A CONCEPT FOR A TRANSPARENT DATA ACQUISITION AND DISTRIBUTION SYSTEM FOR SPACEFLIGHT APPLICATIONS

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ABSTRACT

The emergence of “smart” sensors onboard space missions is forcing a reexamination of the procedures by which NASA acquires, multiplexes, transmits, annotates, and distributes sensor data to the user community. Increasingly we find that “smart” sensors are being planned for future space missions which will search for specific unusual phenomena and, when present, record these phenomena in great detail. This gives rise to the need for a widely varying bandwidth requirement from each instrument in response to the occurrence of phenomena that cannot be anticipated in advance.

An asynchronously multiplexed packet telemetry concept is described which, within broad limits, permits instruments to acquire and transmit information at the rate appropriate for the experimental phenomena being observed. Data from a single instrument, along with the necessary ancillary data (typically time, position, and attitude), will be assembled into self-contained packets and will be subsequently transmitted over various communications links (i.e., space telemetry channel, ground communications circuits, etc.) to the experimenter’s facility in near real time. Reliable error control coding will be included in each link transmission to protect the integrity of the data packets.

A major objective is to make the entire data acquisition and distribution process completely transparent to the experimenter in the sense that the output terminal of the distribution system will be physically, logically, and electrically identical to that of the experiment output channel. To provide greater inter-mission portability of instruments and to reduce the instrument interfacing costs, the emerging national and international telecommunications standards (ADCCP/HDLC/SDLC, X.25, etc.) will be utilized as the instrument interface standards wherever practical. Except for the time delay imposed by propagation and nominal queueing considerations, the experimenters will observe an interface identical to that which would occur if the instrument were physically located at their facilities.

INTRODUCTION

The Modular Data System (MDS) of the NASA End-to-End Data System (NEEDS) Program is intended to develop and demonstrate the technology that will provide greater instrument autonomy; faster data dissemination; and less costly instrument development, testing, integration, and analysis. The key feature of MDS is that data representing a set of experimental observations from a single instrument will be encapsulated into a data packet at the source and this packet then becomes the basic transmission unit in the distribution of instrument data to the users. Provisions will be made for the encoding and dissemination of ancillary data (typically time, position, and attitude) needed for the interpretation of the observational data from the instruments.

RATIONALE

To understand the rationale for the MDS concept, it is necessary to consider how spaceborne instrumentation has evolved—and is still evolving—since the early days of space exploration. The early space instruments were typically sensors which surveyed some phenomenon (i.e., magnetic field, particle flux, etc.) and generated a fixed rate of observational data points. The telemetry multiplexing requirements from such sensors were easily accommodated by the word-multiplexed telemetry frame approach adopted for these early missions. Although some flexibility has since been added by implementing a number of commendable transmission rates and data formats, our present mode of telemetry multiplexing and information distribution has changed little from the early space missions.

The nature of the space instrumentation has drastically changed from our fledgling start in the late 1950’s. While instruments of a general survey variety will continue to be flown, there is a clearly discernible trend towards more specialized instruments which will search for phenomena of an unusual or transient nature whose occurrences cannot be predicted in advance. To be responsive to the data requirements of these newer instruments, greater instrument autonomy is needed along with an adaptive method of allocating onboard storage and telemetry bandwidth resources among the various instruments on the basis of current need.

Most imaging instruments being planned for space applications still rely on a synchronous scanning mechanism which generates observational data at a fixed but very high rate. However, considerable activity is underway to develop processors which will perform onboard data extraction. Thus the need for adaptive resource allocation for imagery sensors will shortly parallel the present need for such capability from science payloads.

