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Cabin Escape System: critical subsystems identification and separation subsystem design

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List of Acronyms

CAC	Calculation of Aerodynamic Coefficients
CES	Cabin Escape System
CFD	Computational Fluid Dynamics
CRM	Capsule Rescue Motor
CRS	Capsule Rescue System
ECLSS	Environmental Control and Life Support Subsystem
EDL	Entry Descent and Landing
FC	Flight Computer
FCS	Flight Control Subsystem
FM	Flight Management
GLOW	Gross Lift-Off Mass
GNC	Guidance, Navigation and Control
HYPMOCES	HYPersonic MOrphing system for a Cabin Escape System
ISS	International Space Station
MECO	Main Engine Cut Off
RCS	Reaction Control System
RLV	Reusable Launch Vehicle
RPA	Rocket Propulsion Analysis
SRB	Solid Rocket Booster

SRM	Solid Rocket Motor
SRP	Solid Rocket Propulsion Analysis
STSM	Space Transportation System Mass
TAEM	Terminal Area Energy Management
TCS	Thermal Control Subsystem
TOSCA TS	Trajectory Optimization and Simulation of Conventional and Advanced space Transportation System
TPS	Thermal Protection Subsystem

Introduction

In the next years the field of high atmosphere and Space transportation could be no more only directed to prepared astronauts, aware of the challenging environment and trained for high body stresses but also opened to private civil passengers. One of the visionary ideas of the last years is to utilize high atmosphere-Space transportation vehicles for ultra-long distance travels, enabling to connect different points on Earth in very short times (e.g. Europe-Australia could be flown in 90 minutes). Also Space tourism for "everyday" people is a concept which could become realistic and find a mature market. Since now the only way to reach high altitudes or even the Space is to utilize launch vehicles based on high performance rockets. These systems manage lot of energy and therefore are linked to inherent safety challenges. Thus, if the intention is to open the market of high atmosphere transportation to civil passengers, extremely safe vehicles must be developed. In case of a catastrophic failure, taking into account the possible mission profiles and the recovery option concepts developed since now, an effective solution to ensure passenger survival could be the use of a Cabin Escape/Rescue System (CES or CRS). This rescue concept consists on the separation of a Capsule self sustained in terms of structure, propulsion system, electrical system and thermal control.
A Cabin Escape System is indeed studied for the hypersonic point-to-point vehicle "SpaceLiner" under development in DLR Bremen. Investigating the potential critical subsystems required for a Cabin Rescue System scenario in this thesis particular attention has been posed on the separation motors. Four options of separation motors, considering solid rocket motors, SpaceX' SuperDraco engines and a new concept of liquid propellant engines (based on SuperDraco's performances), have been studied designed and dimensioned with regards to a worst-case scenario. A further analysis of the capsule escape in others critical trajectory points has been performed. As result, all the four options fulfil the considered requirements and limitations but only one could be elected as the best option. More work could be performed in the point of view of structural mass analysis, propellant composition and constraints linked to fragmentation debris originated from a possible explosion.

Part I

High atmosphere and Space transportation emergency rescue systems

Chapter 1

Identification of missions for civil passenger and manned Space - High atmosphere transportation

In this Chapter is reported an overview of the possible missions which allow human space transportation. A further distinction regarding mission phases, catastrophic events and vehicle configuration is analysed in the following sections. As first approach is possible to split out the missions for human space transportation in:

- **Access to Space;**
- **Suborbital flight;**
- **Point to Point.**

Access to Space: This type of missions are focused on introducing a vehicle beyond 100 km of altitude (Karman's Line, commonly representing the boundary between Earth's atmosphere and outer space) in order to begin an orbit around the Earth or to reach a defined orbit. Once in orbit, the spacecraft can perform different in-space operations (e.g. releasing payloads, docking with existing infrastructures, following interplanetary trajectories, etc. . .).

Suborbital flight: This type of missions are thought to let paying passengers, astronauts (in training) or scientific payloads experiencing few minutes of microgravity. The spacecraft can reach the Karman's Line altitude (100 km) but it will not complete an entire orbit. In a typical mission profile, engines are shut down before reaching the target altitude and the vehicle coasts up to its highest point (let passengers experiencing few minutes of weightlessness) and after that a re-entry phase starts immediately. In some cases, the re-ignition of the engines can assure the possibility for the vehicle landing on the same site.

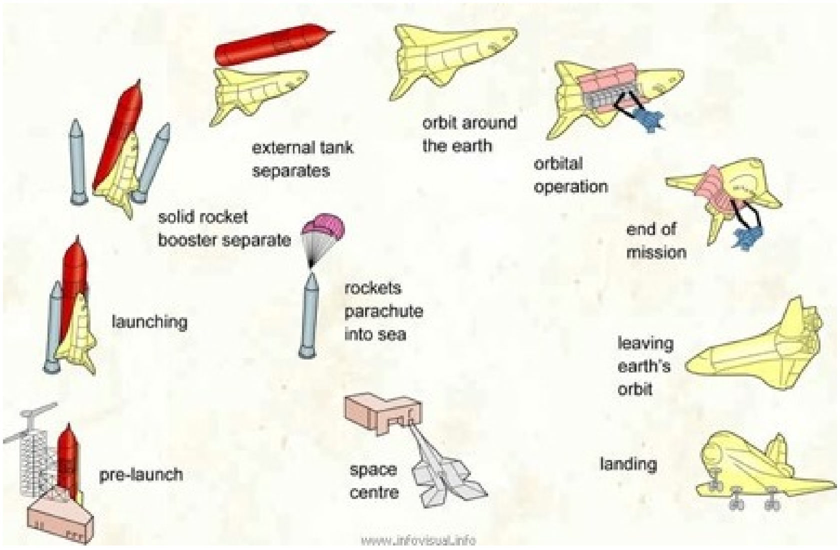


Figure 1.1: The Space Shuttle mission was an example of Access to Space mission.

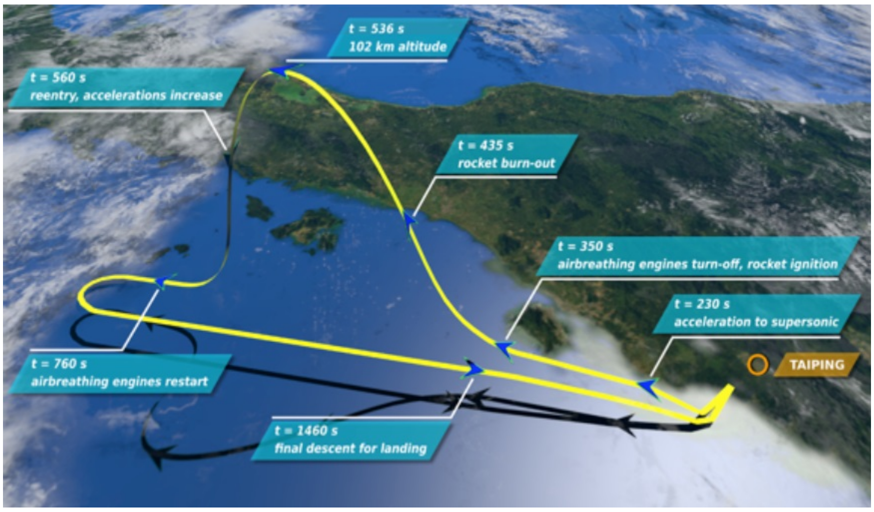


Figure 1.2: Example of Suborbital Flight profile.

Point to Point: This type of missions are focused on transporting paying passengers between antipodal sites on the Earth surface (I.e.: Europe-Australia, North America-Asia) strongly reducing the time of flight. The idea is to drive the vehicle until high stratospheric flight levels in order to perform a hypersonic flight.

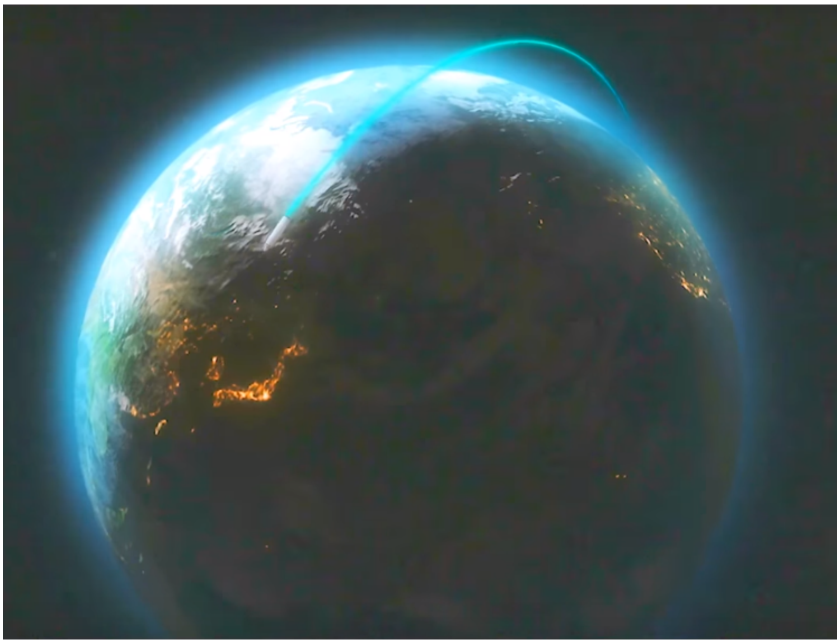


Figure 1.3: Extract of SpaceX' video for the presentation of BFR as hypersonic civil passenger transport Point-to-Point rocket for the route New York-Singapore.

1.1 Identification of mission phases

For each defined family of missions, it is important to identify the main mission phases. This is a preparatory activity for the hazard analysis that should be carried out for each single mission phase. From an accurate investigation is found that some phases are common for all the types of mission while others are characteristic for a determined mission. The phases division is presented in Table 1.1, Table 1.2 and Table 1.3:

	Access to Space Phases
1)	Prelaunch and Lift-Off/Take-Off
2)	Ascent
3)	Separation of possible stages
4)	Orbital phase
5)	Separation of others possible stages
6)	Re-entry
7)	Descent
8)	Landing

Table 1.1: Access to Space mission phases.

	Suborbital flight Phases
1)	Prelaunch and and lift-off/take-off
2)	Airbreathing engines ascent
3)	Airbreathing shut-down, rocket ignition
4)	Rocket ascent
5)	Separation of possible stages*
6)	Cruise
7)	Descent
8)	Glide phase
9)	Airbreathing restart
10)	Final descent and landing

Table 1.2: Suborbital flight mission phases.

	Point-to-Point flight Phases
1)	Prelaunch and lift-off/take-off
2)	Ascent
3)	Separation of possible stages
4)	Cruise
5)	Descent
6)	Landing

Table 1.3: Point-to-Point mission phases.

*Depending on the specific mission profile, the stage separation may occur before Phase 3).

1.2 Identification of possible catastrophic events for each mission phase

The associated hazards related to a certain phase of the mission lead to the determination of the type of rescue and escape system which should be used to ensure the survival of the crew. It is important take into account that many hazards can be the same for all flight phases. For example, malfunction in life or mission critical subsystems can occur during any phase, and it can be catastrophic. Aerospace systems engineers developed techniques, such as system redundancy, to avoid this type of predicament. Similarly, structural failure can occur during any phase of flight. Again, aerospace structural engineers developed techniques, such as defining a design limit for a load and preserving a factor of safety against that load, to prevent failures under anticipated design conditions. The job of a rescue system designer is to consider design solutions for those scenarios not covered by design techniques. The use of the odds it's a common solution performed by design engineers in order to achieve a practical design solution in terms of weight and performance. For example it is practically impossible to design a spacecraft structure capable to withstand the worst-case meteoroid impact or that can protect the crew and life critical systems for the worst-case solar flare. It is even impossible to install an in-space crew medical facility capable of handling every illness or injury that can arise during flight. For these risks, which are very hard to evaluate and control, a space rescue system often provides the degree of assurance necessary to proceed to flight.

Table 1.4, 1.5 and 1.6 report the possible catastrophic events during each phase of a certain mission.

	Access to Space Phase	**Possible catastrophic event**
1)	Prelaunch and Lift-Off/Take-Off	- Unpredicted explosion at Launch Pad/Runway - Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.
2)	Ascent	- Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.
3)	Separation of possible stages	- Malfunction in the mechanism for the separation, impossibility to realize the separation.
4)	Orbital phase	- Subsystem failure (explosion, loss of altitude control, loss of critical function, toxic material release). Loss of structural integrity due to natural environmental hazard (solar radiation, micrometeoroid orbital debris impact) .
5)	Separation of others possible stages	- Malfunction in the mechanism for the separation, impossible to realize the separation.
6)	Re-entry	- Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure, improper dangerous trajectory.
7)	Descent	- Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.
8)	Landing	- Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory.

Table 1.4: Possible catastrophic events for Access to Space mission

	Suborbital flight Phase	**Possible catastrophic event**
1)	Prelaunch and and lift-off/take-off	-Unpredicted explosion at Launch Pad/ Runway. - Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.
2)	Airbreathing engines ascent	- Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or Airbreathing engines failure.
3)	Airbreathing shut-down, rocket ignition	- Impossibility to turn-off Airbreathing engines due to malfunction, impossibility to switch on rocket engines due to malfunction.
4)	Rocket ascent	- Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or rocket failure.
5)	Separation of possible stages	- Malfunction in the mechanism for the separation, impossibility to realize the separation.
6)	Cruise	- Subsystem failure (explosion, loss of control, loss of critical function, loss of structural integrity, natural environment induced failure).
7)	Descent	- Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.
8)	Glide phase	- Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.
9)	Airbreathing restart	- Impossibility to realize the airbreathing engines restart, subsystem malfunction, airbreathing engines failure, propulsion failure.
10)	Final descent and landing	- Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory, malfunction in the EDL (Entry Descent and Landing) subsystem.

Table 1.5: Possible catastrophic events for Suborbital flight mission

	Point-to-Point Phase	Possible catastrophic event
1)	Prelaunch and lift-off/take-off	- Unpredicted explosion at the Launch Pad/ Runway. - Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.
2)	Ascent	- Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.
3)	Separation of possible stages	- Malfunction in the mechanism for the separation, impossibility to realize the separation.
4)	Cruise	- Subsystem failure (explosion, loss of control, loss of critical function, loss of structural integrity, natural environment induced failure).
5)	Descent	- Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.
6)	Landing	- Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory.

Table 1.6: Possible catastrophic events for Point-to-Point mission

1.3 Identification of possibles configuration alternative options

For each mission (Access to Space, Suborbital flight and Point-to-Point) can be considered three types of stage-configuration:

- Single stage;
- Two stages;
- Three or more stages.

In the mission-phases identification (Chapter 1.1), have more stages leads to consider more phases related to the stages separation.
Today a significant improvement in the stage configuration is represented by the possibility to reuse the stages necessary for the ascent propulsion. In fact, the intent is, once a stage is detached from the rest of the vehicle, to land it in a controlled way and recover it (Example: Falcon 9, Falcon Heavy). This reduces the costs for a single launch allowing more launch per year.

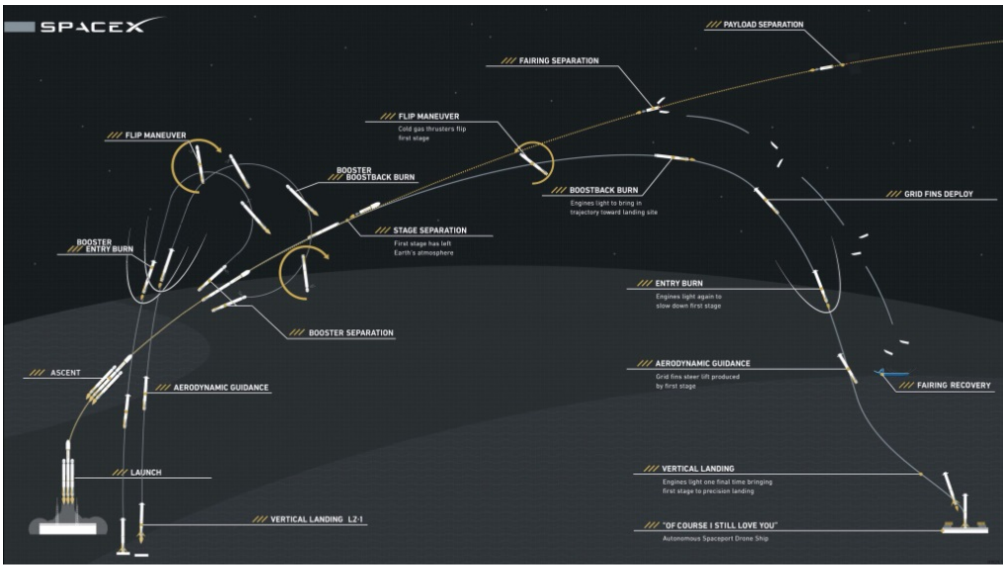


Figure 1.4: Falcon Heavy can be considered a Three stages configuration. SpaceX had expressed hopes that all rocket stages would eventually be reusable*.

*SpaceX has since demonstrated routine land and sea recovery of the Falcon 9 first stage. For the first flight of Falcon Heavy, SpaceX had considered attempting to recover the second stage, but did not execute this plan.

Another subdivision can be done regarding the Take-Off and Landing strategy. The concepts developed until now are such grouped:

- Horizontal Take-Off and Landing (HTOL);
- Vertical Take-Off and Landing (VTOL) ;
- Vertical Take-Off, Horizontal landing (VTHOL).

Horizontal Take-Off and Landing (HTOL): This configuration requires a runway for the take-off as well for the landing. The vehicle could use airbreathing jet engines, ramjets and rockets. An example is the conceptual study of LAPCAT MR2.

Vertical Take-Off and Landing (VTOL): This configuration was often used for military aircraft (I.e.: Harrier) which had to take-off and land on a flattop. In the aeronautical field Helicopters, Gyrodine or Convertiplane are other examples of VTOL . Thinking about a vehicle which has to go in the high atmosphere until now no manned vehicle VTOL was ever tested but in rocket field there are some examples of VTOL like Falcon 9.

Vertical Take-Off, Horizontal landing (VTHOL) This configuration requires a Launch Pad for the launch and a runway for the landing. Seats could change the inclination in order to let g-forces always in forward direction (eye balls in). The Space Shuttle is an example of this family.

Chapter 2

Identification of possible recovery options for passengers rescue

In this Chapter is presented a literature review of existing concepts from both space and aeronautic domains regarding the rescue of the crew/passengers in case of hazards in the carrying vehicle. Given the conventional wisdom and the reality of historical incidents, the development of rescue and escape systems reflects an approach to control risk during the dynamic phase of flight. Most of the rescue system are only conceptual and few have proceeded into any hardware development stage. As stated in Chapter 1.2 the phase of flight and the associated hazards determine the types of rescue and escape systems that might require to ensure the survival of the crew/passengers.

Prelaunch escape options generally are of two modes. The first is a ground exit mode consisting in disconnecting from the vehicle configuration, opening a hatch in the structure and departing from the launch pad area as fast as possible through some sort of slide wire. For example the Space Shuttle provided this type of escape but also the forthcoming to launch Boeing's CST 100 Starliner tested this type of escape (Figure 2.1) .

The second prelaunch mode is similar to in flight abort modes involving a flyaway concept. Prelaunch and ascent escape flyaway capabilities have been dominated by escape rockets that lift the entire crew module away from the launch vehicle stack. The requirements for these systems are driven by two estimates, the warning time for an imminent explosion and the blast danger radius.
The danger of large blast area combined with very short warning times, forces launch escape rockets to have very high thrust and short firing times. These high thrust and rapid characteristics tend to make escape rocket systems into propulsion units that are of little use in the flight profile except for performing the escape

function. As such, can happen that they are jettisoned during the flight after they are no longer required for escape, decreasing the mass of the launch vehicle.

Figure 2.1: Commercial Crew astronauts slide down wires during a Boeing/United Launch Alliance (ULA) emergency-egress system demonstration at Cape Canaveral Air Force Station's Launch Complex 41 in Florida (June 19, 2018). Ref. [2].

In the category of rocket systems for the escape, Apollo Launch Escape System (LES) has several interesting features (Figure 2.2). First the escape system consists of a solid-fuelled rocket, mounted above the capsule on a tower, which delivers a relatively large thrust for a brief period of time to send the capsule to a safe distance away from the launch vehicle, at which point the capsule's parachute recovery system can be used for a safe landing on ground or water. The tower and rocket are jettisoned from the space vehicle in a normal flight at the point where it is either no longer needed, or cannot be effectively used to abort the flight. These have been used on the Mercury, Apollo, and Soyuz capsules.
The crew are seated in ejection seats as used in military aircraft; each crew member returns to Earth with an individual parachute. Such systems are effective in a limited range of altitudes and speeds. These have been used on the Vostok and Gemini capsules.
The Apollo abort system possesses many of the features typical of a crew escape system. In particular it has several modes of operation depending on altitude and

velocity. However, due to the environment to which they expose an escaping crew member, systems of this type can't assure a rescue with no consequences. The possibility of a relatively unprotected crew member passing through rocket plumes or launch vehicle debris makes these systems less acceptable for use.

Figure 2.2: On the left is the Apollo 11 Saturn V launch vehicle at launch (July 16, 1969). The rocket tower is situated at the very top of the Saturn rocket. On the right is the launch abort system in action – pulling the spacecraft away from the launch vehicle.

In the Space Shuttle program although the vehicle had no crew escape rocket system, the winged vehicle design permitted new options for self rescue that were not possible for previous launch systems. Once the Shuttle's Solid Rocket Boosters were ignited, the vehicle was committed to Lift-Off. If an event requiring an abort happened after SRBs ignition, it was not possible to begin the abort until SRBs burnout and separation about two minutes after launch. There were several abort modes available during ascent, divided into the categories of "intact aborts" and "contingency aborts". The choice of the abort mode depended on how urgent the situation was, and what emergency landing site could be reached. The abort modes covered a wide range of potential problems, but the most commonly expected problem was a Space Shuttle main engine (SSME) failure, causing the vehicle to have insufficient thrust to achieve its planned orbit. The difference between "intact abort" and "contingency abort" modes was that the first represented those missions that because of failures couldn't achieve the planned orbit, thus resulting in landing the Space Shuttle and its crew on a prepared runway. The latter, introduced after the loss of Challenger (1986), were developed in case of impossibility by the Space Shuttle to reach a runway and provided that at a specific altitude, the crew engaged an automated routine to pilot the vehicle in a straight path and, opening the side hatch, bail out through parachutes (Figure 2.3). To facilitate high-altitude bailouts, the crew began wearing pressured suits during ascent and descent. Before 1986, Space Shuttle's crews for operational missions wore only fabric flight suits.

An ejection escape system, sometimes called "Launch Escape System", has been discussed many times for the Shuttle. After the Challenger and Columbia losses, great interest was expressed in this. The first two shuttles, Enterprise and Columbia, were built with ejection seats but It was only these two that were planned to be flown with a crew of two. Subsequent Shuttles were built only for missions with a crew of more than two, including seats in the lower deck, thus ejection seat options were deemed to be infeasible.Challenger, Discovery, Atlantis, and Endeavour were built with no ejection seats. Ejection seats were not further developed for the Shuttle because of difficulties in ejecting seven crew members (when three or four were roughly in the center of the forward fuselage surrounded by vehicle structure), limited ejection envelope (ejection seats only work up to about 5500 km/h and 40 km of altitude) and not applicable for an atmospheric re-entry.

Figure 2.3: Space Shuttle escape pole system represented the "contingency abort" mode (2004).

An alternative to ejection seats was an escape crew capsule or cabin escape system where the crew would be ejected in protective capsules, or the entire cabin would be ejected. Such systems have been used on several military aircraft. Like for the ejection seats, a capsule ejection for the shuttle would have been difficult because of difficulties in exiting the vehicle crew members sat in the middle of the forward

fuselage, surrounded by substantial vehicle structure.
Cabin ejection would work for a much larger portion of the flight envelope than ejection seats, as the crew would be protected from temperature, wind blast, and lack of oxygen or vacuum. In theory an ejection cabin could have been designed to withstand re-entry, although that would entail additional cost, weight and complexity. Nevertheless, cabin ejection was not pursued for the Space Shuttle because of several reasons such as the need of a long period of inactivity in order to make major modifications and the need to add lot of weight to the Orbiter's mass which required the design of an offset balance weight in order to maintain inviolate the Orbiter's center of gravity. This meant huge sacrifice in payload mass and major costs.

Regarding the soviet shuttle Buran, it was planned to be fitted with the crew emergency escape system, which would have included ejectable seats and full-pressure suit, qualified for altitudes up to 30 km and speeds up to Mach three. Buran flew only once in fully automated mode without a crew, thus the seats were never installed and were never tested in real human space flight.
In the Buran program (1976-1992) an interesting feature had been the study of a concept for escape system. The study provided to use the nose of the shuttle as rescue vehicle. The Escape Nose Part of the orbital vehicle included the double-deck cabin, solid propellant motors for emergency escape (mounted in the nose), stabilizing flaps, retractable fans and a landing gear. The device could extend its application range both in low and high atmosphere and beyond any stage of the flight trajectory at any possible emergency conditions, including the flight vehicle explosion. As stated before Buran never tested with crew thus the concept of the nose part as rescue system remained on paper.

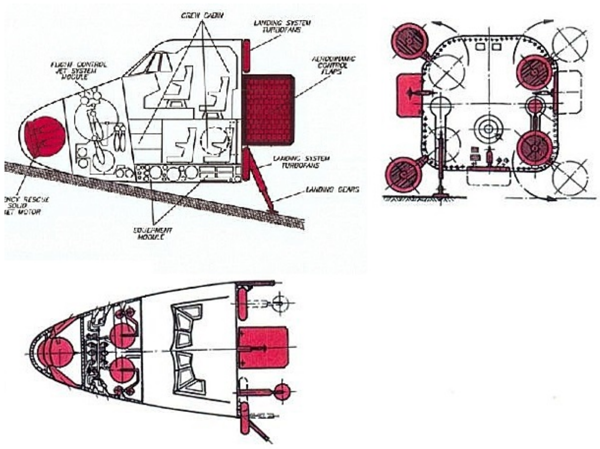


Figure 2.4: Separable rescue nose part of Buran. In red the emergency devices.

Regarding ejection seats, in the military ambit have been developed bailout systems which provide the ejection of the pilot through a capsule able to enclose the seat and than ensure the landing with parachutes up to slightly beyond the troposphere. In this way it would be possible survive at high altitude (around 12 km) and supersonic velocities (around Mach 2). This was the system utilized for the first American supersonic bomber B-58A Hustler (Figure 2.5). Also military aircrafts like XB-70 Valkyrie and General Dynamics F-111 used escape systems based on an ejectable capsule able to enclose the seats.

In the ambit of aeronautical civil transportation, a system of ejection seat for each passenger has been studied for the rescue during subsonic flight (Figure 2.6). The idea is, in case of catastrophic accident, to eject each passenger/pilot seat after having first ejected the upper part of the vehicle fuselage. To each capsule a parachute will be provided. The parachute will automatically open to allow a soft landing of the passenger/pilot. Considering missions for human transportation in high-atmosphere (beyond the stratosphere) like the ones in Chapter 1, a system of ejection seat for each passenger could be potentially applied for the rescue only in the tropospheric horizontal flight and would be better develop capsules able to enclose each seat in order to increase the possibility of survive for untrained passengers.

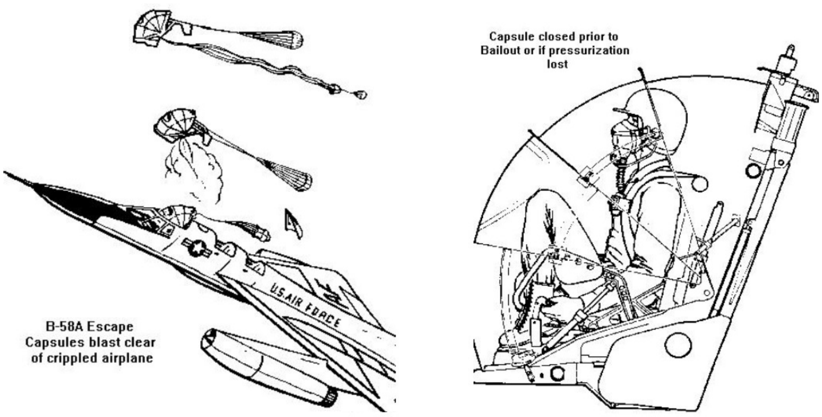


Figure 2.5: Bail out of B-58A Hustler's escape capsule (1962). The capsule during normal flight remains open.

Remaining in the category of commercial aircraft other interesting systems for the rescue of the passengers in case of severe malfunction have been studied. This concepts are based on ejectable-capsule/s that is/are attached to the fuselage and can if necessary be separated from the aircraft in few seconds.

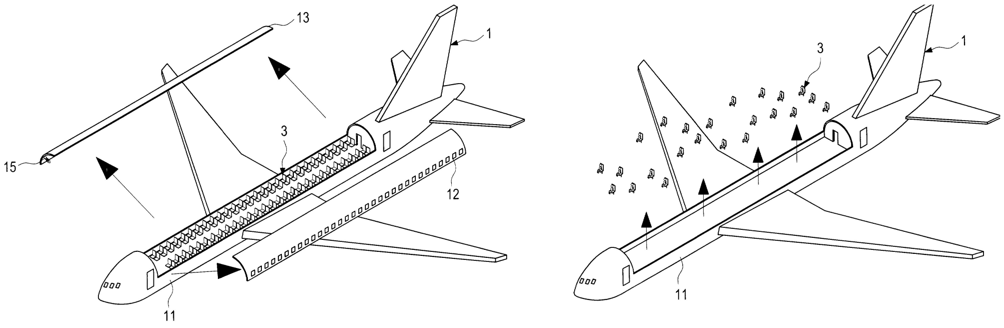


Figure 2.6: Patent US 20040016850A1 (2004). Concept of ejection seats for a civil passenger airplane. Add capsules able to enclose the seats could ensure the survival at supersonic velocities in the troposphere.

The one in Figure 2.7 provide individual pods that are separable from the aircraft and can eject individually, following the separation and ejection of the upper part of the fuselage. Parachutes are deployed to assist the safe descent of the pods. Airbags are also deployed to soften the landing and provide flotation in case of water landing.
In the concept of Figure2.8 the capsule is attached to the fuselage trough detachable mounts, all connections of the aircraft with the capsule can disconnect. For example, power cables can be disconnected by detachable couplings. The capsule descent uses parachutes and it can come down on an inflatable raft or land on a shock absorbing platform.

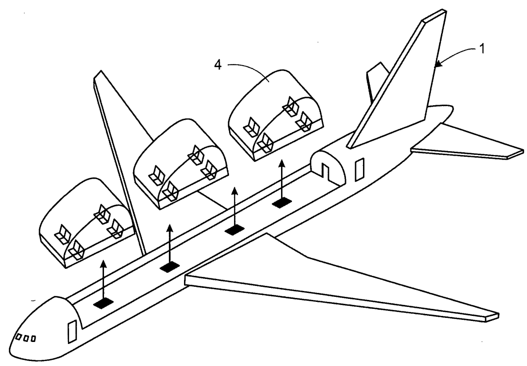


Figure 2.7: Patent US 20110233341A1 (2010). Ejectable pods able to assure the rescue of the passengers in a commercial aircraft.

Figure 2.8: In commercial aircrafts escape systems through detachable capsule have been studied since late 80's. Here a concept (2015) of the ukranian engineer Vladimir Tatarenko.

Returning to the field of human space transportation, since the retirement of NASA's Space Shuttle fleet in 2011, there's been just one vehicle ferrying crew members to and from the International Space Station (ISS): Russia's Soyuz spacecraft. So, for the past seven years, the American space agency has been paying its Russian counterpart for crew transportation services. The arrangement isn't cheap; each seat on the three-passenger Soyuz costs more than 70 million. But things could change. SpaceX and Boeing have been developing their own reusable astronaut taxis for years, under multibillion-dollar NASA commercial crew contracts. SpaceX's first crewed test flight is currently scheduled for April 2019, and Boeing's is supposed to happen in the middle of that same year. The two companies are developing two private crew-carrying spaceships: SpaceX's Crew Dragon V2 capsule and Boeing's CST-100 Starliner.
Crew Dragon V2 is a modified version of its cargo counterpart Dragon, can transport up to seven astronauts and launch atop the Falcon 9. Dragon V2 riders will be able to kick back during their trips to and from the ISS, as the capsule is designed to be completely autonomous. Boeing's CST-100 Starliner is similar to Crew Dragon in several fundamental ways. It's also a reusable, seven-passenger capsule designed to dock with the ISS autonomously, and it comes back down to Earth under parachutes.Boeing's capsule is designed to be compatible with multiple launch vehicles and touches down on land, not in the ocean, and therefore also provides impact-cushioning airbags at its rounded base.

These spacecrafts have the peculiarity that are outfitted with emergency escape system. For SpaceX's Dragon V2 it consists in eight SuperDraco engines built into the capsule's walls. If something goes wrong at any point during a Crew Dragon flight, these engines can fire up and carry the spacecraft and its passengers to safety.

Starliner's emergency escape system consists of four launch-abort engines built into the capsule's service module. Boeing performed a "hot-fire" test of these engines, which were provided by aerospace company Aerojet Rocketdyne, in June 2018 and detected a propellant leak shortly afterwards. The company traced the leak to a problem with some engine valves and is working to fix the issue, Boeing representatives said recently.

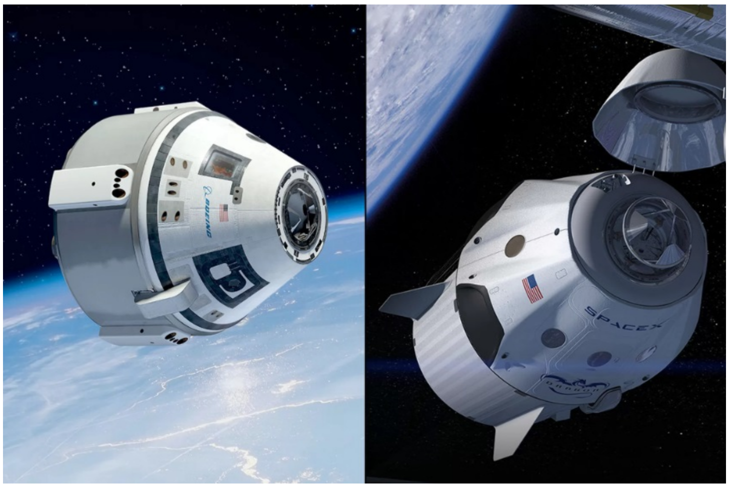


Figure 2.9: Artist's illustration of Boeing's CST-100 Starliner capsule (left) and SpaceX's Crew Dragon in Earth orbit. Both vehicles are part of NASA's Commercial Crew Program to ferry astronauts to and from the International Space Station.

