SPACE TRANSPORTATION SYSTEMS – MISSIONS, OPERATIONS, AND GROUND INFRASTRUCTURE

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OVERVIEW

The DGLR S4.1 Working Group on Space Transportation Systems (Fachausschuss S4.1 Raumtransportsysteme) is a forum for members from agencies, institutions, industry and universities. Gathering and analysing information and argumentation on space transportation systems' past, status and future is the objective of the group. The analysis and documentation is coordinated around the topics

- Demand / Market
- System Concepts & Subsets
- Propulsion, Structures & Subsystems (System related aspects)
- Missions & Operations (incl. Ground infrastructure)
- Cost (Development, Production & Operation)
- Projects/Programmatic (Development & Demonstration)

Subject of this paper is to give an overview on the mission and operation aspects of space transportation.

1. INTRODUCTION

Due to the very high technological requirements and project budgets needed the successful accomplishment of space programs depends heavily on cooperation at national, European, and international levels. This is especially essential in using the space programs infrastructure. This infrastructure encompasses space operations facilities, launch vehicles and the ground infrastructure. Since building and operating this infrastructure is a costly endeavor the efficient use of these resources is a very important issue.

The most visible part of space programs are the missions themselves. But behind the scenes a network of infrastructure consisting of research, manufacturing, test, launch, operations, and management facilities has to work seamlessly. Therefore we want to discuss space programs in this paper as a whole by first looking at different space missions and their according launcher requirements, followed by a general overview of operations and finally the infrastructure. Our analysis will be restricted on the European launcher sector.

A significant part of launcher and mission costs originate from operations prior and during a mission, due to the amount of manpower included. Thus, benefits for future cost savings may also be generated by improvements in launcher operations.

2. MISSION & REQUIREMENTS

The requirements for the launch system to serve for a specific mission can be derived form the requirements of the target orbit. Orbiting satellites are used for several applications, such as

- weather, Earth and military observation
- communication (television, telephone, military)
- scientific missions
- interplanetary missions
- navigation and space information

Due to the intended mission, the satellite has to be placed in a suitable target orbit by the launch system, defining some important requirements for the launch systems.

The most important target orbit is the geostationary orbit (GEO) for weather and communication satellites, which is in most mission scenarios reached via the GTO transfer orbit. The demand of a orbit inclination of 0° prefers launch sites near the equator for such missions. GEO satellites are the commercially most important launcher payloads. Due to their long life time the satellites are –today- rather large and heavy (~4 metric to.). The second most used orbit is the polar orbit and the SSO (sun synchronous orbit) for earth observation and recognizance missions. Due to the almost 90° inclination, launch sites with higher latitude can serve these orbits without great performance loss. Satellites to these orbits range from very small (Bird) to very large (e.g. Envisat). A also important commercial deducible orbit is the medium Earth orbit (MEO) which is used by e.g. navigation satellites and communication constellations. Due to the high number of spacecrafts for such constellation systems, the launch rate demand is rather high. The satellites are typically of medium size and weight. Other operational orbits but with low launch rates are the low Earth orbit (LEO, excluding polar orbits/SSO) and escape trajectories for interplanetary probes. LEO is mainly used for manned space flight missions and supply for international space station (ISS); these missions are actually not of great commercial interest. In Europe, the autonomous transfer vehicle (ATV) will become the support vehicle for ISS, launched on ARIANE 5 into LEO.

TAB 1 summarizes the different operational orbits and lists the derived requirements for the launch system. As mentioned before, GEO is – today - in most cases reached via a GTO orbit, where the transfer from GTO to GEO is achieved by the satellite itself. From operations point of view (and to be more adaptable) a direct insertion into GEO by the launcher would be preferable. This direct GEO puts some requirements on the upper stage of the launcher, i.e. the capability to reignite and to perform a coasting arc of 10 or more hours between maneuvers. The same requirements are true for MEO insertion and also for LEO missions. Furthermore, interplanetary missions will benefit from such capabilities. Additionally tasks may be required by the payload to be performed with the upper stage, such as spin or de-spin of the payload before separation. To decrease costs per payload, multiple satellite launch has become standard in the Ariane program for GTO missions. The capability of launching more than one spacecraft during one launch campaigns requires an appropriate payload mass capability and a dual separation system with reorientation during release of the first and second payload. TAB 1 is based on outcomes of market analysis [1]. The most important aspect to our opinion for future success of a launch vehicle is comprised by the dual launch capability for the commercial market to save cost, a flexible upper stage for multi purpose use, which means a reignitable engine and an operation time of some 10 hours to allow for coasting phases (highlighted in TAB 1). It seams that especially the GTO market is due to the number of expected payloads is commercially most interesting. Therefore, Ariane 5 is optimized for this type of missions.

