"on-board" is used as an adjective and should be one word.

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ON-BOARD FILE MANAGEMENT AND ITS APPLICATION IN FLIGHT OPERATIONS

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ABSTRACT

With the advancement of flight computers, operating systems, and mass storage for the flight system, the management of flight data can be vastly simplified if they are treated as files, thus reducing the size of the operations team and its cost. In a similar fashion, sequences and flight software loads can be uplinked and managed as files to ensure reliable delivery and to remove the labor intensive memory management task from the operations team.

In this paper, the author presents the minimum functions required for an on-board file management system. We explore file manipulation processes and demonstrate how the file transfer along with the file management system will be utilized to support flight operations and data delivery. The autonomous flight system concepts to be validated in ~~the~~ NASA's New Millennium Program, are used for illustration, although these file methods can be applied to traditional flight operations as well.

1. ON BOARD FILE MANAGEMENT SYSTEM

The file management system provides the tools necessary to access files and portions of their contents. A file management system, in its simplest form, is an object that consists of a non-volatile storage area, a data structure, and a method. The storage area is where the files are physically stored. The data structure maintains the directory of the stored files. The method provides file manipulation services to its user. The on-board file system will have these three basic elements.

The directory contains information about the files such as file name, file size, physical location, creation date/time, and current status. The directory is a file itself which is also stored in the non-volatile storage area. The directory is subdivided into subdirectories which are assigned to different applications. A subdirectory is a container for storing application programs and data files. The file names assigned by the application could be descriptive of their contents and the extension could be used to indicate the file's type. For example a file 182103352to182224145.eng is a file containing engineering data from time 182:10:33:52 to 182:22.41.45.

The file manipulation services provided by the file management system are typically implemented by software processes. These processes provide a set of primitives for other on-board processes to store, retrieve and manipulate files. The following are a minimum set of primitives.

Directive	Parameters	Description
open	'filename', options {e.g. create, update, append, read, lock}	Open the specified file with the specified options. When the option is create, update, or read, the access position is automatically set to the zero, i.e. the start of the file. When appending to a file the position is automatically set to the end of the file. 'Open' returns a descriptor which is used by the other primitives to specify the opened file for access.
seek	descriptor, position	Set the specified file read/write pointer to the particular position
read	descriptor, buffer, size	Read the specified number of data bytes (size) from the specified file. The file position is advanced by the number of bytes read. Buffer is the location where data are to be read into
write	descriptor, buffer, size	Write the specified number of data bytes to the specified file. The file position is advanced by the number of bytes written. Buffer is the location of data source
close	descriptor	Close the specified file
delete	'filename'	Delete the specified file from the specified subdirectory

The following are primitives to manipulate the directory.

Directive	Parameters	Description
rename	'oldfilename','newfilename'	Change a filename. Replace the old name with new name in the directory. The data in the storage area stay untouched
remove	'filename'	Erase the directory entry but leave the data in storage area intact
makeDir	dir_name	Create a new subdirectory with dir_name

Using these primitives, file transport, manipulation, and complex file management function can be achieved. This paper will focus on the methods that can be implemented for file manipulation and how these methods aid the operations team in support of control and science data acquisition process.

2. FLIGHT OPERATIONS MODEL

The flight operation model contains a space segment and ground segment, as depicted in Figure 1.

