Peering into the future of Propulsion from the past

- A description of the past – Hybrid propulsion
- Propulsion systems – handling instabilities – a challenge
- Solid propulsion
- Recent progress on solid propellant modeling – steady and unsteady and what is needed?
- "Brave (were we so in the past?)" new thoughts for the future – the role of hybrids

H S Mukunda,
PJP memorial workshop, 27, 28 Feb 2016,
VSSC, Trivandrum

Hybrid propulsion in the past

- At IISc, research and development was conducted on hybrid rockets between 1970 – 1980 as a part of two ARDB projects for storable hybrids (RFNA – special compound coated rubber) and LOX – rubber semi-cryo system
- Based on literature examination, the projects aimed at seeking the lowest cost "safe" propulsion system as possible high energy options.
- Fuel burn rate dependence on mass flux and pressure were researched (Prof Paul's Ph. D thesis was on this subject) and test-firing systems with data acquisition were performed.
- Based on the knowledge base and analysis of options for large size rockets, a proposal was made to ISRO for them to benefit from these ideas.
- Even though some research was being done in VSSC, our proposals were not considered favorably.
- Thus, this R & D died a quiet death (even if it resulted in half-a-dozen publications)
- Ideas on resurgence were floated as a part of "low cost access to space" in 1998 - more of it later…

Propulsion systems – handling instabilities – a challenge

- 1976-77 With ISRO – High Altitude Test facility instability problem at SHAR range on Diesel-turpentine + RFNA based rocket system for generating hot gases (Ayyappan Pillai, VSSC and Annamalai, SHAR)
- 1976 – 1978 VIKING liquid engine instability related issues with LPSC, VSSC, ISRO (Ayyappan Pillai)
- 1978 – 1985 Valient engine instability issues – DRDL, Hyderabad (Venugopalan, P)
- 1978 – 1982 Instability in hybrid rockets (P. J. Paul's Ph. D thesis included this aspect); Biju kumar's thesis (PJP supervisor) was on LOX- LH_2 instabilities
- 2011+ Instability problems in solid rockets – DRDL – started initially as a review committee chairman and became obsessed as a student of the problem – Varun, IITM as a partner…more on this subject later……

Solid Propulsion - 1

- In early times, ISRO was so strongly biased towards solid propulsion that liquid propulsion development had considerable hick-ups.
- The choice of the binder went through several changes PVC, PU, PBAN, PBAA, CTPB and finally HTPB much like in the international scene.
- I am familiar with burn rate studies and attempt to understand the role of additives by Athithyan both at Veli hills (PED) and SHAR.
- These were essentially fits to get to a composition that would be close to the desired one.
- Aluminum (30 to 40 microns) at 17 % solid loading for achieving high I_{sp} posed no issues of instability (Issues of nozzle erosion in steady operation were handled relatively easily)
- ERDL, later HEMRL is concerned with a variety of compositions for tactical rockets – burn rate control, mechanical integrity at high g, doing away with Aluminum in part or a whole lot were the issues they faced.
- Propellant design has by and large been apothecary – intuition and decision of the divisional head with trial and error approach playing a major role.

Solid Propulsion - 2

- Pursuing the longitudinal instability problems on tactical rocket motors at DRDL led Varun and me to look at very difficult open questions to resolve.
- These concern origin of instability and a phenomenon known as DC-shift that needs yet a satisfactory explanation.
- Earlier attempts at explanation by Culick and Flandro credit this to non-linear wave propagation mechanics without addressing energy generation mechanisms that lie in propellant combustion process.
- On a careful consideration of the physics, this led to thoughts of the refinement of the steady burn rate modeling of composite solid propellants.
- Work on model development using literature information, earlier work by Raama (PAR) and experimental data augmented by those in cooperation with PEL has resulted in substantial progress in a matlab run model to offer it as a tool in development of propellants
- Much like reactive CFD in combusting flows, it is suggested that one can use this as a development tool. More on it by Varun later……

On CATS – Cheap Access –to- Space

1. India is involved in several new developments – RLV test, Multi-satellite launching operations (commercial) with PSLV, Moon mission, Mars mission, and Venus mission (not yet?)
2. Some of you remember I was not exactly a "fan" of moon mission in 2000-2001. I do not regret it even now. Raama (Prof. Ramakrishna) had organized a lecture titled "Can Mukunda defend himself…." at IISc around this period.
3. The point I had made was that there is an even more important national mission of international significance, namely low cost access to space that must be put on "high importance" mode.
4. What I argued for those days appears to have become now an international paradigm (CATS = Cheap Access To Space).
5. The key question (for each nation) to ask before itself is how much of Science mission and how much of Technology mission. Both are connected but not strongly.
6. For DOS (or DRDO), I strongly argue that technology mission must subsume science mission and not the other way around.

