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THE DECISION FOR INDIAN HUMAN SPACEFLIGHT PROGRAMME - POLITICAL PERSPECTIVES, NATIONAL RELEVANCE AND TECHNOLOGICAL CHALLENGES

Mukund Kadursrinivas Rao[a*], Prof. Sridhara Murthi K. R[b], and Prasad M. Y. S.[c]

[a] *National Institute of Advanced Studies, Indian Institute of Science Campus, Bangalore 560012, India, mukund.k.rao@gmail.com*
[b] *Jain University and National Institute of Advanced Studies, Indian Institute of Science Campus, Bangalore 560012, India, krsmurthy09@gmail.com*
[c] *Former Director of SHAR, India, prasadmys1@gmail.com*

(* Corresponding Author)

ABSTRACT

In recent times, debate is intense for an Indian Human Space flight programme. An assessment of the challenges in the development of a human space flight transport system has been studied by India - centring on development of indigenous launch capability for a two-member crew to low earth orbit and return safely to pre-determined destination on earth. However, India has yet to take a decision for a human space flight programme.

At National Institute for Advanced Studies (NIAS), we have looked into the decision-process that could lead to the crucial decision. We feel that establishing a political perspective for commitment, building a national consensus and also addressing the technological challenges are important steps. Our paper addresses these in a holistic manner:

- a critical factor of engagements at political level to obtain commitment for long term implications - of almost 20-30 years, needs to be initiated. The democratic, multi-party framework of India - which has to deal with aspirations of Indian society will also have to decide on the long-term development of Indian human space flight programme. It will be a critical exercise to build the political perspectives.

- consider the financial implications of a long-term human space-flight programme development - not just the one-time investments required for demonstrating national capability BUT also for continued human space flight pursuit with national gain. The assessment of returns and benefits has to be clearly articulated.

- key technological challenges - crew module design, environmental control and life support system, mission management with human in-loop, crew escape system, launch facilities, astronaut training etc. We also feel that strategic options are important - in terms of indigenous technology development cycles, technology acquisition, collaborative synergies at international level or even alignment/competing with growing global private initiatives in human space-flight programme.

The papers outlines the above and identifies some key parameters that would determine decision and goals for India to pursue human space flight - including, attraction for long term commitments and deepening investments at the cost of competing priorities, articulation of economic outcomes, apportionment of benefits across diverse political interests and time-frames, various risk dimensions and ascertainment of public perceptions, impact on social objectives, international cooperation and positioning, achieving high technological excellence in multiple sectors. The paper finally would outline the path that still needs to be pursued for the national decision.

Keywords: Indian Space, Human Space Flight, Space Policy, Decision Perspective

1. INTRODUCTION

Indian space activities 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 has driven the Indian Space Programme with spectacular achievements. As of September 2017, India has realised 167 missions (92 Spacecraft; 64 LV; 1 SRE; 1 RLV-TD and 9 student missions). India has successful missions in space exploration (Chandrayan-1, MOM &

ASTROSAT), Satellite Navigation (IRNSS & GAGAN). Independent access to space is realised through a reliable and operational PSLV launch vehicle and a proven operational indigenous geostationary launch vehicle, GSLV, incorporating an indigenously developed cryogenic stage. India use these space assets in communications, meteorology and remote sensing for wide outreach of TV signals to almost whole of the country through DTH and VSAT data communication business; use of IRS images and geographical information techniques into many governance and national building activities and derive operational weather and ocean services from INSAT and Oceansat images/data on a variety of ocean and atmospheric phenomena. Forays in planetary missions have been made through Chandrayaan-1 and MOM-1 for advanced scientific studies. Global commercial operations of Indian space through launch services to 209 commercial/foreign satellites on PSLV; sale of IRS images and, more lucratively, transponder lease business are bringing good revenue.

In recent times, debate is intensified on an Indian Human Space Flight (IHSF) programme. There is no programmatic approval for IHSF - though the National Space Agency initiated studies and assessment towards technologies of IHSF. According to the website of Vikram Sarabhai Space Centre (VSSC) of ISRO, the Indian Human Spaceflight Programme (HSP) is a proposal by ISRO to develop and launch, using the GSLV MkIII, the ISRO Orbital Vehicle, which would carry a two-member crew to the Low Earth Orbit to about 300 km low earth orbit and their safe return[1]. This initiative will involve number of technical design and development challenges like crew module design, environmental control and life support system, mission management with human in loop, crew escape system, launch pad related facilities and establishment of dedicated astronaut training facilities BUT a long-term vision is lacking. If technology development is the motive, the question of "What after that" would remain un-answered and unknown to the nation.

