2 A System-Level View of Space Projects

Malcolm Macdonald

Until well after World War II, with no meaningful definition distinguishing the terminology, the fields of aerospace, aeronautics and astronautics were synonymous. Indeed even today, the terms are widely misunderstood and misused. However, the great Hungarian aeronautical engineer and physicist, Theodore von Kármán (original Hungarian name: Szőllőskislaki Kármán Tódor; 1881–1963) believed a clear distinction between aeronautics and astronautics could, and should be made. Therefore, in the early 1950s, and in consultation with the International Federation of Astronautics (IAF), founded 1951, and the Fédération Aéronautique Internationale (FAI), von Kármán undertook the task of defining the respective terms.

In aeronautics, the presence of an atmosphere is critical, while in astronautics its absence is critical. As altitude is increased the atmospheric density decreases. Thus, for steady level flight, controlled by aerodynamic forces, the velocity of the vehicle must increase until eventually the required velocity will overcome the circular orbit velocity. Hence, aerodynamic forces are no longer required to maintain steady level flight. The converse is true for astronautics. As altitude is decreased, the notion of a free-fall orbit becomes meaningless due to the increasing atmospheric density, leading to an increase in the drag force. In conclusion, von Kármán and his co-workers determined that the nominal boundary could be set at an altitude of around 100 km, a definition readily accepted by the IAF. Meanwhile the FAI, who to this day administrate aeronautics records and hence had a slightly different interest in the definition, created a new category of flying machine, named spacecraft, which from that point on would have separate records to aircraft. Section 8 of the FAI Sporting Code would, thereafter govern such machines, and the distinction between aeronautics and astronautics.[1] The code defines the nominal boundary to space as the von Kármán ellipsoid, an ellipsoid at 100 km altitude; often termed simply as the Kármán line. A spacecraft is thus a vehicle or vessel designed to operate beyond the von Kármán ellipsoid. By extension of this definition, crafts such as rovers, landers or (non-Earth) atmospheric probes are also termed spacecraft. Note that the plural of spacecraft is spacecraft.

Having established a simple and clear definition of a spacecraft, reality must unfortunately intervene. Within the space community, the term spacecraft has two contradictory meanings in common parlance. The first refers to the spacecraft as the whole vehicle, while the other refers only to the platform onto which the payload is mounted. For this reason, the term satellite is often used, a term which simply means a body orbiting another of larger size. However, not all spacecraft orbit and hence the terms space probe or space vehicle can be used when satellite is inappropriate, such as a Mars lander. Within this book, all of these terms are used in-line with in common parlance (Fig. 2.1).

Just as the von Kármán ellipsoid is not actually a hard and clear boundary between aircraft and spacecraft, space technology cannot be considered solely as the space vehicle, rather the vehicle is part of a much larger system. A space system can be considered the entirety of hardware, software and human resources required to conduct a space mission. The space system is typically subdivided into the space segment and the ground segment.

The space segment is the spacecraft, while the ground segment is the system on Earth that manages and controls the spacecraft, and its data products. The ground segment can be subdivided into two core components; the flight operations segment, relating to the spacecraft housekeeping,

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[1] See www.fai.org.

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Fig. 2.1 Image of the upper regions of the Earth's atmosphere, from approximately 28 km altitude, leading to space and including the region of the von Kármán ellipsoid. *Image* University of Strathclyde

or telemetry data, and commanding, and the payload data ground segment, relating to the spacecraft data product. The flight operations segment will typically be managed by a single control center. However, this center may itself be supported by other secondary centers. The spacecraft control center is ultimately responsible for the safe operations of the spacecraft. Moreover, under nominal operations it will be the sole originator of all spacecraft commands.

The spacecraft's data product can be disseminated in many ways, typically defined by the spacecraft mission, as shown in Fig. 2.2. It should also be noted that the overall architecture need not include a direct-link from spacecraft to ground, but can use an inter-spacecraft link, as also shown in Fig. 2.2.

The final component of the space system is the launch vehicle, which has the primary objective of traversing the von Kármán ellipsoid to deliver a payload, i.e. a space vehicle, into space. The launch vehicle need not specifically establish its payload in an Earth orbit, rather it can enter a suborbital, or parabolic arc, it can place the payload directly onto an Earth escape trajectory, perhaps *en route* to another planet, or it can place it into an Earth orbit. The final orbit of a spacecraft is often actually achieved through a combination of the launch vehicle and the spacecraft's own propulsive capabilities. For example, a geostationary communications spacecraft is typically inserted by the launch vehicle into a geostationary transfer orbit (GTO) with apogee at geostationary distance, see Chap. 4, and perigee at only a few hundred kilometers altitude. The communications spacecraft will thereafter use its own propulsive capabilities to maneuver into a geostationary orbit (GEO). Thus, the functional boundary between the final stage of the multi-stage launch vehicle and the propulsive capabilities of the launch vehicles payload is somewhat ambiguous. As such, within this handbook space transportation systems are considered simply as a different type of spacecraft mission objective or phase.

2.1 The Space Segment

The space segment is defined as everything beyond the von Kármán ellipsoid. As shown in Fig. 2.2 the space segment architecture can take different forms, perhaps with spacecraft providing services to other spacecraft in a manner which may, or may not, have been envisaged when either spacecraft was commissioned. Most typically, such services include communications or navigation assistance.

