Mission Planning On the International Space Station Program. Concepts And Systems.

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Abstract – This paper attempts to identify the current mission planning process on the International Space Station (ISS) program, to examine the lessons learned through experience and to consider ways forward. In order to accomplish this end, the paper begins by reviewing the experience obtained during operations to date and "lessons learned" gained by the author, former co-lead of the Integrated Planning System Team (ISS Program Office), and then describes a planning-centered approach to long duration mission support and discusses several aspects of the planning process at Canadian Space Agency (CSA). The paper focuses on the following items:

- Long duration mission planning. Definition and verification of concept viability.
- MIR, Space Shuttle and ISS programs. Achievements and lessons learned. What can we take from past and current experience to better future projects?
- Mission planning items, classification, hierarchical data model, and resources management.
- Integrated Planning System (IPS).
- Planning a robot component - Mobile Service System (MSS) activity on the ISS program. Latest experience.

The principal result of the work are a planning-centered approach for mission planning on the ISS program and particularly the planning of MSS activity as a robot component on the program. Together with a proven unified operational language (Short Term Plan) and a hierarchical planning data structure which are proposed for usage on both pre-mission stage and real-time mission operations the approach is a workable solution for effective mission planning.

Demand for future mission development has already been realized. Development of a holistic mission planning business model and eventually a global distributed mission planning system based on the proposed concept and planning data structure as well as on up-to-date tools are the next steps.

From a multi-mission program perspective the paper examines key issues and recommends strategies for long duration mission planning to future Mars exploration missions.

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1. Introduction

In preparation for deep space exploration there is an unique opportunity to verify and validate our mission planning concepts, approaches and tools on the ISS program, particularly in the field of Robotics. The initial euphoria of the first operations on-board ISS, in particular Mobile Servicing System (MSS) operations, is now being replaced by more mature expectations of quality for both pre-mission and real-time mission operations that perfectly meet or exceed requirements established by the ISS program (ISSP).

The mission planning process is the core of what is being termed as "manned space mission preparation and support." While conducting mission planning, whatever the nature of the operations may currently be, the following fundamental factors must always be kept in focus:

[1] 0-7803-7651-X/03/$17.00 © 2003 IEEE
[2] IEEEAC paper #1439, Updated December 12, 2002

a) keep and maintain consistency with the ISSP planning processes and established approaches that have been adopted by all International Partners (IPs)

b) harmonize Robotics-related activities (both of pre-mission and real-time mission support) with other IPs.

The viability of the adopted long duration mission planning concept has been demonstrated for more than fifteen years on the ISS program and in the recent past on the MIR program (part of which was called "Phase 1" of the ISS program). The ISSP, in turn, could be considered as an opportunity to assess the feasibility of the human mission to Mars program. For this reason, validation of and "best-of-breed" selection from our established mission planning concepts and approaches is very important.

The planning concept which has been adopted on the ISSP has created "game rules" which are common for all operations on the ISS without exception - whatever the nature of the operation. In other words, the current mission planning process for all on-board activities on ISSP including very specific operations, such as Extravehicular Activity (EVA) and Extravehicular Robotics (EVR) ideally reflect the concept proven on previous space programs.

Unlike previous projects in the manned space mission area, except only the MIR program, the ISS operates on a continuous basis with execution planning, logistics planning, and on-orbit operations occurring simultaneously for long periods of time. Additionally, the unique size and constraints of the station compared to other spacecraft such as the Space Shuttle demand a different approach to both planning and operations. The ISS planning process is very complex, and involves many interfaces and products. Utilizing the results of this planning process for operations as well as translating the results of current operations into future planning is a sophisticated process, in which CSA plays a distinct role. The following sections introduce the overall process, place and role of Robotics planning in the ISS planning hierarchy as well as the major products and activities of each of the four phases of ISS planning that are important aspects of real-time operations.

2. ISSP Planning Terminology

Before discussing the ISS planning process in depth, it is important to be familiar with definitions of some of the terms used extensively in the program.

Mission planning is the process of allocating elementary planning items on a timeline within a given timeframe to satisfy chosen criteria in terms of existing operational constraints.

The elementary planning item in the process is the procedure (or procedure step) with the corresponding resources (which are usually attributes of the procedure) that are required to complete the procedure.

