

only a reflection of will and commitment. There can be no two opinions that there should be no compromise with the quality of research. The role of peer review in mission mode should not at all be relaxed. However, it would certainly mean assured funds in a given direction if there are takers. It has to be realized that many activities required for the success of a programme may not be research questions per se. Funding of such activities is crucial for questions to be answered. This can only be possible in the mission mode. The mission mode

is not a reservation or protection. It is a commitment, an encouragement, or even an inducement.

What is important is to ask what India can contribute to HGR effort. What are likely to be the fallouts and the by-products of such an effort? One would have to identify or create groups and nurture them. An environment will have to be created to bring out an interaction between these groups. All this would need to be done at a speed that is commensurate with the rest of the world. A central organization with

effective communication is necessary for such a venture. This can only be possible in a mission mode, whether it be in the form of a separate PAC or a unit or an agency. However, if investment in HGR effort is not in national interest then it is a different matter altogether.

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TECHNICAL NOTES

Augmented Satellite Launch Vehicle (ASLV)

M. B. Reddy and M. S. R. Dev

The launching of ASLV-D3 at 0600 hrs on 20 May 1992 preceded by a flawless countdown, resulting in the successful injection of SROSS into low earth orbit is a major milestone for the Indian Satellite launch vehicle development programme. ASLV project was designed as a low-cost launch vehicle for highly complex technologies which is incorporated in the polar satellite launch vehicle (PSLV) and geostationary satellite launch vehicle (GSLV) and to launch 150 kg class payloads into low earth orbit. The development of complex technologies such as canted nozzle, bulbous metallic heatshield, design and fabrication of strapon motors, achieving and demonstrating the differential thrust requirement between strapon motors and closed loop guidance system were primary objectives. A new concept of integration had to be evolved resulting in the design and building of a new launch pad with mobile service structure for ease of vehicle integration. ASLV is configured as a five-stage solid propellant vehicle weighing 40 tonnes and a length of 23.8 m. The total flight time of the mission was about 500 s.

Design considerations

Configuration

During configuration finalization of ASLV, certain guidelines like utilization of proven technologies, realizing the launch at a reasonable cost and schedule were considered. In addition, ASLV was identified as a base line vehicle for proving some of the technologies required for future generation launch vehicles of ISRO and to use this launcher for space science and appli-

cation missions. Hence ASLV was configured (i) to maximally utilize ISRO's first launch vehicle SLV-3 systems to retain the heritage, (ii) to develop and qualify technologies in the areas of strap-ons, close loop guidance, bulbous metallic heat shield, vertical integration etc. required for future launch vehicles.

ASLV is a five-stage rocket with all the stages having solid propellants. It has a gross lift-off mass of 41.8 t and an overall length of 23.852 m. The configuration of ASLV shown in Figure 1 has the following features.

Two strapon boosters (ASO) (1 m dia and 10 m long) having total weight of 11.60 t each and nozzles with 9° cant constitute zeroth stage. First stage (AS1) with similar dimensions had a total weight of 11.7 t. As in the case of ASO and AS1, the second stage (AS2) booster case was loaded with hydroxy terminated poly butadiene (HTPB)-based propellant in the 'star' shape for radial burning. AS2 with a total weight of 4.4 t was 6.3 m long and 0.8 m in dia. The third and fourth stage motors were loaded with high energy fuel code named HEF-20 and slotted con-

