Description of Launch Vehicle

Annex 1

1. Introduction

The object of this Annex is to provide an overview of the Ariane 4 series of launch vehicles. The following description is given by functional system.

Ariane 4 is a three-stage-launch vehicle with up to four strap-on boosters, above which is mounted an equipment bay. Various fairings can be mounted on the equipment bay for housing the payload. The launch vehicle maximum total lift-off mass is 471 tonnes, its height being 58.76 m. (see fig. A1.1.)

2. Electrical systems

2.1. Introduction

Most of the Ariane electrical systems are housed in the equipment bay at the top of the 3rd-stage; only a limited number of system elements are, for functional reasons, placed at various locations in the stages.

An on-board digital computer coordinates the activities of the various electrical subsystems of the vehicle. The electrical system provides the vehicle with total in-flight autonomy with the sole exception of the telecommand destruct signal sent from the launch centre.

Batteries are the only on-board electrical energy sources.

2.2. Guidance and control system (see fig. A1.2)

The vehicle guidance system computes the vehicle attitude command from the data of an inertial platform so as to optimize the vehicle performance for placing the payload mass on the chosen orbit.

The vehicle control system generates the nozzle-swivelling commands for the different stages maintaining the vehicle attitude to that computed by the guidance system.

The guidance function is performed by an on-board programmed flight computer, which executes the navigation calculations and implements the guidance law. It is active from the beginning of the 2nd-stage propulsion phase until the cut-off command of the 3rd-stage. 1st-stage flight is not guided, the vehicle having a preprogrammed attitude law.

The control function is performed with the aid of:

- sensors: inertial platform,
- command-generating units: the digital on-board computer calculates the attitude deviation (difference between the actual attitude and the attitude required by the guidance system) and generates the swivelling commands to the 1st, 2nd and 3rd-stages nozzles, the roll command for the 2nd-stage, and the attitude control commands for the 3rd-stage.
- executing units: each stage has amplification systems and actuators regulating the position of the nozzles.

The 1st-stage has four nozzles oscillating in the plane tangential to the thrust frame. This configuration enables pitch, yaw and roll control to be carried out by these nozzles.

The launch vehicle will have either no, 2 or 4 strap-on boosters depending on the required performance. Two types of booster are available with either solid (PAP) or liquid (PAL) propellant, equipped with fixed nozzles.

The 2nd and 3rd-stages each have a single nozzle and are equipped with ancillary systems for roll control.

