lateral framework. High-level political collaboration has been initiated by the governments of India and Japan – Space Technology Cooperation for realising joint missions, joint industrial ventures etc are potential candidates for cooperation.

The extremely high level technological capabilities in EO, space science, planetary missions, positioning etc. indicates that a India-Japan joint space mission is of high potential making – this will be a great boost to space activities at the regional and global level.

Both countries also have considerable industrial capability and this can be one major area for industrial collaboration between the two nations. The potential for Japan of using Indian space capability platform through industry involvement and at space agency-level to leverage costs is tremendous.

Significant similarities among the objectives of the policy, the policy drivers and paradigms are pushing renewal of policy environment for outer space in Japan and India. This creates tremendous opportunities and potentials for cooperation in policy discourse on contemporary concerns like space security, space science/ human space flight operation, and space industry cooperation for strengthening space infrastructure needs of both countries as well as the region, joint missions that address humanitarian concerns as well as technological advances that promise 'New Space' developments.

Policy studies can be one great opportunity for collaboration between like-minded institutions in India and Japan – especially extending the University of Tokyo and NIAS collaboration.

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REFERENCES

[1] James Clay Moltz, *Asia's Space Race: National Motivation, Regional Rivalries, and International Risks* (New York: Columbia University Press, 2012, 43-69.

[2] Kazuto Suzuki, "Transforming Japan's space policy-making," *Space Policy*, 23, 2007, 73-80; Kazuto Suzuki, "A Brand New Space Policy or Just Preparing over a Political Glitch?" *Space Policy*, 24, 2008, 171-174.
[3] Suzuki, "Transforming Japan's Space Policy-Making"; Kazuto Suzuki, "Administrative Reforms and the Policy Logics of Japanese Space Policy," *Space Policy*, 21, 2005, 11-19.
[4] Suzuki, "Transforming Japan's Space Policy-Making", 73-80.
[5] Kagaku Gijutsu Cho (Science and Technology Agency) ed., *Wagakuni no Uchukaihatsu no Ayumi* (*History of Japan's Space Development*) Okurasho Insatsukyoku, 1978, 1-6.
[6] ISAS (Institute of Space and Aeronautical Science) at the University of Tokyo was reorganized in 1981 as Institute of Space and Astronautical Science (ISAS) under the Ministry of Education.
[7] For more information, see < http://www.isas.jaxa.jp/e/index.shtml>.
[8] Yasushi Sato, "A Contested Gift of Power: American Assistance to Japan's Space Launch Vehicle Technology 1965-1975," *Historical Scientiarum*, vol. 11-2, 2001, 176-204; John Krige, Angelina Long Callahan, and Ashok Maharaj, *NASA in the World: Fifty Years of International Cooperation in Space* (New York: Macmillan, 2013)185-210.
[9] Uchu Kaihatsu Iinkai (Space Activities Commission), *Uchu Kaihatsu Seisaku Taiko* (*Outlines of Space Development Policy*), March 17, 1978.
[11] Suzuki, "Transforming Japan's Space Policy-Making."
[12] *Ibid.*
[13] Joan Johnson-Freese and Lance Gatling, "Security Implications of Japan's Information Gathering Satellite (IGS) System," *Intelligence and National Security*, vol. 19 no. 3, Autumn 2004, 538-552.
[14] Suzuki, "Transforming Japan's Space Policy-Making."
[15] Strategic Headquarters for Space Policy, *Basic Plan on Space Policy*, January 9, 2015.
[16] *Ibid.*
[17] *Basic Space Law*, May 28, 2008.
[18] *Ibid.*
[19] *Basic Plan on Space Policy*, January 9, 2015.
[20] The Ministry of Defense, "Basic Guidelines for Space Development and Use (revised)," August 28. 2014.
[21] *Basic Plan on Space Policy*, January 9, 2015.
[23] *Basic Plan on Space Policy*, January 9, 2015.
[24] *Ibid.*
[25] *Ibid.*
[26] *Basic Space Law*, May 28, 2008; *Basic Plan on Space Policy*, January 9, 2015.
[27] *Ibid.*
[29] *Basic Plan on Space Policy*, January 9, 2015.
[30] *Ibid.*
[31] *Basic Space Law*, Article 25, 2008.
[32] Foreign Policy Bureau, the Ministry of Foreign Affairs, "Establishment of Space Policy Division," April 5, 2012. <http://www.mofa.go.jp/policy/outer_space/pdfs/space_policy_division.pdf>
[34] Mukund Rao; KRS Murthi and VS Ramamurthi (2014). FUTURE INDIAN SPACE - RENEWING POLICY DIMENSIONS (IAC-14.E3.2.7). Paper presented at 65th IAC in Toronto, Canada during October, 2014. Accessible at https://iafastro.directory/iac/paper/id/20955/ext/appendix/IAC-14,E3,2,7,x20955.pdf
[35] Satellite Communications (SATCOM) Policy, 1999 (http://www.isro.org/news/pdf/satcom-policy.pdf)
[36] Satellite Communications (SATCOM) Policy, 1999 (http://www.isro.org/news/pdf/satcom-policy.pdf)
[37] Mukund Rao and K R Sridhara Murthi, Perspectives for a National GI Policy, (Report R 11 - 2012) National Institute of Advanced Studies, Bangalore, September, 2012. Report No: R11-2012. (www.nias.res.in/docs/R11-2012-GI-Policy.pdf)
[38] RSDP (2011), Remote Sensing Data Policy, 2011 from http://www.isro.org/news/pdf/RSDP-2011.pdf
[39] 12th Five Year Plan (2012-17). http://planningcommission.gov.in/plans/planrel/12thplan/pdf/12fyp_vol1.pdf
[40] http://www.thehindu.com/news/national/andhra-pradesh/developing-futureready-tech-says-isro-chairman/article7669473.ece?ref=tpnews