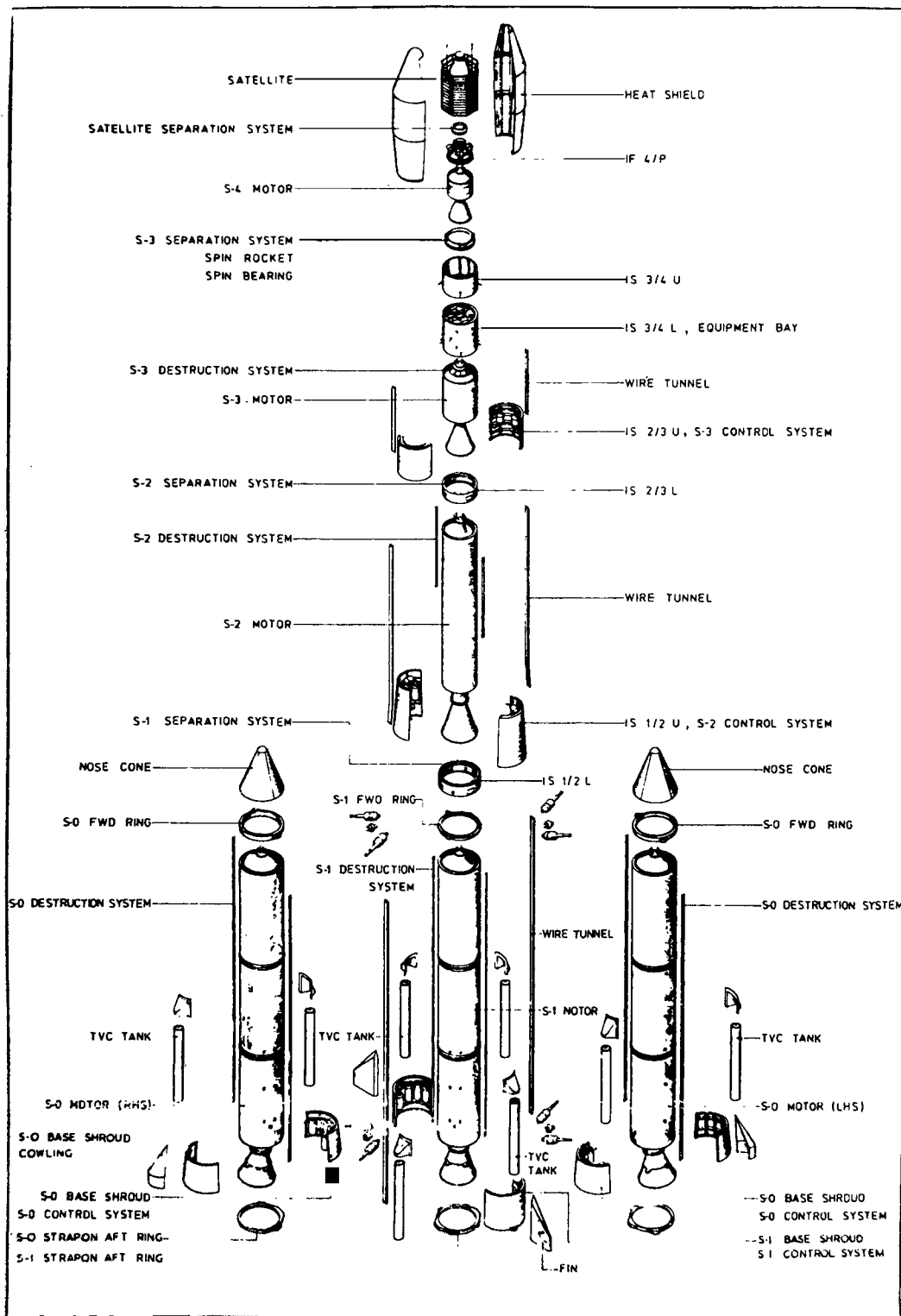


Figure 1. Exploded view of ASLV-D3.

figuration to have a higher mass ratio. The salient features of the stage motors are given separately.

Both strap-on boosters have secondary fluid injection thrust vector control (SITVC) system for controlling the vehicle and roll during the strap-on thrusting phase. During the first stage thrusting, vehicle is controlled in pitch and yaw by SITVC derived from first stage booster. Roll was controlled in two phases, first stage ignition up to strap-on booster separation using 300 kgf bipropellant reaction control system (RCS) thruster and later using 50 kgf monopropellant RCS. Based on ASLV D2 post-flight analysis it was observed that roll control augmentation was necessary during critical phases of flight regime like strap-on burnout/stage transition. Since cold gas control provided earlier could not be augmented further, instead of introducing a new system, bipropellant and monopropellant RCS used in stage-2 and stage-3 were adopted. Vehicle was controlled during second and third stage boosting and coasting phases using RCS thrusters of bipropellant and monopropellant respectively. Fourth stage stabilization was achieved by spinning about its longitudinal axis using four miniaturized solid motors.

Vehicle electronics consisted of telemetry, tracking, telecommand, instrumentation, power and control electronics. The telemetry system was to monitor inflight performance parameters covering all stages from lift-off to satellite injection. C-band transponder, tone range receiver, S-band range and rate transponder (SRRT) together formed the tracking system. The telecommand system was for destroying the vehicle in case of any unacceptable deviation from the normal trajectory.

Instrumentation included monitoring of the sensors designed for health and flight parameters of the vehicle during lift-off to satellite injection.

ASLV employs open loop guidance up to the first-stage separation. From second stage ignition to third stage separation closed loop guidance scheme was followed. The closed loop guidance was to compute velocity to be gained at every instant to achieve the angular momentum and the apogee specified. The stabilized platform inertial navigation system (SPINS) was employed to follow computed trajectory on-board. On-board computer system is a fault-tolerant redundant system.

Strap-on boosters were attached to the core vehicle using ball and socket mechanism and separated by firing pyro-mechanical devices. The required jettisoning velocity to separate the spent boosters from the core vehicle was imparted by high energy disc springs. First and second stages were separated using a pyro device called flexible linearly shaped chord (FLSC) by cutting the monocoque structure on which it was mounted. Third stage and the satellite separation are again pyro-mechanical devices consisting of ball release mechanism with which by firing a detonator, the balls are released and the separation takes place. Two fairings of the heatshield were separated and jettisoned using a pyro actuator coupled with the release of merman band at the aft end of the H.S. and coil springs located at the interface of the fairings.

Aerodynamics

It is essential to shape the launch vehicle configuration aerodynamically to have minimum drag and desired static stability margin. Aerodynamic design of ASLV configuration involves in particular the proper choice of heat-shield configuration, as it has to cater to larger satellites and attachment of strap-on boosters to core vehicle in addition to other general aerodynamic considerations.