The space segment can also be constructed of several spacecraft working in isolation, and largely operated as individuals, to provide a coherent ground-segment data product; this is termed a spacecraft constellation. Several spacecraft constellations are in service today. Perhaps the most widely known of these is the global navigation satellite system (GNSS) maintained by the United States government, under the stewardship of the Department of Defense, as a national resource, called the Global Positioning System (GPS). Historically, the other principal GNSS system was the Russian GLObal Navigation Satellite System (GLONASS), which was used solely by the Russian military until 2007, when it was made available to civilians. However, as discussed in Chap. 1 several other nations are now keenly pursuing this technology, including the Chinese BeiDou-2 navigation system and the European Union's Galileo positioning system. It is of note that many spacecraft today use GPS to aid in-orbit navigation. Another spacecraft constellation of note is the Iridium constellation, owned and operated by Iridium Communications Inc., consisting of over 60 spacecraft providing voice and data coverage to satellite phones, pagers and integrated transceivers over Earth's entire surface. A key feature of the Iridium constellation, and all other space-backbone mobile phone systems, is the ability to operate in areas of limited infrastructure, making them of significant value not only to the military, but also in disaster relief efforts where the infrastructure has been destroyed (Fig. 2.3).

Alternatively, spacecraft can work co-operatively to form a single integrated space segment, this is termed formation flying and quite a few natural formations are possible, see Chap. 4. Indeed, several spacecraft are claimed to have flown in formation, for example, ESA have previously flown the ERS-2, European Remote-Sensing Satellite-2, spacecraft and ENVISAT, Environmental Satellite, in a tandem formation enabling synthetic aperture radar (SAR) interferometry, or InSAR measurements to be made. InSAR combines two or more SAR images of the same site to allow slight variations that may have occurred between image acquisitions to be detected. As shown in Fig. 2.4, the

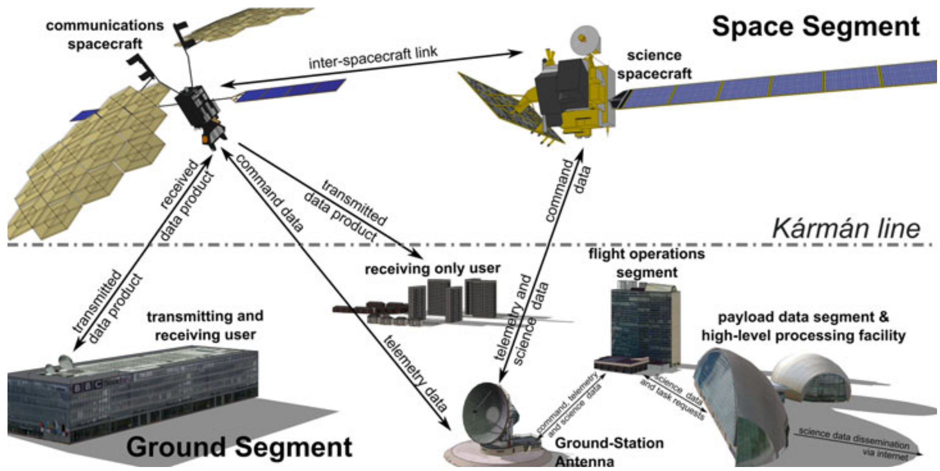

Fig. 2.2 The generic space system (not to scale); comprising the space segment and the ground segment. *Image* Malcolm Macdonald

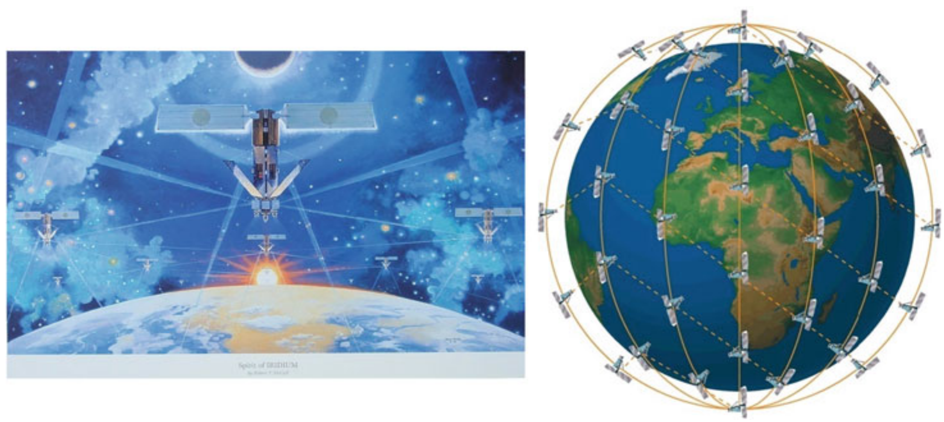

Fig. 2.3 An early Iridium poster (*left*) and the Iridium constellation (*right*). *Image* Iridium Communications Inc

ERS-ENVISAT tandem formation was configured such that SAR images of the same site would be acquired 28 min apart, enabling rapid variations to be detected. Figure 2.4 shows a sea ice displacement map acquired by the ERS-ENVISAT tandem formation where sea ice displacements of over 150 m were detected in less than half an hour. It should be noted however that the ERS-ENVISAT tandem formation is really closer to a two spacecraft constellation than a formation. Formation flying is perhaps best illustrated by mission concepts where the spacecraft are required to act in a coordinated manner in order to provide the required data product. Examples of this are the joint ESA/NASA Laser Interferometer Space Antenna (LISA), mission concept, or ESA's free-flying X-ray observatory mission concept, Xeus, where the mirror and detectors would be located on separate spacecraft, flying in formation 50 m apart.