Figure 2.10: Dragon V2 pad abort test (May 2015).

Another concept of escape system developed in the last years since 2013, is represented by the European Commission project HYPMOCES (Hypersonic Morphing for a Cabin Escape System). The aim of the project is to investigate and develop technologies in the area of control, structures, aerothermodynamics, mission and system required to enable the use of morphing in a capsule escape systems for future hypersonic transport aircrafts.

In case of hypersonic flight, escape systems are necessary to face both with the risk associated to high energy management and the system reliability, mainly for the propulsion. A large cabin escape system able to change its shape and automatically reconfigure during an abort event after ejection would balance the compromise between the constraints.
In fact its implementation is challenged by the integration with a larger structure, the load factors for the passengers, the ejection propulsion concept, the capability to withstand extreme thermal environment (plasma flow) and the adaptability to wide rang of abort scenarios (low and high speed and altitude). This multi-phase nature of the return flight makes morphing an attractive solution for a hypersonic escape system. The increase of the lifting capability after ejection of an escape capsule and the increase of aerodynamic control surfaces is a strong requirement in order to safely return to ground the crew composed also by untrained persons. HYPMOCES project is discussed more in detail in Chapter 6.

Figure 2.11: HYPMOCES Baseline Concept, detailed design (arrows:morphing).

After the perspective of the various existing concepts for passenger's recovery and rescue, it could be possible draw up a general subdivision for the rescue solutions, applicable for the missions specified in Chapter 1, in the following categories:

- **Launch Escape System**: system connected to a space capsule, used to quickly separate the capsule from its launch vehicle rocket in case of a launch abort emergency, such as an impending explosion. These systems permit rescue only for failures at the launch;
- **Cabin Rescue System**: system which provides the separation of a rescue cabin from the rest of the damaged spacecraft in case of catastrophic event. The design of such type of systems is often very complex.
- **Ejection seats**: system which, in case of catastrophic accident, ejects each passenger/pilot seat after having ejected the upper part of the fuselage. This concept is applicable only in horizontal flight phases. To each seat a parachute is provided and it automatically opens to allow a soft landing of the passenger/pilot.
- **Rescue with the consecutive stages (For multi-stage configurations)**: taking into account a multi-stage configuration, during launch and ascent (when the stages are connected yet), if a failure is detected in a previous stage, a good survival option could be to move up the separation of the consecutive stage from the previous one and realize an emergency landing.

In this list is not present the solution which uses seats hooked on slide wires for the escape from the tower of Launch Pad in case of Prelaunch hazard. This solution could be applied mostly for vehicles with vertical Lift-Off and thanks to its simplicity could be effective and low cost only for Prelaunch abort.

Chapter 3

Identification of possible scenarios for the rescue re-entry vehicle

Basically there are three different shapes of re-entry vehicles:

- **Ballistic;**
- **Semiballistic;**
- **Controlled.**

Ballistic re-entry: in this type of re-entry the trajectory and the attitude are not possible to control. Some precautions are adopted to try to control the attitude, for example positioning heavier material carefully in order select the gravity center of the vehicle and expose the crew to g-forces in forward direction. The re-entry trajectories are steep and this type of geometry is often used for returning payload back to Earth. It was used in the beginning of space flight era because of its convenience. Examples are the Soviet Vostok, Mars and Venera vehicles. Accelerations are in the order of 8-9 g.

Semiballistic re-entry: the most manned re-entry vehicles are semi-ballistic (Soyuz, Apollo, Shenzhou). They produce a small amount of lift, enough to reduce the heat flux and deceleration for a manned crew. Accelerations are in the order of 4 g.

Controlled re-entry: this type of re-entry requires a complex vehicle. A winged orbiter (like Space Shuttle orbiter, Buran, Hermes, HYPMOCES) realizes the re-entry in a controlled way thanks to subsystems installed on board (FCS, RCS, FC, FM and others). Generally looks more like a conventional aircraft and could be able to land on a runway.

Another distinction could be done for the rescue vehicle configuration shape in terms of Lift/Drag ratio:

- Low efficiency;
- Medium efficiency;
- High efficiency (Lifting body).

Ballistic re-entries are performed through vehicles with low efficiency shape configuration. In semiballistic re-entries the shape configuration is characterised by medium efficiency while, as their name, Lifting bodies produce an amount of Lift thanks to their high efficiency shape which include wings.

Chapter 4

Identification of possible subsystems needed for the rescue system

In Table 4.1 are reported the possible subsystems to install on board a rescue system and their relative functionality. Depending on the recovery option and on the type of re-entry scenario selected, some subsystems could be used and others not. Nevertheless, there are some subsystems that are essential in any case. These subsystems are: the electric subsystem, the rescue propulsion subsystem, the propellant required for the propulsion, the separation mechanism and the Entry Descent and Landing subsystem.
More is the accuracy required for the control of the re-entry vehicle, thus for the scenario of re-entry, more are the subsystems installed on board. For example, subsystems like the Flight Control Subsystem and the Reaction Control Subsystem are installed only in rescue systems which provide controlled navigation and attitude. While, for vehicles destined to high atmosphere or Space, if is necessary an atmospheric re-entry, subsystems like Thermal Protection Subsystem, Thermal Control Subsystems and Environmental Control and Life Support Subsystem are essential. Body Suits could be further elements for ensure passengers survival in unpredicted environments. Whenever are required communications, displays, flight management or navigation, an avionic subsystem is also necessary.
Increase the type of subsystem on-board leads to more complex rescue system with larger mass, power and volume budget.

Subsystem	**Function**
Electric Subsystem	- Provide electric energy to the system.
Thermal Control Subsystem	- Provide control and regulation of thermal loads.
Thermal Protection Subsystem (TPS)	- Provide passive resistance to high thermal loads.
Propellant	- Provide fuel and oxidizer to the propulsion subsystem.
Propulsion subsystem	- Provide the thrust required by the mission profile.
Entry Descent and Landing (EDL)	- Permit the landing of the system.
Flight Control Subsystem (FCS)	- Permit the navigation and control of the system with aerodynamic surfaces.
Separation mechanism	- Realize the separation of the system from what is seriously damaged.
Reaction Control Subsystem (RCS)	- Provide the attitude control of the system.
Avionics	- Provide Communication and Audio, Displays, Flight Control, Flight Management, Identification and Surveillance, Navigation.
Environmental Control and Life Support Subsystem (ECLSS)	- Manage of the atmosphere, water, wastes and food inside the system.
Body Suit	- Provide pressurization and oxigen to pilots and passengers.

Table 4.1: Possibles subsystems – functions for a rescue systems.

Scenarios-Subsystems Tables and critical subsystems identification

In "Appendix" are reported several tables for a preliminary study of the subsystems required to install on board a rescue system which operates in a certain scenario. A wide number of scenarios is studied, investigating the subsystems selection for a specific rescue scenario classified according to the type of mission, the phase of flight, the possible catastrophic event, the main vehicle configuration, the recovery option, the shape efficiency and the type of rescue flight. Not interesting for this subsystem study is the option to use emergency seats on slide wires for Prelaunch escape. This because the preliminary analysis aims to identify aerospace subsystems to install on a escape system integrated with the main vehicle.
From the investigation through the tables is found that some subsystems are indispensable for every scenario of emergency rescue. This subsystems, eligible as "critical" are: the electrical subsystem, the separation mechanism, the propellant required for the separation and the Entry Descent and Landing subsystem.
Subsystems like TCS or TPS could be critical in case of their use (for example if is required an atmosphere re-entry) but are not indispensable for every scenario.

Part II

Study of different options for Cabin Rescue System of DLR's Spaceliner

Chapter 5

DLR's SpaceLiner and its mission

The SpaceLiner (Figure 5.1) is a hypersonic point-to-point passenger transportation concept developed by the German Aerospace Center (DLR) since 2005. With the capacity of 50 passengers, it is capable of travelling between Western Europe and Australia in roughly 90 minutes on a suborbital trajectory. Further, an extended 100 passenger variant for travelling between e.g. Western Europe and the West Coast of North America is also under investigation.
The SpaceLiner consists of two fully reusable parallel stages based on liquid rocket propulsion technology; a winged Liquid Fly-Back Booster (LFBB) and the main orbiter, each containing LOX/LH2 propellant and the relative engines.

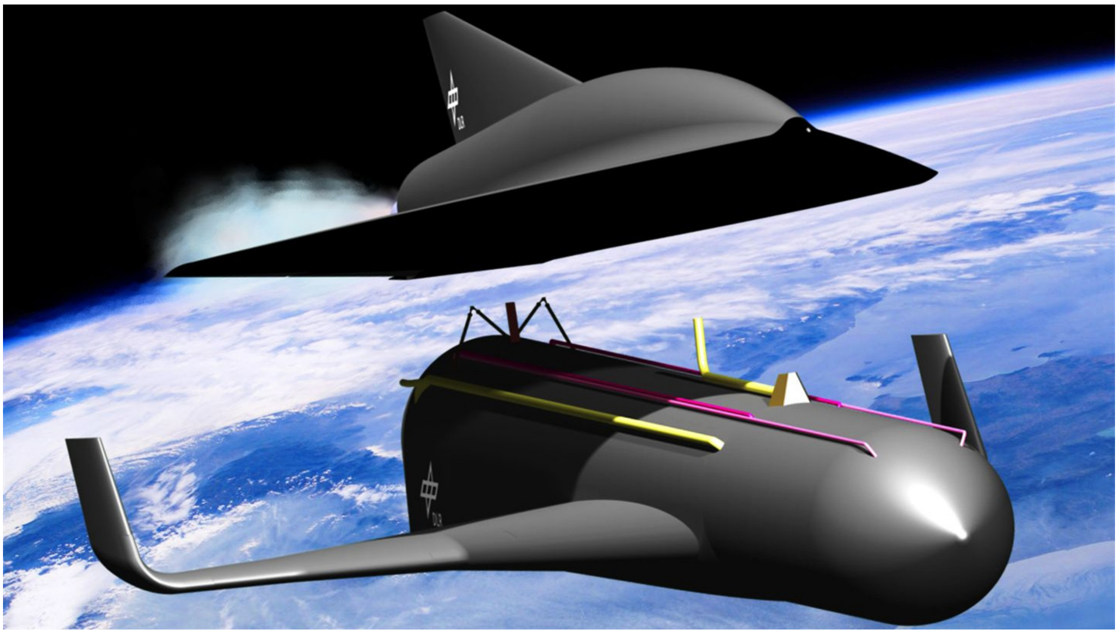


Figure 5.1: DLR's SpaceLiner

The key premise of the original concept inception is that the SpaceLiner ultimately has the potential to enable suitable low-cost space transportation to orbit while at the same time revolutionizing ultra-long distance travel between different points on Earth. The number of launches per year should be strongly raised and hence manufacturing and operating cost of launcher hardware should dramatically shrink.
Ultra-long distance travel from one major business center of the world to another major agglomeration on Earth is a huge and mature market. Since the termination of Concorde operation, intercontinental travel is restricted to low-speed, subsonic, elongated multi-hour flight. An interesting alternative to air-breathing hypersonic passenger airliners in the field of future high-speed intercontinental passenger transport vehicles is a rocket-propelled, suborbital craft. Such a new kind of "space commercial transportation" based on a two stage RLV has been proposed by DLR under the name SpaceLiner.
Ultra-fast transportation far in excess of supersonic and even potential hypersonic airplanes is definitely a fundamental new application for launch vehicles.
By no more than partially tapping the huge intercontinental travel and tourism market, production rates of RLVs and their rocket engines could increase hundredfold which is out of reach for all other known Earth-orbit space transportation. The fast intercontinental travel space tourism, not only attracting the leisure market, would as byproduct, also enable to considerably reduce the cost of space transportation to orbit as demonstrated by vehicle design and cost estimations in Ref. [3]. The functionality of rocket propulsion is a proven technology since decades and their performance characteristics are well known. Furthermore, a rocket powered RLV-concept like the SpaceLiner is highly attractive because the flight durations are two to three times lower than those of even the most advanced airbreathing systems.
Although additional times for travel are to be accounted, the actual time needed for travelling with the SpaceLiner might still be reduced by 75% to 80% compared to conventional subsonic airliner operation (Ref. [4]). In contrast to the first generation of SST, thus a substantial advantage in travel times and hence improved business case can be expected.

5.1 SpaceLiner architecture and geometry

The current arrangement of the reusable booster and of the orbiter is presented in Figure 5.2. Stage attachments are following a classical tripod design. The axial thrust of the booster is introduced through the forward attachment from booster intertank into the nose gear connection structure of the orbiter. The aft attachment takes all side and manoeuvring loads. The option of a belly to belly connection is no preferred for two reasons: the first is related to the generation of a strong unintended aerodynamic interaction of the two wings and propellant crossfeed lines on the booster which would be directly affected by hypersonic flow during re-entry of this stage; the second is that all LOX-feedlines and LH2-crossfeed connection are attached on the booster's top outer side, thus, subjected to flow in the relatively cold wake region. The feedlines of the upper stage are completely internal and ducted underneath the TPS.

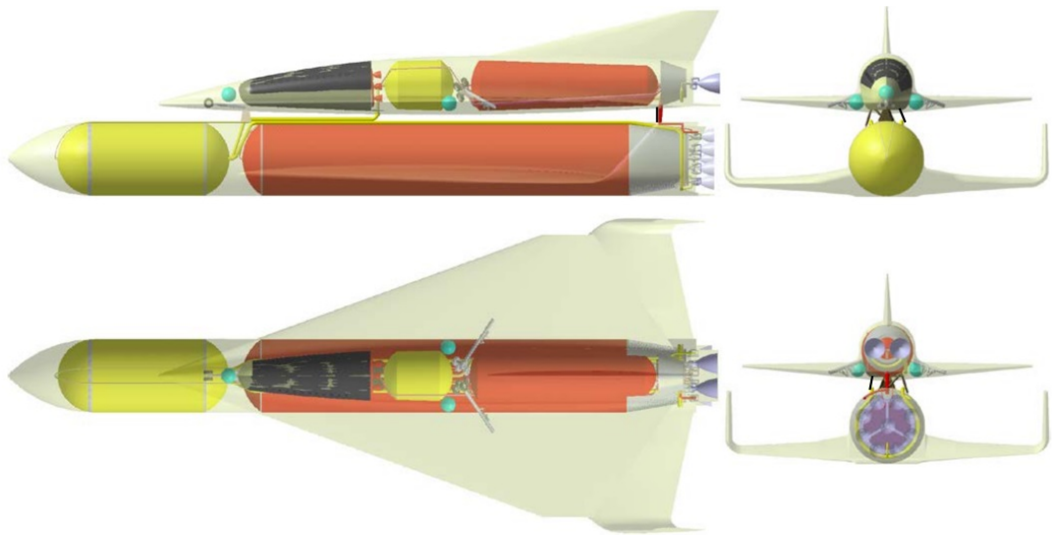


Figure 5.2: Sketch of SpaceLiner launch configuration

The main dimensions of the booster configuration are listed in Table 5.1 while major geometry data of the SpaceLiner passenger stage are summarize in Table 5.2

Length $[m]$	Span $[m]$	Height $[m]$	Fuselage diameter $[m]$
82.3	36.0	8.7	8.6

Table 5.1: Geometrical data of SpaceLiner booster stage

Length [m]	Span [m]	Height [m]	Fuselage diameter [m]
65.6	33.0	12.1	6.4

Table 5.2: Geometrical data of SpaceLiner passenger stage

5.2 SpaceLiner system masses

The SpaceLiner mass budget is iteratively calculated. System margins of 14% (12% for propulsion) are continuously added to all estimated mass data despite more and more detailed vehicle and subsystem design. This relatively conservative approach is chosen in order to ensure a robust development phase of this advanced vehicle with ambitious safety and reusability requirements.
The preliminary structural sizing of the booster fuselage resulted in a significant increase in the structural mass of the large integral LH2-tank. Overall booster stage dry mass is slightly below 200 *tons* (Table 5.3). The passenger stage mass is derived as listed in Table 5.4. The total fluid and propellant mass includes all ascent, residual, RCS propellants and the water needed for the active leading edge cooling.The SpaceLiner GLOW reaches about 1832 *tons* (Table 5.5) for the reference mission Australia-Europe.

	Value	Unit
Structure	123.5	*tons*
Propulsion	36.9	*tons*
Subsystem	18.9	*tons*
TPS	19.1	*tons*
Total dry	198.4	*tons*
Total propellant loading	1272	*tons*
GLOW	1467	*tons*

Table 5.3: Mass data of SpaceLiner booster stage

	Value	Unit
Structure	55.3	*tons*
Propulsion	9.7	*tons*
Subsystem	43.5	*tons*
TPS	22.3	*tons*
Total dry	129	*tons*
Total fluid and propellant loading	232.1	*tons*
GLOW incl. passengers and payload	366	*tons*

Table 5.4: Mass data of SpaceLiner passenger stage

	Value	Unit
Total dry	327.4	*tons*
Total propellant loading	1502	*tons*
GLOW incl. passengers and payload	1833	*tons*

Table 5.5: Mass data of SpaceLiner passenger launch configuration

5.3 SpaceLiner passenger transport mission

The ambitious west-bound Australia-Europe mission has been used as the reference case since the beginning of the SpaceLiner investigations. This flight distance should be served for 50 passengers on a daily basis in each direction. Several other, shorter intercontinental missions exist, which potentially generate a larger market demand. For this reason SpaceLiner configuration derivative has been studied, which could transport up to 100 passengers.

The launch and ascent noise as well as the sonic boom reaching ground are most critical for a viable SpaceLiner operation in the future. The selection of potential SpaceLiner launch and landing sites will likely be influenced by constraints due to generated noise. Therefore, operational scenarios of the SpaceLiner are established taking into account realistic launch and landing sites as well as groundtracks which are acceptable with respect to sonic boom constraints overflying populated areas and fast accessibility to major business centers.

Conventional existing airports located close to densely populated areas are not suitable for SpaceLiner operations. Three alternative launch and landing site concepts should fit for almost all potential locations:

- On-shore close to sea or ocean;
- Arificial island;
- Off-shore launch site and on-shore landing site.

All three options are not entirely new and have already been realized in the past. A specific choice depends on the particular location where a spaceport is planned to be built with climate and geographical location playing an important role. Different trajectory options have been traded in the past mostly for Australia-Europe reference mission for up to 50 passengers. These were following standard launch vehicle vertical ascent with an initial azimut in North-Eastern direction overflying the Artic Sea before approaching Europe from North-Eastern Atlantic. The propulsive phase of approximately 8 minutes duration is directly followed by hypersonic gliding succeeded by landing approach after approximately an additional hour and 20 minutes of flight.

The Europe-Australia and return route is the baseline for other investigations. As a preliminary and currently non-binding assumption, the flight connection is assumed for two on-shore launch landing sites located in Queensland, Eastern Australia and in the German North-Sea coastal region. Both locations have the advantage of the complete launch ascent and supersonic gliding approach capable of being performed over the sea while still being relatively close to each continent's major business centers. These are two key-requirements for successful future SpaceLiner operation. The descent ground track of the nominal reference mission and the potential return flight are shown in Figure 5.3. Noise and sonic boom impact on inhabited areas is very low and actual proof of full public acceptability of the vehicle flying at very high altitude is under assessment.

Figure 5.3: Simulated Spaceliner ground track for nominal mission Australia to Europe (left) and Europe o Australia (right).

The reference mission from Australia to Europe of the SpaceLiner is demonstrated fully feasible, meeting all requirements imposed by the vehicle: dynamic pressure, acceleration and heat flux. The covered range is approximately 16000 km and the simulated flight time no more than 71 minutes to TAEM cylinder before final landing approach.
The MECO conditions reached at the end of the ascent flight is approximately 7.2 km/s in an altitude of 73.1 km and the flight path angle γ is close to 0°. The corresponding maximum Mach number is slightly beyond 25 and approximately 9000 km (more than 50% of the overall distance) are flown at Mach numbers larger than 20 (Figure 5.4).

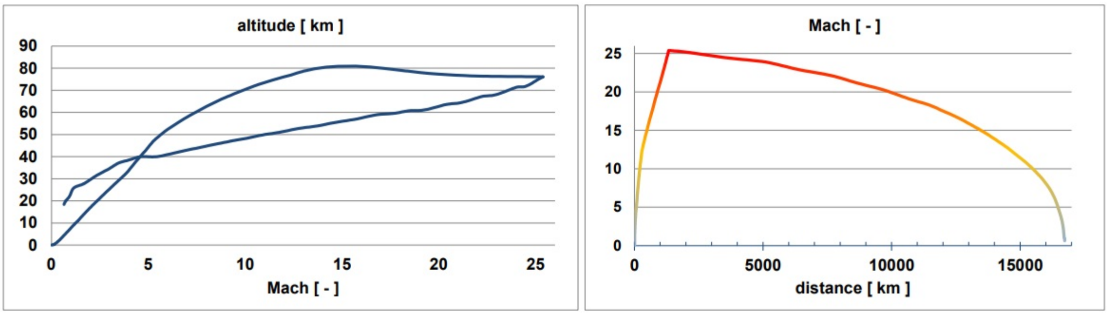


Figure 5.4: SpaceLiner simulated ascent and descent trajectory data for nominal mission Australia to Europe.

The flight route from Australia to North-East America, previously never investigated for the SpaceLiner, has now been studied and is found more difficult and challenging to be achieved under similar constraints. Although it is possible to reach the East Coast of United States, either approaching from the north or the south, the assumed potential launch sites for return trajectories were not suitable to complete the mission. The proposal for a new launch site on the west coast of Florida seems to be most promising for the North East America-Australia mission. However, this option might cause problems during the ascent phase over a highly traffic loaded area (Gulf of Mexico).

Chapter 6

SpaceLiner Cabin and Rescue System

Although the main propulsion systems of the SpaceLiner are designed specifically for enhanced reliability and reusability compared to the current state of the art Ref. [5], it cannot be excluded that a catastrophic failure of the vehicle can occur. In case of such events, passenger safety must be guaranteed and thus a reliable rescue system must be developed. Preliminary study of a rescue system for the SpaceLiner has been conducted and it was concluded that a capsule design is the most effective approach. In order to enable quick and easy separation, the capsule is intended to be self-sustained in terms of its structural, thermal protection, electrical and propulsion systems. The passenger cabin of the SpaceLiner is designed with double role. Provide a comfortable pressurized travel compartment and serve as a reliable rescue system in case of catastrophic events. Thus, the primary requirements of the cabin are the possibility of being firmly attached late in the launch preparation process, fast and safely separated in case of an emergency.

The capsule should be able to fly autonomously back to Earth's surface in all separation cases. The abort trajectories are primarily influenced by the mass of the capsule and the aerodynamic performance with the most important subsystems being the separation motors, the thermal protection system (TPS) and the structure.

A fundamental requirement for the design of the rescue capsule is its integration in the front section of the passenger stage as shown in Figure 6.1. The capsule should be separated as easily and quickly as possible. Therefore, it cannot be an integral part of the fuselage structure, however, its upper section is conformal with the SpaceLiner's fuselage while the lower side is fully protected by the fuselage bottom structure.

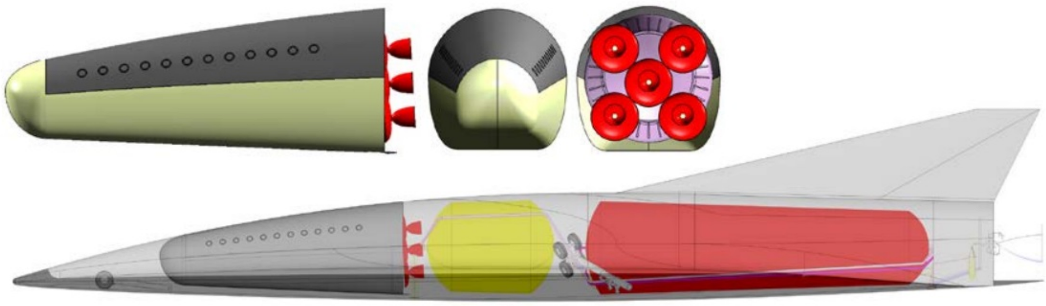


Figure 6.1: SpaceLiner rescue capsule (at top in side, fwd. and aft view) and integration.

The capsule can be subdivided in a pressurized cabin of conical shape and an outer aerodynamic shell formed by the Thermal Protection System (TPS) and which provides space for housing several non-pressurized subsystems. The TPS of the SpaceLiner capsule is required to withstand several different heat load conditions driven by the different nominal and abort cases it encounters. During nominal flight the capsule is considered part of the orbiter.
The current requirement of capsule separation being feasible at any flight condition and attitude is highly challenging from a technical point of view. Analyses revealed some critical issues to be addressed in order to improve the safe functionality of the cabin rescue system. Alternative capsule integration concepts have been studied and analysed, however, each of the explored design options is linked to severe challenges and drawbacks.
Further investigations have been initiated to find a promising and reliable separation concept and system. A highly innovative investigation on design options to improve the capsules' flight performance after separation has been performed in the European Commission funded FP7-project HYPMOCES (HYpersonic MOrphing system for a Cabin Escape System) aiming to investigate and develop the technologies in the area of control, structures, aerothermodynamics, mission and system aspects required to enable the use of morphing structures. The project was lead by DEIMOS Space S.L.U. with the participation of Aviospace, ONERA and DLR-SART.

A multidisciplinary design approach has been successfully introduced since the beginning of the project to achieve a satisfactory design. From an initial trade-off of conceptual designs two preliminary design solutions (one "baseline" and one "backup" CES morphing system) were designed as an optimum equilibrium of conflicting objectives among the different disciplines involved, namely: mission analysis, flying qualities, GNC, aerodynamics, structure, mechanism and system.

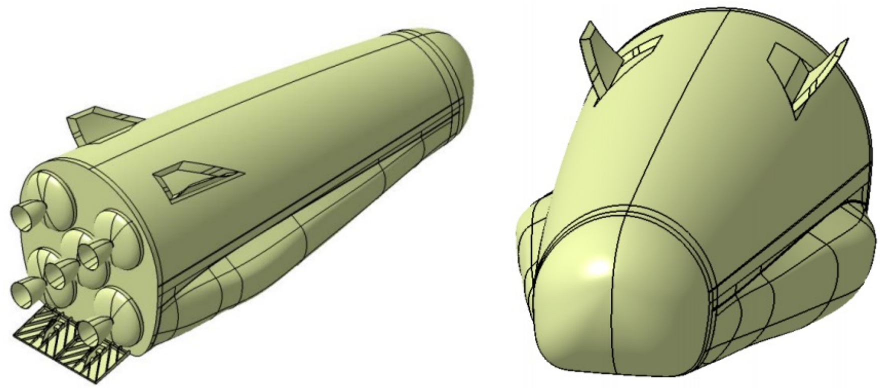


Figure 6.2: SpaceLiner capsule option with inflatable morphing lower section and deployable fins.

Inflatable as well as rigid deployable wing options have been studied. The "baseline" design is inflating its lower section after safe separation in order to increase the flat lower surface for increased lift in hypersonic flight enabling better gliding rate. The shape of the capsule's lower side before its inflation is compact for storage inside the passenger. The fully inflated lower section and capsule with deployed rudders and deflected bodyflaps are visible in Figure 6.2.

The challenges in designing the inflatable morphing structure are finding a membrane material of sufficient flexibility to be easily stowed, rapidly deployed and then being stiff enough to keep a defined external shape in varying flow conditions. As to be used in hypersonic, the material needs to withstand severe aerothermal loads and temperatures. All these design tasks were addressed by Aviospace in close cooperation with HYPMOCES project partners. The preferred membrane choice is a composite design with severe layers of Nextel, Pyrogel, Carbon fiber and Saffil. The driving mechanism of the morphing motion is a system of eight airbags on each side as shown in Figure 6.3. These bags are to be inflated by commercially available solid gas generators.

Within the HYPMOCES project also micro-aerothermodynamic phenomena have been investigated by ONERA for the capsule including protuberances like steps, gaps, cavities or stiffeners for flaps. The detailed CFD results produced by ONERA have been used by DEIMOS Space as anchor points for the fitting of a full aerothermodynamic database, covering the extensive range of flight conditions (Mach, angle of attack, angle of sideslip, flap deflections) where the vehicle is expected to fly. Based on this input, advanced multidisciplinary optimization tools focused on the tightly coupled areas of mission analysis, Flying qualities and GNC have been applied by DEIMOS Space.

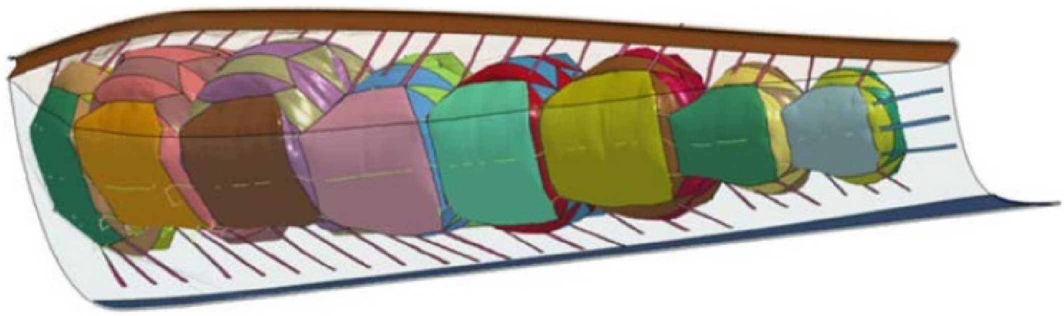


Figure 6.3: Deployed bags' final design (Aviospace).

6.1 Capsule Subsystems definition

A preliminary design for the capsule main subsystems has been elaborated within HYPMOCES project. This includes the body flaps, deployable rudders, the parachute system for transonic stabilization/ landing, the electromechanical actuators with their batteries and the reaction control system (RCS).

The overall length of the designed capsule for 50 passengers (without separation motors) is 15.6 m and its maximum external height is 5.6 m.

The flap design developed by Aviospace in Turin matches the constraints induced by demanding thermo-mechanical environment experienced during hypersonic flight.

Adding two symmetrically attached rudders in the aft section of the capsule is significantly enhancing its flying qualities in case of autonomous flight. However, the rudders should be stored in a position not disturbing the outside flow when the capsule is integrated into the passenger stage during nominal flight. Therefore, in this case the rudder is inside a cavity in the TPS outside of the pressurized section with the external vehicle surface continuous and smooth. A special design must be implemented to protect the vessel under the cavity and to reduce the heat flux and vortex in this area when the rudder is deployed.

A preliminary design for the RCS has been performed and three manoeuvres are identified as cases of interest: compensation of potential thrust imbalance caused by the separation rocket motors, roll manoeuvre of cabin and stabilization of flight in nominal (almost exo-atmospheric) conditions. The preferred RCS choice is characterized by 2 cluster of thrusters located in the rear part of the capsule. This architecture allows performing quick manoeuvres and is characterized by sufficient volume available also for implementing larger thrusters. A non-toxic bi-propellant combination is desirable for passengers' safety and ease of handling and this precludes the use of any variant of hydrazine. From an operational standpoint the storability is especially attractive due to the fact that once the tanks are filled, multiple flights can be performed without needing to empty or refuel them.

Parachutes are assumed to be deployed and operate in a certain altitude-Mach-box to decelerate the capsule during the final landing phase.

The estimated masses (6.1) are about 25.5 *tons* for the dry capsule, about 7600 *kg* for the passengers, crew and luggage, and 3800 *kg* for all propellants of separation motor, retro-rockets and RCS.

	Value	Unit
Structure	9.4	*tons*
Propulsion	0.9	*tons*
Subsystem including Cabin	10	*tons*
TPS	5.2	*tons*
Total dry	25.5	*tons*
Total fluid and propellant loading	3.8	*tons*
GLOW including passengers and payload	37.2	*tons*

Table 6.1: Mass data of SpaceLiner passenger capsule

	Value	Unit
Overall capsule length	15.6	*m*
Maximum external height	5.6	*m*

Table 6.2: Geometrical data of SpaceLiner passenger capsule

Chapter 7

Study of different options for Capsule Rescue Motors of SpaceLiner

As reported in Chapter 6, a preliminary study of a rescue system for the SpaceLiner has been conducted and it was concluded that a capsule design is the most effective approach. In case of imminent emergencies, the Capsule Rescue System (CRS) can be separated utilizing its own propulsion system, represented by a certain number of Capsule Rescue Motors (CRM), accelerate away and eventually land in a controlled manner.

Thus, the principle function of the CRM is to enable the capsule to reach a safe distance such that the resulting overpressure from an expanding blast wave would not compromise the structure and cause a catastrophic failure. The sizing of the CRM must be performed in respect to the worst-case scenario encountered by the SpaceLiner. Further, parachutes need to be deployed far enough away from eventual debris and at high enough altitude in case of a ground launch in order to facilitate a controlled landing. These requirements necessitate the CRM to provide a very high acceleration in a small-time frame.

This Chapter aims at defining some options for the rescue motors including performance parameters, level of thrust, size and mass.

7.1 Definition of worst case scenario

This scenario can be identified as occurring at the launch pad where the vehicle retains maximum amount of fuel and where the atmosphere is densest. The latter condition triggers the largest propagation effects of an explosive blast in terms of speed and magnitude while giving the greatest reduction of rocket motor efficiency compared to a vacuum environment. It's thus necessary analyse the requirements imposed on the CRS in such a scenario.