Heatshield configuration is a bulbous one with nose cone semi-vertex angle being 20 deg and bluntness ratio of 0.25. The boat tail is 5°. Generally the bulbous type heatshield configuration causes flow separation and buffet problem during transonic phase. The configuration selected for ASLV is seen to be buffet prone but falls under the category of stable separation flow. A large number of wind tunnel tests were carried to evaluate the adequacy of chosen configuration.

The shape of the nose cone mounted on top of strap-on booster was chosen to be the same as that of heatshield. The shock boundary layer interaction in the region of nose cone and core vehicle posed a major problem that required extensive analysis and wind tunnel testing. In view of unsymmetry of the vehicle, fins were introduced to have the static stability margin in yaw, whereas the location of strap-on make the vehicle statically stable in pitch. The strap-on base shrouds in which the

canted nozzles of strap-on motor housed are made into conical flange shape. Fuel and gas external storage tanks of control system are located optimally to improve static stability of the vehicle.

In order to aerodynamically characterize the configuration i.e. to estimate the forces and moments and also the distribution of aerodynamic forces in addition to well-established theoretical methods such as slender body theory lifting line and lifting surface theory for supersonic speeds, shock expansion methods etc. an extensive wind tunnel testing was carried out for all Mach number regimes.

Stage separation, aerodynamic noise during flight and jet noise during lift-off, lift-off dynamics at the launch pad, strap-on jet flow interference and aerodynamic heating were some of the key issues considered under aerodynamic design considerations.

Separation of strap-ons also posed major aerodynamic problems in estimating the forces and moments acting on the core configuration in the presence of separated strap-on boosters as well as for determining the trajectory dynamic of the separated boosters. This problem was overcome by the so-called time marching process method. Here, initially at the time equal to zero of separation certain aerodynamic data was generated on each strap-on in the wind tunnel, the trajectory for each stage was run for a time t (theoretically), the two stages were again reset in the tunnel to the position and altitude as predicted by the trajectory programme and new aerodynamic data was obtained. The procedure gets repeated until strap-on stages were safely separated.

First and second stage separations involved engineering analysis and partial simulation tests. Essentially it deals with the jet behaviour of ignited stage and its impact on the separated stage and the mass flow rate in the gaps created during separation.

Prediction of noise levels during flight and jet noise during lift-off, lift-off dynamics, impact point prediction for the separated stages and base flow parameters to study strap-on jets interference were some of the other aspects considered under aerodynamic design consideration.

In addition, all the computational fluid dynamics (CFD) tools like panel methods, finite difference, finite volume and finite elements were used in detailed analysis.

Table 1.

Parameter	Transonic		Q_{max}		ASO/AS1 Transition	
	Pitch	Yaw	Pitch	Yaw	Pitch	Yaw
Q (N-rad/m ²)	3793	3657	4224	4241	3063	4836
Control force (N)	3130	6920	2830	4900	3490	7730
Differential thrust (N)	—	8350	—	14050	—	22980
Cowling force (N)	9220	—	7220	—	5240	—
Fin force (N)		2800		3440		3920
Dynamic pressure (Pa)	79,000		88,000		77,000	

Structures

The atmospheric flight is generally the most severe load condition for launch vehicle structure. The load analysis method adopted for ASLV for these conditions was comprehensive and include the following:

(i) Axial and transverse loads due to propulsion, inertia, aerodynamic and control forces and tracking error, (ii) Dynamic loads resulting from control dynamics, transonic buffeting, wind shear and gust, and (iii) stage separation and vehicle flexibility. Although loads have been estimated for various phases of flight, three critical conditions were considered for structural elements design. They are (i) transonic, (ii) Q_{max} and (iii) ASO/AS1 transition phases. The details of the parameters and loads considered are given in Table 1.

Two softwares namely FLOAD and FLEXTRAJ were developed to estimate the vehicle loads for the above conditions. FLOAD was used to determine vehicle structural element loads for specified angle of attack due to accelerating mass and control force. Inertial forces were based on mass distribution, bending moment and shear forces. FLEXTRAJ was used to determine vehicle loads considering structural flexibility, adequacy of control design with reference to control-aerostructural interaction, control power plant sizing and reconstruction of flight trajectory of wind profiles, control dynamics and perturbed air load.

The major structural elements of the vehicle consist of metallic motor cases, composite cases of fibre reinforced plastic (FRP) and KEVLAR with metallic end fittings, light alloy structure and the associated interface joints/openings. These elements were designed for a factor-of-safety (FS) of 1.15 against global yielding and 1.5

against ultimate failure. The bulbous heat shield and the strap-on booster were studied from aeroelastic point of view specially from buffet loading at transonic scaled-down wind tunnel models. Extensive analysis was carried out for frequency and mode shape and structure damping to study control-aerostructural interaction problems. Estimation of joint rotation constant (JRC), one of the inputs in the above calculation, was found difficult to estimate theoretically. It was found necessary to develop suitable sensors to measure small differential displacements. Currently JRC of all joints are measured experimentally using these sensors. Further full scale ground resonance test (GRT) was carried out using typical flight hardware for the total vehicle to confirm frequency mode shapes and to generate structural damping factors. Testing involved design and realization of suspension systems to provide near-free support condition as expected in flight.

