LAUNCH VEHICLE TECHNOLOGY DEVELOPMENT AND PERSPECTIVES

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Introduction

Over the past three and half decades since the beginning of the development of rockets for upper atmospheric research, ISRO has developed and tested four launch vehicles viz., SLV-3, ASLV, PSLV and GSLV. Of these SLV-3 and ASLV have been technology development platforms and PSLV and GSLV the operational launch vehicles. To date 8 PSLV launches and 3 GSLV launches have taken place. Excepting the very first PSLV, all the launches have been remarkably successful. The maturity of technology achieved through the development of these launch vehicles is sought to be gainfully employed in developing the larger GSLV MKIII for doubling the GTO launch capability to 4 Mg. Plus.

Having achieved the capability to service the needs of the nation in the launch of all foreseen application spacecraft, the question arises what next in the launch vehicle area. This is a common question facing the entire launch vehicle community around the world. There seems to be a need for paradigm shift on access to space. Globally two possible goals are spoken. One space tourism and two interplanetary missions and space solar power. Considering the recent successes in sub-orbital flights into space by spaceship one may say it will be difficult to compete with spaceship one unless something very substantially better at a comparable cost is offered by the LV community. Whereas the second aspect namely interplanetary missions and space solar power plants are hardcore requirements demanding superior capability at greatly reduced cost.

Costs

Currently in the international markets the cost of launching 1 kg of payload into GTO is about US $30,000. Our own cost, with all possible improvements in the payload capability will be about US $ 20,000 for GSLV MKII This is expected to reduce close to US $10,000 in the case of MK III. However the long term goal is generally taken to be US $1000 per kg. This is large reduction calling for innovative ideas.

Reusable Launch Vehicles (RLV)

As is axiom by now, one way of significant cost reduction is if the hardware which forms the single largest segment of the cost of a launch vehicle at two thirds (Fig.1) can be recovered and reused say hundred times, the per kg. Cost can reduce to one third of current cost. Similarly if the semi cryogenic propulsion is adopted with Liquid Oxygen and kerosene as propellants, the total cost reduction can be to the tune of 75 percent. However further cost economy can be achieved only through reducing other costs such as management, services and much improved payload capabilities to achieve economy of scale. Overall there are possibilities to reach quite close to the target value of US $ 1000 per kg.

Development of Reusable Launch Vehicle

The definition of reusable launch vehicles have been exercising the minds of the LV community for close to two decades. Various combinations of single and two stages with different take-off and landing modes have been proposed (Fig.2).

However with the demand for a structural factor better than 8 percent to achieve positive payload capability has put paid to these early dreams. To achieve this structural factor we need materials which are one order stronger and stiffer. May be the single wall nano tube (SWNT) composites will some day meet this goal. As the development such exotic materials will take few more decades, the SSTO may be practicable in 2030 to 2050 time frame (Fig.3).

As a logical next option two stage to orbit seems to near term goal, as the structural mass fraction of the order of 15 percent as in the case of percent LV’s are acceptable. Thus two stage to orbit (TSTO) is the configuration of next generation LV’s (Fig.4).

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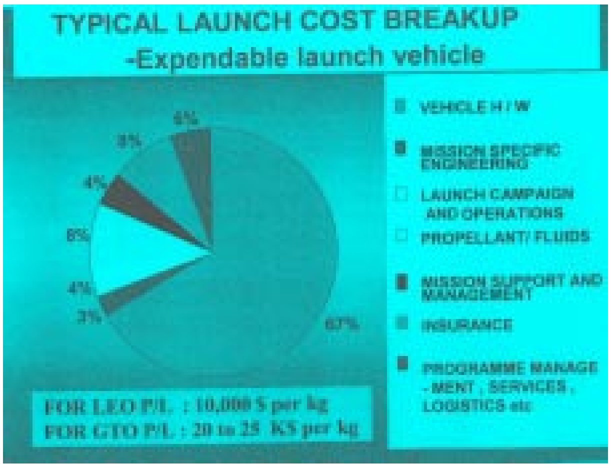
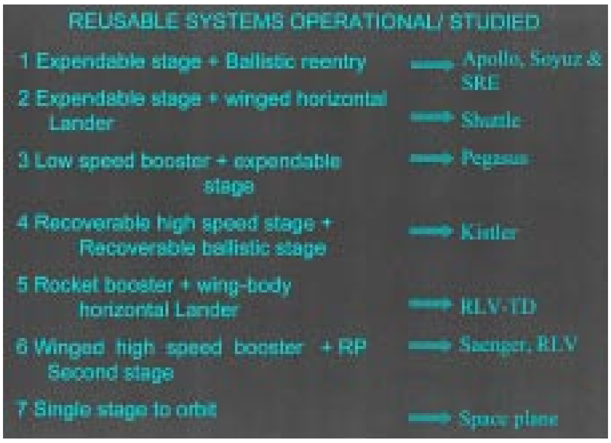