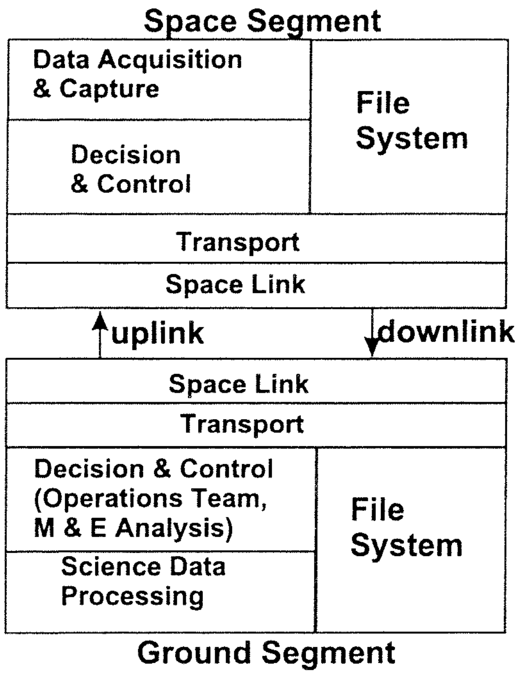

Figure 1 Flight Operations Model

The decision and control logic is distributed between space and ground. The weight of the distribution depends on individual mission design. A simple spacecraft may leave all the decisions to the ground with the spacecraft capable of only executing control sequences forwarded from the ground. On the other side of the spectrum, a fully autonomous spacecraft can make all the decisions on its own without ground intervention. It is often required that details of the spacecraft's operations and status be downlinked to the ground for monitoring and analysis. Decisions made on the ground are then translated into commands, which are then uplinked to the spacecraft for execution. The smarter the spacecraft, the lighter the flight operations traffic on the space link. Future JPL missions will follow the later paradigm, reducing operational cost by on board data analysis and infrequent tracking passes.

NASA's New Millenium program is driven by space technology. It plans to fly autonomous spacecraft that can perform automatic flight operation on board the spacecraft. In this approach, the decision and control logic resides on the flight segment. The short monitor and control loop, provided by this approach, allows the spacecraft to make more effective in situ decisions. The ground need only react to situations that can't be handled by the on board intelligence. It is important, therefore, that the ground have enough visibility into operations to assist the on board system when required.

The mission plan is a high level form of mission goals that is stored as a file in the mission planning directory on board the spacecraft prior to launch. The mission plan is segmented into multiple planning horizons each separated by way points and each stored as a separate file. The on board planner retrieves the goals of a planning horizon from mission plan and generates a script file that contains the detailed steps for execution by the spacecraft Smart Executive. Figure 2 shows a simplified block diagram.

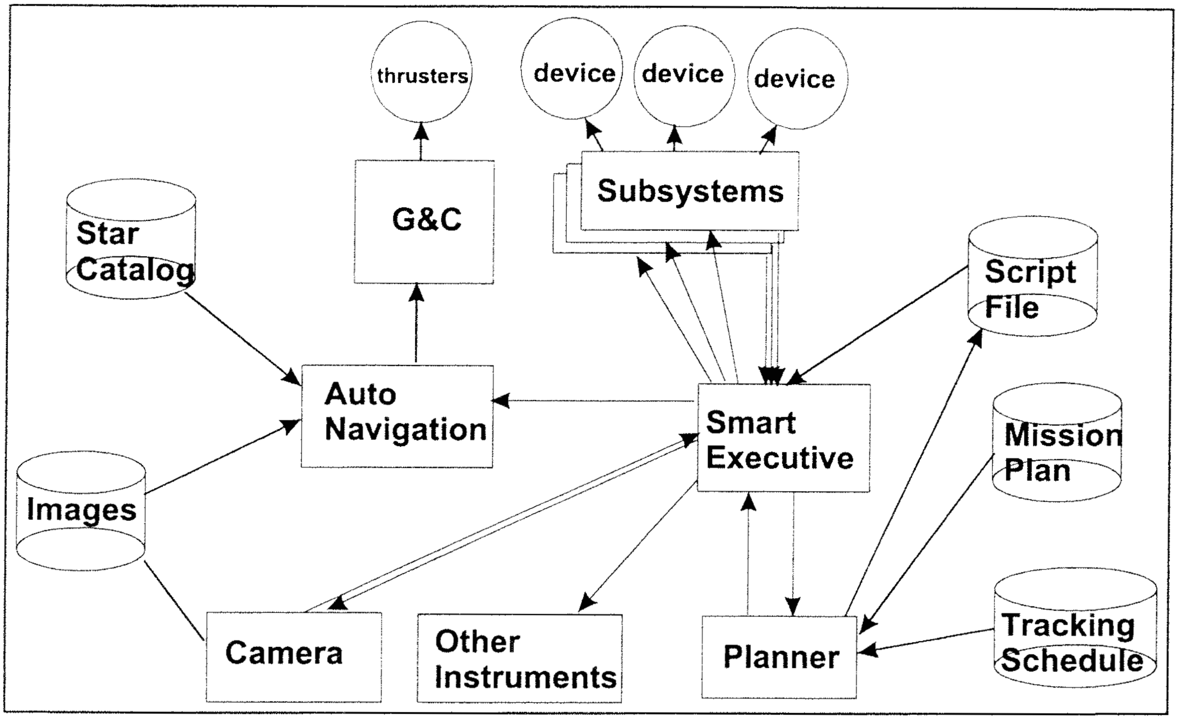

Figure 2. New Millenium's Flight Operations concept

Ideally, the autonomous spacecraft can perform planning and execution to accomplish the mission goal without ground interference. However, it is necessary to allow plan changes due to unexpected situations or changes in spacecraft performance. It is sometimes required to replace a script with a new one. To tell the spacecraft when to phone home, new tracking schedules are uplinked periodically. The star map, which is used for auto navigation needs to be refined occasionally. These activities require data transfer between the spacecraft and ground systems.