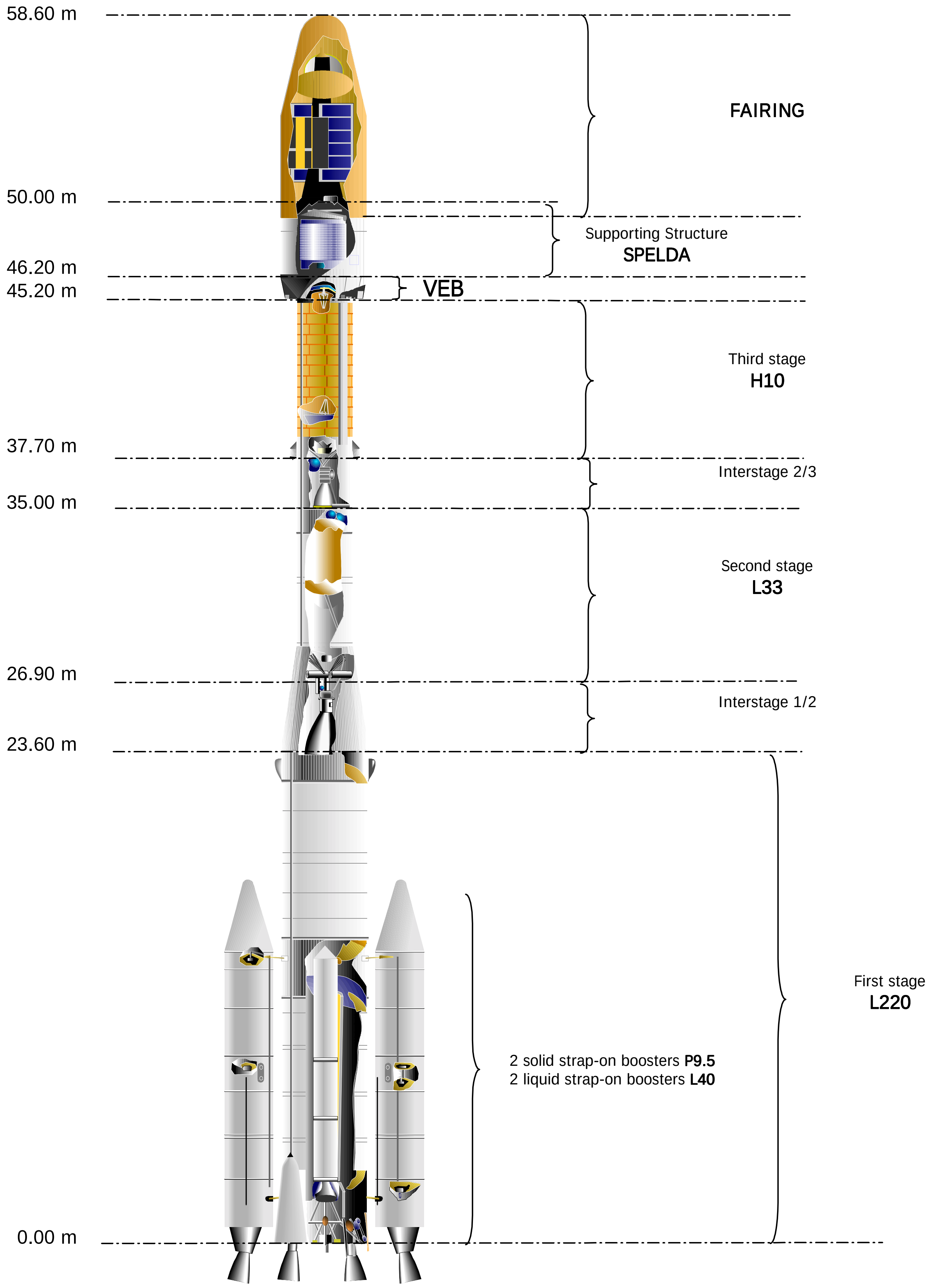

Fig. A1.1 – Ariane 44LP

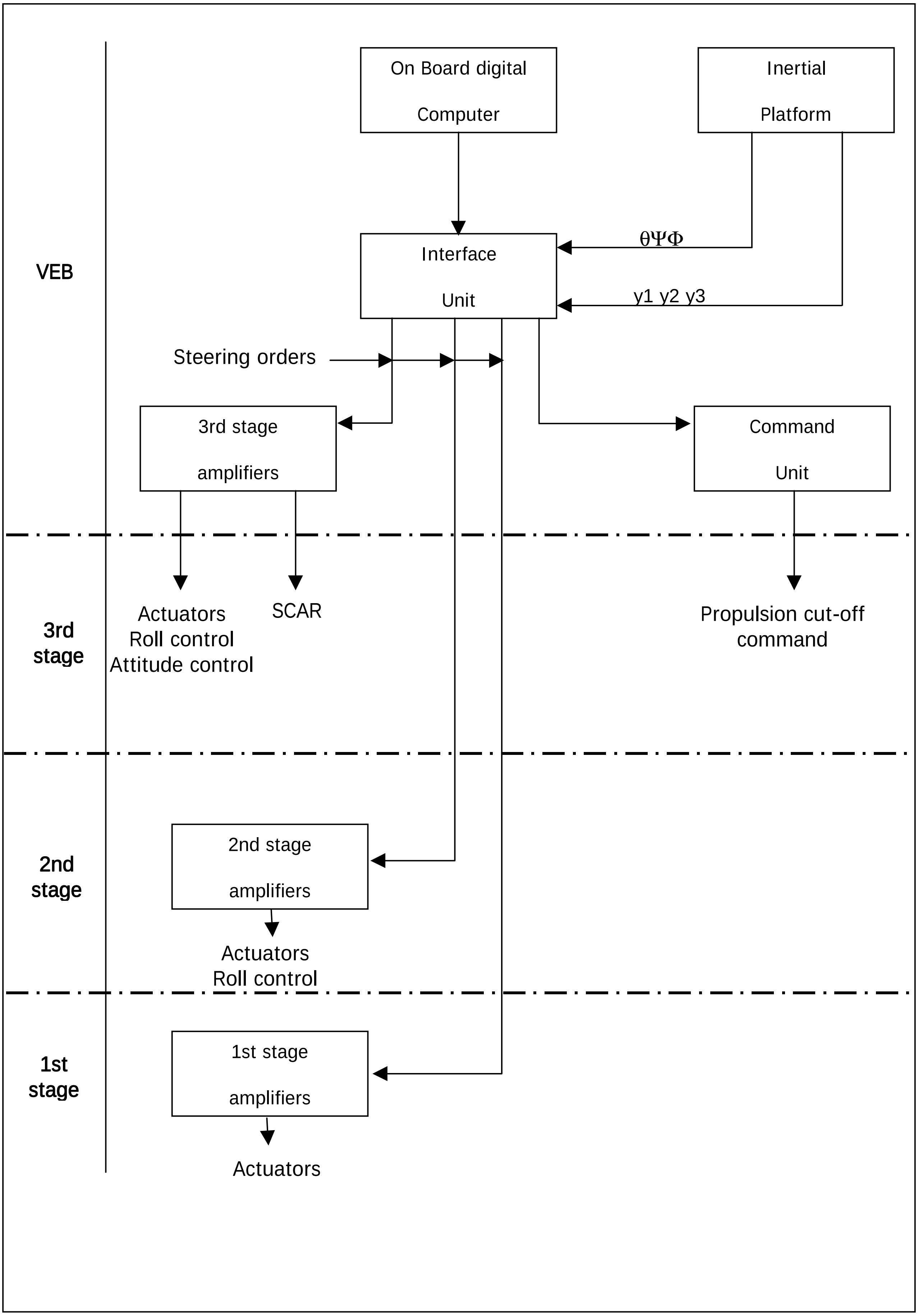

Fig. A1.2 – Inertial guidance chain diagram

These ancillary systems consist of sets of independent nozzles fed with hot gases from the gas generator on the 2nd-stage, and with cold pressurization gas on the 3rd-stage.

The ancillary system on the 3rd-stage is also designed to provide three-axis control after main engine cut-off. This enables an accurate injection of the payload in the desired attitude and, if required, a slow spin-up can be provided.

2.3. Sequencing system (see fig. A1.3)

The sequencing system initiates all the commands required for the execution of the various sequences governing the vehicle's in-flight behaviour. It is commanded by the on-board computer, which transmits commands in the order prescribed by the flight programme.

The sequencing of commands is reset after engine cut-off of each stage on detection of thrust decay.

A command transmitted by the computer, through its interface unit, is processed by a sequencing unit, which transmits signals matched to the executing units of the stages.

Command processing is carried out by two fully redundant systems, from the interface unit to the executing units.

The command signals from the sequencing system result in the following operations:

- electrical: change of PCM telemetry format, propulsion commands, operation of anti Pogo devices,

- pyrotechnic: initiation of acceleration and retro-rockets, 3rd-stage engine ignitors, stage separation, fairing jettisoning, satellites separation.

2.4. Tracking and destruction system