In the upcoming Spacelab mode of operation we can expect a greater number of missions, each with a shorter mission operational period (5-7 days), with a shorter pre-launch planning and implementation period. To meet these data processing and distribution requirements using our present mode of operation would require far more personnel and monetary resources than will be available. The MDS concept seeks to provide more efficient and cost-effective data processing and distribution by eliminating the mission- and instrument-unique functions in the intermediary stages of the overall data management process. By performing source encoding of the data from each instrument into an autonomous data packet format and providing user-transparent telecommunications within each intermediary transmission link, an end-to-end “Bent-Pipe” mode of operation will be achieved which is simultaneously more cost-effective and responsive to the user requirements.

DATA STRUCTURES FOR MDS CONCEPT

It is important to distinguish among several different levels of telecommunications protocols and standards. Each of these levels operate on a different hierarchical plane and are decoupled from each other.

The lowest level (Level I) is concerned with the physical and electrical interchange signals and conventions for data transfer. This level defines such parameters as voltage levels, impedances, modulation characteristics, signalling rates, connector types and pin specifications, and similar details. Examples of Level I standards are EIA RS-232, IEEE-488, and the physical/electrical signal specifications of the IRIG and NASA Telemetry Standards.

The Level II protocols or standards are concerned with the logical data structure needed for the reliable and efficient telecommunications over a single link. Included in this level are mission unique telemetry frame multiplexing formats, the Nascom digital data block formats, the link-unique error control procedures, the logical data structure specifications of the NASA/GSFC PCM Telemetry Standard as well as the non-NASA standards such as the BiSync, SDLC. HDLC, and ADCCP protocols.

Level III protocols apply to the end-to-end data structure extending from the source to the users. The Consultative Committee on International Telephony and Telegraphy (CCITT) has proposed a so-called Level III standard known as X.25 which is gaining acceptance but is not universally recognized at this time. However, X.25 is not truly an end-to-end standard but rather is a means for interfacing a data terminal to a data communications network. There is no currently accepted standard end-to-end protocol for data communications, although the American National Standards Institute (ANSI) and the International Standards Organization (ISO) are working on this problem.

There is no present data structure used by typical NASA missions which extend from end-to-end. Typically we have spacecraft encoded telemetry frames which are later decommutated by a ground data processing system in order to generate experiment data files which are then distributed to the user. The MDS concept would extend the umbrella of telecommunication control to Level III.

MDS DATA FLOW

In the following description the MDS concept will be explained on the basis of a fully implemented system. It must be recognized that it will undoubtedly be necessary to phase various features into the overall system in an evolutionary rather than revolutionary manner. During this phaseover period, it would be necessary to provide for support for conventional missions as well as missions with varying degrees of MDS implementation.

Figure 1. represents the data flow from the sensor to the primary ground station. Level III encoders or packet generators associated with each of the individual instruments and spacecraft subsystems will encode a set of experimental observations into a data packet along with the necessary ancillary data (typically time, position, and attitude) needed to permit the subsequent analysis and interpretation of the observational data on a stand-alone basis. The Level III format for each data packet will be instrument-unique subject to some very general overall constraints such as packet header specification and maximum packet length. Via either a polling or interrupt procedure, the Level III Multiplexer will recognize when a packet has been assembled in a packet encoder and will direct a transfer of this packet into the Level III Multiplexer over the Packet Bus. It should be noted that the rate at which packets are generated and forwarded to the multiplexer is variable; thus, queueing buffer(s) must be provided to accommodate surges of packets which temporarily exceed the telemetry transmission rate.

Under the control of the Level II encoder, packets will be transferred from the Level III Multiplexer into the Level II encoder where each packet will be assembled into one or more telemetry frames complete with error control coding. These encoded telemetry frames from a single source packet will be sequentially transmitted over the telemetry link and will also be temporarily held in a retransmission control buffer.