Fig.1



REUSABLE SYSTEMS OPERATIONAL/ STUDIED

1 Expendable stage + Ballistic reentry ⟶ Apollo, Soyuz & SRE

2 Expendable stage + winged horizontal Lander ⟶ Shuttle

3 Low speed booster + expendable stage ⟶ Pegasus

4 Recoverable high speed stage + Recoverable ballistic stage ⟶ Kistler

5 Rocket booster + wing-body horizontal Lander ⟶ RLV-TD

6 Winged high speed booster + RP Second stage ⟶ Saenger, RLV

7 Single stage to orbit ⟶ Space plane

Fig.2

Propulsion System for TSTO

The next question to be decided is the propulsion system, which the second most critical factor. There have been proposals in the past on air breathing propulsion as a viable option. However for a launch vehicle whose primary purpose is access to space, pure air breathing seems to be of limited use. There is the initial acceleration phase to reach mach 2 plus to enable start up of the Ram/Scam jet propulsion. Again when the craft leaves the atmosphere, it must have both oxidizer and fuel on board, which needs rocket propulsion. Thus it is seen rocket based propulsion is essential both initially and certainly when we leave atmosphere. Thus by and large all space agencies have come to the conclusion that Rocket based two stage to Orbit vehicles are The viable reusable launch vehicles in the near term and can be operationalised between ten and twenty years.

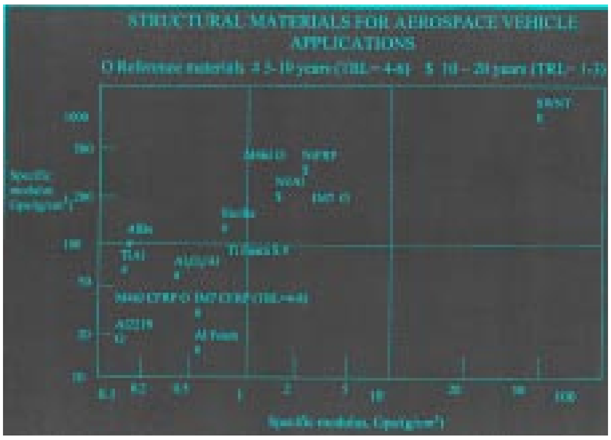


Fig.3

Fig.4

There have been a strong school of thought in India that if air breathing phase of the flight can be combined with air liquefaction may ideally suit the twin purpose of accelaration in the upper reaches of atmosphere and the liquefied LOX along with the stored liquid hydrogen will meet the exo-atmospheric propulsion requirements most effectively. It is hoped in the long term scenario of the SSTO, this technology also will become feasible. If so a highly efficient transportation system to space is feasible.

How do we Achieve TSTO

The booster stage of the TSTO is going to be lifting and vehicle to be fully and automatically controlled. The flight regime is going to cover from high hypersonic mach numbers to low subsonic mach number. Thus there is large regime of flight, the knowledge about which is very inadequate. Therefore the initial focus has to be on hypersonic aerodynamics and aero thermodynamics. This may call for a good reasonably sized hypersonic wind tunnel followed by a carefully planned series of flight tests in the hypersonic regime using a technology demonstrator very much like SLV and ASLV.

The second question to be addressed is the materials for both high temperature usage and as thermal protection systems. Basically there are three regions viz., the leading edge and nose caps which are subjected to very intense heating, the windward side with moderate heating and leeward side with much lower heat input. These requirements can be met by carbon-carbon composites, if required with SiC protective coatings for the leading edges, silica like based systems for the windward side. Flexible ceramic felt based systems will meet the leeward side requirements. This shall be later replaced by ceramic matrix composites, metallic hot structures or carbon foam based composite structures. However in each of these areas, we need to initiate and progress a focused development programme (Fig.5).

Manpower - An Area of Great Concern

The futuristic and ambitious space programme in RLV area calls for highly competent manpower. Of late this has become an area of great concern. The problems is one of distorted salary structure prevalent in India since the beginning of the software boom. Even earlier the cream of manpower to some extent was lost to purely managerial roles in consumer product sector and central services. In most of these areas, I am sure one is underemployed vis--vis the inherent intellectual capability one may possess. This distortion has become even more acute with advent of the software industry. Yes there are challenging tasks in developing hardware and software products with engineering and process applications in business, health and management sector. However software products from India are known for their absence absence than presence. This is thus the hardware engineering sector is starved of competent manpower which is a fundamental requirement to plan or even dream for a globally competitive role for Indian aerospace industry.