This enables the launch vehicle to be destroyed in-flight in the event of abnormal behaviour which could constitute an environmental hazard. The destruct command signal is generated on board in the event of premature stage separation. A destruct signal commanded from the ground results from an operational decision based on the processing of data for the actual trajectory of the vehicle. These data are obtained in real time by the vehicle tracking network consisting of ground tracking radars and transponders located in the vehicle equipment bay.

The tracking and destruction system is fully redundant, comprising two radar transponders and two telecommand receivers. The vehicle destruct commands are generated in a safety unit, which decodes the telecommands. The 3rd-stage destruct charge is commanded directly by this safety unit. The destruct charges of the 1st and 2nd stages are each fired by a Self/Telecommanded Destruct logic circuit ("Destruction Commandée et Automatique" - DCA), which receives or generates the destruct command; the logic circuits of this system are located in their respective stages.

The telecommand-destruct receiver system may be inhibited by the receipt of the OFF command sent from the CSG while the vehicle is still visible or in range.

Details of the destruction devices are given in paragraph 5 below.

2.5. Telemetry system

The S-band (frequency $\simeq$ 2.100 MHz) telemetry system transmits to the ground about 600 on-board measurements monitored during the flight of the vehicle. Knowledge of these enables the behaviour and performance to be evaluated throughout the flight. The PCM telemetry system is generated by a 240 kbit/s central unit linked by a data bus to various data acquisition units distributed in the launch vehicle subsystems.

3. Propulsion and pressurization systems

3.1. Introduction

The 1st-stage, Liquid Boosters (PAL) and 2nd-stage propulsion systems are similar and use the hypergolic liquid propellants UH25 and N_2O_4. The 3rd-stage propulsion system uses the cryogenic propellants liquid oxygen and liquid hydrogen, in a low-pressure chamber.

