VOYAGER UPLINK PLANNING IN THE INTERSTELLAR MISSION ERA

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ABSTRACT

The Voyager Project has entered its last phase of discovery - the Voyager Interstellar Mission (VIM). Because of the reduced scope of the project and a lower budget, new ways had to be developed to program two spacecraft with fewer people, allowing for some sequence development flexibility without additional risk. In the previous cruise era, it took a seven-person sequence team 12 weeks to develop a nominal eight week cruise sequence. Today it takes a three-person team six weeks to develop a 13 week sequence load. This paper will describe in detail the sequencing strategy which reduces the volume and frequency of sequence loads, and the new tools and processes developed which reduce the manual effort required to generate these sequences without adding risk.

KEY WORDS: Uplink Process, Baseline, Overlay, Ground Blocks and Spacecraft Blocks

1. INTRODUCTION

With many successful planetary encounters behind them, the two Voyager spacecraft began a new pilgrimage - the search for the Heliopause, where the sun's bow shock meets the interstellar medium. This last phase of the mission would primarily concentrate on fields, particles and waves experiments, and astronomy observations by the Ultraviolet Spectrometer (the sole inflight UV observatory in its wavelength range). Because these activities are repetitive, less sophisticated, and not as densely packed as encounter activities, the sequence process by which these activities are planned and processed into spacecraft commands could be streamlined. This became a necessity when the decreased VIM budget resulted in reduced Sequence Team staffing. The small team could only develop one spacecraft load at a time, so the development time had to be greatly reduced. New software tools to aid in efficiency had to be developed. The challenge was to define, build and transition to this new uplink system in about a year's time to meet the lower VIM funding.

2. THE "PRE-VIM" UPLINK PROCESS

2.1 The Process Flow

In preparing for the Neptune Encounter, the Voyager Project chose an uplink process similar to those used for previous encounters. This process was comprised of two distinct sequencing strategies and it allowed for the generation of "tailor-made" sequences. One strategy was to develop nominal cruise sequences, typically eight weeks in duration. The other strategy, a twofold plan, was used to build the Neptune Encounter sequences. The first of the two encounter plans budgeted for a lengthy advanced planning stage where a detailed (to the command level) sequence was designed using the latest ephemeris data. It was then implemented, approved and placed "on the shelf". The second encounter plan allowed for updates to the "on the shelf" products to incorporate newer ephemeris data as well as any additions, deletions and/or modifications to encounter sequence activities just prior to uplink. Listed below are the typical durations for each sequencing strategy:

Cruise Sequence Development - 12 weeks
Encounter Advance Planning - 22 weeks
Encounter Updates - 12 weeks

2.2 Sequence Team Workforce

The pre-VIM Sequence Team included a Team Chief and Deputy, and four subteams which included support from seven technical areas to allow for parallel sequence development efforts. This workforce could execute the sequence strategies necessary to build two cruise sequence loads (Voyager-1 & Voyager-2), one advanced planning encounter load and one encounter updates load at the same time.

2.3 Sequence Strategy Success

The success of the Neptune Encounter confirmed the fact that the sequencing strategies used in the preparation of the Voyager Neptune Encounter were effective, sound and complete. Unfortunately, these sequencing strategies were highly labor intensive and would not be suitable for the next phase of the Voyager Project's life span.

3. THE NEW VIM UPLINK PROCESS

3.1 New Mission Objectives

The VIM objectives for both Voyager spacecraft are to investigate the interplanetary and interstellar media and to continue gathering data from the Ultraviolet Spectrometer (UVS), the only operational instrument left on the scan platform.

To accomplish these objectives, the Voyager Project approved a plan to have a series of recurring fields, particles and waves calibrations and digital tape recorder playbacks folded into an "on-board" baseline sequence which would continue to operate on both spacecraft indefinitely, without any required ground intervention. This baseline sequence would also accomplish the necessary activities to maintain spacecraft health and antenna earth pointing. The baseline sequence activity would be augmented by "ground transmitted" overlay sequences of 13 week durations. These overlay sequences would nominally be used for UVS observations, and engineering calibrations.

3.2 Budget Concerns

The VIM staffing budget would only allow for a maximum five-person Sequence Team to accomplish the VIM mission objectives. This meant that there would be no staffing for emergencies, but the quality and completeness of the sequence products could not be sacrificed.