Dynamic response studies were carried out through coupling of structural elements to determine clearance between nose fairing and satellite under dynamic loading and transient loads at various vehicle sections due to ignition and staging.

All the structural elements underwent a qualification test to validate design considerations. In the structural testing scheme, the design loads are applied on the component through test adaptors with appropriate interfaces which partially simulates the flight conditions. The loads simulated are mainly axial, bending moment and shear force. The thermal loads are simulated only on heat shield since it does not have any impact on other structures. Instrumentation is mainly for obtaining data on load transfer, design validations at critical locations and to determine the actual margins. In the case of pressure vessels

like motor cases and control system tanks, in addition to qualification, acceptance tests are carried out on the flight identified hardwares.

Stage auxillary systems

Stage auxillary systems include stage separation and jettisoning mechanisms and destruct system devices. Mostly these are of pyro-mechanical devices in nature and have to work to very high reliability.

For ASLV, two major systems were developed in addition to the modification/improvements carried out to the stage separation and destruct system devices developed during SLV-3 programme. The new systems are the strap-on booster separation system and the heat shield/fairings separation.

Two strap-on boosters each weighing 11.6t at lift-off and 3t during jettisoning having a length of 10.8 M attached to the core vehicle had to be separated at 55 s from lift-off at an altitude of 15.8 km. The overall system design and development was critical in view of high dynamic pressure and angle of incidence during separation. In addition it was necessary to minimize the disturbances and to have clean separation.

The system design included structural integrity for propulsion and flight loads, functional requirements for separation and jettisoning and reliability requirements. The boosters were attached at the fore end and aft end with ball and socket joints connected with pyro devices. Lateral rigidity was provided using spring thruster in which high energy disc springs are loaded. A large number of simulation tests were conducted to qualify the system performance and reliability.

Heat shield (HS) was provided to protect the satellite (SROSS), the

Table 2. Salient features of solid motors

	Strap-on motor ASO	First stage ASI	Second stage	Third stage	Fourth stage
Max Pr (MP)	4.66	4.66	4.40	4.40	2.95
Action time (s)	47.00	48.50	39.40	46.70	33.40
Max thrust (KN) VAC	657.00	657.00	265.00	88.00	33.90
Prop wt. (kg)	8595.00	8935.00	3205.00	1080.00	320.00
Specified impulse (N s/kg) VAC	2545.00	2545.00	2716.00	2745.00	2745.00
Mass ratio	0.842	0.850	0.812	0.878	0.889
Nozzle area ratio	6.504	6.662	14.2	25.73	28.56
Motor case	Steel	Steel	Steel	Fibre glass/Carbon EPOXY	Kevlar EPOXY

fourth-stage motor and the associated systems including electronic packages from heating during atmospheric ascent. HS is 1 m in diameter and 3.2 m long with two aluminium alloy fairings of skin-stringer construction. Fairings were provided with phenolic bonded cork insulation to limit the skin temperature to 120°C from zero-thermal heating. Twelve latches with springs housed inside were provided, six on each side for connecting the two fairings in the vertical plane and the aft end of the heat shield was fastened to the main vehicle with 'merman band' type joint. With the actuation of the pyro jack mounted at the tip of the HS, both the latches and merman band which are interconnected release simultaneously affecting separation of the fairings with the required velocity at about 70 km altitude during coast phase after stage-2 burn out. A large number of structural, functional and thermal tests were conducted under simulated conditions and finally validated during D3 flight.

Materials

Ferrous, non-ferrous, composite materials, elastomers and some special materials were used in the fabrication of various components, hardware etc., for ASLV. In the case of rocket motor cases low alloy carbon steel (15CDV6) having ultimate tensile strength (UTS) of 105 kg/mm² was used for lower stages. In addition many brackets fixtures and interface rings were fabricated from this material. For upper stages, composite materials namely glass FRP and Kevlar epoxy were used because of higher stiffness and strength ratios (1.94, 4.3 & 5.29, 8.37 respectively) compared to

15CDV6 (2.69, 1.28). Nozzles were made of ablative materials namely silica phenolic and carbon phenolic. Depending on the location at which it is intended to use (convergent or divergent portion of the nozzle) the fabrication process was altered. Graphite was used for the nozzle throat.

Interstages, baseshrouds, heatshield fairings were fabricated from Al. alloy AA 2014-T6, 2014-T652, 6351-T6, 2024-T4 in the form of sheets, forgings, extrusions, rivets etc. For realization of control components the materials used included ferrous (ASISI 302, 304, 304L, 316, 430F, 44-L, 230 U3TR, 17-4PH, 15CDV6, EN-24), non-ferrous Al. alloy (AA 2014, 2024, 7075), elastomers (Butyl, Nitrile, EPDM, Viton, EPR) and special materials like catalyst – iridium molybdenum Cu matrix and tungsten Cu matrix. Titanium forgings were used for fabrication of spherical tanks. In addition propellants like RFNA, N2H4, strontium perchlorate, hydrazine, nitrogen were used.

