

Operations Planning for the International Space Station

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Introduction

As a consequence of the ISS's long operational lifetime, the mission planning process is being performed in several distinct steps - Strategic, Tactical and Execution Planning - with distinct planning products covering different time intervals ranging from several years to just a few days. It has to take into account lead-time constraints imposed by the launch vehicles and the time scales needed to develop new equipment, which may begin several years before the in-orbit operations are performed although detailed schedules may not be

development of ESA-specific plans and products, though the multilateral teams still control the way in which some of them are developed and integrated.

To avoid unnecessary complexity, this article focuses on the planning processes after the completion of ISS assembly.

Multi-Increment and Strategic Planning

The Multi-Increment and Strategic Planning covers a five-year period. The Multi-Increment Planning Integrated Product Team (MIP IPT) and the Utilisation Operations Panel in which ESA will have direct representation, develop the Operations Summary and its Addendum, which provide the system-related projections of the ISS resources and flight manifests for the coming 5 years. This document serves as an input for two parallel processes with ESA participation: (a) development of the Composite Operations Plan (COP), which covers the ISS system and servicing aspects; and (b) development of the various Partner's utilisation plans, which will then be consolidated by the Utilisation Operations Panel into the Composite Utilisation Plan (CUP). The COP and CUP will provide the Utilisation Operations Panel with the necessary input for the development of the Consolidated Operations and Utilisation Plan (COUP), which constitutes the end-product of the annual strategic planning cycle. It provides the annually-based data upon resources and their share for each Partner, payload list and accommodation, non-routine operations and maintenance, support services, and direction/guidance for the execution.

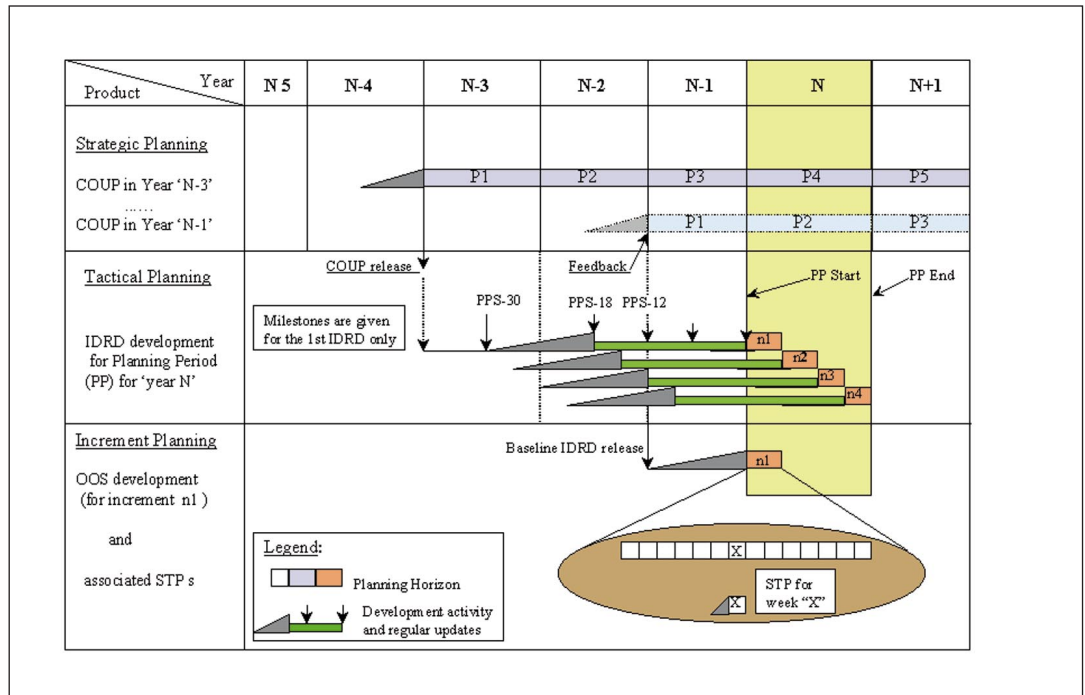
Each year the new period 'P5' will be added and the period of the previous year 'P1' will be removed. Details for years 'P4' and 'P3' details will be refined, while the data for 'P2' and 'P1', which are the years closest to execution, merely reflect information provided by the tactical planners who provide the strategic planners with visibility and feedback on their implementation of the COUP (Fig. 1). The