Incremental steps in HSF would be myopic in aspiration and just lead to "developing technology" (more of "me too") AND would not result in meaningful attainment of significant national benefit from HSF. We feel that India has to take a more holistic and strategic development for Indian Human Space Flight programme – this would require a long-term visualisation and consideration. One has to think beyond - what after the crew-module return; should India have an orbiting space station of its own; would Indians want to create habitations on Moon or visualise Indian presence on Mars; does India harbinger industrial material production in space; would India want to have space travel/tourism; would India consider deep-space human travel; how much of these aspirations be met from international cooperation and so on.

While India is yet to decide on the IHSF, at National Institute for Advanced Studies (NIAS), we have decided to "suo-moto" assess and look into the decision-process that could lead to the crucial decision of such an IHSF. A HSF mission cannot be just "proving a launch capability of a crew-module to LEO" BUT has to be much more of careful considerations of a variety of other perspectives. One has to realise that IHSF would be a long-term commitment of the nation and its decision would have to be an amalgam of establishing a political perspective, along with the commercial and social considerations, and also carefully addressing the technological challenges.

We are clear that it is **time for India to systematically and strategically consider the case for Indian Human Space Flight programme**.

2. HUMAN SPACE FLIGHT

Travel of man into the Outer Space had been always an important consideration right from the beginning of the development of the space field. Scientific fiction apart, the great scientists who had invented the fundamentals of Space sciences and engineering always advocated man venturing into Outer Space and into universe. Konstantin Tsiolkovsky, the inventor of the rocket equation, guided the humanity, way back in 1930s, by saying earth is only the cradle of humanity and man has to go out of the cradle as he grows up and proposed "anthropocosmism" and grand ideas about space industrialization and the exploitation of its resources [2]. All the other leaders who contributed for the technology and science to bring Outer Space to the reach of man always dreamt of **travel into Outer Space** and technologies need for it. Wernher von Braun[3] and Sergi Korolev always kept travel of man into Space as one of their long term targets right from the beginning of their Space technology initiative.

Human Spaceflight, which is a notable dimension of space accomplishments, is distinguished by the first successful landing on the Moon in July 1969. Habitable Space station platforms, such as Salyut, Mir and Skylab in the near earth orbit environment have enabled conduct

[1] http://www.vssc.gov.in/VSSC_V4/index.php/technology/human-space-flight

[2] https://www.nasa.gov/audience/foreducators/rocketry/home/konstantin-tsiolkovsky.html

[3] https://history.msfc.nasa.gov/vonbraun/bio.html

of various experiments in the fields of astrobiology, material sciences, astronomy, life sciences, space weather and so on under micro-gravity conditions and these space stations have also facilitated long duration stay of astronauts in these stations, performing various experiments and extra vehicular activities including on-orbit servicing and repair of a few spacecraft.

Since the early times of space development, only USA and Russia demonstrated their autonomous capability to perform the Human Space Flight. In 2003, China became the third and most recent nation to demonstrate capability to conduct human space flight mission. In recent times, the International Space Station Freedom, which is a multinational collaborative effort represented by the five space agencies NASA (USA), Roskosmos (Russia), JAXA (Japan), ESA (Europe), and CSA (Canada) has played a pivotal role in hosting several international crews of astronauts from different countries and a wide range of in-space experiments on materials, astro-biology, space medicine, long-term effects of space, radiation studies etc.

Human Space flight has several dimensions of impact that include political, technological, industrial and strategic. Intense debates have occurred in the USA, Russia, Europe, China and Japan on the technology justification and costs of maintaining and growing human space flight programmes.

Apart from economic considerations, there had been other drivers for human space flight as seen by the forays made by China in this area in the recent decade. The advances in technology in next few decades and initiatives of private sector globally are transforming the economics of access to space, which can open up possibilities of large structures in space.

2.1 RUSSIA – HUMANS TO MOON

For the first time, Yuri Gagarin was successfully put into Earth's orbit and safely brought back by former USSR in 1961 and this heralded the historic phase of Human Space Flight. Over the next decades, former USSR operationalised Space stations Salyut and the Mir space station where Russian cosmonauts remained in space for long durations.

Russia is an important partner for the International Space Stations (lead by USA). After retirement of Space Shuttle by USA, Russia happens to be the main crew transport service provider to the ISS.

In 2017, Russia has announced new direction for its space programme and recognised that the primary focus should now be on practical applications of spaceflight (remote sensing, navigation, meteorology, communications), with science coming in second place and piloted spaceflight relegated to third place. Russia is now working so that the Moon should take center stage in the human program with "stay" as a goal and not as a "stepping stone" to Mars, leaving flights to the asteroids and Mars as objectives for the distant future. The main objectives of the lunar program is science, resource utilization, and testing of new technologies. Russia plans for first Russian human lunar landing mission in 2030, to be followed by the gradual establishment of bases scattered across the lunar surface in a process of "the conquest of a new continent."[4]

In this strategy, Russia has plans for the development of a new heavy-lift launch vehicle as well as standardized transportation and habitation systems that could also be used for future exploration of the moon, asteroids and Mars.