7.1.1 Pressure Hazard

On the launch pad, SpaceLiner contains roughly 1500 *tons* of liquid LH2 and LOX spread across both the orbiter and booster. In an unlikely event that all the propellant content ignites concurrently, the resulting explosion will be equivalent to detonating 900 *tons* of TNT in accordance with Ref. [6]. An overpressure region created by the shockwave then travels radially from the center of the explosion with the magnitude and propagation time given in Figure 7.1 for a reference explosion. From this information, it is possible to model an arbitrary explosion size and at any altitude through a scaled distance d' defined according to Eq. 7.1:

$$d' = d \cdot \left(\frac{1}{m_T}\right)^{1/3} \cdot \left(\frac{\rho_{atm}}{\rho_{atm_{SL}}}\right)^{1/3} \tag{7.1}$$

Where d is the actual radial distance, m_T the equivalent TNT mass, ρ_{atm} and $\rho_{atm_{SL}}$ are respectively the atmospheric densities at given altitude and at sea-level.

If t' and $(p/p_0)'$ are the arrival time and overpressure ratio for the scaled distance d', then the actual arrival time t and overpressure p are given by

$$t = t' m_t^{1/3} \cdot \left(\frac{\rho_{atm_{SL}}}{\rho_{atm}}\right) \cdot \left(\frac{\sigma_{SL}}{\sigma}\right) \tag{7.2}$$

$$p = (p/p_0)' \cdot p_0 \tag{7.3}$$

Where σ and σ_{SL} are the speeds of sound at given altitude and at sea-level while p_0 is the ambient atmospheric pressure.

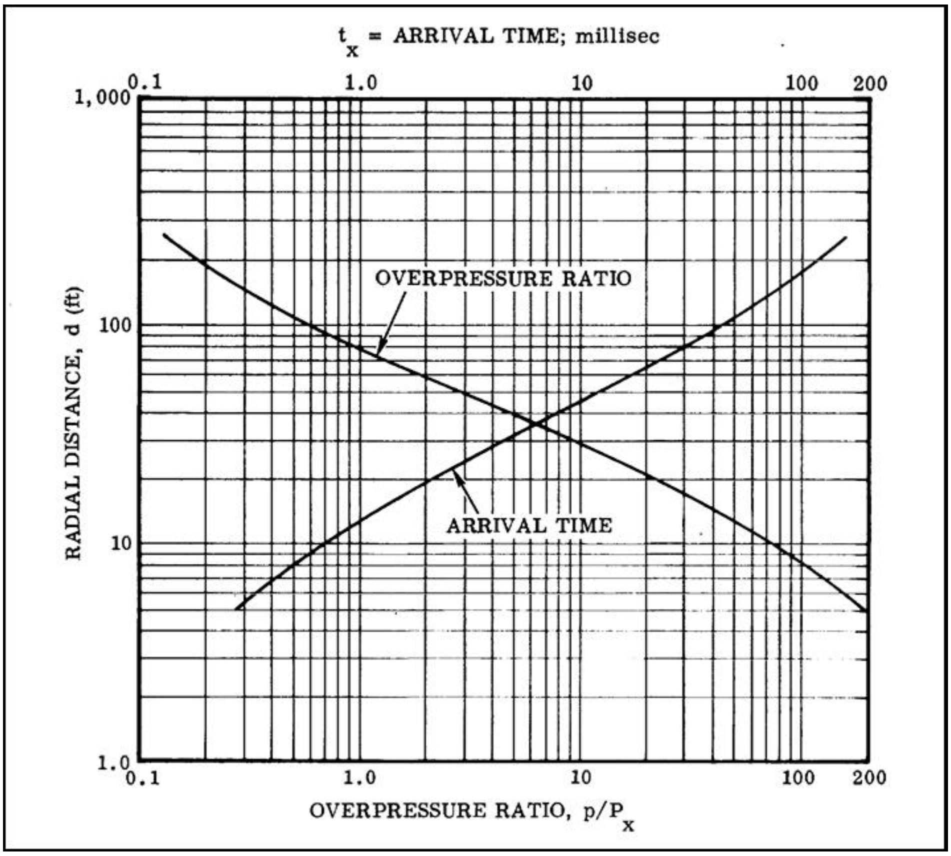


Figure 7.1: Explosion characteristic of one ton of TNT at sea level conditions (Ref. [6]).

Two overpressure limits (OPL) for the CRS are investigated. The first is based on a moderate limit of 60 kPa recommended for nominal capsule designs in accordance with Ref. [6]. It can be deducted from Figure 7.1 that the required safe radial distance with this limit is a minimum of 289 m at sea level with the pressure wave arriving after 410 *milliseconds*. A second higher pressure limit of 150 kPa is also examined and represents an assumed upper ceiling for the structural tolerances of the capsule. From Figure 7.2, the required minimum radial distance from the explosion in this instance is 184 m at sea level and an arrival time of 180 *milliseconds*. Given the short arrival times of the shockwaves, it can be concluded that if the rescue system is actuated simultaneously with the explosion, the capsule must accelerate more than 350 G. As this is an unrealistic proposal from a physical and practical standpoint, an early warning system is required that can predict an imminent explosion before it occurs. Accordingly, Ref. [6] also suggests that by sensing the chamber pressure, an automatic escape system could be triggered approximately two seconds before the vehicle reaches a critical condition. If, due to technological advances since 1969, 0.5 *seconds* (of 2 *seconds*) could be allotted for turning the capsule to an escape vector and to initiate the CRM, then a total of 2.41 s and 2.18 s respectively are available for the capsule to travel the required minimum distances. This translates to approximately 10 G for the 60 kPa limit and 8 G for the 150 kPa limit, thus below the tolerable threshold.

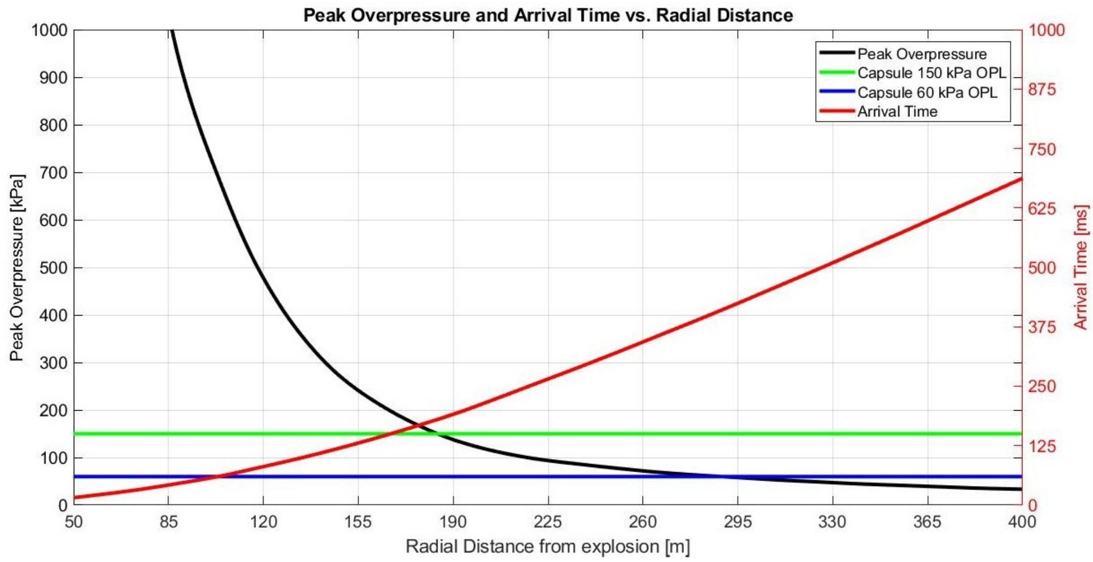


Figure 7.2: Shockwave propagation for an explosion of 1500 tons of LOX-LH2 propellant at sea level.

7.1.2 Thrust reduction

At sea-level conditions, the thrust output produced by rocket motors is reduced due to the ambient atmospheric pressure compared to a vacuum environment. This is represented by the pressure thrust term in the total thrust equation:

$$T = \dot{m}v_e + (p_e - p_0) \cdot A_e \tag{7.4}$$

The losses amount approximately to between 10 % and 30 % (Ref. [7]) of the overall thrust.

7.2 Requirements

As previously reported the main function of the Capsule Rescue Motors (CRM) is to enable the capsule to reach a safe distance such that the resulting overpressure from an expanding explosion wave would not compromise the structure and cause a catastrophic failure. A further consideration regards parachutes which have the task to facilitate a controlled landing and the need to be deployed far enough away from eventual debris and at high enough altitude in case of a ground launch. These requirements lead the CRM to provide a very high acceleration in a small-time frame.

However, as the passengers of the SpaceLiner are assumed to be untrained for high acceleration environments, a strict limit to the acceleration and its duration need to be imposed. Analyses of such tolerances have been conducted in Ref. [6] where it can be concluded that a maximum of 15 G in forward direction (eyeball in) and 8 G in upward direction for a time of three seconds is recommended (Figure 7.3).

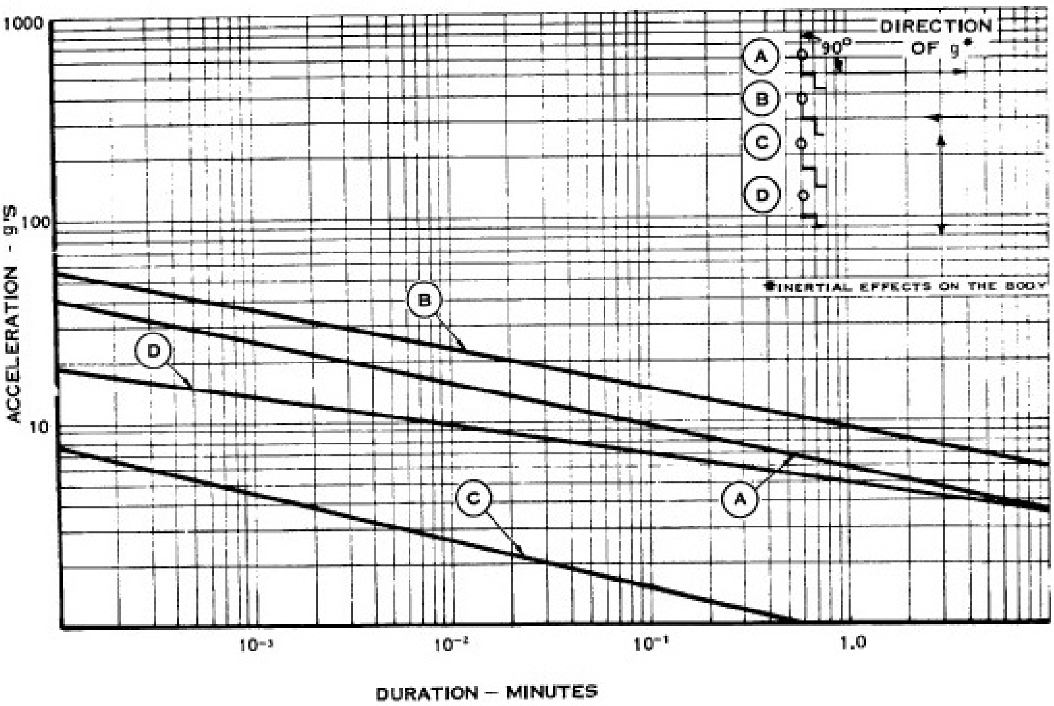


Figure 7.3: Recommended maximum tolerance limits to acceleration for unconditioned passengers defined by NASA.

In addition to acceleration and distance requirements (analysed in Chapter 7.1.1), limitation to the length and to the diameter of the CRM are imposed such that they do not intrude on the propellant tanks and structure of the orbiter. Thus, based on current CAD models, some geometrical boundaries are considered. The aft cross-section of the capsule is shaped as a half ellipse on top of a rectangle with a transverse diameter of 5.85 meter and a height of 5.60 meter while the axial distance between the capsule and the main fuel tank of the SpaceLiner is 1.5 meter.

The requirements are listed as follows:

- Considering OPL 60 kPa limit, in order to escape the blast radius intact, the capsule must travel 289 m within 2.41 s;
- Considering OPL 150 kPa limit, in order to escape the blast radius intact, the capsule must travel 184 m within 2.18 s;
- The maximum acceleration in the forward direction is limited to 12 G for three seconds ;
- The maximum acceleration in the upward direction is limited to 3 G for three seconds ;
- The capsule is required to reach an horizontal distance of 750 m from the center of an explosion, assuming worst-case conditions, in order to reach a safe distance from possibles debris of the launch pad ;
- The capsule is required to reach a vertical distance of 750 m from the center of an explosion, assuming worst-case conditions, in order to ensure the deployment of the parachutes ;
- The maximum height for the CRM installed must not exceed 5.60 m due to geometrical constraint of the capsule aft cross-section;
- The maximum width for the CRM installed must not exceed 5.85 m due to geometrical constraint of the capsule aft cross-section;
- The maximum axial length for the CRM installed must not exceed 1.5 m in order to not intrude with the propellant tanks of the orbiter.

7.3 Methodology

Three types of analyses for possible configurations of Capsule Rescue Motors are performed. The first investigates the utilize of Solid Rocket Motors (Figure 7.4) and follows an iterative approach where the first task is to define a suitable vacuum thrust law for the CRM. This enables detailed analysis of the motor through the internal ballistics solver SRP giving the motor geometry, performance parameters and losses. The resulting trajectory for the abort scenario is then investigated in TOSCA TS in order to demonstrate that the requirements specified in Chapter 7.2 are met. This process is repeated until a suitable thrust law and geometry which satisfy the requirements are found. The second (use of SpaceX' SuperDraco Engines) and third (use of a new type Liquid Propellant Engines) analyses use an iterative approach as well but start defining the motor geometry through RPA (giving performance parameters) which is a multi-platform analysis tool for conceptual and preliminary design of chemical rocket engines. Then, for the analysis of SuperDraco Engines is decided the number of Engines which could satisfy the requirements (Figure 7.5) meanwhile, for the analysis of a new concept of Liquid Propellant Engines as CRM is chose the trust level as performance parameter and once obtained the geometry and size of the motor is analysed if the requirements are satisfied (Figure 7.6).

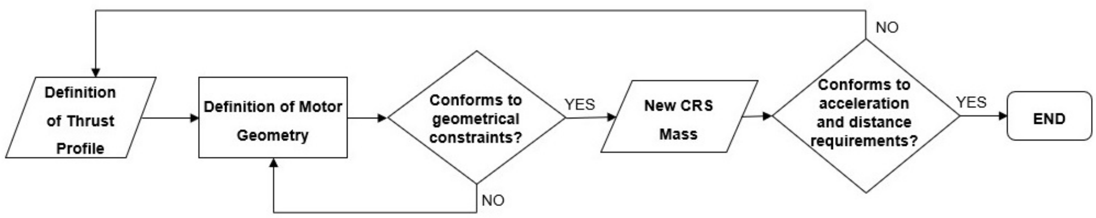


Figure 7.4: Analysis process for Solid Rocket Motors as CRM.

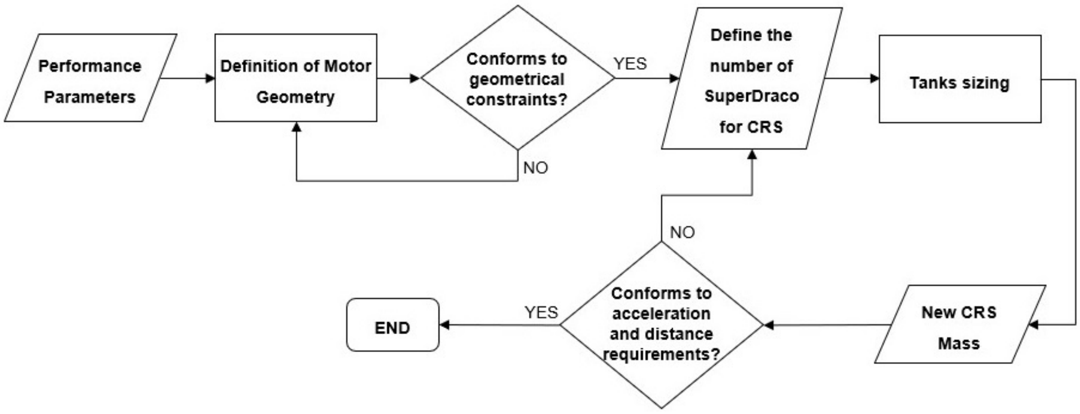


Figure 7.5: Analysis process for SpaceX' SuperDraco as CRM.

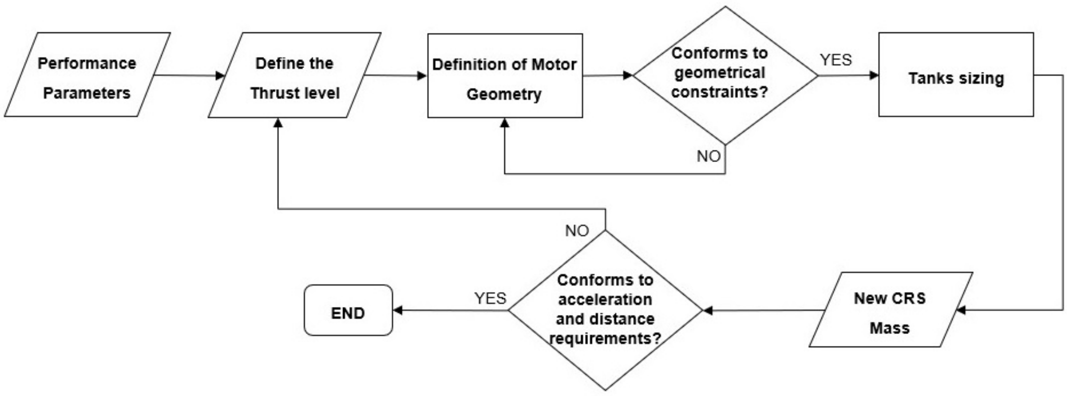


Figure 7.6: Analysis process new type Liquid Propellant Engines as CRM.

7.4 Computational Tools

Analysis of the SpaceLiner CRM is performed with the following internal computational tools within DLR and SART:

- CAC (Calculation of aerodynamic coefficients) – Calculates aerodynamic coefficients of predetermined geometries from subsonic through hypersonic Mach numbers;
- SRP (Solid Rocket Propulsion Analysis) – Conducts internal ballistics calculation of Solid Rocket Motors;
- STSM (Space Transportation System Mass) – Utilized for the determination of subsystem masses, stages and complete launchers;
- TOSCA TS (Trajectory Optimization and Simulation of Conventional and Advanced space Transportation System) – Performs 2D trajectory simulation and optimization;
- RPA (Rocket Propulsion Analysis) - for conceptual and preliminary design of chemical rocket engines.

7.5 Option 1.1 - Solid Rocket Motors

Since Solid Rocket Motors are simple, reliable and can give constant thrust level (which is what is pursued for the CRM of SpaceLiner) the "Option 1.1", sized for OPL 60 kPa (most conservative case), is considered the Nominal configuration. A five-Solid Rocket Motor configuration is selected to best utilize the available cross-sectional area at the aft of the capsule while incorporating a level of redundancy if a motor fails to ignite. Regarding the grain, an end-burning type is selected due to its compactness, simple design and stable thrust output (suitable for short burning times). The sizing of motors is performed following the iterative approach reported in Chapter 7.3. The analysis starts defining a suitable mass flow $\dot{m}$ law at which corresponds a vacuum thrust law. With these data is possible to obtain performance parameters, losses and motor geometry through the internal ballistics solver SRP. Once obtained the geometry (which must satisfy the constraints), the mass estimation is then done. The new mass estimation leads to a new M_{CES} (Cabin Escape System mass). Therefore, the escape trajectory is investigated trough TOSCA TS using as inputs the defined mass flow $\dot{m}$ law and the new M_{CES}. The iterative procedure ends when the requirements specified in Chapter 7.2 are met.

7.5.1 Motor geometry and performance analysis

First, it is defined a suitable mass flow $\dot{m}$, p_C (chamber pressure) and T_C (chamber temperature). With these parameters is possible to obtain A_t (throat area) through Eq. 7.5:

$$A_t = \frac{\dot{m}}{pc \cdot \left[\left(\frac{\gamma}{RT_c} \right) \cdot \left(\frac{2}{\gamma+1} \right)^{\left(\frac{\gamma+1}{\gamma-1} \right)} \right]^{1/2}} \tag{7.5}$$

Where γ and R depend on the composition of the grain. Hence D_t (throat diameter) is obtained from A_t which is adapted to give a chamber pressure of approximately 15 MPa, a value that is deemed high enough to sustain good performance while low enough to not require extensive structural support. A throat erosion rate ΔD_t is then determined empirically from internal SRM modeling (Ref. [8]) expressed from:

$$\Delta D_t = P_c^{1.92} \cdot (8.817 \cdot 10^{-5} D_t^2 + 5.398 \cdot 10^{-6} D_t + 5.780 \cdot 10^{-5}) \tag{7.6}$$

As a back-burning grain type is selected, the inlet and port diameters are equal and equivalent to the grain diameter whereas the grain diameter itself is constrained by available space at the aft of the capsule. In order to fit five motors comfortably, given additional space for casing and certain margins, a grain diameter of 1.9 m is chosen. The input data to SRP includes geometrical data of the motor with a summary of the chosen properties given in Table 7.1 for both investigated overpressure limits.

CRM propreties	OPL 60 kPa	OPL 150 kPa	Unit	Remarks
Initial throat diameter	0.207	0.181	$[m]$	Adapted to $p_c = 15MPa$, $Tc = 3550K$
Throat Erosion Rate	0.9449	0.9290	$[mm/s]$	Calculated
Inlet Diameter	1.900	1.900	$[m]$	Constrained by Capsule
Nozzle Half Angle	15.00	15.00	$[deg]$	Constrained by Capsule
Submergence Ratio	0.000	0.000	$[-]$	Zero due to End-Burning Grain
Port Diameter	1.900	1.900	$[m]$	Constrained by Capsule
I_{sp} Loss Gradient	0.000	0.000	$[-]$	Default for Typical Motor
I_{sp} Constant loss	2.000	2.000	$[-]$	Default for Typical Motor
Burning Rate	58	58	$[mm/s]$	Realistic and achievable
Burn Rate Exponent	0.400	0.400	$[-]$	Exponent for HTPB/AP/AL
Burn Rate Coefficient	7.82	7.82	$[m/sPa^{-n}]$	From Burning Rate formula
Sub.(Compr.) Ratio	84.24	110.66	$[-]$	$(Di/Dt)^2$
Sup.(Exp) Ratio	15.00	15.00	$[-]$	Constrained by Capsule
Propellant Composition (Mass fraction)	68% AP 20% Al 12% HTPB	68% AP 20% Al 12% HTPB		High Aluminium Content Default Propellant Composition

Table 7.1: SRP input values per CRM

Due to the limited space available between the capsule and the main fuel tanks of the orbiter, the nozzle length needs to be kept at a minimum. It is thus decided to utilize an 80% length Bell nozzle for maximum performance and minimum size. This type of nozzle has a high angle expansion section in front of the throat followed by a gradual reversal of the nozzle contour slope such that the exit divergence angle is small. Thus for an equivalent conical nozzle with an expansion ratio of 15 and nozzle half angle of 15 degrees calculated in SRP, the real nozzle length is given by Eq. 7.7 in accordance with Ref. [7]. Further, a 0.37% increase in specific impulse is also gained compared to a conical counterpart due to a more efficient flow field and are taken into consideration during the design.

$$L_{nzz} = 0.8 \cdot \frac{D_t(\sqrt{\epsilon} - 1)}{2tan(\theta)} \tag{7.7}$$

An additional important parameter is the burning rate of the grain, which affects the mass flow rate and in turn, the thrust. The relation between the burning rate r and the grain diameter D_c for an end-burning grain can be expressed as

$$r = \frac{4}{\pi} \frac{\dot{m}}{D_c^2 \cdot \rho \cdot b} \tag{7.8}$$

Where the burning rate can be rewritten through Saint Robert's Law, i.e.

$$r = ap_c^n \tag{7.9}$$

Of which a is the burn rate coefficient, n the burn rate exponent and p_c the chamber pressure in Bars giving r in mm/s. Through the iterative process, it is realized that in order to satisfy the distance requirements, a high thrust, high mass flow motor is necessary. Consequently, given the restrictions in grain diameter, a high burn rate of approximately 58 mm/s is required if a lower OPL of 60 kPa is assumed. Available research in e.g. Ref. [9] shows that by embedding aluminium or silver fibres along the burning vector of the grain, it is possible to increase the burning rate of a conventional propellant by an average factor of around three. Correspondingly, analysis of short duration (sub 1 second) burning grains in Ref. [10] indicates that conventional AP based propellant can reach a burning rate of 150 mm/s at 70 MPa if the propellant is catalyzed with metal oxide producing catalysts like Ferric Oxide (Fe_2O_3), Copper Oxide (CuO) or Manganese Dioxide (MnO_2) Ref. [11]. It is thus not inconceivable to assume a 58 mm/s burning rate to be realistic and achievable. This rate can be attained by setting the burning exponent to 0.4 which is consistent with unmodified HTPB/AP/AL propellant and then adding a suitable catalyzer that strictly modifies the burning coefficient (Ref. [7], Ref. [11]).

The resulting thrust and pressure profiles gained through the iterative process are displayed in Figure 7.7 and Figure 7.8 where the designs of the profiles follow three main phases. In phase one, an initial rise of the thrust and pressure is experienced as the propellant is ignited. Following in phase two, the grain burns in a quasi-steady state with a slight increase of thrust due to formation of concave cones which occurs as the grain burns faster close to the outer bondline than the center. This can be attributed to increased stresses and strains at the bound surface and chemical migration of burning rate catalysts towards the circumference (Ref. [7]). Lastly, in phase three the grain is burnt out resulting in a rapid drop of thrust and pressure.

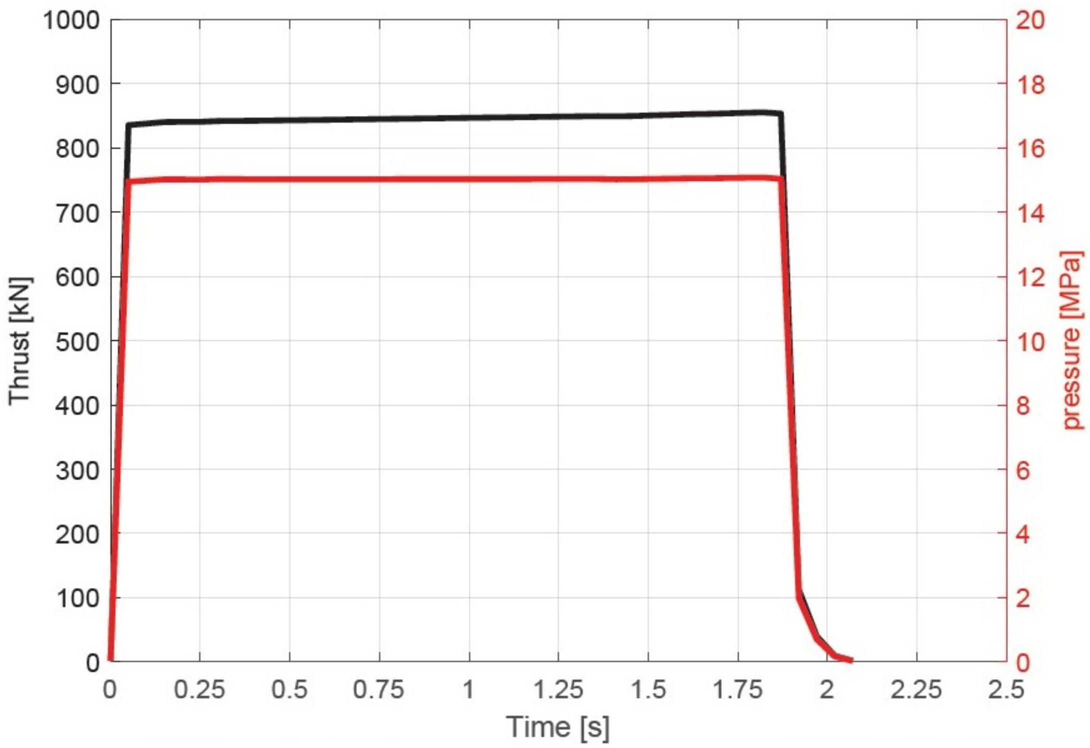


Figure 7.7: Final sea-level thrust and pressure laws for each individual CRM with a 60 kPa OPL.

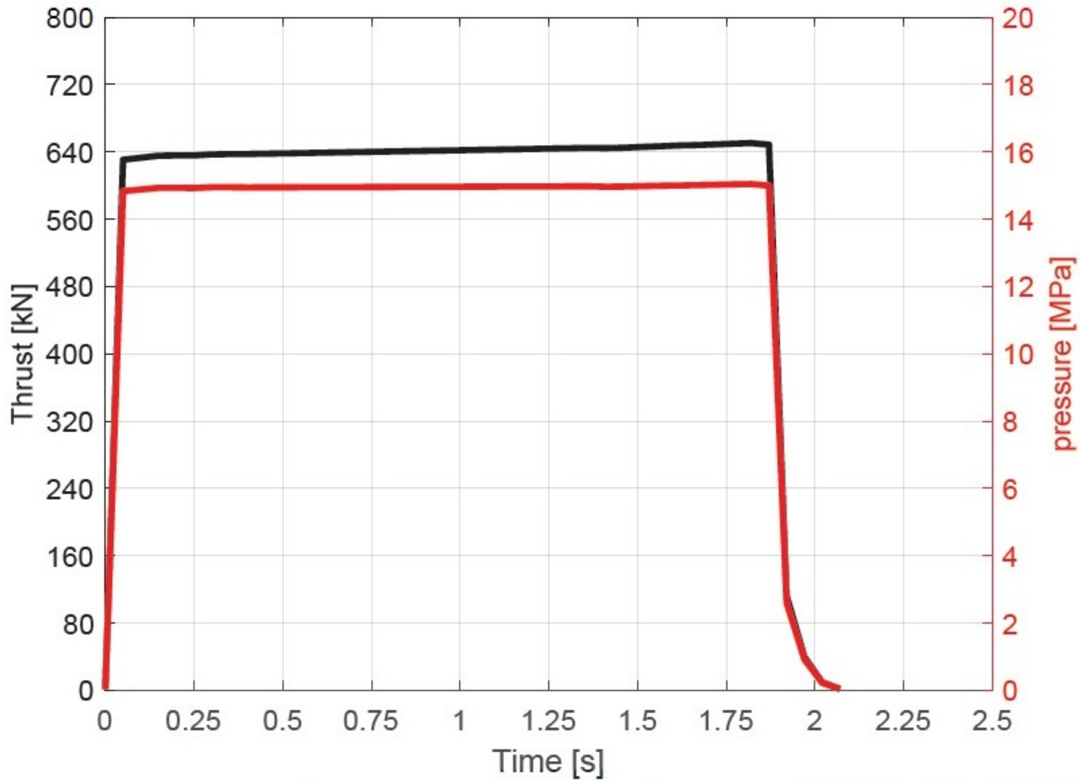


Figure 7.8: Final sea-level thrust and pressure laws for each individual CRM with a 150 kPa OPL.

Some important parameters are given as output from SRP and are summarized in Table 7.2. Of note is that the length of the grain for a 60 kPa OPL is 111 mm with a consumed propellant mass of 605.50 kg given a propellant density of 1976 kg/m^3. A maximum sea-level I_{sp} approximately of 268 s is calculated for both pressure limits which are comparatively low given the chamber pressure but expected due to the short nozzle employed. Furthermore, Table 7.2 shows that the exit pressure is 0.15 MPa, a value which is not proper a condition of adapted nozzle for a rescue at the Launch Pad but consequent from the selected geometry for the nozzle which may satisfy the geometrical constraint.

	OPL 60 kPa	OPL 150 kPa	Unit	Remarks
Pressure and Thrust				
Maximum Chamber Pressure	15.07	15.04	$[MPa]$	0-D Analysis
Maximum Throat Pressure	8.715	8.696	$[MPa]$	0-D Analysis
Maximum Exit Pressure	0.150	0.150	$[MPa]$	0-D Analysis
Maximum S/L Thrust	855.97	650.7	$[kN]$	With Bell nozzle efficinecy gains
Maximum Vacuum Thrust	908.01	690.3	$[kN]$	With Bell nozzle efficinecy gains
Efficiencies				
Maximum S/L I_{sp}	268.08	267.8	$[s]$	With Bell nozzle efficinecy gains
Maximum Vacuum I_{sp}	284.69	284.4	$[s]$	With Bell nozzle efficinecy gains
Propellant data				
Total Burn Time	2.070	2.070	$[s]$	-
Propellant Density	1976	1976	$[kg/m^3]$	-
Burnt Propellant Mass	614.0	460.1	$[kg]$	-
Burned Web Distance	111.2	111.3	$[mm]$	-

Table 7.2: Output data from SRP per CRM

7.5.2 Mass estimation

Casing

The structural mass of the casing can be estimated with membrane theory for a cylindrical base together with two caps for the dome structure at the front and rear of the cylinder. The thickness of the cylinder and caps is a function of the chamber pressure, casing diameter and material properties utilized. In order to keep the mass down, the latter is chosen to be of a high strength unidirectional Kevlar 49 composite (Ref. [12]). This material retains a very high ultimate strength to density ratio but has the disadvantage of being brittle. However, for the purpose of a non-reusable SRM protected inside the orbiter under non-use conditions, the brittleness can in this instance be accepted. Table 7.3 gives an overview of the material properties and safety factors for the casing and other major components of the motor.