The planning process for the decade-long operation of the International Space Station (ISS) has to take into account the unique characteristics of this endeavour with its five International Partners: the USA (NASA), Russia (RSA), Japan (NASDA), Canada (CSA) and Europe (ESA). Each Partner is providing at least one space-segment element and will operate it quite independently within an agreed resource envelope. Each Partner, apart from Canada, will also provide an Earth-to-orbit vehicle for Space Station re-supply and logistics operations. The major European contributions are the Columbus Orbital Facility (COF) and the Automated Transfer Vehicle (ATV) launched by Ariane-5.

developed until just a few days before the equipment is operated. The relatively high degree of independence of each of the International Partners means that the planning process has a strongly decentralised component which drives the implementation.

ESA's own ISS operations planning activities are performed in two distinctly different modes. During both the Strategic and Tactical Planning process, they are generally subservient to those of the various multilateral teams - cadres of personnel from each of the International Partners - who develop high-level annual and increment details and plans from information supplied by the Partners. During the Increment Planning (also referred to as Execution Planning) process and the Operations Evaluation process, however, ESA's activities are far more independent and result in the

Figure 1. Generic template for the planning products and milestones in preparation of operations during 'year N'



COUP is the key input document for the Tactical Planning.

Tactical Planning

Tactical Planning (TP) covers a period of approximately one year, generally from the first manned launch in the calendar year until the first launch of the next calendar year. This planning period will generally encompass four increments, each of which is defined as the time between two launches with crew exchanges. Unmanned launch vehicles are covered within the increment.

Integrated Tactical Planning is performed by the Tactical Planning Integrated Product Team (IPT). The formal planning activities start 30 months before the planning period start (PPS-30), which is 6 months after the annual COUP release.

It is on the basis of these COUP requirements that the appropriate International Partner entities provide their proposals according to their flight-element and user needs. The breakdown of the annual resources into resource allocations per increment and per individual payload has to be performed. Based on the Partners' inputs, the Tactical Planning IPT will then develop the main planning product, the Increment Definition and Requirements Documents (IDRD). The latter is baselined in two iterations, the Preliminary Planning Period IDR released at PPS-24 months and, after review by the International Partners, the first release of the Baseline Planning Period IDR at PPS-18 months (Fig. 1).

Each IDRD serves two purposes:

- (a) As input to the Increment Planning, it defines for its specific increment mission operations and utilisation objectives, the top-level cargo manifest (up-/down-loads), payload complement, accommodation and resource allocations, crew rotation and training plan and in-orbit maintenance.
- (b) In addition, a set of summary documents is provided which are used to inform the strategic-level planners about what has been planned for Years 1 and 2 of the upcoming COUP, and the degree to which these IDRDs have met the previous COUP's requirements.

For ESA these activities are primarily performed by the tactical planners of the Mission Management Team, with support from the COF and ATV engineering organisations, the Payload Integration, Payload Operations and the Utilisation teams. During the period PPS-30 months to PPS-24 months, the Mission Management Team has the task of breaking down the annual resources allocated to ESA into resource allocations per increment and payload. To perform this efficiently, a Resource Assignment tool (RAS) has been integrated into the Mission Management Support Tools (MMST). Two other MMST integrated tools, the Tactical Parameter Data Collection System (TPDCS) and the Engineering and Logistic Data Collection System (ELDCS), serve to collect from the various European operations teams the following data sets for each increment of this planning period:

- (a) projected COF accommodations, resources and services for each increment

- (b) utilisation requirements such as payload objectives, manifesting requirements, on board placement requirements, campaign requirements, high-level operations and resource requirements
- (c) COF logistics and maintenance requirements
- (d) COF system corrective and preventive maintenance requirements.