3. FLIGHT OPERATION WITH FILE TRANSFER

The on board file management system can be used remotely by the ground operations team. The on board file management system provides its services to the operations team thus eliminating the team's need to manipulate the flight system's data at the byte level. The spacecraft's data is store on-board as named data files. The operations team can request information about these stored files and then request actions to be performed on these files (e.g. transfer the file to the operations center). A special file transfer protocol that can reliably perform~~s~~ the file transfer in the deep space communications environment is needed for this type of flight operation~~s~~.

or
these types of flight operations

3.1 FILE TRANSFER CHARACTERISTICS

A file transfer protocol provides connectivity between the spacecraft and ground systems. The file transfer entity that implements the space link file transfer protocol provides the capability to move files, manipulate files, and deliver messages. Moving a file is a point-to-point process that transports a file from one file storage to another file storage. The metadata associated with a file is also transported in the move file transaction. The file manipulation process included within the file transfer entity performs the load file, replace file, patch file, and append file functions per instructions contained within the transaction's metadata.. Message delivery is a user-to-user function. A user message when included within the metadata, is delivered to the destined user application at the time and condition specified in relation to the file transfer. These three elements play important roles in supporting flight operation. A file transfer protocol that possesses the subscribed capabilities can be found in Reference 1. Figure 3 shows the spacecraft architecture including the file transfer entity using autonomous spacecraft design.

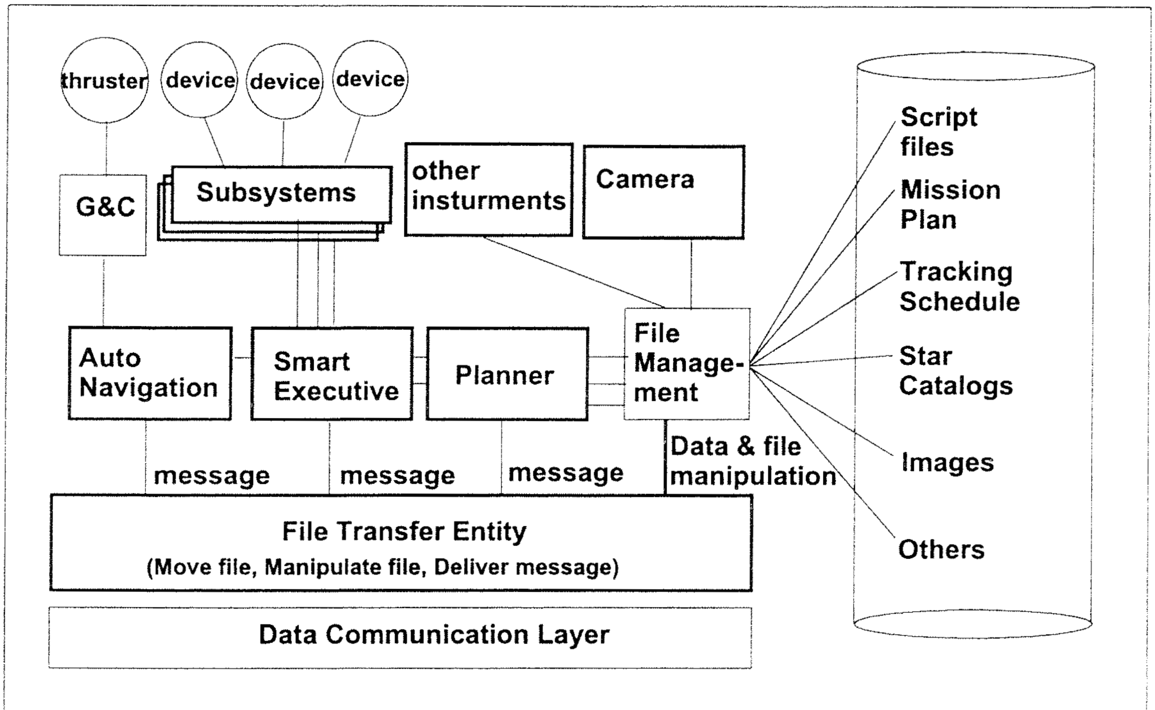

Figure 3. Autonomous Flight Operations using file transfer

To move a file, the file transfer entity utilizes the file management system to open a file, reads the file segment by segment, then uses the data communications service to send the file segments to the destination file transfer entity. The destination file transfer entity uses the segment offset to position the write directive. The segment offset allows the re-construction of a file with file segments delivered out of order. The move file element of two file transfer entities work together to accomplish the move file function. The received file is given a temporary file name for the file manipulation process to access. Multiple files may be in transfer simultaneously. The metadata of each file transfer contains an enterprise unique identifier to be used to identify each temporary file.