2.2 USA – JOURNEY TO MARS

From the early days of Mercury to the lunar adventures of Apollo, from the innovation of the space shuttle to the technological advancements of the International Space Station, NASA has created a successful human space flight programme for more than four decades. Starting with Mercury, USA's first human space flight program, the moon was set foot on by Apollo by successful lunar landings. This was followed by orbiting space laboratories where humans could live and work in space for extended durations. The Shuttle brought the easy face of space flight and along with Russian MIR, the opportunities and challenges to build the International Space Station (ISS) became successful. The ISS opened a whole new window for space research, manufacturing and long-term human presence in space.

NASA is now on a journey to Mars, with a goal of sending humans to the Red Planet in the 2030s. Missions of orbiters, landers and rovers have dramatically increased knowledge about the Red Planet and is paving the way for future human explorers – for them to live on Mars and also the possibility of exploiting Mars minerals and resources. NASA's Space Launch System (SLS) will be the most powerful rocket that will enable astronauts to begin their journey to explore destinations far into the solar system. NASA's Orion spacecraft is built to take humans to Mars - the exploration vehicle that will carry the crew to space, provide emergency abort capability,

[4] The status of Russia's human spaceflight program from http://www.thespacereview.com/article/3184/1

sustain the crew during the space travel, and provide safe re-entry from deep space return velocities.

NASA is also developing a first-ever robotic mission to visit a large near-Earth asteroid, collect a multi-ton boulder from its surface, and redirect it into a stable orbit around the moon. Once it's there, arriving astronauts will be able to explore it and return with samples. This Asteroid Redirect Mission (ARM), planned for 2020s, is to advance the new technologies and spaceflight experience needed for a human mission to the Martian system in the 2030s.

Private sector and industries in USA are actively involved in developing many of the components for the journey to Mars. SpaceX has unveiled a vision of making humans a multi-planetary species with a wholly industry crewed Mission to Mars in 2018 and a mission to Mars and return[5].

2.3 CHINA – LEO STATIONS AND MOON

Development of space technology independently was chosen by China as one of its strategic areas - embarking on human space flight missions in the early 2000s. Now, China is following up to construct and operate its own Space Station (Tiangong) in the near Earth orbit and its declared missions to the Moon and Mars. It is seen that drivers for China to embark on human space missions is its national capability and urge to prove its status as a great global space power. It should be noted that like, in all other developing countries, the space technology helped Chinese society in their national development and providing a large number of services through Space systems and technologies. China takes the space industry as an important part of the nation's overall development strategy and has opened up a path of self-reliance and independent innovation, and has created the spirit of China's space industry. Hence, the manned missions are considered to further consolidate its industrial capabilities and provide a higher level of targets.

In a December 2016 release of China's Space Activities in 2016[6], the vision is set to "explore outer space and enhance understanding of the earth and the cosmos; to utilize outer space for peaceful purposes, promote human civilization and social progress, and benefit the whole of mankind; to meet the demands of economic, scientific and technological development, national security and social progress; and to improve the scientific and cultural levels of the Chinese people, protect China's national rights and interests, and build up its overall strength". In the next 5 years, China plans to continue trips to earth-orbiting Tiangong-2 space laboratory, and research and master key technologies for cargo transport and replenishment to accumulate experience in building and operating a space station and strive to acquire key technologies and conduct experiments on such technologies to raise manned spaceflight capacity, laying a foundation for exploring and developing cis-lunar space. China also has aims of returning samples from moon and Mars and harbours a possible human space flight to these destinations, in the long run.

2.4 RELEVANCE OF HUMAN SPACE FLIGHTS FOR INDIA

It is clear that the future interests in sending humans is either to Moon or/and Mars – that is the way the 3 major space nations are envisioning and working upon. While USA is targeting for Mars, Russia is aiming of sending Russians to Moon and China has announced more rigour to its Space Station missions and explore for human landings on Moon.

In these scenarios, India must formulate strategies and the goals for IHSF - human space flight field must not escape Indian attention. With Indian economy poised to further grow based on its growth since 1990s, such a growth can be consolidated in the long term only through development of science and technology.

Human Space flights are frontier field in the science and technology. The Indian industry will find large opportunities through participation in the highly demanding Space missions. A country like India with a large and young man power, and large pool of scientific and technical man power cannot afford to ignore future frontier of travel for mankind – i.e. human Space travel. The challenges the Human Space Flights provide to India, and the benefits accruing from taking up those missions will be very high and will lead to further thrust for technological developments in the country.

Throughout history, it is evident that spirit of exploration and venturing into new frontiers have been key to huge opportunities for progressing knowledge and accessing new resources and for seeking solutions to long standing problems. The advances in technology in next few decades and initiatives of private sector globally

[5] Elon Musk's presentation at the 67th International Astronautical Congress in Guadalajara, Mexico, September 26–30, 2016. Summary in New Space, 2017.