The Voyager Project needed an uplink process which would allow this reduced Sequence Team to continuously produce overlay sequences for both spacecraft, while in parallel, be able to generate unplanned sequences such as heliopause encounter sequences, baseline update sequences or anomaly investigation/corrective-action sequences. In order to meet the 13 week duration criteria for an overlay sequence and allow for unplanned work, this VIM Sequence Team would require a six week sequence development schedule to prevent the overlapping of on-going sequence tasks.

3.3 Assumptions

It was known that during VIM, it would be difficult to acquire seventy meter Deep Space Network (DSN) antenna coverage. In order to limit the number of these requests, the baseline sequence design strategy would require clustering activities with similar DSN telecommunication performance needs. Due to advanced knowledge of baseline sequence activity, other projects would be able to correlate their DSN antenna coverage requirements with key Voyager activities to avoid conflict.

The Project required that no additional operations risk be factored into the new uplink process above that accepted prior to VIM. Fortunately, this requirement could be achieved by (1) continuing to use the Voyager simulation tool, COMSIM, to validate every sequence prior to spacecraft transmission, (2) maintaining the same degree of constraint checking as in the pre-VIM era, and (3) using the overlay sequence to capture baseline sequence playback data lost from weather problems or DSN antenna coverage conflicts.

The Project also mandated that new or updated VIM software programs not be targeted for design and execution on JPL's mainframe UNISYS system unless absolutely unavoidable. Dependance on the institutional mainframe needed to be avoided due to budget, operations and maintenance concerns.

3.4 Implementation Strategies

A VIM uplink process robust enough to comply with the VIM objectives, the budget guidelines and project assumptions, would require major changes in both the spacecraft and ground systems.

3.4.1 Spacecraft System Redesign

The Spacecraft Team led the effort to design a set of eleven on-board software routines (spacecraft blocks) which when called for execution, would be expanded to the command level and sent to the appropriate spacecraft subsystem to perform the intended activity. The Sequence Team engineered the detailed design strategies to build the baseline sequence. Both spacecraft were then reprogrammed to contain (1) all spacecraft blocks, (2) a table of high gain antenna earth pointing information to keep each spacecraft properly pointed for approximately 25 years, (3) the baseline sequence, comprised of a set of repeated activity calls at a specified frequency to designated spacecraft blocks (looping cyclics), and (4) the Backup Mission Load which reduces the complexity of the baseline sequence and allows it to continue if ground commandability is lost.

3.4.2 Uplink Process Redesign

The uplink process is the operation by which science, engineering and navigation requests are translated into spacecraft computer instructions. For details see the process flow diagram shown in *Figure 1*.

There are three phases to developing a sequence: design, implementation and validation. The design phase is where inputs are integrated into a sequence plan. The implementation phase converts the integrated sequence requests into commands, and the validation phase translates the commands into spacecraft computer instructions and simulates the sequence for soundness.

The uplink process for the overlay sequence begins six weeks prior to the execution of the sequence. The first week begins the design phase, devoted to the detailed planning of the sequence. The preliminary sequence requests (SRs), which come from the Science, Spacecraft and Navigation Teams are gathered. These SRs are evaluated and costed for computer words and manual work effort. They are then integrated. A strawman timeline is built showing the most current DSN antenna coverage and all planned activities. A coordination meeting is held to work out any issues or conflicts.

The SRs are finalized and formally approved at the beginning of the second week, which is the start of