Propulsion

ASLV uses only solid rocket propulsion for boosters and upper stages. Solid rocket propulsion started in early 1970's and a series of rocket motors of different categories were developed. A number of improvements/modifications were carried out in the propellants, nozzles etc. in the past few years to meet the ASLV specifications.

The zeroth stage/strap-on stage (ASO) boosters had 9° fixed canted nozzles. To reduce the dispersion in the burn time between two strap-on motors, simultaneous casting was employed by distributing the mixed propellant slurry

equally among the pair motor segments. Subsequent to D2 flight review and mission requirement, certain changes were incorporated in the grain burn rate for different segments of the motor to achieve the desired thrust-time curve and reduce dynamic pressure at critical phases of flight. Further to estimate the thrust-time parameters more accurately for the flight motors, three motors were cast simultaneously of which one was tested on ground and the other two identified for flight use.

For these motors as well as the first stage (AS1) and second stage (AS2) motors, an indigenously developed high energy hydroxy terminated poly butadine (HTPB)-based propellant was used in place of poly butadine acrylic acid acrylonitrile (PBAN) used during SLV-3.

Pyrogen igniters having a fast burning propellant composition in FRP chamber were employed for ignition purposes. Nozzles have two parts, convergent and divergent. Carbon phenolic liners of rosette construction for the convergent portion of the nozzle, and tape wound carbon phenolic liner for the fore end of the divergent and tape wound silica phenolic liner for aft end portion were used. Graphite was employed at the throat portion with silica phenolic back-up. These ablative materials were supported with a metallic structure. The upper stages namely third stage (AS3) and fourth stage (AS4) were made up of glass FRP and Kevlar epoxy respectively. The fore and aft end domes of the case were insulated by moulded domes of nitrile rubber placed in position on collapsible winding mandrels prior to winding of the cases. High energy propellant code named HEF-20 functionally similar to carboxy-terminated

Table 3. Functional details of ASLV control power plants

Parameter	ASO/ASI SITVC sys	ASO RCS system	ASI RCS + ACS sys.	AS2 RCS system	AS3 RCS system
Max. side force (kgf)					
Pitch and yaw (Thrust regime)	2100	—	—	215	25
Pitch and yaw (Coast regime)	—	—	—	215	5
Roll	—	300 (2 nos)	50 (8 nos)	10	2
Injectant/propellant/ gas stored (kg)	186 (per sys)	19 (per sys)	26	57	12.9
Pressurant Injectant/propellant	Strontium perchlorate soln	RFNA hydrazine	Nitrogen gas Hydrazine	RFNA hydrazine	Hydrazine
No. of sys	Two for ASO One for ASI	Two	One	One	One
Mode of operation	Proportional to command signals	On-off	On-off	On-off	On-off
Operational duration (s)	52	10	52	58	361

poly butadine (CTPB)-base propellant was employed. AS3 and AS4 have radial slotted grain configuration for the port achieved by machining using formed tools. Ignition was by means of pyrogen igniters as in the lower stages. Similarly, nozzles were of similar construction as that of booster stage except that there were no convergent entry sections and AS4 had a contour nozzle.

A large number of qualification tests were carried out to demonstrate the required reliability in meeting the specification. Table 2 gives the features of the solid motors.

Control systems

ASLV is controlled from lift-off up to the end of third-stage coast phase to ensure (i) proper attitude control against disturbances caused during the flight and (ii) to follow the flight trajectory either pre-determined or as commanded in real time to meet ultimate state vector at the end of controlled flight regime.

ASLV adopts 8 numbers of control power plants (CPP) out of which (a) three were secondary injection thrust vector control (SITVC), (b) three of bipropellant reaction control system and two of monopropellant reaction control system to meet control requirements during different phases of flight regime.

The functional details of the control power plants (CPP) are given in Table 3

In SITVC system, force was generated by injecting aqueous strontium perchlorate solution into the nozzle through electrohydraulic injection valves mounted on the nozzle. This created an oblique shock which deflected the exhaust gases of main motor. Red fuming nitric acid (RFNA) and hydrazine were used in combination with the bipropellant reaction control system. Monopropellant reaction control system uses hydrazine in combination with indigenously developed iridium-based catalyst bed. All the CPP systems were of constant pressure fed design using pressure regulator at 210 KSC pressure using nitrogen as gas.

After lift-off, vehicle derives control force from two ASO and SITVC systems functioning in tandem to control in pitch, yaw and roll. Towards burn out of ASO, when the thrust is tapering, control force is derived from ASI SITVC System for pitch and yaw control. The transfer from ASO burn out to ASI ignition is initiated by sensing chamber pressure on real time. The roll control force after ASO burn out is derived from ASO and ASI RCS systems. Towards the end of first stage burn-out control transition takes place again on real time by sensing vehicle acceleration. Bipropellant RCS of second stage provides control force to control in pitch, yaw and roll both during thrusting and coasting. Similarly third stage monopropellant RCS provides control force till guidance termination and orients the AS4 thrust vector for optimal orbit before separation.