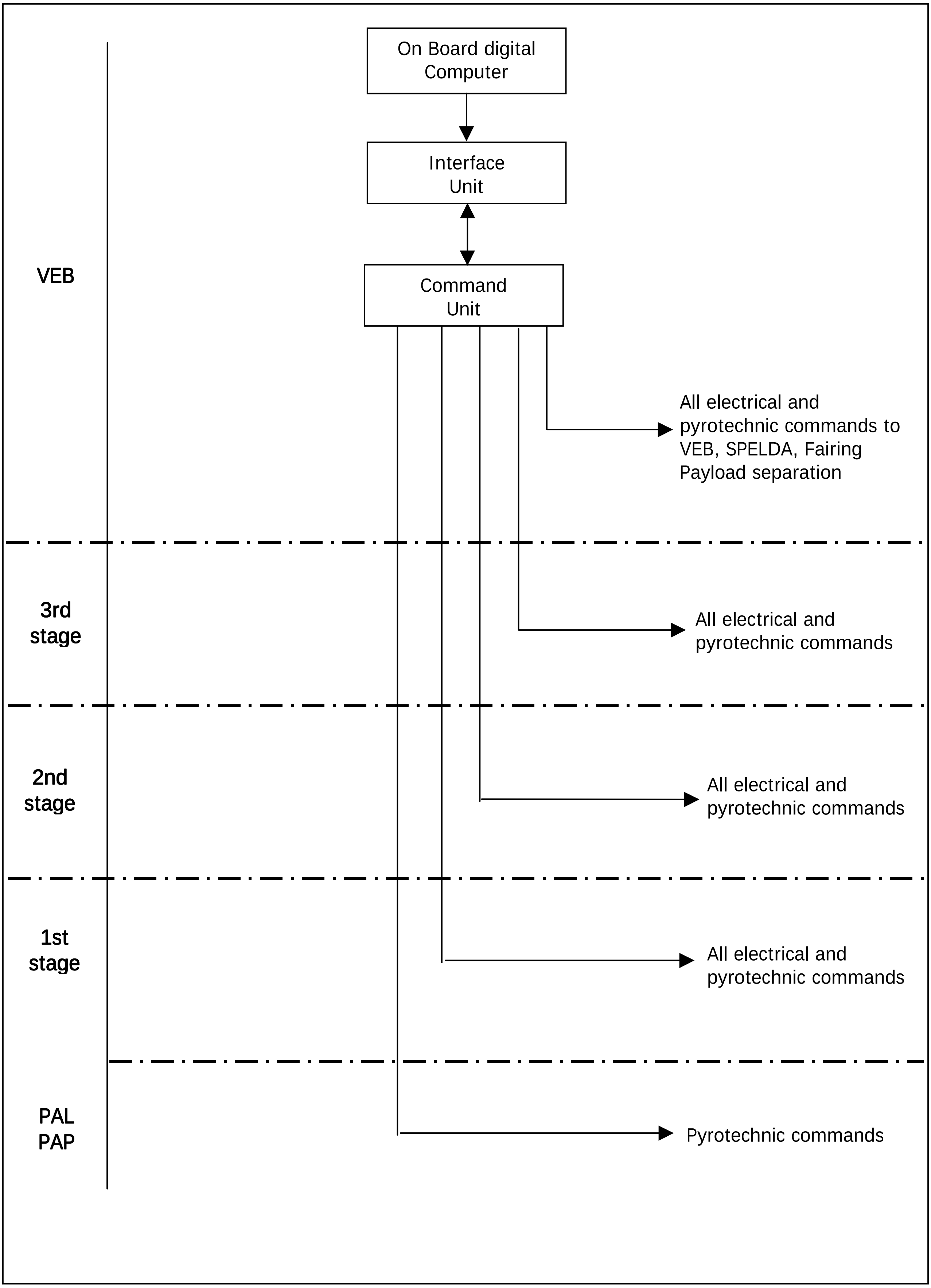

Fig. A1.3 – Control logic

3.2. First-stage propulsion system

3.2.1. Principle

The system comprises four Viking V engines developing a total thrust of about 2700 kN on the ground (about 3000 kN in vacuum) and up to 4 strap-on boosters equipped with Viking VI engines developing the same total thrust of about 2700 kN. The velocity increment imparted to the vehicle by the 1st stage with 4 liquid boosters (A44L) is approximately 3040 m/s.

Each engine forms an independent assembly supplied via individual valves from the propellant and water tanks; start-up is initiated simultanously for the four first stage engines, and for the liquid booster motors if used, by a ground command; ignition is spontaneous in the combustion chambers (hypergolic fuels). The operation of each engine is controlled by slaving its core pressure to a "reference" pressure supplied by nitrogen bottles. A gas generator fed with propellants in the stochiometric ratio, and with water to lower the temperature, supplies both the gas turbine, which drives the propellant and water pumps on a single shaft, and the tank-pressurisation system. Lastly, a balance regulator compares the propellant-injection pressures and acts on the N204 pressure down-stream from the pump in order to keep the propellant-mixture ratio constant in the combustion chamber.