Target Orbit	GEO via GTO	GEO direct	MEO direct	SSO direct	LEO ATV	interplanetary experimental
payload mass /kg	3000-6000	1500-3000	1000-4000	1000-8000	20000	1000-3000
payload volume	medium - large	medium - large	medium	small - large	large	small - medium
advantage of launch site at equator	+	+	(+)	-	(+)	+
launch window constraints	yes	yes	yes	yes	yes	yes
dual launch	+	+	(+)	/	no	no
reignitable upper stage	(+)	+	+	(+)	+	(+)
duration of coasting phases	short	long	long	short	short	short
upper stage reorientation /spin	+	+	(+)	(+)	/	(+)
precise navigation	+	+	+	+	(+)	+
launch frequency / availability	high	low	moderate	moderate	low	low

TAB 1. Requirements for the launch systems according to the intended target orbit of the payload

3. EUROPEAN COMMERCIALLY PROVIDED LAUNCH SYSTEMS

Besides the ARIANE 5 launch vehicle, provided by Arianespace [2], Europe has also gathered access to space within cooperation with Russian launch systems. The Soyuz launch vehicle is provided in its unmanned version by the consortium STARSEM [3], the Rockot launch vehicle is brought to market in the Eurockot joint venture [4] and the Cosmos 3M is used by COSMOS International [5]. The different launch vehicles cover the requirement of small to heavy payloads, using Rockot and Cosmos for small satellites, Soyuz for medium and Ariane for the heavy payload. These four will be gathered by a fifth launcher system – Vega (also provided with Arianespace [2]) – within the end of this decade. Vega has comparable performance as Rockot and Cosmos but is not jet operational.

FIG 1 depicts the four (five) available launch vehicles. Ariane 5 and Vega are European product, while the other are manufactured in Russia and only brought to market by European consortiums. The European launch site in Kourou (French Guyana) has a unique geographic position for rocket launches, especially for GTO missions. Close to the equator it is used for Ariane 5 launcher and will be used also by Vega in the future. Actually, the Soyuz launch vehicle in the configuration with the Fregatt upper stage is launched from Baikonur and Plesetsk, but currentrly, a launch facility is erected for Soyuz in Kourou. With the first launch of Soyuz from Kourou in 2009, the payload capability of this launcher will be increased significantly for GEO missions. The Rockot and Cosmos launcher fill the lower payload mass gap and are launched from either Plesetsk or Kapustin Yar.

FIG 1. European launch vehicle market; left to right: Ariane 5, Soyuz, Rockot, Cosmos, Vega (pictures not to scale)

Ariane 5 as one of the most powerful rocket today, is available in different version, either for heavy payloads up to 10 to. to GTO (Version A5ESC-A) or can use the reignitable stage with lower payload performance (6.9to. GTO, Version A5ES) but restartability and higher flexibility. With this spectra of launch vehicles, the current demand in space launch capability can be covered and the performance is sufficient as of today. Prediction of future payload demands (see [1]) indicate that a increase in payload capability will become mandatory for the heavy lift vehicle Ariane 5 if a dual launch capability for GTO should be maintained. The dual launch option is important in terms of cost control (see [6]). With the Ariane 5 in combination with the automated transfer vehicle (ATV) Europe is offering a unique autonomous transport capability to ISS, the importance of which is very high due to the missing transport capability to ISS after the retirement of the Space Shuttle system 2010.

Currently, Europe lacks on an own access to space for manned mission.

4. MISSION AND LAUNCH OPERATIONS

Launch vehicle operations require immense efforts in management, infrastructure and workforce. As of today, each mission is a unique scenario that has to be planned and organized specifically. Generally launch operations can be divided in pre-launch activities and the launch campaign itself. In this section an overview of launch vehicle operations is given based on the Ariane 5 operations [6].