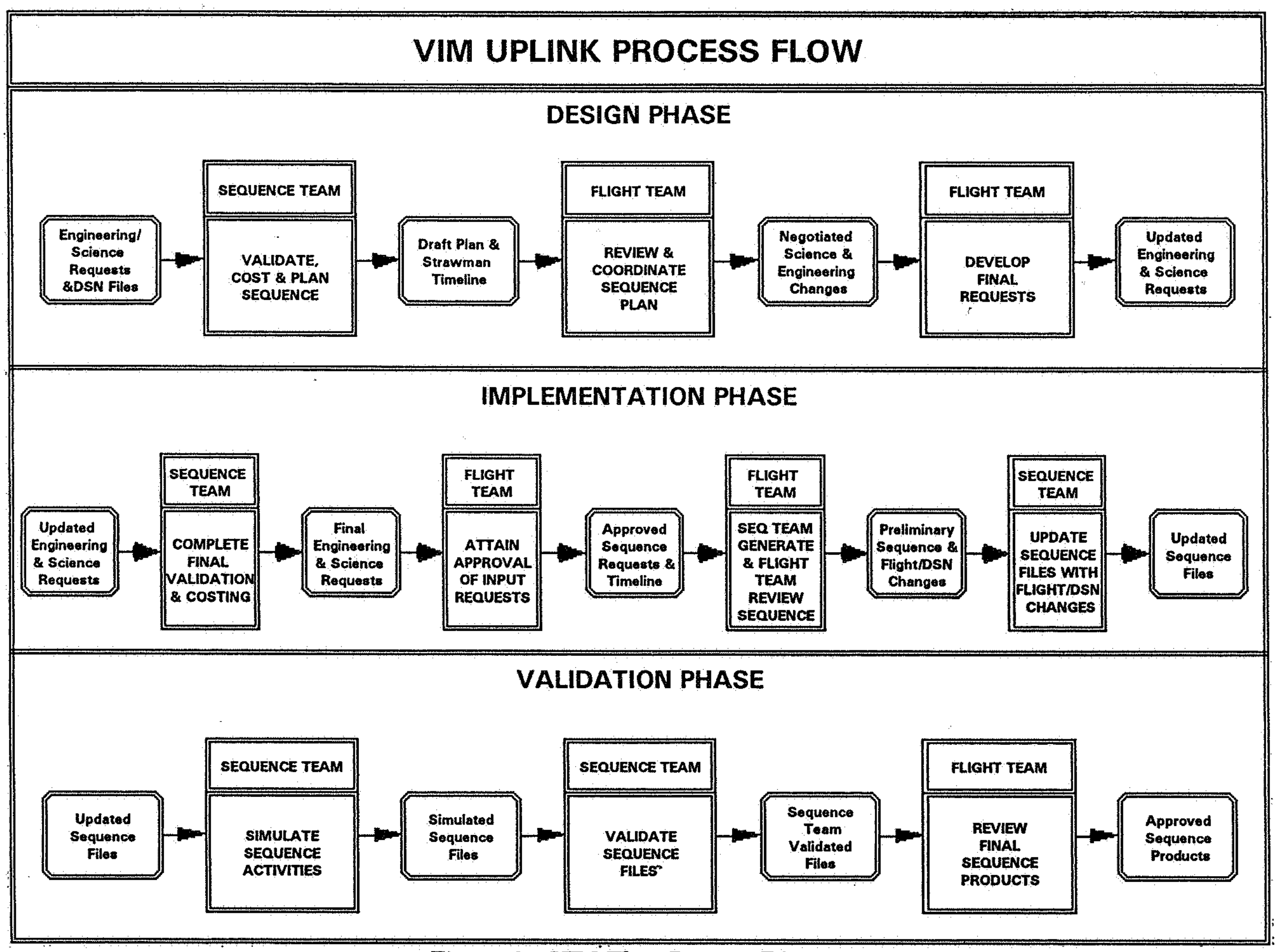

Figure 1: VIM Flow Process Diagram

the implementation phase. The UVS input request file (generated by the Science Team) is merged with hand-generated engineering and navigation requests. Electronic files are generated necessary to build an integrated timeline, the spacecraft command file, and the sequence-of-events document. Review products are generated for a flight team review. Modifications to the sequence are then made based upon review comments and updated DSN antenna coverage. This completes the implementation phase.

The fourth week is devoted to simulating the sequence activities through the Voyager COMSIM program to ensure all spacecraft systems will operate correctly. The end product of this simulation is the Ground Command File (GCMD). Validation follows simulation and, by the fifth week, review products are generated for a final review by the flight team. This completes the validation phase.

During the sixth week, the GCMD is translated into a spacecraft command file and uplink approval is attained. The load is then transmitted to the spacecraft by the DSN. The Monday following this uplink marks the execution start of the new sequence, and the beginning of the uplink process for the other spacecraft.

The process to modify the baseline sequence follows the same operational scenario as the overlay, but is drawn out over a period of four months to lessen its impact on the concurrent, more highly time-constrained overlay sequence development. The baseline sequence was developed using looping cyclics of spacecraft blocks, which are automatically restarted each year. It is at this point that modifications can be introduced, allowing for change only once per year.