Data set (a) is provided to the Tactical Planning IPT early in this period since it is needed to generate the initial increment resource and accommodation allocations to Partners. In addition, the TP IPT generates the initial service allocation per Partner, in particular re-supply/return allocations.

Based on these initial allocations, the tactical planners of the Mission Management Team select from data sets (b), (c) and (d) a compatible set of system and utilisation requirements for each increment in the planning period and submit these data to the TP IPT. The data exchange between the ESA MMST and the NASA Tactical Planning System (TPS in Fig. 7) is performed electronically.

Having received these data from each Partner, the TP IPT develops the Preliminary Planning Period IDR and releases this for review by the Partners via TPS. The Mission Management Team coordinates the ESA review, which involves each of the teams mentioned above. Discrepancies are negotiated and resolved between the ESA Mission Management Team and the TP IPT, which then develops the Baseline Planning Period IDR, which will be updated every 6 months if required. As the tactical planning period covers several increments, the maturity of the data for later increments in the period will usually increase with the release of later updates to the IDR. Besides the already-mentioned feedback to the strategic-level planners, this IDR provides the basic input for the Increment Planning as described below.

Increment Planning

The purpose of Increment Planning is to develop increment-specific operations products and the associated information necessary to prepare and conduct real-time operations. The information generated through this process is exploited by users, International Partners, sponsors, flight crews, ground controllers, ground processing, training, and management to plan the preparation and execution of an increment and to help make management decisions. Ground rules and constraints define the boundaries of the planning process. They include rules for crew

scheduling, resource distribution and management, Extra-Vehicular Activity (EVA) planning, trajectory planning, robotics operations planning, and integrated Earth-to-Orbit Vehicle (ETO) joint operations.

Planning as defined for the International Space Station, and in particular for the Columbus Orbital Facility (COF), is based on a distributed hierarchical concept with participants such as the Space Station Control Centre, the Payload Operations Integration Centre and other Partner centres. Each Partner in the Space Station Programme is considered a single planning entity, distributed geographically, tasked to integrate and plan their respective Partner element activities and resource utilisation. A so-called international Increment Execute Planning Team (IEPT) is formed to perform these tasks in a geographically distributed manner. The planning concept reflects a bottom-up integration of plans (Fig. 2). Finally, all plans are integrated into a Space-Station-wide set of products reflecting the operations activities carried out during an increment. Planning for the COF has to consider and reflect the sharing of resources within the COF between US and European payloads, and therefore the role of a planning entity changes.

Planning is divided into two major planning phases: the pre-increment planning phase and planning during the increment. The former develops an overview of all activities carried out during the increment and considers resource utilisation for the most critical resources on-board. Planning during the increment details portions of the increment further, usually one or two weeks, and therefore develops more detailed plans and schedules. The main products that characterise the outputs of these phases are the On-Orbit Operations Plan (OOS) and the Short-Term Plans (STP). The OOS gives a listing of activities being performed on a weekly basis, and where necessary on a daily basis. The STP details one week of the OOS and gives a more detailed view of the activities to be carried out during this week. The activities reflected in the STP are categorised into those to be carried out within the week, those to be carried out on a particular day of the week, and those that are scheduled to start at a particular time of the week. The short-term planning therefore combines operational flexibility and traditional timelining of operations activities into one single plan.

During the pre-increment planning phase, only a small subset of the Space Station's total resources are considered. The international Increment Execute Planning Team (IEPT) is responsible for determining which resources

