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Contract NAS 9-14264

Formulation of Detailed Consumables Management Models for the Development (Preoperational) Period of Advanced Space Transportation System

EXECUTIVE SUMMARY

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CONTENTS

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LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Future manned space programs that will have increased launch frequencies and reusable systems require an implementation of new consumables and systems management techniques that will relieve both the operations support personnel and flight crew activities. These techniques must be developed for the optimum combination of an onboard and ground support consumables management system consistent with the goals of the program. Effective operational performance of the consumables management techniques of a total system requires that a very explicit definition of the time, place, and method of performance of each function be determined by trade studies to ascertain that the operational methods do, indeed, meet these goals. This requires that the complete consumables management cycle be considered by including the mission planning and scheduling functions, prelaunch activities, onboard mission functions, ground mission support functions, and postmission activities.

Formulation of models required for the mission planning and scheduling function and establishment of the relation of those models to prelaunch, onboard, ground support, and postmission functions for the development phase of Space Transportation Systems (STS) was conducted under Contract NAS 9-14264 during the period 1 November 1975 to 31 October 1976. The preoperational Space Shuttle is used as the design baseline for the subject model formulations.

Analytical models were developed which consist of a Mission Planning Processor with appropriate consumables data base, a method of recognizing potential constraint violations in both the planning and flight operations functions, and a Flight Data File for storage/retrieval of information over an extended period which interfaces with a Flight Operations Processor for monitoring of the actual flights.

The Final Report for the Formulation of Detailed Consumables Management Models for the Development Period of Advanced Space Transportation Systems consists of an Executive Summary and five Technical Volumes. The Technical Volumes include information required for the implementation of a Consumables Management System. The individual volumes consist of:

Volume I. Detailed Requirements for the Mission Planning Processor

Volume II. Consumables Data Base Workbook

Volume III. Study of Constraints/Limitations for STS Consumables Management

Volume IV. Flight Data File Contents

Volume V. Flight Operations Processor Requirements

Two additional documents were issued in the course of the contract execution. These reports support the development of the Consumables Management System. The reports are:

Study of Existing Analytical Models for STS Consumables Management, dated February 1976.

Documentation of Computer Routines Developed to Determine Cyclic Probability (CYCPRO) Trends of Shuttle Heater Usage, dated September 1976.

This Executive Summary presents an overview of the results of this effort and describes the significant context of the technical volumes for those readers interested in following the progress of the system development as potential users of the Consumables Management System and/or as supporting information in the development of spacecraft mission planning and operations systems.

A system of the type described is applicable for both flight planning and as a real-time replanning tool for flight operations. The development of such a system is accomplished by 1) a definition of phases and activities to be used as the basic building blocks, 2) development of a processing scheme for the mission planning phase, and 3) definition of the flight monitoring and replan applicability to varying degrees of spacecraft autonomy for flight operations.

The analytical models for such a consumables management are summarized in the subsequent text. The reader is referred to the Technical Volumes of this report for greater detail.

2.2 FLIGHT/MISSION COMPONENTS

The definition of standard flight/mission components, representing portions of a flight which are to be combined in various sequences to satisfy a particular mission, is of practical necessity in simplification of a consumables management scheme. The concept of dividing a flight profile into a series of distinct segments or phases for the purpose of analysis in support of training and flight operations is not unique to this effort. Several efforts, such as that reported in Reference 5, are devoted to a standardization of such phases for the Shuttle. A particular set of Flight/Mission components has been selected for consumables management with a view toward compatibility with sets defined by the referenced studies while still maintaining the structure required by consumables related mission planning. The structure is typical for an advanced spacecraft and is adaptable to change as other aspects of mission planning and flight operations converge on a unique and standardized set for the Shuttle.