Avionics system

Avionics system for ASLV can be classified into two groups (i) navigation, guidance, control (NGC) and flight sequencing system and (ii) instrumentation, power, telemetry, tracking and command (TTC) systems. A typical flight sequence followed for ASLV (Figure 2) shows open loop guidance upto stage-1 separation and then onwards it is a closed loop guidance up to third stage separation. The main principle used by closed loop guidance is to compute velocity to be gained at every instant to achieve the angular momentum and apogee specified. It generates steering programme using cross-product steering law.

The overall configuration of NGC and sequencing system are shown in Figure 3. The stabilized platform inertial navigation system (SPINS) used in ASLV has an inertial platform module (IPM) which is 4 gimbal platform employing 3 single-degree-of-freedom rate-integrating gyros and 3 servo accelerometers. The gyro maintains the inertial frame all through the flight and the accelerometers measure the 3 components of vehicle accelerations along the three inertial axes. On board the computer (OBC) system is a fault-tolerant multi-distributed architecture consisting of two independent and identical computing chains performing identical functions. If one of the computing chains fails, its self-checking hardware disables it and the other system continues with computations.

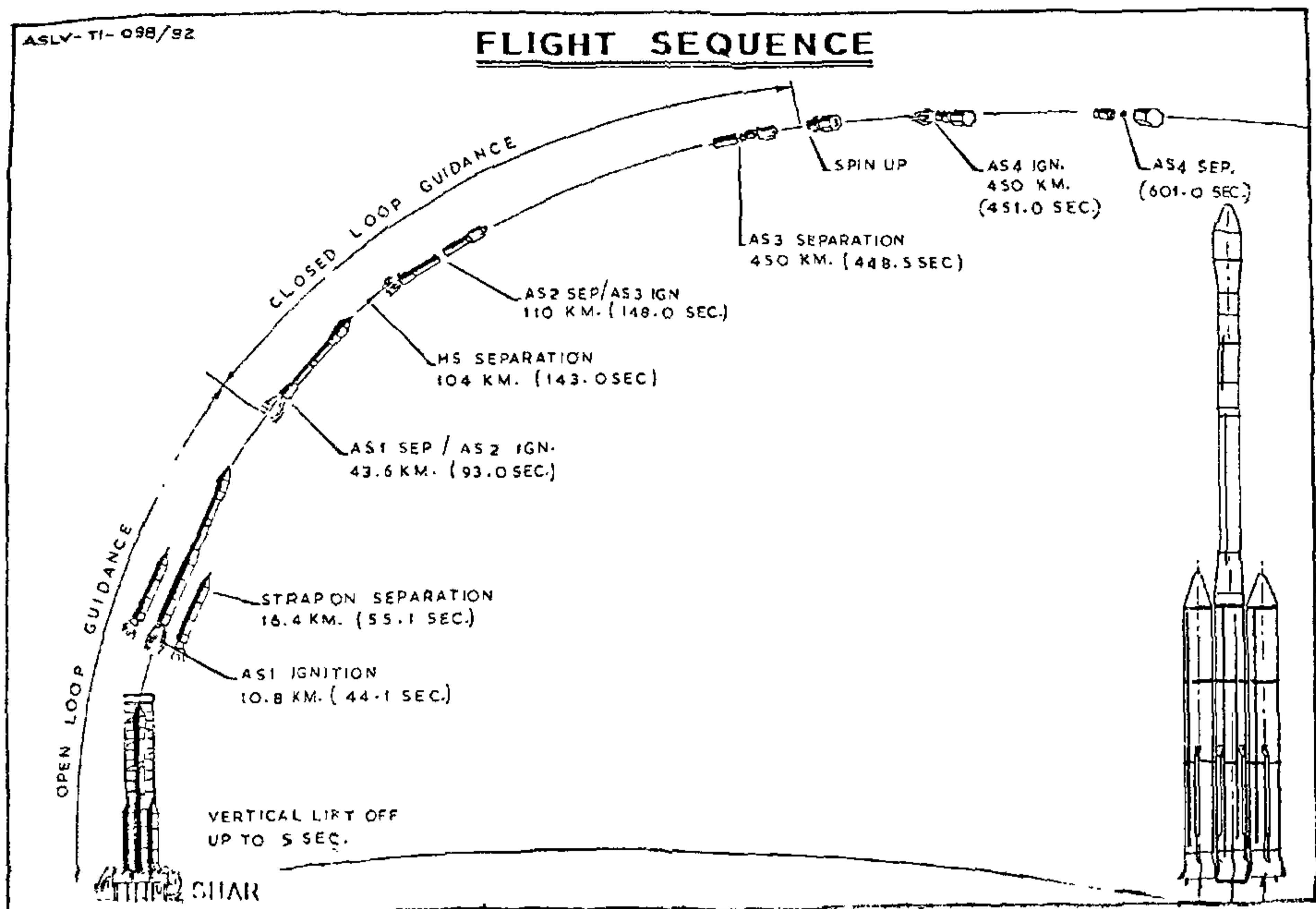


Figure 2. Flight sequence.