4.1. Pre-Launch Activities

With the decision to launch a specific payload on a specific launcher a series of mission analysis steps have to be taken. Questions concerning the interface between payload and launcher have to be defined and in case of dual or multiple payloads, a set of payload partners with the same target orbit have to be combined. Due to the fact that each launch is in some kind unique, a detailed trajectory planning of the ascent flight has to be performed prior to the mission. Aspects of guidance, navigation and control have to be decided, maneuver sequences must be coded to software and tested in simulation runs. The compatibility of launcher and satellite has to be proven in numerical couple analysis of the structures. Also the organization of the production of the launcher and delivery to the launch site facilities for integration has to be organized. As of today the launchers are expandable and the complete production of a launch vehicle takes about 32 month (Ariane 5), also some launchers are produced in advance. In parallel a lot of pre-flight testing and quality assurance topics have to be performed. The pre-launch activities are finished with the launcher (in parts) and payload delivery to the launch site, the infrastructure to transport these delicate freight is described later.

Launch operations begin two years before launch. The tasks include

- Launch vehicle procurement & adaptation
- System engineering
- Launch campaign preparation (last year)
- Launch campaign & launch (last 2 months).

System engineering is one of the most challenging tasks and includes interface control, mission analysis, spacecraft (S/C) compatibility analysis and post launch analysis.
Extensive mission analysis is needed to identify a successful, robust and secure flight profile, the separation conditions, flight manoeuvres, separation & collision avoidance methods, coupled loads, EMC & RF compatibility, thermal loads, while considering mission constraints and operational constraints such as solar aspect angle, spin limitation, gyro saturation, and launch window. S/C compatibility must be analysed to guarantee electrical and mechanical interfaces between the S/C and launch vehicle (L/V) and the ground segment equipment. Finally the post launch analysis delivers the valuable data which is needed for the S/C operations which start after payload separation, for improving L/V operations, and diagnostics.

4.2. Launch Campaign

The launch campaign is a step by step timed approach to the final countdown (example Ariane 5, see [7]), lasting about 4 weeks. It starts with launcher integration and payload checkout in parallel. The payload(s) is (are) mated to the interfaces, fueled and housed by the fairing.

It is then mated to the launcher stages that have been mated together before. Fig 2 depicts this sequence.

After integration the rocket is transferred to the launch pad itself. Fueling of the stages is performed prior to launch, and after final reviews, the mission starts with the ignition of the main engines. The launch mission ends with the payload separation from the launch vehicle.

