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Technical Report
for
Contract NAS 9-14264

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

VOLUME V

FLIGHT OPERATIONS PROCESSOR REQUIREMENTS

November 1976

Prepared by
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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 volume of the technical reports, Volume V, defines the functional requirements for the Flight Operations Processor. The Flight Operations Processor is that element of the Consumables Management System providing support during the flight operations.

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1.0 INTRODUCTION

The Flight Operations Processor provides consumables management during flight operations; starting at that point in the planning and operations cycle at which the spacecraft enters the joint control of the Mission Control Center and the Launch Processing facility, and continuing through the flight and postflight activities. The purpose of this report is to define and document the functional requirements of the Flight Operations Processor.

Consumables status information, including redline, constraint and limit checking, comparison of predicted versus actual consumables usage, evaluation, and end-of-mission quantities projection, are provided by the Flight Operations Processor by the processing and analysis of a) the premission consumables predictions generated by the Mission Planning Processor and b) the real-time telemetry parameters of the consumables related subsystems. In addition, the Flight Operations Processor provides real-time mission replanning capability by a subprocessor which is equivalent to the Mission Planning Processor.

A general description, structure, and basic functions of the Processor are defined and presented in Section 2.0. Section 3.0 delineates the functional requirements of the various elements of the Processor, while Section 4.0 introduces a plan for the application of the Processor as part of the onboard software with options ranging from a system providing simple limit checks to an autonomous consumables management system.

2.0 GENERAL DESCRIPTION

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 1 performs the following functions: 1) acquire and convert spacecraft real-time telemetry data, 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.

The basic functions of the Flight Operations Processor are to provide consumables management support during the flight operations phase including the prelaunch, flight, and postflight activities of a given mission.

2.1 PREFLIGHT OPERATIONS

Support to the preflight activities is initiated by providing the flight controllers the consumables data corresponding to the mission delineated in the operational flight plan. These data, generated by the Mission Planning Processor, are obtained from the Flight Data File and include the initial consumables quantities for every subsystem, as well as their predicted usage history throughout the planned mission. This information will be used as the basis to compare actual consumables consumption and evaluate subsystems performance during flight. The Flight Operations Processor provides the mechanism to access the predicted consumables data during the early