The flight sequencing events number 25 during closed loop guidance controlled by OBC having necessary software and hardware interlocks. Flight sequencing was done at predetermined times by comparing the register time with the event time and by using a look-up table. Position of the rocket was computed onboard with reference to launch pad inertial (LPI) coordinate system. The cycle time of 500 ms was used without losing the overall position accuracy. The gravity computation, sensor error compensation and integration of velocity to obtain position are specific features of navigation.

One of the crucial changes made from D2 to D3 flights was with respect to incorporation of real-time decision (RTD) during control transition from strap-on (ASO) to stage-1 (AS1) and stage-1 to stage-2 (AS2). AS1 ignition and control to be transferred is decided onboard in real time by sensing the ASO chamber pressures and in the case of AS1 and AS2 by sensing inertial acceleration.

Telemetry was provided to monitor inflight performance parameters covering from lift-off to satellite injection. The base band was the pulse code modulation (PCVM) scheme which was phase-modulated to S-band RF carriers. Three telemetry chains were used, two of them with 500 kb/s and one with 70 kb/s. Important features such as data acquisition, multiplexing, analog-to-digital conversion and transmission were done in remote unit (RU). Two types of RUs, RU I and RU II having 64 and 96 and 16 and 32 analog and digital channel respectively were linked to the central control unit which contains telemetry format.

The tracking system includes a C-band transponder which can take up interrogation from two ground-based radars. The tone range and interferometry subsystem was also used with 513.64 MHz uplink and 240 MHz down link which are of frequency modulation type. Telecommand subsystem was planned for destroying vehicle in the case of any

deviation from normal trajectory (safety zone).

The primary power subsystem for the vehicle was silver zinc batteries used with DC/DC converters to obtain regulated voltages to power various units. Instrumentation of the vehicle includes measurement of accelerometer, performance monitoring of stage motors, control system, stage separation devices, temperature, strain, vibration and acoustics.

Engineering aspects

Fabrication

Realization of hardware and components for ASLV of different types to stringent dimensional tolerances demand extra effort in fabrication process and facility upgradation. From conventional fabrication methods to special methods, facilities were needed