When the telemetry signal is received at the primary ground station, it is processed by a Level I decoder which performs demodulation, bit synchronization and detection, and passes the detected bit stream over to a Level II decoder. There frame synchronization and error control decoding is performed. Retransmission request messages are uplinked to the spacecraft for any frames that cannot be reliably decoded. When a complete packet has been reliably detected, it is then stripped of its Level II control fields (coded telemetry frame format) and reassembled as a data packet (Level III). It is then forwarded to the

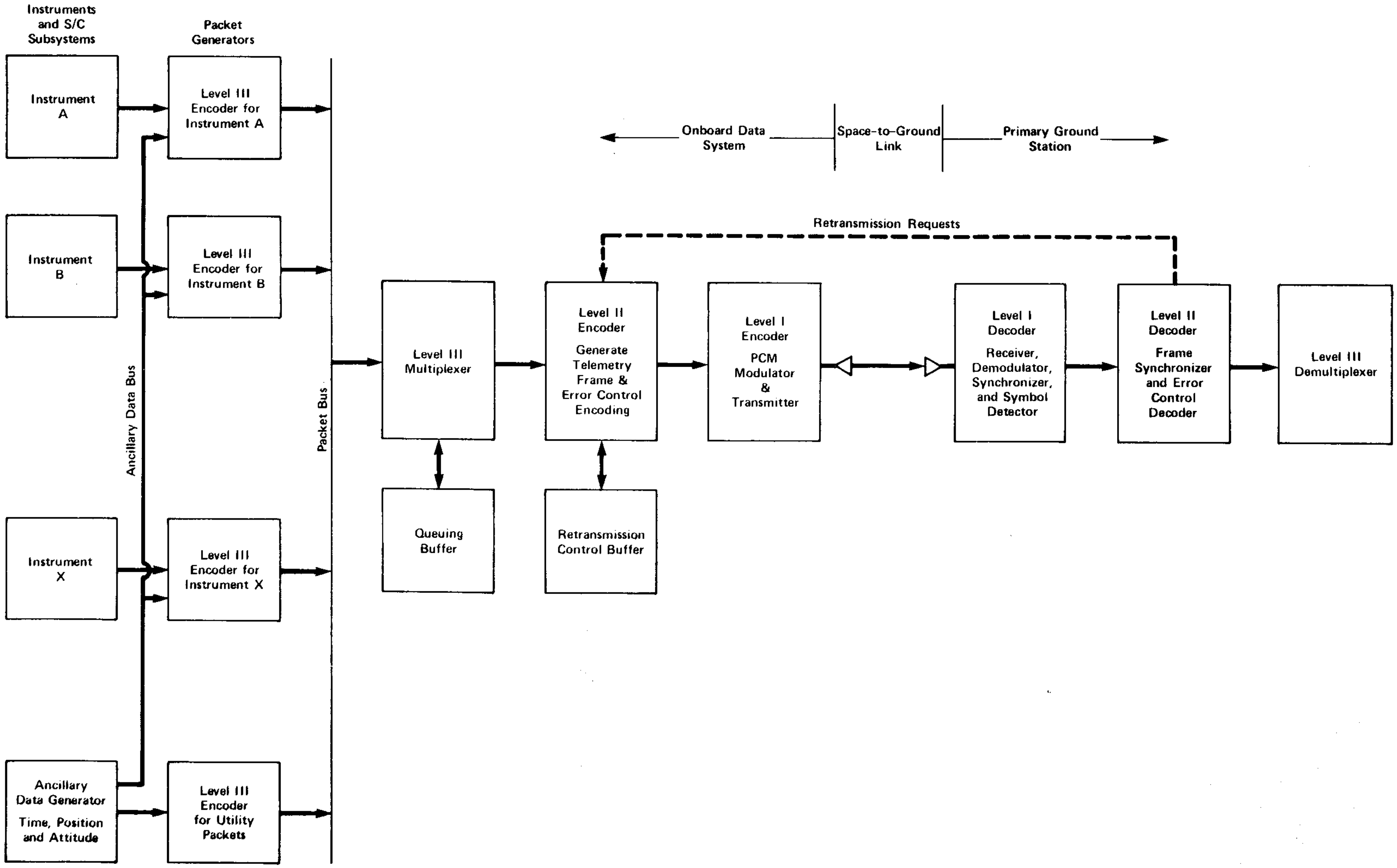

Figure 1. MDS Data Flow from Sensor to Ground Station

Level III Demultiplexer which distributes the packet to the user(s) via the data flow shown in Figure 2.

