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APPLE in Retrospect

RM Vasagam

It is a momentous occasion when we are celebrating fifty years of space activities in India. As one who was fortunate to join the Indian space programme in its formative years and also had the opportunity to lead APPLE, India's first geostationary experimental communication Satellite Project during 1977-83, I would like to highlight the challenges and exciting moments of the project from concept to completion. APPLE was an acronym Ariane Passenger PayLoad Experiment and it was based on a free launch opportunity on the Ariane launch vehicle under development by European Space Agency (ESA) in the 1970s. APPLE made India to master the state-of–the-art technologies in satellites for space communication missions as well as technologies for Earth observation and scientific satellite missions.

The project, conceived in 1975, chosen by ESA from among seventy-two competing proposals in 1976 and approved by Government of India in May 1977 with thirty months' time schedule and Rs 21 crore outlay, culminated in launch on 19 June 1981 from Kourou, French Guiana atop Ariane LO3.

APPLE was designed and built as a sandwich passenger carrying Meteosat on top and CAT (Capsule Ariane Technologique) module below. APPLE incorporated integral orbit transfer and orbit and

attitude maintenance propulsion systems, three axis attitude control system with momentum wheel and Sun and Earth sensors, driven deployable solar panels and nickel-cadmium batteries, carbon fibre face skin antenna, honey comb deck plates, multilayer thermal blankets and optical solar reflectors for thermal control, C-band communication transponders and VHF tracking, telemetry and command system. Judicious choice was made for using space-proven and indigenously developed systems compatible with the tight time schedule of thirty months. The C-band communication payload compatible with Satellite Telecommunication Experiments (STEP) infrastructure was planned to carry out advanced satellite communication experiments beyond SITE and STEP using ATS-6 and Symphonie satellites.

Structural tests including combined stack tests, thermo-vac tests mission and software activities and control systems simulation were all done at hectic pace. In all, five-and-a-half models were built for structural, thermal, engineering, proto- flight, flight and flight spare purposes. APPLE development plan spanned over six years. Many work centres were involved in the project (see figure at p.274).

There were moments of successes and setbacks in this project. The project activities were taking place at all ISRO Centres and also in all continents. Please note that this was at a time when only telephone and telex were available for domestic and overseas communication and that too you had to book and wait for your call to come through. Same was the story for mission operations. You had to hire dedicated link from OCS (Overseas Communication System). As ISRO did not have enough mainframe computers, the computing time needed for structural, thermal and mission analysis could be met only through our engineers availing the night hours at IISc, IIT Madras and TIFR! Our means of realising the hardware were centred around HAL, BEL, ITI and ECIL, setting up the three-in-a-batch solid motor casting facility at SHAR, enhancing Vibration Test Facility at STEX, High Altitude Test (HAT) facility for solid apogee motor tests (with steam generation capacity equivalent to 200 MW thermal power station and based on nitric acid,

diesel and water rocket) and setting up APPLE Mission Control Centre at Sriharikota were posing great challenges all the time. The development of tribology laboratory for momentum wheels and solar array drives, carbon fibre antenna and honey comb deck plates, and Vacuum Ignition Testing Facility at VSSC were taken up with exemplary speed. The facilities at Space Application Centre for building the payload and antenna tests were equally difficult to come through. Thermo-vacuum chamber of 4 m diameter at ISAC was to be ready for thermal model testing and also for tests on proto-flight and flight models. We can look back with satisfaction that everything was accomplished in time with less than 5 per cent escalation, well within the contingency provisions.

More than that, we met the demands of ESA. In case the flight model of APPLE was not ready in time, we were to launch the flight-worthy structural model stored at Toulose, after composite stack test, which would be returned to India only after the launch. What a shame it would have been if we had not delivered the flight model on the agreed date? We also had to set up an independent safety office in ISRO. We did the coupled loads analysis for the first time! Transporting of solid apogee motors on aircraft and its storage in France, moving it to Kourou later, transporting Indian-made hydrazine to Kourou by ship, etc., were things accomplished against great odds. Air India had been our carrier but at a critical moment we were facing difficulty of getting the chartered aircraft to come to Toulose to carry the spacecraft to Kourou owing to violation of Lome Convention of 1975. Kourou being a French overseas territory, we had to engage Air France! But it turned out to be cheaper! During launch the Australian Post, Telephone and Telegraph workers went on strike severing our redundant overseas communication link from Kourou. For every one day delay in launch on our account, we would have to pay 100,000 Francs penalty! At Kourou we had the CNES staff strike jeopardising the launch schedule. But the French military personnel came to the rescue and manned the facility. The only problem was that we had to move around with passes and passwords even at the launch tower! Further we had to pray for success of the third developmental launch as the second