2.1.1 Payload

For space science missions the payload is typically a bespoke suite of instruments. Meanwhile for commercial spacecraft, such as communications platforms the payload, and its supporting platform, will typically have some significant flight heritage and may be produced many tens of times. However, it is easily forgotten by the spacecraft engineer that the payload is the *raison d'être* of any spacecraft. Indeed, the Merriam Webster Dictionary gives a particularly adept definition of payload as "*the load carried by a vehicle exclusive of what is necessary for its operation; especially: the load carried by an aircraft or spacecraft consisting of things (as passengers or instruments) necessary to the purpose of the flight.*" In other words, the payload is the biological passengers, or the part of a robotic vehicle that produces revenue, a product or a service. The principal purpose of the rest of the spacecraft is thus to serve the needs of the payload, positioning it where it needs to be in space, while providing it with power, communications and the desired thermal environment, whilst also ensuring it is pointing in the correct direction on a sufficiently stable platform.

It should be noted that the term payload is often used at various levels of the space system to denote different things; typically, this can be understood by considering the purpose of the vehicle. For example, the launch vehicle payload is the spacecraft, while the spacecraft may have a payload that

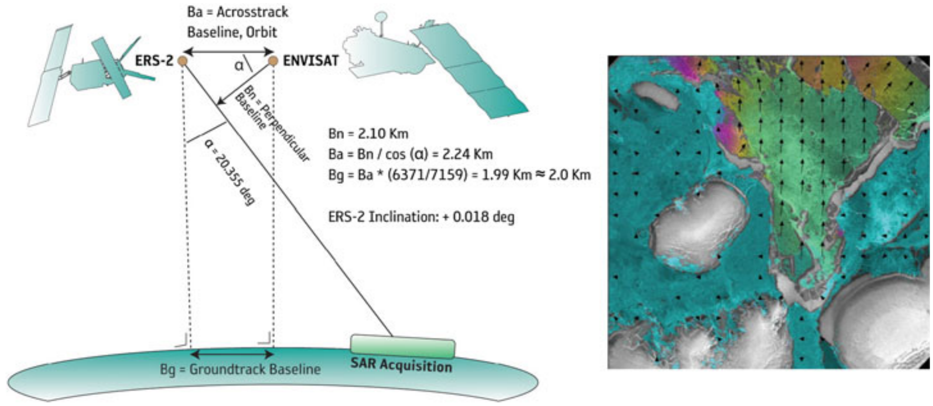

Fig. 2.4 Geometry of ERS-envisat tandem operation (*left*) and geocoded sea ice displacement map (*right*); the *green* areas correspond to an observed sea ice displacement of about 160 m in 28 min. The image brightness corresponds to the backscattering of the Envisat image. *Image* ESA

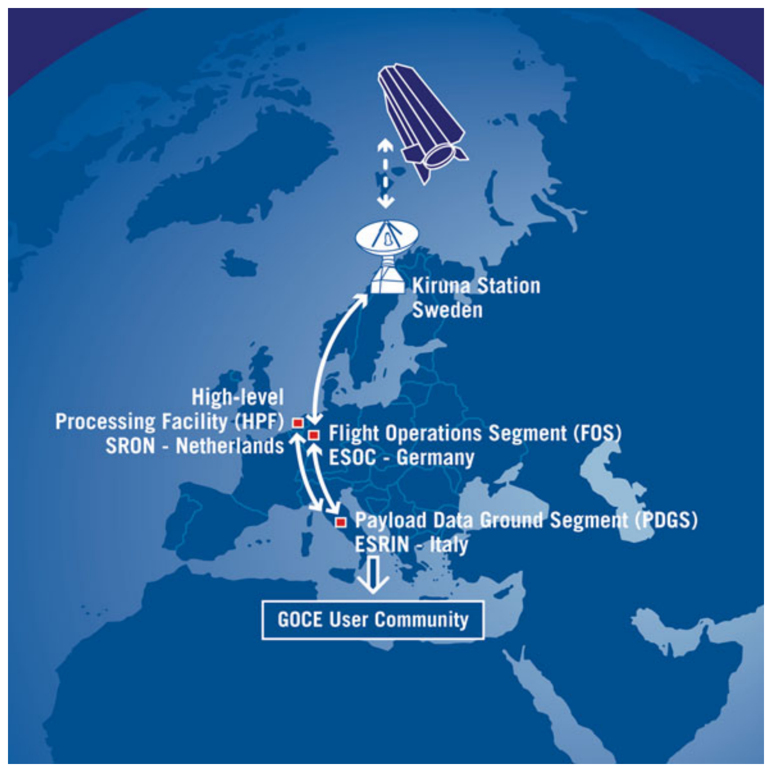

Fig. 2.5 The gravity field and steady-state ocean circulation explorer (GOCE), mission space system and data flow. *Image* ESA—AOES Medialab

is a communications system, science instruments, or, say, a lander. The lander then may have a science suite on board, but it may also carry a payload of a rover, and the rover may in turn have a science suite payload.