The next higher-level items are:

Increment (I) - a timeframe from the launch of a vehicle rotating ISS crew-members to the undocking of the return vehicle for that crew.

Planning Period (PP) - a period on which much of ISS planning is based. It spans approximately 1 (one) calendar year, but is tied to the beginning and end of ISS increments.

Strategic Planning - long range planning that begins at approximately PP- 5 years (5 years before planning period) and continues through PP-3 (3 years before planning period execution).

Tactical Planning - long range planning that begins at about PP-30 months with development of the PP Increment Definition and Requirements Document (IDRD).

Pre-increment Planning - long range planning that begins at about I-18 months with delivery of the Baseline PP IDRD, and continues until increment launch. This phase is when actual flight and increment products are produced.

Increment Execution - an execution planning which begins with the start of the increment (i.e. launch).

3. Factors Making Planning on ISSP Different

The first factor is product delivery dates. Some products, such as MSS Reconfiguration files developed by the CSA Mission Operations Team and several types of flight software are required for every ISS assembly flight at launch minus (L-) X months. Others, such as the Multilateral Increment Training Plan, which includes the MSS crew training plan, are produced for an entire increment (which usually includes several launches) at Increment minus (I-) Y months. Since an increment can include several flights, the challenge is to synchronize templates and product delivery dates. Harmonization of processes between NASA and IPs, such as CSA's CoFR (Certification of Flight Readiness), NASA's SORR (Station Operations Readiness Review) and NASA's documentation workflow is often a challenge.

The second challenge is international integration. This includes issues such as the language of operations and documentation and the merging of different cultural styles of planning. Integrating governmental programs is, in itself, a significant challenge - not only merging CSA programs with NASA programs, but also merging NASA programs (e.g. ISS and Space Shuttle Programs (SSP)) themselves.

The final area that is a particular challenge to ISS is resource management. Crew time, electrical power, communication time and bandwidth are just some of the resources that are limited for ISS and must be carefully managed in order to achieve ISS program objectives. Many of these resources, such as crew time, also fall under Partner allocation agreements made at both the ISSP and government levels. Planners from all the Partners must work very closely together to optimize resource consumption and ensure that each Partner is receiving appropriate levels of resources over time. It is a well known fact that MSS operations require significant amounts of power and crew time. In other words, the operations are so called "high-rate resource consuming operations". Since assembly operations have the highest priority the illusion of unlimited resource availability for robotics (MSS) operations is created by the fact that the ISS is still being built. Due to the major Robotics operations are currently conducted during Shuttle missions (Shuttle docked to ISS) the operations planning process is currently very similar to SSP planning. Priorities will shift from assembly to maintenance and science over the next two to three years, so there is a need to develop different planning skills and to implement planning approaches appropriate to the evolution of the ISSP.

The Space Shuttle Program is very stable though it has contingency planning templates. An effort is being made to shorten the templates. The ISSP is new and the effort is being placed on establishing more time-conservative templates. Some of the principal differences between the planning approaches on the two programs are presented in the Table 1 below.

SSP	ISSP
Flights for a short time period (about two weeks usually)	Permanent manning flight. Extendable lifecycle. Nominal duration is ~15 years.
Planning is performed using many manual independent processes	Most of manual independent processes (will) have been eliminated due to integrated environment. and replaced with what?
Most decisions are made on the ground with lengthy pre-mission discussions before procedures are executed	Resource management is inherent within the overall planning process for the ISS. Just-in-time planning principles are used because it is the only practical way to deal with the fact "inherited resources/inherited problems" will continue plague advanced planning
The same object (Shuttle) is being controlled by ground segment	MSS as well as ISS itself changes and should be monitored on a daily basis, starting from Acceptance Review