A set of Flight/Mission components is shown on Table I. The set consists of five flight phases from prelaunch through entry and landing. The flight phases must be performed sequentially in the flight profile. The phases are further divided into phase components. The phase components are either sequential or non-sequential with respect to the profile. For all flight phases other than on-orbit, the phase components are sequential. The on-orbit phase is divided into two sets of non-sequential phase components. The two sets, orbital phases and orbital activities,

Table I. Flight/Mission Components

PRELAUNCH PHASE

ASCENT PHASE

- GSE-Liftoff
- Liftoff-MECO
- MECO-ETS
- ETS-OMSign

ON-ORBIT PHASES AND ACTIVITIES

- Orbital Phases
    - OMS Maneuver
    - RCS Translation Maneuver
    - Attitude Hold
    - Rendezvous
    - Station Keeping
    - Dock
    - Undock
    - PTC
    - EVA
    - IVA
    - Manipulator Ops
    - IMU Alignment
- Orbital Activities
    - Payload Bay Doors
    - Payload Consumables
    - Computer
    - TV
    - Downlink
    - Uplink
    - Fuel Cell Purge
    - Eat
    - Sleep
    - Waste Management
    - APU Checkout
    - CO_2 Management

DEORBIT PHASE

- Deorbit Prep-Deorbit Burn
- Burn to Interface

ENTRY AND LANDING PHASE

- Interface to Stop Roll
- Stop Roll to GSE Connect

are distinguished primarily by their operational characteristic with respect to the profile. Orbital phases are unique to a mission and, in general, items from this set cannot be performed simultaneously. Orbital activities are cyclic type of operations which may vary in magnitude and location with respect to the profile, but are, in general, operationally required on all flights. This distinction is significant in consumables management in that early flight planning will consist of standardized flight phases, standardized magnitude and location of orbital activities, selected orbital phases, and several unique orbital activities required to satisfy the particular mission objective.

2.3 MISSION PLANNING PROCESSOR

Consumables management is a continuous process throughout the mission planning cycle from long-range planning through post-flight analysis. The Mission Planning Processor is a user oriented tool for consumables management during that period. The user need not be a consumables analyst. The Mission Planning Processor is an interactive system using demand mode terminals for input/output/display and interfacing with the updateable Flight Data Files. The files for each mission in the data bank are generated and used by the Mission Planning Processor. The amount of detail in the mission files is a function of where the mission lies in the planning cycle.

During long-range planning (launch - 10 years) mission plans can be developed using discrete event data disassociated from the time of occurrence of the event. The effects of these events on consumable usage can be tallied by the Mission Planning Processor to determine mission feasibility and consumable subsystem requirements. The results can be stored in the Flight Data Files for recall.

During near-term planning (launch - 6 years to launch) the Mission Planning Processor can be used to build and use mission plans with increasing detail and fidelity to mission time of events. The Mission Planning Processor will provide immediate feedback to the user concerning scheduling conflicts and consumable usage rate limit violations. The user has the option to generate and display event timelines, consumable usage versus mission time, and total consumables used and/or end of mission reserves for each consumable subsystem. The results can be stored in the Flight Data File for recall.

During the pre-launch and inflight periods, a version of the Mission Planning Processor will be used to verify mission success and to perform real-time mission replanning assessments. During the post-flight period the Mission Planning Processor can be used to update mission planning factors based on flight data. The refined factors will be entered into the Mission Planning Processor functions and utilized in future mission planning.

An overview of the Mission Planning Processor is shown on Figure 1. Detailed flow diagrams for the system are given in Volume I of this report. An explanation of the user interface via the terminal unit, the internal processing including the consumables data base and subsystem constraint violation technique, and the file/retrieval system afforded by the data file are given in this section.

2.3.1 User Interface

The Mission Planning Processor may be used either to execute a computerized version of the long range planning worksheet of Reference 1 or to execute a flight profile (timeline) in the latter stages of mission planning. This section describes the user interface to the Mission Planning Processor in the construction of a flight profile.

The first timeline display presented to the user is a summary of the times associated with the flight phases. This display is shown on Table II. The run mode indicators presented atop the display will depict the operational mode such as editing an existing flight, building a new flight, etc. The display presents the start time, stop time, and span of each flight phase. The variable notation is defined in Table III as used on this and subsequent displays.

With the display 100 on the CRT, the user may elect to work with any of the five phases by keying the appropriate item number.