2.2 The Ground Segment

The ground segment is defined as everything before the von Kármán ellipsoid and consists of the entirety of hardware, software and human resources required to manage and control a space vehicle. As discussed above, the ground segment can be subdivided into two core components, the flight operations segment and the payload data ground segment. The flight operations segment is relatively independent of the spacecraft mission, and is focused on the command and control of the spacecraft. However, the payload data ground segment is heavily defined by the mission objectives and the data product. For example, in a science mission the primary spacecraft control center will typically receive the flight operations data as well as the science data product. The data product will then be passed

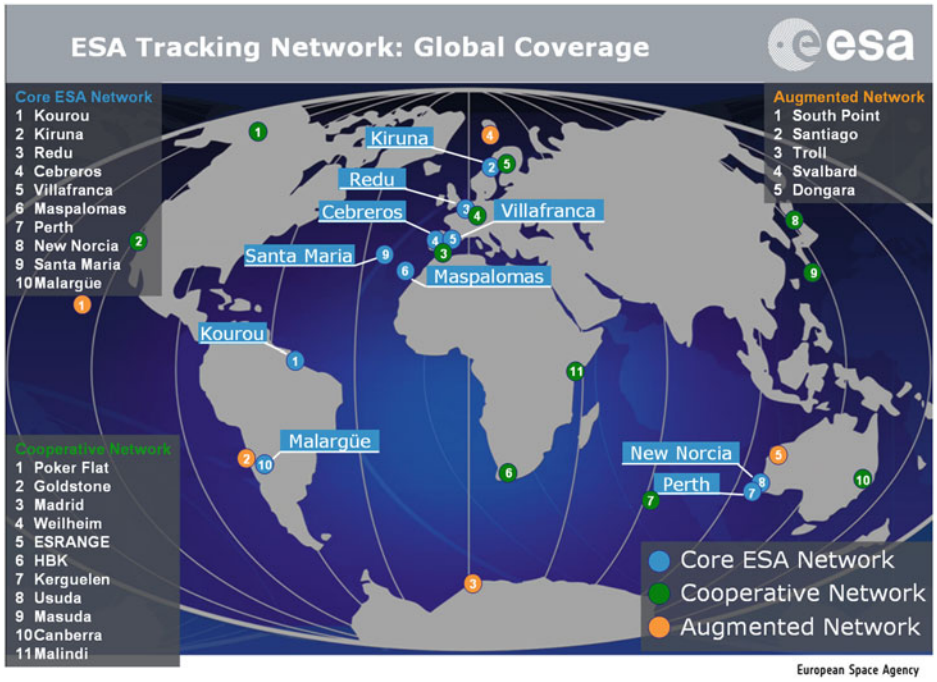

Fig. 2.6 The ESA tracking network in january 2011. *Image* ESA

to the payload data ground segment, which may or may not be collocated. The payload data ground segment will then pass the data product to a science principal investigator (PI) for some initial high-level processing prior to the data being distributed widely, typically via the Internet as shown in Fig. 2.2. Furthermore, in a science mission the request for specific data products will also be managed by the spacecraft control center, as shown in Fig. 2.2. The ESA Gravity field and steady-state Ocean Circulation Explorer (GOCE), mission space system and ground-segment data flow is shown in Fig. 2.5.

Alternatively consider, for example, a communications spacecraft, where the flight operations segment will typically not be directly concerned with the data product, as shown in Fig. 2.2, and may in fact be wholly separate. Indeed, typically commercial data products, such as Direct-to-Home television, or mobile phone communications, are depended on this type of space system and ground segment architecture.

2.2.1 Ground Stations

To provide high quality, reliable and robust communications with spacecraft it is typical to use multiple ground stations, often positioned at geographically strategic locations. For low inclination spacecraft, the ground stations will ideally be distributed in longitude to ensure at least one communications window per revolution. While for polar orbiting spacecraft, ground stations close to the poles will provide one communications window per revolution.

Two well-known examples of ground station networks are ESA's tracking station network (ESTRACK), a worldwide system of ground stations providing links between spacecraft and ESA's Operations Control Centre at ESOC, and, the NASA-JPL operated Deep Space Network (DSN), which supports both Earth orbiting spacecraft and interplanetary missions. Note that the DSN is separate from NASA's Near Earth Network (NEN), which provides orbital communications support for Earth orbiting platforms via various NASA ground stations and is operated out of the Goddard Space Flight Center. The ESTRACK network is shown in Fig. 2.6.

It is perhaps a sign of the maturity of robotic space technology that the traditional divide between ground and space segment is, perhaps most notably disappearing when discussing ground station system architectures. An example of this is NASA's Space Network (SN) project established in the early 1980s to replace NASAs worldwide network of ground tracking stations. SN provides communications support to Earth orbiting spacecraft, such as the International Space Station, using both a traditional ground segment and a space segment, through geostationary Tracking and Data Relay Satellites (TDRS). SN can provide tracking and data acquisition services over 100 % of a spacecraft's orbit for altitudes between 73 and 3,000 km. The SN architecture is shown in Fig. 2.7, where it is seen that the traditional ground-segment is, in effect, being extended into the space segment. Note the proposed European Data Relay Satellite (EDRS) system, also mentioned in Chap. 1, is a further example of this type of extension.