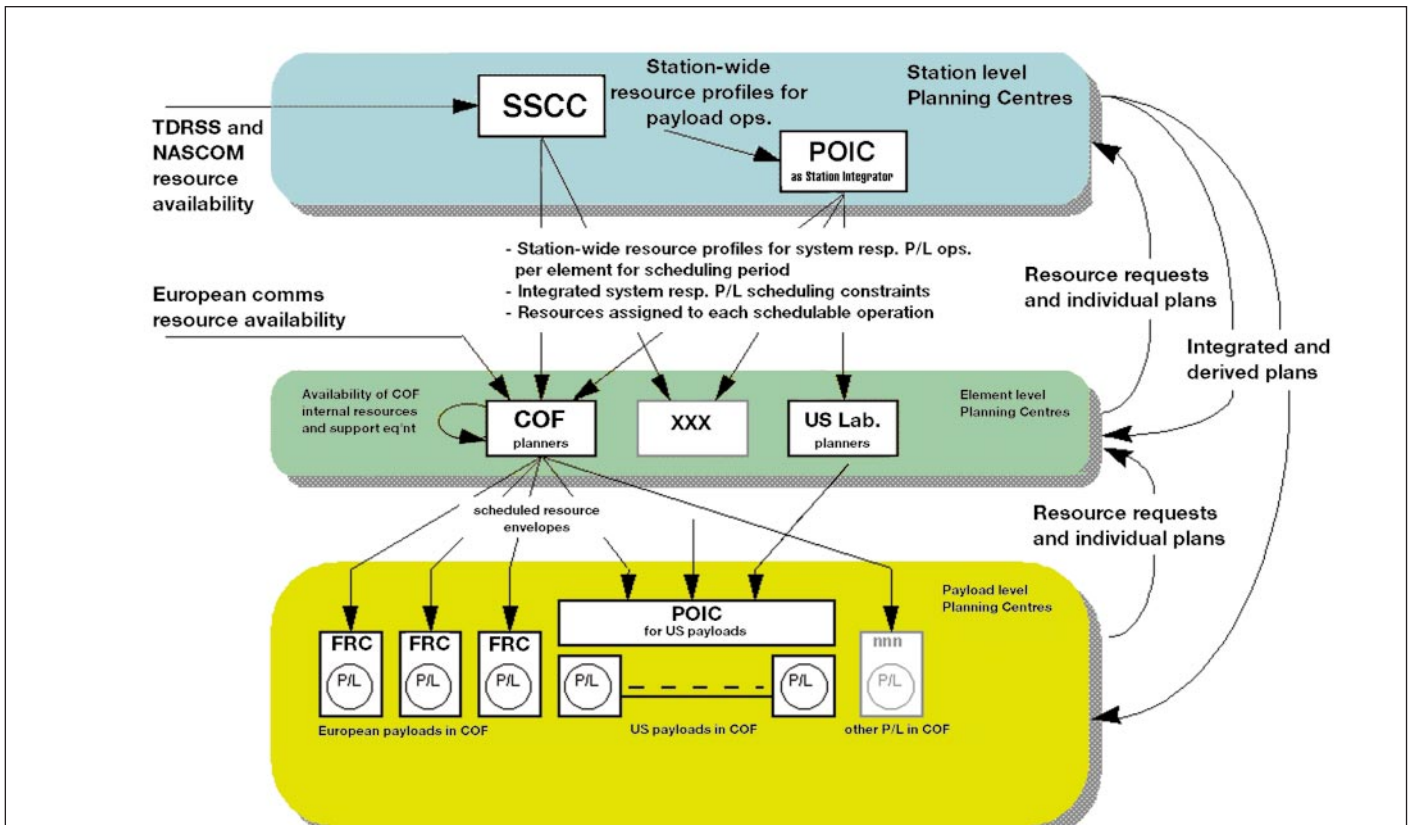


Figure 2. Execution Planning

are considered during this planning process, namely those resources whose availability can be predicted in the pre-increment time frame. Prior research has shown that crew time, power and communications are the major resources that are predictable, as they depend primarily on vehicle configuration (number of crew onboard, number of operational solar arrays, etc.). Another reason for limiting the number of resources considered pre-increment is that only a few resources truly constrain the planning and scheduling of onboard activities. For example, crew time is a very limited resource that is needed for many onboard activities.