[6] China's Space Activities in 2016 from http://www.scio.gov.cn/zxbd/wz/Document/1537091/1537091.htm

could transform the economics of access to space, which can open up possibilities of large structures in space. Such developments could lead to use of space resources and environment for energy solutions for earth. The Helium 3 from lunar surface could be one such clean source apart from the solar radiation source.

Indians are motivated by space activities – which is clear from the tremendous political and public appreciation of space activities (be it a PSLV or GSLV launch OR launch of INSAT/IRS/IRNSS for operations OR specialised missions like to Moon and Mars). In fact, space is at fore-front of excellence and continuous achievement in India and the development of the space agency culture has fascinated many over the years. Thus, HSF will also generate and receive national acceptance and appreciation, once implemented. The public and national prestige is thus a great motivation for IHSF - if we disregard this motivation, less will be accomplished because nation will be less motivated. It is difficult to measure the cost-worth of such a national motivation, but it is significant. In view of the long term interests of India, it is necessary that it acquires certain basic capability in elements that constitute human space flight and also make some unique contributions to the global developments.

The next generation inspiration is through technological and progressive achievement – HSF will provide that inspiration to the youth and also the national public mainstream. Thus inspiring Indians with the journey and living on Moon or Mars or even orbiting stations will "open dream" for the future. HSF would inspire young generation into notable achievements and enable them to play their legitimate role in challenging future activities like creation of space habitats, lunar bases and planetary exploration and exploitation of resources from space (asteroids and other near earth bodies). The requirements of new breed of technologies and complexities of realizing quantum jumps in reliabilities of facilities and systems will be a positive gain that will spin off new industrial capabilities in the country.

HSF will also thrust good research and technology development. With a large number of researchers with proper equipment involved, HSF will thrust significant research – materials processing, astro-biology, resources mining, planetary chemistry, planetary orbital calculus and many other areas.

There are inherent difficulties to assess the value in having a capability for HSF. The ability to send men into space is inherently valuable, just like any other capability.

The larger aspect is whether India can miss this frontier human endeavour to go out and live in space – WHEN IT HAS THE POTENTIAL CAPABILITY. Would it not want to be where the action is "with USA/Russia/China" out there - if it is not in there then it cannot be in fore-front.

3. HSF PROGRAMME – DECISION PERSPECTIVES

At National Institute for Advanced Studies (NIAS), we have looked into the decision-process that could lead to the crucial decision:

- a critical factor of engagements at political level to obtain commitment for long term implications - of almost 20-30 years, needs to be initiated. The democratic, multi-party framework of India - which has to deal with aspirations of Indian society will also have to decide on the long-term development of Indian human space flight programme. It will be a critical exercise to build the political perspectives.

- key technological challenges - crew module design, environmental control and life support system, mission management with human in-loop, crew escape system, launch facilities, astronaut training etc. We also feel that strategic options are important - in terms of indigenous technology development cycles, technology acquisition, and collaborative synergies at international level or even alignment/competing with growing global private initiatives in human space-flight programme.

- consider the financial implications of a long-term human space-flight programme development - not just the one-time investments required for demonstrating national capability BUT also for continued human space flight pursuit with national gain. The assessment of returns and benefits has to be clearly articulated.

3.1 POLITICAL PERSPECTIVES OF IHSF DECISION

India is a democracy – a developing one at that. It has tremendous push-and-pull for development and emerging to meet the aspirations of multi-faceted society. Thus Aspirations are high BUT Attainment levels in the political systems could be low. India is also in the midst of Asian nations that have varying capabilities in space but the presence of China and Japan does pose a "competitive spirit" in the public perception in many spheres of activities – space being one of them.

Indian democracy follows a 5-year cycle and in recent times political aspirations cycle through the main elected parliament. Though this 5-year cycle has not impacted political and national support for space activities till now, it must be borne in mind that present space activities were shorter in term and could fit well into the democratic cycles.

HSF has to be a long-term commitment – say of almost 20-30 years and calls for a high level of national commitment of resources and determination to patiently see through the possible achievements. So the political system must consider this long-term commitment and assess the national benefits over time so that it will maintain momentum over time.

The national justification for a HSF must be well assessed – the merits and benefits for the nation must be articulated politically. Why should India undertake a HSF – considering its long-term costs? This has to be well answered in the decision process. In our view, the reason or purpose cannot be to just attain the technology BUT must have a larger goal-setting – like, it could be:

- a vision to see Indians and Indian enterprise on Moon or Mars;
- national technological capability building for future generations;
- inspiring the young and future generation and creating high-end employment opportunities;
- being a part of the first-landers to be able to shape global policies for Moon/Mars etc;
- possible space security implications;
- international cooperation and diplomacy.

Right set of primary and secondary goals justification would be very important for IHSF!!