Before describing the subsequent data flow it is appropriate to consider two questions that the preceding discussion may have raised:

1.) Why not use forward error correction rather than the previously implied error detection/retransmission mode of error control?

and, 2.) Why aren't the data packets transmitted directly, thus eliminating the telemetry frame structure alltogether?

The answer to the first question is that forward error correction is not excluded by this concept; however, neither is it the only form of error control which we can consider. It is well known that error detection/retransmission control techniques are more robust in that they will perform reliably over a much wider range of channel error conditions than can forward error correction methods. It is interesting to note that ground-based telecommunication systems utilize error detection/retransmission control techniques virtually exclusively whereas space communications has utilized forward error correction only. Why? The use of retransmission control for ground telecommunications is based on the previously mentioned insensitivity to channel error statistics. Historically the use of forward error correction for the space link was based on the lack of an adaptive telemetry multiplexing technique (to retransmit the occasional frame originally received in error) and the requirement for temporary onboard storage of transmitted telemetry frames pending verification from the ground. The MDS concept provides adaptive multiplexing and the rapid advances in digital logic technology makes onboard storage feasible. As space technology matures, it is both natural and desirable that the proven techniques for ground based systems be at least considered for comparable space applications.

The encoding of packets into telemetry frames is recommended since the very wide dynamic range of the packet length formats needed by different instruments will, in general, be incompatible with reliable error control on the space-to-ground link. Thus the instrument design of a synchronously scanning imaging instrument may require a logical packet length of a million or more bits. Under the expected RFI and random noise environment, there is no way that forward error correction coding could provide the necessary data integrity assurance for such long packets. Furthermore, retransmission control procedures would be very inefficient due to the excessive number of retransmissions that might be needed. Thus an intermediary data structure such as a fixed-length telemetry frame bridges the gap between the logical packet size requirements of instrument designers and the need for reliable error control. As a Level II structure, the telemetry frame encoding/decoding process will be completely transparent to the user and will serve only to protect the space-to-ground data integrity.