A PAL propulsion system differs from that of a stage by the fact that the engines are fixed (not gimbaled), the nozzle axis being canted at 10° to the central core axis.

Solid-strap on boosters (if used) are ignited by ground command when the main first stage engine thrust has reached a predetermined value.

3.2.2. Operation

During the automatic launch sequence, the vehicle checkout system verifies the correct operation of the vehicle, gives the signal for ignition of the first stage and monitors the engine behaviour. If everything proceeds normally, a command, opening the vehicle release jaws, is given four seconds after ignition. In the event of an anomaly, the release jaws are kept closed and the engines shut down.

Ignition of the Ariane solid strap-on boosters occurs approximatly 4 seconds after main engines ignition and prior to lift-off.

The main operating characteristics for the VIKING engines are: (typical first stage values):

- Chamber pressure ....58.5 bar
- Turbopump rotor .... 10 000 rpm
- H20 delivery pressure. ....65 bar
- UH25 delivery pressure ....67 bar
- N204 delivery pressure ....69 bar
- Generator gas temperature .... 650°C
- Generator gas pressure...........................35 bar
- Tank pressurization level.......................... 5 bar
- Specific impulse in vacuum .... 278 s

The specific impulse (standard conditions) of the solid strap-on booster (PAP) motors is 264 s and the total impulse is 21 500 kN.s per PAP. The PAPs are jettisoned about 68s (A44LP), 71s (A44P), 95s (A42P) after ignition.

The PALs are jettisoned about 142s (A42L), 147s (A44LP), 150s (A44L) after ignition.

Propulsion stops on depletion of one of the propellants (UH25 or N204). The on-board computer detects this depletion by monitoring the acceleration of the vehicle and commands closure of the main propellant valves as soon as the acceleration becomes less than half its full-thrust value; at the same time, it initiates the 1st/2nd-stage separation sequence described in para. 4.

3.3. Second-stage propulsion system

3.3.1. Principle

This system comprises a single Viking IV engine developing a thrust of 800 kN in vacuum; the specific impulse is about 293s. The velocity increment imparted to the vehicle by the 2nd-stage is close to 2560 m/s.

The 2nd-stage propulsion system differs from that of the 1st-stage by having:

- a single gimbal mounted engine instead of four engines,
- an independent roll-control system,
- an engine nozzle adapted to operation in vacuum,
- helium-pressurization of propellants and water.

3.3.2. Operation

Engine ignition is commanded by the computer 0.3 seconds after 1st/2nd- stage separation. Start-up is assisted by acceleration rockets (see para. 4) which provide an acceleration acting on the propellants following 1st-stage engine cut-off.

The engine nozzle, initially set in a zero position receives swivelling commands for pitch and yaw correction, as soon as thrust, and hence acceleration, reaches its normal value. Guidance starts about 10 second after 1st-stage separation.

The main difference in operating characteristics from those of the 1st-stage are:

- Helium-bottle pressure .... 300 bar
- Tank pressurization level .... 3.5 bar
- Maximum roll torque .... 1000 m.N

The guidance system generates the propulsion cut-off command when the velocity increment to be imparted by the 2nd-stage is reached. A command is sent by the computer to simultaneously close the propellant inlet valves. At the same time, the computer initiates the 2nd/3rd-stage separation sequence described in para. 4.

3.4. Third-stage propulsion system

3.4.1. Principle

This system comprises a single HM7B type cryogenic engine developing a thrust of 64.7 kN in vacuum ; the specific impulse is 446.5 s. The engine is gimballed along the pitch and yaw axis. Roll control is achieved by a system of auxiliary nozzles fed with gaseous hydrogen.

The operation of the 3rd-stage propulsion system, as for the lower stages, requires a turbopump fed with gases from a generator supplied with liquid oxygen and liquid hydrogen in a mixture ratio close to 0.9 in order to limit the temperature to 880°K.

The turbopump has two shafts. On the first, rotating at about 60 000 rpm, are the turbine and the hydrogen pump and on the second, rotating at about 13 000 rpm, is the oxygen pump ; the turbopump is actuated by a solid-cartridge starter and feeds the gas generator and the engine with liquid H_2 and liquid O_2. As these propellants are not hypergolic the generator and the engine are ignited by a pyrotechnic device. Operation of the engine is controlled by a system regulating the injection flow rate into the generator by means of cavitating venturis and by a pressure regulator on the oxygen circuit only. This device limits variations in engine operating parameters particularly for the thrust and mixture ratio, whose variations are in the order of 1.5 %. The engine injector diffuses into the chamber liquid, oxygen directly from the pump together with gaseous hydrogen at 150°K obtained by heating the liquid H_2 in the upstream (regenerative) section of the nozzle. A small part (6 %) of the liquid H_2 circulates in the divergent section of the nozzle, maintaining its temperature at about 1080°K, and escapes at the extremity of the divergent section.