With the long-term goal setting, politically there has to be commitment to sustain financial resources for the IHSF activity. In India, presently a 7-year planning cycle is adopted and financial commitments are tuned to this cycle. IHSF goals would have to obtain financial resources and budget over 3-4 such 7-year cycles – legislative and political mechanisms have to be developed for this.

3.2 TECHNICAL CHALLENGES AND DECISION-MAKING

There are many technical challenges in realizing and carrying out IHSF. The weakest system in manned missions is man himself – his inability to live in the harsh environment of the outer Space or his limitation to live only in the environment he is used to on Earth. Any manned mission will have to plan for safe return of the crew after completion of mission, and safety of the crew in case of any emergencies during all phases of flight.

Philosophy of IHSF must get defined – whether aim is to fit IHSF to LEO stations OR reaching out to Moon OR reaching out to Mars or even beyond. The stages of achieving the goals are important to define – as they would help determine the technological developments required. One way can also to define stages of the overall vision – first, send Indians to LEO stations; second, use that base to foray to Moon or Mars.

The possibility of India taking on its own the IHSF ab-initio versus joining in as an international cooperation activity (like NASA-JAXA-ESA-Canada) and gaining advantage. Ab-initio approach has been undertaken by China but is like "discovering the wheel again" and non-optimal use of resources. Joining in International Cooperation can be an option – like India could join the ISS and partner with USA for HSF programme. India could its launch of GSLV variant for interregnum access to ISS (limited payload capacity).

The important issue to consider for India is about the LEO station as a stepping-stone ahead for HSF. Should India develop its own Orbiting Space station (as has been done by China) OR participate in international ventures along with other nations for using LEO stations. India must carefully consider these 2 possibilities. India can certainly consider joining and participation in ISS and also future plans for LEO stations.

International Cooperation could be the core of IHSF – especially if India aims to leap-frog and reach process of "catching up" and quickly attain/contribute to international activities.

India is still at "nascent level" as far as technology for IHSF is concerned – though it has demonstrated the re-entry and also a "dummy" crew-module mock-up in test flights on GSLV. A host of technologies will need to be developed:

- **Reliable man-rated launch vehicle**: Today, GSLV MkIII is touted for the HSF. The GSLV can carry about 5-6 tons (very limited restriction for HSF) of payload to NEO and is considering a futuristic new generation launch with semi-cryogenic technology that can take 8-10 tons payload. However, contemporary launch capacity for HSF in world is said to be around 20-30 tons in LEO. In fact, SpaceX is aiming for 550 tons on its future Mars vehicle (incidentally the old-horse Saturn had a 135 tons capability).

Re-usability of rocket (either shuttle-type or stages) is order of future and India has to develop these technologies. Refuelling in space is being talked of by industries and technologies will open up in future for same. Rocket engines are considering new generation methane-oxygen fuel (SpaceX Raptor engines) to bring better efficiency over traditional kerosene and oxygen and high-performance thrust-weight ratios.

With the present GSLV MkIII the human space flight capabilities would be limited and not in tune with the overall long-term goals of IHSF. Thus, India has to really assess it HSF rocket – especially in terms of capacity. One possibility is to leap-frog and develop a totally new launch vehicle in class of 20-30 tons payload capability – which will bring its technological status on par with the world. Design improvements to propulsion, structures, materials, manufacturing, avionics, software and analysis techniques can be new technologies that have to be developed for a cutting-edge launch vehicle for IHSF.

- **Crew Module**: The size, volume, and weight of the crew module along with the orbit chosen is critical in design consideration. The US Orion is slated for a 78k pounds lift-off weight with a 4 crew-module of 22k pounds (Apollo command/service module weighed 32k pounds at lift-off). Chinese Crew Module is said to be 14-20 tons at lift-off. Other crew modules having capacity for either 2 or 4 members weigh 10-12 tons. Many sub systems like control actuators are single–point–failure prone and calling for different design approach for the manned missions. Hence complex redundant sub systems in certain critical areas have to be developed. The response time for detection of failures and switch over to redundancies, either hot or cold, without cascading effect of any failure is the real criticality in launch vehicles.

- **Launch escape system** in case of any accident at launch pad: Planning of a launch escape system to escape on the launch pad from the main vehicle is essential. It has to be planned considering the risks involved during ground preparation and testing phases of the launch vehicle. Special consideration for the tests conducted after crew enters the crew cabin. The most important phase is the propellant filling and maintenance activity which usually goes on up to the time of take-off. Any leaks of the propellant in the launch vehicle before take-off is another criticality which should be addressed. The escape system should be able to take away the crew to a reasonable distance and properly land there. This requires more reliable thrusters and motors.

- Planning and feasibility of abort modes for any contingency during the flight: Abort modes have to be planned in the mission sequence to safely abort the mission and take the crew to a safe condition in case of malfunction of the launch vehicle during flight. The abort modes designed into Space Shuttle launch vehicle are very extensive and can be a guide to plan flight abort scenarios.