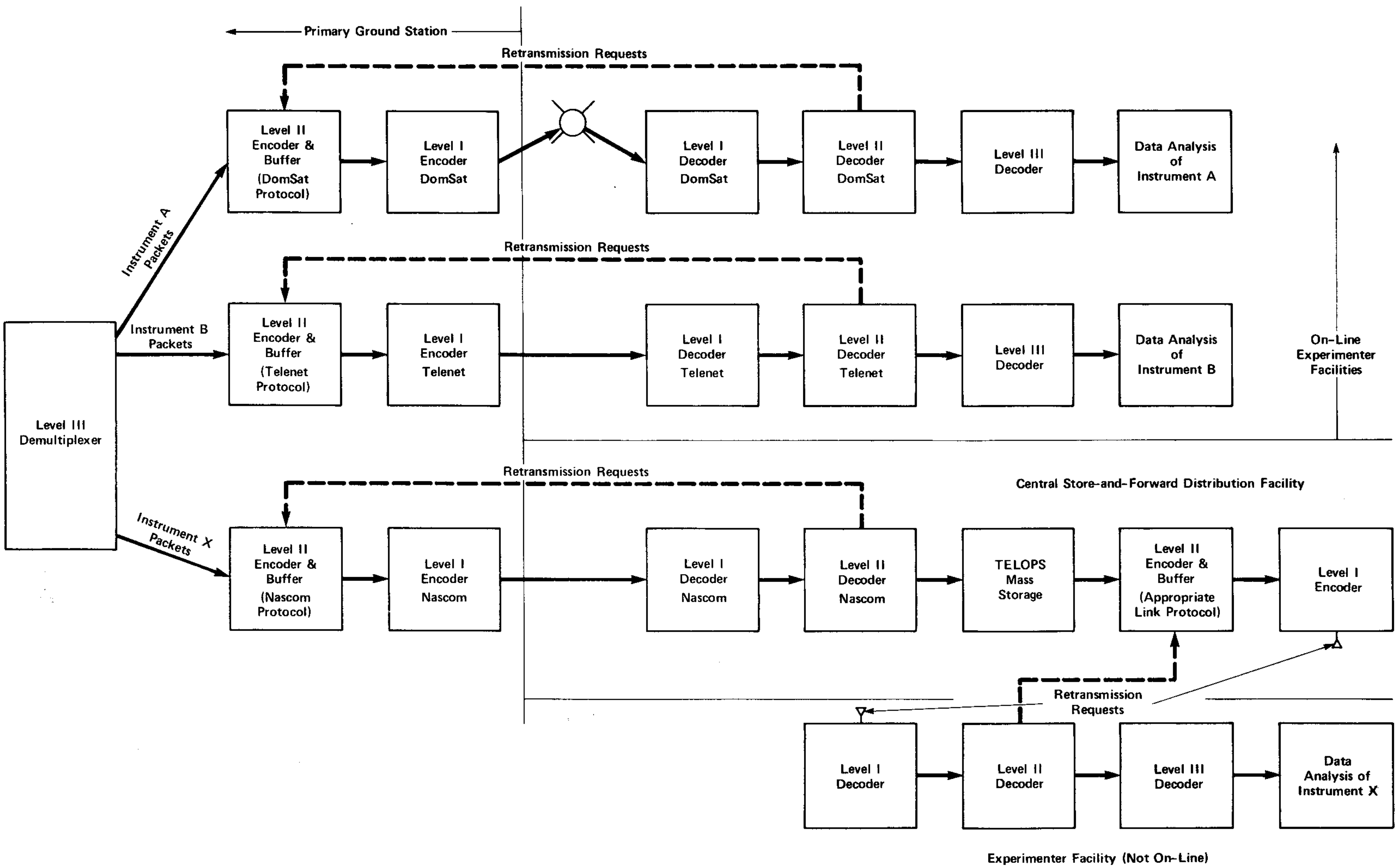

Figure 2. MDS Data Flow from Ground Station to User

A major goal of the MDS concept is to reduce errors in all transmission links to a negligible level. Why the sudden emphasis on nearly error-free transmission since we have had to learn to cope with non-negligible error rates in past space missions? There are two answers to this question. First, with the adaptive multiplexing capability afforded by MDS, transmitted telemetry data can be expected to become far less redundant than in past missions. Therefore the information value per transmitted bit will increase, thus placing greater importance on insuring the data integrity of the non-redundant data which is transmitted. The second answer is that there is a very heavy cost involved in the extensive data consistency, validation checking, and correction process that is currently needed to mitigate the effect of these transmission errors. The effort is spread over the entire data management cycle so that it is very difficult to estimate the total magnitude of this expense. However, it is clear that considerable cost reduction would be achieved if transmission errors were reduced to a negligible level.

It should be noted that in addition to transmission noise errors there are also sensor noise errors and MDS does nothing to correct the latter. However, sensor noise is an anomaly with which the Principal Investigator or Facility Instrument Team must inevitably wrestle. There are no blanket answers to sensor noise problems; however, it is certain that the cognizant personnel can deal more effectively with sensor noise if it is the only noise source in the received data set.

Figure 2. illustrates the expected data flow from the Level III Demultiplexer to the individual users. This is anticipated to involve two modes of operation: 1.) direct on-line transmission, and, 2.) delayed transmission via a central store-and-forward facility. In this figure packets from Instrument A and B follow the direct mode and Instrument X packets follow the delayed mode.