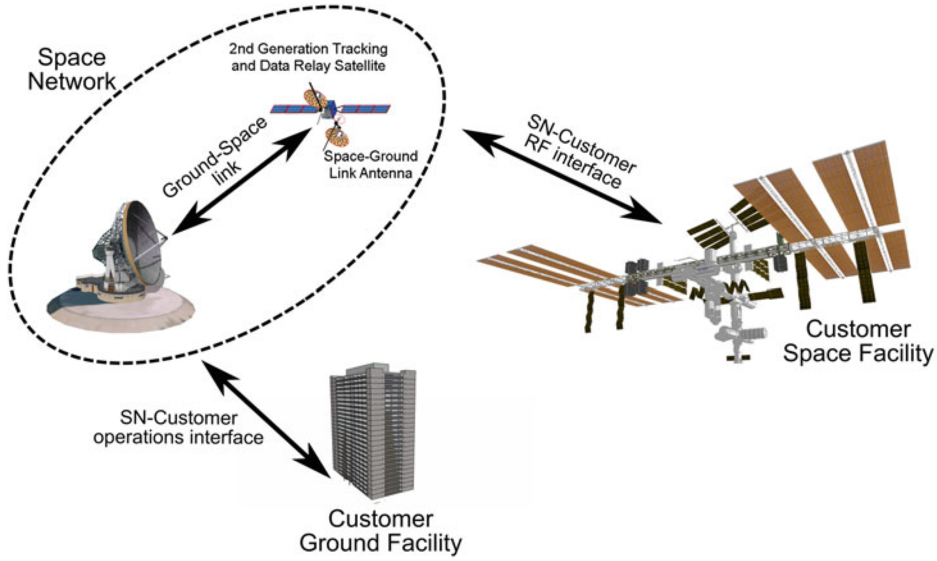

Fig. 2.7 Space network customer and operations interface. *Image* Malcolm Macdonald

2.2.2 Operations

The operation of a spacecraft is often the only part of the space system which directly involves humans, other than of course human space flight. The operations team is the fundamental human element, integrating the system and the mission. Success will often depend on the quality of this team. As such, the operations team will develop carefully considered and detailed operations procedures, documents and manuals, and will train ahead of launch using an operations simulator. The operations simulator will also be used in-flight to check spacecraft commands prior to actually sending them to the spacecraft. The operations team of the Mercury Sigma-7 spacecraft is seen in Fig. 2.8, training in the control room prior to launch. Meanwhile, the operations team of CryoSat-2 is similarly seen in training almost 50 years later in the same figure. It should also be noted that the operations team extends significantly beyond the control room, to include support and specialist engineers, scientists and technologists, hardware and software support as well as general project, site and administrative support.

2.2.3 Two-Line Elements

A key objective of the ground segment is to determine the orbital ephemeris of the spacecraft. The Keplerian orbital parameters, see Chap. 4, can be encoded in a number of formats, but the most commonly used is the NORAD (North American Aerospace Defense Command) 'Two-Line Element', TLE, format due to its concise nature. The orbital ephemeris of many thousands of space objects, including both active spacecraft and orbital debris, is determined by NORAD, and freely distributed via the Internet in the form of TLEs.[2] Two-Line Elements can easily be automatically retrieved for use in spacecraft trajectory simulation software. A sample TLE is shown in Table 2.1, where it is seen that the TLE consists of a title, followed by two lines of formatted text. From Table 2.1 it is seen that the International Space Station is in an orbit inclined 51.6° to the equator, completing 15.7 revolutions per day in a virtually circular path. Note that the BSTAR term in column 54 of line one of the TLE is an adjusted value of the ballistic coefficient, see Chap. 4, where the ballistic coefficient is multiplied by half of a reference value of atmospheric density.

2.3 Space Project Planning, Implementation and Technology

The space project begins with a set of top-level objectives, for example, the GOCE mission, launched in March 2009, had the objective to measure the Earth's gravity field, and model the geoid with an unprecedented accuracy and spatial resolution. The mission analysis and design process then defines the space system, considering system and technology constraints, to define measurable mission objectives and metrics that can be achieved within the ultimate mission constraint of cost.

Several tools, methodologies and standards are available to the space system engineer to facilitate the process of mission analysis, design and technology assessment. Some of these are introduced here.

[2] See http://celestrak.com/.

Fig. 2.8 View of mercury control center, September 10, 1962, prior to the Mercury-Atlas-8 (MA-8) flight of the Sigma-7 (*top*; Photo IDs: S62-05139 and KSC-62PC-128), and the CryoSat-2 Mission Control Team in Main Control Room ESA-ESOC, December 8, 2009 (*bottom*; ID Number: SEMTLKOJH4G). *Image* NASA and ESA

2.3.1 ECSS: European Cooperation for Space Standardization

The European Cooperation for Space Standardization (ECSS),[3] was established in 1993 to develop a coherent and definitive set of standards for use in all European space activities. Despite being intended as a European initiative, ECSS has gained a global importance and provides an excellent resource for the development of good practice. The ECSS standards are typically mandated for use in ESA missions and users are encouraged to provide feedback on usage to ensure the standards remain 'live' documents.