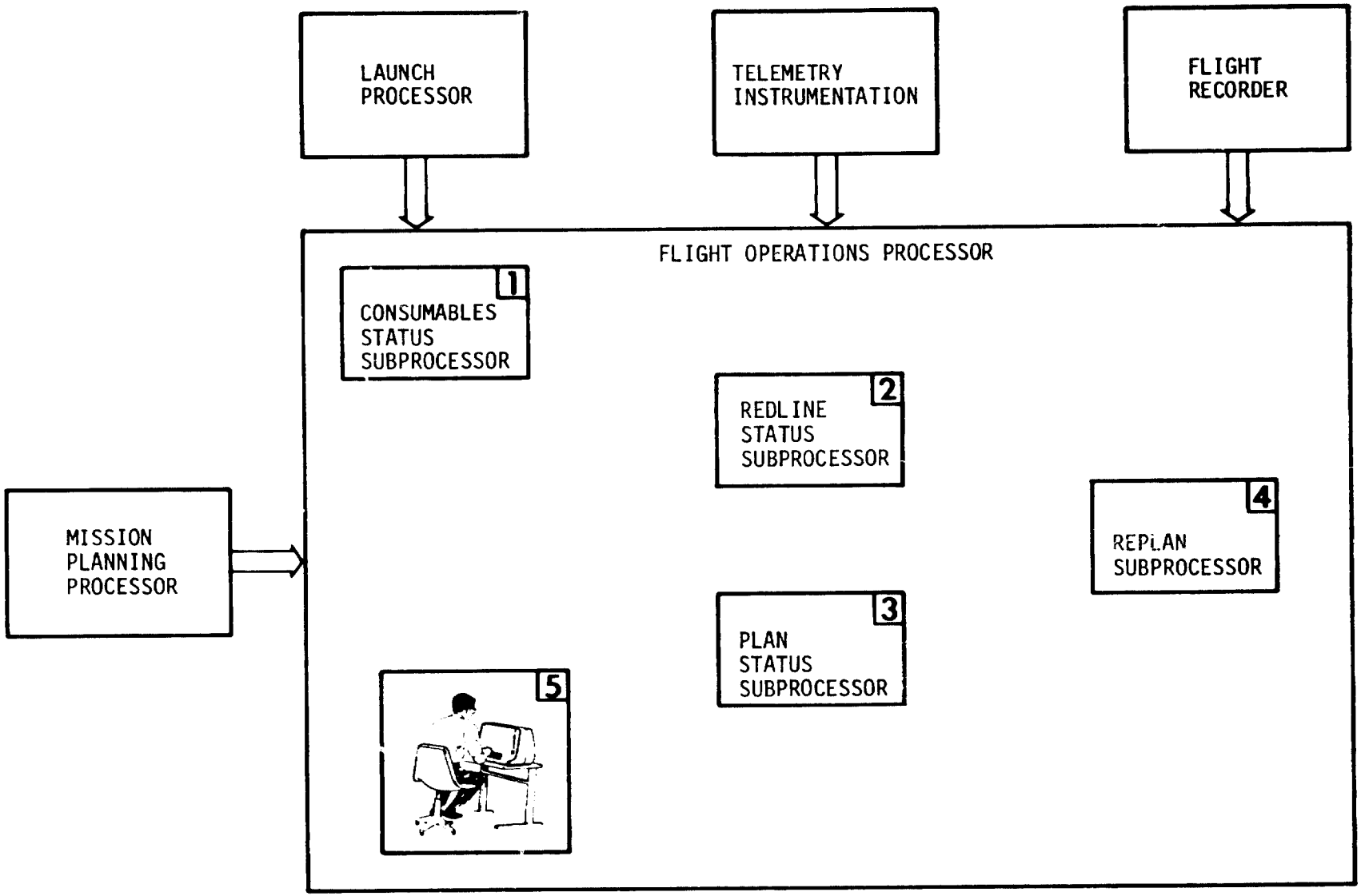

Figure 1. Flight Operations Processor and Interfaces

preflight operations to initialize the MOCR consumables related subsystems and to provide mass properties and reset data points in support of preflight simulations. At the completion of the loading and servicing procedures and when actual spacecraft systems data is received at the Mission Control Center from the Launch Processing facility, the Flight Operations Processor checks the actual loaded consumables quantities against the prescribed maximum or minimum redline values; violations of these operating parameters will be flagged and made available to the user. If redline violations are not detected but a difference exists between the predicted and actual loaded quantities, the Processor will be initialized with the latter parameters and the mission reprocessed to obtain the consumables requirements based on the actual loaded quantities. The last function of the Processor prior to liftoff is to reprocess the mission to reflect final timeline or activity scheduling changes, and provide the consumables requirements data for loading into the onboard software.

2.2 IN-FLIGHT OPERATIONS

The function of the Flight Operations Processor during the flight operations is that of overall consumables management and mission replanning. The Processor monitors consumables related instrumented parameters of all spacecraft subsystems, performs redline and constraint limits checks, compares actual versus predicted usage rates, and establishes updated consumption rates to project end-of-mission quantities remaining. The predicted values used in the Processor correspond to the quantities initially obtained from the Flight Data File during prelaunch and revised accordingly to reflect any changes occurring during that phase of the mission. The Processor further provides the capability to replan the mission at any stage of the flight and calculate the updated consumables requirements due to any additions, deletions, or modifications to the data, timeline, or activity scheduling.

2.3 POST-FLIGHT OPERATIONS

The function of the Flight Operations Processor during the post-flight activities is that of acquiring and analyzing the flight data to update the spacecraft, subsystems, and activity characteristic data used in the Mission Planning Processor to establish consumables requirements during premission planning.

3.0 FUNCTIONAL REQUIREMENTS

The Flight Operations Processor as shown in Figure 1 consists of four elements; Consumables Status, Redline Status, Plan Status, and Replanning Subprocessors. The Processor is initialized with the premission consumables data contained in the Flight Data File and obtained from the Mission Planning Processor. Consumables management is effected by the processing and analysis of the predicted data and the actual spacecraft consumables parameters observed throughout the flight. A modular approach was used in the design of the four subprocessors to facilitate its application to the Onboard System, which will be presented in Section 4.0. The functional requirements of the Processor are given in terms of the requirements of each of the Subprocessors.