developmental flight ended up as a failure in boost phase itself (on recovering the hardware from Atlantic ocean it was later found to be attributed to a piece of cloth in the engine assembly).

APPLE had an anomaly. One of the solar panel did not deploy and the mission team evolved the operations plan in real time and succeeded. While one panel power was sufficient for operations in geostationary orbit, problems arose in thermal management. With one half of OSR (Optical Solar Reflector) blocked, we had temperatures rising and finally we had to do pitch rotation to even out the Sun load for four months around the winter solstice. The reacquisition of Earth was hampered by scintillation problems.

The successful functioning of the transponder was tested using a live dance programme signal sent to and received from the satellite. The time delay for nearly 80000 km (to and fro distance to satellite) is about 270 milliseconds. APPLE transponder also transmitted Rabindranath Tagore's dance drama Chitrangada. While characterising the end-to-end performance of the APPLE communication link, it was our own way of blending the best of the East and West!

APPLE was dedicated to the nation on 13 August 1981 by then Prime Minister Indira Gandhi. It was again a unique experiment and an experience to all when the APPLE development team members, assembled at the Vikram auditorium at Space Application Centre, were introduced to the Prime Minister by Satish Dhawan, then Chairman ISRO, present at New Delhi Earth station, through two-way videoconferencing – one half of the screen showing the Delhi Earth station scene and the other half showing Vikram auditorium! APPLE development story was telecast to all metros having TV stations and relayed through transportable terminals as well. But it was black-and-white TV as colour television came to the country a few years later during the Asian games. The Prime minister symbolically handed over the model of APPLE to the Minister for Communications and said that APPLE marked the 'Dawn of India's satellite communication era'. The Prime Minister's address to the nation on 15 August from the Red Fort was carried live to the country by APPLE.

The APPLE spacecraft was utilised for more than twenty-seven months in orbit and was used by ISRO and Telecommunication Research Centre of P&T for conducting advanced satellite communication experiments like TDMA, SSMA, computer networking, telemedicine, teleconferencing, tele-education, emergency communication and disaster mitigation, hook-up for national events using mobile and transportable terminals.

A moving experience happened when APPLE was harnessed to link Gandhinagar Secretariat and Amreli District Collector's office when the entire road and communication network collapsed due to cyclone hitting Amreli district. With emergency communication terminals at both the places and ESCES acting as a hub to achieve the link margins, more than 50,000 messages (from the birth of a child to bereavement to postponement of betrothal) passed through APPLE for 10 days. The Chief Minister of Gujarat came to SAC for thanksgiving and he said, When we gave our land at Jodhpur Tekra for ESCES we never knew that it is going to be extremely useful in our times of distress. You are our friend in need.' Similar was the experience during a volcanic eruption at Andaman Islands. Real-time interbank reconciliation performed with SBI Bombay and Calcutta branches using rooftop terminals, printing of *The Hindu* newspaper at Bangalore (using APPLE link and Chengalpat Earth station acting as hub and jeep-mounted small terminals at Madras and Bangalore of *The Hindu* office) with much less error compared to microwave links were some of the experiments paving the way for dedicated operational systems.

Another experiment of great interest was for tracking the location of wagons of Indian Railways, the major source of earning for them. APPLE was also used to conduct satellite communication course, APPLE telling its own story to seven campuses in India with audio-video downlink and audio uplink for interaction in a sequential mode. The Robotics course of the Institute of Electrical and Electronics Engineers was conducted for students at seven locations with resource persons at Ahmedabad, New Delhi and Detroit. Operational systems soon followed. The successful month-long telemedicine experiment between AIIMS, New Delhi, and

Civil Hospital, Ahmedabad, extensive trials of the emergency communication and also the VIP terminals became operational services in the INSAT period.