The oxygen tank is pressurized by means of helium, which is stored in a bottle at 100°K and 200 bar.

The hydrogen tank is pressurized by gaseous hydrogen at 100°K obtained by mixing liquid H_2 with gaseous hydrogen tapped at the exit of the regenerative section. This system is activated at engine start-up. During 1st and 2nd-stage flight, pressurization is maintained with helium. In the event of self-pressurization due to excess natural vaporisation, the tank pressure is limited by a safety valve. The propellant feedlines are cooled throughout 1st and 2nd-stage flight by a continuous flow of a small quantiy of waste propellant.

3.4.2. Operation

Engine start-up is commanded by the computer 3 seconds after 2nd/3rd stage separation. The stage nominal thrust is reached approximately 10 seconds later.

The main operating characteristics are (typical values):

- Chamber pressure.................................. 36 bar
- Rotor speed of the turbine and H2 pump .... 60 750 rpm
- Rotor speed of the the O2 pump .... 12 960 rpm
- Temperature of generator gases .... 880° K
- Pressure of generator............................. 24 bar
- H2 tank pressurization level.................... 2.9 bar
- O2 tank pressurization level................... 2.1 bar
- Maximum roll torque .... 800 N.m

The guidance system generates the propulsion cut-off command, when the required transfer orbit is reached. The propulsion cut-off sequence starts with a command which closes the O_2 circuit valve at the gas generator input.

Gaseous hydrogen is used to provide 3 axis control after 3rd stage engine cut-off which occurs approximately 790 s after ignition. A total impulse of more than 13 500 N.s is available for attitude and spin maneuvers.

4. Separation systems

4.1. Introduction

The operation of the vehicle involves the jettisoning of mass whose usefulness has ceased in the course of flight, e.g. the solid and/or liquid strap-on boosters, the fairing, above a given altitude, as well as spent stages.

4.2. Separation systems

Seven separation systems are available: two for the strap-on boosters, one for the interstages, one for the fairing, one for the SPELDA upper part, one for the SYLDA upper part, and one for the spacecraft. Each separation requires mechanical disconnection of the assemblies to be separated, followed by distancing.

4.2.1. Liquid strap-on boosters separation

This occurs after about three quarters of the first stage flight corresponding approximately to mach 5. Separation is achieved by pyrotechnicaly cutting the three attachment fittings. The strap-on boosters are then forced away from the first stage central core by 6 rockets of the same type as those used for the interstage separation.

4.2.2. Solid strap-on boosters separation

This occurs at the end of subsonic flight.
Separation is achieved by pyrotechnicaly cutting the two attachment fittings.
The strap-on boosters are then forced apart from the first stage central core by 4 high energy spring systems.

4.2.3. Interstage separation

This occurs at periods of virtually zero vehicle acceleration. Disconnection is obtained by a pyrotechnic cutting cord. The cord is fired simultaneously at two points and separation is achieved in less than 1 ms.

The two stages are forced apart by retro-rockets mounted on the lower stage, which decelerate that stage.

During the separation phase, acceleration rockets on the upper stage are fired, imparting acceleration in the direction of its velocity ; this is to ensure that the fuels collect in the tanks in such a manner that they flow correctly to the engine ; it also contributes to forcing the two stages apart.

4.2.4. Fairing jettisoning

This occurs during 2nd-stage flight, i.e. during vehicle acceleration. Separation is achieved by first ejecting the clampband by pyrotechnic action, and then the two half fairings are separated from each other by pyrotechnic cutting action along their joint line and are ejected laterally, while remaining parallel to one another (due to the action of a linear thrusting joint).

4.2.5. Vehicle/spacecraft separation

This occurs after burn-out of the 3rd-stage, which then remains attitude-controlled. Separation is achieved by releasing the clampband by pyrotechnic action. The vehicle and payload are forced apart by the action of springs located around the periphery of the interface frame.

4.2.6. SPELDA-top separation (if dual launch)

Separation of the SPELDA-top structure is achieved by means of a linear charge cord device which cuts the structure separating its upper and lower halves. Springs then impart a vertical impulse to jettison the SPELDA upper part.