Further on CATS

From: "America's Space Futures: Defining Goals for Space Exploration", *Marshall Institute "What's a space exploration program for?"*, ***The Space Review, January 6, 2014***

- "In the 21st Century, an aptitude for commercial space is a distinguishing feature of nations, that are, or will be, great in space.
- Whichever country achieves cheap access to space first will start a virtuous cycle that will deliver tremendous economic and security benefits to that nation.
- This nation will dominate the carrying trade and create new markets, which will drive new technologies and new capabilities, which will increase flight rates and lower launch costs, which will allow that nation to expand into more new markets.
- Thus a virtuous cycle begins. CATS is the connection between space commerce and space power. "
- This was what I had identified in 1998 as the single most important aspect.

A few bits from history…because history repeats itself

- In 1905 America (Wright brothers) showed the way to fly autonomously through science and repeated experiments.
- However, even after repeated demonstrations of world leadership, US ignored it till 1911.
- However, after flight demonstrations in Paris in 1908, the entrepreneurship in France got ignited and they invented many critical aviation technologies - fuselage, wheeled landing gear, aileron, rotary engine, and stick and rudder control system, added to the Wright Brothers' innovations and quickly captured world leadership. Others in Europe also did their bit and all this fast-forwarded their contribution to aeronautics.
- By WW I – 1914, France was a World leader in aviation. It had spent 8 M$ at that time (Europe 16 M$) and US, about 2 million USD!
- However, US recovered its leadership from about 1925+ with Boeing in place.
- Boeing accounts for 12000 commercial airliners, France 8000, Others 3000!
- Safety and reliability (comfort, of course) are primary features.

- **Leadership for doing this class of wook comes from doing new stuff with intensity.**

In recent times

- The X-prize (Ansari Prize) foundation and SpaceShip1 that won the prize in 2004 for going to 100 km from ground and returning safely after reentry using an air-breathing engine and a hybrid rocket.
- **From Scientific American, Oct 2014 –** "Looking back on that historic moment 10 years ago, it's clear that theAnsari X Prize was a huge victory for the winners, but it is also the success story of X Prize Foundation chairman Peter Diamandis and the power of his Steve Jobs-like ability to bend reality to his will"
- **SpaceShip2 failure, Nov 2014 - T**he aerospace company Scaled Composites, which built the spacecraft, also "set the stage" for the accident through its "failure to consider and protect against the possibility that a single human error could result in a catastrophic hazard to the SpaceShipTwo vehicle.
- **On Feb 20, 2016**, Virgin Galactic sought to move on from that accident in and put the company firmly back on a path toward delivering tourists to the edge of space by unveiling a new version of its spacecraft named VSS Unity.
- **I think we should do better because even they knew what they had was not a high performance system. Also SAFETY must be of main concern.**

Old-New ideas on CATS

Thoughts based on earlier work…….

Studies on an aerial propellant transfer space plane (APTSP)

N. Jayan[1], K.S. Biju Kumar[1], Anish Kumar Gupta[1], Akhilesh Kumar Kashyap[1], Kartik Venkatraman[*,2], Joseph Mathew[2], H.S. Mukunda[3]

Acta Astronautica 54 (2004) 519–526

Essential ideas

- Space vehicle must function like aircraft in terms of safety, take-off and landing operations.
- This implies it must be an SSTO (single stage-to-orbit vehicle)
- Horizontal take-off – wings providing reasonable L/D ~ 4 to 5.
- Uses conventional aircraft turbo-fan engines for within-atmosphere operations
- For the space segment needing a rocket, it must use the most safe rocket, namely, Hybrid rocket.
- What is carried from ground to an altitude of say 10 to 12 km is only a polymer based fuel (Aluminum not excluded) in the combustion chamber.
- Oxidizer is LOX (or H_2O_2). It need not be carried from ground.
- LOX (or H_2O_2) can be transferred aerially (that is why APT – aerial propellant transfer), this feature reducing the take-off weight (idea originated from Joseph and Kartik).