The ECSS documentation architecture contains three branches, these are 'Management', 'Product Assurance' and 'Engineering', each of which contains a subset of standard documents split into four hierarchical levels, defined to the detail level of detail required to differentiate major functions, disciplines and activities. These four levels are defined as

- *Level 0 (ECSS-P-00)*—describes the policy and objectives of the ECSS system and its architecture together with the principal rules for the creation, validation and maintenance of documents.
- *Level 1 (ECSS-M-00, ECSS-Q-00, ECSS-E-00)*—describes the strategy in the specific domain, gives a global view of the requirements, and outlines the interfaces between the elements (and the documents) at Level 2.
- *Level 2 (ECSS-M-10, ECSS-Q-10 …)*—describes the required objectives and functions for all aspects in the individual domain (project organization, quality assurance, system engineering, etc.).

[3] See www.ecss.nl.

Table 2.1 The TLE of the International Space Station on April 4 (day 94), 2011

International Space Station Two-Line Element			
ISS (ZARYA)			
1 25544U 98067A 11094.38711506 .00060886 00000-0 44580-3 0 1260			
2 25544 51.6466 179.6373 0002360 82.3471 6.0048 15.72587753709286			
Column	**Characters**	**Description**	**Example**
Title Line			
1	24	Satellite Name	ISS (ZARYA)
LINE 1			
1	1	Line No. Identification	1
3	5	Catalog No.	25544
8	1	Security Classification	U
10	2	International Identification (last two digits of launch year)	98
12	3	International Identification (launch number of year)	067
15	3	International Identification (piece of launch)	A
19	2	Epoch year (last two digits of)	11
21	12	Epoch day (day of year and fraction of day)	094.38711506
34	10	First time derivative of mean motion, divided by two	.00060886
45	8	Second time derivative of mean motion divided by six, decimal point assumed	00000-0
54	8	BSTAR drag term, decimal point assumed	44580-3
63	1	'Ephemeris type', now just the number 0	0
65	4	Element number	126
69	1	Checksum (modulo 10)	0
LINE 2			
1	1	Line No. Identification	2
3	5	Catalog No.	25544
9	8	Inclination	51.6466
18	8	Right Ascension of Ascending Node	179.6373
27	7	Eccentricity with assumed leading decimal	0002360
35	8	Argument of the Perigee	82.3471
44	8	Mean Anomaly	6.0048
53	11	Revolutions per Day (Mean Motion)	15.72587753
64	5	Revolution Number at Epoch	70928
69	1	Check Sum Modulo 10	6

- *Level 3*—describes methods, procedures and recommended tools to achieve the requirements of Level 2 documents. In addition, it defines the constraints and requirements for interfaces, and the performance of the specified product or activity. The Level 3 documents are guidelines and are allowed to be adapted to the needs of a project.

2.3.2 Project Phasing

The ECSS divides the space mission project life cycle into seven phases; these are defined in Table 2.2 alongside the equivalent six NASA phase definitions. It should be noted that other established space institutions, such as the US Department of Defense, often use their own project life cycle phasing.

Each project phase is associated with certain activities and project milestones, typically in the form of project reviews, which will also likely be payment milestones. The basic activities during each mission phase are illustrated in Fig. 2.9, where the ECSS-defined milestones are given alongside additional NASA-defined milestones. Note from Fig. 2.9 that on occasion the same review will be given a different name by ECSS and NASA. A detailed description of each mission phase can be found in the ECSS documentation;

Table 2.2 Space mission project life cycle phases as defined by ECSS and NASA

Phase ID		Phase name	
ECSS	NASA	ECSS	NASA
0	Pre-A	Mission analysis/needs analysis	Advanced studies
A	A	Feasibility	Preliminary analysis
B	B	Preliminary design	Definition
C	C	Detailed design	Design
D	D	Qualification and production	Development
E	E	Utilization	Operations
F		Disposal	