Can we beat the salary problem. To me this looks feasible. Today an engineer, thanks to the software engineering tools, is far more productive than that three decade back. This multiplier effect on the productivity has not been adequately recognized, understood and factored into the salary structure. Thus it would not be out of place to say that a software tools enabled young engineers can easily replace three or more engineers of old times. This in other words means that he can be paid thrice the salary too. If we do this then the attracting talent does not look difficult.

Fig.5

How do you do this in an existing organization with a large percentage of existing staff. This may be feasible through skill up gradation of the existing staff to the extent possible. Where such skill up gradation becomes rather difficult, the introduction of a new organizational structure may be feasible. This can be done through creation of subsidiaries or farming out the jobs to private enterprises to be established in the area of design, and analysis of aerospace systems. It s to be noted that in the automobile sector large scale contracting to India in design and analyse is going on in a big way may say between Detroit and Bangalore. The nature of work and software packages involved are not very different.

There is also urgency in the area of skill transfer. In sixties and seventies, the halcyon days public sector large manpower pools were created in units like HAL as also ISRO. This generation at the end of three decades of active service have acquired tremendous engineering skills. It also happened that there has not been significant addition to manpower over the years except may be in nineties under the LCA programme or mid eighties under PSLV programme. Thus there is imminent danger of the loss of the engineering heritage as and when the PSE elders retire from service. This is a challenging task. We however see some examples of these elders bonding together and carrying on the job under contract mode. May be there is a need for these PSE elders to join with the private sector youngsters and work together in ensuring the skill transfer and skill enhancement.

Infrastructure Creation

Efficient and quantity production are an essential requirement to meet market oriented demands of value for money and assured schedules. Thanks to the enlightened planners of ISRO starting with the SLV programme in the seventies a decision was made that what can be done in industry will not be done in-house. Accordingly all structural hardware manufacture both using steel like in motor cases in high strength steel and interstage structures in aluminium alloys were contracted out. What was retained in-house were the composites, avionics, propellant casting and pyro devices. As ISRO embarked on operational programmes like PSLV, and GSLV, this principle was adhered to even where new infrastructure has to be created with funding support from ISRO. Various examples are the light alloy structures facility and the propellant production. First time avionics production was also farmed out through creation of space electronics division in a public sector undertaking. Thus by late eighties, quality production of both PSLV and GSLV were enabled. Currently actions are on with reference to enhancing the production capability further to produce 5 to 6 launch vehicles per annum. Also to enable the increased number of launches, delivery of fully integrated stages are being contracted out. Together with the facilities augmented by in-house capital expenditure and capital funding by ISRO notably in public enterprises will form an adequate industrial base towards the commercialization of the currently operational launch vehicle. Towards the development and supply of the Mark III GSLV similar approach has been adopted.

One other important aspect that needs to be highlighted under infrastructure is the indigenisation of critical inputs. On hardware side import of large number of ring forgings have been a concern. A private company near Chennai has now established a large ring rolling mill which shall meet all of ISRO's requirements. India is also dependent upon foreign sources for the aluminum alloy products like sheets, plates and bars. Here also concerted action is being taken to augment the infrastructure in an Indian Industry which will lead to meeting the bulk of the requirements indigenously in the near future.

On the avionic parts also action has been mounted over a period time to indigenise. Standardisation and building ASIC based systems have been adopted to replace microchips. Essential hardware for signal conditioning connectors, cables, fasteners etc. all have been substantially indegenised. ISRO has also been from the beginning following development of propellants and other chemicals and productionising the same through industries. Many space craft materials like thermal points, metallised mylar films, special magnets, heat pipes, magnetic torquers etc. have been indegenised. Another area of special mention in indigenous capability is to build optics required for various payloads. All these enable India to stand on its own feet and offer a comprehensive end to end to product to customers in the expandable launch vehicle and spacecraft area.

The same diligent planning is called for when we embark on the reusable launch vehicles. Considering everywhere work has commenced in the RLV only recently, we have for first time an opportunity to work in a contemporary time frame and develop the required technologies, infrastructure required and try to be the first in the market place.

Development of Technologies

The core strength of ISRO has been the inhouse development of technologies in the area of launch vehicles, spacecraft and ground stations. This has been possible through the steadfast commitment in this aspect. Two most notable examples are the inertial sensors and electro optical sensors including the optics. Today the launch vehicles are equipped with inertial system with unprecedented accuracies as demonstrated in the GSLV F01 mission. Similarly the momentum wheels, solar assembly drives etc. are being indigenously produced and used. Similarly all onboard sensors of the spacecraft like earth, solar and sensors are indigenous. The large optics required for the remote sensing satellites in the area of cartographic applications are made indigenously.