- **Environment control and life support system (ECLSS):** The planning of the ECLSS system is closely linked to the number of astronauts in a mission and duration of the mission in the Space. The oxygen to be carried, carbon dioxide scrubbing sub systems, the heat exchangers, and the waste disposal system are to be primarily designed for easy and reliable operation. The increasing threat of Space debris in the low earth orbits dictates the use of double walled crew modules to avoid depressurization of the cabin in case of collision with small debris.

- The systems and modules to maintain the **health and working condition of astronauts** in Space: The equipment needed for physical exercise of the astronauts like treadmills and jogging systems have to be designed for reliable operation in micro gravity. Maintenance of the health of the astronauts in Space largely depends on the training given on the ground, and the apparatus for exercises on board the cabin. The systems which will force blood circulation to the lower parts of the body are very important for longer duration Space flights.

- The **health management and emergency doctor consultation systems**: The tele-medicine systems have to be planned on board the crew module in the Human Space Flight for use in any medical emergency. Then the tele-medicine systems can be very effectively used in handling medical emergencies.

- **De-orbit and re-entry travel systems** (like propulsion, re-entry heat shield etc): The main propulsion system of the HSF crew modules should have good configuration with built-in reliability and redundancies. The mission management should also consider auxiliary propulsion systems as a contingency against malfunction of main propulsion system. The mission planning should also consider crew survival sub systems in case of a re-entry and landing on Earth in an unplanned location.

- **Safe landing systems**: The weight penalty, and risk of carrying propellant during reentry are to be considered carefully in designing the landing system.

Landing the crew module using parachutes, or by firing the clusters for soft landing is to be decided in this trade off.

- **Possible docking system**: The inability of the crew modules to execute re-entry safely is one of the biggest technical challenges. To avoid losing crew in such a situation is most difficult, and has to be planned right from beginning. With operational Space stations in orbit, and with International cooperation the best way for future Human Space Flights has to be standardized. This can be standardizing and planning a docking system in every Human Space Flight mission which is compatible with the orbiting Space stations. Such systems can come to the rescue of the astronauts in case of a potential crew–losing situation.

- **Astronaut Training Facility**: Astronaut selection and training would be a complex process of preparing selected Indians for their HSF missions before, during and after the flight. This would include rigorous process of selection and training - including medical tests, physical training, extra-vehicular activity (EVA) training, HSF procedure and process training, rehabilitation process training, simulations of operations, extreme scenario simulation tests, experiments training etc. Environments to be confronted during launch, in space flight and during re-entry and landing must be simulated and training modules generated.

3.3 *SOCIAL CONSIDERATIONS FOR IHSF DECISION*

Space activities have been attracting great public attention ever since the launches of Aryabhata and the Indian SLV-3, feeding much to the national pride and drawing appreciation of a broad cross section of Indians due to continued progress and consistent performance of the India's space programmes. This extensive public interest and support has also been reflected hitherto by the support of the members in Indian Parliament cutting across all party lines. From a societal perspective, the space agency and its activities had also earned enormous goodwill because of their focus on contributing solutions to the problems in society. Indians in different walks of life view ISRO as a model organization because of its long record of many successes.

Demographically India is in a unique situation with 50 % of its population below the age of 27 years. Even in 2030, the median age is expected to be 31 years. Indian youth aspire to find channels for demonstrating their extraordinary talents and are looking out to challenges, which can excite them. Hence unique opportunities and challenges present in human spaceflight calling for an extraordinary team work, courage and representation from multi layered social fabric and instrumental for winning a significant international recognition of national capability would be welcomed by the contemporary Indian society which is on a path to express its own characteristic role and relevance in the present globalising and interconnected world.

In balance to this likely social disposition, there are also huge challenges of social and economic transformation which place competing demands on financial and motivational resources in India. Till India is able to fairly tackle the problem of inequity that excludes a sizeable section of population to have access to basic needs and acceptable quality of life, the huge expense for human spaceflight will be highly questionable. Hence the society will critically weigh proportion of resources demanded and also likely results in these two different domains. It is fairly clear that human spaceflight will only fit into a transformed socio economic context of India. Fortunately there are many signs of that transformation taking place and its prospects too – India's reasonably consistent economic growth, government's thrust on programs that provide for basic needs and employment, emphasis on skill development and so on. Social transformation is also being accelerated as education is spreading and women are being empowered. In a scenario of rising aspirations, the constraints are making people more innovative. Space activities have been capturing the mind of Indian youth like no other endeavour. The demonstration of extending human capability/experience against inherent risk of very high order for exploring new frontiers in deep space or celestial bodies by a fellow national would create a compelling new identity in people. From a social perspective, human activities in space by fellow nationals will transform the way people look at themselves and their ultimate goals.