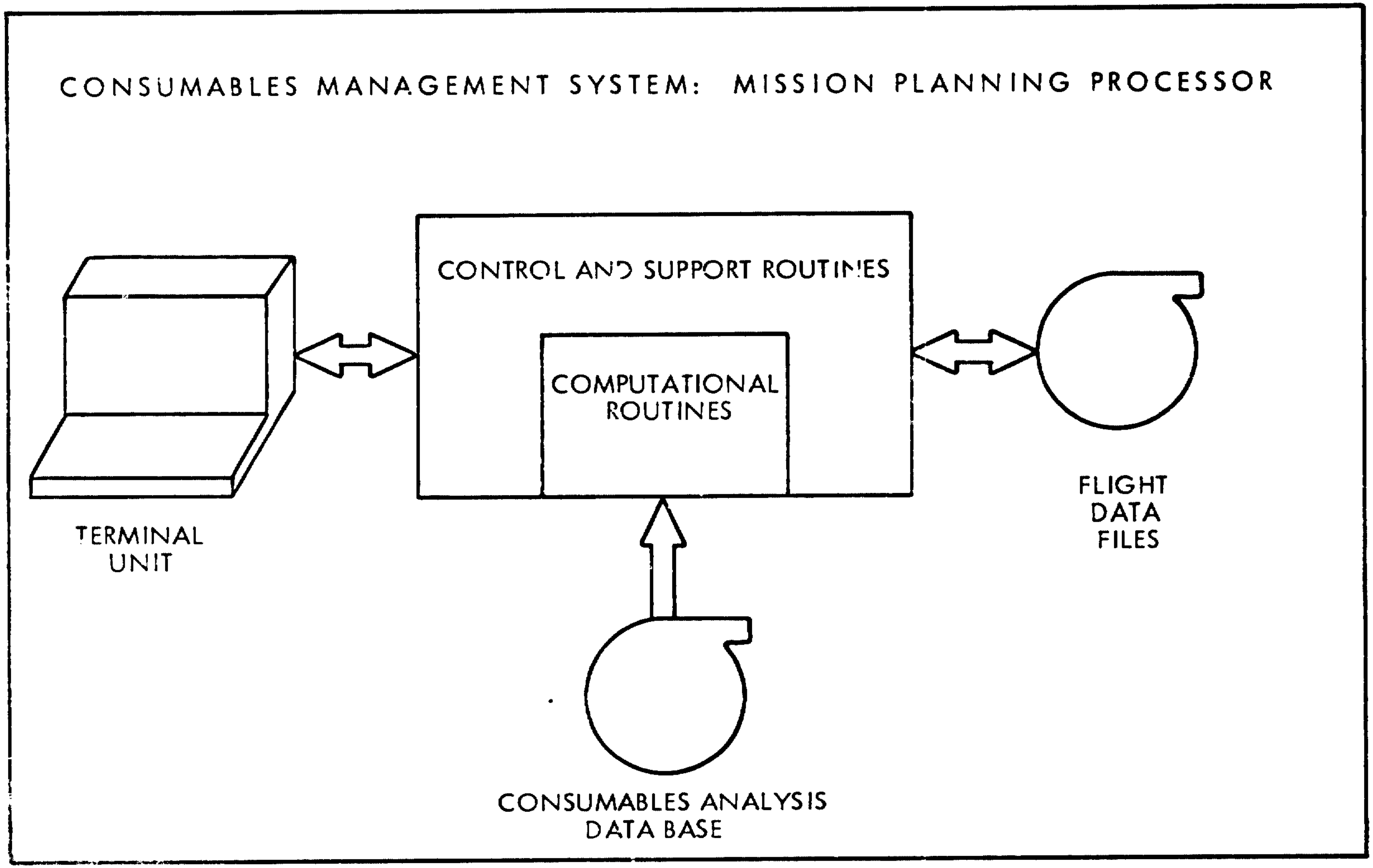

Figure 1. Mission Planning Processor Overview

Table II. Format, Flight Block Display 100

100 FLIGHT BLOCK

MISSION ID: RUN MODE:

ITEM	PHASE	START TIME	STOP TIME	DELTA TIME	MOD FLAG
1	PRELAUNCH	YY	YY	AA	I
2	ASCENT	YY	YY	XX	I
3	ON ORBIT	YY	YY	XX	I
4	DEORBIT	YY	YY	XX	I
5	ENTRY/LAND	YY	YY	XX	I

Table III. Symbols

YY	- Dependent Variable
AA	- User Editable Default Value
BB	- User Enter or Editable Value
XX	- User Editable Value, but not at this Display Level
I	- Modified Value Indicator 0 - Default Resident 1 - User Entered Value Resident
J	- Number of Entries Resident
K	- Number of Entries Resident. Operational Default Values Resident Initially

Item 1: The user may modify the existing prelaunch period. A modification will be reflected in both the prelaunch period and the start time of the prelaunch.

Items 2 through 5: Will bring up the display of phase components for the phase selected.

Selection of items 2, 4, or 5 brings up one of three similar displays. Table IV illustrates Display 200 for the selection of item 2. Here, similar to Display 100, the user may modify the liftoff time and/or the delta time associated with any or all of the ascent phase components. Modifications and their effect are immediately reflected on this display and in the data resident for the remaining displays. The entry of a "5" will return Display 100 to the CRT. In general, the entry of an item number higher than the greatest displayed will return the calling display.

With Display 100 on the CRT, a selection of item 4 or 5 will bring up the phase components for these phases as shown on Tables X and XI. Manipulation and modification with these displays on the CRT is similar to the operations with Display 200. That is, the user may modify the period of any or all of the phase components. With these displays the entry of a "3" will return Display 100 to the CRT.

Table IV. Format, Ascent Block Display

200 ASCENT BLOCK

MISSION ID: RUN MODE:

ITEM	COMPONENT	START TIME	STOP TIME	DELTA TIME	MOD FLAG
1	GSE-LIFT OFF	YY	AA	AA	I
2	LIFT OFF - MECO	YY	YY	AA	I
3	MECO - ETS	YY	YY	AA	I
4	ETS - OMS IGNITION	YY	YY	AA	I

Selection of item 3 with Display 100 on the CRT will bring up display 300 as shown on Table V. With this display the user can modify the total time on-orbit, bring up a phase or activity menu, or request a summary of the phases or activities resident. The on-orbit phase menu, display 320, is shown on Table VI.

Display 320 provides the user with a menu of on-orbit phases which the user may wish to add, delete, or modify. The number of resident entries of each phase is also displayed in addition to a modified indicator. The mod indicator refers to the residence of other than a default value where appropriate.

A typical on-orbit phase display is shown on Table VII. Table VII, Display 321, affords the user addition, modification, and/or deletions of OMS Maneuvers to the timeline. As shown, there are N* OMS maneuvers with their respective start time, stop time, and ΔV resident which may be modified or deleted or OMS maneuver N+1 may be added. Procedure is as follows:

<u>ADD</u>: The user enters the number N+1 and the corresponding start time and ΔV for the additional OMS maneuver. Entered values and the calculated stop time are immediately displayed along with the next potential entry number of N+2.

<u>MODIFY</u>: The user enters the item number of the resident OMS maneuver to be modified along with the appropriate new start time and ΔV. Modified and calculated values are immediately displayed.

<u>DELETE</u>: The user enters the negative integer value of the resident OMS maneuver item number to be deleted. This display will delete the values of that item number and re-order the subsequent item numbers. That is, the display will now reflect N-1 OMS maneuvers resident and OMS maneuver N may be added.