Table 1. SSP planning versus ISSP planning

4. Main Phases and Products on ISSP Planning

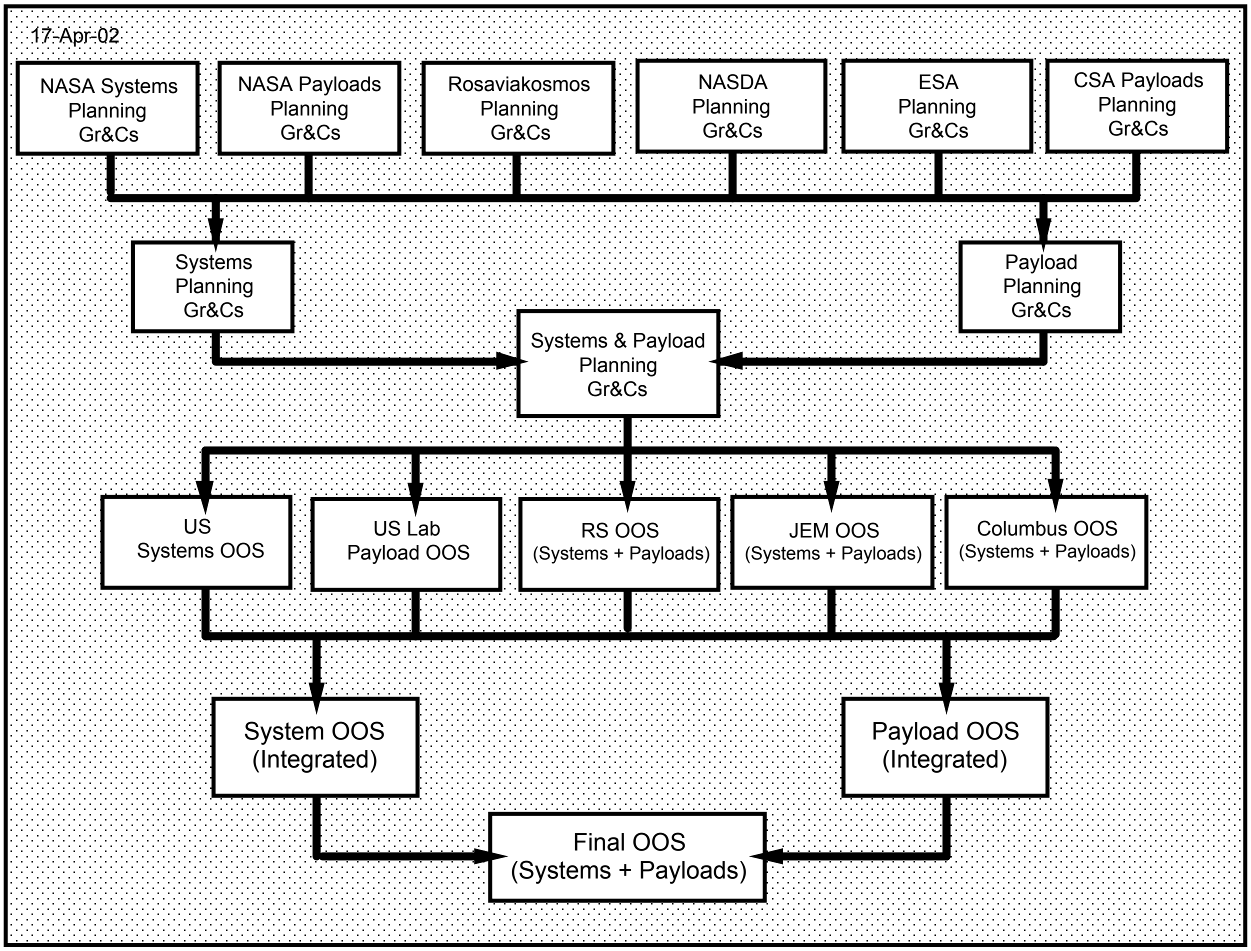
The major planning phases and their respective products are presented in Table 2.