The capability to generate unplanned sequences (commands sent to the spacecraft in a time-critical manner) is a necessary part of operations. These sequences are not scheduled in the normal way. They must be built quickly with careful correlation to the ongoing spacecraft activities. The development milestones for these sequences are conducted in parallel with scheduled sequence tasks.

The new process allows the Sequence Team to operate within the maximum five-person limit. A three-person rotating sub-team is used for nominal overlay sequence development. The remaining personnel are involved in baseline and unplanned sequence development work, software upgrade user and regression testing, and ground block database maintenance. The rotation of duties on a regular basis keeps the knowledge current and minimizes turnover impact.

For two years the VIM uplink process has proven its merit in the development of the baseline, overlay and unplanned sequences. Since that time, both spacecraft have been performing with greater than expected science and engineering return.

3.4.3 Ground System Redesign

The software system supporting the uplink process is typically called the Mission Sequence System (MSS). A constraint on the redesign of the VIM MSS was that new development be PC based since the Sequence Team was already equipped with compatible machines.

The major redesign efforts within the MSS were concentrated in altering or building new programs for the design and implementation phases of the new six week sequence development process. The pre-VIM process used eight weeks for these two phases and was highly labor intensive. The goal was to not only automate tasks as much as possible, but to also replace entire sequence team positions with software capabilities. Today, three weeks are needed to complete the design and implementation phases.

Just as the spacecraft system redesign relied heavily upon the use of spacecraft blocks, the MSS redesign required the use of established ground blocks to define requested overlay sequence activity. The ground blocks were designed to group relatively timed commands for frequently used sequence activity. This allows the user to furnish a minimum set of parameters to initiate the block implementation. These ground blocks not only documented the necessary command activity for a specific sequence request, but also included the detailed notation needed to generate human readable sequence review products.

Figure 2 represents the data flow for the redesigned MSS using the associated acronyms mentioned below.

The Design Phase of the VIM uplink process was enhanced by developing four programs to accomplish the following:

- Build UVS input request files for overlay activities (UVSPRC).
- Build a working strawman timeline containing

baseline & UVS overlay activities, DSN view periods, antenna coverage and associated data rate capabilities (Strawman T/L).

- Constraint check for data rate capabilities (TSP).
- Constraint check for scan platform and UVS pointing violations (AACSPRC).

The Implementation Phase was upgraded by modifying one existing program and designing two new programs to achieve the following:

- Merge Science, Engineering and Navigation Requests and expand to the command level (BLKPRC, AACSPRC).
- Check for ground and spacecraft constraint violations (BLKPRC, TSP).
- Translate the overlay sequence into binary bits readable by the on-board computer (SEQTRAN).
- Build the integrated baseline & overlay sequence timeline (Laserjet T/L).

The Validation Phase, where COMSIM is executed, was updated to allow for the following:

- Enable COMSIM to simulate the modification made to the spacecraft flight software.
- Pass ground block notation to the Sequence of Events (SOE) software.

3.4.5 Ground System Redesign Costs

The Mission Sequence System Functional Requirements Document (MSS FRD) was completed in a four month time span. This was due to the fact that experienced users worked side by side with software engineers to coordinate necessary software capabilities with VIM operational scenarios. Existing flight team members participated in this effort and no additional staffing was required to complete the MSS FRD.

Software implementation of the MSS redesign was folded into a two phase development plan. The Phase 1 delivery contained the minimum set of programs needed to generate command files for baseline and overlay sequence transmission. The Phase 2 delivery completed the set of programs needed to allow the VIM Flight Team to generate an overlay sequence within the allotted six week sequence development schedule. Phase 1 was completed in six months with Phase 2 following six months later. The existing software development staff of three was augmented by one additional programmer for a six month period.