I have to now bring out the tense moments we went through. On orbit, APPLE had an anomaly. One of the solar panels failed to deploy. The power from one panel was adequate for the on-orbit phase but we met with a formidable thermal problem. One half of the optical solar reflector surface was blocked and it led to a raise in the temperature of satellite subsystems like the Earth sensors, momentum wheel bearings and batteries operating near their qualification limits during the period around the winter solstice. A pitch rotation manoeuvre was designed to rotate the spacecraft like rotisserie manoeuvre for four hours every day in the night time and to reacquire Earth lock after four hours and continue normal operations for the rest of the day. The mission operations team at Sriharikota had nightmarish experience to regain Earth lock as the VHF TT&C link was affected by ionospheric scintillation and succeeding after a number of attempts each day. One has to remember at this juncture that 1981 was ‘UN Year of the Handicapped!’

APPLE teams had many other interesting experiences .The apogee motor of APPLE with 314 kg propellant load was capable of supporting 616 kg spacecraft weight; but owing to increase in spacecraft weight it was able to take it to a twenty-two-and-a half-hour equatorial orbit from the initial elliptical transfer orbit for a period of ten hours and a half, inclined to the equator at 17 degrees. We loaded the hydrazine tanks full availing the final margins released by Ariane LO3 mission. Attaining the final Twenty-four-hour orbit was made possible by series of burns of four of the 1 N hydrazine thrusters for hours in continuous burn mode at appropriate times in orbit. The orbit-raising strategies for INSAT and Chandrayaan-1 and planned Mars missions go back to those days of doing things out of necessity. Necessity is the mother of invention. How true it has turned out to be!

APPLE operated for over twenty-seven months in orbit exceeding its design life of two years. The last moment of APPLE occurred on 19 September 1983. Sitting at ISAC at Peenya in constant

communication with the operations team at Sriharikota, we witnessed the fall of thrust from hydrazine thrusters. Slowly, the last few drops of hydrazine came out and the thrusters were no more capable of producing rotation and translation of the spacecraft. As a last-ditch effort, attempts were made to access residual quantity of hydrazine trapped in two of the tanks due to a shut latch valve. However, this did not bear fruit. With tears in our eyes, we had to send the last command to shut the spacecraft as part of the predetermined plan of shutting down all subsystems and making the beacon silent. This was the last of the more than 90,000 commands sent to the spacecraft and faithfully executed but for one, which was traced to be due to a fault in the ground system!

APPLE, though 'handicapped', was the most forgiving satellite and it was our test bed for learning from L (learning) board to Experts! We had lost the Sun lock and the Earth lock a number of times due to anomalies in subsystems, and the operations team used to keep the spacecraft in safe mode and start recovery operations, sometimes even taking the ISAC team by bus to Sriharikota. On one such occasion we were able to get the normal operations restored back to support the Indian Air Force fire power demonstration event at Tilpat range just in time! Setting up and locating ISTRAC at Bangalore came out of such APPLE experiences.

Many tense situations occurred during the development and testing of the APPLE spacecraft. The cage instability problem in the momentum wheel was valiantly solved by the Inertial Systems Laboratory paving the way for indigenous momentum and reaction wheels, which became our mainstay for future missions. Similarly, perfecting the vacuum ignition of solid ABM (Apogee Boost Motor) also contributed to the success of SLV-3 project one year ahead of APPLE launch. The rupturing of plumb lines of RCS on the proto-flight model was another incident. This was owing to inadvertent cooling during thermovac test causing demineralised water (used as simulated fluid) to turn to ice leading to expansion. The cause was traced to be the erratic power from mains and the time delay in getting the backup on. It required corrective action at the supplier's facility in a firefighting mode to be back in time to serve as flight

standby. The last minute polarity error detected in Lockheed Earth sensor flight model (traced to be due to change of wiring team at manufacturing stage), collapse of High Bay Building roof of Cast And Cure Facility of SPROB due to hovering of severe cyclonic storm over SHAR for eight hours, collapse of VHF antenna mount due to wind conditions at SHAR, collapse of the 40 m tall water tank feeding High Altitude Facility at STEX, etc., were some of the incidents causing setbacks but fortunately no casualties!