Phase	Product	Comments
Strategic planning	Generic Groundrules, Requirements, and Constraints (GR&C) Part 1: Strategic and Tactical Planning.	Defines generic groundrules and constraints used for program-level planning functions and the generic program-level operations requirements that must be met by the ISS Execute-level organizations.
	Consolidated Operations and Utilization Plan (COUP)	Defines system operations and utilization activities. Establishes the amount of resources and accommodations allocated and subscribed by system and each Partner for utilization.
	Assembly Sequence	The schedule of launches for building and support the ISS.
	Multi-Increment Manifest	Defines traffic and crew rotation plans as well as other key program-level information.
Tactical planning	Increment Definition and Requirements Document	Serves as an internal program agreement on the requirements for the increments. Includes resource allocations, mission priorities, and detailed manifest for each increment and flight.
	Operations and Engineering Feasibility Assessments	Ensures the priorities and objectives of the increments are possible to achieve.
	Payload Integration Agreement	Documents layout the agreements made between the ISS program and its customers.
	Mission Integration Plan	Shuttle Program-to-Station Program agreement.
Pre-increment planning	On-orbit Operations Summary (OOS)	High level activity plan for increment. The activities are planned for a specific day of the increment, but are not for a specific time.
	Flight Rules	Guidelines for real-time decision making.
	Operation Data Files (ODF)	A collection of procedures and reference material required to operate and maintain the ISS systems, payloads and attached vehicles.
Increment execution	Short Term Plan (STP)	The detailed integrated schedule of activities to be performed during 1 (one) week of ISS operations.
	On-board Short Term Plan (OSTP)	The daily updated integrated plan derived from the STP. In addition to scheduled activities contains "Plug-in-Plan" activities, which do not need to be performed at a specific time, but can be performed at the crew's discretion.

Table 2. ISSP planning phases and products

The CSA Mission Operations contribution is affected by most of the products listed on each planning level. The hierarchical planning product tree is presented in Figure 1.

Figure 1. Planning Product Tree (excerpted from Pre-Increment Execute Planning Process Definition Generic April 2002, SSP 50501)



Therefore, the mission planning process on ISSP is a distributed hierarchical process.

The planning products produced in the increment execution phase employ a "just-in-time" development philosophy to ensure the availability of up-to-date plans and to minimize the need for frequent replanning.

5. Planning-Centered Approach and Planning Data

Because execution planning is the lowest level of mission planning on the ISSP, the corresponding planning products (STP and OSTP) represent the lowest level of detailed planning products. A sample of the STP is presented in Figure 2.

The STP, as a detailed planning product, contains all data needed for mission planning and serves as a focal point for crew and ground personnel during pre-mission planning and real-time mission operations.

The STP-specific format represents the common unified language developed and used within the international mission support community.

By adding specific ground segment procedures to the OSTP in the same format as is used by the flight crew, we put all pieces of the planning puzzle together in one place. Moreover, since the prime task of each and every "console position" is to ensure that the crew activities, system configurations, and resource consumption are in accordance with the approved STP/OSTP, we get a powerful performance measurement and reporting tool. Analyzing recorded deviations from the approved timeline in the same STP format would allow CSA to have a unique opportunity to make a high-level performance assessment of the following:

- MSS
- MSS System Operations Data File (SODF)
- MSS operator
- Planning and relative products
- Ground support procedures