	Value	Unit	Remarks
Chamber-Kevlar 49 Matrix			
Ultimate Strength	1800	$[MPa]$	Ref. [12]
Density	1440	$[kg/m^3]$	Ref. [13]
Safety Factor	1.5	[-]	Ref [14]
Nozzle-Carbon-Carbon			
Ultimate Strength	280	$[MPa]$	Nominal value Ref. [15]
Density	1990	$[kg/m^3]$	Nominal value Ref. [15]
Safety Factor	1.5	[-]	-
Insulation – Propylene Diene Rubber			
Ablation Rate	0.2	$[mm/s]$	Nominal value Ref. [16]
Density	1100	$[kg/m^3]$	Ref. [16]
Safety Factor	2	[-]	Ref. [7]

Table 7.3: Material properties and safety factor for SRM components

The thickness of the casing τ_c can thus be expressed as

$$\tau_c = \frac{s_f \cdot p_c \cdot D_c}{2\sigma_t} \tag{7.10}$$

Where the safety factor s_f is set to 1.5 and correlates to a nominal value for manned spacecraft in accordance with Ref. [14] and where D_c is the chamber diameter of the grain including surrounding insulation, with the thickness of the latter treated in the relative following section.
The volume of the chamber can then be estimated as the sum of the main cylinder encompassing the grain, a spherical cap at the aft and a spherical cap at the front representing the burning chamber, i.e. Eq. 7.11. The latter assumption gives an upper bound of the mass as the opening for the nozzle is not considered.

$$m_{casing} = \rho_c(V_{front} + V_{aft} + V_c) \tag{7.11}$$

Where the volume for the cylinder V_c and caps V_{cp} are respectively

$$V_c = \frac{\pi \cdot L_c}{4}[(D_c + 2\tau_c)^2 - D_c^2] \tag{7.12}$$

$$V_{aft} = \frac{\pi}{6}\Big[H_c\Big[\frac{3}{4}\Big(D_c + 2\tau_c\Big)^2 + H_c^2\Big] - h_c\Big(\frac{3}{4}D_c^2 + h_c^2\Big)\Big] \tag{7.13}$$

$$V_{front} = \frac{\pi}{6}\Big[H_c\Big[\frac{3}{4}\Big(D_c + 2\tau_c\Big)^2 + H_c^2\Big] - h_c\Big(\frac{3}{4}D_c^2 + h_c^2\Big)\Big] \tag{7.14}$$

With:

$$H_c = \frac{\eta}{2}(D_c + 2\tau_c) \tag{7.15}$$

$$h_c = \frac{\eta}{2}D_c \tag{7.16}$$

In the study of “Option 1.1 - Solid Rocket Motors” is decided to consider two types of spherical caps: the dome at the aft is designed with height-to-radius ratio $\eta = 0.25$ while the one in the front with $\eta = 0.05$. This is chosen to try to reduce the overall length of the motor compared with the previous study for CRM done in 2012 where two domes of $\eta = 0.25$ are used. With this new configuration, bigger stress is expected in the front dome casing and in the connections between the front dome and the main cylinder. This requires an increase of the thickness for the casing which will be considered in the mass calculation of the motor adding an additional mass of a $\eta = 0.25$ dome. This way of proceeding is an approximation, in the future more accurate structural analysis utilizing FEM could determine with more accuracy the proper increase of structural mass required.

Nozzle

Due to high thermal stresses and erosive environment encountered in the nozzle, particularly in the throat area, a multidirectional carbon-carbon (C-C) composite material is chosen for this application. This material has also been successfully utilized in existing rocket motors, e.g. on the second stage of the Athena II launch vehicle (Ref. [17]). Furthermore, the manufacturing process of C-C composites enables the creation of one-piece nozzles which enhances the tailorability and reliability compared to other multi-piece nozzles, thus making this material an attractive choice (Ref. [18]). Many variants of fibers, matrix architecture and density are available for multidirectional C-C materials but for this study, nominal values are utilized which are listed in Table 7.3.

The thickness of the nozzle can be estimated by assuming it to function similar to a pressure vessel, i.e. through application of Eq. 7.10 with a safety factor of 1.5. Further, the pressure term is adapted to the throat pressure (Table 7.2), which is the highest pressure encountered by the nozzle. The shape can be considered as a truncated cone with the length given by Eq. 7.7. The mass of the nozzle structure is thus

$$
\begin{aligned}
m_{nzz} = \frac{\pi L_{nozz}\rho_{nozz}}{12}&[[(D_e + 2\tau_{nzz})^2 + (D_e + 2\tau_{nzz})(D_t + 2\tau_{nzz}) + (D_t + 2\tau_{nzz})^2] \\
&- [D_e^2 + D_e D_t + D_t^2]]
\end{aligned}
\tag{7.17}
$$

Of which the throat and exit diameters include the insulation thickness.

Insulation

Thermal insulation is lined between the propellant and casing of the motor with the purpose of protecting the case from hot gas and particle streams produced during the burn sequence. Likewise, insulation is also present in the inner wall of the nozzle with the same purpose. The insulation material chosen for this application is an Ethylene-Propylene Diene Terpolymer (EPDM) rubber which is a widespread insulator used e.g. in the booster rockets of the Space Shuttle. The main attributes of this material are its indefinite shell life, low density and low surface regression rate (Ref. [19], [16]). Summarized in Table 7.3 are the characteristic properties of this material.

The thickness of the insulation can be expressed as a function of the grain burning time t_{br}

$$\tau_{ins} = t_{br} \cdot r_{ins} \cdot s_f \tag{7.18}$$

Where a safety factor of 2 is utilized and where r_{ins} is the surface regression rate which for the chamber is set to the nominal value in Table 7.3 and to the throat erosion rate according to Eq. 7.6 for the nozzle. Thus, the mass of the insulation can be calculated from Eq. 7.11 - Eq. 7.17 with insulation specific density and thicknesses.

Igniter and Residual Propellant

The mass of the entire ignition system including its propellant and structure can be estimated empirically through

$$m_{ign} = 0.0003 V_F^{0.7} \tag{7.19}$$

Where m_{ign} is the mass of the ignition system in kg and V_F the free volume of the motor chamber in cubic inches (Ref. [7]).

$$V_F = \frac{\pi}{4} D_c (L_{mot} - L_{nozz} - L_{gr}) \tag{7.20}$$

Of which L_{mot} is the total length of the motor and L_{gr} the length of the grain.

Furthermore, an additional 2% of the propellant is considered as unburned and is included in the structural mass during calculation. Table 7.4 summarizes the results of the mass budget estimation for each individual CRM.

	OPL 60 kPa	OPL 150 kPa	Unit	Remarks
Casing	52.67	49.94	$[kg]$	With one additional $\eta = 0.25$ dome
Nozzle	14.42	9.60	$[kg]$	-
Insulation	7.89	6.21	$[kg]$	-
Igniter	0.17	0.17	$[kg]$	-
Residual	12.11	9.20	$[kg]$	2% propellant mass
Total Dry Mass	87.26	75.12	$[kg]$	Including 2% fuel residual
Propellant Mass	605.50	460.07	$[kg]$	Propellant mass for single motor
Total Mass	3463.86	2675.97	$[kg]$	Dry mass and propellant mass for five motors

Table 7.4: Structural mass budget per CRM

In Table 7.5 and 7.6 are reported the results of the dimensioning for each single Motor considering OPL 60 kPa and 150 kPa.

	OPL 60 kPa	OPL 150 kPa	Unit
Casing Diameter (largest diameter)	1.9	1.9	$[m]$
Casing Thickness	11.9	11.9	$[mm]$
Casing Main Cylinder Length	0.111	0.084	$[m]$
Casing Aft Dome Height	0.240	0.240	$[m]$
Casing Front Dome Height	0.048	0.048	$[m]$

Table 7.5: Motor dimensions part.1

	OPL 60 kPa	OPL 150 kPa	Unit
Nozzle Length	0.888	0.775	$[m]$
Nozzle Exit Diameter	0.802	0.700	$[m]$
Nozzle Thickness	5.0	4.4	$[mm]$
Insulation Thickness (for casing)	0.83	0.83	$[mm]$
Insulation Thickness (for nozzle)	3.9	3.8	$[mm]$
Total Motor Length L_{mot}	1.287	1.147	$[m]$
Constraint L_{mot}	1.500	1.500	$[m]$

Table 7.6: Motor dimensions part.2

CAD models of the resulting motors are displayed in Figure 7.9 and illustrates that by including the nozzle, with the length calculated through Eq. 7.7, the combined length results 1.287 m for OPL 60 kPa and 1.147 m for OPL of 150 kPa. Thus, they fit the limit imposed by the requirement.

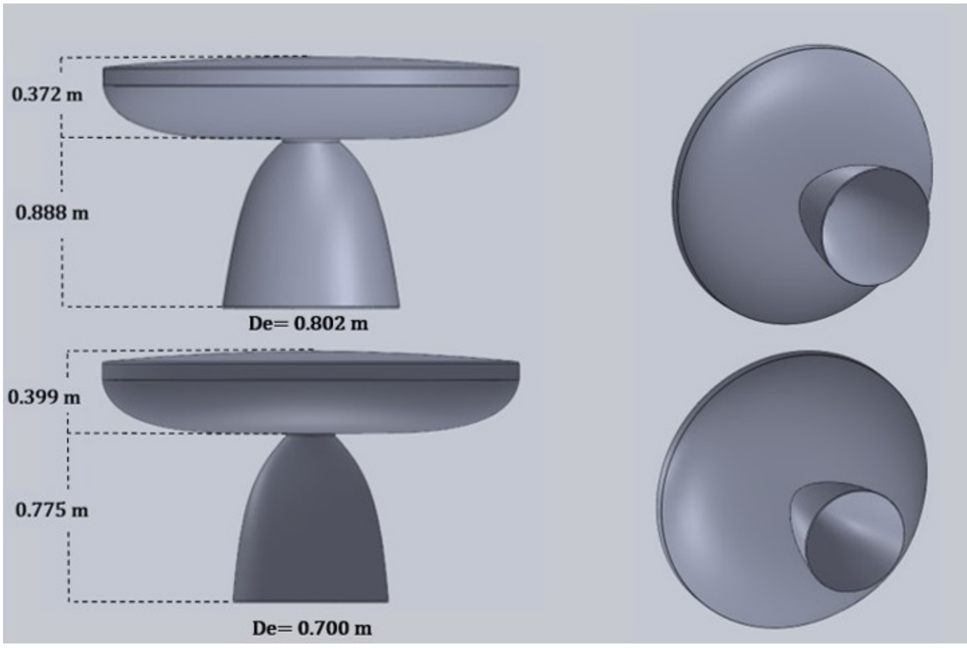


Figure 7.9: CAD Model of final CRM configuration (above OPL 60 kPa, down OPL 150 kPa).

7.5.3 Validation in TOSCA

Once designed the Motors for the CRS it's necessary to demonstrate that with that Motors the Capsule could satisfy all the requirements specified in Chapter 7.2. The resulting acceleration, velocity and distance experienced by the vehicle during an abort scenario at the launch pad are given in the trajectory simulation program TOSCA TS. This software takes into consideration the aerodynamic data supplied through CAC which includes lift, drag and moment coefficients for a wide range of Mach numbers. The program requires, as input, the Mass Flow rate which is derived from the Thrust Profile used in SRP. Masses, Centers of Gravity (CoG) and moments of inertia data for various subsystems through STSM are also entered. From Table 7.4 the Total Mass required for five Solid Rocket Motors is known. The Capsule Mass without Separation Motors is 33403.10 kg. This value is obtained subtracting 3496.90 kg (Total Mass for the five Solid Motors of 2012 study) from 36900.00 kg (Overall Capsule Mass in accordance with Ref. [20]). Considering the "Option 1.1 - Solid Rocket Motors", the consequent Overall Capsule Mass is 36867.06 kg for OPL 60 kPa and 36079.17 kg for OPL 150 kPa. Summary of relevant input data are given in Table 7.7 for both the 60 and 150 kPa computations. The Initial Escape Angle is selected to try to maximize both the horizontal and vertical distance from the Launch Pad.

Property	Value	Unit
Number of Motors	5	[-]
Capsule Mass without Separation Motors	33403.1	$[kg]$
Overall Capsule Mass OPL 60 kPa	36867.06	$[kg]$
Overall Capsule Mass OPL 150 kPa	36079.17	$[kg]$
Reference Area	5	$[m^2]$
Initial Velocity	0	$[m/s]$
Initial Altitude	0	$[m]$
Angle of Attack	2	$[deg]$
Initial Escape Angle OPL 60 kPa	67	$[deg]$
Initial Escape Angle OPL 150 kPa	70	$[deg]$

Table 7.7: Input data for the escaping capsule at sea-level

TOSCA TS results are summarized in Table 7.8 and confirm that with "Option 1.1 - Solid Rocket Motors" all acceleration and distance requirements are satisfied.

	OPL 60 kPa	OPL 150 kPa	Limit	Unit	Remarks
Max N_X Acceleration	11.91	9.20	12.00	[G]	-
Max N_Z Acceleration	≈ 0	≈ 0	3.00	[G]	-
Acceleration Time	2.07	2.07	3	[s]	-
Total Distance @ 2.18 s	-	185.48	184	[m]	Only applicable for 150 kPa OPL
Total Distance @ 2.41 s	290.13	-	289	[m]	Only applicable for 60 kPa OPL
Time to Max Vertical Distance	15.19	13.22	-	[s]	-
Maximum Vertical Distance	1222	831	750	[m]	-
Horizontal Distance	1363	789	-	[m]	At maximum vertical distance

Table 7.8: Acceleration and distance results compared to requirements

Figure 7.10 and Figure 7.11 show plots of some TOSCA TS results. In order to successfully deploy parachutes, a 180° degree rolling maneuver must also be performed during the abort which places the capsule in an upright position. The parachutes are the deployed at the apex of the trajectory where the vertical velocity vector turns negative.

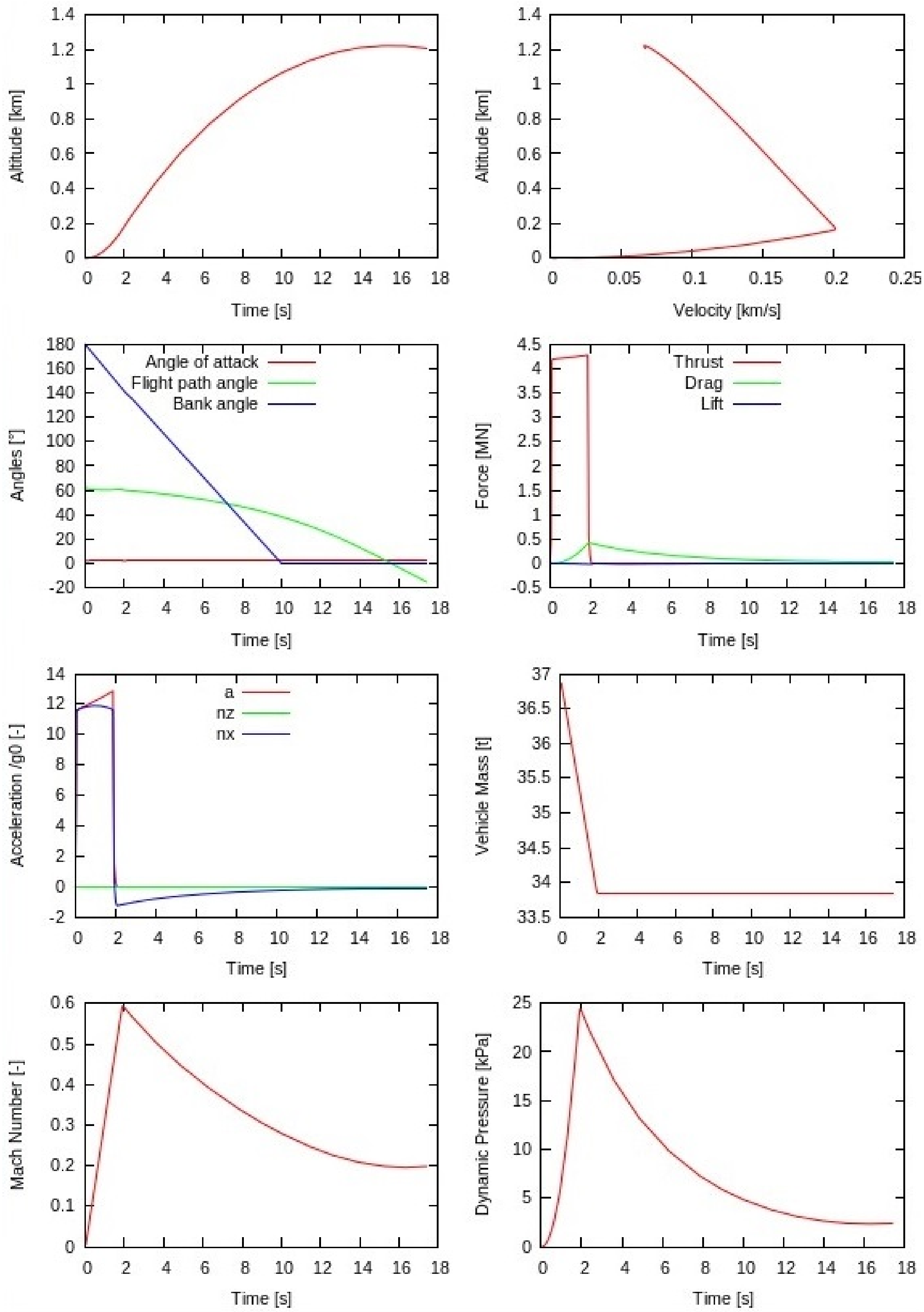


Figure 7.10: TOSCA results "Option 1.1 - Solid Rocket Motors" OPL 60 kPa.

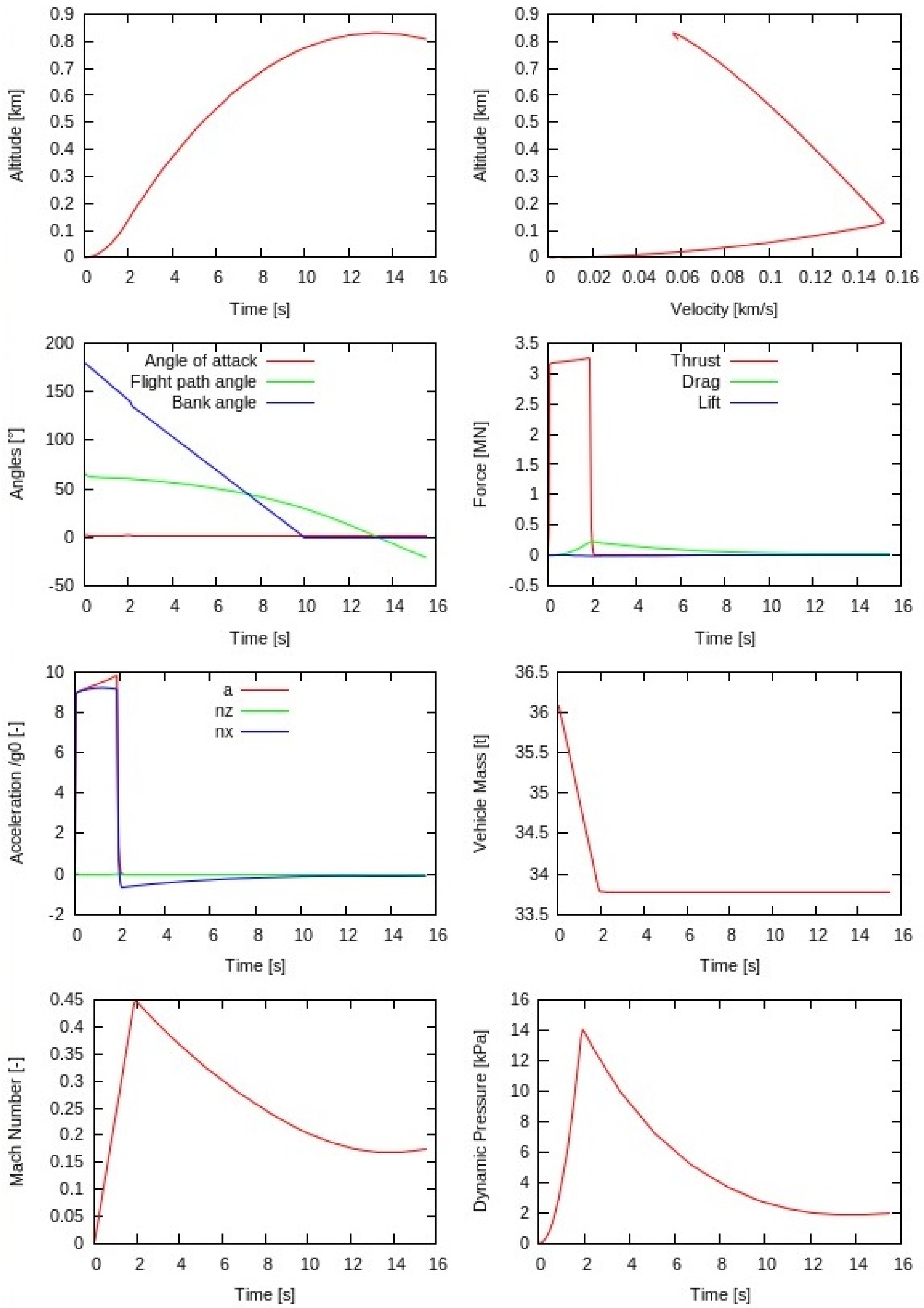


Figure 7.11: TOSCA results "Option 1.1 - Solid Rocket Motors" OPL 150 kPa.

7.5.4 Innovative multiple nozzle configuration for Rescue Motors

In the point of view of reducing the total motor length L_{MOT} an analysis with multiple nozzles arranged around periphery of nozzle block instead of a single central nozzle for each CRM is done. Thus, the study is performed still considering five motors, but a different number of nozzles for each motor. The analysis concerns two types of configuration: 5 and 8 multiple peripheral nozzles. The idea is to design the motors through SRP maintaining some parameters of the Solid Motors "Option 1.1" specified in Chapter 7.5.1 (i.e.: p_c, T_c, p_e, Nozzle half angle, burn rate) but changing the mass flow and some other parameters for the sizing of each nozzle. Indeed, the throat area A_t is obtained from Eq. 7.21:

$$A_t = \frac{\frac{\dot{m}}{number\ of\ nozzles}}{pc \cdot \left[\left(\frac{\gamma}{RT_c} \right) \cdot \left(\frac{2}{\gamma+1} \right)^{\left(\frac{\gamma+1}{\gamma-1} \right)} \right]^{1/2}} \tag{7.21}$$

The mass flow for each nozzle is calculated dividing the suitable mass flow $\dot{m}$ selected in Chapter 7.5.1 by the number of nozzles. The throat diameter D_t is derived from A_t and then the throat erosion rate ΔD_t is determined empirically from Eq. 7.6. Another consideration is done for the inlet diameter D_i which is supposed from the lateral view of the motor with multiple nozzles (See Figure 7.12). The expansion ratio is slightly changed in order to obtain $p_e = 0.15\ MPa$. Table 7.9 gives an overview of the differences between the configuration with one central nozzle (Nominal Motor OPL 60 kPa) and five or eight peripheral nozzles.

Through SRP, using as input the vacuum thrust law derived from the mass flow for each nozzle, with the same propellant composition specified in Chapter 7.5.1 and with the parameters reported in Table 7.9, is deduced the required propellant mass for each nozzle. This value is then multiplied for the number of nozzles of the configuration resulting in 609.8 kg and 611.4 kg respectively for five and eight peripheral nozzles.

Using the same equations of Chapter 7.5.1 and Chapter 7.5.2, for the sizing and mass estimation of the motors, is possible to obtain Table 7.10 and Table 7.11.

	1 Central Nozzle	5 Peripheral Nozzles	8 Peripheral Nozzles	Unit	Remarks
Chamber pressure p_c	15	15	15	[MPa]	-
Chamber Temp. T_c	3550	3550	3550	[K]	-
Exit pressure p_e	0.15	0.15	0.15	[MPa]	-
Nozzle Half Angle	15	15	15	[deg]	-
Burn Rate	58	58	58	[mm/s]	-
Throat Diameter D_t	0.207	0.093	0.073	[m]	Derived from A_t
Throat Eros. Rate ΔD_t	0.9449	0.8899	0.8841	[mm/s]	From formula
Inlet Diameter D_i	1.9	1.9/3.5	1.9/5	[m]	Supposed from Figure 7.12
Sub. (Compr.) Ratio	84.24	34.34	26.93	[-]	A_i/A_t
Sup. (Exp.) Ratio	15	14.85	14.85	[-]	To obtain $p_e = 0.15\ MPa$
Exit Diameter D_e	0.802	0.358	0.284	[m]	$D_e = \sqrt{(A_e/A_t) \cdot D_t}$

Table 7.9: Parameters for different configuartions of nozzle “Option 1.1” OPL 60 kPa

Table 7.10 and Table 7.11 show that a multiple nozzle configuration reduces the total length of the motor, allowing more margin in the area limited by the constraint. Regarding the masses, from results of equations of Chapter 7.5.2, a multiple nozzle configuration decreases the mass required for the structure of the nozzles although the mass of propellant required for the performance slightly increases. CAD models of the resulting motors are displayed in Figure 7.12. With the same procedure of Chapter 7.5.3 the escape simulation, considering CRM with multiple nozzles configuration, is validated in TOSCA TS.

	1 Central Nozzle	5 Peripheral Nozzles	8 Peripheral Nozzles	Unit	Remarks
Casing Diameter (largest)	1.9	1.9	1.9	[m]	Same of Nominal Motor
Casing Main Cylinder Length	0.111	0.112	0.113	[m]	Depends on prop. volume
Casing Aft Dome Height	0.240	0.240	0.240	[m]	Same of Nominal Motor
Casing Front Dome Height	0.048	0.048	0.048	[m]	Same of Nominal Motor
Nozzle Length	0.888	0.397	0.314	[m]	From formula Eq. 7.7
Total Motor Length L_{mot}	1.287	0.797	0.715	[m]	Constraint 1.5 [m]

Table 7.10: Motor dimension, different nozzles config., “Option 1.1” OPL 60 kPa

	1 Central Nozzle	5 Peripheral Nozzles	8 Peripheral Nozzles	Unit	Remarks
Motor Dry Mass without Nozzle(s)	66.74	66.91	66.98	[kg]	With 1 additional $\eta = 0.25$ *dome*
Single Nozzle Mass	20.53	2.526	1.418	[kg]	Considering also the insulation for the Nozzle
Total Nozzle(s) Mass	20.53	12.63	11.34	[kg]	Multiplying Single Nozzle Mass for the number of Nozzles
Total Dry Mass 1 Motor	87.27	79.54	78.32	[kg]	-
Propellant Mass	605.5	609.8	611.4	[kg]	From SRP
Overall Mass 1 Motor	692.8	689.3	689.7	[kg]	-
Overall Mass 5 Motor	3464.0	3446.5	3448.5	[kg]	Mass installed on the CRS

Table 7.11: Mass budget, different nozzles config., “Option 1.1” OPL 60 kPa

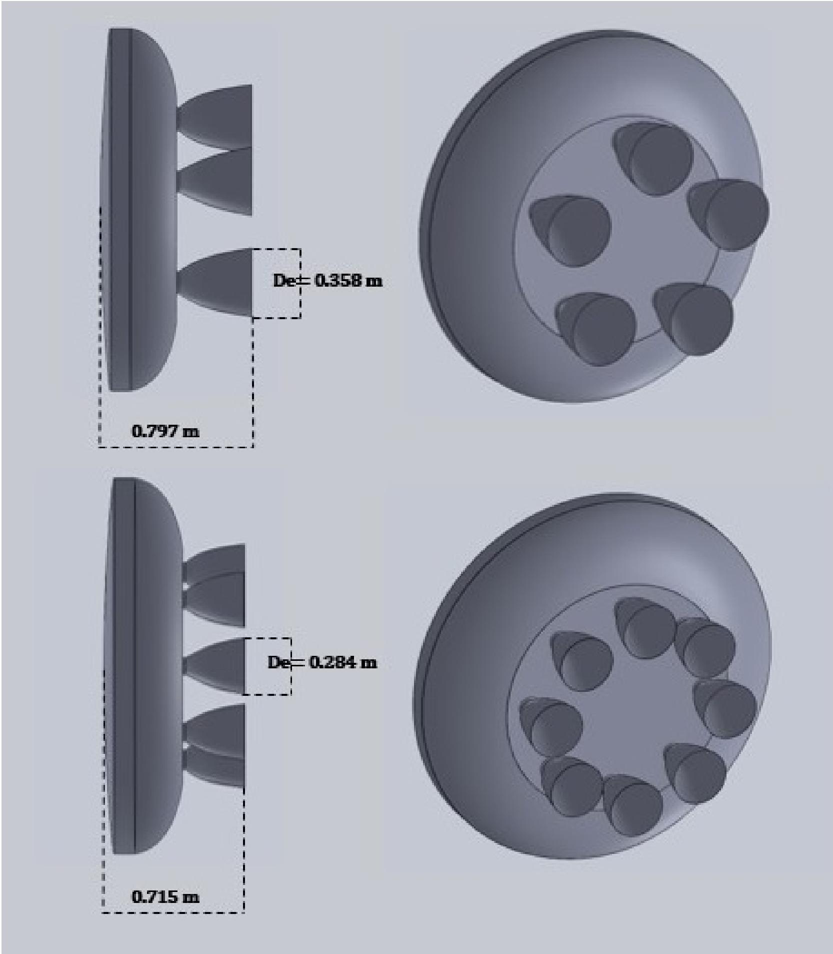


Figure 7.12: CAD Models of 5 and 8 Multiple Nozzle configuration “Option 1.1” OPL 60 kPa.

7.5.5 Considerations for Solid Rocket Motors, Option 1.1

In Chapter 7.5, at the begin of the SRP design analysis for the Nominal Option ("Option 1.1 – Solid Rocket Motors", OPL 60 kPa), some high-level parameters suppositions are taken as inputs. These, understandably, have an influence on the results. This chapter treats some re-considerations on two high-level parameters: the specific impulse I_{SP} and the burning time t . The aim is figure out if new suppositions on these parameters permit to obtain a better solution in terms of mass, dimensions and propulsive acceleration of the Motors and if not, design the Motors with the new improved parameters. Regarding I_{SP}, considering the Eq. 7.22 for the thrust of rocket engines, could be interesting realize if maintaining the same level of thrust, increase I_{SP} could bring a benefit based on the reduction of the mass flow $\dot{m}$ which is related to the mass of propellant which in turn influences the size and mass of the motors. Instead, regarding the burning time t, is investigated if its reduction/increase, respect to the value for the Nominal Option, could lead to an improvement in terms of mass/size/acceleration.

$$T = I_{SP} \cdot \dot{m} \cdot g \tag{7.22}$$

Increase I_{SP}

As stated above, the objective in the increase of I_{SP} is to understand if is possible to reduce the mass and size of the motors due to the fact that less propellant could be required since that the mass flow (if the thrust is kept constant) must decrease. In rocket engines, considering chemical propulsion, I_{SP} is related to the propellant utilized and to the geometry of the nozzle. Since the propellant HTPB/AP/AL is strictly defined to ensure a high burn rate (necessary for the requirements of the mission), in order to increase I_{SP} is decided to act on the geometry of 80% bell nozzle. In particular, is possible to increase I_{SP} from 286.69 (Nominal, SL) to 270.26 (SL) seconds reducing the nozzle half angle from 15° (Nominal) to 10°. It is then calculated a new mass flow from Eq. 7.22 maintaining the same sea level thrust profile. From the mass flow is possible to define the high-level geometrical parameters required as input in SRP. The expansion ratio is maintained constant. Through the SRP analysis is found that, as expected, the mass of propellant is reduced (but only of 5 kg, for each motor) and the pressures inside the motor slightly increase. The problem appears during the sizing of the motor when applying Eq. 7.7 is found that the length of the motor exceeds the constraint. This result is consistent if it is thought that the nozzle has a lower half angle but the same expansion ratio. Since is noticed that the expansion ratio does not affect much I_{SP} is thus supposed to analyse if reducing it, is possible to decrease the length of the nozzle and in turn of the motor. With this further assumption, the investigation brings to the result that the motor length fits the constraint, but its dry mass increases due to bigger pressures inside the motor as consequence of the reduction of the expansion ratio. This means that even if the propellant mass is slightly reduced, there is no advantage in the attempt to increase I_{SP} because the benefit is cancelled with the increase of the dry mass. Therefore, is decided to maintain I_{SP} equal to 286.69 seconds.

Figure 7.13: Effects of increase I_{SP}.

Decrease the burning time t

The idea behind decrease the burning time is to design a motor which provides a larger thrust for less time (in comparison with the Nominal Motor). In terms of propellant mass could be translated in a reduction of the latter because the mass flow $\frac{dm}{dt}$ increases if the time considered is reduced. The decrement of the propellant mass could also bring to a slightly reduction of the size of the motors. In the investigation is considered a burning time of 1.87 seconds instead of 2.07 seconds (Nominal) and a thrust level in the thrust-time profile increased in order to ensure the achieving of the radial safe distance, from the explosion, within the time imposed by the requirement. What is found from the analysis is that the propellant mass, in fact, is decreased (565.72 kg instead of 605.50 kg, for each motor) but the constraint on the N_X acceleration for the passenger (maximum 12 G) is exceeded. This is comprehensible if is thought that is increased the thrust of the motors and reduced the time in which is provided. Therefore, decrease the burning time from the nominal value, for the mission of the CES does not lead to advantages.

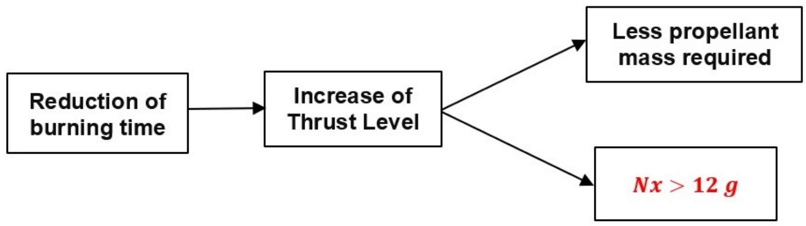


Figure 7.14: Effects of the reduction of the burning time t.

Increase the burning time t

The last analysis performed is an investigation on the consequences of the utilize of a larger burning time (2.27 seconds) compared to the nominal case (2.07 seconds). The objective is to understand if it's possible to have an advantage in terms of reduction of propellant mass. During the analysis is reduced the mass flow because the time in which is provided the thrust is increased, thus, in order to ensure a safe radial distance of 289 meters within 2.41 seconds, is possible to slightly reduce the thrust level compared to the nominal case thanks to a bigger time provided for the propulsion. With this assumption, from TOSCA simulation is found that the requirements concerning the escape safe distance and the accelerations are satisfied. But from SRP is observed that there is no advantage in increasing the burning time because the mass of propellant rises to 654.79 kg (instead of 605.50 kg, for each motor). This can be explained thinking that the mass flow is reduced, but the time for the propulsion is bigger. Even if the motors are sized is ascertained that there is no advantage for the motors dry mass.

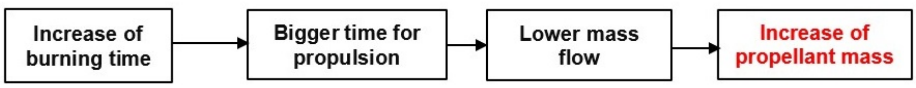


Figure 7.15: Effects of the increase of the burning time t.