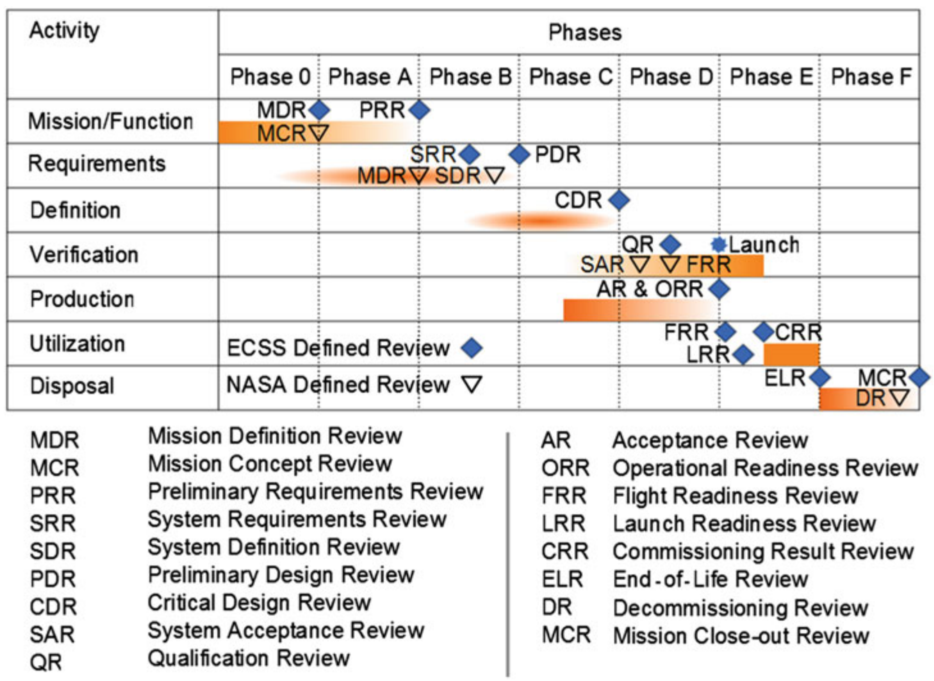

Fig. 2.9 A typical space mission life cycle with ECSS and NASA defined milestones. *Image* Malcolm Macdonald

see ECSS-M-ST-10C Rev. 1, “Project planning and implementation”, and will be discussed in more detail in Chap. 7.

2.3.3 TRL: Technology Readiness Level

The concept of ‘Technology readiness level’ (TRL), is used widely in aerospace to assess and define the maturity of a technical concept, capability or product. Nine technology readiness levels are defined and shown in Fig. 2.10, along with a more detailed, but NASA-centric, tabular definition in Table 21.1.

The technology readiness levels can be defined further as

TRL 1. *Basic principles observed and reported*: Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

TRL 2. *Technology concept and/or application formulated*: Applied research. Theory and scientific principles are focused on a specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

TRL 3. *Analytical and experimental critical function and/or characteristic proof-of concept*: Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.

TRL 4. *Component/subsystem validation in laboratory environment*: Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.

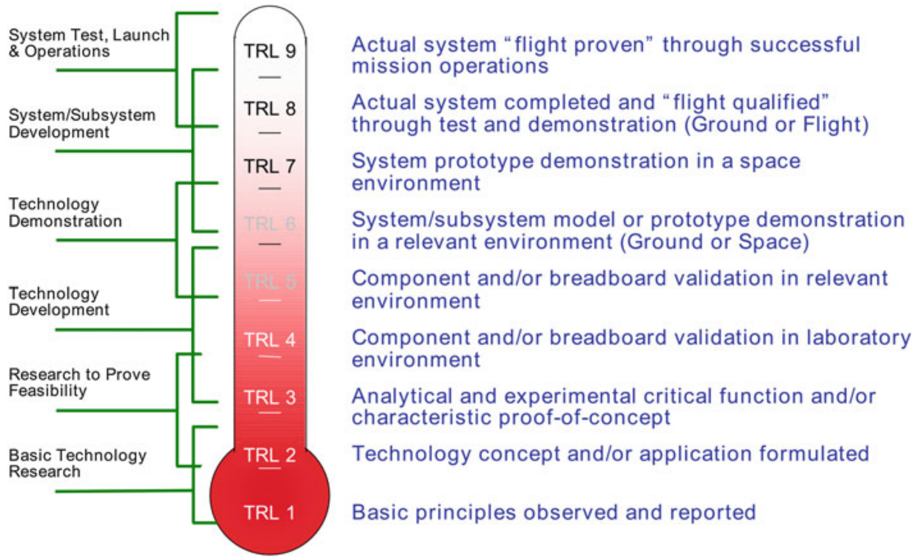

Fig. 2.10 The technology readiness level (TRL), barometer. *Image* NASA

TRL 5. *System/subsystem/component validation in relevant environment*: Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.

TRL 6. *System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space)*: Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.

TRL 7. *System prototyping demonstration in an operational environment (ground or space)*: System is at or near scale of the operational system, with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited user documentation available.

TRL 8. *Actual system completed and 'mission qualified' through test and demonstration in an operational environment (ground or space)*: End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.

TRL 9. *Actual system 'mission proven' through successful mission operations (ground or space)*: Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

Understanding the TRL of a technology is critical to understanding the risk associated with that technology and, as such, an accurate assessment of a technology's TRL is a critical part of the mission analysis and design process. The application of TRLs to technology management will be discussed in Chap. 21.

2.3.4 AD^2: Advancement Degree of Difficulty

It was recognized within NASA when the TRL granularity was expanded from seven to nine levels in the mid-1990s that TRLs give an incomplete understanding of the technical concept, capability or product being assessed. As such in 1998 John Mankins, who had developed the increased TRL granularity proposed a 'Research and Development Degree of Difficulty', R&D^3, system as "*a measure of how much difficulty is expected to be encountered in the maturation of a particular technology*" [1]. Within the R&D^3 system five levels of difficulty were defined, giving the probability of success with 'normal' levels of research and development effort as between 20 and 99 %. Although the TRL concept is today widely used, the R&D^3 system was never widely adopted or used.

Using the core principles of the R&D^3 system, the 'Advancement Degree of Difficulty' (AD^2), system was proposed in 2002 [2], focusing on the issues with the development and incorporation of new technologies into a space systems. As a result, the AD^2 system provides nine levels of risk, from 0 to 100 %, associated with the advancement of a technology from one TRL to the next, as shown in Fig. 2.11. Only by combining TRL and AD^2, or some similar assessment, can a complete understanding be gained of the maturity and applicability of a technical concept, capability or product.

