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FLIGHT DATA DISPLAY STUDIES for REAL TIME COMPUTER FLIGHT EVALUATION

FINAL REPORT
CONTRACT NAS8-11276

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by C.F. Matthews
J. W. Tuttle
J. C. Flint

Submitted to:

COMPUTATION DIVISION
MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

Submitted by:

RADIO CORPORATION OF AMERICA
DEFENSE ELECTRONIC PRODUCTS
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SECTION 1

SUMMARY

This report presents the results of a study of real-time displays for monitoring the flight of Saturn launch vehicles at the Huntsville Operational Support Center (HOSC) at the Marshall Space Flight Center.

The study was conducted to support the current Saturn I Block II flights, which were monitored in an interim HOSC facility, and to study display requirements for future Saturn IB and Saturn V missions. The specific objectives were to determine:

- data to be displayed
- data sources
- formats for display

These tasks have been accomplished. The support for the current flights was provided in Monthly Contract Progress Reports.[1] This final report presents a general analysis of the display requirements and includes specific examples of the application of this analysis to a Saturn I Block II vehicle (SA-9) and to a Saturn IB vehicle (SA-201).

The report emphasizes the importance of providing reliable and valid display data and identifies the major factors involved in achieving this capability.

SECTION 2

INTRODUCTION

2.1 PURPOSE

Real-time data facilities and displays at the Huntsville Operations Support Center (HOSC) are intended to:

- Provide a focal point of personnel and data to support Saturn pre-launch and launch operations
- Provide personnel responsible for post-flight evaluation of the launch and flight with data and information that minimize the time and effort required to recognize, isolate and analyze problem areas if and when they develop
- Provide a focal point of personnel and data to support real-time mission control
- Provide general information to selected technical and administrative personnel regarding the progress, success and problems of the mission.

This real-time operation at MSFC is, at present, an evolutionary process in that it is being carried out in a changing environment consisting of facilities which are rapidly expanding in capability, missions which are changing in objectives, and vehicles which are changing in configuration. The changes in facilities include the recent addition of a data link to Cape Kennedy and the imminent addition of new HOSC facilities now under construction. The mission objectives are changing in emphasis from launch vehicle research and development towards eventual application to manned and unmanned operational missions. In many respects, therefore, current real-time operations are "learning curves" of activity evolving toward the support of operational missions.

The purpose of this study was to aid this operational support evolution. Specifically, the objectives, as defined in the contract work statement, were as follows:

- Determine the most meaningful data for Saturn real-time display at MSFC.
- Determine the information required to furnish these displays.
- Determine appropriate formats for the displays.

2.2 SCOPE

The period of performance of the contract, July 1964 to June 1965 (extended to September 1965), encompassed the Saturn I Block II vehicles SA-7 to SA-10 (Figure 2-1) and preceded by some months the planned flight date of the initial Saturn IB vehicle. Correspondingly, the study was concerned with the current Saturn I flights as well as the future Saturn IB flights.

The Saturn I flights were covered by interim reports issued with the monthly contract reports[1]. Originally it was intended that one interim report would be prepared for displays for vehicles SA-7 through SA-10. However, a single interim report was not adequate because of continuing changes in the data and display facilities available for succeeding Saturn I flights.

Based on the detailed display investigations conducted for the Saturn I Block II vehicles, generalized display requirements have been developed which can be applied to future vehicles and flights. Typical

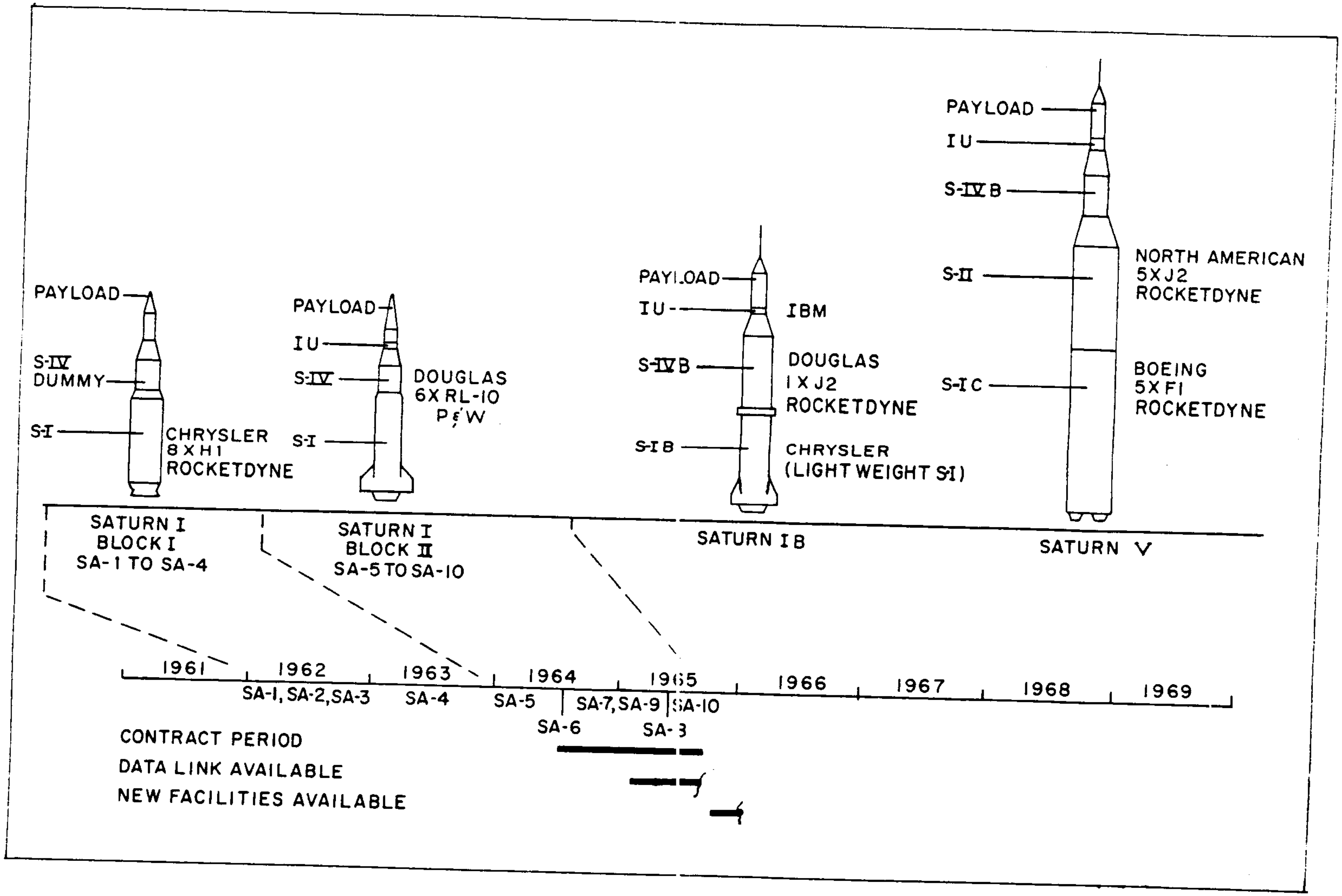


Figure 2-1. Saturn Vehicles

detailed application examples of the generalized requirements are given in the Appendices for SA-9 and SA-201. Because of the lack of an early precise definition of the planned new facilities for the Saturn IB era, the study was conducted with particular emphasis on those areas which are primarily independent of the exact configuration of the facilities and the vehicles. The result of this study was a series of analyses which form the basis of this report. They are indexed in Table 2-1.

The organization of this report closely follows the delegated tasks outlined in Section 2. 1 above.

- Real-time Display Requirements are in Section 3.
- Information for Display is in Section 4.
- Displays are treated in Section 5.

Chapter 6 is a brief summary of the Saturn real-time operations to date. Some practical operational considerations are also discussed in this chapter. Conclusions and recommendations are given in Chapter 7.

Table 2-1. Index of Vehicle and Systems Display Analysis Conducted

SUBJECT	GENERAL	SA-5 6 7	SA-9	SA-8	SA-10	SA-201	FINAL REPORT See Section:	INTERIM REPORTS (Notes Issued As Enclosures to Monthly Reports No: - . (Ref. 1)
• General Review of MSFC Real-Time Operations	x	x						Internal RCA Reports
• Review of SA-6, 7 Displays		x						3
• Systems of Interest in Real-Time	x						3.5.1	3
• Trajectory	x		x	x			3.5.3 App. B	5, 6, 9, 12
• Abort Systems	x				x	x	3.5.2 3.5.5 App. D	11
• Stabilization and Control	x		x	x		x	3.5.5 App. D	6, 9
• Propulsion	x	x	x			x	3.5.6 App. E	3, 6
• Electrical Systems	x		x			x	3.5.7 App. F	
• Events	x		x	x		x	3.5.4 App. C	9
• Display Requirements	x		x	x	x	x	3 App. B to F	3, 4, 6, 9, 11
• Display Formats	x		x	x			5 App. G	2, 4, 5, 6, 9, 11
• Operational Considerations	x						4, 6	8, 12

SECTION 3

REAL TIME DISPLAY REQUIREMENTS

3.1 GENERAL

Section 2.1 in the Introduction identified the fact that real-time facilities of HOSC are provided for a variety of reasons. However, this study is concerned only with the displays associated with monitoring the flight phase of the Saturn launch vehicle operations. Thus we are concerned with providing information for:

- support of real-time mission control
- real-time "quick-look" at data of interest to post flight analysts to generate a feel for problem areas, if and when they develop.
- general displays of interest to an audience of selected technical and administrative personnel.

These display and monitoring requirements can be considered to consist of some combination of:

(i) maintaining a running check on the status of the flight and the vehicle systems

(ii) detection of problems or the unexpected

(iii) validation of (ii)

(iv) prediction of the effects of the situation identified in (ii)

(v) identification of the cause of the situation identified in (ii)

The required depth of concern in each of the above areas depends to a great extent on the overall objectives of the displays. However, before these factors are put in perspective so that the question, "What can and should be displayed in real-time?" can be answered, some general remarks on the use of real-time displays are in order.

In Section 3. 2 some historical notes provide background of direct interest. Section 3. 3 presents some constraints on real-time displays. Following these general remarks, basic rules and concepts for displays are given in Section 3. 4. These sections provide the framework of the Saturn applications developed in Section 3. 5.

3. 2 HISTORICAL BACKGROUND

Having established our basic interests in real-time displays as:

- aid to post-flight evaluation
- support to mission control
- displays for a general audience

it is appropriate and meaningful to briefly review some of the pertinent historical background in each of these areas so that the present study and real-time activities at MSFC can be viewed in perspective.

3. 2. 1 POST-FLIGHT EVALUATION

Post-flight evaluation has had a long period of evolution starting with aircraft, then ballistic vehicles, and now space launch-vehicles and spacecraft. In this evolution, the evaluation programs associated with the ballistic and space launch-vehicles are the most sophisticated and have advanced the art of evaluation and its techniques appreciably. These programs encompass many vehicle systems and large volumes of data from many and different sources including, for example, multiple tracking, multiple telemetry, meteorolgical and photographic sources.[32]

Pre-eminent in this evolution have been the evaluation programs developed for the Redstone-Jupiter family of vehicles, which have culminated in the present modus operandi for Saturn post-flight evaluation.[46] In the course of these programs, the number of measurements has grown significantly, and analog strip chart data plotting has been replaced, or supplemented in many cases, by digital techniques. Even some "quick-look" analysis is being done digitally.[50] Until recently, "quick-look" required the MSFC specialist to be at Cape Canaveral (essentially wasting time if launch was delayed) and then to laboriously pore over seemingly endless strip charts spread out on the floor in Hangar D. To cope with the increase in the number of measurements, amount of data and number of evaluation personnel, and a decrease in the time between flights, the present method brings the data to the analysts at MSFC rather than takes the analysts to the data. If this data transfer (or at least significant parts of it) is in real-time, initial "quick-look" can be implemented effectively with displays. Integrating this "quick-look" activity with mission control support activities, and data, provides the analyst with an immediate and effective appreciation of the overall mission. It helps him to identify and understand the problems encountered which will require immediate attention in subsequent detailed post-flight analysis.

A major step in this evolution in the use of real-time data to support post-flight evaluation has been the recent activities at MSFC associated with Saturn I Block II flights and which are a part of this study and report. (Table 2-1, and References 2, 3, 7, 9, 15, 16, 20, 57, 58, 60).

3.2.2 MISSION CONTROL

Space flights and the launch-vehicles involved are in many ways, evolutionary products of military ballistic missiles. Whereas this heritage has been a major factor in the growth of launch vehicle design, launch operations and post-flight evaluation, it has been less significant in the development of command and control of space missions. In the ballistic missile firing, once the button is pushed, the operations crew "may as well go home" for there is nothing they can do to affect the flight from that point on. In sharp contrast, the command and control of a space mission, after lift-off, can be a sophisticated operation designed to significantly increase the capability, flexibility and reliability of the mission well beyond that possible without such added support.[34, 41]

Space mission control concepts for manned flight grew primarily from experiences gained in aircraft experimental flight testing. In particular, the concepts used in mission control for Project Mercury[26] were the offspring of aircraft flight testing techniques and philosophies developed by NASA at Langley Research Center, and at Edwards Air Force Base-,[54] coupled with flight test experiences of personnel from the aircraft industry*. From this background, the following evolved.

The elements of space mission command and control were initially established in two basic parts:

- mission control
- vehicle control

Mission control is concerned with directing the flight to achieve the mission objectives - i. e., a flight plan. Vehicle control is concerned with the detailed operation of the vehicle and its systems in order to achieve this flight plan. Control implies monitoring of performance or status, and therefore monitoring can be expected to be a major element in both mission control and vehicle control. A simple and historical example of this is the technique, originated in early trans-

*An early example (mid 1950's) of real time aircraft mission control involved direct tie-in between air crew, NORAD tracking (for navigator aid) and a ground based group of monitors (in radio contact with the air crew viewing real time telemetry data to verify that the planned experimental flight could be safely continued).

Atlantic flying, of monitoring the fuel consumed versus the distance flown. If, when half the fuel was gone, the halfway point had not been passed, the aircraft turned back. The fuel-distance plots were of a form that provided useful prediction and were termed "Howgozit" charts, a term originating no doubt from periodic pilot-to-navigator queries "How-goes-it ?"

In manned space mission command and control, the various monitoring functions are keyed to the following questions:

- Howgozit for the mission?
- Howgozit for the spacecraft?
- Howgozit for the crew?

and during powered flight phases the additional question is asked:

- Howgozit for the launch vehicle?

When answers to these questions show unsatisfactory or dangerous conditions, the philosophy of design and operation is that alternative means should be available to achieve the mission objectives, or, if this is not possible, a safe return "home" must be provided. These four seemingly naive questions plus the philosophy of alternate capability and safe return were the very foundations of the command and control network development for Project Mercury; they were also the basis for the flight operations.[44] These same questions and philosophy persist for Gemini and Apollo.[33,45] The answers to the questions may be more sophisticated, and the equipment more exotic (and expensive), but the questions and philosophies are identical. They are, in essence, the paradigms for manned space flight command and control.

Real-time answers to the set of "howgozit" questions form the basis for a series of real-time decisions on which the success and safety of the flight are highly dependent. These decisions, shown for a typical orbital operation in the simplified schematic of Figure 3-1, are made by

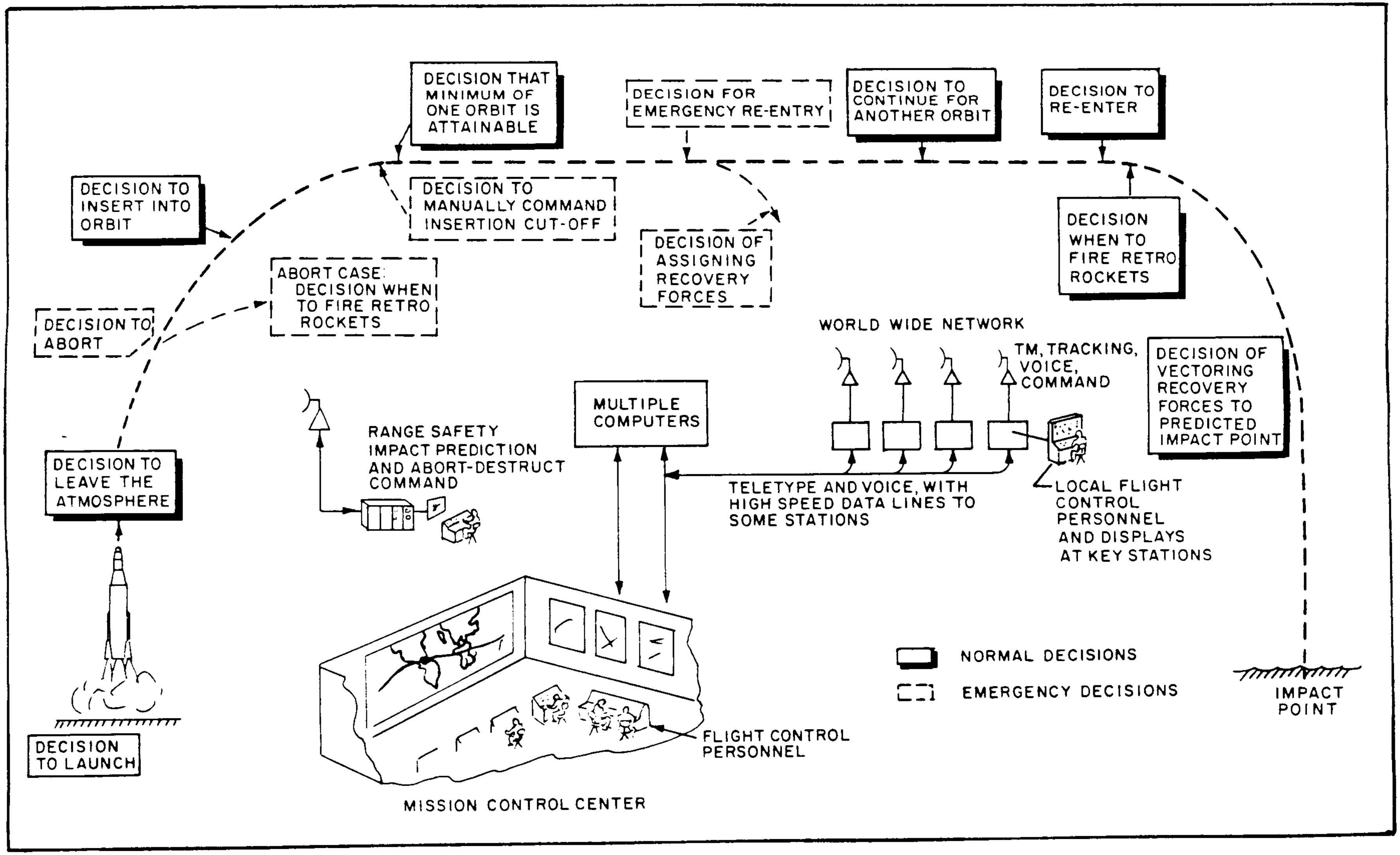


Figure 3-1. Basic Decisions in Command and Control of Manned Orbital Operations

the crew in the spacecraft, and/or by a team of Flight Controllers in the Mission Control Center* in accordance with a set of "Mission Rules"[35, 36, 42] which define appropriate criteria for the decisions. The decisions are carried out in accordance with procedures documented in Standard Operating Procedures (SOP), and the Spacecraft Flight Operations Manual.

An important and unique feature of the ascent phases of manned flight is the provision for aborting the flight** and escaping from the launch vehicle when catastophic events in the launch vehicle are imminent, or when the spacecraft or crew status is such that insertion into orbit should not be carried out. The launch vehicle abort criteria can be automated or merely displayed for manual action, or both. In either case, the ascent is carried out with continuous monitoring of the abort parameters by the crew and/or the ground personnel; periodic positive "go" checks are made on the launch vehicle, spacecraft and crew status, culminating with a "go for N orbits" status check made immediately after insertion. If an abort decision is made and the command initiated, the monitors are then interested in the subsequent events, e.g., engine cut-off, separation, etc.

During the Mercury-Redstone flights the abort parameters (attitudes, rates, critical pressures, and electrical power)[55] were displayed at a launch-vehicle console in the Mercury Control Center. MSFC (ABMA) personnel manned the position which had displays consisting primarily of analog plots on an 8-channel extended-table recorder.

*The Mercury Control Center (MCC)[40] at Cape Kennedy was used for all Mercury and inital Gemini flights (to GT-3). For initial Mercury-Redstone flights, an interim flight monitoring facility was built in a trailer[45] but was not used because MCC was completed in time for the M-R flights. The Integrated Mission Control Center (IMCC) at MSC, Houston,[66,67] will be used for later Gemini flights and Apollo.

**Range Safety Officer (RSO) functions, of monitoring potential impact point (IP) and initiating engine cut and/or destruct commands when the IP exceeds limits, remains essentially the same as for unmanned missions. RSO concern is for the safety of ground based personnel, and RSO activities are separated, both in terms of responsibility and physical location, from the mission control activity.

In future manned missions, abort criteria monitoring during ascent will also be an important function in real-time mission control. In addition, the monitoring and prediction of in-orbit booster performance and capability will be an added area of concern.

It is within the context of mission control described in the previous paragraphs that MSFC support to mission control activities can be provided. Specifically, this support is aimed at aiding in answering the real-time operational question "Howgozit for the launch vehicle?"

3.2.3 GENERAL DISPLAYS

The third area of interest in real-time is the display of general flight data to selected technical and administrative personnel not directly involved in flight analysis and mission control. At the launch site, in the past, a very limited number of such personnel could view the operation from the blockhouse, or Range Safety area. More often, they watched the launch directly from various vantage points. In designing the MCC, however, the importance of providing for a general audience "visual" and "aural" presentation was recognized. It was also realized that it must be separated from the active monitoring personnel and this was accomplished by providing a large "isolation booth" overlooking the control room and wall displays. Those with good eyesight could even read some of the plotboards and consoles. However, the specialized displays suitable to flight controllers may perplex rather than enlighten the general viewer uninitiated in the details even though he is generally reluctant to admit it. The following is a classic example of how "specialist" data can be misinterpreted by general viewers. On the pioneer Abel-Baker monkeys' flight on a Jupiter vehicle, a number of eminent medical doctors were stationed in the spare launch blockhouse adjacent to the launch pad. They monitored the monkeys' condition (EKG's, etc.) on a scope, and, as the flight progressed to its terminal phase, they continued to nod their heads in satisfaction and remark on how well the monkeys were doing, not realizing that telemetry contact had been lost for some time and all they were looking at was noise.

It is evident that, when facilities permit, the displays for a general interest group preferably should be separate and different from operational displays, and should be summary in nature and simple to interpret. MSFC facilities for future flights are planned to have such capability.

3.2.4 MSFC REAL-TIME FACILITIES

The beginning of real-time activities at MSFC can be considered to have been the introduction, earlier in the Saturn program, of the Launch Information Exchange Facility (LIEF) in support of launch activities at KSC. This provided a focal point of personnel and communications media for technical consultation between the Centers during countdown. The future full-fledged real-time operations at MSFC will be realized for Apollo Missions. They will consist of LIEF support to KSC launch activities, support to IMCC mission control activities, support to MSFC post flight evaluation, and will provide displays to a general MSFC audience. These activities will be in a facility now under construction called Huntsville Operations Support Center (HOSC).

In the interim, in addition to LIEF pre-launch activities, real-time flight data has been displayed at MSFC in varying degrees, depending primarily on the status of communications links and display capability. (See Figure 3-2.) This interim period has been used to develop and utilize (on a limited basis) real time monitoring concepts, requirements and techniques. This interim period encompasses the work in this report.