The results of the investigations show that considering as high-level parameters 286.69 seconds for I_{SP} and 2.07 seconds for burning time, remains the best assumption.

7.6 Option 1.2 - Solid Rocket Motors with change in $p_e = 0.09\ MPa$

In Chapter 7.5 is performed the design analysis for the Nominal Option to use for the motors of the Cabin Escape System of SpaceLiner. It can be observed that in "Option 1.1" due to the limited space available between the capsule and the main fuel tanks, it is chosen an 80% length bell nozzle for a maximum performance and a minimum size of the Solid Rocket Motors. But focusing on the exit pressure of the nozzle, in "Option 1.1", from Table 7.2, can be ascertained that p_e is equal to 0.15 MPa, a value not proper close to the condition of adapted nozzle at the Launch Pad. Actually, this value is adopted with the intent to choose a certain supersonic ratio which permits that the length of the motor maintains a certain margin from the constraint (the motor length may not exceed 1.5 m). But, the supersonic ratio of "Option 1.1" was supposed in a former analysis (2012) not considering the possibility to use a multiple nozzle configuration which could reduce the length of the motor.

Thus, for this reason, in this Section is designed a configuration which contemplates a larger supersonic ratio in order to have an exit pressure of the nozzle very close to the condition of adapted nozzle at the Launch Pad ($p_e = 0.09\ MPa$). With this assumption, is considered first a configuration with a single nozzle of which is demonstrated that the length of the motor exceeds the constraint (in the case of OPL 60 kPa) because a larger supersonic ratio is required. However, using configurations with multiple nozzles will reduce the length of the motor which will be characterized by a good margin from the length constraint and by a performance close to the optimum.

The analysis in this Section follows the same procedure of the one used to design the "Option 1.1" (Figure 7.4). The only thing that changes compared to Chapter 7.5 is, during the input assumption for SRP, the supersonic ratio. The latter is set to obtain an exit pressure of 0.09 MPa (differently from Chapter 7.5 where it is set to obtain $p_e = 0.15\ MPa$). The consequence of this choice can be seen immediately in the outputs of SRP: considering the same thrust/time profile of that in Chapter 7.5, using a nozzle with a bigger supersonic ratio reduces the amount of propellant required to obtain the same performance. Another consequence is that the pressure in the throat is slightly reduced. From the SRP outputs it is then sized the motor with a single nozzle of "Option 1.2" and is found that it exceeds the length constraint. Therefore, is studied a multiple nozzle configuration in the next Section 7.6.1

Table 7.12 reports the input values used for SRP, the only parameter that changes from "Option 1.1" is the supersonic ratio

CRM propreties	OPL 60 kPa	OPL 150 kPa	Unit	Remarks
Initial throat diameter	0.207	0.181	$[m]$	Adapted to $p_c = 15MPa$, $Tc = 3550K$
Throat Erosion Rate	0.9449	0.9290	$[mm/s]$	Calculated
Inlet Diameter	1.900	1.900	$[m]$	Constrained by Capsule
Nozzle Half Angle	15.00	15.00	$[deg]$	Constrained by Capsule
Port Diameter	1.900	1.900	$[m]$	Constrained by Capsule
Burning Rate	58	58	$[mm/s]$	Realistic and achievable
Burn Rate Exponent	0.400	0.400	$[-]$	Exponent for HTPB/AP/AL
Burn Rate Coefficient	7.82	7.82	$[m/sPa^{-n}]$	From Burning Rate formula
Sub.(Compr.) Ratio	84.24	110.66	$[-]$	$(Di/Dt)^2$
Sup.(Exp) Ratio	22.00	22.00	$[-]$	Constrained by Capsule
Propellant Composition (Mass fraction)	68% AP 20% Al 12% HTPB	68% AP 20% Al 12% HTPB		High Aluminium Content Default Propellant Composition

Table 7.12: SRP input values per CRM "Option 1.2"

SRP requires also for input the thrust/time profile which is supposed to be the same of the one for OPL 60 kPa and OPL 150 kPa on Figure 7.7 and Figure 7.8. Table 7.13 shows an overview of SRP's outputs for "Option 1.2".

	OPL 60 kPa	OPL 150 kPa	Unit	Remarks
Pressure and Thrust				
Maximum Chamber Pressure	14.69	14.60	$[MPa]$	0-D Analysis
Maximum Throat Pressure	8.494	8.439	$[MPa]$	0-D Analysis
Maximum Exit Pressure	0.09	0.09	$[MPa]$	0-D Analysis
Maximum S/L Thrust	831.69	632.04	$[kN]$	With Bell nozzle efficinecy gains
Maximum Vacuum Thrust	908.01	690.39	$[kN]$	With Bell nozzle efficinecy gains
Efficiencies				
Maximum S/L I_{sp}	267.21	266.78	$[s]$	With Bell nozzle efficinecy gains
Maximum Vacuum I_{sp}	293.03	291.73	$[s]$	With Bell nozzle efficinecy gains
Propellant data				
Total Burn Time	2.07	2.07	$[s]$	-
Propellant Density	1976	1976	$[kg/m3]$	-
Burnt Propellant Mass	590.26	448.54	$[kg]$	-

Table 7.13: Output data from SRP per CRM "Option 1.2"

Comparing Table 7.13 with Table 7.2, it could be seen that for the motors of “Option 1.2” the burnt propellant mass and the pressures are slightly reduced compared to “Option 1.1”. From SRP outputs is possible to proceed with the sizing of the motor which includes the geometry definition and the mass estimation. The used equation and supposed materials are the same of Chapter 7.5.2. When is performed the geometry analysis for the motor with a single central nozzle OPL 60 kPa, is noticed that the length of the motor exceeds the constraint. Hence a configuration with multiple nozzle is necessary to fit the length constraint. The geometry for the motors with one single nozzle of “Option 1.2” is reported in Table 7.14 and is obtained through Eq. 7.5, Eq. 7.7, Eq. 7.12 and Eq. 7.16.

	OPL 60 kPa	OPL 150 kPa	Unit	Remarks
Casing Diameter (largest diameter)	1.9	1.9	[m]	From geometrical constraints
Casing Main Cylinder Length	0.108	0.082	[m]	From Eq. 7.12
Casing Aft Dome Height	0.241	0.241	[m]	From Eq. 7.16
Casing Front Dome Height	0.048	0.048	[m]	From Eq. 7.16
Nozzle Length	1.141	0.995	[m]	From Eq. 7.7
Nozzle Exit Diameter	0.972	0.847	[m]	From Eq. 7.5
Total Motor Length L_{mot}	**1.538**	1.365	[m]	
Constraint L_{mot}	1.500	1.500	[m]	

Table 7.14: Motor geometry "Option 1.2".

Only for the case of OPL 150 kPa is possible to proceed with the mass estimation of the motor, because the motor with a single nozzle for OPL 60 kPa does not fit the geometrical requirement. Hence for the motor with a single nozzle for OPL 150 kPa, through the same equations of Chapter 7.5.2 it is calculated that the dry mass is equal to 405.28 kg that with 2242.7 kg of overall propellant lead M_{CES} to 36051.18 kg. Through TOSCA TS it is then demonstrated that with motors of “Option 1.2” for OPL 150 kPa the escape satisfies the requirements of Chapter 7.2. Nevertheless, motors of “Option 1.2” for OPL 60 kPa must be still sized.

7.6.1 Innovative multiple nozzles configuration for Rescue Motors of "Option 1.2"

In the analysis of "Option 1.2", like in the previous study of "Option 1.1", could be investigated a configuration which provides multiple nozzles arranged around periphery of nozzle block instead of a single central nozzle. The advantage in adopting a multiple nozzle configuration is, as demonstrated in Chapter 7.5.4, the reduction of the motor length; in fact, the nozzles are bigger in number but shorter in length and sustain the same overall performance. In this Chapter the analysis concerns two type of configuration with 5 and 8 multiple peripheral nozzles. The sizing only deals with the motors for OPL 60 kPa, but all the following procedure can be applied also for the motors of OPL 150 kPa. Like in Chapter 7.5.4 the motors are designed maintaining some parameters of the motors with one central nozzle (i.e.: p_c, T_c, p_e, Nozzle half angle, burn rate) but in order to size the nozzles, in SRP, the mass flow and other parameters are changed. The throat area A_t is obtained through Eq. 7.21.

The mass flow for each nozzle is calculated dividing the suitable mass flow $\dot{m}$ selected in Chapter 7.5.1 by the number of nozzles. The throat diameter D_t is derived from A_t and then the throat erosion rate ΔD_t is determined empirically from Eq. 7.6. Another consideration is done for the inlet diameter D_i which is supposed from the lateral view of the motor with multiple nozzles (See Figure 7.16). The expansion ratio is slightly changed in order to obtain $p_e = 0.09\ MPa$. Table 7.15 gives an overview of the differences between the configuration with one central nozzle ("Option 1.2" OPL 60 kPa) and five or eight peripheral nozzles.

Like in Chapter 7.5.4 through SRP, using as input the vacuum thrust law derived from the mass flow for each nozzle, with the same propellant composition specified in Chapter 7.5.1 and with the parameters reported in Table 7.15, it's deduced the required propellant mass for each nozzle. This value is then multiplied for the number of nozzles of the configuration resulting in 594.85 kg and 596.64 kg respectively for five and eight peripheral nozzles

Using the same equations of Chapter 7.5.1 and Chapter 7.5.2, for the sizing and mass estimation of the motors, is possible to obtain Table 7.16 and Table 7.17.

Table 7.16 and Table 7.17 show that a multiple nozzle configuration reduces the total length of the motor, allowing more margin in the area limited by the constraint. Regarding the masses, from results of equations of Chapter 7.5.2, a multiple nozzle configuration decreases the mass required for the structure of the nozzles although the mass of propellant required for the performance slightly increases. CAD models of the resulting motors are displayed in Figure 7.16. With the same procedure of Chapter 7.5.3 it's then investigated, considering CRM of "Option 1.2" with multiple nozzles configuration, if the requirements related to the escape are satisfied. Considering the new mass for CES, it's thus demonstrated through TOSCA TS that all the requirements are met.

	1 Central Nozzle	5 Peripheral Nozzles	8 Peripheral Nozzles	Unit	Remarks
Chamber pressure p_c	15	15	15	[MPa]	-
Chamber Temp. T_c	3550	3550	3550	[K]	-
Exit pressure p_e	0.09	0.09	0.09	[MPa]	Parameter for "Option 1.2"
Nozzle Half Angle	15	15	15	[deg]	-
Burn Rate	58	58	58	[mm/s]	-
Throat Diameter D_t	0.207	0.093	0.073	[m]	Derived from A_t
Throat Eros. Rate ΔD_t	0.9449	0.8899	0.8841	[mm/s]	From formula
Inlet Diameter D_i	1.9	1.9/3.5	1.9/5	[m]	Supposed from Figure 7.16
Sub. (Compr.) Ratio	84.24	34.34	26.93	[-]	A_i/A_t
Sup. (Exp.) Ratio	22	21.85	21.85	[-]	To obtain $p_e = 0.09\ MPa$
Exit Diameter D_e	0.972	0.433	0.342	[m]	$D_e = \sqrt{(A_e/A_t)} \cdot D_t$

Table 7.15: Parameters for different nozzle/s configurations "Option 1.2" OPL 60 kPa

	1 Central Nozzle	5 Peripheral Nozzles	8 Peripheral Nozzles	Unit	Remarks
Casing Diameter (largest)	1.9	1.9	1.9	[m]	Same of single nozzle Motor
Casing Main Cylinder Length	0.108	0.109	0.109	[m]	Depends on prop. volume
Casing Aft Dome Height	0.241	0.241	0.241	[m]	Same of single nozzle Motor
Casing Front Dome Height	0.048	0.048	0.048	[m]	Same of single nozzle Motor
Nozzle Length	1.141	0.508	0.402	[m]	From formula Eq. 7.7
Total Motor Length L_{mot}	**1.538**	0.906	0.800	[m]	Constraint 1.5 [m]

Table 7.16: Motor dimensions, different nozzle/s configurations, "Option 1.2", OPL 60 kPa

	1 Central Nozzle	5 Peripheral Nozzles	8 Peripheral Nozzles	Unit	Remarks
Motor Dry Mass without Nozzle(s)	66.38	66.39	66.39	[kg]	With 1 additional $\eta = 0.25$ *dome*
Single Nozzle Mass	30.15	3.696	2.076	[kg]	Considering also the insulation for the Nozzle
Total Nozzle(s) Mass	30.15	18.48	16.62	[kg]	Multiplying Single Nozzle Mass for the number of Nozzles
Total Dry Mass 1 Motor	96.53	84.85	83.01	[kg]	-
Propellant Mass 1 Motor	590.26	594.85	596.64	[kg]	From SRP, each motor
Overall Mass 1 Motor	686.79	679.70	679.65	[kg]	-
Overall Mass 5 Motor	3433.95	3398.50	3398.25	[kg]	Mass installed on the CRS

Table 7.17: Mass budget for different nozzle/s configurations "Option 1.2", OPL 60 KPa

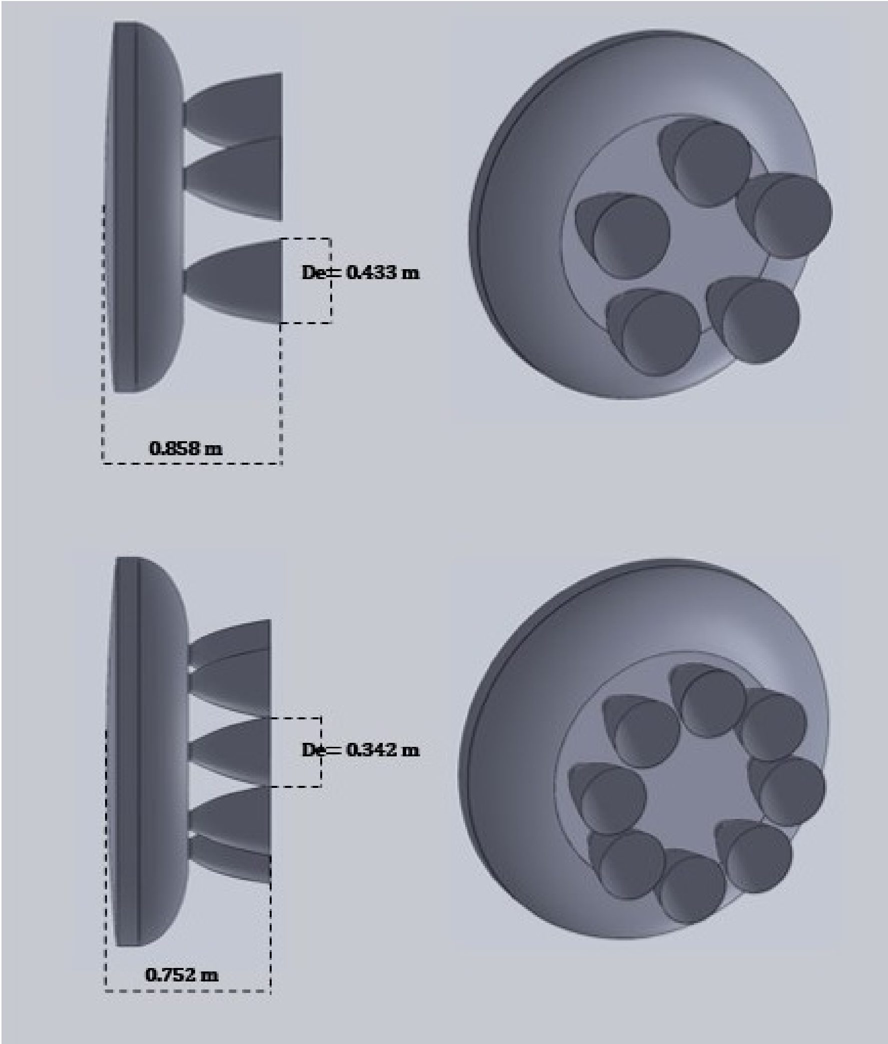


Figure 7.16: CAD Models of 5 and 8 Multiple Nozzle configuration “Option 1.2” OPL 60 kPa.

7.7 Option 2 - SpaceX' SuperDraco engines as Rescue Motors

SuperDraco is a hypergolic propellant liquid rocket engine designed and built by SpaceX. Is part of SpaceX's Draco family of rocket engines and is employed in an array of eight in the Dragon V2, passenger-carrying, space capsule providing fault-tolerant propulsion for a launch escape system and the possibility of a propulsive-landing thrust. SuperDraco engines use a storable propellant mixture of Monomethylhydrazine (MMH, fuel) and Dinitrogen Tetroxide (NTO, oxidizer) and are designed to be highly throttleable in order to provide precise control during propulsive landing of Dragon Capsule on Earth or another planet. The combustion chamber of SuperDraco is 3D-printed, made of Iconel and regeneratively cooled. The idea in this Chapter is to analyse and size a possible option for SpaceLiner's Cabin Rescue Motors which uses SpaceX' SuperDraco engines for the escape.

First, is important to collect all the known performances of this type of engine from the available literature (Table 7.18), then, from these, is obtained a preliminary design of SuperDraco through RPA (Rocket Propulsion Analysis). Following the process of Figure 7.5, once defined the possible motor geometry a supposition on the number of SuperDraco, required for the capsule escape, is done. Consequently, is performed an analysis on the dimensions and masses needed by the tanks and feed system. At the end, with an iterative process, knowing the overall mass required by "Option 2", a new M_{CES} is calculated and through TOSCA TS is investigated if the requirements specified in Chapter 7.2 are met. The study ends when with a certain number of SuperDraco all requirements are satisfied.

	Value	Unit	Remarks
Maximum Thrust (SL)	71	[kN]	From Ref. [21]
I_{SP} (SL)	235	[s]	From Ref. [22]
Chamber pressure p_C	6.9	[MPa]	From Ref. [23]
Propellant NTO/MMH	[-]	[-]	From Ref. [24]
Mixture Ratio	0.86	[-]	To have I_{SP}(SL)=235 [s] in RPA
Sub. (Compr.) Ratio A_c/A_t	1.5	[-]	Supposed from Figure 7.17
Sup. (Exp.) Ratio A_e/A_t	4	[-]	Supposed from Figure 7.17

Table 7.18: SuperDraco engine high-level performance parameters

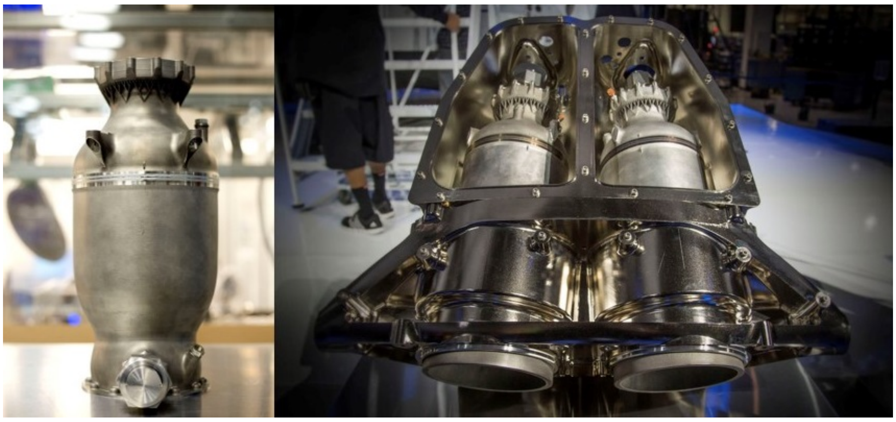


Figure 7.17: Images of SuperDraco's combustion chamber (left) and of a pair of SuperDraco (right) where it's possible to see the nozzle installed .

From Figure 7.17 (left) is possible to evaluate the compression ratio A_c/A_t equal to 2.01. Figure 7.17 (right) gives A_e/A_c equal to 1.99. Then through Eq. 7.23 is possible to obtain the expansion ratio A_e/A_t which is calculated equal to 4.0:

$$\frac{A_e}{A_t} = \frac{A_c}{A_t} \cdot \frac{A_e}{A_c} \tag{7.23}$$

High level performance parameters of Table 7.23 are used as inputs in RPA tool which gives in return the geometry of the motor, the mass flow required and the hypothetical dry mass of the motor. Table 7.19 shows some RPA's outputs.

The geometry parameters seem consistent with the images available. The total motor length is 0.732 meters. SuperDraco engines are very smaller compared to Solid Rocket Motors of "Option 1.1". The maximum thrust at sea level conditions for a single SuperDraco, is "only" 71 kN while for a single Motor of "Option 1.1" is 855 kN. Indeed, to perform the CRS escape, several SuperDraco will be required.
In order to understand how many SuperDraco are necessary for the rescue, is important to evaluate the overall mass related to "Option 2" which means the sum of motor mass, propellant mass, tanks mass and feed system mass.
In this way, for each iteration, is possible to obtain the value of M_{CES} and investigate through TOSCA TS if, with a certain number of SuperDraco engines (which are related to a global mass flow profile), the requirements are satisfied.
From the iterative process is evaluated that in order to satisfy the constraints of

Chapter 7.2, the escape requires 65 or 49 SuperDraco engines respectively considering OPL 60 kPa or OPL 150 kPa.

	Value	Unit
Casing Diameter	0.136	[m]
Nozzle Exit Diameter	0.192	[m]
Nozzle Throat Diameter	0.096	[m]
Casing Length	0.516	[m]
Nozzle Length	0.216	[m]
Total Motor Length L_{mot}	0.732	[m]
Mass flow	30.73	[kg/s]
Motor Dry Mass	32.19	[kg]

Table 7.19: SuperDraco engine geometry obtained through RPA

The use of Iconel alloy for the combustion chamber (which requires to withstand p_C=6.9 MPa) leads to a dry mass quite high (32.19 kg for each motor, RPA output). The required propellant mass is obtained integrating the mass flow rate considering a burning time of 2.07 s. The masses of MMH and NTO are thus derived from the propellant mass considering the mixture ratio. From the required mass of MMH and NTO is calculated the related volume to store through Eq. 7.24

$$V_{MMH/NTO} = \frac{M_{MMH/NTO}}{\rho_{MMH/NTO}} \tag{7.24}$$

Where ρ is considered equal to 1011 kg/m^3 for MMH (T=293 K) and to 1440 kg/m^3 for NTO (T=293 K). Considering a blow-down pressurization system, to determine the mass and volume of the pressurant gas, which is supposed Helium, Eq. 7.25 and Eq. 7.26 are combined:

$$V_{MMH} + V_{NTO} + V_g = M_g R_g T / p_{g,EOL} \tag{7.25}$$

$$V_g = M_g R_g T / p_{g,BOL} \tag{7.26}$$

Where $p_{g,EOL}$ is the lowest acceptable inlet pressure which is assumed as the condition at the end of life and $p_{g,BOL}$ is the pressure when all the pressurant is in its tank/s. Since the Helium must pressurize the propellant tanks to force fuel and oxidizer to the combustion chamber and to maintain adequate flow, the tank pressures must exceed the combustion chamber pressure. The values of He mass, He volume and of the various supposed pressures are reported in Table 7.20.
Three types of configuration for the tanks are studied: the first (Figure 7.21) considers for each engine three tanks respectively for He, MMH and NTO; the second (Figure 7.19) is designed to have a unique tank of He for all the engines and for each engine two tanks respectively for MMH and NTO; the third (Figure 7.20) uses three overall tanks respectively for all the He, all the MMH and all the NTO required. The aim is to understand the volume and the mass required by the different configurations. Considering spherical tanks and a further volume of 0.4% of ullage, is possible to calculate the consequent radium of each sphere through Eq. 7.27 from the volume of fuel/oxidizer/pressurant which must be stored

$$R_{tank} = \Big((V_{to\ store} + 0.4 \cdot V_{to\ store}) \frac{3}{4\pi} \Big)^{1/3} \tag{7.27}$$

Furthermore, the thickness of the casing for each tank must be calculated. It depends on the maximum internal pressure, on the casing material ultimate strength (σ_u) and on the geometry of the tank. For a spherical tank the thickness is calculated through Eq. 7.28

$$t = \frac{R_{tank} \cdot p_t}{2 \cdot \sigma_u} \cdot s_M \tag{7.28}$$

Where p_t is the maximum internal pressure of the tank and s_M is the structural margin set to 2.
The subsequent step is to calculate the mass related to each tank. Is calculated the volume enclosed between the sphere of radium R_{tank} and the sphere of radium $R_{tank} + t$, after that this volume is multiplied for the density of the material chosen for the casing which is the titanium alloy Ti-6Al-4V (a typical aeronautical alloy

with a high strength to weight ratio). Table 7.21 and Table 7.22 show the results of the sizing of the tanks.

To obtain the overall mass required by "Option 2", during the sizing, might be considered also the mass of the feed system lines and valves. Since forecast the length of the various lines is very complex, these will be neglected in the calculation but an estimation on the mass of the valves is performed. Indeed, for each SuperDraco Engine, are considered four pyrotechnical valves, each of mass 0.160 kg (a value in accordance with Ref. [25]). Thus, the mass of the Cabin Escape System (M_{CES}) considering "Option 2" as Cabin Rescue Motors is calculated through Eq. 7.29

$$\begin{aligned} M_{CES} = M_{capsule\ without\ separation\ motors} + n_{motors} \cdot M_{dry\ motor} + M_{MMH} \\ + M_{NTO} + M_{He} + M_{tanks\ overall} + M_{valves} \end{aligned} \tag{7.29}$$

The value of M_{CES} calculated for OPL 60 kPa and for OPL 150 kPa is reported in Table 7.23. Once obtained M_{CES} is possible to perform the analysis through TOSCA TS, investigating if, with the mass flow related to the number of SuperDraco elected for the escape from a certain blast shockwave, the constraints of Chapter 7.2 are satisfied. With 65 SuperDraco and 49 SuperDraco is demonstrated that requirements respectively for OPL 60 kPa and OPL 150 kPa are met.

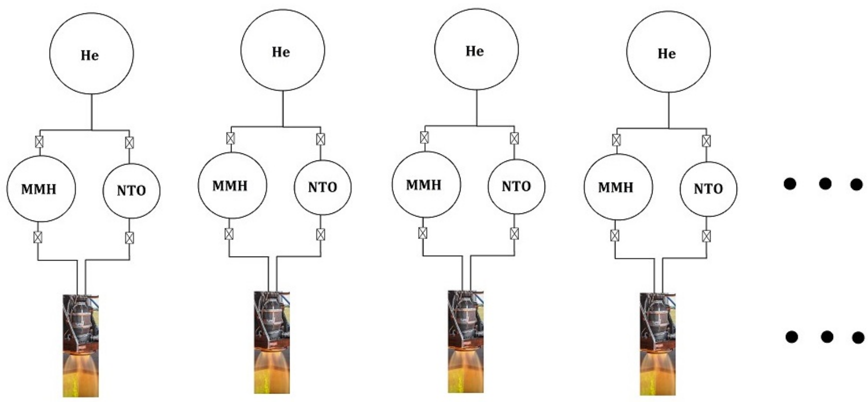


Figure 7.18: Tanks Configuration 1.

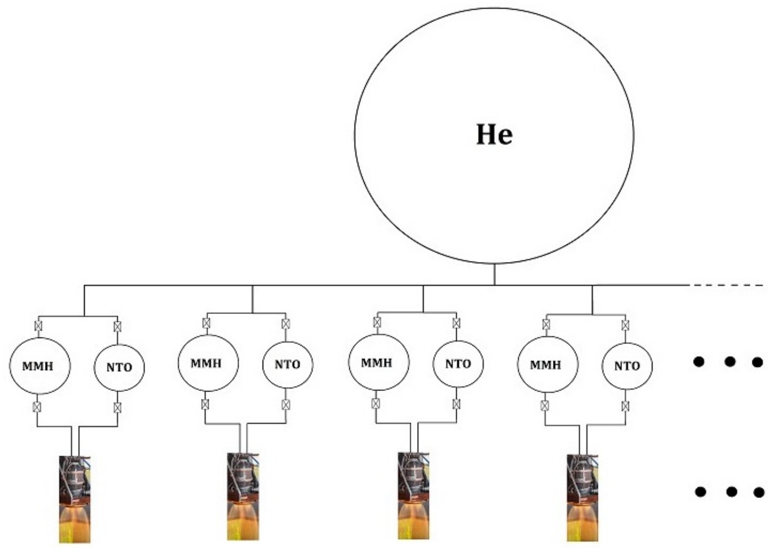


Figure 7.19: Tanks Configuration 2.

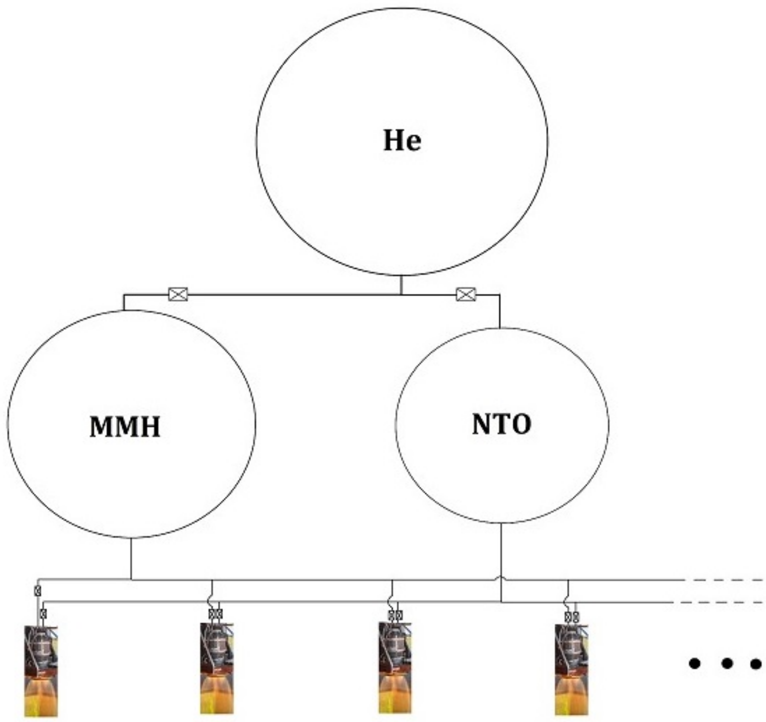


Figure 7.20: Tanks Configuration 3.

	OPL 60 kPa	OPL 150 kPa	Unit	Remarks
Number of SuperDraco required	65	49	[-]	To satisfy constraints Chapter 7.2
Propellant mass flow	30.74	30.74	[kg/s]	Mass flow for 1 SuperDraco
Burning time	2.07	2.07	[s]	-
MMH mass required	2003.3	1505.6	[kg]	Considering all the engines
NTO mass required	1723.0	1295.0	[kg]	Considering all the engines
MMH volume	0.031	0.030	[m^3]	Considering all the engines
NTO volume	0.018	0.018	[m^3]	Considering all the engines
He mass required	38.48	28.92	[kg]	To pressurize all propellant tanks
He volume required	3.177	2.38	[m^3]	To pressurize all propellant tanks
$p_{g,BOL}$	30	30	[MPa]	He tank/s pressure at begin of life
$p_{g,EOL}$	15	15	[MPa]	He tank/s pressure at end of life
p_t	9.9	9.9	[MPa]	MMH and NTO tank/s pressure
p_c	6.9	6.9	[MPa]	SuperDraco chamber pressure

Table 7.20: "Option 2" tanks high-level parameters

	Conf. 1	Conf. 2	Conf. 3	Unit	Remarks
Number of He tanks	65	1	1	[-]	-
Number of MMH tanks	65	65	1	[-]	-
Number of NTO tanks	65	65	1	[-]	-
He tank Radium	0.230	0.924	0.924	[m]	-
MMH tank Radium	0.196	0.196	0.789	[m]	-
NTO tank Radium	0.166	0.166	0.667	[m]	-
He tank thickness	2.4	9.6	9.6	[mm]	-
MMH tank thickness	2.0	2.0	8.2	[mm]	-
NTO tank thickness	1.7	1.7	7.0	[mm]	-
Density Ti-6Al-4V	4429	4429	4429	$[kg/m^3]$	-
Ult. strength Ti-6Al-4V	950	950	950	[MPa]	-
He tank Volume	0.0508	3.31	3.31	$[m^3]$	For a single tank
MMH tank Volume	0.0317	0.0317	2.06	$[m^3]$	For a single tank
NTO tank Volume	0.0191	0.0191	1.24	$[m^3]$	For a single tank
He tank Mass	7.706	500.87	500.87	[kg]	For a single tank
MMH tank Mass	4.435	4.435	288.29	[kg]	For a single tank
NTO tank Mass	2.678	2.678	174.10	[kg]	For a single tank
Overall Tanks Mass	963.26	963.26	963.26	[kg]	Considering all the masses of the tanks

Table 7.21: "Option 2" tanks system sizing for OPL 60 kPa

	Conf. 1	Conf. 2	Conf. 3	Unit	Remarks
Number of He tanks	49	1	1	[-]	-
Number of MMH tanks	49	49	1	[-]	-
Number of NTO tanks	49	49	1	[-]	-
He tank Radium	0.230	0.840	0.840	[m]	-
MMH tank Radium	0.196	0.196	0.718	[m]	-
NTO tank Radium	0.166	0.166	0.607	[m]	-
He tank thickness	2.4	8.8	8.8	[mm]	-
MMH tank thickness	2.0	2.0	7.5	[mm]	-
NTO tank thickness	1.7	1.7	6.3	[mm]	-
Density Ti-6Al-4V	4429	4429	4429	[kg/m^3]	-
Ultimate strength Ti-6Al-4V	950	950	950	[MPa]	-
He tank Volume	0.508	2.484	2.484	[m^3]	For a single tank
MMH tank Volume	0.0317	0.317	1.549	[m^3]	For a single tank
NTO tank Volume	0.0191	0.0191	0.935	[m^3]	For a single tank
He tank Mass	7.70	376.47	376.47	[kg]	For a single tank
MMH tank Mass	4.42	4.42	216.69	[kg]	For a single tank
NTO tank Mass	2.67	2.67	130.85	[kg]	For a single tank
Overall Tanks Mass	724.01	724.01	724.01	[kg]	Considering all the masses of the tanks

Table 7.22: "Option 2" tanks system sizing for OPL 150 kPa

	OPL 60 kPa	OPL 150 kPa	Unit	Remarks
Number of SuperDraco required	65	49	[-]	To satisfy constraints Chapter 7.2
$M_{DRYMOTOR}$	32.19	32.19	[kg]	From RPA, single motor mass
M_{MMH}	2003.3	1505.6	[kg]	Mass required by all engines
M_{NTO}	1723.0	1295.0	[kg]	Mass required by all engines
M_{He}	38.48	28.92	[kg]	To pressurize all propellant tanks
Overall tanks mass	963.26	724.01	[kg]	Considering all the tanks
Valves Mass	41.6	31.36	[kg]	Considering all the valves
“Option 2” Overall Mass	6861.99	5162.2	[kg]	-
Capsule Mass without separation motors	33403.1	33403.1	[kg]	-
M_{CES} **Cabin Escape System Mass**	40265.09	38565.3	[kg]	Value used as input in TOSCA

Table 7.23: Calculation of CES mass for "Option 2".