As in the space link, it is anticipated that some form of Level II coding will be needed for all transmission links. The nature of this coding will be dependent upon the characteristics of the individual links. Depending on geography, sophisication of user facilities, and bandwidth requirements, some of the telecommunication network possibilities are FTS, Nascom, ARPANET, TELENET, and SBS-leased channels through domestic communications satellites. Most of these networks will impose some control over the Level II transmission protocols.

It will be necessary to develop Level I and II encoding/decoding interfaces and processors for the link conversions that are needed on the space-to-ground link and the various telecommunications networks to be utilized. However, these are one-time development expenses and no recurring mission-unique development cost will be incurred. In addition to the cost savings that can be anticipated, the elimination of mission-unique hardware/software development will improve the reliability of the overall information transfer process.

EXPECTED BENEFITS DUE TO THE MDS CONCEPT

The preceding discussion has concentrated on the benefits of the MDS concept during the mission operations phase. A summary of these benefits are:

- Permits instruments to acquire data at a rate appropriate for the process being observed rather than at some arbitrary assigned sampling rate

- Permits onboard memory and bandwidth resources to be dynamically allocatable on the basis of the current resource demands among all instruments

- By providing ancillary data annotation at the source, the need for intermediary processing steps to generate and merge the observational and ancillary data is eliminated

- Permits on-line distribution of instrument packets to users over a variety of cost-effective communications networks

- Reduces noise errors due to the transmission and distribution process to a negligible level

- Eliminate mission-unique hardware/software development in the information transfer process thereby reducing cost and improving system reliability.

There are a number of other benefits of the MDS concept which extend beyond the mission operations phase. Carefully designed Level I (IEEE-488) and Level II (SDLC/HDLC/ADCCP) standards have been developed and low cost LSI chips to implement these standards are commercially available. Level III standards and LST implementations are expected shortly. If these standards are adopted for the data interface between instrument packages and the spacecraft telemetry subsystem, then these LSI components will both simplify and reduce the cost of the instrument design. These standards will also facilitate the establishment of a single data interface during all phases of the instrument's life as well as promoting portability of spaceflight instrumentation among different missions.

An Instrument Test and Analysis Subsystem (ITAS) is customarily designed concurrent with the development of each spacecraft instrument to stimulate, exercise, (calibrate, and analyze the data from the instrument during the fabrication and bench testing periods, During these pre-launch phases, this interface between the instrument package and the ITAS is thoroughly exercised to the point where the investigator develops considerable confidence in the total system. Typically the ITAS will include access to a digital computer and specialized software will be developed to exercise the instrument and to analyze the resulting data. Because of the lack of adequate data autonomy in the current mode of operation, this trusted interface is broken during the spacecraft integration phase and new interfaces and formats are established. Typically this requires a considerable redesign of both hardware and software on the investigator's part. Furthermore, since there is only a very limited amount of pre-launch checkoutime with the new interface, misunderstandings concerning formats and conventions can easily arise which causes both confusion and a need for re-engineering during the mission operations phase.

In the "Build-to-Operate" mode shown in Figure 3, the data interface between the instrument package and the ITAS remains identical during all mission phases. During the mission operations phase, a number of additional modules within the spacecraft and the ground distribution system will be added in series to this interface; however, each link within the chain will be designed to be transparent to the user. Data in the same logical format will be supplied over the same type of electrical connector with the same electrical conventions during the mission operations period as during the pre-launch bench testing period.

SUMMARY

The MDS concept is designed to provide efficient and cost-effective data acquisition and distribution from space instrumentation to the user community. Emphasis is placed on defining a compatible hierarchy of standard interfaces and protocols that will both provide a convenient user-interface and insure reliable end-to-end data transfer.