Inputs to the Increment Planning Process

Increment planning begins with the increment- and flight-specific requirements, guidelines, and resource allocations documented in the Increment Definition and Requirements Document (IDRD), Mission Integration Plans (MIPs), and Generic Planning Groundrules and Constraints Document, Station Programme Implementation Plan, Programme Planning and Manifesting, and operations requirements specifications. These planning data inputs are needed to develop the various operations planning products. An example of resource allocations as reflected in the IDRD is shown in Figure 3.

Outputs of the Increment Planning Process

The major end-products of the Increment Planning process are the Joint Operations Plans for visiting vehicles (ETOV), the On-orbit

Operations Summary (OOS) and the Short-Term Plans (STP). OOSs are high-level plans that provide a summary of system and payload activities information for the entire increment. The ETOV Joint Operations Plans provide the detailed definition of operations for the period of joint operations described at a high-level in the OOS. Generic Ground Rules and Constraints, Increment and ETOV specific planning rules include specific resource distribution decisions determined in accordance with the resource allocations in the IDRD.

On-orbit Operations Summary (OOS) development

Prior to the development of the Plans identified above, the available resources have to be analysed and considered together with the general and specific rules and constraints. Usually, so-called resource profiles (Fig. 4) are developed which define the boundaries of plan development. These resource profiles define the possible limits for each resource over a defined period of time, which can be the increment itself or a lower granularity similar to the one that the increment plans cover, weeks or days. It is the result of a preliminary plan which covers the whole increment. This plan reflects the sum of resources being consumed by the system and payload activities and might include margins to cover changes and uncertainties. Such a breakdown of resources as defined in the IDRD is shown below, covering an increment of four weeks' duration, taking the share of US payloads into account.

Once the initial plan has been developed, the process of developing the OOS begins. This planning process differs between the Basic and Final OOS development cycles. The Basic cycle is a complete end-to-end generation of data and products. The Final cycle process updates the data and products generated during the Basic cycle. It is less perturbing to planning organisations to simply assimilate updates to planned operations than it is to receive new products which may be completely different from those generated in the previous planning cycle.

For example, the Basic OOS may show that certain systems/payloads operate during certain weeks of the increment. A Final OOS that is an update would likely keep many of those operations planned as they were during

the Basic OOS. A Final OOS that is regenerated may show those operations planned at completely different times. This update philosophy allows planners to minimise the number of changes made from the Basic OOS to the Final OOS, which reduces the impact on users/facilities and operations personnel. An example of an OOS is shown in Figure 5.

Short-Term Plan (STP) development

This process consists of two phases: short-term planning and re-planning. Short-term planning is the process through which the detailed schedule of systems and payload operations activities is developed and the long-range plan of activities throughout the rest of the increment is updated. Plan updating is the process by which the schedule is updated

| CATEGORY/ AGENCY | Accommodations | Energy | Crew | Data |
|---------------------|-------------------|-----------------|---------------------|---------------------------|
| | Rack Locations | Energy (kWh) | Crew Hours (hrs) | TDRSS Ku-Band (hrs) |
| | ISPR # | | | |
| ISS Capability | 20 | 45158 | 1246 | 336 |
| RSA Allocation | 0 | 0 | 534 | 0 |
| System Total | 0 | 15805 | 249 | 118 |
| Utilization Total | 20 | 29353 | 463 | 218 |
| NASA Allocation | 0 | 22484 | 355 | 167 |
| STA Allocation | 10 | 3757 | 59 | 28 |
| CSA Allocation | 0 | 676 | 11 | 5 |
| ESA Allocation | 10 | 2436 | 38 | 18 |
| % of Capability | | | | |
| RSA Allocation | 0% | 0% | 42.9% | 0% |
| System Total | 0% | 35% | 35% | 35% |
| Utilization Total | 100% | 65% | 65% | 65% |
| % of Utilization | | | | |
| NASA | 0% | 76.6% | 76.6% | 76.6% |
| STA | 50% | 12.8% | 12.8% | 12.8% |
| CSA | 0% | 2.3% | 2.3% | 2.3% |
| ESA | 50% | 8.3% | 8.3% | 8.3% |