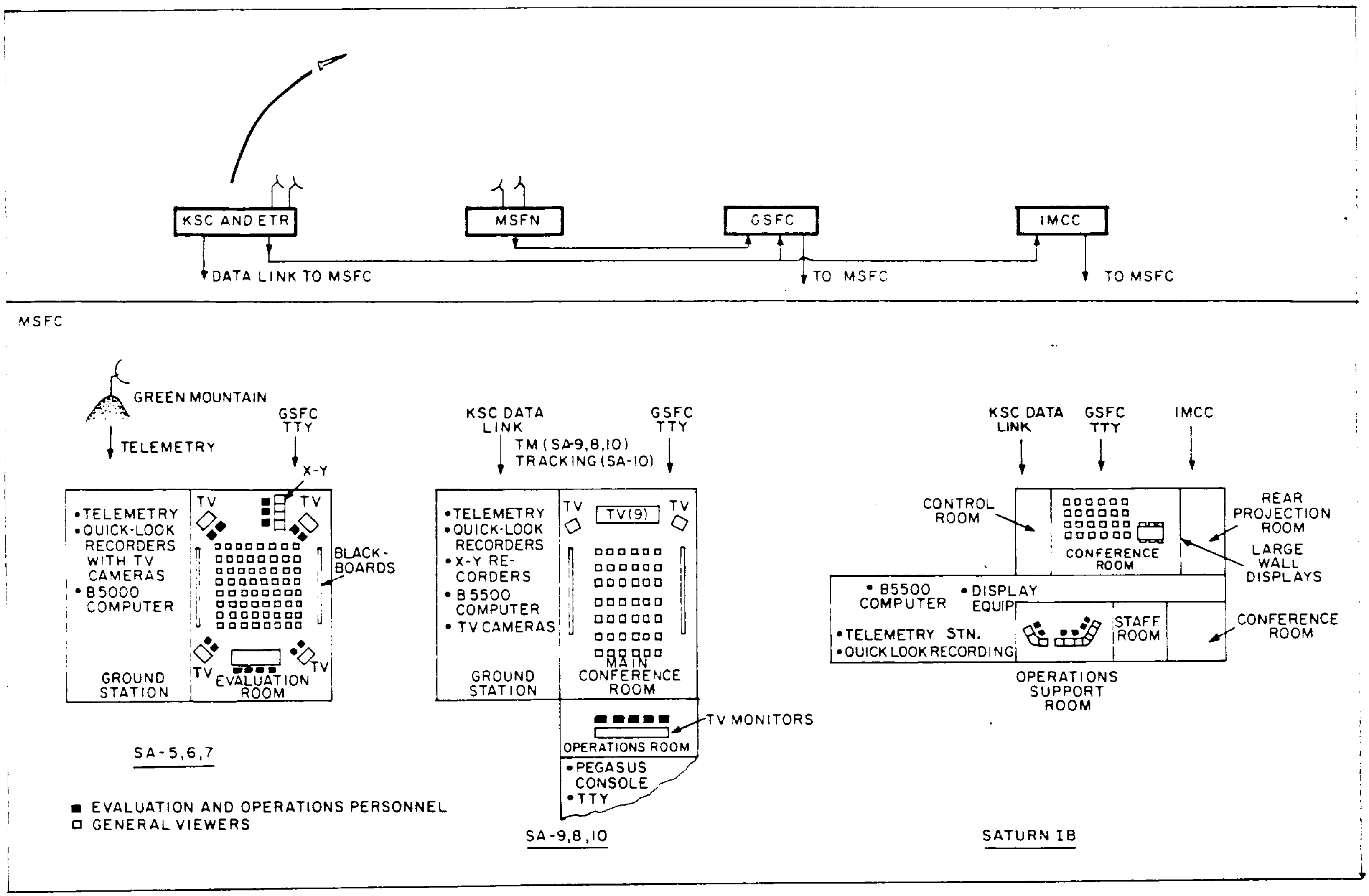


Figure 3-2. MSFC Real-Time Facility Development

The future HOSC facilities will be more sophisticated than the interim, with provisions for individual consoles, wall displays and the separation of the general viewers from the active flight monitors. The future display capabilities and requirements will be correspondingly more sophisticated in some areas than those utilized in the interim.

3.3 CONSTRAINTS

The wealth of post-flight evaluation experience accumulated at MSFC (Section 3.2.1) has resulted in procedures, techniques and personal preferences which reflect the need for detailed and exacting analysis of vast quantities of recorded data. The addition of real-time operations can augment these evaluation activities; however, real-time operations depend on some unique concepts and different requirements. These concepts and requirements are, in effect, constraints on real-time operations. Effective real-time operations depend on adequate understanding of and adaption to these constraints.

The basic constraint, of course, is time. There is a limit to how much data an individual can absorb in the time available. If more data is desired or required, more or different displays and perhaps more personnel may be required to monitor the data. However, as a result of increasing the number of personnel, the problem of communications between personnel arises and grows proportionally.

Because of the implications associated with the time constraint, data displays must be limited to some practical amount. The amount of data displayed and the kind of data displayed are governed not only by the analysis or evaluation to be made but on the effect that erroneous or missing data will have on the operation. If the real-time monitoring is only to aid post-flight evaluation, a high volume of data without serious concern for validity or cross correlation of information (in real time) might be desirable. The high volume would be aimed at detailed fault identification and isolation. In contrast, if the real-time monitoring is primarily aimed at supporting mission control, greater emphasis on validation of data in real-time becomes mandatory, and the data to be displayed would concentrate more on functional go/no-go type criteria rather than on failure analysis. The second constraint, therefore, is concerned with the need for and extent of validity criteria. This in turn is dependent on the third constraint which is posed by the question: "How much emphasis is desired on Failure Analysis versus Mission Support?" It is evident from this that the evolution toward support of operational missions can have an appreciable effect on these constraints and, therefore, on the data and displays (and communications between displays).

The fourth constraint is data availability. Data availability has varied in previous flights and will continue to vary in future flights. Until the introduction of the data-link from KSC (on a limited basis for SA-9), telemetry data was obtained from Green Mountain. Coverage from Green Mountain is such that essentially only the S-IV stage data could be gathered and even this was incomplete because the orbital insertion point was out of range. With the introduction of the data link, full flight coverage has been possible. As the capacity of the link was increased, increased data rates and/or channels became available to the extent that some tracking data was added to the telemetry data for SA-10. The telemetry inputs to the data link have been limited in general to PCM links and uncommutated FM/FM links. In the future, the insertion point of Saturn flights will extend further down range beyond the coverage of Antigua* or Bermuda**. Therefore, the availability at MSFC of real-time telemetry and tracking data at the insertion point will depend solely on

* End of the ETR cable.

** End of eastward cable supporting MSFN.[69]

the capability and availability of communication links to the station covering insertion. Data during orbit and escape injection are similarly dependent on communications capabilities (except for "overhead" at Green Mountain).

In summary, the four major constraints are:

1. Time (volume of data per monitor and intercommunications required)
2. Validity Criteria (dependent on Item 3)
3. Failure Analysis versus Mission Support
4. Data Availability

A fifth constraint is provided by the availability of display equipment, interdisplay communications, data control and computer capacity. This constraint has been a particularly severe one for Saturn I Block II flights where maximum use was made of existing equipment and facilities. This will be alleviated when the new facilities, consoles and equipment installations are completed. The final design configuration, capacity and capability of the complex and communications had not been determined at the time when major portions of this study were conducted. Therefore, the study was made ignoring any specific constraints due to hardware and software configurations of facilities. This is valid in that it results in a more comprehensive statement of "What can and should be displayed". Therefore in the future, by associating priorities with the various items of interest, a choice of data and displays can be made to fit the available facilities. Simultaneously, it will focus attention on those areas of interest for which added capability should be considered.

3.4 BASIC RULES AND CONCEPTS FOR REAL-TIME DISPLAYS

In addition to the constraints listed in Section 3.3, there are several general statements of philosophy that should be applied to Real-Time operations. In many respects, the MSFC real-time operation is characteristic of Command and Control Systems, particularly in terms of its interface with IMCC operations. In this respect it is interesting to note that experience[30] indicates that the user's desires for automated support are modified as he learns to use the machines provided to him, and that the dynamic nature of the requirements suggests his needs are best satisfied by an evolutionary approach which continually increases the total capability of the system. In recognition of this, the following remarks are aimed primarily at the initial establishment of a real-time system capability in order to provide a firm foundation for the inevitable evolution.

First and foremost is the philosophy that an absolute minimum amount of data conditioning, manipulation, computing and display should be carried out (consistent, of course, with the objectives). The purpose of this is to maximize reliability and data validity, as well as to minimize display requirements and communications, and to release displays for other data of interest. Strict adherence to this will no doubt raise conflicts of interest between personnel whose personal preferences or interests would lead to duplication of essentially the same information in a variety of formats. It also means that if raw data is sufficient for monitoring it should not be processed just because a capability for such processing exists; or, if processing is required, the simplest practical method should be chosen. Experiments to assess different approaches for processing and display for a given flight, of course, should not be restricted by this concept. This minimum concept will affect the choice of individual parameters, equations, amounts of smoothing, computation rates and display rates.

Coupled with the minimum concept is the philosophy that all data displayed should be able to be verified for validity by some means or other in real-time. In addition, where a problem is identified, sufficient additional information should be available for an understanding of the problem. It is at this point that the differences between real-time aid to post-flight evaluation analysis (PFE) and real-time aid to mission control appear. For PFE, the prime interest is CAUSE. For mission control, the prime interest is EFFECT and/or PREDICTION OF EFFECT in later mission phases. These validity and understanding functions normally are provided by backup information. The application of this "backup information" concept has particular significance with respect to parameters which are computed for display. This implies the following. Consider that an equation containing measurements M_1, M_2 and M_3 is displayed, and that it deviates from expected values. The question then arises whether all the input data (M's) are valid or not. If a telemetry fault is present in, for example, M_1, the computed value is usually useless, and more important, unless the invalid status of M_1 is recognized, the computed value can be grossly misleading. Therefore, it should be common practice for each individual parameter used in computations to be monitored separately. Various means are possible to provide this, depending on the particular case.

The need for predictive information has been suggested. A useful concept for this in real-time mission control is the use of "Howgozit" charts where actual data is superimposed on pre-plotted information in a format that allows prediction of end results. In effect this is the kind of plot used in Range Safety to present go/no-go trajectory criteria. In many cases it will be found that there is not much one can do to improve upon a simple plot of predicted and actual data versus time. With suitable limits this becomes a Howgozit chart. Three restrictions on providing limits are sometimes found for these charts.

- In some cases a multitude of possible cases makes plotting of references or limits more difficult than useful.
- In other cases, personnel monitoring the data and who are very familiar with it sometimes consider the plotting of limit data as unnecessary. For mission control it is mandatory.
- Finally, there is the odd case where it may be difficult to arrive at an agreed upon limit. In such cases it is often found that the particular measurements need not or should not be displayed.

The implied emphasis in producing a format for the above Howgozit displays is on utilizing man's unique capability[61] to give meaningful interpretation to data, and in particular to exploit his ability to integrate and extrapolate. In some cases, computed prediction is also required and/or desirable. Impact point prediction for Range Safety use is a case in point where it is required as a means for making real-time command decisions. In the context of our interest, such mechanized extrapolation is seldom required or even desirable. It should be used with caution as the implementation is often more complex than the usefulness provided.

The general rule for predictive displays therefore is this: Display formats should maximize the inherent predictive capabilities of the monitor. The use of computed predictions should be minimized.

Based on the general philosophies that have been postulated, the requirements for real-time displays can be briefly summarized as follows:

- IDENTIFY: Identify any degradation of performance that will compromise the mission capability.

- VALIDATE: Validate this identification.
- EFFECT: Determine, where practical, the effect on the remaining mission phases.
- CAUSE: Of secondary interest in real-time is the isolation of the problem and identification of the cause.

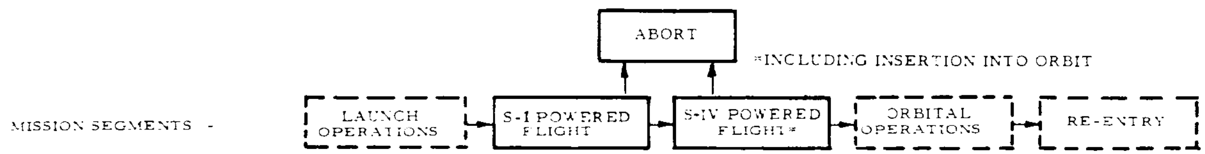
This division of interest suggests a hierarchy of display requirements. The need for and the usefulness of such a hierarchy was recognized in the contract work statement which suggested three levels of displays (I, II and III). Implementation of such a hierarchy depends on such factors as display capability, display call-up capability, and relative interest in validity, effect, and cause, as well as others.

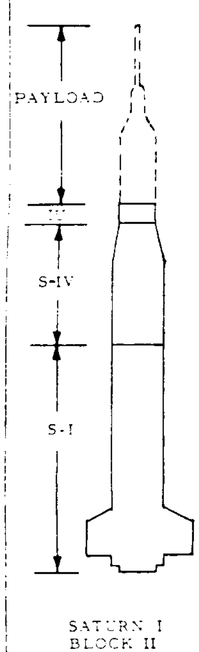
3.5 APPLICATIONS

3.5.1 ELEMENTS OF FLIGHT OPERATION OF INTEREST FOR REAL-TIME DISPLAYS

A summary of the general elements of the flight operations is given in Figure 3-3 for a Saturn I Block II vehicle from launch to orbital insertion. In Saturn IB and/or Saturn V, Orbital Operations including engine restarts and escape will also be of interest.

The various systems or subject matters of concern are rated in Figure 3-3 in terms of real-time "Interest Levels" according to the scale High (H), Medium (M) and Low (L). The items rated Low are of little or no concern in real-time. Figure 3-3 also breaks down the items in accordance with stage and flight segment. Note that a question is posed regarding the need for monitoring certain S-IV parameters during S-I flight. This question is concerned with the need or ability to predict whether the S-IV will be able to stage, ignite and perform. For Mission





	ELEMENTS OF FLIGHT AND VEHICLE OPERATION		DURING S I POW'D FLIGHT	DURING S IV POW'D FLIGHT	DURING OVERALL POW'D FLIGHT	INTEREST LEVEL
1	TRAJECTORY				✓	H
2	GUIDANCE				✓	H
3	CONTROL -	S-I	✓			H
		S-IV		✓		H
4	PROPULSION -	S-I	✓			H
		S-IV	(?)	✓		H
5	ELECTRICAL - SYSTEMS	S-I	✓			H
		S-IV			✓	H
		IU			✓	H
6	FLIGHT FUNCTIONS				✓	H
7	SEPARATION				✓	H
8	STRUCTURES -	S-I	✓			L
		S-IV & Interstage			✓	L
		IU			✓	L
9	AERODYNAMICS		✓			L
10	INSTRUMENTATION -	S-I	✓			M
		S-IV			✓	M
		IU			✓	M
11	ENVIRONMENT -	S-I				M
		S-IV				M
		IU				M
12	MASS					L
13	ABORT SYSTEM (on later vehicles)				✓	H
14	EVENTS (including items from 6, 7, and [illegible])				✓	H

ITEMS NOT INCLUDED

REAL TIME
INTEREST LEVELS - H - HIGH
M - MEDIUM
L - LOW (NO INTEREST IN REAL TIME)

Figure 3-3. General Elements of Flight Operation of Interest for Real-Time Displays

Control, this question is significant. For post-flight evaluation it is less important.

A further detailed breakdown of items of interest in real time is given in Table 3-1. Again the items are rated H, M, and L with many of the L items which are of no concern merely omitted. Of the items of Figure 3-1 and 3-2, the most significant areas for real time monitoring (more or less in order of interest) are:

- Abort System
- Trajectory*
- Events
- Guidance*
- Control*
- Propulsion
- Electrical Systems

Each of these are discussed in turn in the following sections. In these sections, the general considerations applicable to any vehicle (Saturn I, IB, or V) or stage are emphasized. This emphasis on the general aspects rather than details is desirable in that it provides basic guidelines which can be applied to more than one flight or vehicle. This is in contrast to a number of the contract monthly reports where the data and displays were identified in greater detail (measurement, number, and channel number, etc.). Detail of this kind is given in the Appendices where appropriate.

3.5.2 ABORT SYSTEM (or EMERGENCY DETECTION SYSTEM, EDS)

The Saturn I vehicles were not equipped with an abort system; however, later Saturn-Apollo vehicles will be so equipped. Interim flights can potentially be used as a means for obtaining first-hand experience in displaying abort system parameters.

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*The three categories Trajectory, Guidance, and Control are discussed in subsequent sections under the two headings Trajectory, and Stabilization and Control.

Table 3-1. Detailed Elements of Flight Operations of Interest for Real-Time Display

			Interest Level	
1.	Trajectory	. Comparison with nominal . Comparison vehicle generated trajectory data . Insertion conditions . Orbital predictions	H H H H	Including accelerations
2.	Guidance	. Computer outputs . Error signals . Air bearing GN_2 supply system	H H M	
3.	Control SI SIV General	. Control deflections . Slosh . Control deflections . Slosh . Attitude . Angular velocities and accelerations . Angle of attack	H L H L H H M	 — — — — — — — — — — — — — — — —
4.	Propulsion SI SIV	. Overall . Individual engines . Press system . Prop. utiliz. system . Hydraulic system . Retro rocket . Overall . Individual engines . Cool . Start . Steady . Cut-off . Press system . He. supply . Control press system . Prop. utiliz. system Hydraulic system . Ullage	H H M L M L M L H M M M M L M L	 — — — — — — — — — — — — — — — — — — —Except for event signals — — — — — — — — — — — — — — — —
5.	Electrical SI SIV IU	. Voltages . Currents Voltages . Currents . Voltages . Currents	H M-L H M-L H M-L	 Including inverter Including inverters
6.	Flight Functions	. Major events	H	
7.	Separation	. Event	H	
8.	Structures	— — — — — — — —	L	— — — — — — — —
9.	Aerodynamics	— — — — — — — —	L	— — — — — — — —
10.	Instrumentation (SI, SIV and IU)	Telemetry quality monitor Tracking quality monitor Other — — — — — — —	M M L	 — — — — — — — —
11.	Environment (SI, SIV and IU)	Pressures Temps	M-L M-L	
12.	Mass	— — — — — — — —	L	Although propellant utilization would be useful if it could be measured for real-time use

NOTE: Real-Time Interest Levels

H High (Particulary those which will indicate major problems)

M Medium (Particularly of interest to verify (H) items and/or to further identify problems)

L Low Items of low interest (L) are not considered in real-time. A few have been listed, and many others have simply been omitted.

First, however, consider what the role and interest of MSFC monitors would be in these parameters. An abort system in manned flight is used during powered ascent to orbital insertion when catastrophic events in the launch vehicle are imminent, or when the spacecraft or crew status is such that insertion into orbit should not be carried out. The launch vehicle abort criteria can be automated or merely displayed for manual action, or both. In either case, the ascent is carried out with continuous monitoring of the parameters by the crew and/or the ground personnel and periodic positive "go" checks are made on the spacecraft and crew status as well as the launch vehicle culminating with a "go for N orbits" status check made immediately after insertion. If an abort decision is made, and the command initiated, the monitors are then interested in the subsequent events, e.g. engine cut-off, separation, etc.

In most abort cases, it is highly unlikely that personnel at MSFC could respond quickly enough to inform IMCC personnel of pending catastrophy. Nevertheless, the abort parameters and associated event and status signals should be of basic interest to the monitoring team for if an abort does occur the information displayed is a starting point for ensuing analysis.

Of more current interest is the fact that display of abort system parameters at MSFC on unmanned flights will allow MSFC to thoroughly develop and exercise the kinds of displays which could ultimately be used in the IMCC.

Parameters in an abort system generally fall into the following broad categories:

- Vehicle attitude and/or rates
- Electrical power
- Critical pressures affecting structural integrity (where applicable)
- Thrust (Chamber pressure)

Some of the eventual abort system parameters may have been displayed at MSFC for Saturn I Block II flights. However, the display of these parameters when they are applied to an abort system is generally more involved for the following reasons.

- In addition to predicted values, precise limits (corresponding to the manual and/or automatic criteria) are required to be preplotted in a readable fashion.
- In general, abort systems involve redundancy. In any decision to abort, the validity of the abort data is of major concern and therefore the display of redundant data must be considered.
- The response rate or resolution desired for abort displays may be greater than for general displays.
- The grouping of abort parameters (including redundant data) is an important factor. It is highly desirable that they be grouped together, rather than spread among several groups (i. e. trajectory, electrics, etc.).

MSFC has had prior experience with real-time displays of abort parameters. This was during the Mercury-Redstone flights in which a number of parameters (including attitudes, angular velocities, chamber pressure, and control voltage)[34, 55] were displayed at a launch-vehicle console in the Mercury Control Center.[26] MSFC (ABMA) personnel manned the position. The displays consisted primarily of analog plots on multi-channel extended-table type of direct-writing pen recorders. This provided sufficient viewing time-span (before the trace disappeared into the roll) for trends to be identified. This method had the advantage that most of the data of concern were on one recorder. It had the disadvantages that the vertical resolution was small, and the limits had to be marked external to the paper. During these flights, there was at least one situation where displayed parameters became a matter of real-time concern.

Also of interest in the display of abort parameters is the sequence of flight events. These are the normal events as well as abort case events, and are best displayed by event-lights with built-in or programmed warnings of due and overdue events.

As experience is gained, and when abort limits are well defined, the use of the computer to monitor these limits appears desirable. This identification of the potential use of the computer in monitoring abort system limits immediately raises the question regarding outputs. The most appropriate is a light(s) to warn the monitor(s) who is looking at the analogs. The question is immediatly raised as to whether noise in the data system, not the abort system, will be a problem and how to deal with it. In any event, the abort limit signals should not be locked in by noise as has occurred in some event display systems. Whether the signals should be locked in (once initiated) during any loss of telemetry signal depends on the overall monitoring operation. For MSFC activieies, no locking appears to be warranted.

3.5.3 TRAJECTORY

It is convenient to treat trajectory monitoring in four basic sequential phases:

- Ascent Phase
- Orbital Insertion
- Orbital Phase
- Escape Phase

These are shown in Figure 3-4 with the corresponding basic trajectory elements of interest. Because Saturn guidance is inertial (with appropriate guidance data transmitted to the ground by telemetry) two completely independent sources of trajectory information are potentially available for use in real-time:[56] telemetry data, and tracking data.

The telemetered trajectory data consists primarily of outputs from the guidance computer.