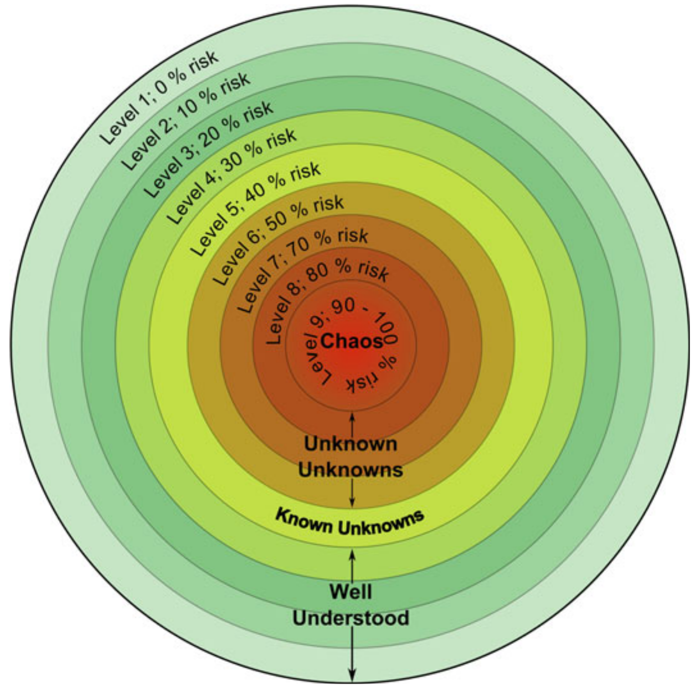

Fig. 2.11 Advancement degree of difficulty (AD^2), levels of risk. *Image* Malcolm Macdonald

The AD^2 can be defined further as

Level 1. Exists with no or only minor modifications being required. A single development approach is adequate.

Level 2. Exists but requires major modifications. A single development approach is adequate.

Level 3. Requires new development well within the experience base. A single development approach is adequate.

Level 4. Requires new development but similarity to existing experience is sufficient to warrant comparison across the board. A single development approach can be taken with a high degree of confidence for success.

Level 5. Requires new development but similarity to existing experience is sufficient to warrant comparison in all critical areas. Dual development approaches should be pursued to provide a high degree of confidence for success.

Level 6. Requires new development but similarity to existing experience is sufficient to warrant comparison on only a subset of critical areas. Dual development approaches should be pursued in order to achieve a moderate degree of confidence for success. Desired performance can be achieved in subsequent block upgrades with a high degree of confidence.

Level 7. Requires new development but similarity to existing experience is sufficient to warrant comparison in only a subset of critical areas. Multiple development routes must be pursued.

Level 8. Requires new development where similarity to existing experience base can be defined only in the broadest sense. Multiple development routes must be pursued.

Level 9. Requires new development outside of any existing experience base. No viable approaches exist that can be pursued with any degree of confidence. Basic research in key areas needed before feasible approaches can be defined.

2.3.5 ITAR: International Traffic in Arms Regulations

A further issue to consider in the availability of technology, especially for technologists outside the USA is the impact of the 1976 Arms Export Control Act of the US government, which gives the President of the United States the authority to control the import and export of defense articles and services. The provisions of this act are implemented within International Traffic in Arms Regulations, often termed simply ITAR. ITAR dictates that items on the United States Munitions List (USML) are export-restricted items. USML items are subject to change and re-interpretation. For example, following the February 1996 launch failure of the Long March-3B carrying Intelsat-708, which contained sophisticated communications and encryption technology, several parts of the spacecraft debris were never recovered by the satellite's American developers. This led to the suggestion that debris may have been recovered by the government of the People's Republic of China, with

Intelsat and the Clinton administration suffering domestic criticism for possibly allowing technology transfer to China. Following an investigation by the US Congress, in 2002 the United States Department of State charged Hughes Electronics and Boeing Satellite Systems with export control violations in relation to the failed launch of Intelsat-708 and the prior failed launch of the APSTAR-II satellite. As a result, space technology become subject to scrutiny within the ITAR framework.

The goal of ITAR is to limit arms proliferation, safeguard the national security of the US and further its government's foreign policy objectives. However, the selection of USML items can have significant adverse programmatic effects for space programs outside the USA, limiting, for example, launch vehicle options or even the end-customers access to the purchased system. As such, 'ITAR-free' components, sub-systems or even platforms are a major selling point for commercial components, sub-systems, systems and platforms in Europe and beyond.

The impact of ITAR was a reduction of the US share of the commercial spacecraft production market from 83 % in 1999, when the State Department took over the export regulation of spacecraft, to 50 % in 2008 [3]; moreover, European manufacturers wherever possible avoid the use of ITAR (and hence US) components. In 2010, the US Congress requested an assessment of the risks of removing spacecraft and their components from the USML. The study, known as the 1,248 report, was completed in April 2012. In late 2012, the US Congress passed the fiscal 2013 defense authorization bill, which allows the president to remove commercial spacecraft and there components from the USML. It also allows him to decide which satellite technologies are the most important to protect while continuing to restricts export to China, Cuba, Iran, North Korea, Sudan, and Syria. The impact of this change, along with the effectiveness of its implementation, will take a number of years to assess.

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