Figure 3. Resource allocations as reflected in the IDR

| Resources | STP-1 | STP-2 | STP-3 | STP-4 | Increment |
|------------------------------------|---------|---------|---------|---------|-----------|
| COF System Energy (kwh) | 756.32 | 756.32 | 756.32 | 756.32 | 3025.28 |
| COF System Crew (hours) | 12.50 | 0.00 | 3.08 | 0.00 | 15.58 |
| COF System ku-band (IDRD units) | 0.16 | 0.06 | 0.06 | 0.06 | 0.35 |
| COF P/L Total Energy (kwh) | 443.25 | 937.52 | 949.24 | 835.46 | 3165.47 |
| COF P/L Total Crew (hours) | 29.37 | 37.79 | 39.49 | 22.48 | 129.13 |
| COF P/L Total ku-band (IDRD units) | 7.50 | 14.21 | 13.93 | 11.27 | 46.91 |
| COF Total Energy (kwh) | 1199.57 | 1693.84 | 1705.56 | 1591.78 | 6190.75 |
| COF Total Crew (hours) | 41.87 | 34.71 | 41.57 | 19.40 | 137.55 |
| COF Total ku-band (IDRD units) | 7.66 | 13.77 | 13.99 | 10.83 | 46.25 |

Figure 4. Resource profiles

| PLANNING REQUEST | mG | STP-1 | STP-2 | STP-3 | STP-4 | Increment |
|-------------------------------------|----|----------------|----------------|----------------|----------------|----------------|
| SYSTEM | | | | | | |
| VDP Exchange | D | S1 | | | | |
| Video for CHXFA filter exch | | S1 | | | | |
| CSWA Dry-out | | S1 | S1 | S1 | S1 | |
| Inventory Check | | S1 | | S1 | | |
| Energy (kwh) | | 756.32 | 756.32 | 756.32 | 756.32 | 3025.28 |
| Crew (hours) | | 12.50 | 0.00 | 3.08 | 0.00 | 15.58 |
| Ku-band(IDRD units) | | 0.16 | 0.06 | 0.06 | 0.06 | 0.35 |
| ESA BIOLAB | | | | | | |
| Expt Ops 1 | R | | S1 | C | | |
| Video Downlink 1 | R | | S28 | | | |
| Spectro Op 1 | R | | S14 | | | |
| BGB EPU Ops | | | S1 | | | |
| BGB Cell Obs1 | R | | | S1 | | |
| Energy (kwh) | | 67.33 | 145.54 | 146.46 | 123.10 | 482.43 |
| Crew (hours) | | 2.00 | 3.92 | 2.76 | 0.16 | 8.83 |
| Ku-band(IDRD units) | | 0.02 | 1.24 | 0.82 | 0.64 | 2.72 |
| NASA ZCG | | | | | | |
| ZCG Set-up | | | S1 | S1 | S1 | |
| ZCG Install Crystals | | | S1 | S1 | S1 | |
| ZCG Stow Crystals | | | S1 | S1 | S1 | |
| ZCG Growth Run 1 | R | | S1 | | | |
| ZCG Growth w/Data | | | S7 | S7 | S7 | |
| ZCG Monitor Crystals | | | S5 | S5 | S5 | |
| Energy(kwh) | | 0.00 | 46.90 | 46.90 | 46.90 | 140.70 |
| Crew(hours) | | 0.00 | 7.33 | 7.33 | 7.33 | 22.00 |
| ku-band(IDRD units) | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NASA OSMF+AG | | | | | | |
| Antigravity | | | S1 | | S1 | |
| Dosimeters | | | | S1 | | |
| Energy(kwh) | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Crew(hours) | | 0.00 | 3.09 | 1.00 | 3.09 | 7.17 |
| ku-band(IDRD units) | | 0.00 | 0.50 | 0.00 | 0.50 | 1.00 |
| COF Tot Energy (kwh) | | 1199.57 | 1693.84 | 1705.56 | 1591.78 | 6190.75 |
| COF Tot Crew (hours) | | 41.87 | 34.71 | 41.57 | 19.40 | 137.55 |
| COF Tot ku-band (IDRD units) | | 7.66 | 13.77 | 13.99 | 10.83 | 46.25 |