Indian society is endowed with cultural diversity that has imbibed timeless values, universal outlook and deep insights into internal world. Exploration beyond the near earth space and sharing of that experience through human connections has tremendous implication for our view of reality and it brings unprecedented opportunities for striking harmony of internal and external words. The prospect of establishing this harmony is a unique opportunity for India, whose cultural heritage had rich contributions to the science of human development.

Another aspect could be potentially significant from a social stand point. It is the message that space enables different nations to come together and work for a common destiny. This will resonate well with long standing Indian ethos of discovering ultimate Individual freedom along with universal well-being as a life's main quest. The exploration of outer worlds in a collaborative environment and expansion of human experience will reinforce the perception of global perspective in the minds of people.

3.4 ECONOMIC IMPLICATIONS

The IHSF by virtue of its own nature of goals, demands a long term commitment for resources for continuity over a horizon of two to three decades to achieve its lofty goals and also a strategic direction for evolving the program. As borne out by the experience of other agencies, the demand of financial resources for Human Space Flight programs would be of a much higher order as compared to other missions involving robotic spacecraft. Therefore, such long term goals and plans are to be divided into a few major phases that can provide for stage gating of resource demands which can be justified by tangible demonstration of capabilities in each major phase.

The investment demands for the human spaceflight will have to be matched by the objectives chosen for the program. It is borne out by experience of other nations that any single objective will not be able to attract sustainable long term support for such a program. Either the expected economic returns from new technologies generated or the strategic advantages of military nature could justify such long term expenditure. Neither that one could expect the allocation of financial resources, which will be a significant percentage of the government expenditure for the scientific nor cultural benefits expected. The expenditure is too huge for any of these objectives. During the peak period of Apollo missions, NASA budget even exceeded 4% of overall US government expenditure. In the other case of International Space Station, it is considered as a 100 Bi$ asset in space for the US.

Hence, the question arises as to what is that worthy goal which would be fitting to commit a nation like India for a three decade long program with progressively higher goals and milestones of accomplishment demanding nearly 0.5% of total government expenditure annually? That goal has to be lofty as an ultimate expression of human potential, and the one that can transform and widen the human experience. That exploration of new frontiers for alternate human habitations is a tough goal which can boost Indian image and recognition among the comity of nations. However, due to competing demands on resources and the progress already made international arena, such an endeavor has to be pursued by India as an international collaborative endeavor, driven by both national and international imperatives of the humanity's long term goals.

India's engagement of human spaceflight and exploration cannot be on a marginal basis but should be based on building capabilities in all critical areas of technology and also substantial value building. The economic implications depend upon the goals set for each stage representing a level of capability. Broadly these should include:

- Transformation of current and future launch vehicles for human rating
- Developing and operating a crew vehicle capable of supporting 'x' members of crew and capable of safe return to earth
- Capabilities for contributing to the modules of a Space Station and assembly
- Human / robotic missions to Moon/ Mars/ Asteroids in preparation to habitation, building outposts and resource exploration

Advances toward these goals would require substantial expansion of human resources in the space agency as well as personnel working in industry with higher level of skills. It is estimated that at the peak of activities, 5000 persons would have to be engaged in the space agency for spaceflight activities along with at least an equivalent number contributed by industry. Key developments should include Crew module with life support, human rating of GSLV Mk III and subsequently Modular Heavy Lift Vehicle, crew escape system, Integration, Assembly, and Test facility for the Vehicle, Crew Spacecraft Assembly facility, Mission Control Centre, Launch Control Centre, Communications Support, Cargo ship, Crew Training facilities and so on.

We tentatively estimate that for initial phases of the IHSF mission goals for LEO operations, the resource commitments to the tune of INR 500 to 700 Billion will be necessary. If one gets in additional goals of Indian habitation on moon and/or Mars the costs required would be atleast 2 or 3 orders more – say, over next 10-20 years.

4. OTHER KEY ISSUES FOR HSF DECISION

Considering the global context as well as national interests, it is necessary to identify India's own unique contributions to this long term endeavour. A strategy needs to be debated to achieve results in the fastest possible way preserving the key capabilities to be accomplished with indigenous efforts.

The national debate or the preparatory steps outlined, culminating in broader political consensus should confirm or modify the primary and secondary objectives

Considering that this program has a horizon of two or three decades, it is necessary to establish that choice of technical strategies like launch system chosen to be human rated would be relevant both cost, capacity and technology wise for the future, if the trends in global market (like plans of private actors) are considered. What the backup strategy would be needs to be drawn out.

Careful articulation of stage gating philosophy should be known. Key hierarchy of decision structure should be spelt – starting with rationales of sizing decisions of crew module, build or buy options and trade-offs.

Selection of Indians for astronauts will be an important step. Procedures and specifications for astronauts and a rigorous selection process is called for. Selection of Air-force Commanders are the closest process that one knows of similar nature – one could adapt and modulate the same to develop an Astronaut Selection Process.