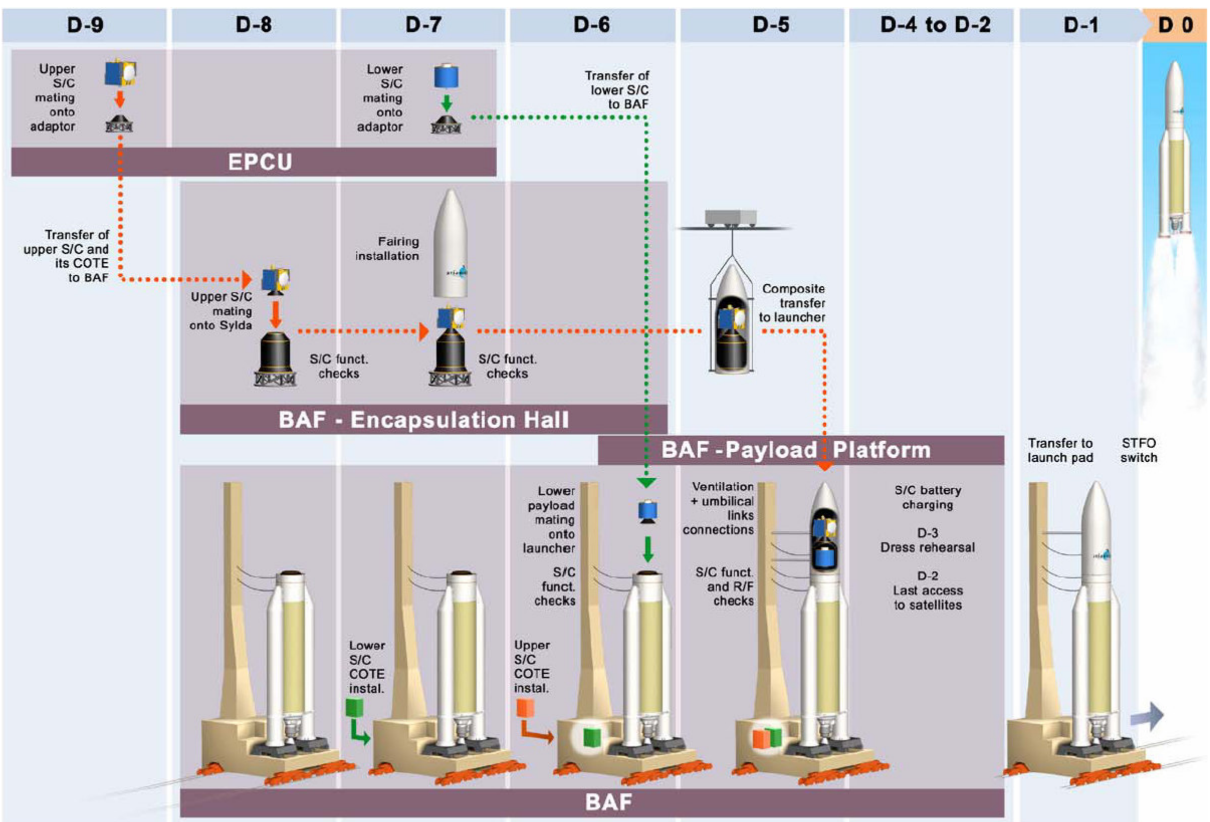

FIG 2. Final payload integration sequence (Ariane 5 [6])

The launch campaign preparation starts one year before launch which is followed by the two-month launch campaign. The main tasks are development of the spacecraft, combined and interleaved/combined operation plans.

The main launch campaign tasks can be grouped as follows:

- Spacecraft autonomous preparation
- Combined operations
- Launch readiness review
- Launch countdown and launch

The spacecraft autonomous preparation includes the preparation and checkout procedures and hazardous operations such as fuelling. During combined operations the spacecraft is integrated with the launch vehicles. This is followed by the launch readiness review. All the three components which are reviewed for their launch readiness are

- The launch vehicle
(Hardware, software, propellants, consumables)
- Spacecraft
(Customer ground segment equipment, S/C communications network including ground stations and the control center)
- Launch range
(Launch pad, communications and tracking network, weather)

If all systems of all above components are ready for launch then the countdown may begin.

5. INFRASTRUCTURE

A complex infrastructure (I/S) is necessary to launch a payload into orbit. It can be divided into several categories:

- Operational I/S
- Launch Site I/S
- Manufacturing and Testing I/S
- Research and Development I/S

For a favourable launch site several properties are required:

- Moderate climate
- Air and sea connection
- Accessible local transportation
- Accomodation

The European launch site Kourou covers all these points and combines them with a wide available launch azimuth range and a low longitude for energetically more efficient launches.

An enormous infrastructure is needed at the launch range. The next section gives an overview.

5.1. Operational & Launch Site Infrastructure

The general Launch site infrastructure is described exemplarily fort he Ariane 5 launch site at the Guyane Space Center (Centre Spatial Guyane, CSG) CSG mainly comprises:

- the CSG arrival area through the sea and air ports
- the Payload Preparation Complex (shared between three launch vehicles)
- the Upper Composite Integration Facility dedicated to each launch vehicle: for Ariane 5, the upper composite integration is carried out in the Final Assembly Building (BAF)
- the dedicated Launch Sites for Ariane, Soyuz and Vega each including Launch Pad,
- LV integration buildings, Launch Centre (CDL, “Centre de Lancement”)
- and support buildings,
- **Mission Control Centre** (MCC or CDC – “Centre de Contrôle”).
- Network of ground stations (TTC and Tracking)

FIG 3. Ariane 5 launch site installations (source: [6])

Firstly sea and air ports and access to local transport facilities are needed at the launch site for the transportation of large S/C and L/V parts. Also an on-site transportation infrastructure capable of personnel, payload, spacecraft and hazardous material transportation is needed.

Hazardous materials must be handled with special care. For this purpose hazardous processing facilities have to be installed. Fuelling, solid booster processing, upper stage tanking, decontamination, propellant and pyrotechnic storage must be done with maximum cautiousness in these facilities.