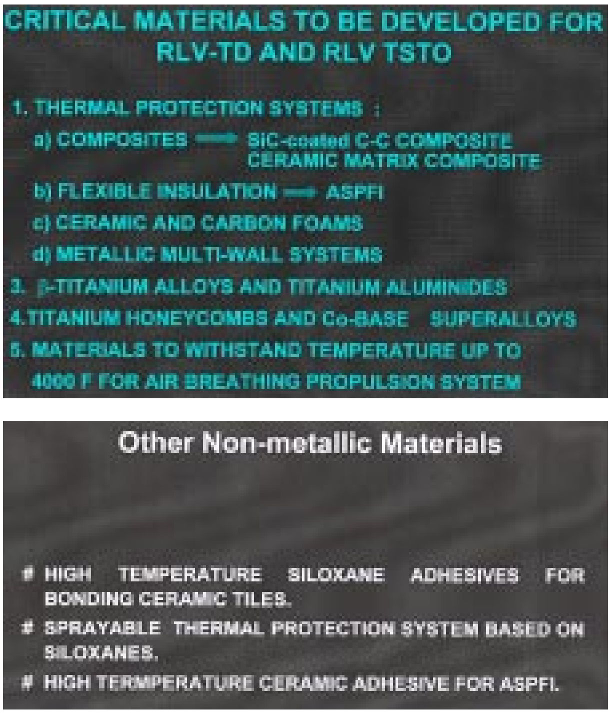
Another area of great importance is the spacecraft thruster including the apogee motors. Both bipropellant and monopropellant systems have been developed. The performance of the systems has been bench marked to those achieved elsewhere and found to be matching. The entire system consisting of the tanks, the propellant acquisition system, regulation valves etc. are designed in-house and parts production is realized through the industries. This is also one area wherein ISRO has been successful in exporting to other spacecraft manufacturers. Thus there is a well laid out policy framework towards the development of indigenous technologies.

The future directions in the launch vehicle towards the reusable launch vehicles is critically dependent on the availability of high temperature and heat resistant materials like hot structures, rigid and flexible thermal protection systems etc. These will employ materials like Titanium aluminide, Colombiam, in diffusion bandedstructural configuration. The carbon carbon structures with and without silicon carbide coatings are required. In critical applications we may have opt for ceramic matrix composites starting with carbon - carbon and impregnated with liquid polymers followed by high temperature sintering. For extremely high temperature applications like flame holders in air breathing propulsion, we may need ceramics like Zirconium boride. Thus there is very large work pending in the area of advanced materials. ISRO has been very active in the development of materials in the past like maraging steel, titanium alloy, special magnets, catalysts, polymers and chemicals etc. It is expected that this activity will gather further momentum to fulfill the requirements of reusable launch vehicles (Fig.6).

The development of RLV also calls for developments in hypersonic aerodynamics. ISRO is already planning to generate necessary infrastructure like a wind tunnel. ISRO has also developed a strong base on computational fluid mechanics. There is also a graded technology build up effort through a ballistic re-entry vehicle followed by flight experiments in the area of RLV's to build up the design base in a well graduated manner, each step specifically addressing a particular aspect of technology leading to building a truly operational vehicle.

The other related areas like structural design and analysis, control actuators, avionics, simulation techniques etc. are within the current capabilities of ISRO. Few aspects like air data acquisition, aided navigation also have to be integrated and tested out.

Overall the technological challenges are within the capability ISRO and other supporting institutions in the country. The needs have been already reorganized and actions are initiated in creating the core teams with appropriate facilities towards development.



CRITICAL MATERIALS TO BE DEVELOPED FOR RLV-TD AND RLV TSTO

1. THERMAL PROTECTION SYSTEMS :
    a) COMPOSITES ⟶ SIC-coated C-C COMPOSITE
        CERAMIC MATRIX COMPOSITE
    b) FLEXIBLE INSULATION ⟶ ASPFI
    c) CERAMIC AND CARBON FOAMS
    d) METALLIC MULTI-WALL SYSTEMS
3. β-TITANIUM ALLOYS AND TITANIUM ALUMINIDES
4. TITANIUM HONEYCOMBS AND Co-BASE SUPERALLOYS
5. MATERIALS TO WITHSTAND TEMPERATURE UP TO 4000 F FOR AIR BREATHING PROPULSION SYSTEM

Other Non-metallic Materials

HIGH TEMPERATURE SILOXANE ADHESIVES FOR BONDING CERAMIC TILES.
SPRAYABLE THERMAL PROTECTION SYSTEM BASED ON SILOXANES.
HIGH TERMPERATURE CERAMIC ADHESIVE FOR ASPFI.

Fig. 6

Conclusion

The time tested mode of development of launch vehicles through inhouse technology and the external production augers well for the future programmes of ISRO like commercialization of operational launch vehicles and development of RLVs. With the continued funding and policy support of the Government and people of India, future growth and success is assured.