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*The implied resident default maneuvers are for standard insertion and circularization burns to a 100 NM orbit

Table V. Format, On-Orbit Block Display 300

300 ON ORBIT BLOCK

MISSION ID: RUN MODE:

ITEM	REQUEST	START TIME	STOP TIME	DELTA TIME	MOD FLAG
1	OMS IGNITION - DEORBIT	YY	YY	AA	I
2	ORBITAL PHASE MENU				
3	ORBITAL PHASE SUMMARY				
4	ORBITAL ACTIVITY MENU				
5	ORBITAL ACTIVITY SUMMARY				

Table VI. On-Orbit Phase Display 320

320 ORBITAL PHASE MENU

MISSION ID: RUN MODE:

ITEM	ACTION	NUMBER SCHEDULED	MOD FLAG
1	OMS MANEUVER	K	I
2	RCS TRANSLATION	J	
3	ATTITUDE HOLD	J	
4	RENDEZVOUS	J	I
5	STATION KEEPING	J	
6	DOCK	J	I
7	UNDOCK	J	I
8	PTC		
9	EVA	K	I
10	IVA	J	
11	MANIPULATOR OPS	J	
12	IMU ALIGNMENT	K	I

Table VII. Format, OMS Maneuver Display 321

321 OMS MANEUVER

MISSION ID: RUN MODE:

ITEM	START TIME	STOP TIME	DELTA VELOCITY
1	AA	YY	AA
2	AA	YY	AA
3	BB	YY	BB
⋮			
n			

The on-orbit activity menu, Display 340, shown on Table VIII is brought up by keying item 4 when Display 300 is on the CRT. Typical on-orbit activity display with appropriate control and input variables is shown on Table IX.

Selection of items 3 or 5 with Display 300 on the CRT will route around the respective MENU and present the phase and activity displays from the selected set sequentially for review.

2.3.2 Internal Processing

The Mission Planning Processor control, support, and computational routines manipulate the user input to build a time history of the consumables for a particular flight. The usage rates are derived from the consumables data base. In addition, the violation of subsystem constraints and activity conflicts resulting from the input schedule of activities are flagged to the user. The consumables data base and the constraint violation flag technique, including the statistical technique used in accounting for cyclic heater operation are presented in Volume II and Volume III of this report, respectively. A brief discussion of these items follows.

2.3.2.1 Consumables Data Base

Consumables characteristic data associated with the performance of the mission activities is required by the Mission Planning Processor to calculate the consumables. The activity data must be defined in terms of discrete time periods having a distinct rate for each consumable required to support the performance of a given operation. An example of such a data base, specifically for the Shuttle Orbiter is given in Volume II of this report.

The data in Volume II is structured in a series of "Consumable Data Worksheets" for each activity that includes a profile of its operations and the rate of the various consumables required to support the given activity. The data worksheets provide for the uniform specification of consumables data, allows for the ready identification of the consumables affected by a given activity, and facilitates the updating process. An activity is defined as a series of operations performed in a prescribed sequence in order to effect a distinct crew and/or spacecraft related function. The

Table VIII. Format, On-Orbit Activity Display 340

340 ORBITAL ACTIVITY MENU

MISSION ID: RUN MODE:

ITEM	ACTION	NUMBER SCHEDULED	MOD FLAG
1	PAYLOAD DOORS	K	I
2	PAYLOAD CONSUMABLES	J	
3	COMPUTER	J	I
4	TV	K	
5	DOWNLINK	J	
6	UPLINK	J	
7	FUEL CELL PURGE	K	I
8	EAT PERIOD	K	I
9	SLEEP PERIOD	K	I
10	WASTE MANAGEMENT	K	I
11	APU CHECKOUT	K	I
12	CO_2 REMOVAL	K	I

Table IX. Format, Payload Door Display 341

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341                  PAYLOAD BAY DOORS

     MISSION ID:                                                  RUN MODE:

ITEM          TIME           TIME           MOD
              OPEN           CLOSE          FLAG

1              AA             AA             I
2              BB             BB             I
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.
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n
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Table X. Format, Deorbit Block Display 400

400 DEORBIT BLOCK

MISSION ID: RUN MODE:

ITEM	COMPONENT	START TIME	STOP TIME	DELTA TIME	MOD FLAG
1	PREP - BURN	YY	YY	AA	I
2	BURN - ENTRY INTERFACE	YY	YY	AA	I

Table XI. Format, Entry/Land Block Display 500

500 ENTRY/LAND BLOCK

MISSION ID: RUN MODE:

ITEM	COMPONENT	START TIME	STOP TIME	DELTA TIME	MOD FLAG
1	ENTRY INTERFACE - ROLLOUT	YY	YY	AA	I
2	ROLLOUT - GSE	YY	YY	AA	I

activities are used as the basic building blocks to formulate a mission and should include every event to be performed and the specific group of consumables affected. The performance of an activity is usually preceded by a series of preparatory steps during which specific subsystems required to support the given activity are activated. Likewise, at the completion of the activity these subsystems must be deactivated and the spacecraft returned to its normal operating configuration. Thus, the activity is divided into three time periods; a preparation period, the activity itself, and a post-activity period. The time span of the pre- and post-periods are fixed. The time span of the activity itself is controlled by user input.

2.3.2.2 Constraint Violation Flag Technique

Constraints analysis determines if transient and short term subsystem limits will be exceeded if the flight is performed as planned. Violation of these limits will cause degradation of subsystem performance or interference with nominal spacecraft operations. Constraints analysis is performed by the Mission Planning Processor during the intermediate planning phase of a flight to determine if any violations occur.

The data used to generate consumables usage rates within the Mission Planning Processor reflect subsystem requirements which may be checked against the subsystem limits. However, in the case of the electrical power subsystem the data reflects average (RMS) cyclic heater power. Variation of the actual power from the average results from the particular status of the various cyclic components at any time. The probable variation about the average is used as a bias to the actual subsystem limit in the Mission Planning Processor Constraint/Violation flagging technique.

A detailed study to ascertain the applicability of such a technique and the bias values to be applied was conducted and is reported in Volume III.

2.3.3 File/Retrieval System

The file contents are defined in detail in Volume IV. The file/retrieval system is structured with respect to update/edit capability and dissemination requirements for multiple flights over an extended planning period.

There are four stages of files. The first two stages are flight design/mission planning oriented, whereas the latter stages represent two levels of consumables information dissemination files. The files are defined as follows:

File 0 - This file contains the influence variable (input) data from a previously constructed long range flight plan. The long range flight plan is a computerized version of the consumables analysis worksheet presented in Reference 1. The stored file is used to update/edit and reconstruct the consumables data during the long range planning stage.

File 1 - This file contains a minimum data set from a previously constructed flight profile. This file is used from the intermediate planning stage through post-flight analysis to update/edit and reconstruct consumables data.

File 2 - This file contains consumables quantities versus time for a given flight profile. This is the first stage of providing consumables history for the flight in support of other mission planning functions. It is applicable to the intermediate and early stage of short term planning.

File 3 - This file contains consumables quantities and parameters required by crew training simulators, flight controllers, launch processing, and the onboard computers. It is applicable through post-flight analysis.

The File 1, in conjunction with the Mission Planning Processor, is capable of reconstructing any of the other files and may be edited or updated during the process. This file is the pivot of the file retrieval system from the intermediate planning stage to flight operations. It provides both the starting point for update and edit during the planning and operations cycle, and the data required to regenerate and disseminate consumables information at any stage in the cycle with a minimum storage requirement. It is neither necessary nor desirable to store the File 2 or 3 data until the latter stages of the planning and operations cycle.

2.4 FLIGHT OPERATIONS PROCESSOR

The Flight Operations Processor is a consumables management tool designed for use in the ground support complex and/or the onboard systems in support of the flight operations as an interactive system using demand mode terminals for input/output/display interfacing with the spacecraft real-time telemetry system. The system as shown in Figure 2 performs the following functions: 1) acquire and convert spacecraft real-time telemetry data for consumables monitoring, 2) perform redline limit checking, 3) compare actual consumption versus mission predictions, 4) replan the mission, and 5) provide user interface via the keyboard control unit. The Flight Operations Processor interfaces with the Mission Planning Processor whose output, the premission consumables predictions contained in the Flight Data File, are used to initialize the system and provide the basis for comparison with the actual consumables values observed during flight. Other interfaces, the Launch Processor and the Spacecraft Telemetry System, provide the actual spacecraft consumables values prior to and after liftoff, respectively. The user, either the flight controller in the MOCR or the astronaut in the spacecraft, interfaces with the system via keyboard CRT display equipment that enables him to monitor the consumables status and evaluate and replan the mission as required. Structuring of the Flight Operations Processor into the processing functions shown on Figure 2 allows for the selection of the degree of autonomy desired on the onboard system during the transition from the development to the operational era. Four options are identified and shown in Table XII for the implementation of the Flight Operations Processor into the onboard computer system. These options range from a minimum onboard capability where spacecraft sensor data is converted into consumables quantities, to a fully autonomous consumables management processing system.