4.2.7. SYLDA-top separation (if dual launch)

Separation of the SYLDA-top structure is achieved by ejecting a clampband by pyrotechnicaly cutting two connecting bolts.

Springs then impart a vertical impulse to jettison the SYLDA upper half.

5. Destruction systems

The vehicle has four destruction systems, one for each stage and one for the PAL.

The 1st-stage destruction system consists of pyrotechnic cords running along a generatrix of each tank.

The PAL destruction system is similar to that of the 1st-stage.

The 2nd-stage destruction system is based on the same principle as the 1st-stage, but has a single cord common to both tanks (located near the common bulkhead, on a generatrix).

The location of the 3rd-stage destruction system is identical to that of the 2nd-stage, but a dihedral charge is used in order to allow for the distance from the wall structure (due to the presence of the Klegecell thermal insulation layer).

6. Structures

6.1. Introduction

All the structures are of light alloy with the exception of the 1st-stage propellant tanks, which are fabricated of steel in order to afford simultaneous protection from temperature and the corrosive action of the pressurization gases, the PAL tanks, which are fabricated in stainless steel, the PAP case, and part of the 1st stage water tank.

6.2. First-stage structures

6.2.1. Central Core

The two propellant tanks are identical, cylindrical in shape (diameter 3800 mm, height 7400 mm) with ellipsoidal bulkheads. They are interconnected by means of a cylindrical inter-tank skirt of the same diameter as the tank and with a height of 2688 mm and by the water tank cylinder with a height of 730 mm. The cylindrical part of the upper tank is extended by the forward skirt, which has the same diameter and a height of 1500 mm. The foward skirt supports the eight 1st-stage braking retro-rockets and connects the 1st-stage with the interstage structure. The thrust frame is generally cylindrical in shape (diameter of 3800 mm and height of 2300 mm) and has a caisson structure whose upper part connects with the UH25 tank and whose lower part provides a mounting for the four engines.

On the top of the UH25 tank, inside the intertank skirt, is the water tank common to the main engines and the PAL, if used. 8200 litres (max.) of water are contained between the upper UH25 tank bulkead and another bulkead, identical in shape, fabricated in glass fibre reinforced plastic, and linked to the tank bulkhead, at the periphery, by an aluminium alloy cylinder, 730 mm high.

6.2.2. Liquid propellant strap-on boosters (PAL)

The liquid strap-on boosters comprise two stainless steel tanks, a reduced version of the first stage central core tanks, with a diameter of 2150 mm and a length of about 4920 mm each. The rear skirt houses the Viking engine, an intertank skirt links the UH25 and N204 tanks and a forward skirt carries a conical head, for aerodynamic reasons. The skirts and the conical head are fabricated in aluminium alloy. Each PAL is linked to the central core by a rear mounting system (PAL rear skirt/central core thrust frame) and a forward 2-point mounting system (PAL forward skirt/central core intertank skirt). The PAL rear skirt and intertank skirt also house the six separation rockets. Total height of a PAL is about 18.6 m.

6.2.3. Solid propellant strap-on boosters (PAP)

The solid strap-on boosters are cylindrical with a conical head, a diameter of 1071 mm and a total height of about 11.5 m. Each contains 9500 kg of propellant. The case is fabricated in steel and the nozzle axis is canted at 12° to the central core axis. The PAP is linked to the central core by rear and forward mounting systems. On the PAP, the mounting systems are located on the rear skirt and on the forward skirt. On the central core, attachment points are located on the thrust frame and on the intertank skirt.

6.3. Second-stage structure

The propellant tanks form a cylinder (diameter 2600 mm, height 6515 mm) with hemispherical bulkeads divided into two vessels by a common hemispherical bulkhead with its concave face forward. The pipework feeding the N204 (upper tank) to the engine passes through the lower tank (UH25). The thrust frame consists of a stiffened skirt comprising a cylindrial section (with the same diameter as the tank and a height of 188 mm) and a conical part (height 1350 mm) bearing the gimbal unit mounting flange.

The second stage aft skirt is conical (height 1570 mm) and connects the 1st/2nd interstage conical skirt (height 3310 mm) and the 2nd-stage thrust frame to which it is attached at the base of its cylindrical part. The rear skirt/interstage skirt conical assembly transmits the 1st-stage thrust to the rest of the vehicle and provides continuity between the 1st-stage diameter (3800 mm) and the 2nd-stage diameter (2600 mm). The rear skirt carries the water torus (average diameter 2240 mm; cross-section diameter 340 mm) attached by rods, and the four acceleration rockets. It houses the pyrotechnic cutting system used for 1st/2nd-stage separation and carries the two braking retro rockets used for 2nd/3rd-stage separation. The cylindrically-shaped forward skirt (height 1245 mm) extends the tank section and connects the 2nd-stage to the carbon fiber 2nd/3rd-interstage cylindrical skirt of the same diameter.