3.1 CONSUMABLES STATUS SUBPROCESSOR

Description

The Consumables Status Subprocessor is that element of the Flight Operations Processor whose function is to acquire and convert subsystems sensor data and make these data available to other subprocessors to provide consumables status information. Consumables status should include usage rates as well as remaining and used quantities.

Interfaces

The Consumables Status Subprocessor interfaces with the Launch Processor, the Spacecraft Telemetry System, and the Flight Recorders where actual consumables information is in turn obtained from each of these sources in accordance with the respective stages of the flight operations. This subprocessor also interfaces with each of the other three subprocessors to which remaining quantities and usage rates parameters are made available.

Input

The input to this subprocessor consists of the real-time consumables related data. These data consist of the pressure, temperature, and flow measurements of the consumables media in the various subsystems which are used to compute usage rates and consumables quantities.

Processing

The processing function of the Consumables Status Subprocessor is to read and convert real-time telemetry data into a form compatible with other elements of the Flight Operations Processor in order to establish the status of the consumables.

The first step in the process is the initialization of control indicators identifying the total number of parameters to be read as well as the order and number of parameters associated with each subsystem. After all subsystems parameters are read, the consumables quantities for each tank are computed and summed to obtain the total quantity of each consumable in every subsystem. Suitable equations of state together with appropriate representation of the storage and distribution system of each consumable should be used in conjunction with the available instrumentation for mass computations. Consideration should be given to the performance of special or additional computations required to establish the usable consumables available, as in the case of the propulsion system for example, in which the fuel and oxidizer mixture ratio required for proper operation of the engine must be considered.

Output

The output of the Consumables Status Subprocessor consists of the consumables quantities for each subsystem, and in addition, other parameters not used in the mass calculations but requiring further processing in the Flight Operations Processor, such as flow rates and quantity measurements.

3.2 REDLINE STATUS SUBPROCESSOR

Description

The function of the Redline Status Subprocessor is to check the measured consumables parameters against predetermined limit values to establish violations to the mission redlines or the operating constraints of the various subsystems. Specific parameters to be checked for redline or constraint violations are dependent on the particular subsystem and consumable under consideration. Other parameters to be checked in this subprocessor include usage rates to determine the difference between actual and predicted values and establish compliance with the minimum acceptable values for predicted end-of-mission quantities remaining.

Interfaces

This subprocessor interfaces with the Consumables Status Subprocessor and the Replanning Subprocessor where the measured and predicted consumables parameters are obtained respectively. An interface also exists with the CRT and other output display devices where redline and constraint related advisories are made available to the user upon query.

Input

The input to the Redline Status Subprocessor consists of the actual spacecraft consumables related measurements obtained from the Consumables Status Subprocessor. This information includes the usage rates and the quantities available of each consumable. Redline data and subsystem constraint parameters are obtained from the Replanning Subprocessor.

Processing

The processing function of this subprocessor is that of comparing the actual consumables information acquired from the Consumables Status Subprocessor against predetermined limits and values obtained from the Replanning Subprocessor to detect violations of subsystems redline values and/or operating constraints. Comparison is also made between actual consumables quantities and pre-established minimum acceptable values to satisfy end-of-mission quantities remaining.

Output

The output of this subprocessor provides the result of the consumables related redline and constraint limit checks performed on all spacecraft subsystems. Output is presented via CRT and other display devices.

3.3 PLAN STATUS SUBPROCESSOR

Description

The function of the Plan Status Subprocessor is to ascertain the degree to which premission consumables predictions agree with the actual consumption observed throughout the flight. In addition, this subprocessor establishes the difference between the predicted and actual values and projects end-of-mission quantities remaining based on actual spacecraft values.

Actual spacecraft parameters are obtained from the Consumables Status Subprocessor, while the predicted quantities correspond to those calculated and loaded into the Replanning Subprocessor prior to liftoff.

Interfaces

This subprocessor interfaces with the Consumables Status Subprocessor where the spacecraft instrumented consumables parameters are acquired and converted to the format required for consumables status determination. An interface also exists with the Replanning Subprocessor where the predicted consumables information is obtained. Other interfaces include keyboard controls, CRTs, line printers, and other display devices where consumables status information is provided to the user upon query.