Before using the new MSS to generate real sequenc-

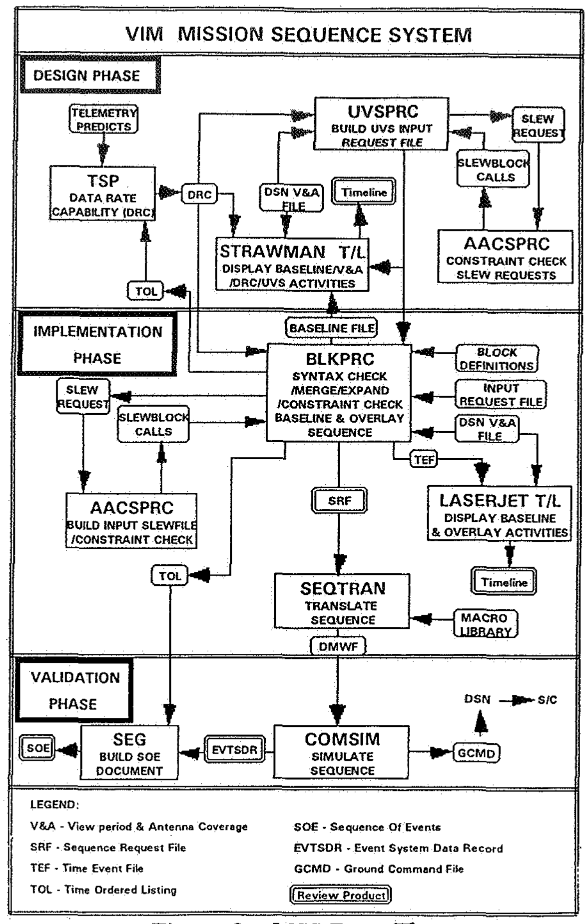

Figure 2: MSS Data Flow

es, an extensive User Test Plan was developed and executed. The plan included the involvement of appropriate flight team members to review sequence products containing every possible combination of ground block calls. The plan also required the simulation of all ground blocks by COMSIM to insure confidence in their usage. The Sequence Team added three personnel for an approximate six month period to complete the user testing.

One year and two months after the Voyager Neptune Encounter, the Phase 1 MSS was used to build the first overlay sequence for spacecraft transmission. Six months later, the Phase 2 MSS was delivered and the six week sequence development schedule was realized.

4. MODIFICATION EFFECTS

The use of blocks to define standardized activities promotes ease in operational sequence implementation (for the requester and the implementer) with maintained reliability. Operating with blocks limits flexibility and science optimization, but allows for automation in uplink development and increases team productivity. Using pre-defined activity blocks also makes training new personnel easier.

Placing a large volume of blocks on-board the spacecraft decreases computer sequence memory, but allows the baseline sequence to operate each spacecraft autonomously.

Transition to the VIM uplink process necessitated the following changes: (1) new procedures had to be written and old ones revised or deleted, (2) fewer sequence products were generated and fewer review meetings needed, (3) the nominal sequence development schedule was shortened from 12 weeks to 6 weeks, (4) greater process automation reduced errors, (5) staffing was reduced thereby saving dollars and (6) the Science, Spacecraft and Navigation teams now play a more integral part in designing each overlay sequence.

5. FUTURE APPLICATION

The VIM uplink process is simple, stable and easily adaptable to the new Discovery class missions of the future. The process is usable for a standalone mission or can be considered adaptable for shared project operations. The Voyager project endorses this new idea and is open to the challenge of a shared project operations environment.

The process can support a planetary cruise effort with few modifications to existing operations plans and procedures. What the process does lack are the necessary steps to incorporate instrument pointing with correlated maneuver strategies. Since these steps were there before VIM, there would be little problem to reinstate them. What makes the VIM process appealing is the baseline/overlay sequence concept, the established interteam/intrateam interfaces and the proven set of procedures for flight team operations.

The ability to accommodate an encounter sequence strategy was built into the VIM uplink process. This part of the process has already been tested by the flight team in the last few weeks. Sequence operations generated special sequences to investigate unexplained radio emissions recently observed by the waves experiment.

6. CONCLUSIONS

The entire Voyager uplink process was transformed to meet the scaled down requirements of the interstellar mission. The many changes described in this paper (using on-board spacecraft blocks and ground blocks, building baseline/overlay sequences, using new PC driven software to simplify the process and modifying the process itself) all resulted in a myriad of savings of time, level of effort, and dollars. The process now fits the task.

The success of VIM's operational redesign is largely due to the fact that the user community was allowed to design a new system using their own experience and creativity.

The primary reason the Voyager Project has been able to automate many of its operations is due to reduced mission complexity. VIM has become an example of a "cheaper, faster, better" mission that the new NASA philosophy holds as the wave of the future. This type of mission is only possible if the idea of "simple" is included in every aspect of the project.

Voyager has been at the forefront of solar system exploration and is now leading the way towards establishing a mission operations concept applicable for Discovery class missions.

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