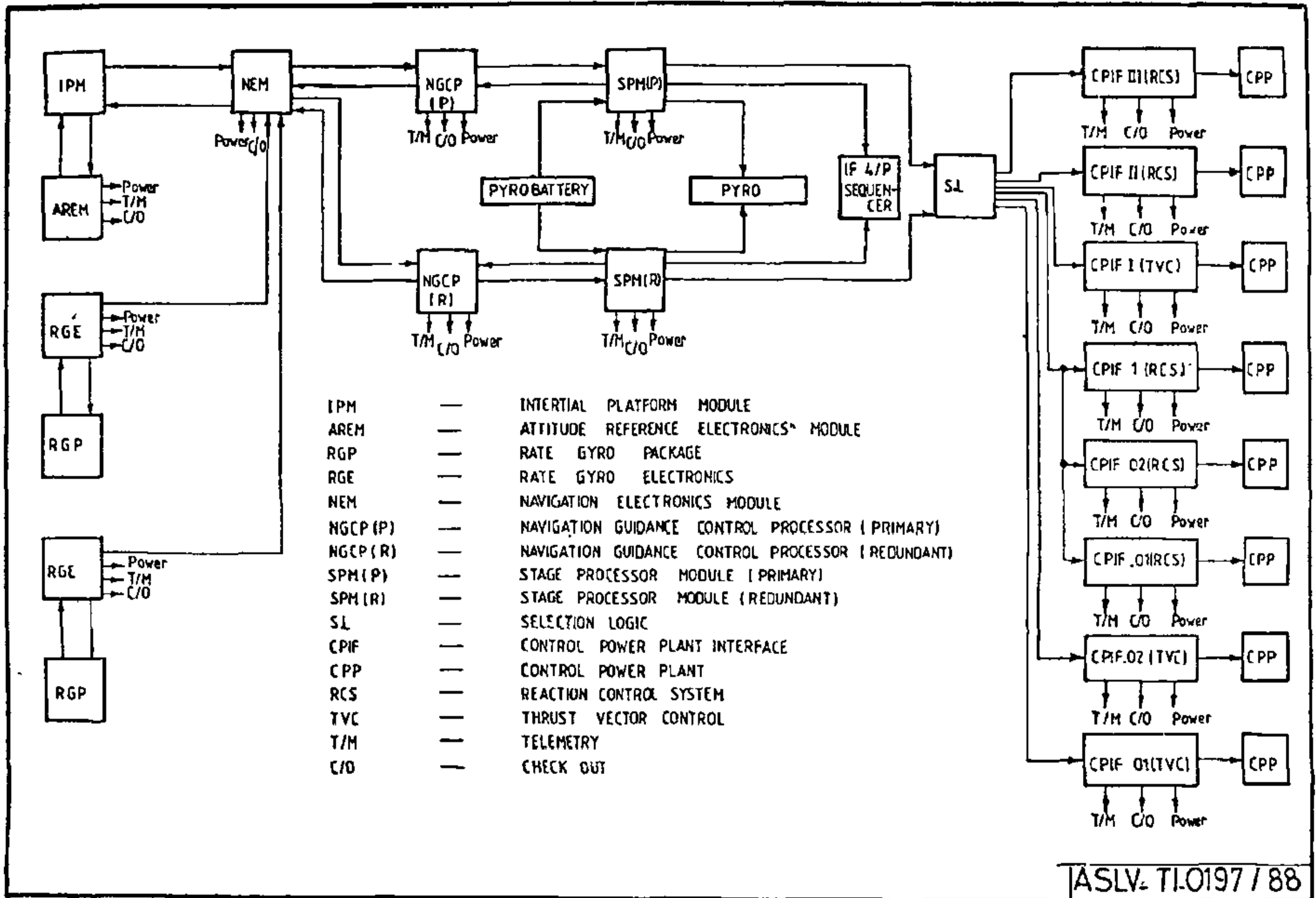


Figure 3. Signal flow in closed loop guidance packages of ASLV.

for realization of different subsystems. In the case of composite motor cases (third and fourth stages), to achieve higher mass ratio 'collapsible' types of mandrels were used to wind fibres in hoop and polar direction. Special methods were followed for realization of nozzle materials including curing under vacuum conditions at elevated temperatures. Although conventional methods were adopted in the fabrication of metallic motor cases, because of stringent dimensional tolerances and size, special tools and optical aids were used to achieve the required specifications. Some of the control components require tolerances up to 5 μ and clean room environment for component assembly. Spherical tanks of titanium (Ti6Al4V) fabricated out of forgings and welded using electronic beam were qualified for 315 KSC pressure. Although the light alloy structures of ASLV are similar to aircraft structures, because of their tighter tolerances and

inaccessibility, special fixtures and processes were adopted.

Integration and checkout

One of the objectives of ASLV launches was to evolve a vertical integration methodology to apply these methods for ISRO's future launch vehicles. It may be recalled that ISRO's first launch vehicle, SLV-3, was integrated fully in the horizontal and tilted to vertical prior to launch. As such a total integration plan was evolved and all the required ground support services like mobile service structure, umbilical tower with retraction mechanism, transportation and tilting devices of stages were developed in parallel. Stages which were prepared in vehicle integration building (VIB) were moved to launch pad in the sequence and the vehicle was built up. Integration, transportation and launch operation of three flights generated

considerable expertise and confidence for future launch vehicle integration. Thus the total ground facility was newly established and functioned without flaw. A computerized checkout system has been installed for conducting functional checks on the subsystems and systems of the launch vehicle such as control and guidance, telemetry and instrumentation, telecommand, tracking, sequencing etc. as well as on the integrated vehicle ensuring satisfactory performance within specified tolerances prior to launch.

Data monitoring and analysis

During the flight regime telemetry provides information about the performance of the launch vehicle in non-serial data mode related to motor pressures, strains, temperatures, control system actuators and electrical parameters and in serial mode data related to

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navigation, guidance, autopilot and sequencing parameters. All these data come in telemetry in pulse code modulator (PCM) streams PCM1, PCM2, PCM3 of 500, 500 and 70 KBPS respectively.

For data analysis, data were acquired in three phases namely real time, near real time and off-line. The telemetry data coming in real time were acquired and stripped from stations SHAR 1, SHAR 2, CARNICOBAR and TRIVANDRUM. The stripped data are sent to mission computer for real time display and data analysis. The parameters are processed and presented in engineering units for easy interpretation and further analysis

Product assurance

Quality and reliability were given the prime consideration in the realization of ASLV from the initial stages of the project. The consistent and dedicated efforts made in this direction were finally rewarded in the form of successful launch of ASLV-D3 where all the systems performed exactly according to specifications. The final countdown was flawless reflecting a high degree of quality and reliability that was built in the realization of systems and launch vehicle as a whole.

Realization of a product from the concept stage involves design, fabrication, testing, development, assembly and integration to exact specifications. In this process it is common to encounter deviations from specification, modification, redesign, retesting, failures etc. Cost and schedule also become critical parameters. Therefore, a properly defined and well thought-out product assurance programme was implemented. These measures can be classified into three major areas namely (i) quality and reliability, (ii) non-conformity and (iii) configuration control measures.

A detailed qualification plan was laid down for all the subsystems, components and materials and it is ensured that these plans were implemented to acceptable levels.

Protocols were defined to study the implication of the deviation at every stage. Experienced personnel from different disciplines were identified to study the deviations in totality and give dispositions.

In order to implement the changes in design and specification found necessary during product development phase it is necessary to study the implications with reference to other systems and interfaces. In order to regulate and document these changes configuration control measures were implemented.

Strict implementation of all these plans and protocols at every stage and an independent assessment on the performance of various systems contributed towards the successful launch

Conclusion

Successful launching of ASLV-D3 demonstrated the indigenous expertise available in the design, development and launch of complex satellite launch missions. It has validated a number of technologies such as strap-on autonomous stages, bulbous heat shield, closed loop guidance, real-time decision making system, digital autopilot, high energy solid propellant system, telemetry, software packages, vertical integration and ground station network interfaces required for future launch vehicle developments and fulfilled the specified objectives of ASLV programme.

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