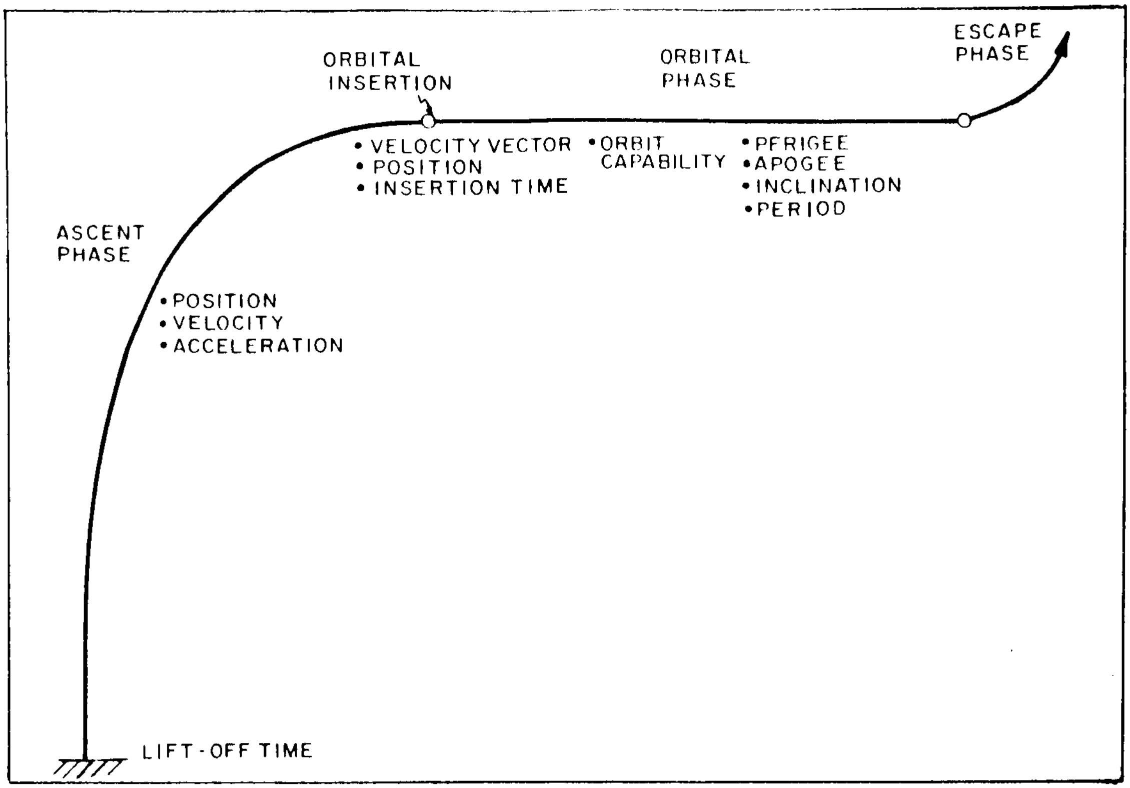

Figure 3-4. Basic Trajectory Elements of Real-Time Interest

a. Ascent Phase

In Figure 3-5 the basic elements of the ascent trajectory are separated into general parameters for display. The parameters are arranged on three levels. Level I contains the most significant information whereas level II contains additional items of interest including back-up information from the second data source, as well as individual measurements used in computations, in order to provide cross-checking of validity. Whether the secondary level (partially or completely) is displayed simultaneously with the primary level, or is merely available by call-up depends on the capacity and capability of displays available. A third level of information is also shown consisting of two types of data. One

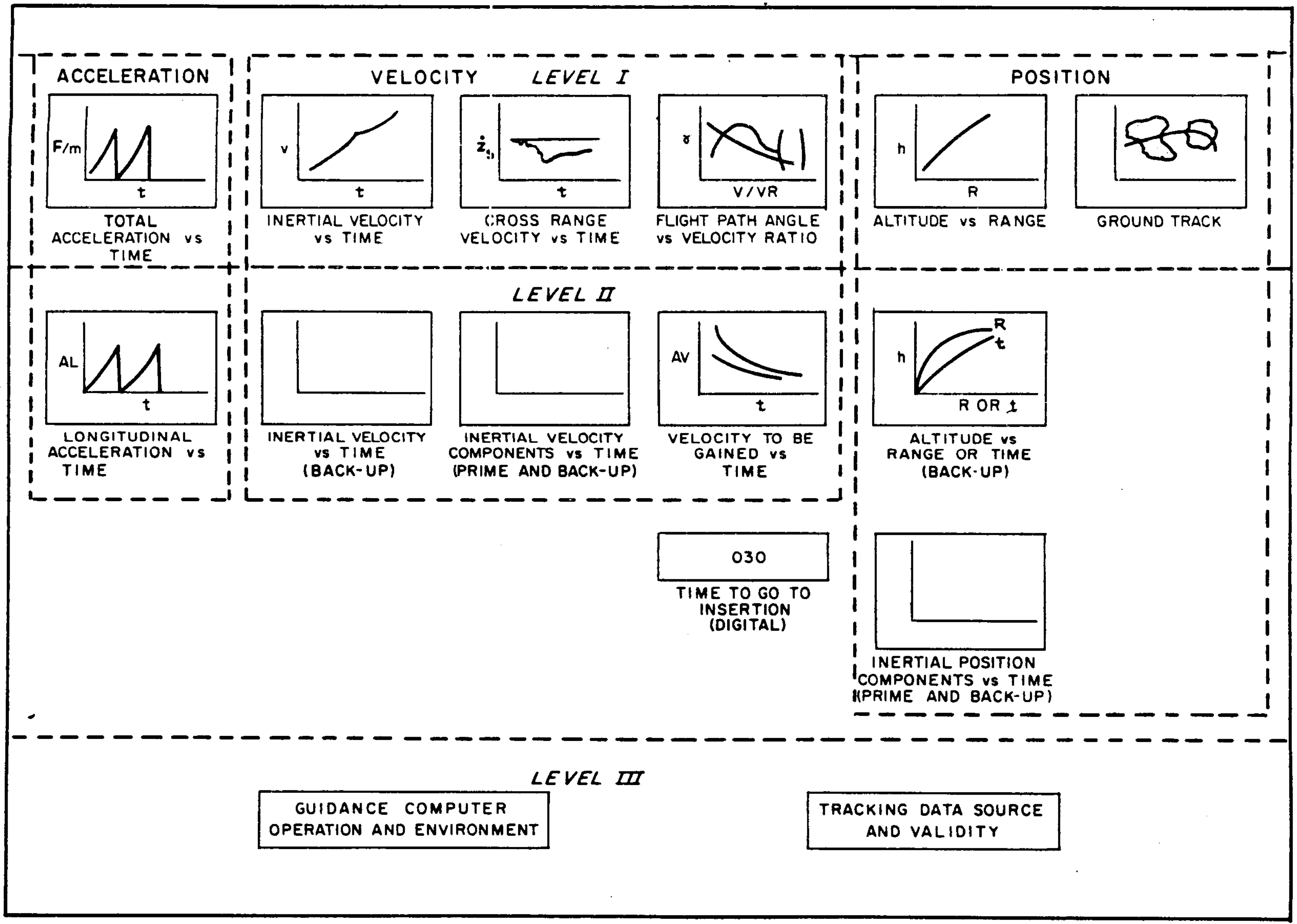

Figure 3-5. Trajectory Display Data

type is concerned with the source and validity of tracking data, and the other provides reference information concerning the onboard computer, although there is some merit in considering the indicators of tracking data validity and computer operation to be primary level items.

Although most of the parameters can simply be plotted versus time, the effectiveness and compactness of displays can be increased in some cases by plotting one parameter versus another as indicated in Figure 3-5.

The specific sources of information for the displays indicated in Figure 3-5 may vary somewhat from vehicle to vehicle. Illustrative sources and corresponding computations are given in Appendix B for Saturn I Block II vehicles (SA-9 in particular).

b. Insertion and Orbital Phases

For Saturn SA-5, 6 and 7, displays at MSFC were generated from telemetry data received at Green Mountain. As the orbital insertion point was essentially beyond the range of this station, insertion confirmation was dependent on GSFC computations based on tracking. The subsequent installation of the data link from KSC provided a capability to receive telemetry data to insertion for SA-9, 8 and 10, and also tracking data for SA-10. For Saturn IB and Saturn V, the insertion points are further down range, and the launch azimuth (for Apollo) will probably be toward Bermuda. Although the insertion (which will probably be beyond the range of Bermuda[32]) will be covered by a tracking ship, it is not certain that either reliable telemetry or tracking data will be available in the USA in real-time. The following, however, assumes that either or both of tracking and telemetry data will be available.

The achievement of a satisfactory orbital insertion consists simply of attaining the right velocity vector at the right altitude. The most important component is the in-plane velocity vector. Based on this, a relatively simple yet extremely effective real-time display of insertion consists of plotting the flight path angle with respect to the local horizon versus [(actual velocity) / (required velocity for insertion)] as shown in Figure 3-6 [26, 37, 39, 42].

This plot has the basic features of operational Howgozit charts. It presents the essential items of interest in a single easy to read and understand trend plot with definable limits. In fact the pre-plotting of underspeed-overspeed limits as well as expected values is the key to the effectiveness of the chart. With such limits and with a large size plot board (30" x 30"), this type of plot has been used as a basis for initiating back-up engine cut-off commands as well as for mission decisions.

A detailed example of Flight Path Angle/Velocity Ratio plotting is given in Appendix B including sources of data and the computation required for generating the plot from telemetry data. The same plot can be generated from tracking data. This raises the question as to whether provisions should be made for both, and if so, should the displays be simultaneous or should one be only available on call-up. An effective compromise appears to be to generate the plot from tracking data and in addition to use the guidance computer data to plot Velocity-To-Be-Gained (See Figure 3-5). As a back-up, the Flight Path/Velocity Ratio plot could be generated from telemetry data by call-up. The choice of tracking data as the prime source was influenced to some degree by the fact that the ASC-15 computer data of interest is temporarily discontinued for a short period (2 seconds) immediately prior to cut-off[4]. However, this may not be characteristic of later vehicles.

The Flight Path Angle/Velocity Ratio plot provides a visual confirmation of insertion. In addition, it is possible to display a light to indicate satisfactory insertion. This would be triggered by a computer check

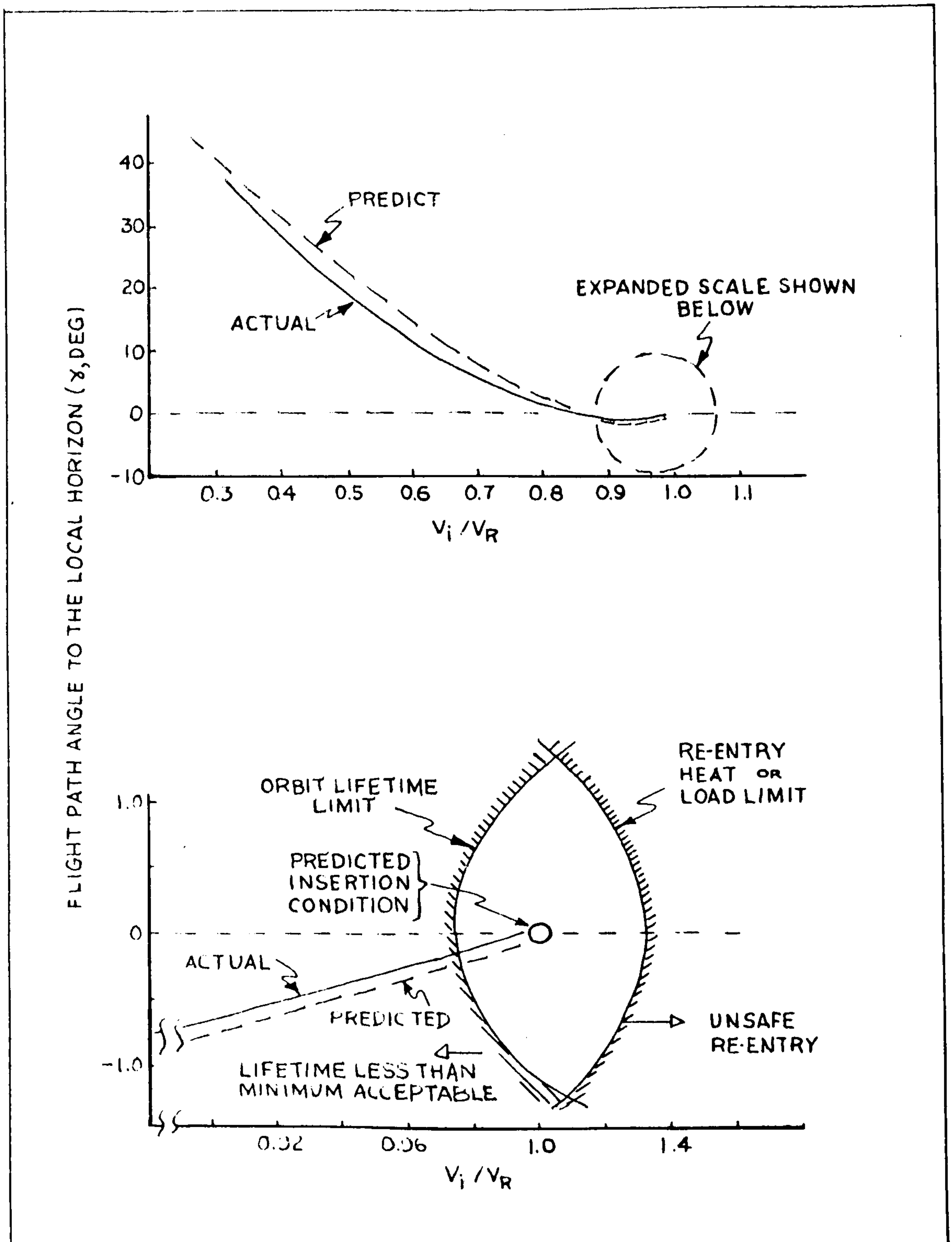

Figure 3-6. Flight Path Angle vs. Velocity Ratio

that cut-off has occurred and the values are within limits, and would be particularly useful as a reference display to monitors looking at data other than trajectory. In effect this is an "orbit go-light" and it indicates that an orbital capability greater than some specified minimum has been achieved. The next (and immediate) question is what is the nominal minimum number of orbits that can be maintained. Following a rough estimate, a more detailed determination of orbital capability and elements can be computed and compared with estimates as given in Appendix B.

It is at this point that the continuous tracking and/or telemetry coverage comes to an end. Subsequent periodic data from remote stations can be used to update these estimates and/or corresponding updated elements obtained directly from GSFC or IMCC.

Once the elements have been established, the basic variables of interest during orbit become ground track and the estimated times of contact for particular stations (including Green Mountain). For missions which include orbital maneuvering or escape, additional trajectory information (both projected and actual) will be desired.

c. Escape Phase

The basic objectives for display of trajectory data during escape, as for orbital insertion, are:

- Monitor the trajectory and performance for significant deviations from predicted.
- Confirm that the injection conditions are adequate.

The injection conditions not only include the velocity vector but the position and time of injection.

Further consideration of how to display these related parameters is warranted when the coverage and communication capability and content are established more clearly. Quite possibly, only final injection conditions may be available in real-time, rendering more detailed consideration of displays at this time somewhat academic.

d. Summary of Trajectory Data

The primary trajectory data are summarized in Table 3-2. Whether these displays are generated from telemetry data, or tracking data, or both, will depend on data availability, display capacity, and capacity of individual monitors to assimilate the information.

3.5.4 EVENTS

Displays of events provide flight monitors with specific discrete indications concerning general progress of the major planned mission sequences, and detailed indication of the operating modes and sequences within individual systems. As such, these displays provide general orientation and reference information as well as functional analysis information. In Figure 3-7, the events of a typical flight are depicted in two levels, I and II. Level I consists of the major flight sequencing items which provide general orientation. Level II includes various commands and responses which provide the specialist monitor with key detailed information of flight progress and system operation. A third level (III), not shown in Figure 3-7 because of the large number of events in this category*, contains a multitude of events which would be of interest to the analyst for detailed review.

The Events of Figure 3-7 are primarily those which indicate the progress of a mission which continues through its planned normal sequences. In future flights when the EDS/launch-escape systems are fully integrated and activated, the sequences associated with an aborted mission will also be of concern.

*See Appendix C for typical detailed lists.

Table 3-2. Summary of Primary Trajectory Data and Display

		Launch to Insertion	Orbital	Escape
Site in Contact	Data Source	D	D	Dependent on Data Availability
Tracker		D	D	
Data Quality or Validity		L	L	
Acceleration versus Time		A		
Velocity versus Time		A		
Cross Range Velocity versus Time		A		
Flight Path Angle versus Velocity Ratio		A		
Altitude versus Range		A	A	
Ground Track		A	A	
Orbital Go/No-Go Light		L		
Orbit Capability		D	D	
No. of Current Orbit			D	
Time of Insertion		D	D	
Insertion Altitude		D		
Insertion Velocity		D		
Insertion Flight Path Angle		D		
Inclination		D	D	
Apogee Altitude		D	D	
Perigee Altitude		D	D	
Period		D	D	
Excess Circular Velocity or Eccentricity		D	D	
Elapsed Mission Time		D	D	

A - Analog
D - Alpha-Numeric
L - Light

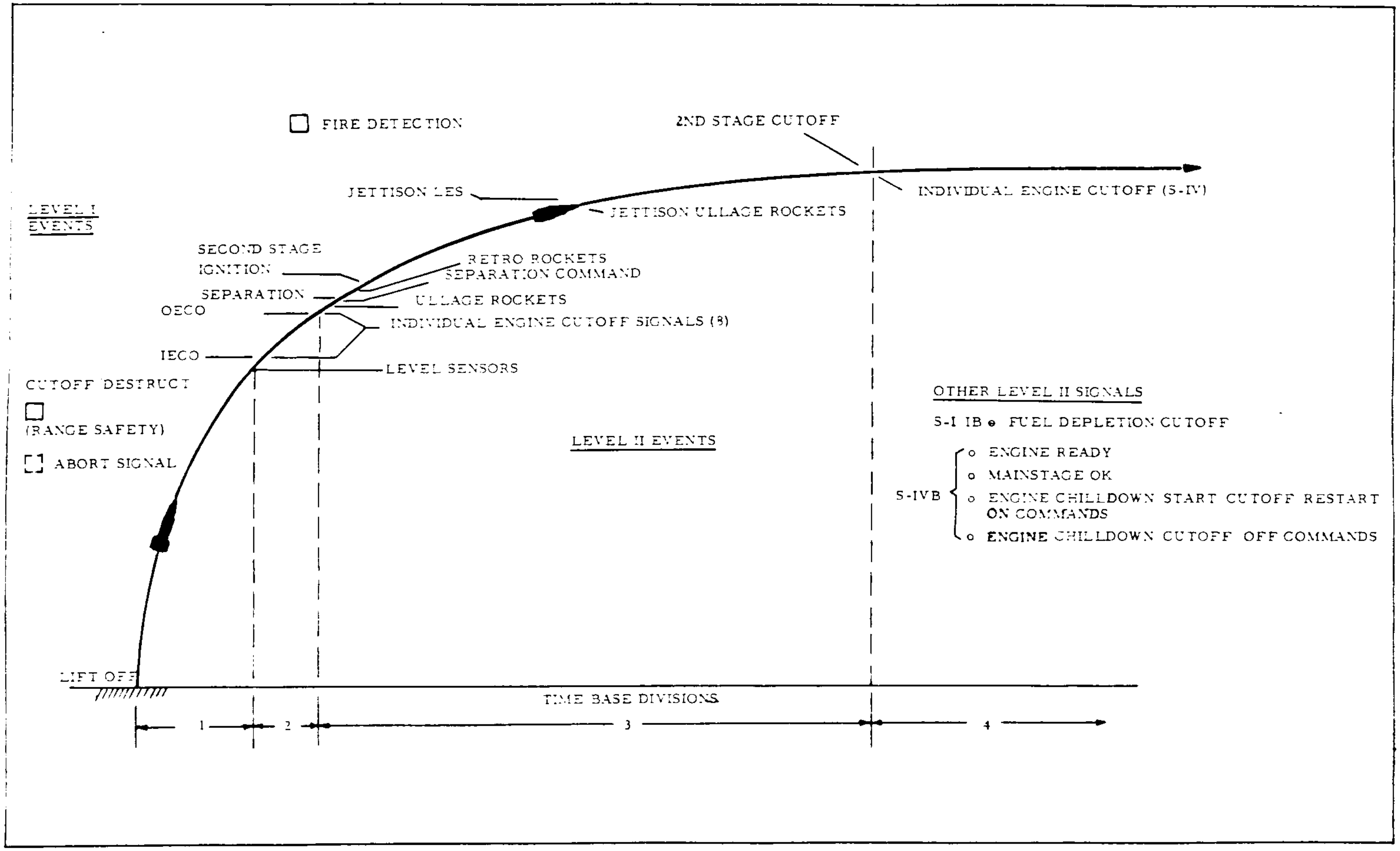

Figure 3-7. Events

In all three levels (I to III) the signals available vary considerably in type, and in telemetry implementation. Types of signals fall into two basic categories, "command" and "response to command". Although the measurement title associated with an event does not always clearly differentiate between these two, a real-time display should always be explicit as to which it is.

In real-time displays it is often the response that is of primary interest and most meaningful as it usually conveys more information than the corresponding command. For example, in the simplified example of stage shutdown and separation shown in Figure 3-8 there are many signals which would be of potential interest of which five are shown.

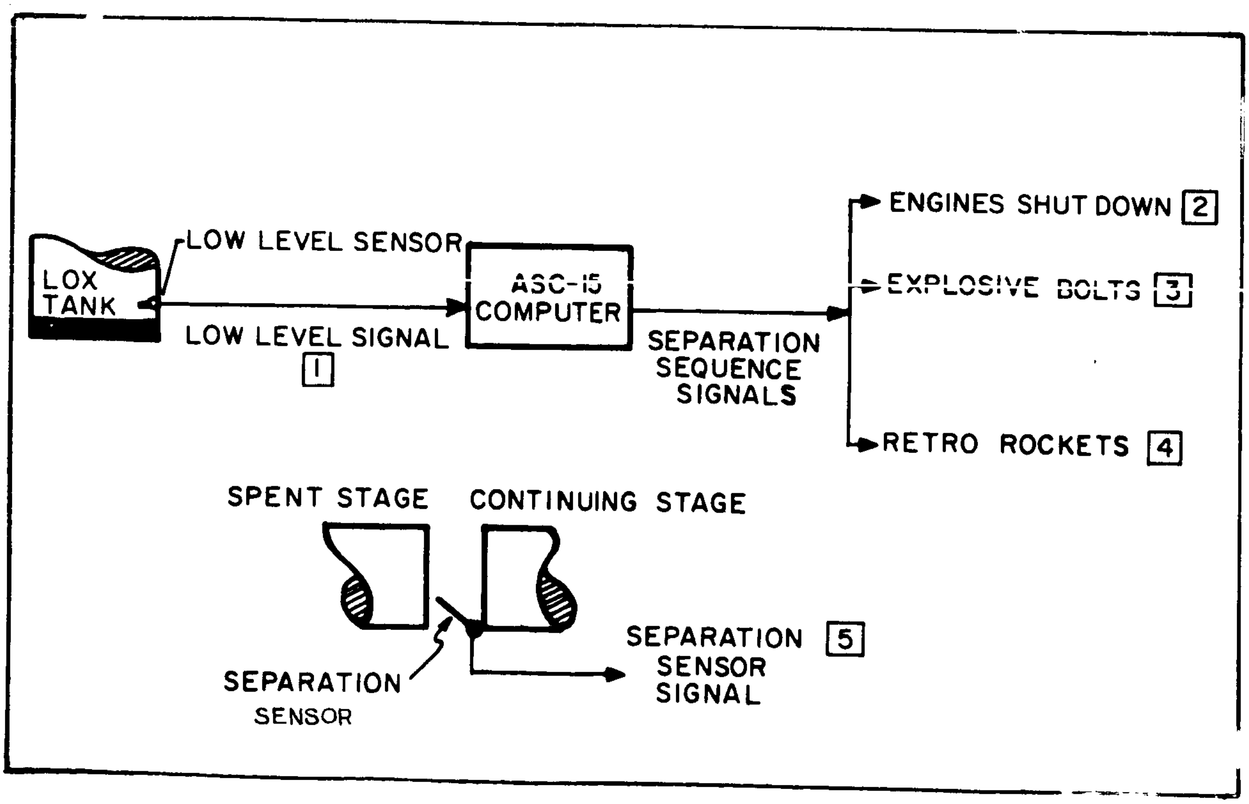

Figure 3-8. Separation Sequence (Hypothetical)

In this sequence, for example, display of the separation signal is the final response and is the first choice for display. It indicates not only that the event of major concern in the sequence, separation, has been accomplished, but it implies that some, if not all, of the other events occurred. If the separation occurred at the planned time and other displays (e. g. acceleration, chamber pressures, etc.) behaved as expected, it would be acceptable to ignore the other event signals in real-time. Examination of Figure 3-7 reveals that the Level I measurements shown reflect this philosophy where practical. The discussion thus far has considered only what is desirable, not what is available. Unfortunately, command signals are usually easier to provide and also are of paramount interest in post-flight analysis. As a result, appropriate response measurements may not always be available unless specifically included in the vehicle for real-time use.