Figure 5. Example of COF On-orbit Operations Summary (OOS)

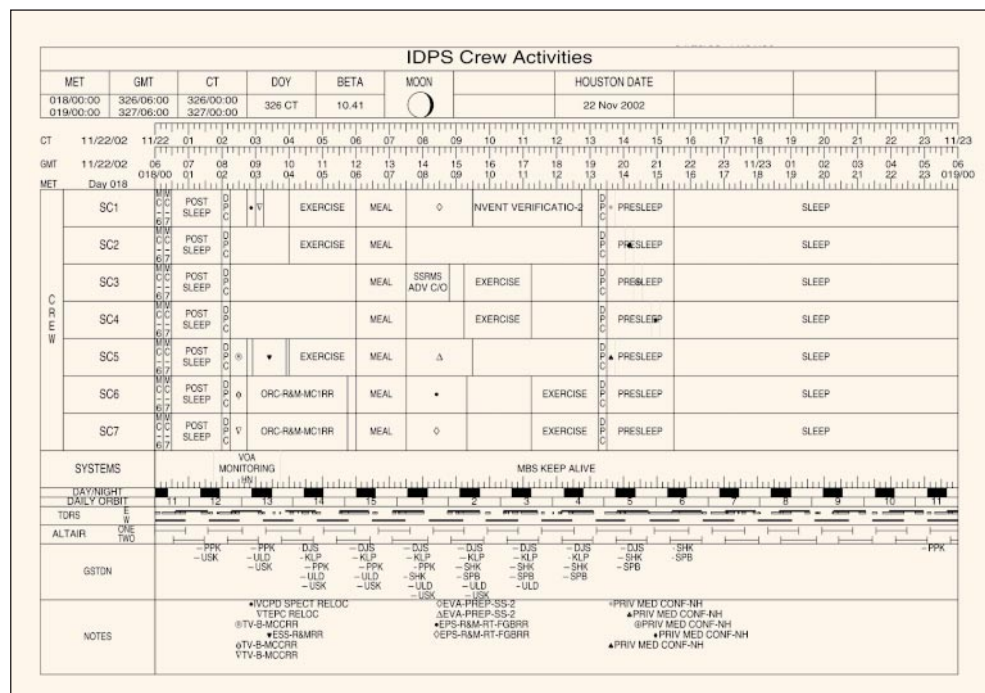


Figure 6. Example of a Short Term Plan (STP)

during operations to reflect desired or required changes to systems or payload operations.

Short-term planning is performed by an international team of systems and payload planners. The detailed schedule developed during this process is used by the ISS crew and the ground controllers to perform the activities defined for the planning period. The long-range plan is used as the basis for generating future detailed plans, and covers the time-frame from the end of the next detailed schedule through to the end of the increment.

Re-planning is performed by the on-console teams in the SSCC, POIC, and Partner Control Centres. The detailed schedule developed during short-term planning is updated by the re-planning process in response to required or desired changes. Updates to the schedule will be performed to maintain a safe and functional ISS, or in response to desired payload operations changes. An example of a Short-Term Plan (STP) is shown in Figure 6.

Implementation

On the Tactical Planning level, the overall configuration of the tools reflects the relative independence of each Partner's domain and, especially in Europe, also the geographically decentralised set-up. As an example, Figure 7 shows the basic principle of the tactical-parameter data collection at NASA and ESA, and the single-channel data exchange across their common interface.