Input

The input to this subprocessor as obtained from the Consumables Status Subprocessor consists of the consumables related parameters of each spacecraft subsystem; specifically this information should include the consumables quantities in each tank element of the storage and distribution system. Other input to this subprocessor includes the predicted depletion profile for each consumable obtained from the Replanning Subprocessor.

Processing

Comparison of actual consumables usage against predicted values and projection of end-of-mission quantities remaining based on actual spacecraft quantities constitute the processing function of this subprocessor. Status of each consumable is determined from the actual and predicted consumption data acquired from the Consumables Status Subprocessor and the Replanning Subprocessor respectively.

Output

The output of this subprocessor provides the status of the consumables in terms of the difference between the actual and predicted usage values. The user is also provided with updated end-of-mission quantities remaining reflecting actual available quantities. CRTs and other display devices are used to present this information.

3.4 REPLANNING SUBPROCESSOR

Description

The Replanning Subprocessor provides the user complete mission replanning capability. This subprocessor, to be used for real-time consumables replanning, is equivalent to the Mission Planning Processor used for premission consumables prediction and analysis. Capabilities of this subprocessor include: check for potential violation of redlines and subsystems operating constraints; end-of-mission quantities projection, timeline and/or activities additions, deletion, modification, and scheduling; generation of revised consumables requirements based on actual quantities and/or schedule modifications.

Interfaces

The Replanning Subprocessor interfaces with the Mission Planning Processor where the preflight predicted consumables data is obtained. Other interfaces are as follows:

1. Consumables Status Subprocessor where the actual loaded consumables quantities are obtained
2. The Redline Status and the Plan Status Subprocessors to provide these elements the predicted consumables data
3. The Launch Processing facility to which redline values must be provided prior to liftoff.

Lastly, an interface also exists with the keyboard control unit which allows the user access to the Flight Operations Processor; and the CRTs, line printers, and other displays mechanisms where consumables information is made available.

Input

The following inputs are required by this subprocessor:

A. Predicted Consumables from Mission Planning Processor

1. Consumables Data Base: Activity definition including consumables usage rates.

2. Redline Definition: Redline values for each subsystem consumable.

3. Constraint/Limit/Conflict Criteria: Subsystems operating limits, constraint limitations, activity scheduling conflict criteria.

4. Timeline: Mission timeline corresponding to the events defined in the Operational Flight Plan.

5. Consumables Data: Subsystem consumables quantities for mission replanning.

B. Actual Consumables from Consumables Status Subprocessor

Instrumented consumables parameters providing the data required to establish consumables status.

Processing

The processing functions of the Replanning Subprocessor are as follows:

- Redline/Constraint/Limit Check for planned mission
- Calculation and projection of end-of-mission quantities remaining
- Mission replanning: timeline, activity, usage rate, configuration changes; calculation of revised consumables requirements.

Output

The output of the Replanning Subprocessor is as follows:

- Redline/constraint violations advisories of planned mission
- End-of-mission quantities projection
- Updated consumables requirements
- Activity scheduling conflict advisories.

4.0 APPLICATION

Consumables management processing by the Flight Operations Processor can be conducted by ground off-line, ground real-time, and/or spacecraft computers. Structuring of the Flight Operations Processor into the processing functions described in the preceding section, 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 I 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 and made available on the onboard monitors, to a fully autonomous consumables management processing system. Figures 2 through 5 depict the application of these options into the onboard system; it should be noted that all processing functions are retained in the ground system for each of the four options as backup during the transition period. A brief description of the various options is provided in the following paragraphs.

Option 1

This option affords the minimum onboard capability which consists in the conversion of spacecraft sensor data into consumables quantities and performed by the Consumables Status Subprocessor. This information is made available to the crew through the onboard CRT displays. All other processing functions are conducted on the ground system where consumables evaluation, updating, and replanning are performed. Figure 2 shows the functions performed by the onboard and ground systems.