An additional problem is that in order to conserve signal channels, a number of signals are telemetered in a form primarily useful for analog strip-chart recording. One common form is to use a multi-level signal with each level indicating a unique event. From examination of the analog results on a strip chart, the event sequences and times can be determined without difficulty (for normal flights). However, this is not an effective means of presenting events in real-time. Event lights and/or digital read-out are preferable. Some caution is warranted however, in implementing digital logic from multi-level signals which have been designed for analog use because in some cases the signal levels may be ambiguous*. Such ambiguity can often be tolerated and resolved in analog readouts but not in discrete or digital displays.

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*Due to factors such as variation in calibration levels on the channel, varying voltages in the signals, minimum separation, and noise.

Assuming that the event signals of interest have been chosen, and that appropriate signals are available, the next concern is that of display. As noted above, event light and/or digital readout are preferable to analog event recording. The use of event lights is particularly desirable for Levels I and II during dynamic flight phases such as Ascent*. Multi-colored lights can be used to indicate whether the event occurred early, on time, or late. In addition, a digital readout of the "off-nominal" time increment is useful. Digital readouts of event times are also useful for events which may be referenced later in the flight, such as lift-off time, insertion time, etc. The most useful digital readout is probably a hard-copy listing of all events, times, and deviations from expected. This is particularly true for detailed checking of S-IVB ascent performance prior to orbital restart. CRT manual call-up of this same list may also be useful. In general, automatic interrupt of analog displays on CRT to present events should not be permitted, but superposition may be acceptable or even desirable in some cases.

The display of "time — deviations from expected" or use of multi-colored lights implies the comparison of actual event-times with expected event-times. However, as shown in Figure 3-7, there is no single time base. (Saturn I Block II vehicles had four.) The question then is whether the deviation should be calculated using only predicted times or whether the actual times of "base events" should be included. The choice depends on the details of the systems and mission, and the use of the displays. For general displays, predicted times appear to be adequate and in some ways preferable. The hard-copy readout can contain both calculations if desired.

One final remark is warranted regarding event times. In general, analog plots on X-Y recorders or strip charts are plotted against time (seconds) from lift-off; and events are listed in reference documents in seconds. It is therefore desirable that a digital clock be provided whose reading is seconds from lift-off.

*In some cases a single light can be used for several signals when only the first signal is important in real time e.g. propellant level signals.

In Appendix C, detailed listings of events (by level) are given for SA-9 and SA-201.

3.5.5 STABILIZATION AND CONTROL

In Section 3.5.3, Trajectories, the vehicle was treated simply as a point mass. Therefore, it is desirable to also monitor the body* motions of the vehicle in terms of attitudes, angular velocities and accelerations, and other parameters related to vehicle stabilization and steering.

These stabilization and control measurements originate in each stage as well as the Instrument Unit (including the platform and the computer). In many instances there are redundant or closely related measurements available, (although they are sometimes not completely independent).

The major Stabilization and Control parameters of interest for real-time display are given in Figure 3-9, with the data divided into three levels (I, II, and III). Level I consists primarily of basic measurements concerned with control. Also included are Emergency Detection System (EDS) rate switch signals and Horizon Sensor "lock" signals (which are of particular interest during orbit). Level II contains angles of attack and horizon sensor outputs as well as measurements which supplement or provide verification of level I measurements. Included are attitude errors calculated from ASC-15 measurements of actual and desired steering attitudes, steering rate ladder commands, and EDS angular velocity measurements. Level III includes additional back-up measurements and various system status measurements relating to the hydraulic control system, auxiliary propulsion (control) system, and platform environment and bearing gas supply.

Detailed tables of data and measurement sources for vehicles SA-9 and SA-201 corresponding in general to Figure 3-9, are given in Appendix D.

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*It is sufficient in real-time analysis to consider the vehicle as a rigid body.

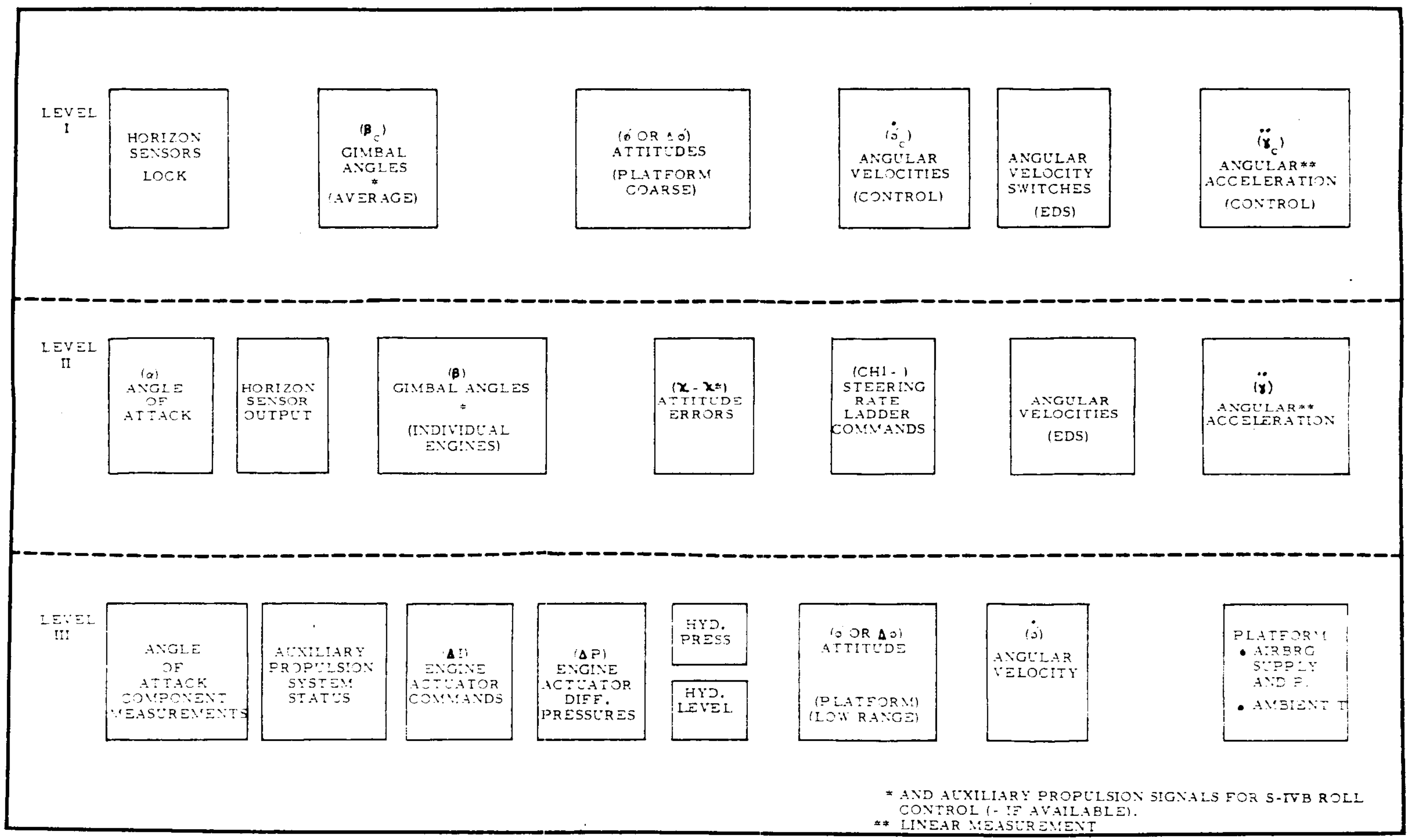

Figure 3-9. Stabilization and Control - General Data for Real Time Display

Some specific considerations of providing displays of the data in Figure 3-9 are given in the following paragraphs.

- <u>Attitudes</u>: Platform measurements of attitude or deviation are listed in level I because they are sensitive indicators of vehicle attitude responses to disturbances and commands and are independent of the computer. Attitude measurements used by the computer to generate steering signals are shown in Figure 3-9 as the computed (B5500) difference between the computed (ASC-15) desired angles (X) and the measured angles ($\dot{X}$*). These are shown as level II measurements. However, there is justification for considering them as level I measurements as was done with the platform attitude measurements. Steering Rate Ladder Commands (CHI-) are also shown in level II. These are proportional to (X-X*) except when limiting is applied. Back-up attitude information is available from the low-range platform attitude measurements.

Attitudes can be displayed effectively on strip-chart recorders provided that the measurement ranges are not large. Thus it is desirable to plot platform deviations and steering errors to minimize the range. Otherwise it may be necessary to use X-Y plotters to obtain sufficient resolution.

- <u>Angular Velocities</u>: Sets of angular velocity measurements and velocity switches form a significant portion of the Emergency Detection System (EDS). The same measurements and switch signals are therefore of special interest for real-time monitoring of vehicles which include these measurements. Because the measurements are used in the EDS in redundant sets and because the signals available on telemetry include the switch status measurements as well as the corresponding angular velocity amplitude measurements, there are at least 18 measurements to consider, precluding simultaneous continuous display of them all. Therefore the philosophy of display is to assign the three angular rate control signals ($\dot{\phi}_c$) to level I and to augment these with EDS angular rate switch signals (lights). EDS angular rate measurements are assigned to level II where they can be referred to (e.g. call-up) based on the level I displays. Additional angular velocity measurements available are assigned to level III.

- Gimbal Angles (β): For multi-engined stages, average gimbal angles are assigned to level I, with individual angles assigned to level II. For single engine stages, gimbal angles will provide indication of pitch and yaw. Corresponding auxiliary propulsion signals (if available) are required for roll.

The usefulness of monitoring β signals in real time is enhanced if they can be related, by appropriate display techniques, to one or more of the control variables. For example, β signals could be combined with attitude deviations as shown in Figure 3-10. The β "lights" in this display are triggered by the sign and magnitude of the average β when it exceeds a β dead band corresponding to normal operation. These displays provide some indication of whether the deviations are being driven by the engine deflections or whether they are being opposed by them and they also provide a measure of data validity checking. Alternatively, this type of display could be applied to angular rates.

3.5.6 PROPULSION

Monitoring the status and performance of the Saturn propulsion systems in detail in real time poses problems because of the multiple-engine, multiple-stage configuration and the multiple-burn capability of upper stages. These factors result in a substantial number of measurements to be considered. It is desirable, therefore, to conduct the monitoring of the propulsion systems within the following general concepts and objectives in order to maintain effective monitoring with a minimum number of parameters on display at one time.

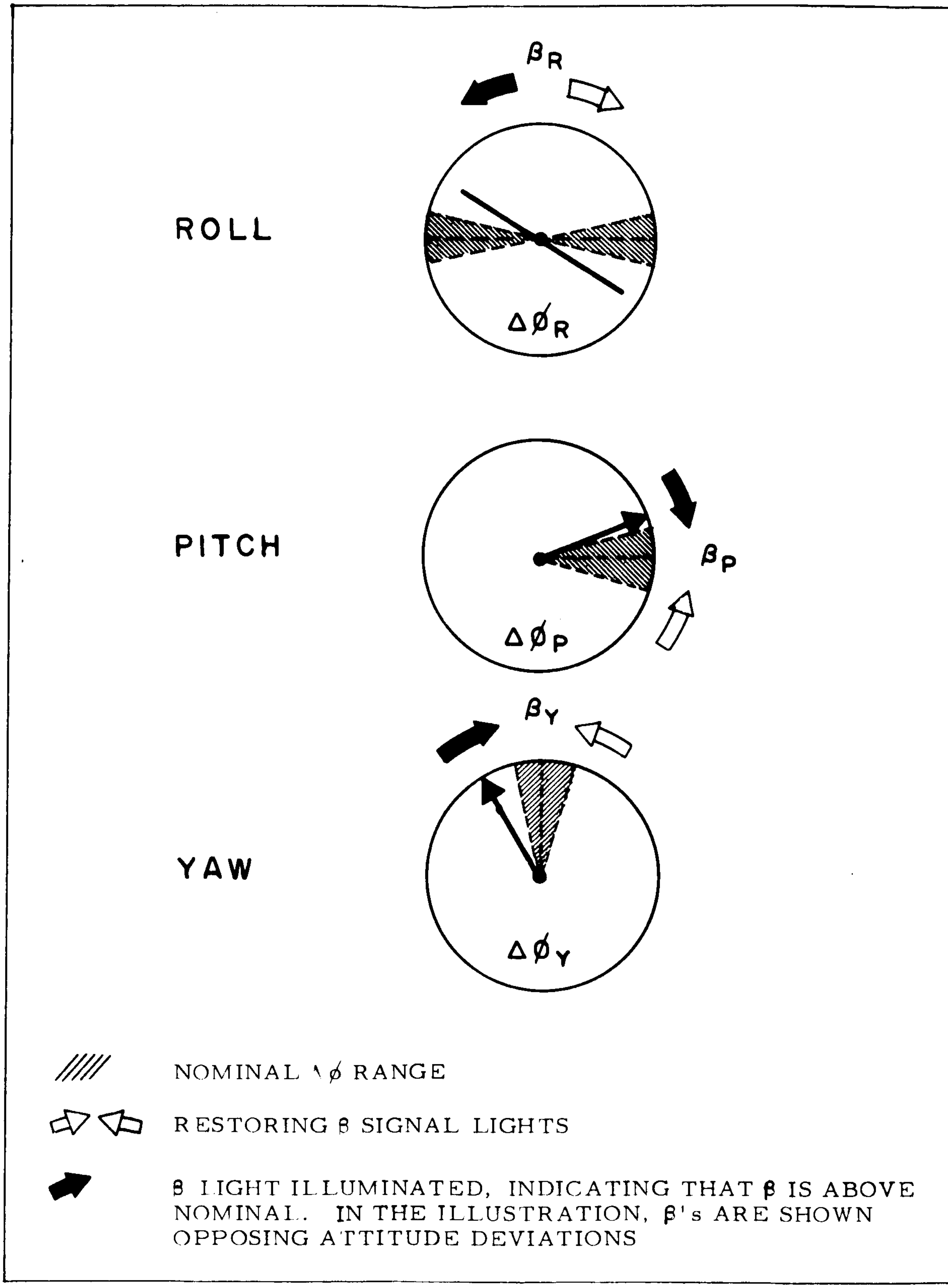

Figure 3-10. β Signals vs Attitude Deviation Signals

- Monitor parameters which can indicate whether the overall performance is as expected.
- Monitor individual engine or subsystem performance in detail only when a problem in the overall performance is revealed.
- Standardize the measurements and formats to be displayed so they are common for all the stages as much as possible.

As an initial basis for implementing these objectives, it is convenient to consider the propulsion system of a typical stage in terms of its subsystems and performance criteria shown in Figure 3-11. As shown in this figure, candidates for overall assessment of performance include:

- Longitudinal Acceleration
- Propellant Consumption
- Thrust
- Specific Impulse
- Chamber Pressure (average)

The most significant single measurement available, which can indicate expected performance, is longitudinal acceleration as shown in Figure 3-11. Acceleration performance is of course the result of the expenditure of propellant, and although vehicle acceleration may be as expected, propellant consumption may be off-nominal for various reasons. Unfortunately propellant consumption is usually difficult to assess in real-time. Assuming that a useful real-time measurement of propellant flow is not readily available (potentially useful measurements and displays are discussed later) the chamber pressure (P_c, average) becomes the next candidate for display. It is not only a significant measurement, but it is directly available. Thrust is considered next. For a given configuration and trajectory, it is essentially proportional to P_c. Finally consider specific impulse. It is in turn

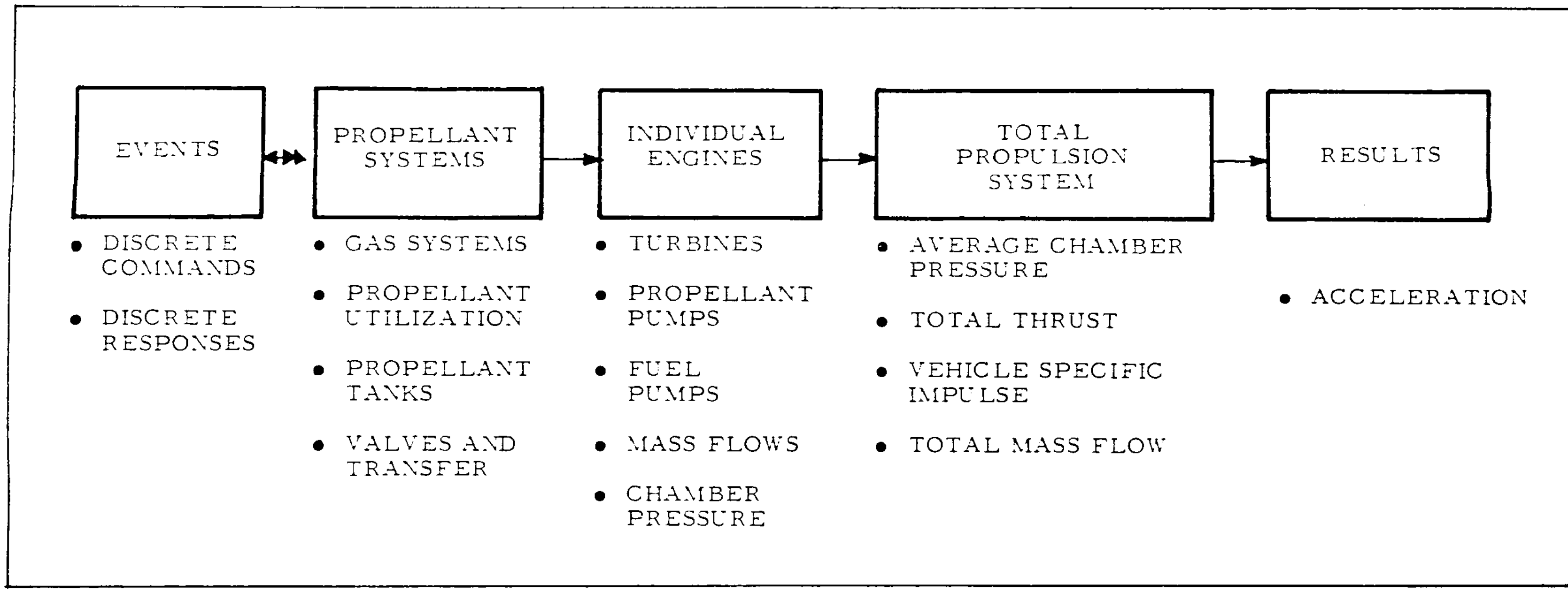

Figure 3.11. General Propulsion System Functional Configuration and Characteristics

proportional to (Thrust)/(Mass Flow Rate).

Therefore, of the five candidates, propellant consumption measurements are generally not useable in real time; calculated values of thrust primarily reflect variations in P_c;* and specific impulse calculations are dependent on consumption measurements.* This leaves longitudinal acceleration and average chamber pressure as the key practical overall measurements for real-time assessment of propulsion. Therefore, these are shown as level I measurements in Figure 3-12.

In addition to monitoring P_c and acceleration it is desirable to present an indication of major propulsion sequencing events. These are primarily concerned with the shut-down commands for one stage and start commands for the next stage.

One added item shown on level I in Figure 3-12 is a measurement of propellant consumption. In spite of the fact that in earlier paragraphs consumption measurements were described as difficult to utilize in real time, a display of consumption is included (shown with dashed lines to indicate its tentative nature) based on the assumed future availability of propellant measurements which are usable in real time (e.g. S-IVB[65]). An example is shown in the "Howgozit" plot of Figure 3-13 where S-IVB Propellant Remaining is plotted vs. Velocity.

Now consider the next level of detail (level II in Figure 3-12) which becomes of particular interest when level I measurements deviate from expected values. Such deviations can be caused by a single engine, or by a subsystem common to all engines.

In level II, the individual chamber pressures serve as back-up and verification for the average chamber pressure and are a prime key to

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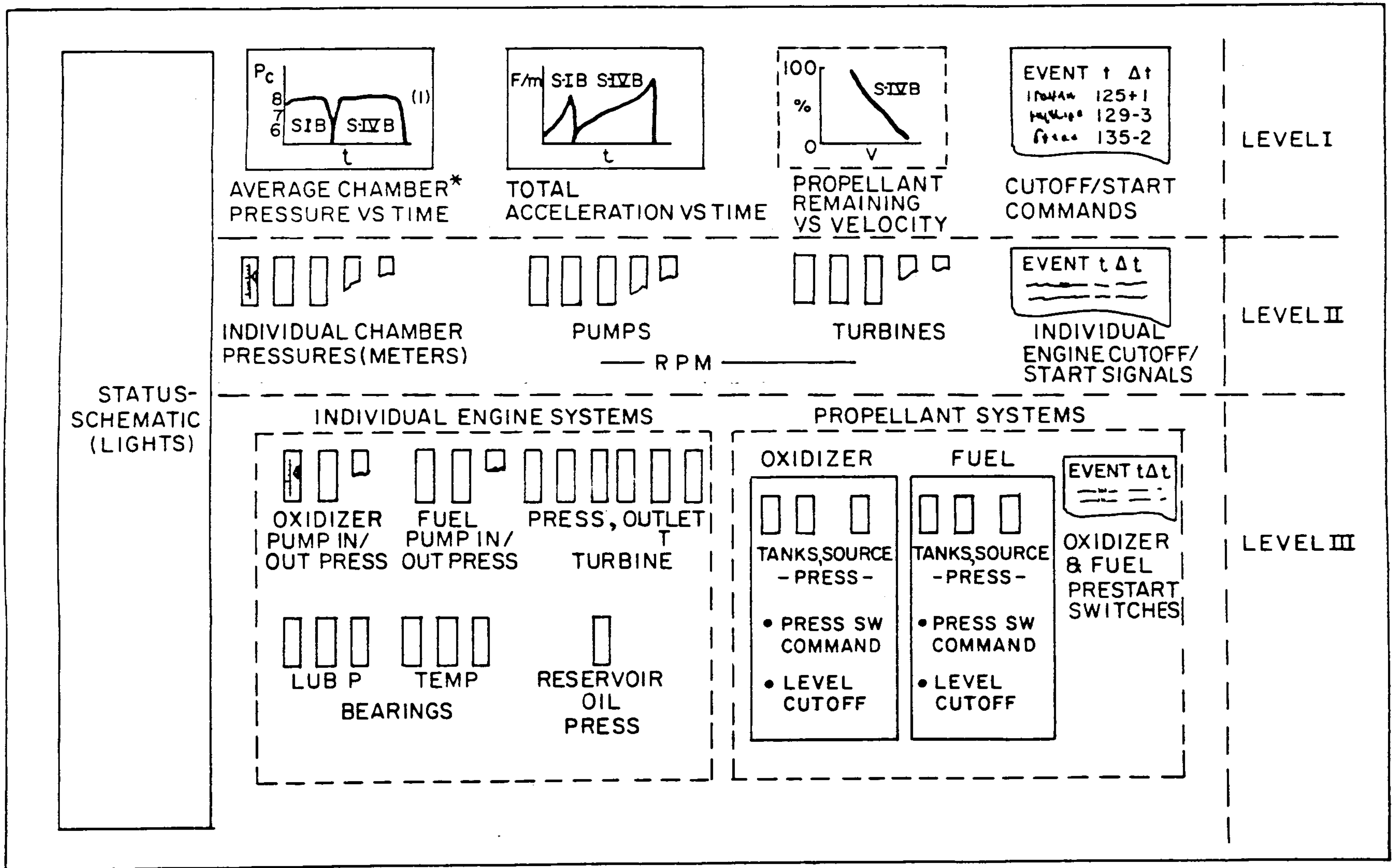
* Methods of assessing thrust and ISP from indirect measurements are not generally ammendable to real-time use.