Another aspect to consider would be what is the canvas Space Science programme for India – there can be considerable synergy in technology development for IHSF and Deep Space Exploration goals and space science missions. A strong scientific, cultural and political imperatives of exploring deep space is required and this can be taken up in tandem with long-term IHSF development. A rich agenda of scientific goals and exploration objectives could be four key destinations for human exploration namely the Moon, Near Earth Objects (like asteroids), Sun-Earth Lagrange point 2 (a point of gravitational equilibrium), and finally Mars. Such future steps will be coupled with robotic exploration, which can bring dramatic synergy with IHSF.

What organisation structures would be called for IHSF? Today, the national space agency (ISRO) has about 15-16k people involved and an additional 3-4k people involved in industry/academia. Thus, a 20k workforce is already active presently – against an annual spend of INR 700 billion. If IHSF would call for an additional spend of another 700-1000 billion then it is safe to expect that another 15k personnel would have to be involved – that is like doubling present human resource of national space agency. We are no doubt that IHSF would require yet another parallel HSF agency to be established. These would be quantum jump in resources that is invested – also bringing increased high-technology jobs. IHSF would need another ISRO added!!! This aspect needs to be considered.

5. INTERNATIONAL COOPERATION AND IHSF

The IHSF strategy could integrate with international programmes through collaborative approach and deriving synergies. This strategy could be meaningful to meet resource challenges as well as sustenance goals and at the same time allowing India to play a significant global role as equal partner with other major players and developing its own capabilities in IHSF.

6. PROCESS AND STEPS FOR DECISION ON IHSF

A robust process of creating the justification for initiating IHSF based on measurable direct benefits is required. At the same time the intangible benefits that could come from IHSF programmes could be convincing or not so convincing. Past experiences of creating a national justification for Chandrayyan-1 is a case in point and could be used as a model for IHSF too.

IHSF approval process must evolve through an elaborate process of consultation and justification with the scientific community, academics, the political system and the public media before this mission was given the go ahead. Such a national consensus process could involve:

- **Germinating the IHSF**: Preparing a comprehensive IHSF programme – including the vision, programmatic elements, outcomes with details of overall costs, schedule, international cooperation and important milestones. The national relevance and the capability assessment in the nation would be important. This could be a long-term strategy plan with sub-modules of development. A National Task Force on IHSF could develop the IHSF Programme National Plan and bring in wide range of experts from national space agency, industries, academia, polity, government and social sphere etc and make this germinating plan for the nation.

- **Broadening the Acceptance**: Consultation and Presentation of the IHSF National Plan to national scientific academies, engineering bodies, government agencies, industries, academia and even citizens through a series of consultation workshops and broadening the ideation. This process will ingest the interests of the government agencies, scientific and industry, academia community – thereby building a strong national and scientific/engineering justification.

- **Firming the Acceptance**: Wide Consultation with Polity and explaining to political system the scope and plan of long-term IHSF. Making the political system aware of the challenges, risks, costs and benefits, and firming the political justification.

- **Bringing the Astronautics justification** through the Astronautical community (in ISRO, defence, aviation etc).

- **Preparing the IHSF Feasibility Assessment** by detailing the national, technological, industrial, scientific and public perceptions.

- **Formal Presentation to Parliament on IHSF** through the Parliament Standing Committees and political sensitisation for the IHSF. This is where the costs vs benefits vs national determination gets firmed for the programme.

- **Defining the IHSF Programme** – detailing the total technical mission and programmatic details for IHSF. This can be coordinated through the National Task Force.

- **Expert Review of IHSF Mission/Programme** – subject the Programme details to an expert review and get technical and programmatic endorsement for the Mission.

- **Obtain the Programmatic approval** from the apex-body of Space Commission and the Prime Minister's Office for IHSF.

This process, spread out over months/years, could then culminate into a final national decision for IHSF to enter the new era of planetary exploration. This is also a good example of a practice of ethics of decision making in science involving consultation of a large cross-section of society and ensuring transparency.

7. CONCLUSION

India is at a crucial juncture at its post independent history to decide upon its long term engagement with the frontier of space and its steps towards human exploration of outer space in the capacity an emerging power in the comity of nations and a prospective leader of evolving human culture and harmony, as a collaborator of global community to expand human experience and explore alternate human habitation beyond earth.

The nature of the decisive steps in the above direction would involve deep implication for present young and future generations and it is important to set a process that will draw necessary political and public support for articulated long term goals with appropriate stage gating for resource allocations based on performances.

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We acknowledge that this paper has many infirmities that needs to be improved – but it is a beginning to bring to fore the large canvas of perspectives that have to be considered. We wish to continue to engage with experts in these fields can improve and flesh out more firm details – but to one needing the visualisation of larger canvas we have tried to cater.

We also acknowledge that we have referred large number of articles and public-domain material on HSF and we have adapted from these.

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