Option 2

Under this option, as shown in Figure 3, constraint and redline violations processing performed by the Redline Status Subprocessor is conducted by the onboard computer system. The Plan Status and Mission Replanning functions are accomplished in the ground processing system. Constraint and Redline Violation information is made available to the crew through the onboard CRT display system. Provisions should be made to relay this consumables status information to the ground system.

Table I. 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				

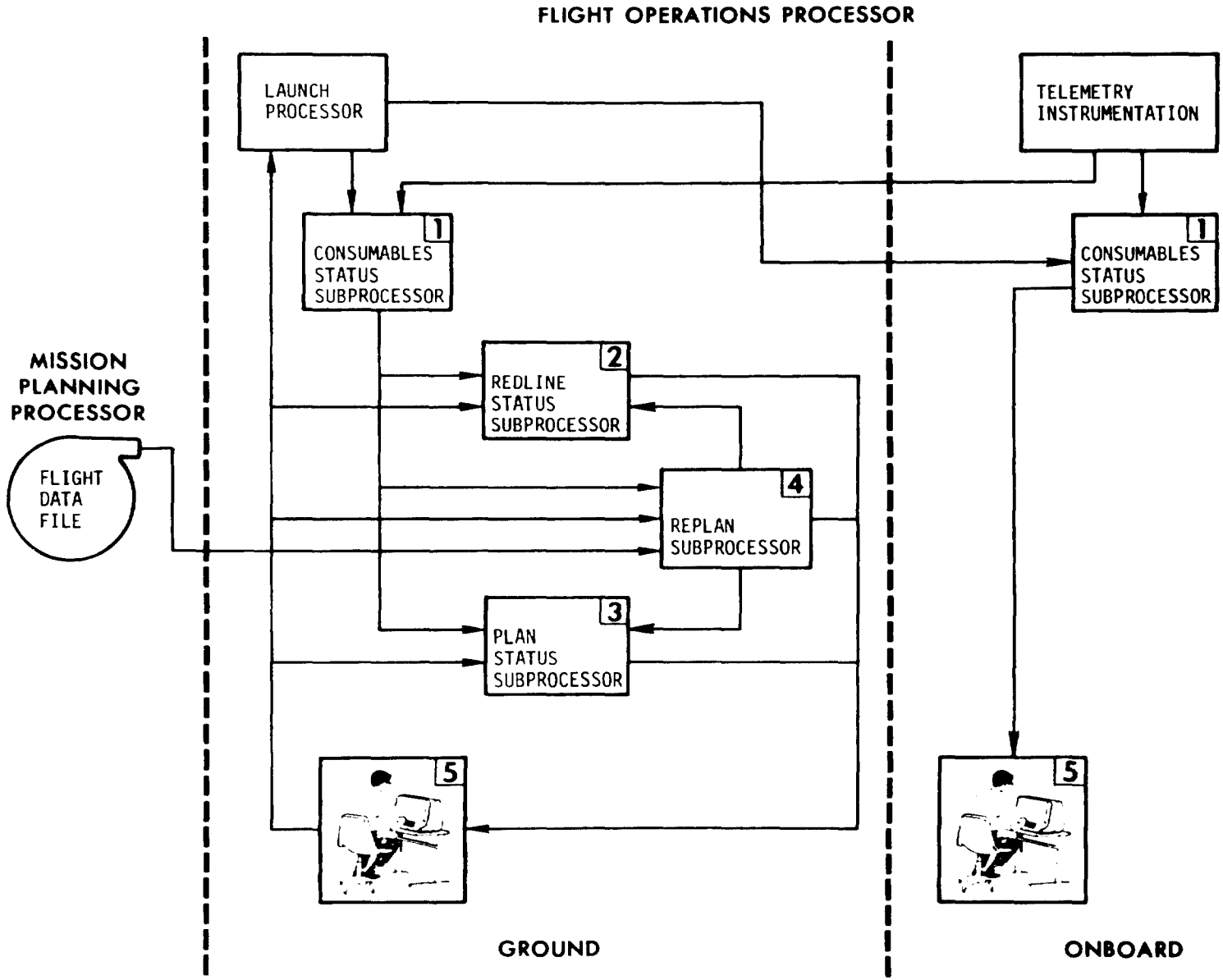

Figure 2. Minimum Onboard Capability (Option 1)