Functional requirements for the Flight Operations Processor as well as a more detailed description of the functions and application are given in Volume V.

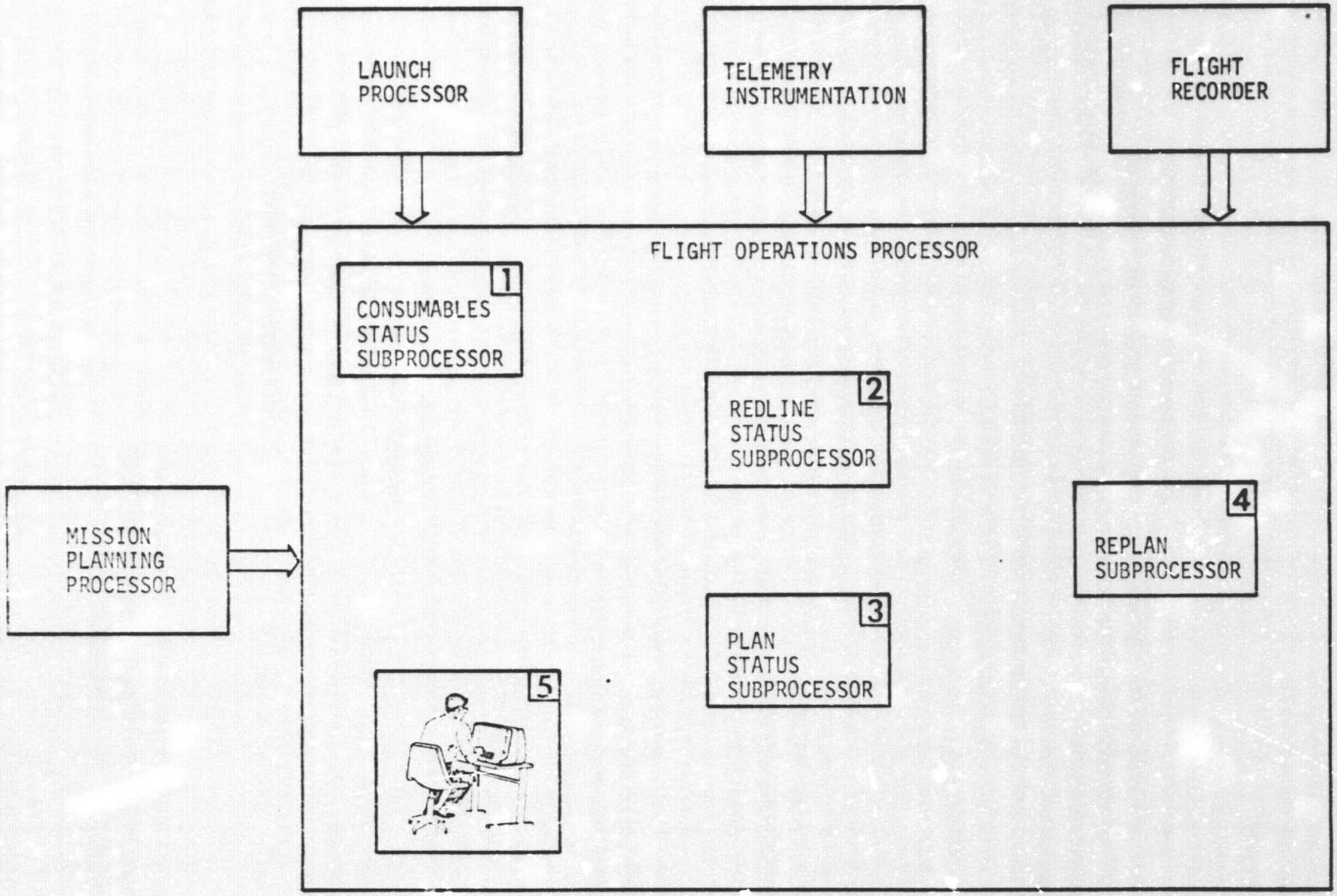

Figure 2. Flight Operations Processor

Table XII. Onboard Processing Options

SUBPROCESSORS / OPTIONS	CONSUMABLES STATUS CONVERT SENSOR DATA TO CONSUMABLES QUANTITIES	REDLINE STATUS CONSTRAINTS AND REDLINE VIOLATION	PLAN STATUS ACTUAL VS PREDICTED PERFORMANCE EVALUATION	REPLANNING REPLAN
OPTION 1 MINIMUM ONBOARD CAPABILITY				
OPTION 2 INTERMEDIATE ONBOARD CAPABILITY				
OPTION 3 ADVANCED ONBOARD CAPABILITY				
OPTION 4 ADVANCED/REPLAN CAPABILITY				

3.0 RECOMMENDATIONS

The detailed requirements for the Mission Planning Processor as developed under this study incorporate several features which are new with respect to traditional consumables methods used on previous spacecraft programs. These items result from a need to apply routine processing by non-consumables oriented personnel for efficient manpower utilization in a highly repetitive/reusable spacecraft program. It is thus recommended that a Shuttle based Mission Planning Processor be developed for applications testing of the system.

The applicability of the system to future spacecraft beyond Shuttle should be demonstrated with a view toward establishing those items required to conserve the generality of the system. Application of the system to a pending program such as Space Station would provide a good base for such a study and ensure extended applicability into distant programs.

It should be noted that the payloads have been directly considered only at the interface with the delivery system. A cascading concept in which both Sortie and deployable payload consumables management system may be developed and applied in series with the delivery system consumables management has been suggested in a previous part of this RTOP. An RTOP should be initiated for this application. Such an application not only provides an organized method of management for payloads and their delivery system, but will also reinforce the interface data required for the host vehicle's consumables management.