Comparing “Option 2” with “Option 1.1” it can be seen that SuperDraco engines of “Option 2” have a smaller length than Solid Rocket Motors of “Option 1.1” but the mass required for the overall “Option 2” system is very bigger compared with “Option 1.1". Moreover, although the space in the aft of the Cabin Escape System could fit 65 SuperDraco or more, the complexity of the feed system with the related tanks and lines to integrate, could be a serious problem in the adoption of “Option 2”.

7.8 Option 3 - New Liquid Propellant engines as Rescue Motors

The idea of this chapter is to rescale the SpaceX' SuperDraco in order to size five new type of liquid propellant engines able to perform the escape, avoiding options with excessive number of engines installed in the aft of the CES. In this analysis are taken as inputs some performance parameters of SpaceX' SuperDraco like the chamber pressure, the type of fuel (MMH) and oxidizer (NTO) employed and the supersonic expansion ratio. Then is elected a mixture ratio able to maximize the specific impulse of the engine. The high-level performance parameters are reported in Table 7.24.

	Value	Unit	Remarks
Number of Engines	5	[-]	-
Chamber pressure p_C	6.9	[MPa]	From SpaceX' SuperDraco
Propellant	NTO/MMH	[-]	From SpaceX' SuperDraco
Sup. (Exp.) Ratio A_e/A_t	4	[-]	From SpaceX' SuperDraco
Mixture Ratio	1.964	[-]	To optimize I_{SP}
I_{SP}(SL)	267.66	[s]	Value obtained from RPA

Table 7.24: New Liquid Propellant engine high-level performance parameters.

After the definition of the high-level performance parameters, as reported in Figure 7.6, the key step in the analysis of "Option 3" is the definition of the nominal thrust for each engine. This assumption influences the geometry, the mass flow and the mass of the engine at which is also related the size and mass of the feed/tanks system. With an iterative process is found a nominal thrust for OPL 60 kPa and OPL 150 kPa which lead to the satisfaction of the requirements of Chapter 7.2. Through RPA, with the nominal thrust and the parameters of Table 7.24 as inputs, is calculated the geometry, the mass flow and the dry mass for each engine. The results are reported in Table 7.25 and a CAD model of the motors is available in Figure **??**. After that, considering as burning time 2.07 s, from the mass flow profile is extrapolated the amount of mass of the required propellant. Therefore, is calculated the mass of MMH and NTO taking into account the mixture ratio. From this point forward, the followed procedure is the same of that in Chapter 7.7. The aim is to size the tanks. Hence, having the mass of MMH and NTO, through Eq. 7.24 is calculated the volume to store. With the combination of Eq. 7.25 and Eq. 7.26 is obtained the volume and the mass for the pressurant gas (Helium) which must pressurize the tanks of MMH and NTO.

	OPL 60 kPa	OPL 150 kPa	Unit
Nominal Thrust	885	670	[kN]
Casing Diameter	0.477	0.415	[m]
Nozzle Exit Diameter	0.673	0.586	[m]
Nozzle Throat Diameter	0.337	0.293	[m]
Casing Length	0.565	0.556	[m]
Nozzle Length	0.734	0.639	[m]
Total Motor Length L_{mot}	1.299	1.195	[m]
Mass flow	337.69	255.65	[kg/s]
Motor Dry Mass	203.72	165.14	[kg]

Table 7.25: New Liquid Propellant Engine geometry obtained through RPA.

Through Eq. 7.27 is calculated the radium required to store the given amount of propellant and pressurant. Eq. 7.28 gives as result the thickness for the tanks. Table 7.26 shows the high-level parameters for the tanks while in Table 7.27 and Table 7.28 are reported the results of the tanks sizing always considering the three types of configuration of Figure 7.21, Figure 7.19 and Figure 7.20.

During the selection of the nominal thrust for the motors, is iteratively investigated through TOSCA TS if the requirements of Chapter 7.2 are met. When a nominal thrust is chosen, is defined (through RPA) the geometry, the mass flow and the dry mass of each motor and consequently the feed/tanks system mass and volume. The sum of the overall dry mass of the motors, the mass of the tanks, the mass of the propellant and pressurant and the mass of the valves supposed in the feed system lead to a defined mass which characterized "Option 3" that if is summed with the mass of the CES without separation motors brings to a specific M_{CES}. Table 7.29 shows the resume of the values used to calculate M_{CES}.

In this way the new inputs for the TOSCA TS analysis are M_{CES} and the overall mass flow consequent to the five motors elected for "Option 3". From the investigation is obtained that all the requirements of Chapter 7.2 are met for both OPL 60 kPa and OPL 150 kPa, therefore the motors designed in "Option 3" could perform the escape from the blast shockwave propagation at the Launch pad.

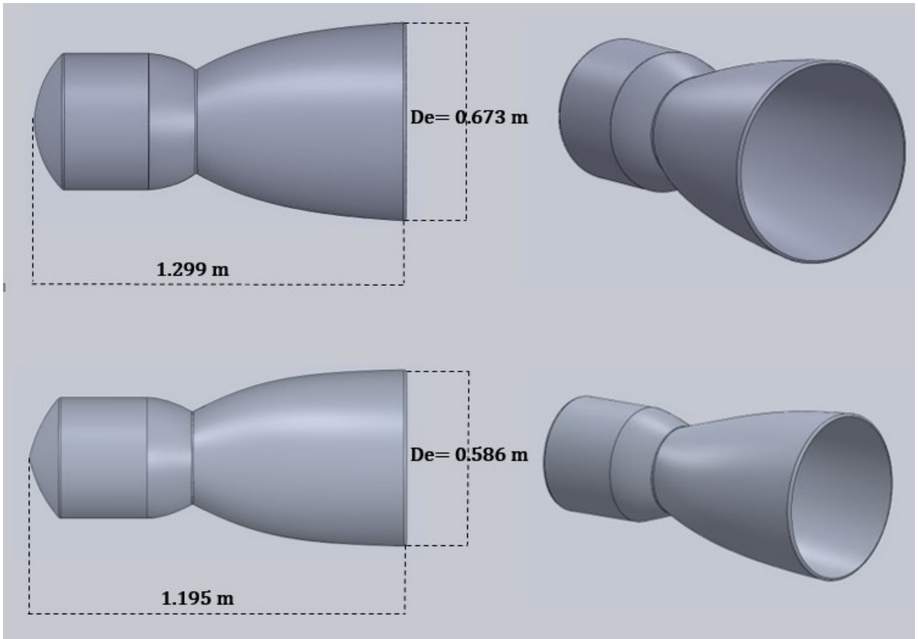


Figure 7.21: CAD Model for New Liquid Rocket Engine OPL60 kPa (above) and OPL150 kPa (down).

The aim of "Option 3" is to design a motor, sized for the particular case of the cabin escape of the SpaceLiner mission, which adopt the same technology of the SpaceX' SuperDraco that is an innovative technology in part already tested. The disadvantage of using a technology based on liquid propellant is the need to design a proper feed/tanks system which involves larger masses and volumes than an option with only solid propellant. But liquid propellant engines have the advantage that can be throttleable, which is a very useful aspect if the objective is to land a capsule with high precision. In this point of view, the requirements for the CES of the SpaceLiner do not impose a constraint in how precise has to be the landing. Is only stated that the capsule must reach at least the altitude of 750 m in order to ensure a proper landing with parachutes. Then, a solution for the Cabin Rescue Motors with liquid propellant engines could be innovative but not necessary for the SpaceLiner mission.

	OPL 60 kPa	OPL 150 kPa	Unit	
Number of Engines	5	5	[-]	-
Propellant mass flow	337.69	255.65	[kg/s]	From RPA, for 1 engine
Burning time	2.07	2.07	[s]	-
MMH mass required	1060.0	800.97	[kg]	Considering all the engines
NTO mass required	2082.2	1573.4	[kg]	Considering all the engines
MMH volume	1.048	0.7923	[m^3]	Considering all the engines
NTO volume	1.446	1.0927	[m^3]	Considering all the engines
He mass required	30.20	22.82	[kg]	To pressurize all propellant tanks
He volume required	2.49	1.88	[m^3]	To pressurize all propellant tanks
$p_{g,BOL}$	30	30	[MPa]	He tank/s pressure at Begin of life
$p_{g,EOL}$	15	15	[MPa]	He tank/s pressure at End of life
p_t	9.9	9.9	[MPa]	MMH and NTO tank/s pressure
p_c	6.9	6.9	[MPa]	SuperDraco chamber pressure

Table 7.26: "Option 3" tanks high-level parameters.

	Conf. 1	Conf. 2	Conf. 3	Unit	Remarks
Number of He tanks	5	1	1	[-]	-
Number of MMH tanks	5	5	1	[-]	-
Number of NTO tanks	5	5	1	[-]	-
He tank Radium	0.498	0.852	0.852	[m]	-
MMH tank Radium	0.373	0.373	0.639	[m]	-
NTO tank Radium	0.416	0.416	0.711	[m]	-
He tank thickness	5.2	8.9	8.9	[mm]	-
MMH tank thickness	3.9	3.9	6.7	[mm]	-
NTO tank thickness	4.3	4.3	7.4	[mm]	-
Density Ti-6Al-4V	4429	4429	4429	[kg/m^3]	-
Ultimate strength Ti-6Al-4V	950	950	950	[MPa]	-
He tank Volume	0.519	2.59	2.59	[m^3]	For a single tank
MMH tank Volume	0.218	0.218	1.09	[m^3]	For a single tank
NTO tank Volume	0.301	0.301	1.50	[m^3]	For a single tank
He tank Mass	72.59	362.94	362.94	[kg]	For a single tank
MMH tank Mass	30.51	30.51	152.55	[kg]	For a single tank
NTO tank Mass	42.078	42.078	210.39	[kg]	For a single tank
Overall Tanks Mass	725.88	725.88	725.88	[kg]	Considering all the masses of the tanks

Table 7.27: “Option 3” tanks system sizing for OPL 60 kPa

	Conf. 1	Conf. 2	Conf. 3	Unit	Remarks
Number of He tanks	5	1	1	[-]	-
Number of MMH tanks	5	5	1	[-]	-
Number of NTO tanks	5	5	1	[-]	-
He tank Radium	0.454	0.776	0.776	[m]	-
MMH tank Radium	0.340	0.340	0.582	[m]	-
NTO tank Radium	0.379	0.379	0.647	[m]	-
He tank thickness	4.7	8.1	8.1	[mm]	-
MMH tank thickness	3.5	3.5	6.1	[mm]	-
NTO tank thickness	3.9	3.9	6.7	[mm]	-
Density Ti-6Al-4V	4429	4429	4429	$[kg/m^3]$	-
Ultimate strength Ti-6Al-4V	950	950	950	[MPa]	-
He tank Volume	0.392	1.96	1.96	$[m^3]$	For a single tank
MMH tank Volume	0.165	0.165	0.894	$[m^3]$	For a single tank
NTO tank Volume	0.227	0.227	1.136	$[m^3]$	For a single tank
He tank Mass	54.85	274.26	274.26	[kg]	For a single tank
MMH tank Mass	23.05	23.05	115.27	[kg]	For a single tank
NTO tank Mass	31.80	31.80	158.98	[kg]	For a single tank
Overall Tanks Mass	548.51	548.51	548.51	[kg]	Considering all the masses of the tanks

Table 7.28: “Option 3” tanks system sizing for OPL 150 kPa

	OPL 60 kPa	OPL 150 kPa	Unit	Remarks
Number of engines	5	5	[-]	-
$M_{DRY MOTOR}$	203.72	165.14	[kg]	From RPA, single motor mass
M_{MMH}	1060.0	800.97	[kg]	Mass required by all engines
M_{NTO}	2082.2	1573.4	[kg]	Mass required by all engines
M_{He}	30.20	22.82	[kg]	To pressurize all propellant tanks
Overall tanks mass	725.88	548.51	[kg]	Considering all the tanks
Valves Mass	3.2	3.2	[kg]	Considering all the valves
"Option 3" Overall Mass	4920.08	3774.6	[kg]	-
Capsule Mass without separation motors	33403.1	33403.1	[kg]	-
M_{CES} **Cabin Escape System Mass**	38323.18	37177.7	[kg]	Value used as input in TOSCA

Table 7.29: Calculation of CES mass for "Option 3".

7.9 Comparisons

Table 7.30, Table 7.31 and Table 7.32 show a general resume of the different CRM options, previous presented, for OPL 60 kPa and OPL 150 kPa :

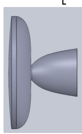
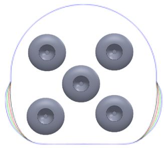
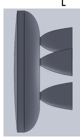
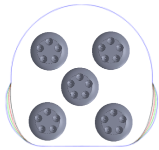
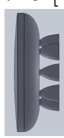
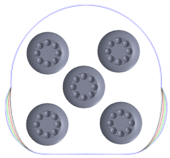
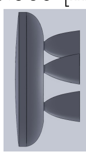
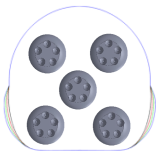
Option	Overall propellant mass	Overall dry mass	Single Motor Length	Aft configuration
Option 1.1 - Solid Rocket Motors pe=1.5 bar	3027.5 [kg] HTPB/AP/AL (solid)	436.36 [kg]	1.287 [m] 	
Option 1.1 - Solid Rocket Motors 5 Multiple Nozzles pe=1.5 bar	3049 [kg] HTPB/AP/AL (solid)	397.70 [kg]	0.797 [m] 	
Option 1.1 - Solid Rocket Motors 8 Multiple Nozzles pe=1.5 bar	3057 [kg] HTPB/AP/AL (solid)	391.60 [kg]	0.715 [m] 	
Option 1.2 - Solid Rocket Motors 5 Multiple Nozzles pe=0.9 bar	2974.25 [kg] HTPB/AP/AL (solid)	424.25 [kg]	0.906 [m] 	

Table 7.30: Overview of different CRM options for OPL 60 kPa, Part 1.

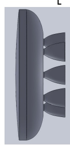
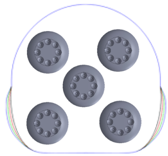
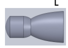
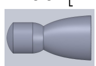
Option	**Overall propellant mass**	**Overall dry mass**	**Single Motor Length**	**Aft configuration**
Option 1.2 - Solid Rocket Motors 8 Multiple Nozzles pe=0.9 bar	2083.20 [kg] HTPB/AP/AL (solid)	415.05 [kg]	0.800 [m] 	
Option 2 - SpaceX' SuperDraco Engines	3726.3 [kg] MMH/NTO (liquid)	3135.69 [kg]	0.723 [m] 	
Option 3 – New Liquid Propellant Engines	3142.2 [kg] MMH/NTO (liquid)	1777.88 [kg]	1.299 [m] 	

Table 7.31: Overview of different CRM options for OPL 60 kPa, Part 2.

Because of time, the options with multiple nozzles have been studied only for the most conservative case (OPL 60 kPa), but the same procedure could be applied also for the options OPL 150 kPa. Considering that all the options presented in Table 7.30 , Table 7.31 and Table 7.32 have been validated through TOSCA TS is possible at this point to make a Trade-Off between the various configurations.

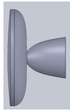
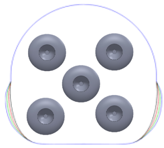
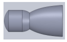
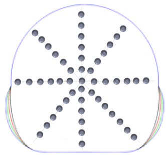
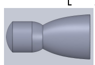
Option	**Overall propellant mass**	**Overall dry mass**	**Single Motor Length**	**Aft configuration**
Option 1.1 - Solid Rocket Motors pe=1.5 bar	2300.35 [kg] HTPB/AP/AL (solid)	375.62 [kg]	1.147 [m] 	
Option 2 - SpaceX' SuperDraco Engines	2800.6 [kg] MMH/NTO (liquid)	2361.6 [kg]	0.723 [m] 	
Option 3 – New Liquid Propellant Engines	2374.37 [kg] MMH/NTO (liquid)	1400.23 [kg]	1.195 [m] 	

Table 7.32: Overview of different CRM options for OPL 150 kPa.

The option selected as "Nominal" is "Option 1.1 – Solid Rocket Motors (OPL 60 kPa)". The reason for this choice is that, Solid Rocket Motors compared to Liquid Rocket Engines are simpler, reliable and can save weight which for liquid propellant increases due to the tanks/feed system. Therefore, there is not the need to have a throttleable motor which could be realized only with Liquid Rocket Engines. For the "Nominal" option is decided to choose a configuration without multiple nozzle because the internal ballistics performances for a configuration with multiple nozzle must be study thoroughly. In the case of study of Ref. [26] is reported that a multiple nozzle geometry could lead to a thrust/time profile no longer flat. Therefore, if a multiple nozzle would be utilized, a more accurate analysis of the consequences related to this type of configuration must be performed.

Chapter 8

Analysis of other critical trajectory points

In Chapter 7 has been identified the Launch Pad as the worst-case scenario due to some consideration regarding the maximum amount of unburnt fuel, the highest atmosphere pressure and the minimum altitude from ground for a safe descent and landing with parachutes. Could be interesting to demonstrate through some simulations that the Launch Pad is effectively the scenario most conservative for the sizing of the Cabin Rescue Motors. In fact, in this chapter, through TOSCA TS are investigated some cabin escape simulations, in order to prove that with the Nominal Motors option for CRM ("Option 1.1 – Solid Rocket Motors", OPL 60 kPa) is possible to perform a safe escape also in other critical points of SpaceLiner trajectory. Figure 8.1 shows the considered critical points of the trajectory taking into consideration the altitude and Mach levels of the trajectory available in Figure 5.4.

The other critical trajectory points taken into consideration are: maximum dynamic pressure (Point 2), booster separation (Point 3), main engine cut off (MECO) (Point 4) and maximum heat flux (Point 5). For each of these points the requirements must be discussed again. The objective is still escape from the blast shockwave in order to limit the overpressure at which is exposed the capsule, always taking into account that the passengers are untrained and could endure a maximum forward and upward accelerations respectively of 12 G and 3 G for three seconds. However, it will be discovered that not for all the points of the trajectory the blast shockwave overpressure is a dangerous issue. This is due to the fact that since the fuel is consumed during the trajectory, the decrease of the latter brings to the reduction of the power of the explosion which is translated in a lower shockwave overpressure; the gain in altitude, as well, leads to weaker blast shockwaves due to the reduction of the atmospheric pressure. Last but not least, an important requirement to consider during the escape simulations, in the other critical trajectory points, is that after the separation, the CES and the SpaceLiner must not have a subsequent collision. This means that must be demonstrated that after the ejection, the CES and SpaceLiner are free from a possible impact during their trajectories.

The methodology utilized to investigate the capsule escape in other critical points is based on trajectory simulations through TOSCA TS. In the program are given as input parameters the initial conditions for the ejection related to the interested critical point. The mass flow considered is the one related to the thrust/time profile of Figure 7.7. Therefore, as stated above, the motors which must be demonstrated satisfactory for all the critical points of the trajectory, are the five "Nominal" Solid Rocket Motors of "Option 1.1", OPL 60 kPa, sized for the ejection at the launch pad.

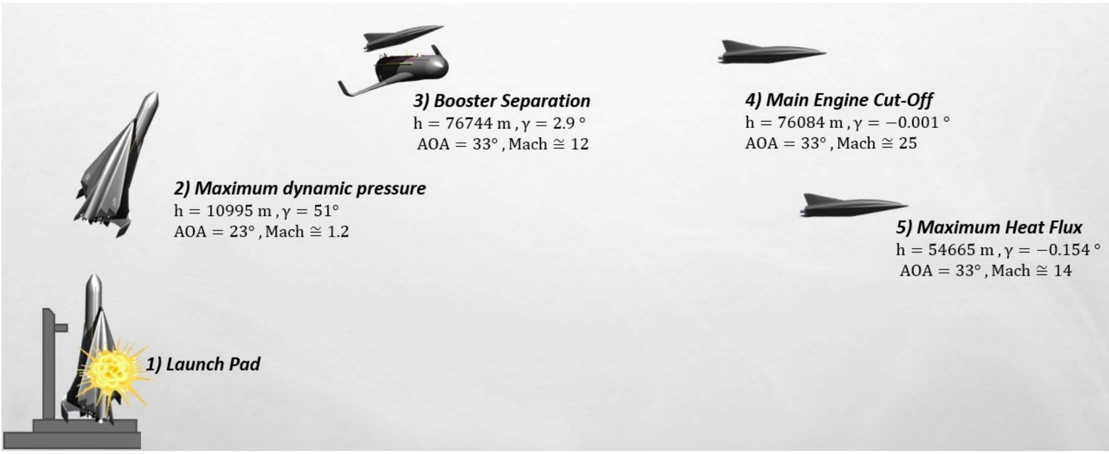


Figure 8.1: Critical trajectory points for SpaceLiner mission.

8.1 Launch Pad (Point 1)

The escape of the capsule in this scenario has been demonstrated satisfactory in Chapter 7.

8.2 Maximum Dynamic Pressure (Point 2)

	Value	Unit
Time	75.70	[s]
Altitude	10995	[m]
Flight path angle γ	51	[°]
Angle of attack for CES	23	[°]
Mach	1.2	[-]

Table 8.1: Initial conditions for CES escape at Point 2.

The initial conditions for the cabin escape at the maximum dynamic pressure point are reported in Table 8.1. In Point 2, since SpaceLiner's tanks are still providing fuel (LH2/LOX), is necessary to perform an analysis on the power and on the arrival time of the shockwave propagation. At Point 2 the fuel available is approximately 1039 tons but to be conservative for the shockwave study are considered the tanks still full of fuel (1500 tons). Thus, what changes the power and arrival time of the shockwave is the condition of 10995 meters of altitude. In fact, is repeated the analysis of Chapter 7.1.1 but this time considering the parameters related to the latter height: $\rho_{atm} = 0.364\ kg/m^3$, $p_0 = 22.632\ kPa$ and speed of sound $\sigma = 295.07\ m/s$. What is found is the graph of Figure 8.2. Comparing the explosion at 10995 meters with the one at Sea Level, it could be deduced from Figure 8.2 that the overpressure is reduced and the arrival time is slightly reduced as well. If is considered that the CES structure could withstand an overpressure until 60 kPa, in order to perform the escape, from Figure 8.2, is realized that the Cabin must travel 233 meters within 2.313 seconds.

In this way, can be listed the requirements for the cabin escape at Point 2:

- Considering OPL 60 kPa limit, in order to escape the blast radius intact, the capsule must travel 233 m within 2.41 s;
- The maximum acceptable acceleration in upward direction (N_Z) must be 3 G for three seconds;
- The maximum acceptable acceleration in forward direction (N_X) must be 12 G for three seconds;
- The Capsule after the ejection must not have a subsequent collision with the SpaceLiner in its trajectory.

These requirements must be verified with trajectory analysis performed through TOSCA TS simulations. Notice that the AOA for the CES is reduced to 23° from the nominal value of 33° in order to reduce the N_Z acceleration for the passengers.

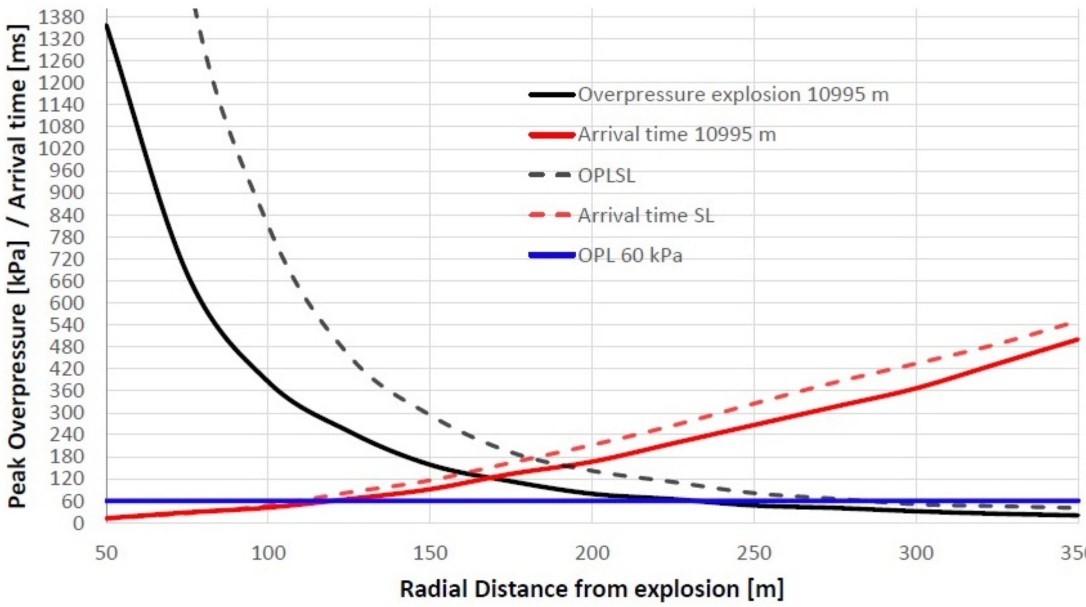


Figure 8.2: Shockwave propagation for an explosion of 1500 tons of LOX-LH2 propellant at 10995 meters of altitude.

In order to investigate the trajectory of the CES and of the SpaceLiner after the cabin ejection, is elaborated a simple MATLAB program which displays in plots the various points of the trajectories performed. The trajectory points are taken from TOSCA TS simulations and interpolated in MATLAB through the function spline. The results must demonstrate that all the previous requirements are satisfied. In fact, through TOSCA TS are checked the accelerations for the passengers while with the MATLAB program are examined carefully the trajectories.
The last thing to take into consideration for Point 2 is that since the SpaceLiner has still propellant in its tanks after a failure could be that it proceeds in its trajectory with thrust or that the failure/explosion compromises the propulsion system and the SpaceLiner goes on without thrust. For this reason, in Point 2 are performed two type of investigation, considering the SpaceLiner's trajectories in these two cases.
For "Point 2 – Maximum Dynamic Pressure" is noticed that in order to perform the escape, five "Nominal" motors are required to satisfy the requirements. Less motors utilized lead to a radial distance from the explosion which does not respect

the requirement of at least 233 meters in 2.231 seconds. Figure 8.3 and Figure 8.4 show the trajectory of CES and SpaceLiner respectively for SpaceLiner which proceeds with thrust after the explosion and for SpaceLiner with no propulsion after the failure.

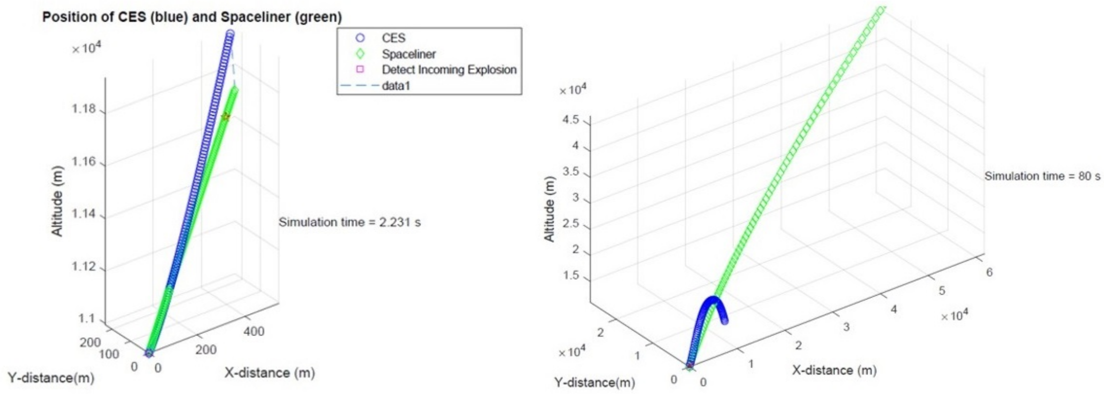


Figure 8.3: Trajectories for CES (blue) and SpaceLiner (green) for Maximum Dynamic Pressure Point with SpaceLiner which proceeds with thrust after the explosion. At the left the simulation time is 2.231 seconds while at the right is 80 seconds.

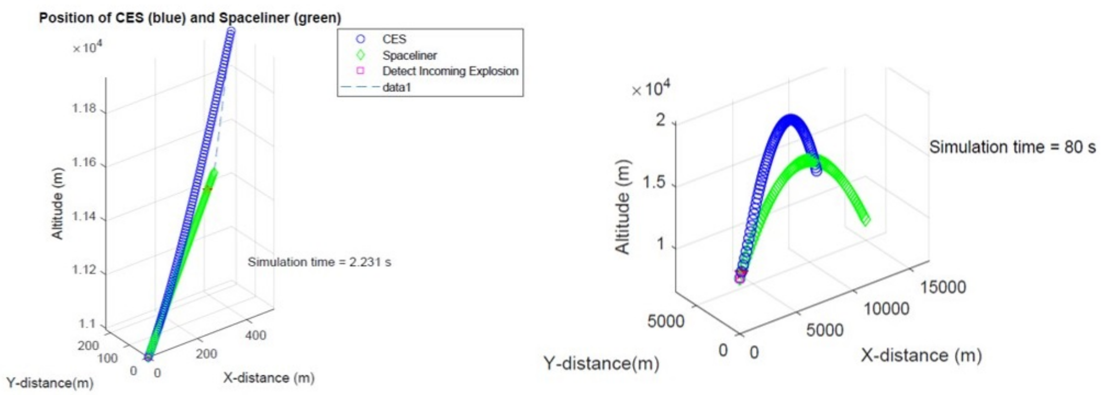


Figure 8.4: Trajectories for CES (blue) and SpaceLiner (green) for Maximum Dynamic Pressure Point with SpaceLiner which proceeds without thrust after the explosion. At the left the simulation time is 2.231 seconds while at the right is 80 seconds.

With these MATLAB plots is demonstrated at the left that after 2.231 seconds the CES has reached at least 233 meters of radial distance from the explosion, while at the right is verified that during the trajectories the CES and the SpaceLiner never collide.

8.3 Booster Separation (Point 3)

	Value	Unit
Time	238.48	[s]
Altitude	76744	[m]
Flight path angle γ	2.97	[°]
Angle of attack for CES	33	[°]
Mach	12	[-]

Table 8.2: Initial conditions for CES escape at Point 3.

The initial conditions for the cabin escape at the booster separation point are reported in Table 8.2. Even in Point 3 SpaceLiner's tanks are still providing fuel. Is thus necessary an analysis on the shockwave propagation generated by a potential explosion. However, the amount of fuel is very low (247 tons) and what is found from the shockwave analysis is that if is considered an overpressure limit of 60 kPa for the structure of the CES, the shockwave is always under this value. This is due to the fact that besides the small amount of fuel, the altitude leads to an atmosphere rarefied which reduces a lot the power of the explosion.
Hence the requirements for the CES escape in Point 3 are the following:

- The maximum acceptable acceleration in upward direction (N_Z) must be 3 G for three seconds;
- The maximum acceptable acceleration in forward direction (N_X) must be 12 G for three seconds;
- The Capsule after the ejection must not have a subsequent collision with the SpaceLiner in its trajectory.

Through TOSCA TS and the MATLAB program is found that in order to satisfy the requirements the best option is to utilize only one "Nominal" motor. This is a consequence from the flight path angle which is very low ($\gamma = 2.97°$). In fact, use a larger number of motors can lead the excess of the constraint in N_X acceleration. Figure 8.5 and Figure 8.6 shows the trajectory of CES and SpaceLiner respectively for SpaceLiner which proceeds with thrust after the explosion and for SpaceLiner with no propulsion after the failure. Notice that in the analysis of MATLB's plots is only verified that the CES and SpaceLiner are free from collision in their trajectories since there is not a constraint for a hypothetical radial distance from the explosion. The simulation time is set at 30 seconds.

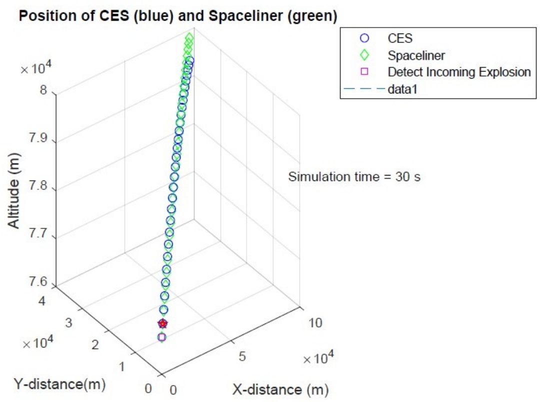


Figure 8.5: Trajectories for CES (blue) and SpaceLiner (green) for Booster Separation Point with SpaceLiner which proceeds with thrust after the explosion.

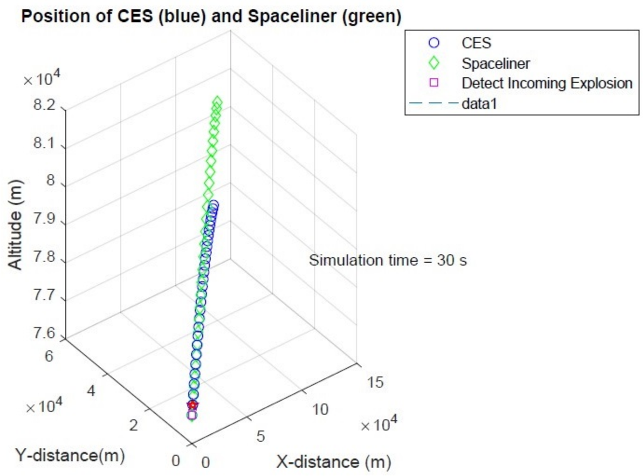


Figure 8.6: Trajectories for CES (blue) and SpaceLiner (green) for Booster Separation Point with SpaceLiner which proceeds without thrust after the explosion.