6.4. Third-stage structures

The propellants tanks form a cylinder (diameter 2600 mm, height 6624 mm) with hemispherical bulkheads, divided into two vessels by an insulating intermediate bulkhead (two concentric spherical caps separated by a phenolic honeycomb layer under vacuum). The tanks carry thermal insulation over their entire surface.

The tank assembly is elongated by a short forward skirt (2600 mm; height 308 mm) connecting with the equipment bay, and by a short rear skirt (diameter 2600 mm; height 112 mm) on which the thrust frame is mounted. This thrust frame consists of a conical structure (height 1105 mm) together with a cylindrical section (diameter 2600 mm, height 420 mm) providing continuity with the rear skirt. The cylindrical section carries the four acceleration rockets and the pyrotechnic cutting system used for 2nd/3rd-stage separation. The 2nd/3rd-interstage skirt (diameter 2600 mm; height 2730 mm) forms the connection between the 2nd and 3rd-stages ; the lower part of this skirt is sealed off by an insulating disk for limiting heat exchange between the two stages.

6.5. Vehicle Equipment Bay (VEB) structure

The VEB consists of 4 parts fabricated in honeycomb material with carbon fibre facing:

- an internal conical part, providing the diameter 1920 mm interface to the payload,
- an external conical part (1000 mm high), carrying either the fairing or the SPELDA with an external diameter of about 4 m, linked at its base with the internal conical part and with the 3rd-stage forward skirt, which has a diameter of 2.6 m,

- an horizontal annular plate, carrying the VEB equipment, attached to the 3rd-stage forward skirt,

- 12 removable panels, enclosing the VEB equipment compartment, between the conical external part and the annular plate. This allows for easy accessibility to the VEB equipment, without interfering with the payload compartment.

The VEB height is about 1 m, and the mass is of the order of 400 kg.

6.6. Fairing structure

The fairing consists of two shells fabricated in aluminium alloy honeycomb with carbon fibre facing. The external diameter is 4 m, the thickness is 25 mm, the height is either 8.6 m or 9.6 m, and the weight is between 800 kg and 900 kg. The fairing halves are linked by rivets which are cut by a pyrotechnic cord at separation. They are secured on top of either the VEB or the SPELDA by means of a two piece steel band tensioned by 2 pyrotechnic bolts.

6.7. SPELDA structure

<u>Short SPELDA</u> (m = 410 kg)
The short SPELDA consists of two parts fabricated in aluminium alloy honeycomb with carbon fibre face sheets.

The bottom part is a cylinder of 4 m external diameter and 2 m height. It is secured on top of the VEB by means of 180 bolts.

The upper part is a cylinder of 1.80 m in height, with an external diameter of 4 m, with a 1 m high truncated cone on top, presenting a ∅ 1920 interface to the upper spacecraft.

The bottom and upper part of the short SPELDA are joined by a pyrotechnic separation device (LCCD), and springs are placed inside the bottom part to impart a separation velocity to the upper part.

<u>Mini SPELDA</u> (m = 320 kg).

The mini SPELDA consists of a cylinder and a truncated cone on top of the cylinder, both manufactured in aluminium alloy honeycourb with carbon fiber face sheets.

The cylinder is 1.8 m high with a 4 m external diameter. The cone is 1 m high and presents a ∅ 1920 interface for the upper spacecraft.

The mini SPELDA is secured on top of the VEB by means of 180 bolts. 59 mm above the bolted joint with the VEB, the mini SPELDA comprises a pyrotechnic separation device, and springs are installed inside the cylinder to impart a separation velocity to the separated mini SPELDA. The springs are fitted on the separated part.

<u>Streched mini SPELDA</u> (m = 350 kg)

The difference between mini SPELDA and stretched mini SPELDA is limited to the height of the cylinder which is 2.1 m for the streched mini SPELDA.

7. Mass breakdown

Approximate propellant masses are as follows at the instant of lift-off:

- 1st-stage: N2O4, UH25, water .... 232 tonnes
  solid strap-on boosters .... 9.6 tonnes each
  liquid strap-on boosters .... 39.7 tonnes each

- 2nd-stage: N2O4, UH25, water .... 35.4 tonnes

- 3rd-stage: Liquid oxigen and
  hydrogen....................................... 11.8 tonnes