This study has been directed toward the consumables management aspects of an overall mission planning and flight operations system for highly repetitive/reusable spacecraft. Similar studies and developments should either be in effect presently, or introduced in the immediate future for other aspects of mission planning and flight operations.

During the course of study, particularly in relationship to Flight Operations Processor development, it was recognized that an operational redline criterion specifically oriented toward reusable spacecraft has not been developed. During previous non-reusable spacecraft, the redline criterion has been essentially crew safety oriented. A reusable spacecraft implies the need for additional consideration of the spacecraft degradation and other items which affect reusability in the redline criterion. It is imperative that a redline criterion and redline values of the significant spacecraft parameters be developed at least prior to the operational phase of STS and preferably in the early development phase.

REFERENCES

1.* Functional Requirements for Ground Support of Consumables Subsystem Management, Technical Report for Contract NAS 9-14264, October 1975, TRW Systems Group, Houston.

2. Study of Existing Analytical Models for STS Consumables Management, Technical Report for Contract NAS 9-14264, February 1976, TRW Defense and Space Systems Group, Houston.

3. Formulation of Detailed Consumables Management Models for the Development (Preoperational) Period of Advanced Space Transportation System, Technical Report for Contract NAS 9-14264, August 1976, TRW Defense and Space Systems Group, Houston.

4. Formulation of Detailed Consumables Management Models for the Development (Preoperational) Period of Advanced Space Transportation System, Technical Report for Contract NAS 9-14264, August 1976, TRW Defense and Space Systems Group, Houston.

5.* A Suggested Classification System for Standard On-Orbit Shuttle Flight Phases, Technical Report for Contract NAS 9-14723, January 1976, TRW Defense and Space Systems Group, Houston.

*Referenced in this Volume