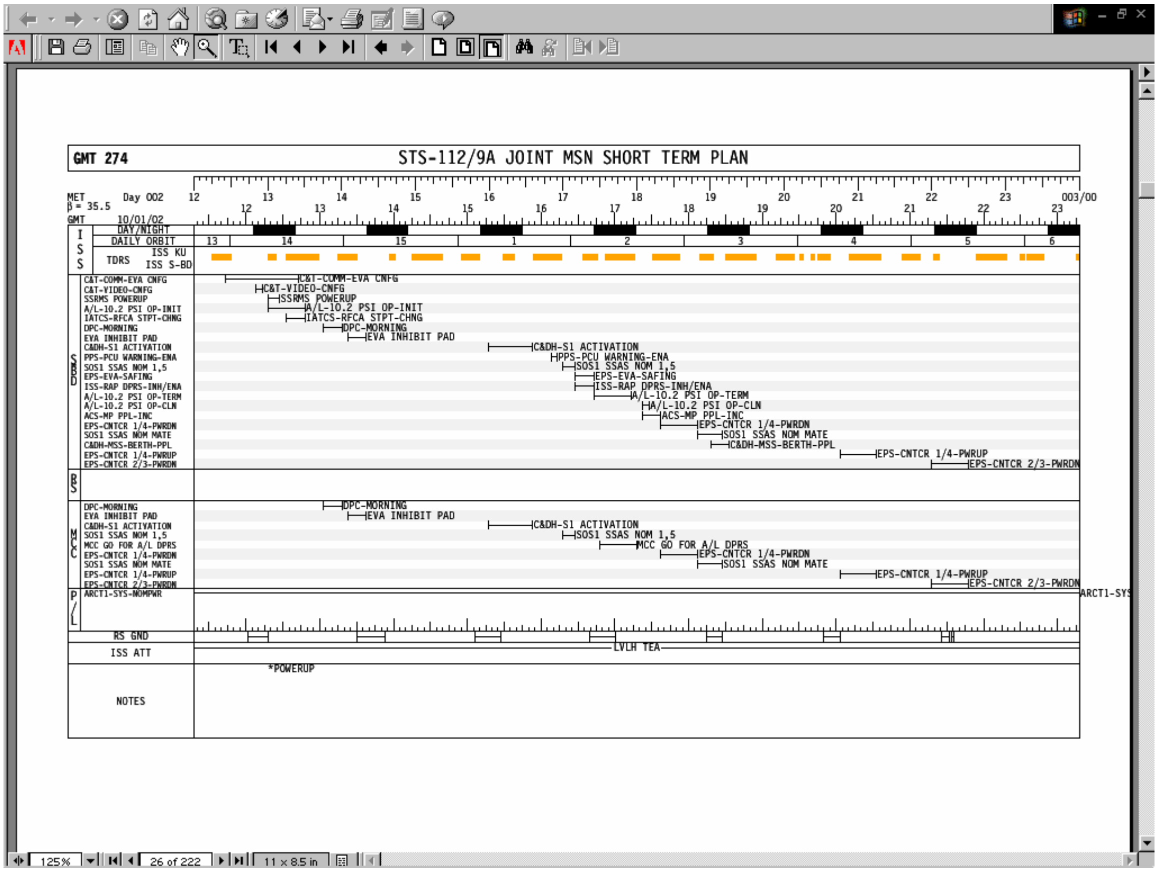
To provide the Robotics community (Training, Planning, and Operations) with feedback, the investigated cases, together with respective corrective actions, would be submitted to the "lessons learned" database, which would serve as both a training and a certification database.
This so called "all-in-one" planning-centered approach proposed by the author to support pre-mission and real-time operations appears as a common approach to develop a unified solution for end-to-end system-level planning on the ISS program as well as on other future programs.
Unlike well-defined planning data such as ISS configuration and attitude, communication coverage, and ballistic information, the ODF (Operations Data File) includes Robotics procedures which are difficult to formalize. Therefore planning data are evolving to achieve the necessary degree of procedure formalization. The nature of the data and respective classifications have been outlined in both working and official documents [1],[3]. SODF procedures are key and elementary planning items. Looking more closely at the MSS Robotics SODF, the following categories of procedures have been established:

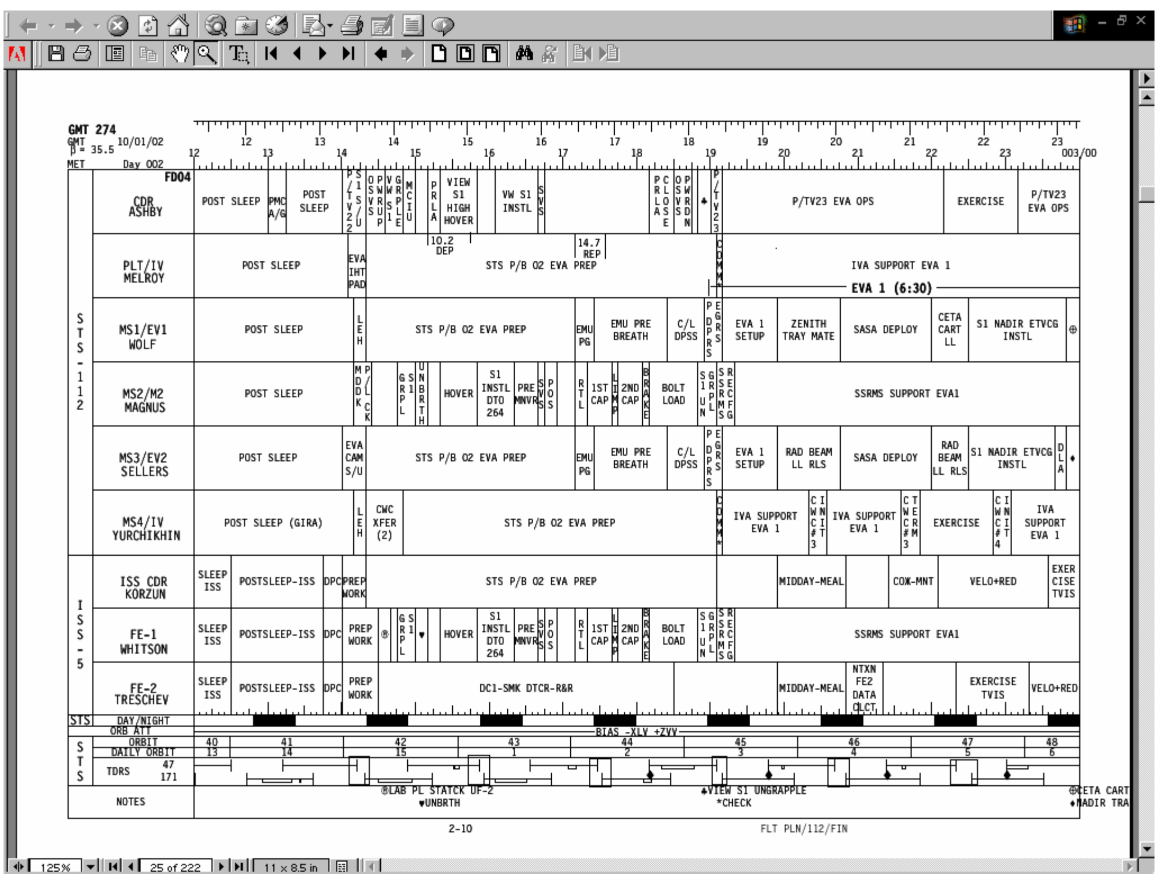
- Activation and Checkout - used for the activation and/or checkout of MSS and its components
- Nominal - used to carry out specific tasks aimed to support ISSP
- Quick Response - used in the event of a failure to quickly safe the system within a very limited amount of time
- Corrective Action - designed to work around or overcome a failure condition
- Reference - includes non-executable ancillary information used to ensure the successful execution of a procedure

The nominal SODF, in its turn, could be categorized as the following:

- Prime procedures - aimed at performing unique ROBO specific tasks (e.g. a truss segment installation)
- Supporting procedures - aimed at supporting another procedure(s) (e.g. docking/undocking viewing
- Dry Run or Test procedures - aimed at verifying/validating a high priority prime Robotics procedure or confirming MSS capability (a new MSS functionality) to complete the procedure
- Performance assessment procedures - aimed at assessing the performance of MSS, MSS operator, and ground processes
- Preventive procedure - acting to defend against or prevent undesirable impacts.

Figure 2. Short Term Plan sample.





Each procedure has been described by a set of its attributes, such as time of completion, required resources, etc.

A procedure can be either stand-alone or a sub-procedure (supporting) which would always be used in conjunction with other (main) procedures. Each procedure has a priority for planning purposes.

All of the SODF attributes the set are necessary in the mission planning process to ensure a high quality final product.

6. The Integrated Planning System.

In order to provide data on resources available, identify conflicts in resource allocation, and distribute Station resources, the Integrated Planning System (IPS) was developed by Lockheed Martin Corporation.

The IPS is an integrated collection of computer applications used for planning and analysis of Space Station operations. The primary users of IPS are flight controllers and planners developing the OOS, STP, and OSTP.

IPS consist of seven major applications:

- Consolidated Planning System (CPS) - used for generation and analysis of both ground and on-orbit activity timelines and plans

- Consolidated Maintenance Inventory Logistics Planning (CMILP) tool - used by ground controllers and planners for onboard inventory tracking, developing Station resupply/return requirements, and for real-time and near real-time support of maintenance operations

- Flight Dynamics Planning and Analysis (FDPA) tool - used by ground controllers and planners to provide high fidelity trajectory, attitude, propellant consumption, and communications coverage analysis

- Procedures Development and Control (PDAC) tool - used by ground controllers to develop and configuration manage operations procedures, develop onboard executable procedures via the Timeliner compiler interface, and distribute procedures electronically

- Resource Utilization Planning and System Models (RUPSM) tool - models the ISS Electrical Power System, Thermal Control System, and Environmental Control and Life Support System (ECLSS) systems

- Robotics Planning System (RPS) - provides software tools to model robotics systems, including both of the MSS and SRMS (Shuttle Remote Manipulator System). RPS is used as a robotics design, analysis, and training tool and provides real-time and near real time robotics operation support

- ISS Mission Operations Directorate (MOD) Avionics Reconfiguration System (IMARS) - IMARS is the central repository for ISS MOD reconfiguration products including MSS reconfiguration files (set of data files which are tailoring the MSS configuration to perform specific tasks on the ISS) and provides the software tools required for processing reconfiguration data. IMARS produces Mission Build Facility (MBF) utilization files of which MSS software executable and reconfiguration files are part.