Notes: Lights and meters - actual and/or scope displayed.
* Average or normalized average.

Figure 3-12. General Propulsion Data for Real Time Displays

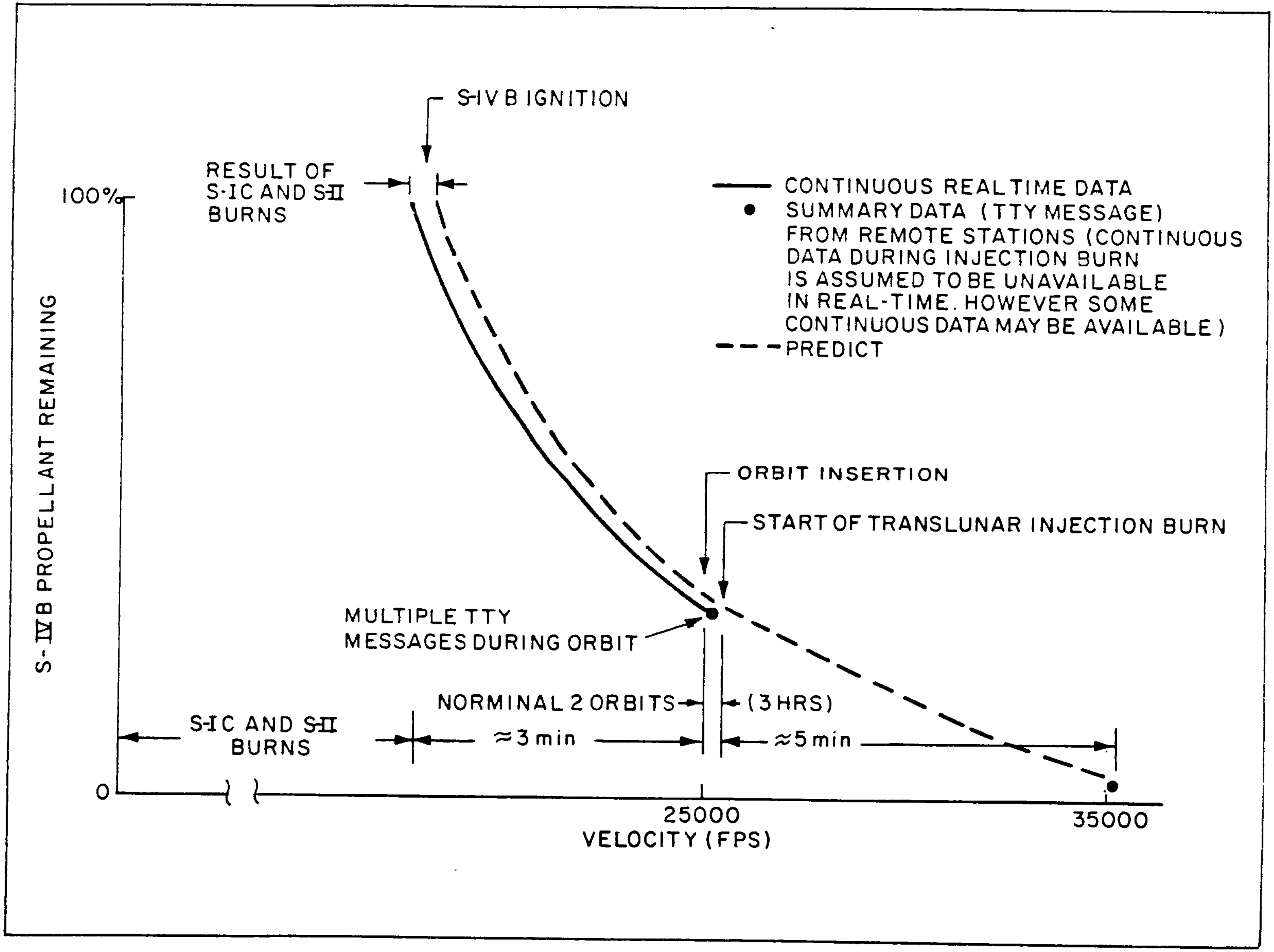


Figure 3-13. Propellant "Howgozit" Chart - S-IVB

identifying individual engine performance deviations. Pump and/or turbine RPM's, and individual engine start/cut-off signals complete the level II displays. The RPM measurements, when available,* are sensitive indicators of potential and actual problems. The engine command start/cut-off signals provide individual engine verification of engine commands. All of these aforementioned level II measurements are concerned with isolating problems to specific individual engines. Similarily, to be consistent it would be appropriate to also include measurements which could isolate problems to propellant systems. For example, tank pressures might be considered the significant key measurements. However, for convenience, all propellant system measurements are grouped together in level III (including tank pressures) to provide a more coherent display organization.

In level III, the parameters to be displayed are divided into two basic groups. One group consists of sets of measurements common to a given engine. The other group contains the detailed measurements which are essentially independent of individual engines, i. e. the propellant systems.

In levels II and III, the number of measurements of interest mushrooms rapidly, particularly for multi-engined stages. As suggested in Figure 3-12, this volume and variety of measurements can be effectively displayed on meters (either actual meters or scope displayed meters), and digitally (for events). However, the problem with such a volume and variety of measurements is not what to display, or whether to use real or simulated meters, or whether to include some analog traces. The real problem is to know where, in this proliferation, to concentrate attention, and, if display call-up is utilized, what to call up. To provide a cue for directing attention and/or for deciding what to call-up, a schematic-status display is suggested as shown in the outline in Figure 3-12 and detailed in Figure 3-14.

*RPM indicators on some stages (e. g. S-I, S-IB) are not compatible for real-time use in present ground status.

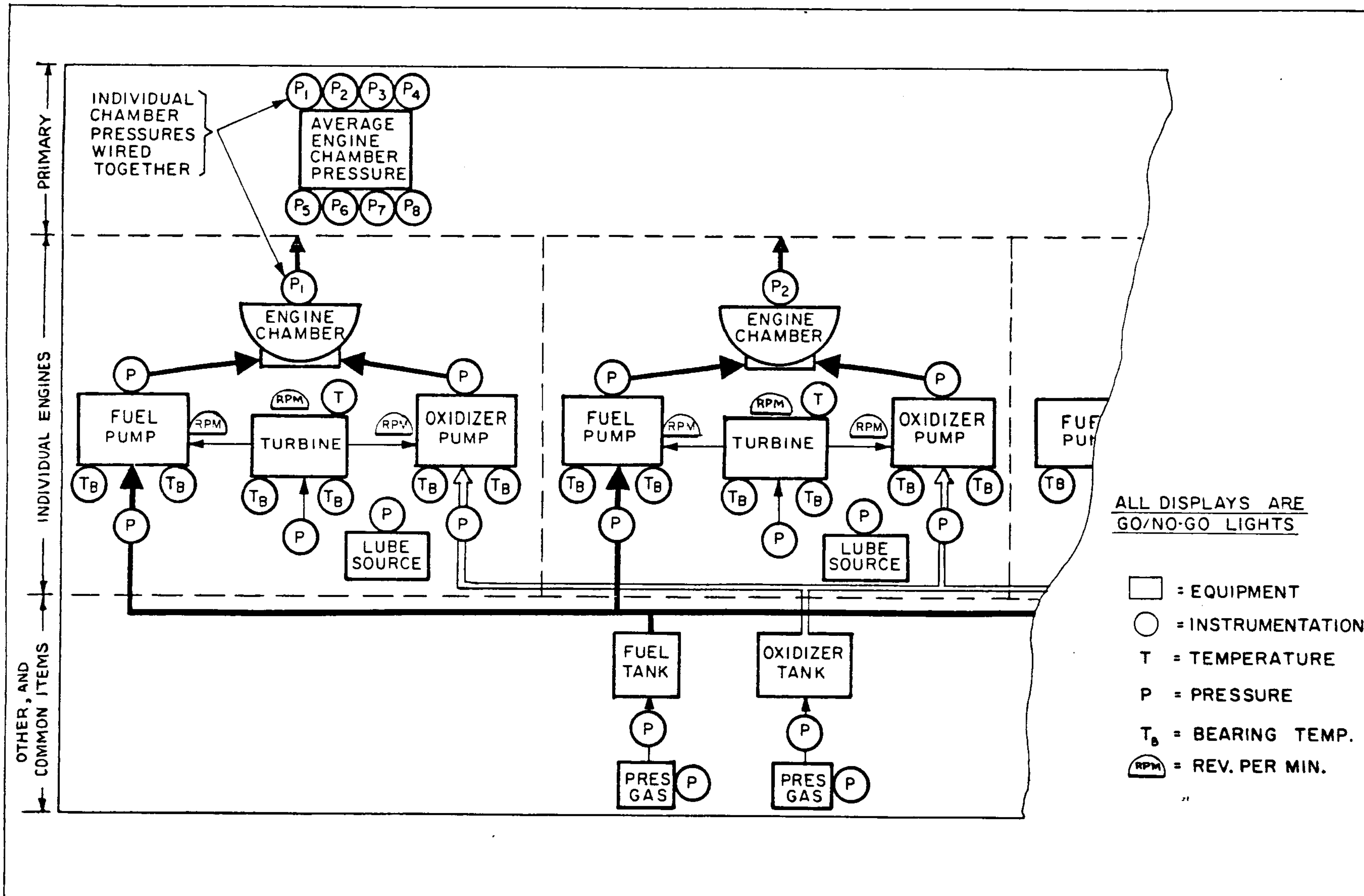


Figure 3-14. Propulsion Schematic - Status Display

This schematic-status display as its name implies is based on a combination of two concepts. These are:

- Status Lights: Any individual measurement which is out of specified tolerance (as determined in the B5500) triggers a light to draw attention to this fact.
- Schematic Display: The lights are arranged in a schematic layout which functionally portrays the propulsion system and the measurements being monitored.

By presenting current status in this functional schematic format, the monitor can correlate the data as to validity and/or meaning and rapidly focus his attention on the detailed areas of concern.

The schematic-status display of Figure 3-14 is generalized. In actual use, it would be desirable to use a unique display schematic for each stage with the constraint that each of these be of the same general format for rapid adaptation of the monitor. Some of the items, particularly events at staging, would be common.

The displays discussed are primarily those of concern in powered ascent. Future missions will also be concerned with restarting the S-IVB engine in orbit and the subsequent performance in the injection burn phase. The coast phase after orbital insertion is nominally two orbits. If this amount of time is actually available, it provides an opportunity for at least one check of S-IVB directly through Green Mountain. The gathering of S-IVB on-orbit data from stations other than KSC and Green Mountain, presumes* that these remote ground stations have the capability of extracting the data from the telemetry in real-time (automatically or manually) and monitoring it on site and/or sending it back to IMCC and/or MSFC. On-orbit operations also add potential problems which should be considered as part of the coasting check including in particular:

*This presumption may not be valid for some (or even any) remote stations, and those that do have some capability may not be able to extract the data from multiple telemetry links.

- tank pressures and venting.
- temperatures, status, and history of certain critical parts, (particularly of any valves which might freeze).
- attitude control

In addition, it may be highly desirable to utilize the time-in-orbit (before the decision-to-inject is made) to re-examine the S-IVB ascent data for more detailed evaluation and correlation than was possible in real-time during the ascent. This type of recall evaluation is not generally satisfied by meter displays. Time histories of a given measurement or a set of measurements are usually more useful. It may also be desirable to print out a digital list of the start/cut-off events and times in much greater detail then was useable during the ascent phase.

Finally, an illustrative example for a given vehicle, of the detailed organization propulsion displays, and data sources corresponding to the discussions and display organization in Figure 3-12, is given in Appendix E for the Saturn SA-9 vehicle, and for Saturn IB, SA-201.

3. 5. 7 ELECTRICAL SYSTEMS

The philosophy of the Electrical Systems display is based on the following:

- Monitoring the basic and primary source voltages provides the initial and most important status information.
- Monitoring the primary currents provides useful performance information.
- Monitoring other voltage supply outputs, distribution point voltages and certain critical temperatures provides additional detail operational information and some fault isolation data.

This philosophy is reflected in the general display data configuration of Figure 3-15. Figure 3-15 also shows the corresponding data for the S-I stage, S-IV stage, and the IU of the Saturn I Block II vehicle and illustrates the basic similarity of the systems and measurements. Note that on the S-IV stage (e.g. SA-9 vehicle) the inverter output voltage is monitored in level I as well as the battery voltages.

In general the Electrical System measurements can be effectively monitored on meter type displays. Although meter type display of current is of limited use for monitoring expected peaks and variations, it can provide indication of continuous abnormal operation. Limit indicators can also be used effectively to augment the displays (or in some cases as a substitute).

Appendix F contains detailed measurement lists and diagrams of the corresponding telemetry data on the Saturn I (SA-9) and Saturn IB (201) vehicles.

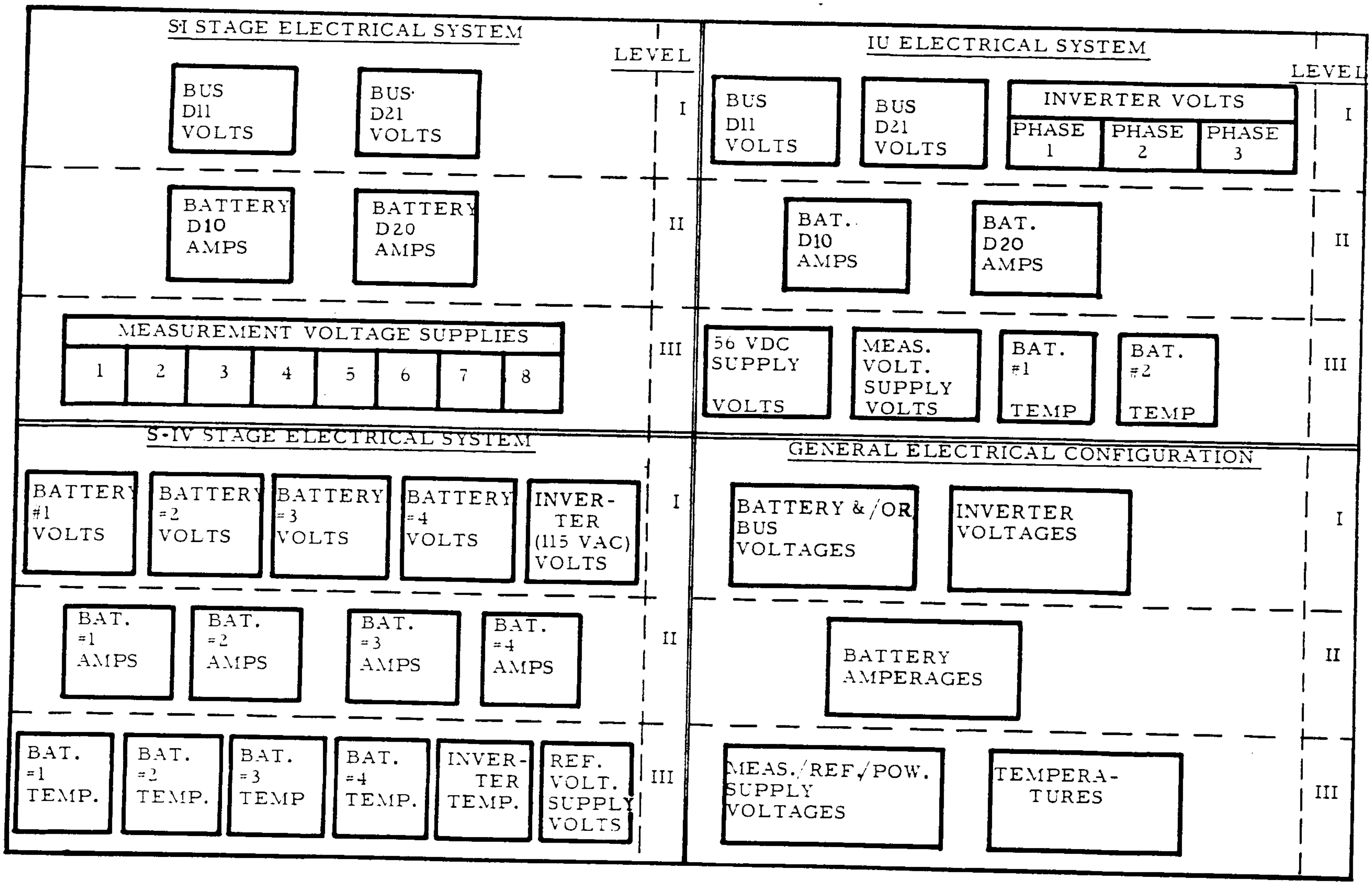


Figure 3-15. Electrical Systems, Saturn I Block II Data for Real-Time Display

SECTION 4

DISPLAY INFORMATION

4.1 GENERAL

In the preceding Section, 3, and corresponding Appendices, various measurements and signals for real-time displays are identified. In the following Section, 5, various types of displays for these data are discussed. These two functions, measurement and display, depend on the functions of "acquisition" and "processing" of the data in order to generate the displays. In this Section, 4, these intermediate functions are discussed in general terms.

The capability for acquiring telemetry and tracking data for real-time displays for Saturn I Block II flights was limited in certain respects and varied flight by flight as existing facilities and communications were augmented. In the future, acquisition of real-time telemetry and tracking data at MSFC will encounter new restrictions as discussed in Sections 4.2 and 4.3.

4.2 REAL-TIME USE OF TRACKING DATA

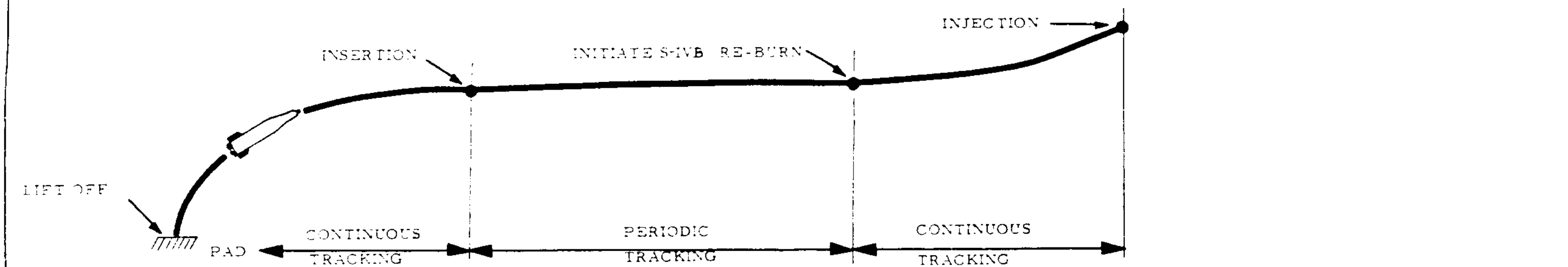
Launch vehicle telemetry data is used in real-time primarily by MSFC personnel (in HOSC and IMCC). Acquisition and processing of this telemetry data therefore is accomplished almost exclusively in response to MSFC requirements. In contrast, tracking data is used in real-time for a variety of purposes, and by a variety of operational control and support agencies. The MSFC requirement for real-time tracking data is therefore just one of many, and in fact may have relatively low priority compared with some others. Because of this, and because of our interest in the use of tracking data (Section 3. 5. 3), the acquisition and processing of tracking data is discussed further in the following paragraphs.

Real-time uses of tracking data can be conveniently categorized as follows:

- Command Guidance Systems
- Range Safety
- Range Control
- Mission Control
- Real-time Quick-Look Flight Evaluation
- Recording for Post-Flight Vehicle and/or Range Evaluation

Some of the significant features of each of these categories, as they will apply to Saturn-Apollo flights, are listed in Figure 4-1[49, 63, 66]. The first of these, Command-Guidance is not used in the Saturn operation; therefore, it is not considered further. Of the others, our prime interest, with respect to MSFC real-time activities, centers around the two categories, Mission Control and Real-Time Quick-Look Flight Evaluation. As shown in Table 4-1, these two categories can have much in common in spite of their one fundamental difference. This difference is the fact that in Mission Control tracking data is used for real-time decisions (right ones or wrong ones) which affect the mission in progress (rightly or wrongly), whereas the Flight Evaluation application can only affect future flights. These decisions include the key decisions whether to continue or abort the mission.

- Coverage: Having established the basic areas of our interest, it is convenient to consider the information of Table 4-1 as it applies to the ascent, orbital, and injection phases of a lunar flight as shown in Figure 4-1. During the ascent phase, continuous coverage is required. During



MISSION PHASE	ASCENT	ORBIT	ESCAPE	REMARKS
RANGE SAFETY	• PRESENT POSITION • IPP	← NOT INVOLVED →		• END OF RESPONSIBILITY AND COMMAND CAPABILITY VARIES WITH LAUNCH AZIMUTH AND MISSION.
RANGE CONTROL	• POINTING DATA	• EPHEMERIS AND POINTING DATA	• POINTING DATA	
MISSION CONTROL	• TRAJECTORY • POSITION • VELOCITY • FLIGHT PATH ANGLE • ABORT AND RECOVERY DATA	• CONFIRM ORBIT INSERTION • BACK-UP CUT-OFF COMMAND IF REQUIRED • ORBITAL PARAMETERS • INITIAL • UPDATED • UPDATE INJECTION CRITERIA • ABORT AND RECOVERY DATA	• TRAJECTORY • CONFIRM INJECTION CONDITIONS • ABORT DATA	• NO ORBIT ADJUST SHOWN.
REAL-TIME QUICK-LOOK FLIGHT EVALUATION	• TRAJECTORY • POSITION • VELOCITY • FLIGHT PATH ANGLE	• CONFIRM ORBIT INSERTION • ORBIT PARAMETERS • INITIAL • UPDATED • UPDATE INJECTION CRITERIA	• TRAJECTORY • CONFIRM INJECTION CONDITIONS	• FOR COMPARISON AND EVALUATION OF TELEMETERED TRAJECTORY INFORMATION.