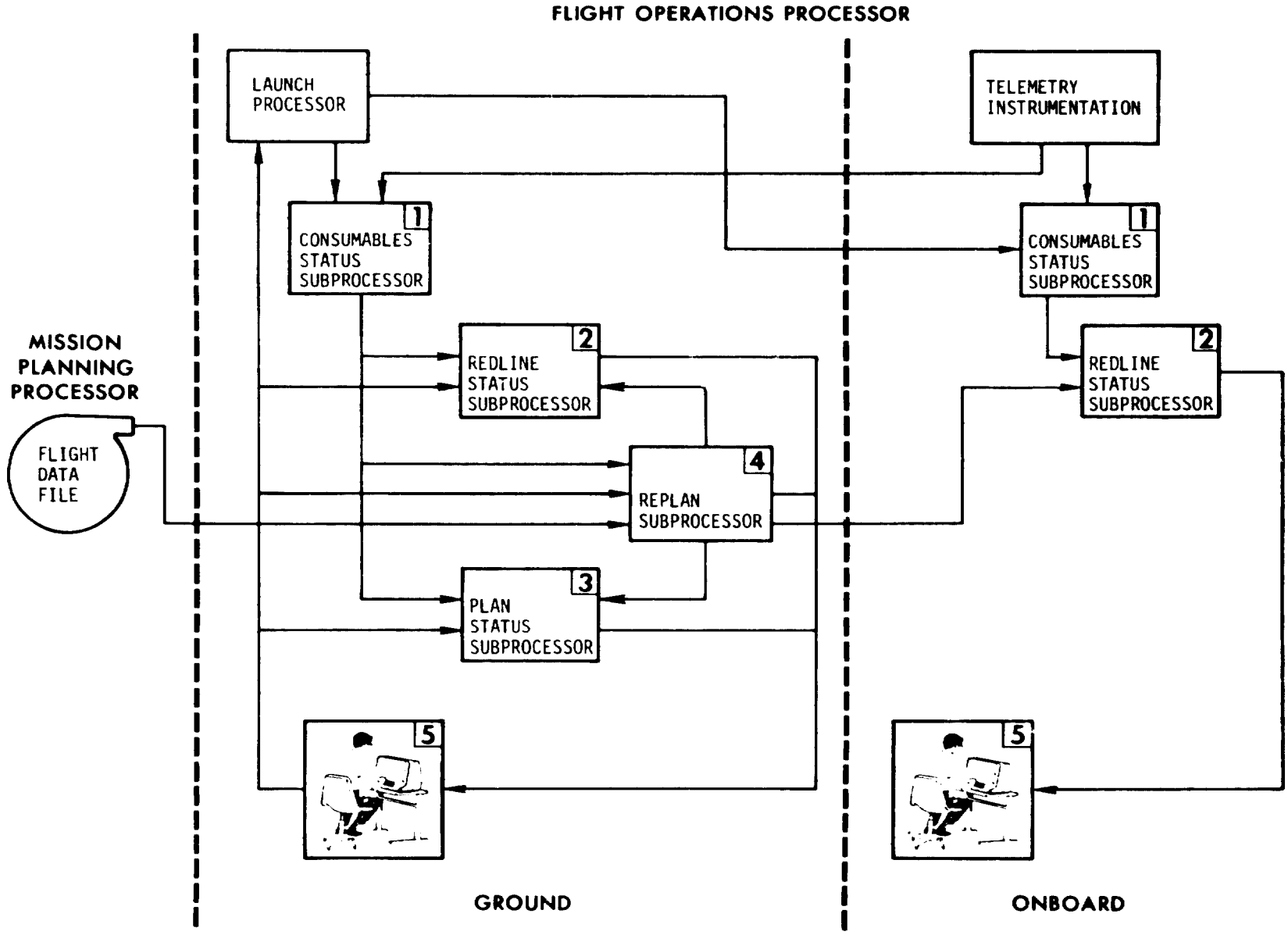

Figure 3. Intermediate Onboard Capability (Option 2)

Option 3

Figure 4 shows the distribution of the processing functions between the onboard and ground systems. This configuration affords the crew the capability to evaluate the performance of the various subsystems by comparison of the predicted versus actual consumables usage rates. As in the case of the other options, this information is made available to the crew through the onboard display system, and it should also be relayed to the ground system for the overall coordination of consumables management.