The IPS is a multi-program support system because it supports both the Space Station and Space Shuttle programs. As an integrated, unified system, the IPS supports all key planning, analysis and real-time functions.

Since the ISS is an international vehicle, inputs to the process are required from all the projects and international Partners as well as from NASA's Marshall Space Flight Centre (MSFC). In order to facilitate the integration of MSFC and IP inputs into IPS processes, IPS hardware and software have been deployed globally and plans are in place for their integration. Therefore, the IPS-based distributed mission planning process serves as the mature prototype to aid in the development of the next generation of mission planning systems.

To identify processes on all mission planning levels and provide consistency with the next generation system development, each Partner has to create his own end-to-end business process model(s).

To produce and deliver MSS reconfiguration files to MBF, a business process model has been developed using ORACLE Designer2000, which is a powerful modeling tool to create business models and system prototypes. The model is a part of the development of the IMPRAS (Integrated Mission Planning and Robotics Analysis System).

Another business model has been developed on the Shuttle Program. It is so called "the one-cycle-to-flight (OCTF) flight preparation template." The OCTF template is the prime flight preparation template and is used as the default template for all Shuttle flights. It is designed to accommodate a training requirement of up to 14 weeks without impact to Space Shuttle Program Office (SSPO) freeze points. When training requirements deviate from the baseline of 14 weeks, the template can be adjusted using standard guidelines as reflected in the corresponding training module, which may result in impacts to SSPO freeze points. The OCTF template consists of a generic one cycle M2P2 (Multi-Mission Production Plan) network, associated modules, and other M2P2 requirements, which all go toward the make up of the generic flight preparation OCTF template is used by the Flight Management and Schedules office (FM&S). This is a tool for flight management, flight scheduling and workstation personnel to understand and manipulate the flight preparation templates.

7. Lessons Learned

There are several lessons learned during ISS operations that deserve special attention. They include:

- The process for correcting on-orbit software on a regular basis imposes a challenge in terms of the overall planning process as well as in management of the software change process.

- The significant amount of time to maintain the space station and its systems is an unavoidable feature of long range mission operations.

- Highly fragmented information flow, so called "islands of information" is a common issue almost everywhere, and space mission operations is not an exception. Without integration, information is confined to individuals and respective systems. System integration remains item #1 in today's "To Do List" to support mission operations at CSA.

8. Conclusion

Canada is establishing itself as a leader in space robotics, and in doing so must establish and maintain a lead position in space Robotics services, such as mission planning and operations. Therefore the following challenges must be overcome:

- Revise and clearly identify goals for the CSA mission operations community in terms of new circumstances - shifting the attainable objectives to a higher level.

- Define and produce MSS end-to-end system-level planning products to be integrated into high level mission planning products (OOS, STP, OSTP) for both Pre-increment planning and Increment Execution phases.

- Identify and develop a format for the system-level planning products which serve as input to the IPS, and, as well, ensure the input is consistent with the IPS.

- Establish regular MSS performance feedback - provide Canadian industry, the scientist community and other stakeholders with direct MSS performance reporting and recommendations on a regular basis.

On the bottom line, there is a need to provide the space community with a well-defined holistic business process for Robotics services based on the ISSP planning concept and up-to-date tools. The business process based on the ISSP planning concept and on the approaches which have been described above could modify the current planning process to meet and exceed ISSP requirements. At the same time a solution as a result of implementation of the business process could serve as a subject of and a starting point for technical discussions on the human mission to Mars program.

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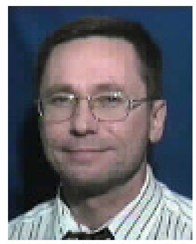

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