Besides hazardous material a launch site also includes storage for water, gaseous Nitrogen, Helium and other consumable fluids and gases.

Spacecraft and launch vehicles are usually delivered to the range in parts. Their autonomous integration which is followed by the integration of the S/C with the L/V are carried out in dedicated integration facilities for the following tasks

- Payload processing (clean rooms, fueling, testing: leakage, x-ray checks, mass distribution, electrical checks)
- Upper composite integration
- Final vehicle assembly

For manned missions additional facilities for astronaut training, preparation, space suit processing also have to be considered.

The whole infrastructure must be supported by additional facilities and management services such as medical care, accommodations, logistics, and security.

The heart of every launch site is the mission control center (MCC). The MCC must be connected to all facilities at the range and all ground stations involved launch operations using a range communication network, long-distance satellite communication networks and range information systems.

Some of the most important functions of the mission control center are

- Management and coordination of the launch operations
- Telemetry processing, spacecraft monitoring
- Assessment of launch readiness states (meteorology, safety)
- Data exchange
- Decisional processes
- Flight monitoring and control

Payload operations start after separation from the launch vehicle. At this point the MCC transfers tracking data and spacecraft position to the operations control center (i.e. ESOC) where the most critical tasks before starting early operations include

- First acquisition of signal
- Sun acquisition and start of battery charging
- Spacecraft attitude stabilization for continuouse communications and battery charging
- Initialization of the spacecraft and payloads

Therefore the information passed from the launch site mission control center to the operations control center play a very important role in the success of a space mission.

5.2. Manufacturing and Testing Infrastructure

Europe has established many manufacturing and testing centers with a high level of technological standards. These European manufacturing capabilities include liquid and solid rocket engines, advanced light-weight structures and thermal protection materials, load-carrying structures, and high-tech manufacturing processes. The established test facilities are for example ESTEC (NL) and IABG (D) and propulsion test facilities at DLR Lampoldshausen and France. More facilities with comparable spacecraft and subsystems testing and manufacturing capabilities are distributed all over Europe in all ESA member states. These are industrial, institutional and research facilities which closely cooperate in the European space program.

5.3. Research and Development Infrastructure

Research and development of future space transportation systems is located in dedicated research institutions including industry, agencies and educational institutes, i.e. the universities offering capabilities in the following areas:

- System, subsystem, and component design and development
- Simulation
- Hardware development
- Software development
- Failure and reliability analysis
- System evaluation and improvement
- Concepts evaluation
- Assembly, integration, verification, test & operation
- Concurrent system engineering
- Mission analysis

In the preservation of know how, technology and committed education of young scientists also micro/nano university satellite programs and student ground stations play a great role. But besides this student satellites also provide the best environment for testing space technology in space. By increasing the cooperation between industry, governmental space institutions and universities the efforts can be coordinated to implement student satellite projects which can strongly contribute to industrial space technology development by providing space technology testing and validation in space.

6. CONCLUSIONS

The European space launch vehicles cover the demands of the market. With current intensions to launch the Soyuz rocket from Kourou, a significant increase in flexibility is achieved for the medium size satellite market. The infrastructure is sufficient for the actual launch rates. Still Ariane 5 is one of the most powerful rockets to launch heavy payload, which is actually used mainly for dual launch of commercial payloads to GTO. With the ATV, Europe will become a great backbone of ISS operations and support. The small launchers fill the gap for the small payloads especially to SSO and MEO orbits. An upgrade of Ariane 5 with an reignitable upper stage would increase the spectra of payloads and orbits to be served with Ariane.

If the satellite launch market increases faster than predicted, the production capability for the rockets will reach an limit. But an upgrade of existing facilities for production and transport seems to be possible if necessary. Otherwise, a slight decrease of operations costs would occur if the launch rate would be little higher than today, to obtain a steady use of the launch facilities and operations teams.

Future developments in the launch market are hard to predict. Actually no really knew concept for space launch missions is in sight for the near future. For new steps Europe has established research facilities in many involved countries and is working on new technologies. The general infrastructure in Europe is prepared for new concepts e.g. in latest manufacturing techniques. Further work has to be tackled for the launch sites if a new launcher will be build.

Acknowledgment

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