The judicious mix of make-buy options paid the dividend. For the main system we chose space-proven items from outside vendors and the redundant systems were indigenously built. After one year in orbit, we switched over to indigenous systems and acquiring performance and qualification data paving the way for self-reliance in critical subsystems like momentum wheels, sensors and RCS. The technology of orbit raising and orbital operations perfected through APPLE and thermal and power management became the core of operational satellite missions like INSAT and IRS which followed.

APPLE being transported on a bullock cart has become a symbol of our innovative approach and has been characterised as collision of centuries by *Newsweek*, which said that between the tail of the ox and the sophisticated APPLE spacecraft kept on a clean tent, centuries are coming together. APPLE was put on a bullock cart to provide a non-magnetic environment and to conduct the antenna test in an open field to remedy the TT&C link problem caused by impedance matching problem. The solution was found in about five hours and at a cost of Rs 150 for hiring the cart! It would have resulted in considerable expenditure and time delay to conduct this test in a facility outside India. We were close to the point of transporting the satellite to Toulose for final tests of the composite along with CAT and Meteosat to be followed by launch from Kourou.

The storage of APPLE ABM was in the French Munitions Facility. Our engineers went every day crossing the fortified barriers including guard dogs to perform rotation of the motors by 120 degrees every day like wine bottle storage to prevent grain de-bonding. This was another unique experience. Hydrazine made at Thumba was transported by ship to French Guiana in specialised

small containers certified for maritime transport of explosives. It is worth noting that the Guiana Centre authorities tested and found our hydrazine to be of superior quality compared to that demanded by US Air Force specifications. While we brought the flight stand by ABMs to India, the balance quantity of hydrazine was neutralised in a special facility at Kourou at our cost as the charge of transportation was much higher. Same was the story of transporting our igniters for mating and testing with the Thiokol safe and arm device in their facility with police escorting in New York and New Jersey States – of course at our cost! Our ITLU (ISRO Technical Liaison Unit) office at Washington had to do such coordination tasks at very short notice.

Release of the flight worthy structural model was authorised only after successful launch of APPLE. This was brought back along with the proto-flight model, ABMs and integration and checkout equipment by Air France to Delhi in pallets and subsequently transported to Bangalore by road.

The excellent performance of ECIL made computers supporting the mission operations in the initial orbit- raising phase for forty-five days in non-stop mode, arranging tanker-loads of liquid nitrogen for twenty-one days from Indian Oxygen, Madras, with special exemption from power cut during President's Rule there, authorisation to the Project Director for granting air travel for one-way and return by train for people accompanying the spacecraft items subject to submission to the DOS and Member (Finance), Space Commission, are some of the things unique to this project.

A team of over 2,500 young engineers, scientists, technicians and administrative personnel ably assisted by Indian and international institutions/industries accomplished the mission. The average age of the APPLE team was twenty-seven years and I was thirty-seven at the beginning of the project. 'We did not know that we did not know' made us to perform in a daring manner against all odds! APPLE symbolised the romantic phase of our space programme. It touched the hearts of all Indians. Dhawan was asked by his highly concerned vegetable vendor "APPLE Kaisa Hai" and he said that APPLE will not be renamed as was done for earlier missions! At Anand Bhavan,

Allahabad, while delivering the Nehru Memorial Lecture I was confronted by the aunt of Indira Gandhi from amongst the audience of a few thousand people on 14 November 2001 as to why APPLE was running hot when the north was facing cold wave and also on consequential misery including loss of life. I had to explain our thermal problem in winter solstice and the remedial pitch rotation operations! The state-level science competitions held next day had so many students demonstrating APPLE elements using simple components. Thus apple had touched the citizens of India cutting across all age groups.

Today we are in the forefront of space communication and Earth observation systems for our needs. We have missions to go to Moon again and Mars as well. Our own navigation satellites and human space flight enablers are in the works.

ESA and ISRO commemorated the silver jubilee of Ariane LO3 and APPLE launch at Paris on 16 June 2006. APPLE symbolises the fruitful cooperation between ESA and ISRO paving the way for strong ties between the two organisations in the years to follow.