Through the MATLAB program, for Point 3, is verified that during their trajectories, the CES and SpaceLiner never collide.

8.4 Main Engine Cut Off (Point 4)

	Value	Unit
Time	441.43	[s]
Altitude	76087	[m]
Flight path angle γ	-0.001	[°]
Angle of attack for CES	33	[°]
Mach	25	[-]

Table 8.3: Initial conditions for CES escape at Point 4.

The initial conditions for the cabin escape at the main engine cut off (MECO) point are reported in Table 8.3. At MECO all the propellant has been consumed. This means that there is not the problem related to a blast shockwave estimation. The requirements for the CES escape at Point 4 are the following:

- The maximum acceptable acceleration in upward direction (N_Z) must be 3 G for three seconds;
- The maximum acceptable acceleration in forward direction (N_X) must be 12 G for three seconds;
- The Capsule after the ejection must not have a subsequent collision with the SpaceLiner in its trajectory.

Through TOSCA TS and the MATLAB program is found that in order to satisfy the requirements the best option is to utilize only one “Nominal” motor. Also in this case, like for Point 3, this assumption derives from the constraint in N_X which could be exceeded with a larger number of “Nominal” motors. From Point 4, differently with the previous points there is no more the differentiation between the cases of the SpaceLiner which proceeds with and without thrust in its trajectory. From MECO, obviously, the simulations are investigated only for the SpaceLiner with no thrust. Figure 8.7 shows the trajectory of CES and SpaceLiner for an ejection at Point 4. The simulation time is set at 80 seconds.

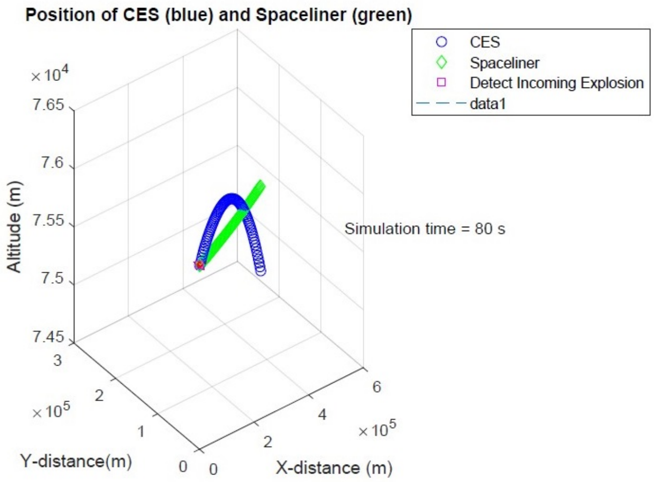


Figure 8.7: Trajectories for CES (blue) and SpaceLiner (green) for Main Engine Cut Off Point.

Through the MATLAB program, for Point 4, is verified that during their trajectories, the CES and SpaceLiner never collide.

8.5 Maximum Heat Flux (Point 5)

	Value	Unit
Time	1976.89	[s]
Altitude	54665	[m]
Flight path angle γ	-0.154	[°]
Angle of attack for CES	33	[°]
Mach	14	[-]

Table 8.4: Initial conditions for CES escape at Point 5.

The initial conditions for the cabin escape at the maximum heat flux point are reported in Table 8.4. Since from Point 4 all the propellant has been consumed there is not the problem related to a blast shockwave estimation.

The requirements for the CES escape at Point 5 are the following:

- The maximum acceptable acceleration in upward direction (N_Z) must be 3 G for three seconds;
- The maximum acceptable acceleration in forward direction (N_X) must be 12 G for three seconds;
- The Capsule after the ejection must not have a subsequent collision with the SpaceLiner in its trajectory.

Through TOSCA TS and the MATLAB program is found that in order to satisfy the requirements the best option is to utilize only one "Nominal" motor. Also in this case, such as Point 3 and Point 4, this assumption derives from the constraint in N_X which could be exceeded with a larger number of "Nominal" motors. Even for Point 5 the simulation is investigated for SpaceLiner with no thrust. Figure 8.8 shows the trajectory of CES and SpaceLiner for an ejection at Point 5. The simulation time is set at 12 seconds.

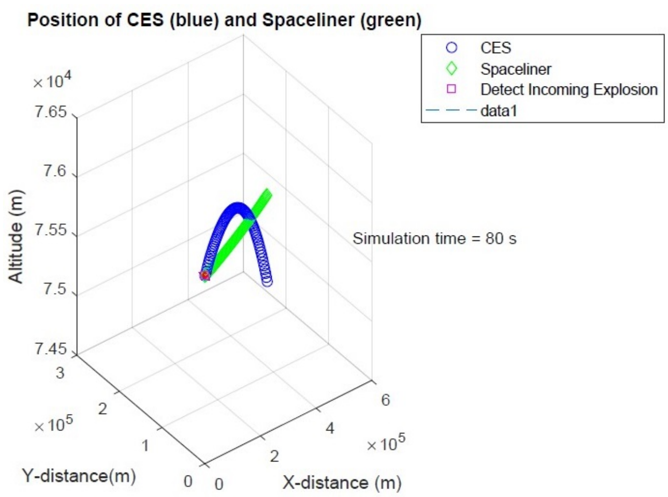


Figure 8.8: Trajectories for CES (blue) and SpaceLiner (green) for Maximum Heat Flux Point.

Through the MATLAB program, for Point 5, is verified that, during their trajectories, the CES and SpaceLiner never collide.

8.6 Overview for other critical trajectory points

Is thus demonstrated that with the “Nominal” option (“Option 1.1 – Solid Rocket Motors, OPL 60 kPa”), sized for the launch pad abort, is possible to perform a cabin escape also for the other critical points of the trajectory of SpaceLiner. In order to satisfy the requirements, the best configurations to use also for other critical trajectory points are reported in Table 8.5. In the aft configuration, the red circle represents that the motor is activated for the escape.

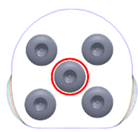
Critical Point	**Number of Nominal Motors to use**	**Safe radial distance constr.**	N_X **constr.**	N_Y **constr.**	**Free from collision with main SpaceLiner**	**Aft Config.**
2) Maximum Dynamic Pressure	5	√	√	√	√	
3) Booster Separation	1	-	√	√	√	
4) Main Engine Cut Off	1	-	√	√	√	
5) Maximum Heat Flux	1	-	√	√	√	

Table 8.5: Overview for the best configuration to utilize in other critical trajectory points.

Conclusion

In order to save passengers in case of catastrophic events, during human high atmosphere - Space transportation missions, several rescue concepts have been studied during the years. The complexity of the subsystems to install on board a certain concept, increases according to the quality of the rescue and to the criticality of the phase of flight when is required an emergency escape from the carrying vehicle.

A Cabin Escape System, able to change its shape thanks to morphing structures, can be an effective solution for the hypersonic point-to-point passenger transportation vehicle "SpaceLiner" studied by the German Aerospace Center (DLR). SpaceLiner's rescue concept aims to permit quick and easy separation thanks to a self-sustained capsule (in terms of structure, thermal control system, electrical system and propulsive system) integrated with the mother aircraft.

From an analysis of the possible subsystems to install on board the Cabin Escape System, taking into account the various scenarios, the propulsion subsystem (which provides the separation) is identified as one of the most critical subsystems.

In this thesis, preliminary design of different options for the SpaceLiner capsule rescue motors, able to provide propulsion for the separation, have been conducted. The motors have been sized for the case of failure at the launch pad, potentially related to the explosion of the vehicle configuration. This scenario has been demonstrated the worst-case scenario due to maximum amount of unburnt fuel, highest atmospheric pressure (which causes most severe thrust losses and highest overpressure shockwaves in case of explosion) and the need for a minimum altitude from ground for a safe descent and landing by parachutes. Simulations of the cabin ejection in other critical points of SpaceLiner trajectory have been performed confirming the assumption.

The motors have been designed for two possible overpressures that the structure of the CES could withstand: 60 and 150 kPa. The most conservative case is OPL 60 kPa.

Three types of analysis have been conducted and four CRM options, with their subcases, have been studied. Option 1.1 and Option 1.2 provide the use of Solid Rocket Motors. Different configurations for the nozzles (with multiple nozzles) and two levels of exit pressure allow a wider overview of subcases. Option 2 is based on the use of SpaceX' SuperDraco liquid propellant engines, already tested for the space capsule Dragon V2. Option 3, instead, designs five liquid propellant engines founded on some SuperDraco's high-level performance parameters.

The results show that the motors of the various options fulfill the requirements drawn up during the study, including radial distance from the explosion, accelerations for untrained passengers and geometry limitations. The configuration selected as "Nominal" option is the one with five Solid Rocket Motors sized for OPL 60 kPa with nozzle exit pressure of 1.5 bar. Is decided to choose solid propellant engines instead of liquid propellant engines for the reason that the latter requires bigger weight and volumes (specially due to the tanks/feed system). Nevertheless some advantages related to liquid propellant engines are lost, like the possibility to be throttleable and to share the tanks with a reaction control system which could ensure a precise controlled landing. Notice that for the "Nominal" option is preferred a configuration with one central nozzle for each motor instead multiple nozzles because the configuration with the latter needs a more accurate study of the internal ballistic.

As this study merely gives a preliminary estimation of the motor performance and mass, many aspects of the work can be further improved upon. It can e.g. be noted that this study does not take the turning maneuver required to position the capsule on an optimal escape angle in the initial phase of the separation. Furthermore, reaction control systems could be necessary in order to stabilize the flight during the escape trajectory. These topics could be considered in a future study.

It can also be noted that besides the overpressure experienced in an explosion, fragmentation from a rapidly expanding debris field also pose a major challenge. The size and speed of the fragments will depend on the characteristics of the vehicle and the mode of explosion. For light debris, a maximum initial velocity of 1750 m/s is reachable [18]. In certain instances, fragments might thus exceed the propagation speed of the pressure shockwave.

A more detailed analysis of the propellant composition can also be conducted in order to ascertain the exact requirements necessary to achieve the stated burning rate.

Material selections for the structural components of the motor can also be considered preliminary with further refinement of the compositions, strengths, densities and safety factors necessary. Lastly, the thickness for casing's spherical domes, for the nozzle and for its insulation can vary depending on the local stresses experienced by the components, thus a more thorough structural analysis through e.g. finite element methods are desirable in order to minimize the structural mass.

Appendix

Through the following tables is reported the preliminary analysis for the subsystems required on board a certain rescue scenario. First are identified several potential scenarios, giving them an identification number (ID), lastly for each ID are investigated the subsystems to install. In the tables "YES" or "NO" is referred to the necessity, in the rescue system, of that particular subsystem.

Access to Space - Single stage:

Phase	Catastrophic event	Configuration	Recovery system option	System configuration (shape)	Rescue scenario	ID Scenario
PRELAUNCH AND LIFT-OFF/ TAKE-OFF	Unpredicted explosion at Launch Pad/ Runway	HTOL	No recovery options available	/	/	1
		VTOL	No recovery options available	/	/	2
		VTHOL	No recovery options available	/	/	3
	Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	4
				Medium efficiency	Semiballistic	5
				High efficiency (Lifting body)	Controlled re-entry	6
		VTOL	Cabin escape	Low efficiency	Pure ballistic	7
				Medium efficiency	Semiballistic	8
				High efficiency (Lifting body)	Controlled re-entry	9
			Launch escape system	Low efficiency	Pure ballistic	10
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	11
				Medium efficiency	Semiballistic	12
				High efficiency (Lifting body)	Controlled re-entry	13
			Launch escape system		Pure ballistic	14
ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	15
				Medium efficiency	Semiballistic	16
				High efficiency (Lifting body)	Controlled re-entry	17
		VTOL	Cabin escape	Low efficiency	Pure ballistic	18
				Medium efficiency	Semiballistic	19
				High efficiency (Lifting body)	Controlled re-entry	20
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	21
				Medium efficiency	Semiballistic	22
				High efficiency (Lifting body)	Controlled re-entry	23

Figure 8.9: Access to Space scenarios, single stage, Part 1

Phase	Catastrophic event	Configuration	Recovery system option	System configuration (shape)	Rescue scenario	ID Scenario
ORBIT PHASE	Subsystem failure (explosion, loss of altitude control, loss of critical function, toxic material release), loss of structural integrity due to natural environment hazard (solar radiation, micrometeorid orbital debris impact)	HTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	24
				Medium efficiency	De-orbiting + Semiballistic	25
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	26
		VTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	27
				Medium efficiency	De-orbiting + Semiballistic	28
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	29
		VTHOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	30
				Medium efficiency	De-orbiting + Semiballistic	31
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	32
RE-ENTRY	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure, improper dangerous trajectory.	HTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	33
				Medium efficiency	De-orbiting + Semiballistic	34
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	35
		VTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	36
				Medium efficiency	De-orbiting + Semiballistic	37
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	38
		VTHOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	39
				Medium efficiency	De-orbiting + Semiballistic	40
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	41
DESCENT	Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	42
				Medium efficiency	Semiballistic	43
				High efficiency (Lifting body)	Controlled re-entry	44
		VTOL	Cabin escape	Low efficiency	Pure ballistic	45
				Medium efficiency	Semiballistic	46
				High efficiency (Lifting body)	Controlled re-entry	47
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	48
				Medium efficiency	Semiballistic	49
				High efficiency (Lifting body)	Controlled re-entry	50
LANDING	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory.	HTOL	Cabin escape	Low efficiency	Pure ballistic	51
				Medium efficiency	Semiballistic	52
				High efficiency (Lifting body)	Controlled re-entry	53
			Ejection seat for each passenger	Low efficiency	Pure ballistic	54
		VTOL	Cabin escape	Low efficiency	Pure ballistic	55
				Medium efficiency	Semiballistic	56
				High efficiency (Lifting body)	Controlled re-entry	57
		VTHOL	Ejection seat for each passenger	Low efficiency	Pure ballistic	58
			Cabin escape	Low efficiency	Pure ballistic	59
				Medium efficiency	Semiballistic	60
				High efficiency (Lifting body)	Controlled re-entry	61

Figure 8.10: Access to Space scenarios, single stage, Part 2

Access to Space - Two stages:

Phase	Catastrophic event	Configuration	Recovery options	System configuration (shape)	Rescue Scenario	ID Scenario
PRELAUNCH AND LIFT-OFF/ TAKE-OFF	Unpredicted explosion at Launch Pad/ Runway	HTOL	No recovery options available		/	62
		VTOL	No recovery options available		/	63
		VTHOL	No recovery options available		/	64
	Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	65
				Medium efficiency	Semiballistic	66
				High efficiency (Lifting body)	Controlled re-entry	67
		VTOL	Cabin escape	Low efficiency	Pure ballistic	68
				Medium efficiency	Semiballistic	69
				High efficiency (Lifting body)	Controlled re-entry	70
			Launch escape system	Low efficiency	Pure ballistic	71
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	72
				Medium efficiency	Semiballistic	73
				High efficiency (Lifting body)	Controlled re-entry	74
			Launch escape system	Low efficiency	Pure ballistic	75
ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	76
				Medium efficiency	Semiballistic	77
				High efficiency (Lifting body)	Controlled re-entry	78
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 2nd stage	79
		VTOL	Cabin escape	Low efficiency	Pure ballistic	80
				Medium efficiency	Semiballistic	81
				High efficiency (Lifting body)	Controlled re-entry	82
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 2nd stage	84
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	85
				Medium efficiency	Semiballistic	86
				High efficiency (Lifting body)	Controlled re-entry	87
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 2nd stage	88
POSSIBLE SEPARATION OF 2nd STAGE	Malfunction in the mechanism for the separation, impossibility to realize the separation	HTOL	Cabin escape	Low efficiency	Pure ballistic	89
				Medium efficiency	Semiballistic	90
				High efficiency (Lifting body)	Controlled re-entry	91
		VTOL	Cabin escape	Low efficiency	Pure ballistic	92
				Medium efficiency	Semiballistic	93
				High efficiency (Lifting body)	Controlled re-entry	94
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	95
				Medium efficiency	Semiballistic	96
				High efficiency (Lifting body)	Controlled re-entry	97
ORBITAL PHASE	Subsystem failure (explosion, loss of altitude control, loss of critical function, toxic material release), loss of structural integrity due to natural environment hazard (solar radiation, micrometeorid orbital debris impact)	HTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	98
				Medium efficiency	De-orbiting + Semiballistic	99
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	100
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage) and the vehicle has still 2 stages	High efficiency (Lifting body)	De-orbiting + Controlled re-entry with 2nd stage	101
		VTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	102
				Medium efficiency	De-orbiting + Semiballistic	103
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	104
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage) and the vehicle has still 2 stages	High efficiency (Lifting body)	De-orbiting + Controlled re-entry with 2nd stage	105
		VTHOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	106
				Medium efficiency	De-orbiting + Semiballistic	107
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	108
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage) and the vehicle has still 2 stages	High efficiency (Lifting body)	De-orbiting + Controlled re-entry with 2nd stage	109

Figure 8.11: Access to Space scenarios, two stages, Part 1

Phase	Catastrophic event	Configuration	Recovery options	System configuration (shape)	Rescue Scenario	ID Scenario
POSSIBLE SEPARATION OF 2nd STAGE	Malfunction in the mechanism for the separation, impossibility to realize the separation	HTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	110
				Medium efficiency	De-orbiting + Semiballistic	111
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	112
		VTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	113
				Medium efficiency	De-orbiting + Semiballistic	114
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	115
		VTHOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	116
				Medium efficiency	De-orbiting + Semiballistic	117
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	118
RE-ENTRY	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure, improper dangerous trajectory.	HTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	119
				Medium efficiency	De-orbiting + Semiballistic	120
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	121
		VTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	122
				Medium efficiency	De-orbiting + Semiballistic	123
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	124
		VTHOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	125
				Medium efficiency	De-orbiting + Semiballistic	126
				High efficiency (Lifting body)	De-orbiting + Controlled re-entry	127
DESCENT	Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	128
				Medium efficiency	Semiballistic	129
				High efficiency (Lifting body)	Controlled re-entry	130
		VTOL	Cabin escape	Low efficiency	Pure ballistic	131
				Medium efficiency	Semiballistic	132
				High efficiency (Lifting body)	Controlled re-entry	133
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	134
				Medium efficiency	Semiballistic	135
				High efficiency (Lifting body)	Controlled re-entry	136
LANDING	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory.	HTOL	Cabin escape	Low efficiency	Pure ballistic	137
				Medium efficiency	Semiballistic	138
				High efficiency (Lifting body)	Controlled re-entry	139
			Ejection seat for each passenger	Low efficiency	Pure ballistic	140
		VTOL	Cabin escape	Low efficiency	Pure ballistic	141
				Medium efficiency	Semiballistic	142
				High efficiency (Lifting body)	Controlled re-entry	143
		VTHOL	Ejection seat for each passenger	Low efficiency	Pure ballistic	144
			Cabin escape	Low efficiency	Pure ballistic	145
				Medium efficiency	Semiballistic	146
				High efficiency (Lifting body)	Controlled re-entry	147

Figure 8.12: Access to Space scenarios, two stages, Part 2

Access to Space - Three stages:

Phase	Catastrophic event	Configuration	Recovery options	System configuration (shape)	Rescue scenario	ID Scenario
PRELAUNCH AND LIFT-OFF/ TAKE-OFF	Unpredicted explosion at Launch Pad/ Runway	HTOL	No recovery options available		/	148
		VTOL	No recovery options available		/	149
		VTHOL	No recovery options available		/	150
	Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	151
				Medium efficiency	Semiballistic	152
				High efficiency (Lifting body)	Controlled re-entry	153
		VTOL	Cabin escape	Low efficiency	Pure ballistic	154
				Medium efficiency	Semiballistic	155
				High efficiency (Lifting body)	Controlled re-entry	156
			Launch escape system	Low efficiency	Pure ballistic	157
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	158
				Medium efficiency	Semiballistic	159
				High efficiency (Lifting body)	Controlled re-entry	160
			Launch escape system	Low efficiency	Pure ballistic	161
ASCENT	Subsystem malfunction, lossof control, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	162
				Medium efficiency	Semiballistic	163
				High efficiency (Lifting body)	Controlled re-entry	164
			Separation of passenger stage (3d) and 2nd stage from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd and 2nd stage	165
			Separation of passenger stage (3d) from 1st and 2nd stage (if the failure is detected in 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	166
		VTOL	Cabin escape	Low efficiency	Pure ballistic	167
				Medium efficiency	Semiballistic	168
				High efficiency (Lifting body)	Controlled re-entry	169
			Separation of passenger stage (3d) and 2nd stage from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd and 2nd stage	170
			Separation of passenger stage (3d) from 1st and 2nd stage (if the failure is detected in 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	171
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	172
				Medium efficiency	Semiballistic	173
				High efficiency (Lifting body)	Controlled re-entry	174
			Separation of passenger stage (3d) and 2nd stage from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd and 2nd stage	175
			Separation of passenger stage (3d) from 1st and 2nd stage (if the failure is detected in 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	176
SEPARATION OF POSSIBLES STAGES	Malfunction in the mechanism for the separation of the 2nd+3rd stage from the 1st stage, impossibility to realize the separation from the 1st stage.	HTOL	Cabin escape	Low efficiency	Pure ballistic	177
				Medium efficiency	Semiballistic	178
				High efficiency (Lifting body)	Controlled re-entry	179
			Separation of passenger stage (3d) from 2nd stage (if is possible the separation between 3rd and 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	180
		VTOL	Cabin escape	Low efficiency	Pure ballistic	181
				Medium efficiency	Semiballistic	182
				High efficiency (Lifting body)	Controlled re-entry	183
			Separation of passenger stage (3d) from 2nd stage (if is possible the separation between 3rd and 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	184
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	185
				Medium efficiency	Semiballistic	186
				High efficiency (Lifting body)	Controlled re-entry	187
			Separation of passenger stage (3d) from 2nd stage (if is possible the separation between 3rd and 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	188
	Malfunction in the mechanism for the separation of the 3rd stage from the 2nd stage, impossibility to realize the separation from the 2nd stage.	HTOL	Cabin escape	Low efficiency	Pure ballistic	189
				Medium efficiency	Semiballistic	190
				High efficiency (Lifting body)	Controlled re-entry	191
		VTOL	Cabin escape	Low efficiency	Pure ballistic	192
				Medium efficiency	Semiballistic	193
				High efficiency (Lifting body)	Controlled re-entry	194
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	195
				Medium efficiency	Semiballistic	196
				High efficiency (Lifting body)	Controlled re-entry	197

Figure 8.13: Access to Space scenarios, three stages, Part 1

Phase	Catastrophic event	Configuration	Recovery options	System configuration (shape)	Rescue scenario	ID Scenario
ORBITAL PHASE	Subsystem failure (explosion, loss of altitude control, loss of critical function, toxic material release), loss of structural integrity due to natural environment hazard (solar radiation, micrometeorid orbital debris impact)	HTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	198
			Cabin escape	Medium efficiency	De-orbiting + Semiballistic	199
			Cabin escape	High efficiency (Lifting body)	De-orbiting + Controlled re-entry	200
			Separation of passenger stage (3rd) from other stages if the failure is in other stages and the vehicle has still stages	High efficiency (Lifting body)	De-orbiting + Controlled re-entry with 3rd stage	201
		VTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	202
			Cabin escape	Medium efficiency	De-orbiting + Semiballistic	203
			Cabin escape	High efficiency (Lifting body)	De-orbiting + Controlled re-entry	204
			Separation of passenger stage (3rd) from other stages if the failure is in other stages and the vehicle has still stages	High efficiency (Lifting body)	De-orbiting + Controlled re-entry with 3rd stage	205
		VTHOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	206
			Cabin escape	Medium efficiency	De-orbiting + Semiballistic	207
			Cabin escape	High efficiency (Lifting body)	De-orbiting + Controlled re-entry	208
			Separation of passenger stage (3rd) from other stages if the failure is in other stages and the vehicle has still stages	High efficiency (Lifting body)	De-orbiting + Controlled re-entry with 3rd stage	209
SEPARATION OF OTHERS POSSIBLES STAGES	Malfunction in the mechanism for the separation of the 3rd stage from the 2nd stage, impossibility to realize the separation from the 2nd stage.	HTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	300
			Cabin escape	Medium efficiency	De-orbiting + Semiballistic	301
			Cabin escape	High efficiency (Lifting body)	De-orbiting + Controlled re-entry	302
		VTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	303
			Cabin escape	Medium efficiency	De-orbiting + Semiballistic	304
			Cabin escape	High efficiency (Lifting body)	De-orbiting + Controlled re-entry	305
		VTHOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	306
			Cabin escape	Medium efficiency	De-orbiting + Semiballistic	307
			Cabin escape	High efficiency (Lifting body)	De-orbiting + Controlled re-entry	308
RE-ENTRY	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure, improper dangerous trajectory.	HTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	309
			Cabin escape	Medium efficiency	De-orbiting + Semiballistic	310
			Cabin escape	High efficiency (Lifting body)	De-orbiting + Controlled re-entry	311
		VTOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	312
			Cabin escape	Medium efficiency	De-orbiting + Semiballistic	313
			Cabin escape	High efficiency (Lifting body)	De-orbiting + Controlled re-entry	314
		VTHOL	Cabin escape	Low efficiency	De-orbiting + Pure ballistic	315
			Cabin escape	Medium efficiency	De-orbiting + Semiballistic	316
			Cabin escape	High efficiency (Lifting body)	De-orbiting + Controlled re-entry	317
DESCENT	Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	318
			Cabin escape	Medium efficiency	Semiballistic	319
			Cabin escape	High efficiency (Lifting body)	Controlled re-entry	320
		VTOL	Cabin escape	Low efficiency	Pure ballistic	321
			Cabin escape	Medium efficiency	Semiballistic	322
			Cabin escape	High efficiency (Lifting body)	Controlled re-entry	323
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	324
			Cabin escape	Medium efficiency	Semiballistic	325
			Cabin escape	High efficiency (Lifting body)	Controlled re-entry	326
LANDING	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory.	HTOL	Cabin escape	Low efficiency	Pure ballistic	327
			Cabin escape	Medium efficiency	Semiballistic	328
			Cabin escape	High efficiency (Lifting body)	Controlled re-entry	329
			Ejection seat for each passenger	Low efficiency	Pure ballistic	330
		VTOL	Cabin escape	Low efficiency	Pure ballistic	331
			Cabin escape	Medium efficiency	Semiballistic	332
			Cabin escape	High efficiency (Lifting body)	Controlled re-entry	333
		VTHOL	Ejection seat for each passenger	Low efficiency	Pure ballistic	334
			Cabin escape	Low efficiency	Pure ballistic	335
			Cabin escape	Medium efficiency	Semiballistic	336
			Cabin escape	High efficiency (Lifting body)	Controlled re-entry	337

Figure 8.14: Access to Space scenarios, three stages, Part 2

Suborbital - Single Stage:

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
PRELAUNCH AND LIFT OFF / TAKE OFF	Unpredicted explosion at Launch Pad/ Runway	HTOL	No recovery options available	/	/	338
		VTOL	No recovery options available	/	/	339
		VTHOL	No recovery options available	/	/	340
	Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	341
				Medium efficiency	Semiballistic	342
				High efficiency (Lifting body)	Controlled re-entry	343
		VTOL	Cabin escape	Low efficiency	Pure ballistic	344
				Medium efficiency	Semiballistic	345
				High efficiency (Lifting body)	Controlled re-entry	346
			Launch escape system		Pure ballistic	347
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	348
				Medium efficiency	Semiballistic	349
				High efficiency (Lifting body)	Controlled re-entry	350
			Launch escape system		Pure ballistic	351
AIRBREATHING ENGINES ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or Airbreathing engines failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	352
				Medium efficiency	Semiballistic	353
				High efficiency (Lifting body)	Controlled re-entry	354
		VTOL	Cabin escape	Low efficiency	Pure ballistic	355
				Medium efficiency	Semiballistic	356
				High efficiency (Lifting body)	Controlled re-entry	357
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	358
				Medium efficiency	Semiballistic	359
				High efficiency (Lifting body)	Controlled re-entry	360
AIRBREATHING SHUT DOWN, ROCKET IGNITION	Impossibility to turn-off Airbreathing engines due to malfunction, impossibility to switch on rocket engines due to malfunction.	HTOL	Cabin escape	Low efficiency	Pure ballistic	361
				Medium efficiency	Semiballistic	362
				High efficiency (Lifting body)	Controlled re-entry	363
		VTOL	Cabin escape	Low efficiency	Pure ballistic	364
				Medium efficiency	Semiballistic	365
				High efficiency (Lifting body)	Controlled re-entry	366
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	367
				Medium efficiency	Semiballistic	368
				High efficiency (Lifting body)	Controlled re-entry	369
ROCKET ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or rocket failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	370
				Medium efficiency	Semiballistic	371
				High efficiency (Lifting body)	Controlled re-entry	372
		VTOL	Cabin escape	Low efficiency	Pure ballistic	373
				Medium efficiency	Semiballistic	374
				High efficiency (Lifting body)	Controlled re-entry	375
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	376
				Medium efficiency	Semiballistic	377
				High efficiency (Lifting body)	Controlled re-entry	378

Figure 8.15: Suborbital scenarios, Single stage, Part 1

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
CRUISE	Subsystem failure (explosion, loss of control, loss of critical function, loss of structural integrity, natural environment induced failure).	HTOL	Cabin escape	Low efficiency	Pure ballistic	379
				Medium efficiency	Semiballistic	380
				High efficiency (Lifting body)	Controlled re-entry	381
		VTOL	Cabin escape	Low efficiency	Pure ballistic	382
				Medium efficiency	Semiballistic	383
				High efficiency (Lifting body)	Controlled re-entry	384
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	385
				Medium efficiency	Semiballistic	386
				High efficiency (Lifting body)	Controlled re-entry	387
DESCENT	Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	388
				Medium efficiency	Semiballistic	389
				High efficiency (Lifting body)	Controlled re-entry	390
		VTOL	Cabin escape	Low efficiency	Pure ballistic	391
				Medium efficiency	Semiballistic	392
				High efficiency (Lifting body)	Controlled re-entry	393
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	394
				Medium efficiency	Semiballistic	395
				High efficiency (Lifting body)	Controlled re-entry	396
GLIDE PHASE	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	397
				Medium efficiency	Semiballistic	398
				High efficiency (Lifting body)	Controlled re-entry	399
		VTOL	Cabin escape	Low efficiency	Pure ballistic	400
				Medium efficiency	Semiballistic	401
				High efficiency (Lifting body)	Controlled re-entry	402
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	403
				Medium efficiency	Semiballistic	404
				High efficiency (Lifting body)	Controlled re-entry	405
AIRBREATHING RESTART	Impossibility to realize the airbreathing engines restart, subsystem malfunction, airbreathing engines failure, propulsion failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	406
				Medium efficiency	Semiballistic	407
				High efficiency (Lifting body)	Controlled re-entry	408
		VTOL	Cabin escape	Low efficiency	Pure ballistic	409
				Medium efficiency	Semiballistic	410
				High efficiency (Lifting body)	Controlled re-entry	411
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	412
				Medium efficiency	Semiballistic	413
				High efficiency (Lifting body)	Controlled re-entry	414
FINAL DESCENT AND LANDING	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory, malfunction in the EDL subsystem.	HTOL	Cabin escape	Low efficiency	Pure ballistic	415
				Medium efficiency	Semiballistic	416
				High efficiency (Lifting body)	Controlled re-entry	417
			Ejection seat for each passenger	Low efficiency	Pure ballistic	418
		VTOL	Cabin escape	Low efficiency	Pure ballistic	419
				Medium efficiency	Semiballistic	420
				High efficiency (Lifting body)	Controlled re-entry	421
		VTHOL	Ejection seat for each passenger	Low efficiency	Pure ballistic	422
			Cabin escape	Low efficiency	Pure ballistic	423
				Medium efficiency	Semiballistic	424
				High efficiency (Lifting body)	Controlled re-entry	425

Figure 8.16: Suborbital scenarios, Single stage, Part 2

Suborbital - Two Stages:

Phase	Catastrophic event	Configurat	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
PRELAUNCH AND LIFT OFF / TAKE OFF	Unpredicted explosion at Launch Pad/ Runway	HTOL	No recovery options available	/	/	426
		VTOL	No recovery options available	/	/	427
		VTHOL	No recovery options available	/	/	428
	Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	429
				Medium efficiency	Semiballistic	430
				High efficiency (Lifting body)	Controlled re-entry	431
		VTOL	Cabin escape	Low efficiency	Pure ballistic	432
				Medium efficiency	Semiballistic	433
				High efficiency (Lifting body)	Controlled re-entry	434
			Launch escape system	Low efficiency	Pure ballistic	435
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	436
				Medium efficiency	Semiballistic	437
				High efficiency (Lifting body)	Controlled re-entry	438
			Launch escape system	Low efficiency	Pure ballistic	439
AIRBREATHING ENGINES ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or Airbreathing engines failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	440
				Medium efficiency	Semiballistic	441
				High efficiency (Lifting body)	Controlled re-entry	442
		VTOL	Cabin escape	Low efficiency	Pure ballistic	443
				Medium efficiency	Semiballistic	444
				High efficiency (Lifting body)	Controlled re-entry	445
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	446
				Medium efficiency	Semiballistic	447
				High efficiency (Lifting body)	Controlled re-entry	448
AIRBREATHING SHUT - DOWN, ROCKET IGNITION	Impossibility to turn-off Airbreathing engines due to malfunction, impossibility to switch on rocket engines due to malfunction.	HTOL	Cabin escape	Low efficiency	Pure ballistic	449
				Medium efficiency	Semiballistic	450
				High efficiency (Lifting body)	Controlled re-entry	451
		VTOL	Cabin escape	Low efficiency	Pure ballistic	452
				Medium efficiency	Semiballistic	453
				High efficiency (Lifting body)	Controlled re-entry	454
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	455
				Medium efficiency	Semiballistic	456
				High efficiency (Lifting body)	Controlled re-entry	457
ROCKET ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or rocket failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	458
				Medium efficiency	Semiballistic	459
				High efficiency (Lifting body)	Controlled re-entry	460
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 2nd stage	461
		VTOL	Cabin escape	Low efficiency	Pure ballistic	462
				Medium efficiency	Semiballistic	463
				High efficiency (Lifting body)	Controlled re-entry	464
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 2nd stage	465
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	466
				Medium efficiency	Semiballistic	467
				High efficiency (Lifting body)	Lifting body	468
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 2nd stage	469
POSSIBLE SEPARATION OF 2nd STAGE	Malfunction in the mechanism for the separation, impossibility to realize the separation	HTOL	Cabin escape	Low efficiency	Pure ballistic	470
				Medium efficiency	Semiballistic	471
				High efficiency (Lifting body)	Controlled re-entry	472
		VTOL	Cabin escape	Low efficiency	Pure ballistic	473
				Medium efficiency	Semiballistic	474
				High efficiency (Lifting body)	Controlled re-entry	475
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	476
				Medium efficiency	Semiballistic	477
				High efficiency (Lifting body)	Controlled re-entry	478