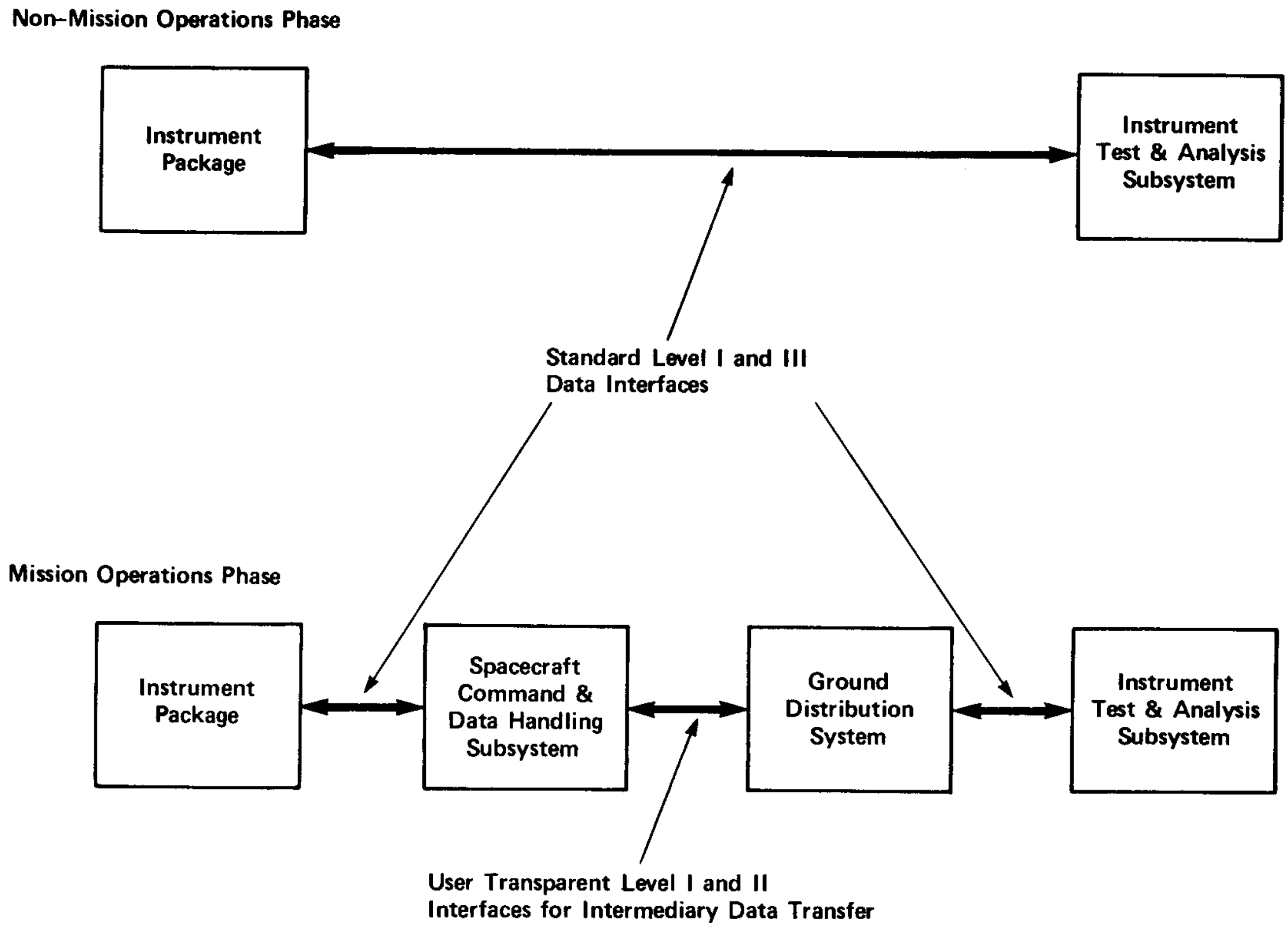

Figure 3. Build-to-Operate Mode