The mission profile

An example:

10 tonne payload
400 km Low Earth Orbit
Structural factor 15 % with possible reduction to 10 %.
Payload fraction 2 %

Propellants for this study – LOX – LH_2 (full cryo)
Aerial refueling of LOX by KC 25 class aircraft

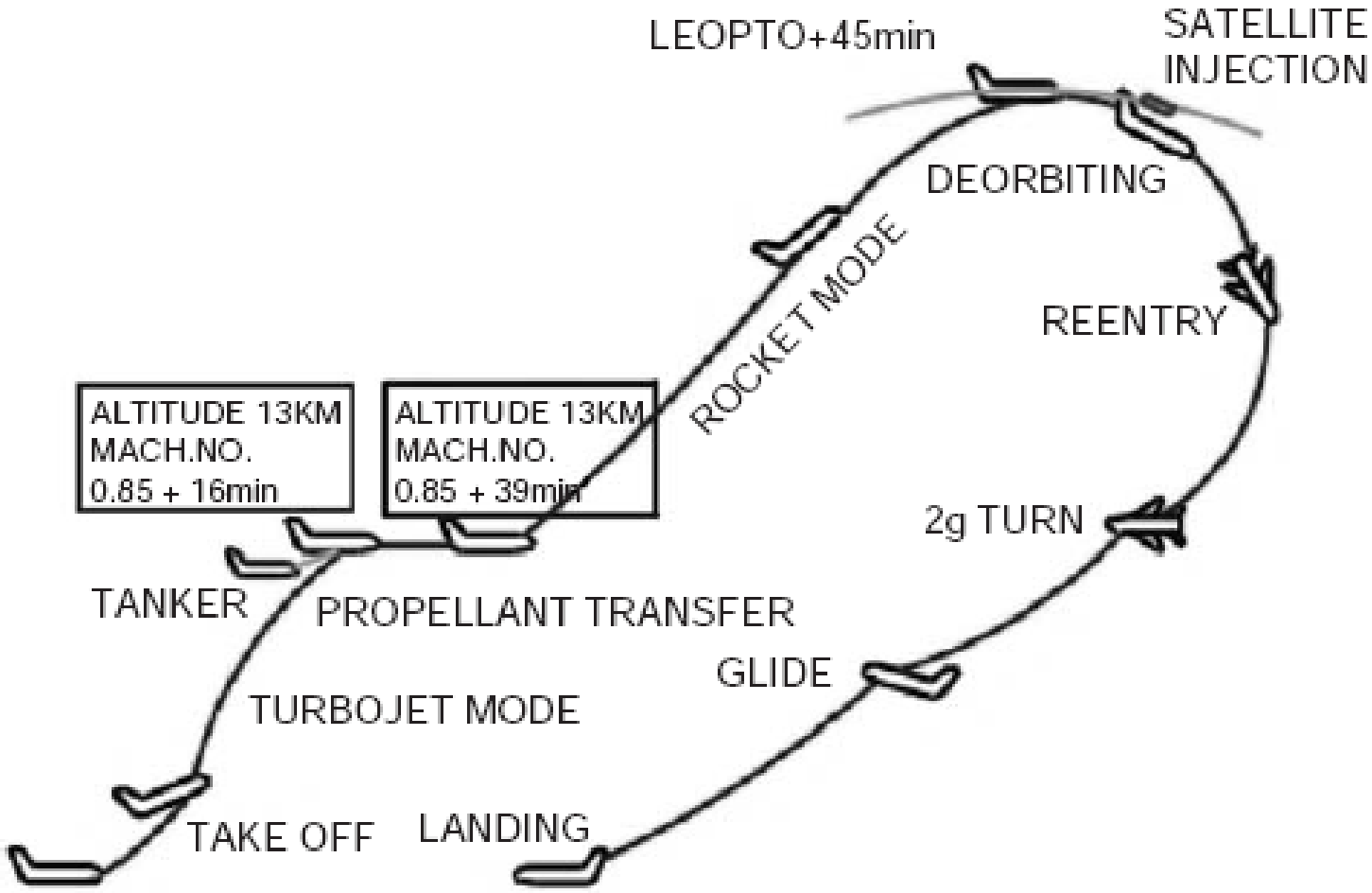
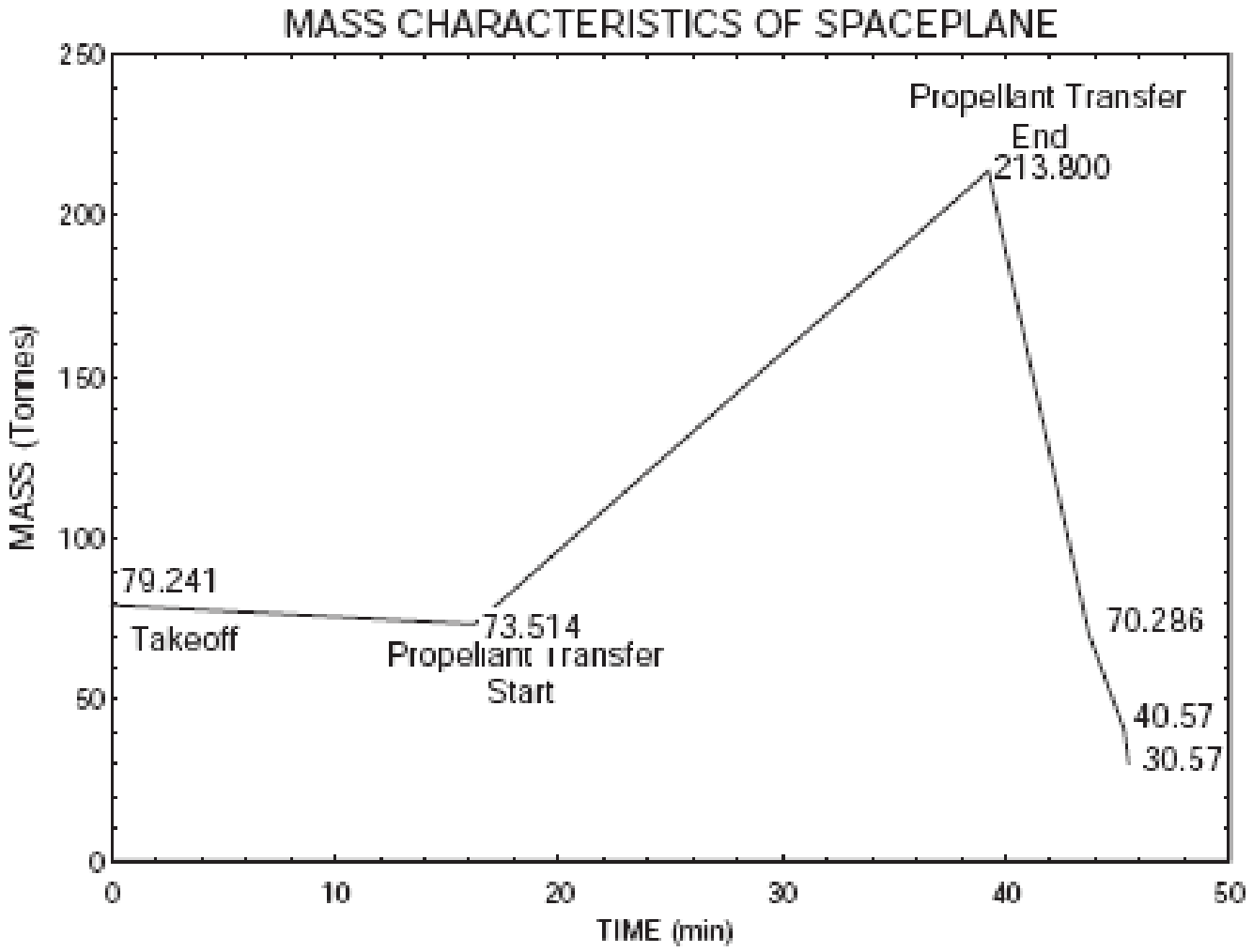