Option 4

This option represents the last step in the enabling of the onboard computer system to perform the entire consumables management functions. The onboard system as shown in Figure 5 has the mission replanning capability in addition to the functions afforded by the other options. This fully autonomous capability by the onboard computers reduces the ground system to a mere monitoring facility.

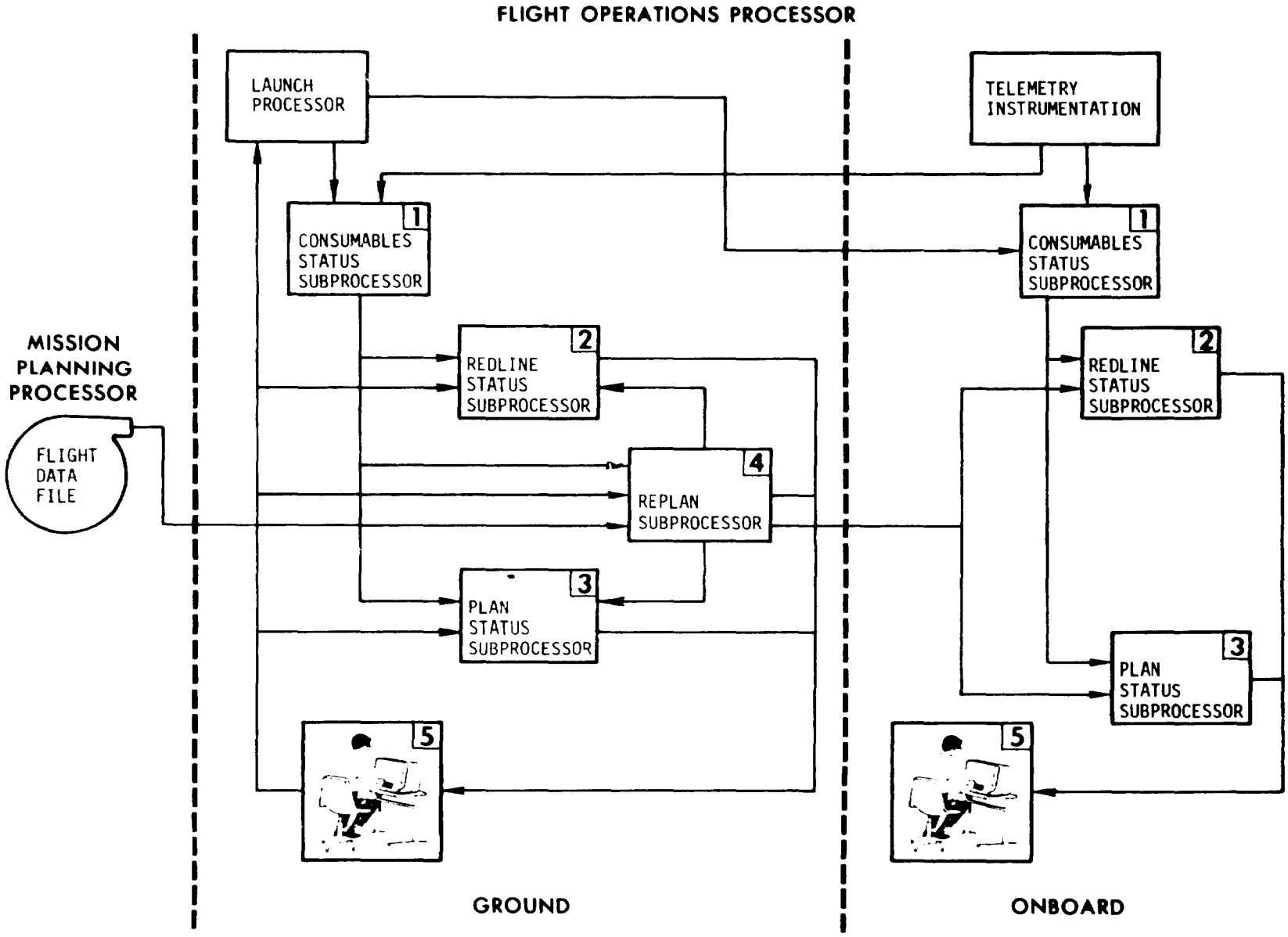

Figure 4. Advanced Onboard Capability (Option 3)