NASA and the Tactical Planning IPT use the Tactical Planning System (TPS) for data collection on NASA's side, for data exchange with the International Partners, and for the dissemination of planning products (IDRDs) to all International Partners. The ESA Mission Management Support Tools (MMST) are the European counterpart to the TPS. With their World Wide Web based user interfaces, the various tools, TPDCS and ELDCS are used to

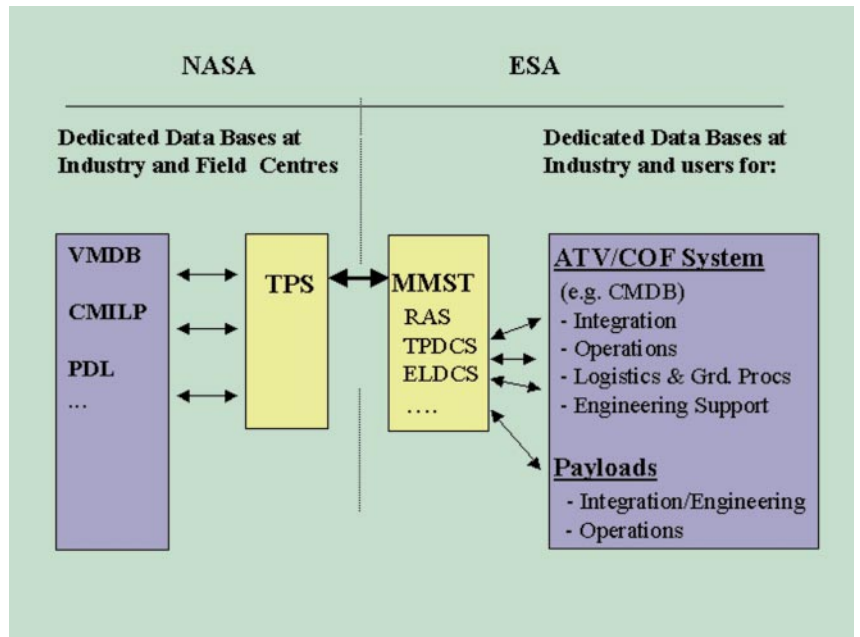


Figure 7. Tactical parameter data collection and exchange between ESA and NASA

collect the necessary data from the various European teams. The single interface between the MMST and the TPS facilitates the exchange of a consistent data set.

The Station-wide plans are developed in an integrated manner by geographically distributed participants using modern communications technologies and tools. The implementation in support of the distributed planning process and the cooperative concept requires a Ground Segment infrastructure utilising the most advanced and modern techniques for information distribution and exchange, to ensure a consistent and coherent information flow between all participants and planning layers. This type of information distribution is based on the principle of 'information casting': all planning participants receive information about their resource requests, such as the relative state with respect to the planning processes, conflicts with other resource requests, indications for conflict resolution and overall resource consumption and usage.

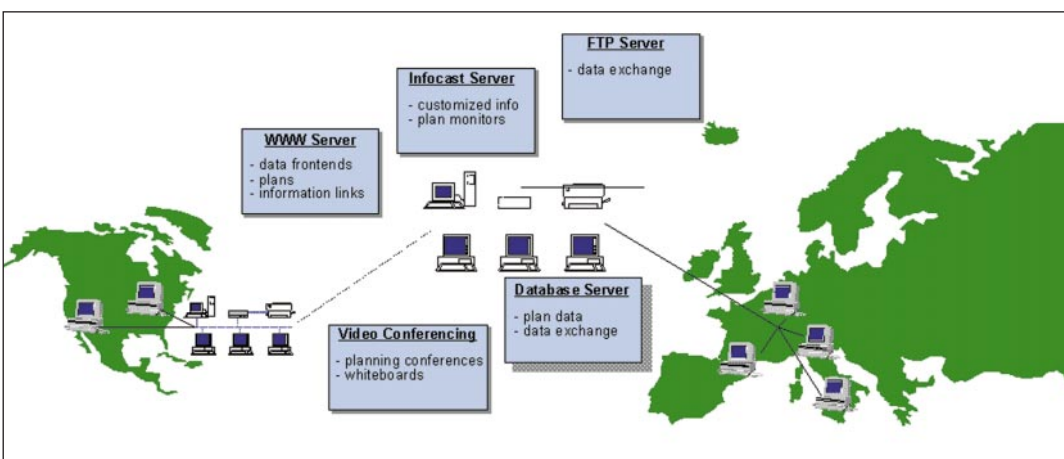


Figure 8. Distributed Planning Environment