Figure 4-1. Real Time Tracking Uses - Saturn-Apollo Launch to Escape Phases

Table 4-1. Real-time Use of Tracking In Saturn-Apollo Launch to Escape Phases

Category	Use	User	Tracking Inputs	Computer Location	Remarks
Command Guidance	Closed loop radio command of trajectory	-------	------	------	Not used In Saturn
Range Safety	For plotting present position and corresponding predicted impact point.	ETR Range Safety Officer	ETR	Cape Kennedy	Powered flight termination and destruct command capability and responsibility varies with launch azimuth and insertion point.
Range Control	Calculation of pointing data for tracking and/or communications acquisition	ETR MSFN	ETR MSFN	GSFC*	*ETR will also compute pointing data for its own use, at least during powered flight.
Mission Control	• Ascent trajectory plotting • Confirm orbital insertion • Initial estimates of orbit • Update estimates of orbit • Determine escape injection conditions required • Confirm injection conditions • Abort and recovery calculations	IMCC (MSFC)	ETR MSFN	IMCC	ETR tracking source and data selection made at ETR. Data may be smoothed or raw. (MSFC): In support of IMCC.
Real-Time Quick-Look Flight Evaluation	• Ascent trajectory plotting • Confirm orbital insertion • Initial estimates of orbit • Update estimates of orbit • Determine escape injection conditions required • Confirm injection conditions	MSFC	ETR MSFN	MSFC	• For comparison with and evaluation of telemetered trajectory information. • Computed outputs from GSFC, ETR, and IMCC are also potentially available
Recording	• Mission evaluation • Range evaluation	MSFN ETR IMCC MSFC	ETR MSFN		Prime use is for post-flight evaluation; however, playback during the mission can be useful in some cases.

GSFC Goddard Space Flight Center
ETR Eastern Test Range
MSFC Marshall Space Flight Center
MSFN Manned Space Flight Network
IMCC Integrated Mission Control Center, Houston

the orbit phase, periodic contact is satisfactory. During injection, continuous coverage is desirable.

The coverage available, particularly during the ascent phase, is highly dependent on the launch azimuth as shown in Figure 4-2. Saturn I vehicles were fired down ETR where available coverage to insertion by land based stations is good and in fact is overlapping. Saturn V-Apollo flights, however, will probably not be launched down ETR but will be launched along the MSFN (as for Mercury and Gemini). In this case, the insertion point is expected to be beyond the reliable range of Bermuda[32, 62] at the altitudes of interest. In this case, augmented coverage from a ship will probably be provided. Similarly, a ship(s) may be used to provide coverage of injection.

In providing the necessary coverage for the various phases, not only are there a number of stations involved, but there is a considerable variety of tracking systems; some are radar trackers, others are C.W. trackers[40, 69]. Not only may the output parameters from these be different, but the accuracies will vary. When multiple tracking pertains, selection and switching of the data to be transmitted and/or processed in real-time must be made based on the time-of-acquisition, order of preference (accuracy), apparent relative data quality, and expected or actual loss of signal.

- Computing Centers: As indicated in Table 4-1, there are three computing centers, over and above MSFC, involved in processing tracking data in real-time (ETR, GSFC and IMCC). Tracking data inputs to MSFC potentially can be obtained from one or more of these.

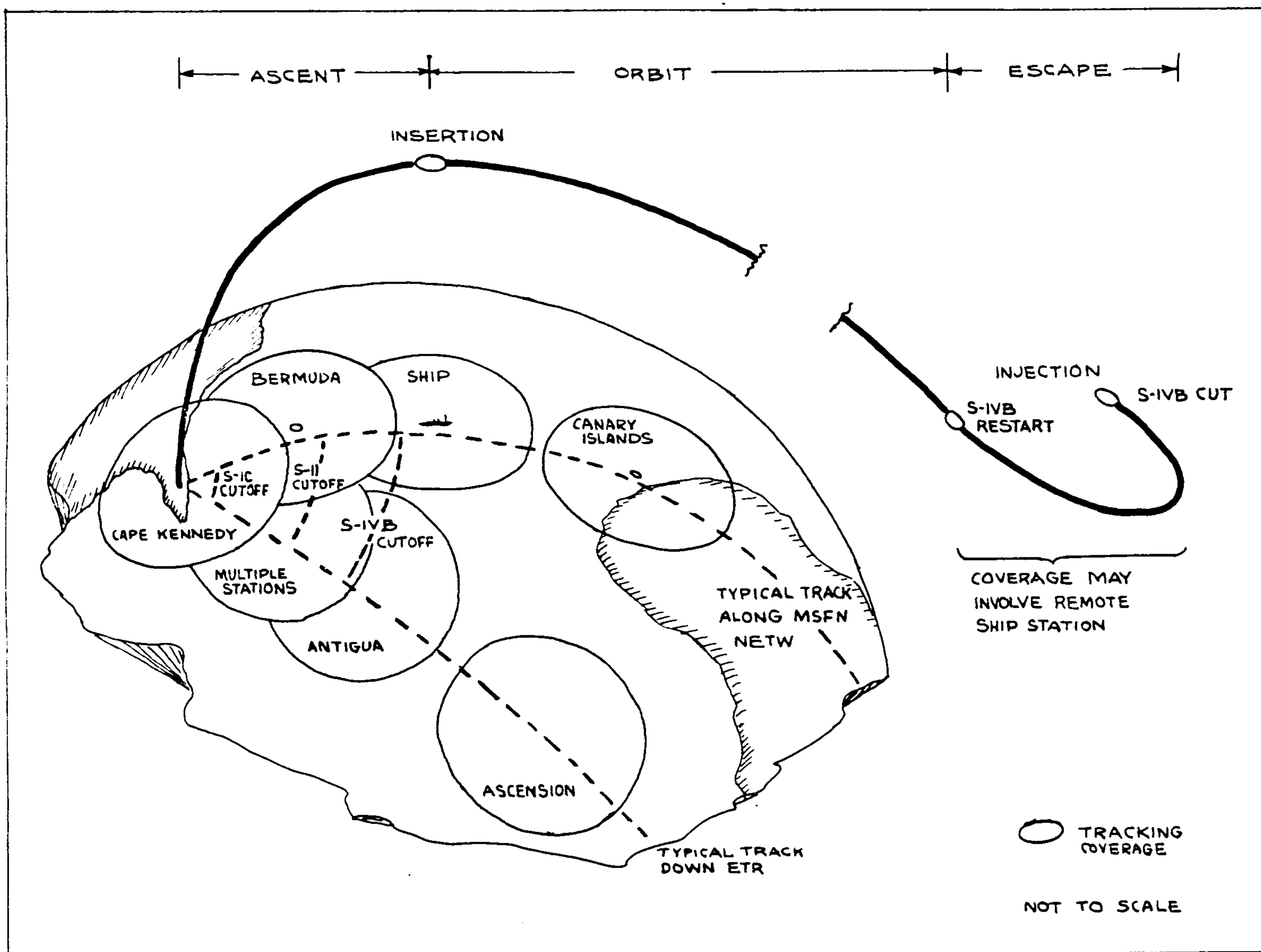


Figure 4-2. Tracking Coverage

Because of their different roles, the tracking data available at each of these will differ. Similarily, the computations carried out at each will differ. The extent of these differences will depend on the mission, the allocation of operational tasks to the centers, and the corresponding interchange of data provided. For example, for unmanned flights down ETR, the tracking data available at ETR may exceed and differ from that available at GSFC, and vice versa for manned flights.

The task interrelationships of the control centers will obviously have a direct impact on the computing at each center. For example, one mode of operation that has been used in the past [48, 49] is for ETR to smooth and edit tracking data, transpose it to position/velocity/time data, (geocentric inertial co-ordinates), tag it with site and radar identification, insert checksum parity bits, and transmit it at ten messages/sec to GSFC for trajectory display and pointing computations. An additional mode of operation is also used to increase system reliability. It provides for bypassing the ETR computer and sending raw tracking data (with appropriate identification) to GSFC where it is accepted, edited and smoothed to maintain the overall computing cycle.

- Communications: As shown in Figure 4-1, tracking data may be acquired from a variety of sites. In general, local computing of trajectories is not provided (nor desirable) at these sites. Therefore, use of this tracking data in operational support of a mission implies communication links between the tracking stations and the computing centers. The existing communications for this purpose fall into two classes:

(a) high speed data links (e. g. 1000 bits/sec.).

(b) low speed data links (e. g. teletype speeds of 60 words/minute, with some as low as 35, and some as high as 100).

The high speed lines are typically well suited to carrying the data associated with the rapidly changing parameters of ascent. The low speed links have proven adequate for orbital operations where the major computing tasks are concerned with periodically revising data which was previously calculated from insertion conditions.

The type of links, their routing, and the data content of transmissions to be employed for communicating tracking data during Saturn-Apollo insertion and escape will have a major effect on the tracking data available at MSFC. At present, two complementary modes of operation are being planned by GSFC for this coverage. The first and most desirable mode is to transmit the tracking data back from the ships by a 2. 4 kilo bit RF link. There is some concern, however, that this data may not be of sufficient quality to be used as a basis for the insertion or injection go-no-go decisions, therefore a second mode of operation is being provided. This consists of installing a complete trajectory computing and display* capability on board the ship(s). This, in effect, is identical to the original configuration and role of Bermuda in Project Mercury flights before the Bermuda-New York cable was installed[26, 49, 69]. The output from this type of operation would probably be the velocity vector at insertion, or injection and/or sampled tracking data** at six second intervals as presently used for stations restricted to teletype speeds. In any case, the problem of providing communications to cover the injection, is potentially the more difficult, for if the injection is over the

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* Also included are telemetry displays and monitoring personnel for vehicle and medical go-no-go decisions (Section 4-3).

** Launch vehicle telemetry data would probably not be included. Summary messages containing a sample or average of a few measurements would be available after the tracking data transmissions are completed (Section 4-3).

Indian Ocean, for example[62], the communication links back to America are more tenuous than from the mid-Atlantic.

- Ascent Phase: Tracking data during ascent is primarily useful for presenting:

  - position
  - velocity magnitude - velocity vector
  - flight path angle

The actual format and display of this information in real-time should be such that it complements the displays of other data from telemetry. Primarily this telemetry data consists of guidance computer outputs; however, certain of the abort system parameters may also be a factor. A more subtle consideration is that MSFC displays should be sufficiently compatible with IMCC displays to allow ready and effective exchange of information.

Tracking displays therefore should:

(a) be comparable with telemetry trajectory data and abort criteria

(b) be compatible (format, nomenclature and units) with IMCC displays

(c) be comparable with predicted trajectory.

- Orbital Phase: Orbital phase displays are concerned with presenting first of all, an immediate indication that an acceptable orbit has been achieved. This can be generally deduced from the velocity ratio/flight path angle plot. Following this, preliminary estimates are desired for the orbit capability and characteristics for comparison with predicted and/or with estimates based on telemetered data.

At this point in the mission, at best, continuous tracking coverage ends. From this point on, tracking data will be received at GSFC at intermittent intervals depending on the station(s) in contact and the communications available. In some cases the tracking data is only available by teletype.

During each pass over a radar site, range, azimuth and elevation measurements are taken for as long as the vehicle remains within effective range. The information from the radar is processed through conversion equipment at the site and transformed into a teletype format for transmission at 60 words per minute (six characters per second into the computer, equals about 1 frame of data every six seconds).

Each teletype sample, or frame, includes raw azimuth, range and elevation measurements, time-of-transmission, station and type-of-radar identification, and a valid-track signal. Time is specified in GMT (hours, minutes, seconds).

Some of the sites have double radars (S-band and C-band) but data from the two radar types at a site equipped with both is never transmitted simultaneously*.

Processing of the sampled raw radar data from individual MSFN sites is done at GSFC taking into account the station location and geometry, prelaunch boresight calibrations, and local site atmospheric conditions which are updated periodically.

The processing is based on empirical criteria that 15 consecutive valid track points must be received before the data can be processed. In addition, updating corrections to the orbit (based on these points) must not exceed certain specified limits.

*Subsequent to tracking data transmission, telemetry summaries are transmitted (Section 4-3).

The GSFC processing edits and smooths the input data from each site. The orbit is then updated by differential correction; and extrapolations are made (for pointing data etc.) based on Cowell's numerical integration.

From the GSFC processed information, the displays of orbit characteristics can be generated and updated.

- Mode of Operation for Tracking Data: From the various discussions in previous paragraphs, the following points are evident.

  - Multiple tracking sites are involved.
  - Multiple tracking systems are involved with various types of outputs and accuracies.
  - Tracking coverage available varies from considerable overlap to intermittent. In cases of overlap, selection is made of which to use. In some cases the selection is made at the site. In others it is made at the range center.
  - Multiple computing centers are active for various reasons. Processing of raw tracking data ready for the "using agency" is carried out at ETR and/or GSFC. In some cases, raw data is supplied to the "user" if processed data is not available.
  - Transmission of tracking data to the computer center(s) in real-time imposes a considerable load on the communications links.
  - Communications links have limited capacity. High speed data lines are available in some cases. In other cases only teletype is available.

With this background in mind, now consider the use of tracking data in real-time at MSFC. There are several apparent sources for inputs to MSFC (now or in the future), as shown in Table 4-2.

Table 4-2. Tracking Data Sources

	HI SPEED DATA		TTY (PROCESSED)	COMPUTED ANSWERS
	RAW	PROCESSED		
GSFC		X	X	X
ETR	X	X		
IMCC	(X)	(X)	(X)	X

Note: ( ) Supplied from GSFC or ETR
TTY = Teletype

The major point of concern is this. At present, tracking data available from ETR provides essentially complete coverage of launch past orbital insertion, and output from ETR is available in one format. In the future, the coverage available from ETR may not include insertion; and outputs from the various sources may be in more than one format.

In any case, whatever the source(s) to be used in the future by MSFC, the present MSFC methods and displays should be a step in the evolution toward the final mode of operation. Eventually, when MSFC is supporting the IMCC, a major objective at MSFC will be to confirm that the launch vehicle is operating satisfactorily. Tracking can contribute directly to this by providing a source of data independent of the telemetry. The questions that arise immediately are these. "How should this tracking data used at MSFC relate to the tracking data at IMCC?" and "Should it be as independent (in source and method of computation) as possible?"

Operationally, it appears that it is preferable that they be as identical as possible, thus providing common points of reference, and simplifying the data flow.

Based on this consideration, the present operations should be implemented with this interface clearly in mind when considering the sources of data, the formats of the data, the computing techniques to be used, the data displays, and the criteria for acceptability.

4.3 REAL-TIME USE OF TELEMETRY DATA

Prior to the installation of the data-link from Cape Kennedy, telemetry data was available only from Green Mountain and essentially covered only S-I shut-down and part of the S-IV powered flight (Figure 4-3). Tracking data was only available from GSFC by teletype. With the installation of the data-link (SA-9), telemetry coverage for all of the ascent phase became available. The capacity of the link was progressively increased and tracking data was also included for SA-10. In each case, however, limitations in the Datakor at KSC or in the ground station at MSFC made it generally impractical to use commutated data or measurements such as rpm which require ground station "counting". This was not serious for Saturn I Block II vehicles because the display capacity available was the actual limiting factor. In future flights however, when the expanded display capability is available, restrictions on the use of commutated data would be annoying, and in some cases could result in decreased flexibility and capability. It has been presumed in this study that commutated data will be available in the future.

- Coverage: As for tracking (Section 4.2), the real-time acquisition of telemetry data at MSFC for future Saturn Flights will be dependent on a number of new factors. For missions launched toward Bermuda, telemetry coverage of S-IC and most if not all of the S-II stage can be provided from ETR* and the selected real-time data entered into the data link to MSFC. However, S-IVB powered flight coverage would be available only from the Bermuda* and ship stations. Communications

* See Figure 4-2 which illustrates tracking coverage. Telemetry coverage is usually somewhat greater than tracking coverage, therefore S-II cut-off may be within range of ETR telemetry and S-IVB cut-off may be within range of Bermuda telemetry.

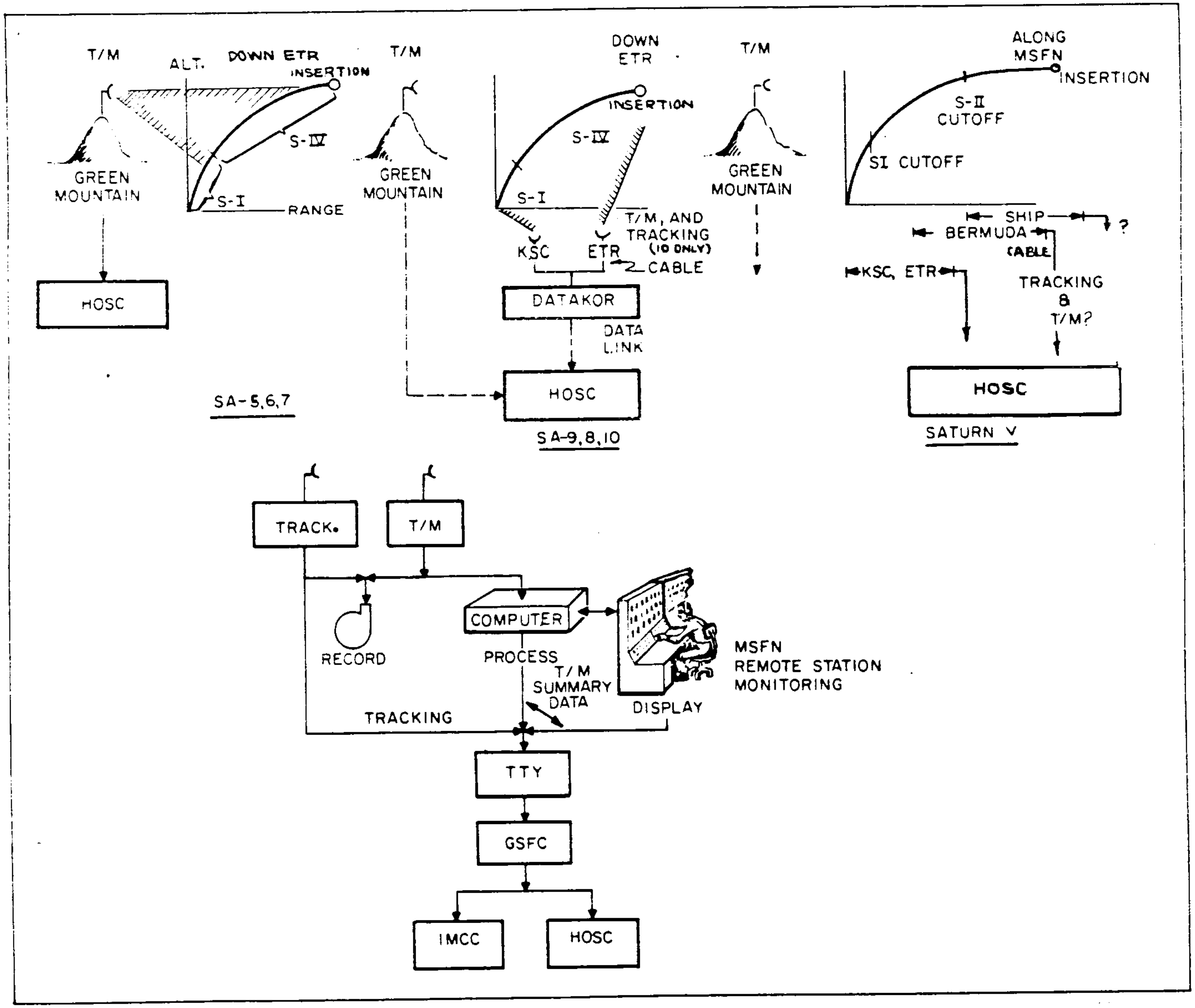

Figure 4-3. Coverage

from Bermuda are via cable. In the past, the number of circuits available to NASA on this cable was limited because it was a commercial facility and therefore could not be assigned exclusively to mission support. In the future, the telemetry load at Bermuda for Saturn flights will be significant (Figures 4-3 and 4-4)[32] and will be greater than for any previous flight (Mercury, Gemini). The amount of telemetry data obtainable at MSFC in real-time from Bermuda will therefore depend on the available cable capacity, and on the allocation of this capcity to tracking data, voice communications, spacecraft telemetry and launch-vehicle telemetry. The minimum amount of launch-vehicle telemetry data that will be available at MSFC will be that data which is required at IMCC which in turn will depend to some extent on how much launch-vehicle monitoring, if any, is to be done by flight controllers at Bermuda. If sufficient cable capacity is not available in real-time it may be desirable to consider playback and transmission of recorded data after loss of telemetry and tracking contact at Bermuda. This would provide the required amount of S-IVB ascent data at MSFC for delayed evaluation during the orbital coasting phase and prior to the second burn of S-IVB.

Telemetry data from the mid-Atlantic ship between Bermuda and the Canary Islands will also depend on the communications available (See Section 4. 2) and the assignment of capacity as for the Bermuda station. The minimum telemetry data available from this station, and other MSFN stations, will be a teletype summary message giving typical or average values of data during the station's contact. This message is generated manually, or automatically, by the flight controllers at the station (Figure 4-3 and 4-5)[46]. The contents of the message generally correspond to the measurements displayed on the console. The display console and meters assigned in Gemini missions to Agena monitoring could be used for S-IVB/IU monitoring.