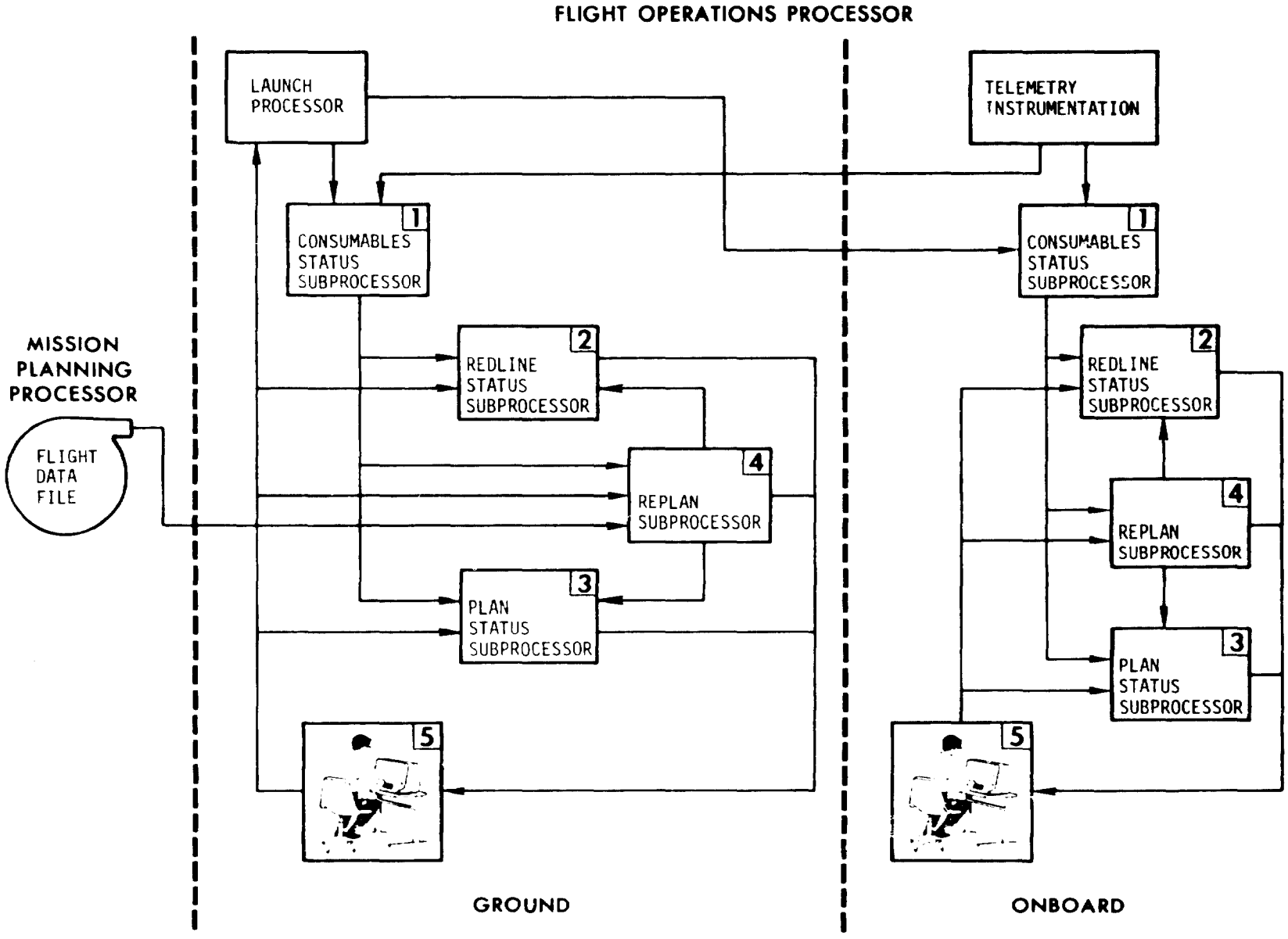

Figure 5. Advanced Replan Capability (Option 4)