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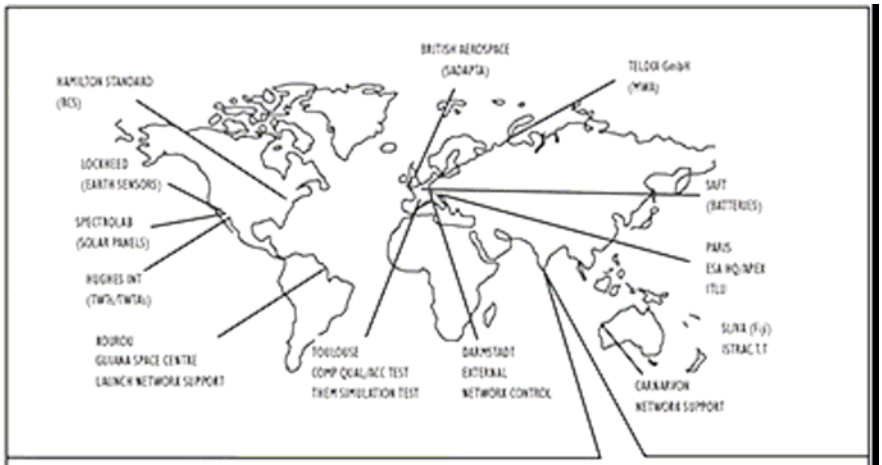
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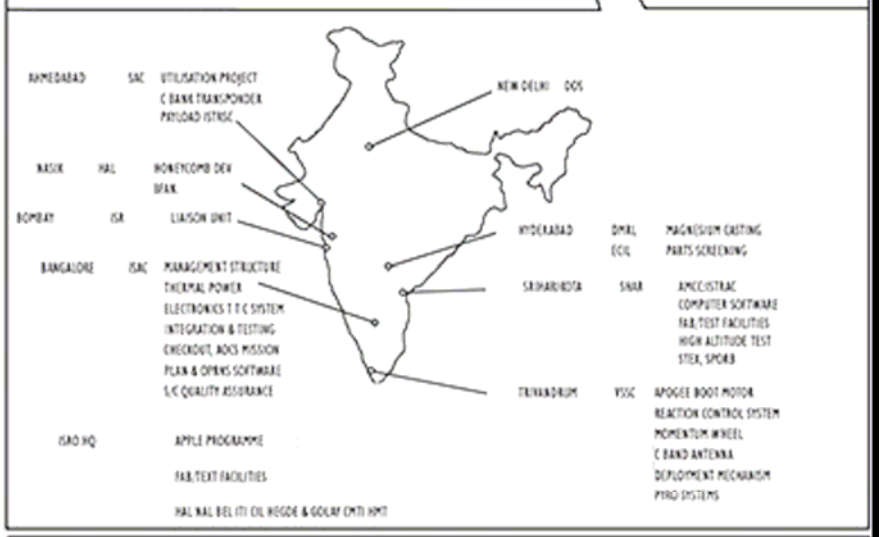
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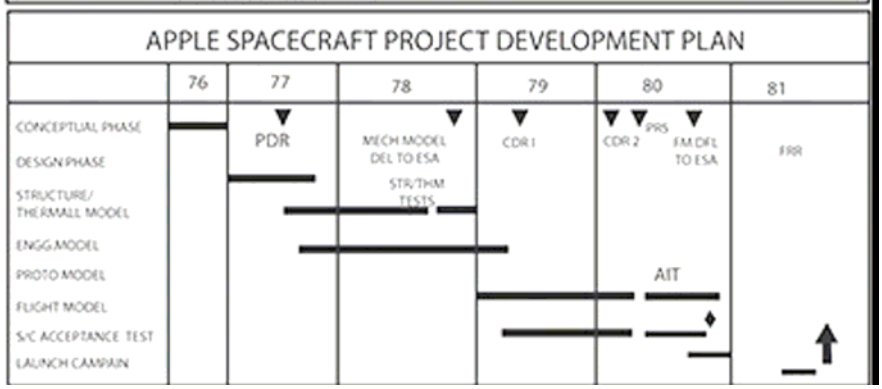
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