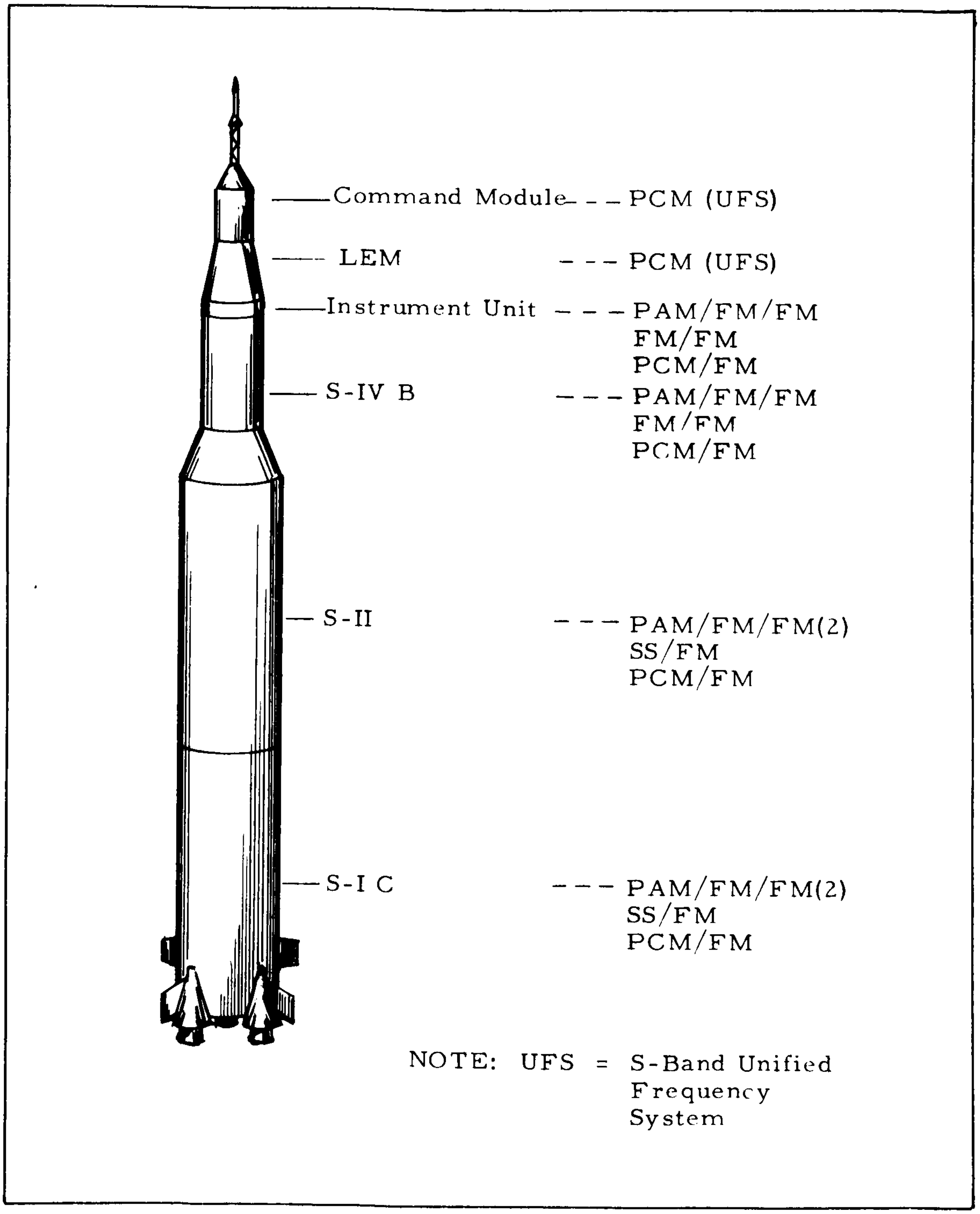

Figure 4-4. Saturn V Telemetry Systems

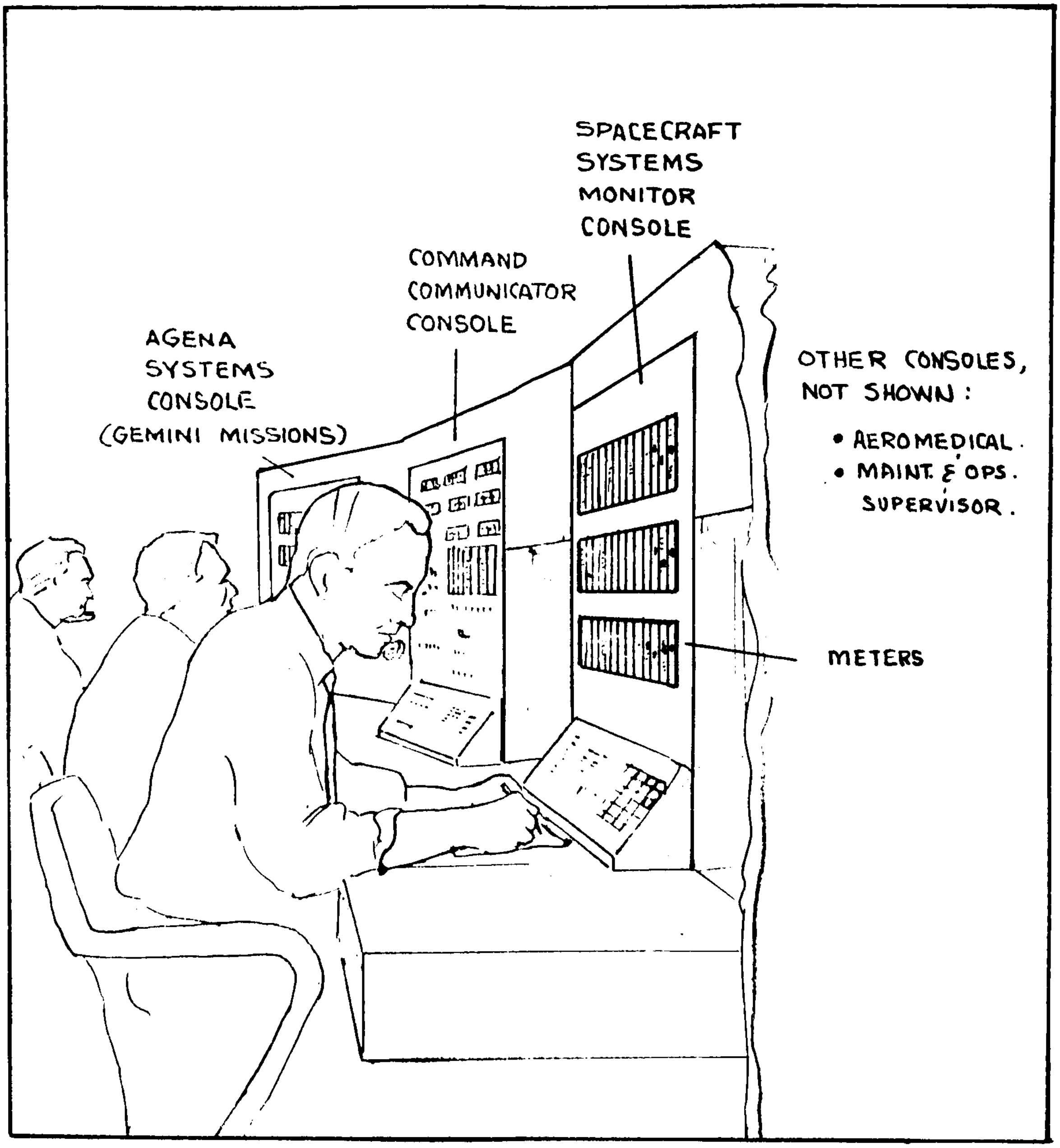

Figure 4-5. Typical MSFN Remote Station Flight Control Consoles

During orbits where Green Mountain can obtain telemetry contact, the real-time "bottleneck" of ground communication links can be bypassed.

From this brief description of real-time telemetry coverage, one paramount factor is evident. The network ground communication systems do not have the capacity to transmit large volumes of telemetry data in real time. Less evident from the discussion, but nevertheless a significant item for consideration, is the fact that the number of telemetry links, six links of three types for the S-IVB and IU (See Figure 4-4), and the diversity of types may create unnecessary problems at remote stations if data is to be selected from all of these for real-time use. It may be necessary (in any case it is advisable) that the data to be extracted at remote stations for real-time use be assigned to one TM link for each of the IU and S-IVB. Preferably these should be the PCM links. If further capacity is available at the sites to handle data from the other links, this capacity could be used for back-up information.

4.4 REAL-TIME DATA PROCESSING

Typical data processing tasks associated with the generation of real-time displays are:

- Conversion
- Calibration (the need for and use of in-flight calibrations in real-time should be avoided)
- Guidance Computer Data Strip-out (required because of varying PCM location assignments of computer telemetry data)
- Trajectory Computations (from tracking and/or telemetry)
- Orbit Calculations[51, 52]
- Limit Sensing
- Logical Operations

- Event Identification and Time Tagging
- Arithmetic Operations
- Display Generation
- Display Selection and Switching Control
- Storage of Data for Recall

In general, these functions are associated with the processing of continuous hard line inputs. In some cases, discontinous data (e. g. from TTY, or manual inputs) may be involved. The organization and implementation of these functions depend in most cases on the specific HOSC system and hardware and is beyond the scope of this study. However, pertinent factors affecting a number of these items are discussed in Sections 3 and 5. Also, some general remarks on the last two functions in the above list are given in the following paragraphs.

- Display Selection and Switching Control: The new HOSC facilities being installed at MSFC include both console and wall displays with considerable flexibility for switching or calling up additional displays. The Datakor facility at KSC which organizes and controls the inputs to the data link to HOSC also has considerable flexibility. On the other hand, the data link itself has a capacity substantially less than the total telemetry load. As a result, the question arises as to whether the HOSC display switching should include the ability to switch data link inputs or only outputs. Switching of the inputs can provide an apparent increase in the link capacity, which may be useful. Caution is required, however, in the manner in which this is done in order to prevent loss of data and/or confusion as outlined in the following remarks.

For illustrative purpose, assume that control of the contents (i. e., input) of the data stream on the data-link is given to console operators. For example, if a console operator requires display of measurement "A" and it is available at KSC but is not on the data-link, he can delete a measurement (e. g. measurement "B") in the data-link stream and substitute measurement "A". However, this will have one or both of the following two effects.

(a) The data-link contents will normally be tape recorded at MSFC for later use and reference. Substitution of parameters on the link at random times will make it difficult to know what is on the tapes (and when) and this can reduce the usefulness of these tapes. Data stored in memory for subsequent real-time recall is similarly affected.

(b) When the console operator who is displaying item "B" decides to delete "B" and substitute "A" in the data-link stream he will disrupt any other consoles which may be displaying "B". (Note that because all the console operators will have access to the stream data in real-time they will not be able to predetermine who is displaying "B" at any given time in order to ensure they are not disrupting someone else.)

These two situations suggest that real-time switching be confined to the output of the data-link, not the input. Interlocks on requests, to prevent loss of data being displayed, will minimize the effects of (b). However, the implementation of an interlock system which will be operationally satisfying in all cases may not be simple and may cause more problems than it solves. On the other hand, this type of input switching would be particularly useful to select back-up measurements if primary measurements failed. However, it would be preferable to have the backup already on the link, and the planned link capacity of 2046 measurements (2 samples/sec.)* should readily permit this.

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*Strapping can be used to obtain higher rates, if required.

- <u>Storage of Data for Recall:</u> The real-time evaluation of the S-IVB ascent phase of the flight may reveal a need for more detailed re-evaluation of the ascent data while the vehicle is parked in orbit. In general the display formats for this recall would be of three types.

  - Time histories
  - Lists (events)
  - Summary of deviation beyond specified limits.

These formats, in some cases, would be different from those used during the ascent. The summary of deviations beyond specified limits could be accomplished by means of a simplified adaptation of the programs developed in Reference 50 for quick-look post-flight analysis.

The tracking and telemetry coverage, and the network communications available for the S-IVB ascent (Sections 4.2 and 4.3) will be a major factor in considering this type of recall. As noted in Section 4.3, playback of data from Bermuda (and possible the ship) may be useful and practical.

In addition to the recall during orbit of ascent data, recall during ascent may be useful in order to generate and display a time-history of a measurement(s) which is being viewed on a meter type display (Section 5.3). Note that recall capability can be compromised by data-link input switching as discussed on the previous page.

SECTION 5

DISPLAYS

5.1 GENERAL CONSIDERATIONS

The HOSC real-time display capabilities for Saturn I Block II vehicles (Figure 3-2) consisted primarily of a number (typically nine) of 10" x 10" X-Y records viewed either directly or by TV monitor. TV monitors were also used for displaying one or more multi-channel direct-writing analog strip-chart recorders and digital messages (events, orbital elements, etc.) generated from the B5500 and TTY.

The new HOSC display facilities (Figure 3-2) include large wall type displays, consoles with CRT type displays (Figure 5-1), 40,67 and direct-writing recorders.

The significant data for real-time display has been discussed in detail in Section 3 and the corresponding Appendices. In this Section, 5, appropriate display formats for the various types of these data are identified. These formats are considered within the general context of the types of display equipment which will be available in the new HOSC facility. However, no attempt is made to assign data or formats to specific consoles or wall displays. Such assignment can only be done adequately with due consideration of total system details, operational organization, and responsibility assignments. As such it is beyond the intent and scope of this study.

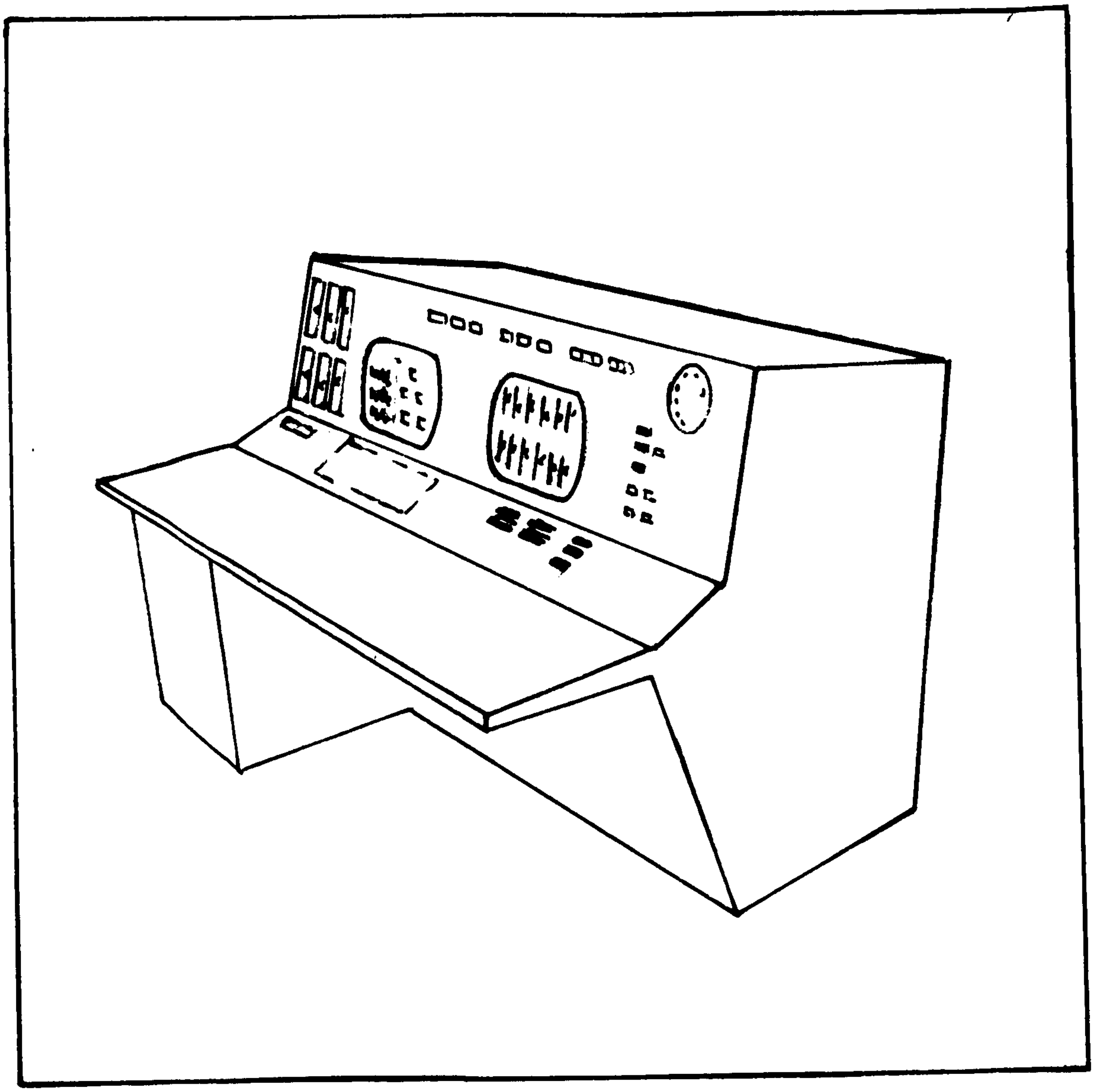

Figure 5-1. Typical Console

In some cases, specific display formats were developed in Section 3 because of the nature of the particular data. These are discussed further where appropriate.

Display formats for our purpose can be conveniently classified in the following general categories. (See Figure 5-2.)

- X-Y
- Strip-chart type time-histories
- Meters
- Alpha-numeric characters and messages
- Lights
- Schematics

The tendency is to associate each of these various formats with specific types of hardware. However, the availability of computer driven CRT display equipment allows the formats to be considered on a more general basis and also to combine them in various ways. In following paragraphs some general remarks are made concerning these categories. However, there are several characteristics of CRT and strip-chart display equipment which are of interest to our application,and these are discussed first.

- <u>CRT Displays</u>

The CRT displays[40, 67] are 14" precision TV monitors with a useable viewing area of only 7.5" x 10". This useable area is actually smaller than had been expected when the monitor sizes were originally selected for the IMCC. Also, the smallest useable alpha-numeric symbol size is larger than expected. As a result, the monitor size is marginal. In IMCC this size is reasonably acceptable because of the large number (400) of TV monitors available, but in the HOSC application, with a limited number of consoles and TV monitors, and with the large number of measurements of interest, the small size may be more critical.

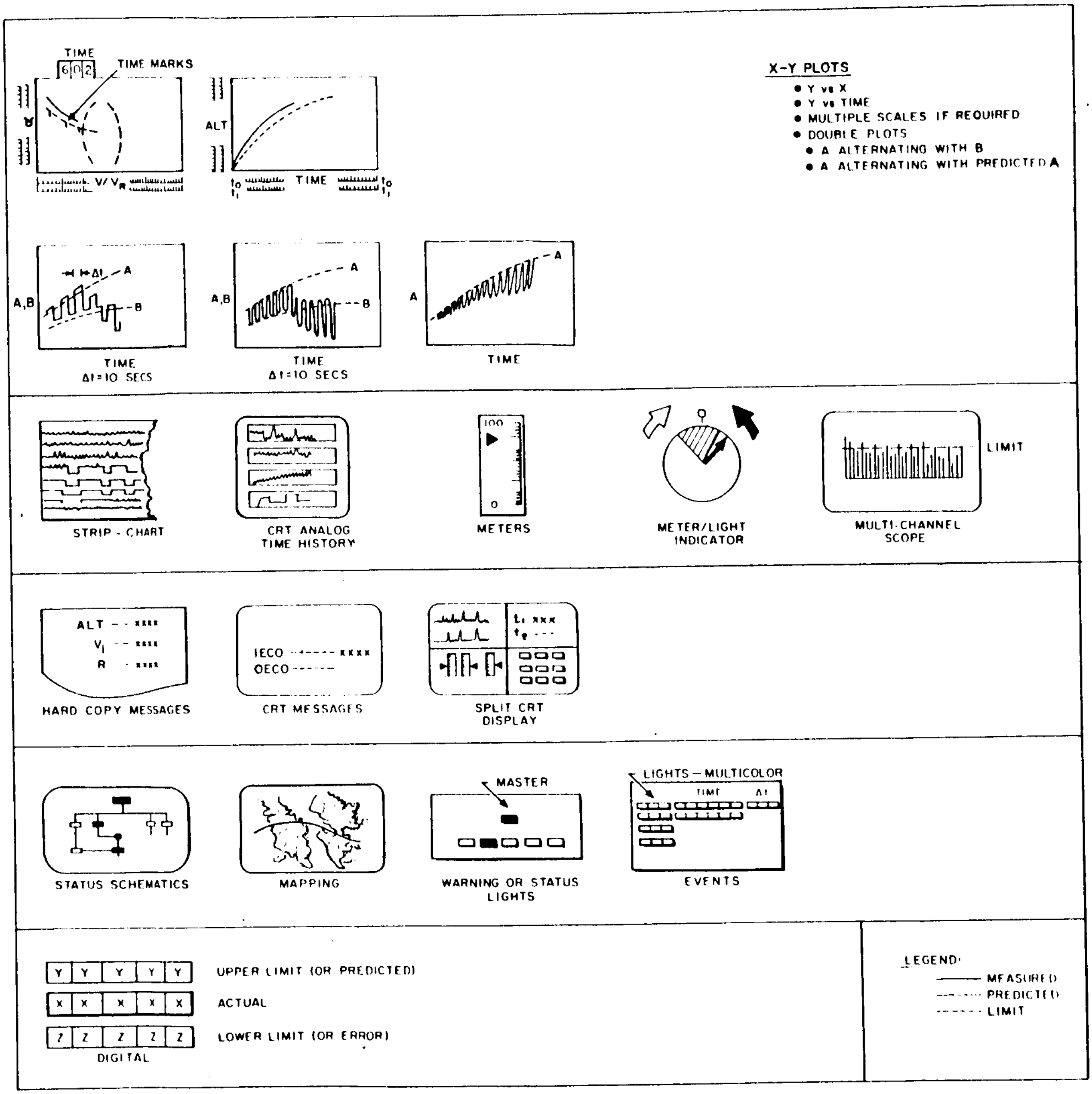

Figure 5-2. Some Basic Types of Displays

Although the size is reasonably well suited for viewing selected detailed data, the size may be a problem for the general displays which provide the cues as to what to select. As a result, considerable care and ingenuity will be required in the assignment of data and formats. The problem is eased somewhat when two scopes per console are available. One can be used for general displays and cues, and the other for detail call-up. Another effective technique is to use split displays as shown in Figure 5-2.

- Multi-Channel Direct-Writing Strip-Chart Recorders

Some objectives in using this type of recorder are:

i Indicate present status and short term fluctuations.

ii Plot trends with time.

iii Present related measurements on adjacent channels.

The real-time application of recorders to meet these objectives involves considerations of the needs and methods to:

(a) Show directly readable scales.

(b) Show directly readable limits.

(c) Provide sufficient visible length of record so that trends can be identified.

(d) Provide quick access to data which has passed beyond (c) (without having to stop the recorder or tear the paper).

(e) Provide adequate resolution without having to compromise the number of channels.

(f) Provide time markers which are directly readable.

(g) Provide physical orientation which accommodates one or more of the following features (which often conflict).

- Provide trace orientation with respect to the viewer so that trends are easily evaluated (e.g. paper moving horizontally left to right.)
- Provide orientation and/or means for applying transparent overlays (implies paper is in the horizontal plane unless some method of attachment is provided).
- Provide location and orientation so that viewer can mark-up plot at points of interest (paper in horizontal plane is best).
- Provide location and orientation of paper with respect to other displays being monitored to simplify the monitor's scanning and correlating tasks (paper in vertical plane adjacent to, or even surrounded by, other displays).

These detailed requirements indicate that recorders which meet the overall objectives (i to iii) for quick-look evaluation (in which case the plots are analyzed after the paper is removed from the recorder) are not necessarily adequate for real-time application. A configuration which emphasizes the most important of the above factors is a horizontal table-type recorder (Figure 5-3) with folded paper storage rather than rolled.

5.2 X-Y PLOTS (Figure 5-2)

X-Y plots can be generated on direct-writing plotters or on TV scopes with the following features available:

- Predicted values and limits can be shown.
- Large scale in Y axis.
- Large physical sizes are possible.

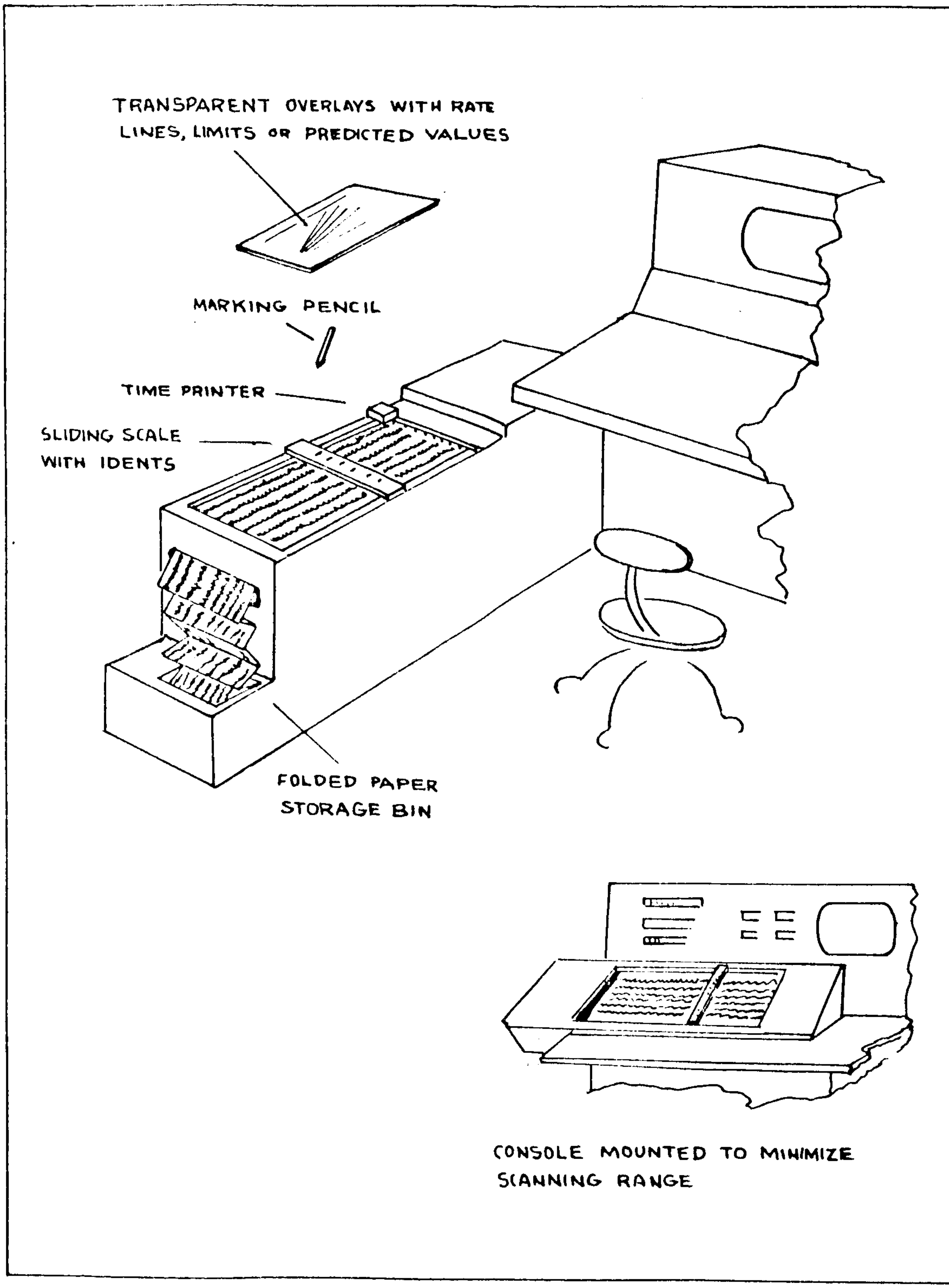

Figure 5-3. Direct Writing Recorders

Their major disadvantage is the limited number of parameters they can display for their size.