The following describes how the file transfer and manipulation processes are used to support the on board decision & control functionality and science data delivery.

3.2 DECISION AND CONTROL DATA TRANSFER

New tracking schedule files are uplinked to the spacecraft on a regular basis. When the ground operation team transfers a new tracking schedule file, it also includes a message, addressed to the Planner, containing the name of the file and instructions for the Planner. The on board file transfer entity forwards the message to the Planner upon completion of the file transfer. Any actions associated with the file will be started by the Planner only after the triggering message is received.

There occasionally will be mission plan updates. The magnitude of these updates will vary. The update could be a tweak, which is accomplished by a file patch; an expansion, which may be accomplished by a file append; or a complete re-vamp, which requires replacement of the original file.

The sequence of activities required to patch, append, and replace, all use the same three steps: (1) perform a move file, (2) trigger the file manipulation process, (3) inform the application that a modification of the file has occurred. A file transfer in the space communication environment could take multiple tracking passes to complete. It is important to perform file modification only when the modification file is completely transferred and error free. The timing of the delivery of the triggering message is important. If the message is not included within the file transaction then a separate transaction would be required to carry the triggering message. If a separate transaction was to deliver the message then it is possible that the message could be lost, or delivered before the file's transfer was complete. This problem could be overcome by having the ground only initiate the transfer of the triggering message after receipt of the file delivery acknowledgment from the spacecraft. The delay associated by this process may be unacceptable; such as a required re-planning can not be done in time, resulting in ripple effect to the subsequent planning horizons.

3.3 TELEMETRY DATA MANAGEMENT AND DELIVERY

Engineering telemetry is normally acquired and transferred to the ground in a continuous stream of engineering measurements. These measurements are carried in either TDM frames or engineering packets. The ground system analyses the incoming stream and determines the health and status of the spacecraft. JPL's future missions are driven by the "Faster, Better Cheaper" paradigm which at JPL can be summarized by less frequent tracking support, and more automated spacecraft. The engineering data for these missions is collected and stored in the random access storage as a file, which contains the engineering packets. This data is summarized and the summary is transferred to the operations team. The operations team then selects which data within the file it would like transferred and whether the file should be maintained or deleted. The accounting for the data is performed at the file level not the packet level, simplifying the data management task in addition to the operations team's task.

Science data collected for a specific activity can be stored in the mass storage system as file. For instance, image and instrument calibration data ~~has~~ have inherent natural boundaries. The field and particle experiment data ~~has~~ have a well defined instrument cycle. The data would be stored as files possibly by data type and in the form that the science data processing desires. One way of organizing the stored data is to assign a science activity to a subdirectory; the acquired data are stored as files within an allocated subdirectory. The operations team could define delivery priorities for this data and defines the order that the files are transferred. It is also reasonable to expect that selected data sets would require complete (reliable) delivery while others could tolerate some loss. As the intelligence necessary to determine which data ~~is~~ are most important or ~~has~~ have the highest scientific interest then the spacecraft itself could prioritize the data transfer. Since the data are all accounted for in files, the ground could use the directory listing to account for the delivery of all acquired data.

4. SUMMARY

Using the on board file management system, the operations team has more flexibility and control of the on board data. The descriptive file name gives the operations team a quick notion of what's in the file. They can selectively retrieve a cluster of files, a particular file, or a partial file. Any un-interested telemetry file can be deleted. The on board file directory also provides information about the usage of storage area and allows the operations team to update its knowledge about the actual memory state.

With autonomous flight operations and more spacecraft in flight for the future, the trend is fewer and less frequent ground tracks. Long propagation delay and infrequent contact make the real time operation meaningless. Instead, ground operations will focus on data summarization, trending, fault isolation, and calibration. The ability to prioritize, select, and pre-process (data compression, editing, summarization, etc.) portions of selected data to downlink make operations more effective. Compression technology is steadily advancing and the use of thumbnail summaries for review and data selection and priority setting will steadily increase. The on board file management and file transfer provide the enabling technology to make it a reality.

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