Figure 8.17: Suborbital scenarios, Two stages, Part 1

Phase	Catastrophic event	Configurat	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
CRUISE	Subsystem failure (explosion, loss of control, loss of critical function, loss of structural integrity, natural environment induced failure).	HTOL	Cabin escape	Low efficiency	Pure ballistic	479
				Medium efficiency	Semiballistic	480
				High efficiency (Lifting body)	Controlled re-entry	481
		VTOL	Cabin escape	Low efficiency	Pure ballistic	482
				Medium efficiency	Semiballistic	483
				High efficiency (Lifting body)	Controlled re-entry	484
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	485
				Medium efficiency	Semiballistic	486
				High efficiency (Lifting body)	Controlled re-entry	487
DESCENT	Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	488
				Medium efficiency	Semiballistic	489
				High efficiency (Lifting body)	Controlled re-entry	490
		VTOL	Cabin escape	Low efficiency	Pure ballistic	491
				Medium efficiency	Semiballistic	492
				High efficiency (Lifting body)	Controlled re-entry	493
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	494
				Medium efficiency	Semiballistic	495
				High efficiency (Lifting body)	Controlled re-entry	496
GLIDE PHASE	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	497
				Medium efficiency	Semiballistic	498
				High efficiency (Lifting body)	Controlled re-entry	499
		VTOL	Cabin escape	Low efficiency	Pure ballistic	500
				Medium efficiency	Semiballistic	501
				High efficiency (Lifting body)	Controlled re-entry	502
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	503
				Medium efficiency	Semiballistic	504
				High efficiency (Lifting body)	Controlled re-entry	505
AIRBREATHING RESTART	Impossibility to realize the airbreathing engines restart, subsystem malfunction, airbreathing engines failure, propulsion failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	506
				Medium efficiency	Semiballistic	507
				High efficiency (Lifting body)	Controlled re-entry	508
		VTOL	Cabin escape	Low efficiency	Pure ballistic	509
				Medium efficiency	Semiballistic	510
				High efficiency (Lifting body)	Controlled re-entry	511
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	512
				Medium efficiency	Semiballistic	513
				High efficiency (Lifting body)	Controlled re-entry	514
FINAL DESCENT AND LANDING	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory, malfunction in the EDL subsystem.	HTOL	Cabin escape	Low efficiency	Pure ballistic	515
				Medium efficiency	Semiballistic	516
				High efficiency (Lifting body)	Controlled re-entry	517
			Ejection seat for each passenger	Low efficiency	Pure ballistic	518
		VTOL	Cabin escape	Low efficiency	Pure ballistic	519
				Medium efficiency	Semiballistic	520
				High efficiency (Lifting body)	Controlled re-entry	521
		VTHOL	Ejection seat for each passenger	Low efficiency	Pure ballistic	522
			Cabin escape	Low efficiency	Pure ballistic	523
				Medium efficiency	Semiballistic	524
				High efficiency (Lifting body)	Controlled re-entry	525

Figure 8.18: Suborbital scenarios, Two stages, Part 2

Suborbital - Three Stages:

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
PRELAUNCH AND LIFT OFF / TAKE OFF	Unpredicted explosion at Launch Pad/ Runway	HTOL	No recovery options available	/	/	526
		VTOL	No recovery options available	/	/	527
		VTHOL	No recovery options available	/	/	528
	Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	529
				Medium efficiency	Semiballistic	530
				High efficiency (Lifting body)	Controlled re-entry	531
		VTOL	Cabin escape	Low efficiency	Pure ballistic	532
				Medium efficiency	Semiballistic	533
				High efficiency (Lifting body)	Controlled re-entry	534
			Launch escape system	Low efficiency	Pure ballistic	535
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	536
				Medium efficiency	Semiballistic	537
				High efficiency (Lifting body)	Controlled re-entry	538
			Launch escape system	Low efficiency	Pure ballistic	539
AIRBREATHING ENGINES ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or Airbreathing engines failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	540
				Medium efficiency	Semiballistic	541
				High efficiency (Lifting body)	Controlled re-entry	542
		VTOL	Cabin escape	Low efficiency	Pure ballistic	543
				Medium efficiency	Semiballistic	544
				High efficiency (Lifting body)	Controlled re-entry	545
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	546
				Medium efficiency	Semiballistic	547
				High efficiency (Lifting body)	Controlled re-entry	548
AIRBREATHING SHUT - DOWN, ROCKET IGNITION	Impossibility to turn-off Airbreathing engines due to malfunction, impossibility to switch on rocket engines due to malfunction.	HTOL	Cabin escape	Low efficiency	Pure ballistic	549
				Medium efficiency	Semiballistic	550
				High efficiency (Lifting body)	Controlled re-entry	551
		VTOL	Cabin escape	Low efficiency	Pure ballistic	552
				Medium efficiency	Semiballistic	553
				High efficiency (Lifting body)	Controlled re-entry	554
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	555
				Medium efficiency	Semiballistic	556
				High efficiency (Lifting body)	Controlled re-entry	557
ROCKET ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or rocket failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	558
				Medium efficiency	Semiballistic	559
				High efficiency (Lifting body)	Controlled re-entry	560
			Separation of passenger stage (3rd) from rocket stage	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	561
		VTOL	Cabin escape	Low efficiency	Pure ballistic	562
				Medium efficiency	Semiballistic	563
				High efficiency (Lifting body)	Controlled re-entry	564
			Separation of passenger stage (3rd) from rocket stage	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	565
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	566
				Medium efficiency	Semiballistic	567
				High efficiency (Lifting body)	Controlled re-entry	568
			Separation of passenger stage (3rd) from rocket stage	High efficiency (Lifting body)	Controlled re-entryy with 3rd stage	569

Figure 8.19: Suborbital scenarios, Three stages, Part 1

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
SEPARATION OF POSSIBLES STAGES	Malfunction in the mechanism for the separation of the 2nd+3rd stage from the 1st stage, impossibility to realize the separation from the 1st stage.	HTOL	Cabin escape	Low efficiency	Pure ballistic	570
				Medium efficiency	Semiballistic	571
				High efficiency (Lifting body)	Controlled re-entry	572
			Separation of passenger stage (3d) from 2nd stage (if is possible the separation between 3rd and 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	573
		VTOL	Cabin escape	Low efficiency	Pure ballistic	574
				Medium efficiency	Semiballistic	575
				High efficiency (Lifting body)	Controlled re-entry	576
			Separation of passenger stage (3d) from 2nd stage (if is possible the separation between 3rd and 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	577
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	578
				Medium efficiency	Semiballistic	579
				High efficiency (Lifting body)	Controlled re-entry	580
			Separation of passenger stage (3d) from 2nd stage (if is possible the separation between 3rd and 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	581
	Malfunction in the mechanism for the separation of the 3rd stage from the 2nd stage, impossibility to realize the separation from the 2nd stage.	HTOL	Cabin escape	Low efficiency	Pure ballistic	582
				Medium efficiency	Semiballistic	583
				High efficiency (Lifting body)	Controlled re-entry	584
		VTOL	Cabin escape	Low efficiency	Pure ballistic	585
				Medium efficiency	Semiballistic	586
				High efficiency (Lifting body)	Controlled re-entry	587
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	588
				Medium efficiency	Semiballistic	589
				High efficiency (Lifting body)	Controlled re-entry	590
CRUISE	Subsystem failure (explosion, loss of control, loss of critical function, loss of structural integrity, natural environment induced failure).	HTOL	Cabin escape	Low efficiency	Pure ballistic	591
				Medium efficiency	Semiballistic	592
				High efficiency (Lifting body)	Controlled re-entry	593
		VTOL	Cabin escape	Low efficiency	Pure ballistic	594
				Medium efficiency	Semiballistic	595
				High efficiency (Lifting body)	Controlled re-entry	596
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	597
				Medium efficiency	Semiballistic	598
				High efficiency (Lifting body)	Controlled re-entry	599
DESCENT	Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	600
				Medium efficiency	Semiballistic	601
				High efficiency (Lifting body)	Controlled re-entry	602
		VTOL	Cabin escape	Low efficiency	Pure ballistic	603
				Medium efficiency	Semiballistic	604
				High efficiency (Lifting body)	Controlled re-entry	605
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	606
				Medium efficiency	Semiballistic	607
				High efficiency (Lifting body)	Controlled re-entry	608
GLIDE PHASE	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	609
				Medium efficiency	Semiballistic	610
				High efficiency (Lifting body)	Controlled re-entry	611
		VTOL	Cabin escape	Low efficiency	Pure ballistic	612
				Medium efficiency	Semiballistic	613
				High efficiency (Lifting body)	Controlled re-entry	614
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	615
				Medium efficiency	Semiballistic	616
				High efficiency (Lifting body)	Controlled re-entry	617

Figure 8.20: Suborbital scenarios, Three stages, Part 2

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
AIRBREATHING RESTART	Impossibility to realize the airbreathing engines restart, subsystem malfunction, airbreathing engines failure, propulsion failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	618
				Medium efficiency	Semiballistic	619
				High efficiency (Lifting body)	Controlled re-entry	620
		VTOL	Cabin escape	Low efficiency	Pure ballistic	621
				Medium efficiency	Semiballistic	622
				High efficiency (Lifting body)	Controlled re-entry	623
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	624
				Medium efficiency	Semiballistic	625
				High efficiency (Lifting body)	Controlled re-entry	626
FINAL DESCENT AND LANDING	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory, malfunction in the EDL subsystem.	HTOL	Cabin escape	Low efficiency	Pure ballistic	627
				Medium efficiency	Semiballistic	628
				High efficiency (Lifting body)	Controlled re-entry	629
			Ejection seat for each passenger	Low efficiency	Pure ballistic	630
						631
		VTOL	Cabin escape	Low efficiency	Pure ballistic	
				Medium efficiency	Semiballistic	632
				High efficiency (Lifting body)	Controlled re-entry	633
		VTHOL	Ejection seat for each passenger	Low efficiency	Pure ballistic	634
			Cabin escape	Low efficiency	Pure ballistic	635
				Medium efficiency	Semiballistic	636
				High efficiency (Lifting body)	Controlled re-entry	637

Figure 8.21: Suborbital scenarios, Three stages, Part 3

Point-to-Point - Single Stage:

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
PRELAUNCH AND LIFT - OFF / TAKE -OFF	Unpredicted explosion at Launch Pad/ Runway	HTOL	No recovery options available	/	/	638
		VTOL	No recovery options available	/	/	639
		VTHOL	No recovery options available	/	/	640
	Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	641
				Medium efficiency	Semiballistic	642
				High efficiency (Lifting body)	Controlled Re-entry	643
		VTOL	Cabin escape	Low efficiency	Pure ballistic	644
				Medium efficiency	Semiballistic	645
				High efficiency (Lifting body)	Controlled Re-entry	646
			Launch escape system	Low efficiency	Pure ballistic	647
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	648
				Medium efficiency	Semiballistic	649
				High efficiency (Lifting body)	Controlled Re-entry	650
			Launch escape system	Low efficiency	Pure ballistic	651
ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	652
				Medium efficiency	Semiballistic	653
				High efficiency (Lifting body)	Controlled Re-entry	654
		VTOL	Cabin escape	Low efficiency	Pure ballistic	655
				Medium efficiency	Semiballistic	656
				High efficiency (Lifting body)	Controlled Re-entry	657
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	658
				Medium efficiency	Semiballistic	659
				High efficiency (Lifting body)	Controlled Re-entry	660
CRUISE	Subsystem failure (explosion, loss of control, loss of critical function, loss of structural integrity, natural environment induced failure).	HTOL	Cabin escape	Low efficiency	Pure ballistic	661
				Medium efficiency	Semiballistic	662
				High efficiency (Lifting body)	Controlled Re-entry	663
		VTOL	Cabin escape	Low efficiency	Pure ballistic	664
				Medium efficiency	Semiballistic	665
				High efficiency (Lifting body)	Controlled Re-entry	666
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	667
				Medium efficiency	Semiballistic	668
				High efficiency (Lifting body)	Controlled Re-entry	669
DESCENT	Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	670
				Medium efficiency	Semiballistic	671
				High efficiency (Lifting body)	Controlled Re-entry	672
		VTOL	Cabin escape	Low efficiency	Pure ballistic	673
				Medium efficiency	Semiballistic	674
				High efficiency (Lifting body)	Controlled Re-entry	675
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	676
				Medium efficiency	Semiballistic	677
				High efficiency (Lifting body)	Controlled Re-entry	678

Figure 8.22: Point-to-Point, Single Stage, Part1.

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
LANDING	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory.	HTOL	Cabin escape	Low efficiency	Pure ballistic	679
				Medium efficiency	Semiballistic	680
				High efficiency (Lifting body)	Controlled Re-entry	681
			Ejection seat for each passenger	Low efficiency	Pure ballistic	682
		VTOL	Cabin escape	Low efficiency	Pure ballistic	683
				Medium efficiency	Semiballistic	684
				High efficiency (Lifting body)	Controlled Re-entry	685
		VTHOL	Ejection seat for each passenger	Low efficiency	Pure ballistic	686
			Cabin escape	Low efficiency	Pure ballistic	687
				Medium efficiency	Semiballistic	688
				High efficiency (Lifting body)	Controlled Re-entry	689

Figure 8.23: Point-to-Point, Single Stage, Part2.

Point-to-Point - Two Stages:

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
PRELAUNCH AND LIFT - OFF / TAKE -OFF	Unpredicted explosion at Launch Pad/ Runway	HTOL	No recovery options available		/	690
		VTOL	No recovery options available		/	691
		VTHOL	No recovery options available		/	692
	Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	693
				Medium efficiency	Semiballistic	694
				High efficiency (Lifting body)	Controlled re-entry	695
		VTOL	Cabin escape	Low efficiency	Pure ballistic	696
				Medium efficiency	Semiballistic	697
				High efficiency (Lifting body)	Controlled re-entry	698
			Launch escape system	Low efficiency	Pure ballistic	699
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	700
				Medium efficiency	Semiballistic	701
				High efficiency (Lifting body)	Controlled re-entry	702
			Launch escape system	Low efficiency	Pure ballistic	703
ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	704
				Medium efficiency	Semiballistic	705
				High efficiency (Lifting body)	Controlled re-entry	706
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 2nd stage	707
		VTOL	Cabin escape	Low efficiency	Pure ballistic	708
				Medium efficiency	Semiballistic	709
				High efficiency (Lifting body)	Controlled re-entry	710
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 2nd stage	711
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	712
				Medium efficiency	Semiballistic	713
				High efficiency (Lifting body)	Controlled re-entry	714
			Separation of passenger stage (2nd) from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 2nd stage	715

Figure 8.24: Point-to-Point, Two Stages, Part1.

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
2nd STAGE SEPARATION	Malfunction in the mechanism for the separation, impossibility to realize the separation	HTOL	Cabin escape	Low efficiency	Pure ballistic	716
				Medium efficiency	Semiballistic	717
				High efficiency (Lifting body)	Controlled re-entry	718
		VTOL	Cabin escape	Low efficiency	Pure ballistic	719
				Medium efficiency	Semiballistic	720
				High efficiency (Lifting body)	Controlled re-entry	721
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	722
				Medium efficiency	Semiballistic	723
				High efficiency (Lifting body)	Controlled re-entry	724
CRUISE	Subsystem failure (explosion, loss of control, loss of critical function, loss of structural integrity, natural environment induced failure).	HTOL	Cabin escape	Low efficiency	Pure ballistic	725
				Medium efficiency	Semiballistic	726
				High efficiency (Lifting body)	Controlled re-entry	727
		VTOL	Cabin escape	Low efficiency	Pure ballistic	728
				Medium efficiency	Semiballistic	729
				High efficiency (Lifting body)	Controlled re-entry	730
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	731
				Medium efficiency	Semiballistic	732
				High efficiency (Lifting body)	Controlled re-entry	733
DESCENT	Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	734
				Medium efficiency	Semiballistic	735
				High efficiency (Lifting body)	Controlled re-entry	736
		VTOL	Cabin escape	Low efficiency	Pure ballistic	737
				Medium efficiency	Semiballistic	738
				High efficiency (Lifting body)	Controlled re-entry	739
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	740
				Medium efficiency	Semiballistic	741
				High efficiency (Lifting body)	Controlled re-entry	742
LANDING	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory.	HTOL	Cabin escape	Low efficiency	Pure ballistic	743
				Medium efficiency	Semiballistic	744
				High efficiency (Lifting body)	Controlled re-entry	745
			Ejection seat for each passenger	Low efficiency	Pure ballistic	746
		VTOL	Cabin escape	Low efficiency	Pure ballistic	747
				Medium efficiency	Semiballistic	748
				High efficiency (Lifting body)	Controlled re-entry	749
		VTHOL	Ejection seat for each passenger	Low efficiency	Pure ballistic	750
			Cabin escape	Low efficiency	Pure ballistic	751
				Medium efficiency	Semiballistic	752
				High efficiency (Lifting body)	Controlled re-entry	753

Figure 8.25: Point-to-Point, Two Stages, Part2.

Point-to-Point - Three Stages:

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
PRELAUNCH AND LIFT - OFF / TAKE - OFF	Unpredicted explosion at Launch Pad/ Runway	HTOL	No recovery options available		/	754
		VTOL	No recovery options available		/	755
		VTHOL	No recovery options available		/	756
	Detected fire or predicted explosion at the Launch Pad/ Runway due to subsystem failure, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	757
				Medium efficiency	Semiballistic	758
				High efficiency (Lifting body)	Controlled re-entry	759
		VTOL	Cabin escape	Low efficiency	Pure ballistic	760
				Medium efficiency	Semiballistic	761
				High efficiency (Lifting body)	Controlled re-entry	762
			Launch escape system	Low efficiency	Pure ballistic	763
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	764
				Medium efficiency	Semiballistic	765
				High efficiency (Lifting body)	Controlled re-entry	766
			Launch escape system	Low efficiency	Pure ballistic	767
ASCENT	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	768
				Medium efficiency	Semiballistic	769
				High efficiency (Lifting body)	Controlled re-entry	770
			Separation of passenger stage (3d) and 2nd stage from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd and 2nd stage	771
			Separation of passenger stage (3d) from 1st and 2nd stage (if the failure is detected in 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	772
		VTOL	Cabin escape	Low efficiency	Pure ballistic	773
				Medium efficiency	Semiballistic	774
				High efficiency (Lifting body)	Controlled re-entry	775
			Separation of passenger stage (3d) and 2nd stage from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd and 2nd stage	776
			Separation of passenger stage (3d) from 1st and 2nd stage (if the failure is detected in 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	777
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	778
				Medium efficiency	Semiballistic	779
				High efficiency (Lifting body)	Controlled re-entry	780
			Separation of passenger stage (3d) and 2nd stage from 1st stage (if the failure is detected in 1st stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd and 2nd stage	781
			Separation of passenger stage (3d) from 1st and 2nd stage (if the failure is detected in 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	782

Figure 8.26: Point-to-Point, Three Stages, Part1.

Phase	Catastrophic event	Configuration	Recovery options	System configuration (Shape)	Rescue scenario	ID Scenario
SEPARATION OF POSSIBLES STAGES	Malfunction in the mechanism for the separation of the 2nd+3rd stage from the 1st stage, impossibility to realize the separation from the 1st stage.	HTOL	Cabin escape	Low efficiency	Pure ballistic	783
				Medium efficiency	Semiballistic	784
				High efficiency (Lifting body)	Controlled re-entry	785
			Separation of passenger stage (3d) from 2nd stage (if is possible the separation between 3rd and 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	786
		VTOL	Cabin escape	Low efficiency	Pure ballistic	787
				Medium efficiency	Semiballistic	788
				High efficiency (Lifting body)	Controlled re-entry	789
			Separation of passenger stage (3d) from 2nd stage (if is possible the separation between 3rd and 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	790
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	791
				Medium efficiency	Semiballistic	792
				High efficiency (Lifting body)	Controlled re-entry	793
			Separation of passenger stage (3d) from 2nd stage (if is possible the separation between 3rd and 2nd stage)	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	794
	Malfunction in the mechanism for the separation of the 3rd stage from the 2nd stage, impossibility to realize the separation from the 2nd stage.	HTOL	Cabin escape	Low efficiency	Pure ballistic	795
				Medium efficiency	Semiballistic	796
				High efficiency (Lifting body)	Controlled re-entry	797
		VTOL	Cabin escape	Low efficiency	Pure ballistic	798
				Medium efficiency	Semiballistic	799
				High efficiency (Lifting body)	Controlled re-entry	800
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	801
				Medium efficiency	Semiballistic	802
				High efficiency (Lifting body)	Controlled re-entry	803
CRUISE	Subsystem failure (explosion, loss of control, loss of critical function, loss of structural integrity, natural environment induced failure).	HTOL	Cabin escape	Low efficiency	Pure ballistic	804
				Medium efficiency	Semiballistic	805
				High efficiency (Lifting body)	Controlled re-entry	806
			Separation of passenger stage (3rd) from other stages if the failure is in other stages and the vehicle has still stages	High efficiency (Lifting body)	De- orbiting + Controlled re-entry with 3rd stage	807
		VTOL	Cabin escape	Low efficiency	Pure ballistic	808
				Medium efficiency	Semiballistic	809
				High efficiency (Lifting body)	Controlled re-entry	810
			Separation of passenger stage (3rd) from other stages if the failure is in other stages and the vehicle has still stages	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	811
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	812
				Medium efficiency	Semiballistic	813
				High efficiency (Lifting body)	Controlled re-entry	814
			Separation of passenger stage (3rd) from other stages if the failure is in other stages and the vehicle has still stages	High efficiency (Lifting body)	Controlled re-entry with 3rd stage	815
DESCENT	Subsystem malfunction, loss of control, loss of a part of TPS, loss of structural integrity, natural environment induced failure or propulsion related failure.	HTOL	Cabin escape	Low efficiency	Pure ballistic	817
				Medium efficiency	Semiballistic	818
				High efficiency (Lifting body)	Controlled re-entry	819
		VTOL	Cabin escape	Low efficiency	Pure ballistic	820
				Medium efficiency	Semiballistic	821
				High efficiency (Lifting body)	Controlled re-entry	822
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	823
				Medium efficiency	Semiballistic	824
				High efficiency (Lifting body)	Controlled re-entry	825
LANDING	Subsystem malfunction, loss of control, loss of structural integrity, natural environment induced failure, improper dangerous trajectory.	HTOL	Cabin escape	Low efficiency	Pure ballistic	826
				Medium efficiency	Semiballistic	827
				High efficiency (Lifting body)	Controlled re-entry	828
			Ejection seat for each passenger	Low efficiency	Pure ballistic	829
		VTOL	Cabin escape	Low efficiency	Pure ballistic	830
				Medium efficiency	Semiballistic	831
				High efficiency (Lifting body)	Controlled re-entry	832
			Ejection seat for each passenger	Low efficiency	Pure ballistic	833
		VTHOL	Cabin escape	Low efficiency	Pure ballistic	834
				Medium efficiency	Semiballistic	835
				High efficiency (Lifting body)	Controlled re-entry	836

Figure 8.27: Point-to-Point, Three Stages, Part2.

Scenarios - Subsystems Tables:

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
1	/	/	/	/	/	/	/	/	/	/	/	/
2	/	/	/	/	/	/	/	/	/	/	/	/
3	/	/	/	/	/	/	/	/	/	/	/	/
4	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
5	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
6	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
7	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
8	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
9	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
10	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
11	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
12	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
13	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
14	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
15	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
16	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
17	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
18	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
19	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
20	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
21	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
22	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
23	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
24	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
25	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
26	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
27	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
28	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
29	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
30	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
31	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
32	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
33	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
34	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
35	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 8.6: Scenarios-Subsystems, Part 1

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
36	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
37	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
38	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
39	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
40	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
41	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
42	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
43	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
44	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
45	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
46	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
47	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
48	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
49	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
50	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
51	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
52	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
53	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
54	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
55	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
56	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
57	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
58	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
59	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES
60	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
61	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
62	/	/	/	/	/	/	/	/	/	/	/	/
63	/	/	/	/	/	/	/	/	/	/	/	/
64	/	/	/	/	/	/	/	/	/	/	/	/
65	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
66	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
67	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
68	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
69	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
70	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
71	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
72	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
73	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
74	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
75	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
76	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
77	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
78	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
79	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
80	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES

Table 8.7: Scenarios-Subsystems, Part 2

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
81	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
82	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
84	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
85	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
86	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
87	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
88	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
89	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
90	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
91	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
92	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
93	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
94	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
95	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
96	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
97	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
98	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
99	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
100	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
101	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
102	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
103	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
104	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
105	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
106	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
107	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
108	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
109	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
110	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
111	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
112	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
113	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
114	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
115	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
116	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
117	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
118	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
119	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
120	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 8.8: Scenarios-Subsystems, Part 3

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
121	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
122	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
123	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
124	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
125	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
126	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
127	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
128	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
129	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
130	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
131	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
132	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
133	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
134	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
135	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
136	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
137	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
138	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
139	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
140	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
141	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
142	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
143	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
144	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
145	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES
146	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
147	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
148	/	/	/	/	/	/	/	/	/	/	/	/
149	/	/	/	/	/	/	/	/	/	/	/	/
150	/	/	/	/	/	/	/	/	/	/	/	/
151	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
152	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
153	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
154	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
155	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
156	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
157	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
158	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
159	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
160	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO

Table 8.9: Scenarios-Subsystems, Part 4

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
161	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
162	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
163	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
164	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
165	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
166	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
167	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
168	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
169	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
170	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
171	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
172	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
173	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
174	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
175	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
176	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
177	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
178	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
179	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
180	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
181	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
182	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
183	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
184	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
185	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
186	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
187	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
188	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
189	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
190	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
191	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
192	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
193	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
194	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
195	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
196	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
197	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
198	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
199	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
200	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 8.10: Scenarios-Subsystems, Part 5

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
201	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
202	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
203	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
204	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
205	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
206	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
207	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
208	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
209	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
300	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
301	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
302	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
303	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
304	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
305	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
306	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
307	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
308	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
309	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
310	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
311	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
312	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
313	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
314	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
315	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
316	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
317	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
318	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
319	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
320	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
321	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
322	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
323	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
324	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
325	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
326	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
327	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
328	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
329	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
330	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES

Table 8.11: Scenarios-Subsystems, Part 6

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
331	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
332	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
333	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
334	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
335	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES
336	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
337	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
338	/	/	/	/	/	/	/	/	/	/	/	/
339	/	/	/	/	/	/	/	/	/	/	/	/
340	/	/	/	/	/	/	/	/	/	/	/	/
341	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
342	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
343	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
344	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
345	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
346	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
347	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
348	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
349	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
350	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
351	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
352	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
353	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
354	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
355	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
356	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
357	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
358	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
359	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
360	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
361	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
362	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
363	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
364	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
365	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
366	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
367	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
368	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
369	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
370	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES

Table 8.12: Scenarios-Subsystems, Part 7

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
371	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
372	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
373	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
374	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
375	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
376	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
377	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
378	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
379	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
380	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
381	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
382	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
383	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
384	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
385	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
386	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
387	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
388	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
389	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
390	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
391	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
392	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
393	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
394	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
395	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
396	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
397	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
398	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
399	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
400	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
401	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
402	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
403	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
404	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
405	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
406	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
407	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
408	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
409	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
410	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 8.13: Scenarios-Subsystems, Part 8

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
411	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
412	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
413	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
414	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
415	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
416	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
417	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
418	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
419	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
420	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
421	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
422	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
423	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES
424	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
425	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
426	/	/	/	/	/	/	/	/	/	/	/	/
427	/	/	/	/	/	/	/	/	/	/	/	/
428	/	/	/	/	/	/	/	/	/	/	/	/
429	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
430	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
431	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
432	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
433	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
434	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
435	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
436	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
437	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
438	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
439	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
440	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
441	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
442	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
443	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
444	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
445	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
446	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
447	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
448	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
449	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
450	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 8.14: Scenarios-Subsystems, Part 9

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
451	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
452	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
453	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
454	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
455	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
456	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
457	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
458	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
459	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
460	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
461	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
462	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
463	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
464	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
465	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
466	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
467	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
468	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
469	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
470	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
471	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
472	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
473	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
474	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
475	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
476	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
477	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
478	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
479	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
480	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
481	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
482	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
483	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
484	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
485	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
486	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
487	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
488	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
489	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
490	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 8.15: Scenarios-Subsystems, Part 10

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
491	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
492	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
493	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
494	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
495	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
496	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
497	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
498	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
499	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
500	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
501	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
502	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
503	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
504	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
505	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
506	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
507	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
508	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
509	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
510	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
511	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
512	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
513	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
514	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
515	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
516	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
517	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
518	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
519	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
520	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
521	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
522	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
523	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES
524	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
525	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
526	/	/	/	/	/	/	/	/	/	/	/	/
527	/	/	/	/	/	/	/	/	/	/	/	/
528	/	/	/	/	/	/	/	/	/	/	/	/
529	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
530	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO

Table 8.16: Scenarios-Subsystems, Part 11

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
531	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
532	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
533	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
534	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
535	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
536	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
537	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
538	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
539	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
540	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
541	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
542	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
543	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
544	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
545	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
546	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
547	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
548	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
549	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
550	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
551	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
552	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
553	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
554	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
555	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
556	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
557	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
558	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
559	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
560	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
561	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
562	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
563	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
564	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
565	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
566	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
567	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
568	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
569	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
570	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES

Table 8.17: Scenarios-Subsystems, Part 12

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
571	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
572	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
573	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
574	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
575	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
576	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
577	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
578	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
579	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
580	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
581	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
582	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
583	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
584	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
585	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
586	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
587	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
588	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
589	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
590	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
591	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
592	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
593	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
594	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
595	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
596	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
597	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
598	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
599	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
600	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
601	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
602	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
603	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
604	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
605	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
606	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
607	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
608	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
609	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES

Table 8.18: Scenarios-Subsystems, Part 13

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
610	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
611	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
612	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
613	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
614	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
615	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
616	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
617	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
618	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
619	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
620	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
621	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
622	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
623	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
624	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
625	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
626	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
627	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
628	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
629	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
630	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
631	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
632	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
633	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
634	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
635	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES
636	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
637	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
638	/	/	/	/	/	/	/	/	/	/	/	/
639	/	/	/	/	/	/	/	/	/	/	/	/
640	/	/	/	/	/	/	/	/	/	/	/	/
641	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
642	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
643	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
644	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
645	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
646	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
647	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
648	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
649	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
650	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO

Table 8.19: Scenarios-Subsystems, Part 14

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
651	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
652	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
653	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
654	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
655	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
656	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
657	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
658	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
659	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
660	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
661	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
662	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
663	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
664	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
665	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
666	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
667	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
668	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
669	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
670	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
671	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
672	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
673	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
674	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
675	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
676	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
677	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
678	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
679	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
680	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
681	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
682	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
683	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
684	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
685	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
686	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
687	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES
688	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
689	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
690	/	/	/	/	/	/	/	/	/	/	/	/

Table 8.20: Scenarios-Subsystems, Part 15

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
691	/	/	/	/	/	/	/	/	/	/	/	/
692	/	/	/	/	/	/	/	/	/	/	/	/
693	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
694	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
695	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
696	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
697	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
698	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
699	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
700	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
701	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
702	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
703	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
704	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
705	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
706	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
707	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
708	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
709	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
710	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
711	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
712	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
713	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
714	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
715	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
716	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
717	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
718	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
719	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
720	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
721	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
722	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
723	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
724	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
725	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
726	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
727	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
728	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
729	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
730	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 8.21: Scenarios-Subsystems, Part 16

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
731	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
732	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
733	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
734	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
735	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
736	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
737	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
738	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
739	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
740	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
741	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
742	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
743	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
744	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
745	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
746	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
747	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
748	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
749	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
750	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
751	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES
752	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
753	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
754	/	/	/	/	/	/	/	/	/	/	/	/
755	/	/	/	/	/	/	/	/	/	/	/	/
756	/	/	/	/	/	/	/	/	/	/	/	/
757	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
758	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
759	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
760	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
761	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
762	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
763	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
764	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
765	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
766	YES	NO	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
767	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
768	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
769	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
770	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 8.22: Scenarios-Subsystems, Part 17

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
771	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
772	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
773	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
774	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
775	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
776	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
777	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
778	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
779	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
780	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
781	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
782	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
783	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
784	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
785	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
786	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
787	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
788	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
789	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
790	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
791	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
792	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
793	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
794	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
795	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
796	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
797	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
798	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
799	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
800	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
801	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
802	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
803	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
804	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
805	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
806	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
807	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
808	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
809	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
810	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 8.23: Scenarios-Subsystems, Part 18

ID Scenario	Electric Subsys.	TCS	TPS	Propellant	Propulsion Subsy.	EDL	FCS	Separation Mechanism	RCS	Avionics	ECLSS	Body Suit
811	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
812	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
813	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
814	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
815	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
817	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
818	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
819	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
820	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
821	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
822	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
823	YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES
824	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
825	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO
826	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
827	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
828	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
829	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
830	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	YES	YES
831	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
832	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
833	YES	NO	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES
834	YES	YES	NO	YES	YES	YES	NO	YES	NO	YES	NO	YES
835	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
836	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO

Table 8.24: Scenarios-Subsystems, Part 19

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