Fig. 1. Mission profile of APT spaceplane.



Further exploration of the design should be performed using Hybrid rockets whose performance has some minuses, but some pluses too -

Density of the rocket fuel is very much higher than LH_2. but I_{sp} lower.....

Structural factor reduction?

Boeing says its 3D printed microlattice is 'world's lightest metal' Oct 15, 2015 | By Benedict

- Boeing released a short film demonstrating the huge potential of their unique 3D printed micro-lattice material, which is said to be the world's lightest metal. The material with a density of 0.9 mg/cc, is a metal micro-lattice made of interconnected hollow tubes, which makes it extremely resilient against compression and affords it a high level of absorption.
- 3D printing technology is used to create the groundbreaking metal. The essential architecture is formed using a template using a photosetting photopolymer cured with UV light that creates a 3D form composed of struts and supports. The template is then plated with ultra-thin, electro-less nickel.
- The thermopolymer template material, previously supporting the structure, is removed by etching, leaving only the metallic skin behind. Boeing wishes to use the ultralight material in their aeroplanes, where it could be used for wall and floor panels and other non-mechanical parts. The trick is to fabricate a lattice of interconnected hollow tubes with a wall thickness of 100 nanometers (0.1 micron)

Summary

- As you see, while old technologies like semi-cryo still await development, there are new ideas to pursue that can place India in a different league on the international scene – much like France was and is vis-à-vis the USA
- Many new ideas on materials have come in – metal micro-lattices and it would be conceivable that the structural factors will be brought down
- Mission studies and development of sub-modules could be undertaken

- Meanwhile solid propellants will continue to be with us and it is better to get greater control on burn rate prediction strategies.
- Technology mission should be on the forefront with ISRO/DRDO.
- There are other non-chemical based technologies on the horizon. One should not ignore them.

.....Thank you