X-Y plots are primarily useful for presenting:

- Parameter Y versus time where the range of Y is too large to obtain adequate resulution on a strip chart recorder.
- Parameter Y versus parameter X. Time could appear as time ticks on both the actual and predict plots. This type plot can be an effective means for validity checking when some combinations are clearly impossible. (e.g., pump output pressure versus pump speed.)

Multiple scales are required in a number of cases in order to increase the resolution or in some cases to switch to new parameters at a particular point in the mission.

One method of increasing the capacity of the X-Y display consists of putting more than one parameter on a plot (Figure 5-2). This has several possibilities for certain parameters, particularly those that change slowly. For example, switching can be done at alternate data points or at fixed time intervals (Δt). Both schemes were run on a trail basis by MSFC with SA-7 recorded data with the following measurements.

- V_i and $F/_m$ versus time (Figures G-1 and G-2).
- Altitude and V_i versus time (Figures G-3 and G-4).

The alternate point approach was best. The only problem encountered was 1/4 inches overshoot because of pen response (1 cps plotter response). This type of double plotting however is probably only justified in special cases. The need for significant separation between predict values as indicated in Figure 5-2 is not always required. For example, if A and B are redundant, then wide swings are indicative that one is invalid. If one extreme of the swing is close to predict, it can usually be considered valid. However, if both deviate a similar amount from predict, caution is required to ensure that common instrumentation is not the fault. It may, therefore be advisable not to put redundant measurements on the same display but rather to arrange them in some other manner.

Another version of alternate plotting, consisting of alternating a telemetry measurement with its predicted value, is shown schematically in Figure 5-2. Specific examples (SA-7 data) are given in Figures G-5 to G-14 for 10 different parameters. The main characteristic of this plot, compared with pre-flight potting of predicted values, is that the area between actual and predicted (i.e., the "error") is accentuated by the pen traverses and results is a more distinctive plot. This is particularly desirable for TV reproduction.

Two specific examples of useful X-Y plots are the Howgozit Plots of Flight Path Angle versus Velocity Ratio (Figure 3-6) and the S-IVB fuel remaining plot (Figure 3-13). Another potentially useful display is a plot of orbital ground paths by means of Breckman Charts* (Figure 5-4). Primarily developed as an analytic and planning tool for tracking networks, they can be adapted to operational use with CRT type displays. Their major operational advantage is that orbits appear as straight lines making extrapolation extremely simple.

Where possible, the X-Y display format of a given parameter(s) should provide some measure of intuitive prediction (Howgozit) to the viewer as shown in Figure 5-5. With the use of a CRT type display, a calculated prediction can also be added if desired. In the above example, there is sufficient data available to predict the cut-off condition. This would include a pre-flight predicted tail-off effect. It has been shown, experimentally[28], that rather than display the predicted value as a point, a

*Reference 47. Breckman Charts are copywrited by RCA.

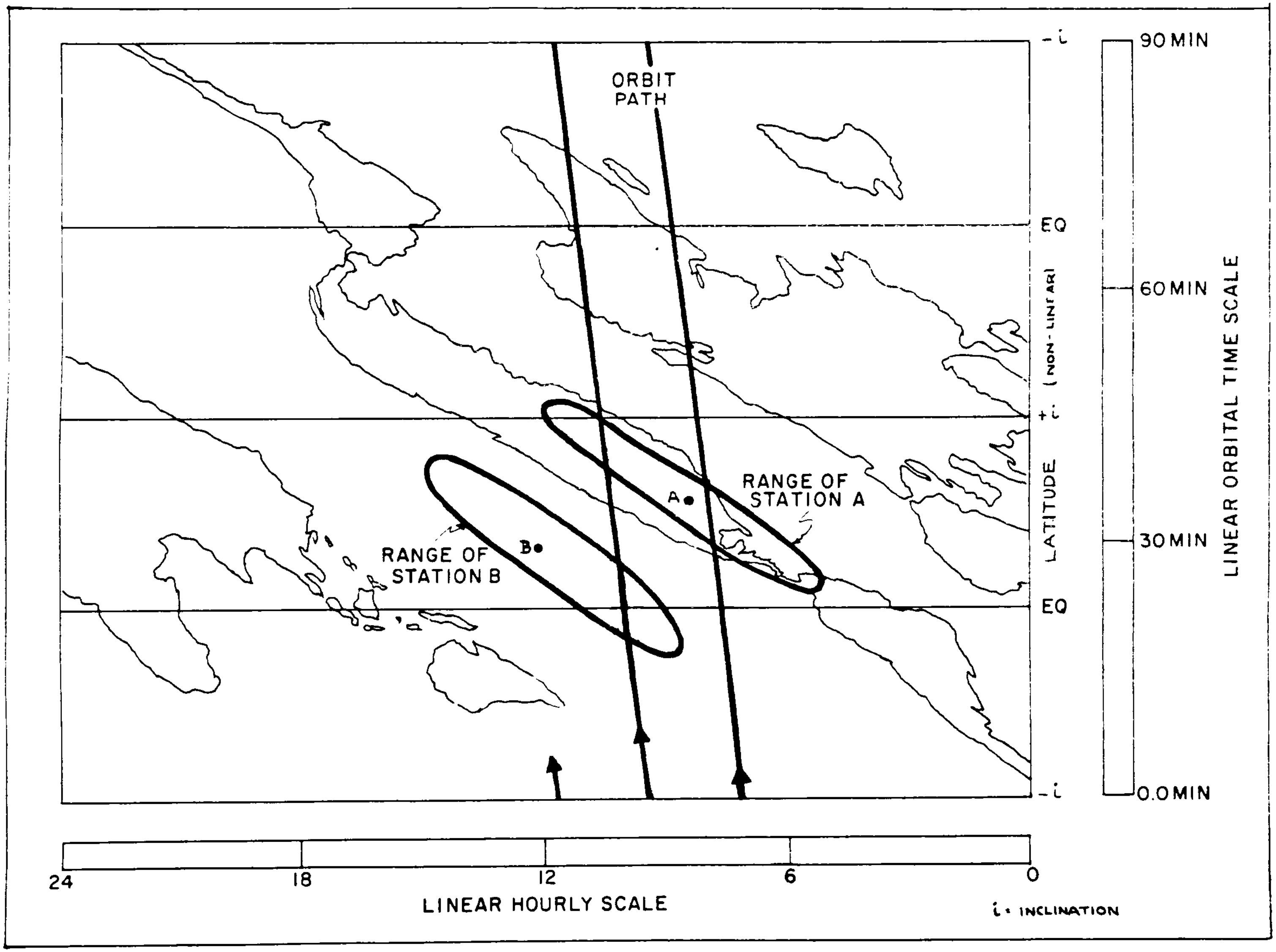

Figure 5-4. Breckman Chart (© RCA)

probablistic type display enhances the user's appreciation of the situation. That is, a predicted circle or ellipse would be used in view of the predicted point. The shape and size of the ellipse would be predetermined, based on normal data. More sophisticated real-time prediction of the shape and size could be potentially considered, but it does not appear to be practical. This particular display is used only to illustrate the potential available and is not recommended for implementation at this time. Computed prediction displays should only be used where a distinct requirement exists.

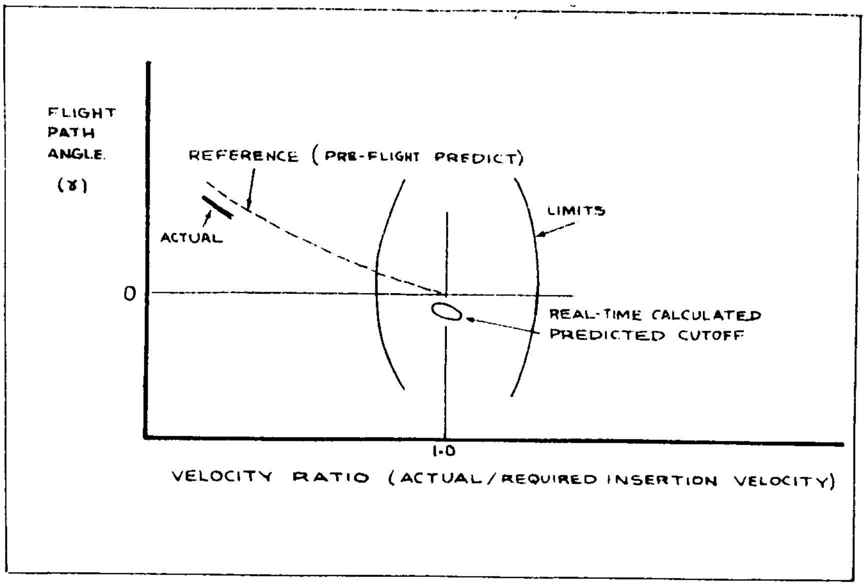

Figure 5-5. Predictive Display

5.3 METER TYPE DISPLAYS

Meter type displays can be presented directly on meters or can be computer generated on CRT displays. Although there are a great many different configurations and formats to choose from, only those most useful for our application will be discussed. Meter displays are usually either the circular type or the thermometer type. For our purpose we are particularly interested in the thermometer type because they are easy to read and interpret, particularly where there are a large number of them (e.g., Figure 4-5).

A typical thermometer type meter display is shown in Figure 5-6. The nominal number of these that can be displayed effectively on one console CRT display is 12 (two rows of six); 14 is considered maximum and 16 is considered too many. This limitation indicates the advantage of fixed meters versus simulated meters on a scope. For example, Figure 4-5 has 40 to 50 meters per panel. The disadvantages of fixed meters is that they are less flexible.

In addition to the measured value, it is usually desirable to show limits of the parameter by markers and/or colored scales* to aid scanning. A more sophisticated presentation can be provided by using the computer to detect out of limits and set a warning symbol over the particular meter display involved. An audio and/or a master warning light could also be triggered. If a number of parameters were out of tolerance, the next step of the monitor might be to call up the schematic which displayed the various out-of-tolerance signals on a functional diagram as an aid in failure pattern recognition. Another useful feature consists of a settable marker which can be set by the monitor to indicate the measured value at a given time. With fixed meters, grease pencils have sometimes been used as a makeshift means of accomplishing this. These set marks are useful after loss of signal to recall what the nominal values were before loss of signal. Although settable markers are usually associated with fixed meters, it may be practical to provide a corresponding setting on the CRT meter displays on demand.

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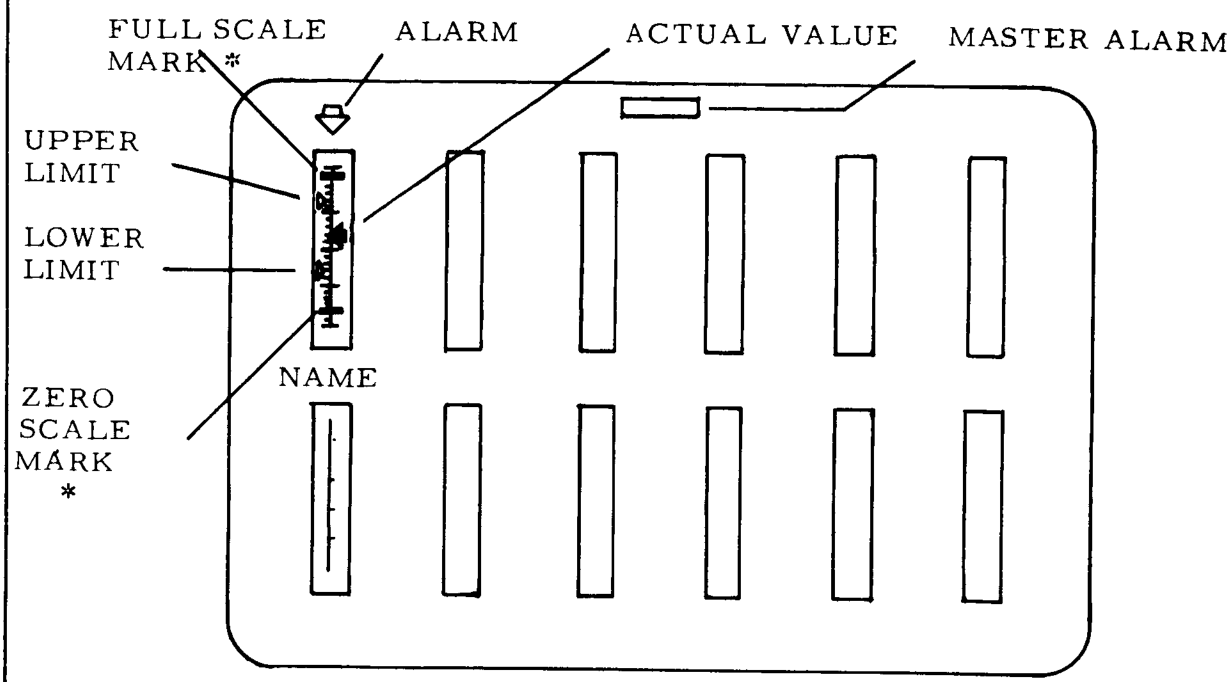
*Color CRT displays (such as now being considered for IMCC)[67] could provide this feature.



- NOMINAL NO. OF METERS/SCOPE = 12
- MAXIMUM NO. OF METERS/SCOPE = 14

* CORRESPONDING TO FULL SCALE AND ZERO SCALE OF TELEMETRY SIGNAL WHICH ARE NOT NECESSARILY THE SAME AS THE ENGINEERING UNITS FULL SCALE AND ZERO.

Figure 5-6. Scheme for Meter Displays on CRT

One of the problems with real-time use of data is that associated with recognizing when a measurement is invalid due to instrument failures which drive the telemetry signal to zero or full scale (which is not necessarily the zero or full scale of the display). It is recommended therefore that means be provided for indicating these signal limits on the display.

Proper grouping of parameters can do much for easing the scanning and interpretation problem. Because of the multi-stage configuration, the organization of displays should make maximum use of common types of measurements. This approach has been emphasized in selecting measurements in Section 3 and corresponding Appendices.

A variation of the thermometer type display which can increase the measurement display capacity appreciably is the multi-channel display (Figure 5-7). Multi-channel (e.g. 100) scopes are commercially available, or the computer driven scope displays can perform an equivalent function. This is an effective format for measurements which should not exceed a given upper limit, such as temperatures. If limits for various measurements are different, the limits become difficult to portray or read unless channel assignments are organized to give an increasing progression of limits, or alternatively a non-dimensional plot (% of limit) can be used, but this requires extra computing. The only major difficulty with this type of display is the identification of a particular channel because of space limitations. With the computer driven CRT type display, identification data could be superimposed automatically (when a limit is exceeded) or on call-up.

When a measurement on the multi-channel display nears or reaches its nominal limit, the question that arises is "What is the trend?" This cannot be answered from the thermometer type display, but it can be answered by a time history of the measurement called up on the CRT. This implies that the time history data be stored and available*.

*In Section 4.4, it is noted that switching of data-link inputs can limit this capability.

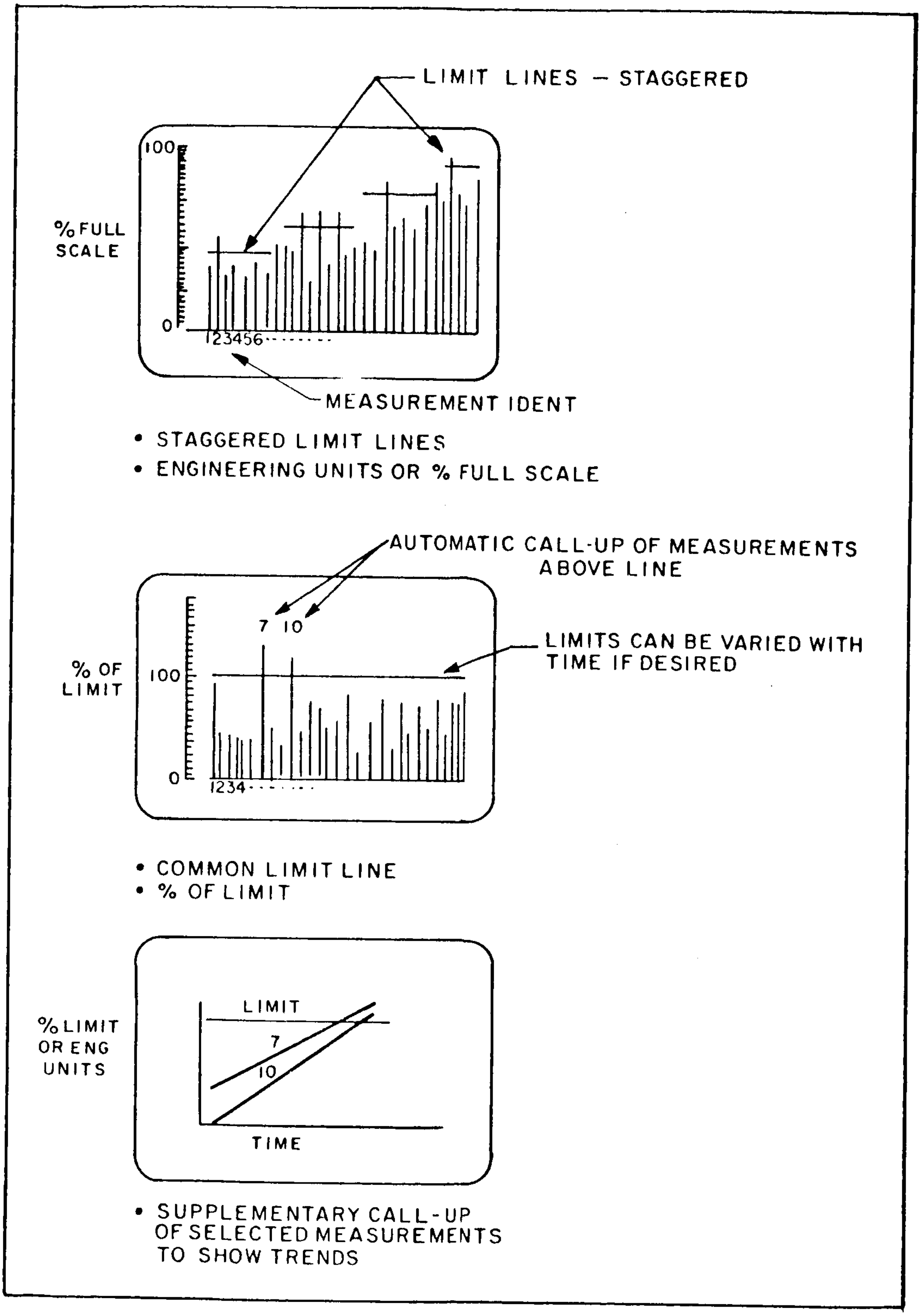


Figure 5-7. Multi-Channel Displays

5.4 LIGHT DISPLAYS

Light type displays (or equivalent symbol type display on a computer driven scope) are useful to present discrete information which is generally classified as:

- Warning
- Event indication
- Status

For a given measurement and display, these classifications often overlap. The displays can also be integrated with other displays (e.g., stutus-schematics, or warning indicators with CRT meter display, Figure 5-6).

Light displays can be triggered by various types and sources of signals such as:

- Out of tolerance of an analog signal (e.g., computer detected low engine chamber pressure)
- Discrete telemetered signal
  - single signal per channel
  - multisignal per channel*
  - manual switch

- Warning Lights:

Four basic types of warnings of interest are:

- Direct telemetered signals (e.g., EDS rate switches)
- Telemetered signal beyond a nominal limit (as detected by the B5500 computer).

*See Section 3.5.4 for discussion of potential problem.

- Out of tolerance of [(telemetered signal)-)predicted signal)], (as detected by the B5500 computer).
- Master warning triggered by any one of a set of measurements.
- Validated warnings (e.g., logic checks of redundant measurements).

These are useful to attract the monitor's attention and to indicate particular data to be monitored more closely or to be called-up.

- Event Lights

Event lights are useful to indicate that an event is due, has occurred, or is overdue. Multi-colored lights in a logical sequence are normally used. In some cases manual overrides are desirable to allow the display pattern to be completed when events are known to have occurred but the event signal has been lost or is invalid.

Event lights are usually supplemented by digital display of time of occurrence and/or out of tolerance time increments as discussed in Section 3.5.4.

- Status Lights

Multi-colored lights can be used in a variety of ways such as:

- By an individual console monitor (manual selection) to indicate to other monitors the status of the system he is monitoring.
- By equipment technicians to inform the monitors of equipment status or signal quality (e.g., IU PCM link lost).
- To indicate stations in contact and/or station which is generating data being used.

These types of indicators can be used effectively to reduce verbal communications and to engender smooth operational procedures.

5.5 ALPHA-NUMERIC DISPLAYS

For purposes of discussion, this type of display can be considered to include the following:

- Parameter display
  - digital meters
  - CRT simulated digital meter displays
- Messages
  - CRT presentation
  - hard copy

Display of certain types of parameters are well suited to digital display. These include measurements which change in an orderly progression (e.g., time), those which are static or are updated infrequently (e.g., orbital elements, event times, etc), and sometimes it is practical to include quasi-static measurements (e.g., temperatures). The display can also include limits (Figure 5-2) and as such it is competitive with analog displays in special cases. This type of digital measurement display does not take much space and it presents the values directly. However, there are some distinct limitations in its use:

- The data must not change rapidly either in the normal situation, or in the situation where the vehicle is operating abnormally.
- The digital display does not show trends.
- When there are more than a few digital displays adjacent to each other, the above two problems interact. As a result, the detection of a change becomes more difficult, and if a number of displays are changing, (some increasing, and some decreasing, even by small amounts), it is difficult, if not impossible

to make sense of the data. This essentially means that digital meters should not be used in groups except for static data.

One of the most effective uses of digital meters is to supplement analog displays and event lights. A specific example is the superposition of digital time on a CRT analog X-Y display. The value of the data can also be displayed.

Display of alpha-numeric messages and lists on a CRT is a useful feature for presenting data from teletype, from reference files and for presenting summary lists of events. Hard copy lists and messages are also useful, especially after orbital insertion. The lists of events can be in one, or both, of two forms.

- In order of normal events
- In order of actual events

In displaying alpha-numeric data, consideration must be given to legibility[68] which is affected by such factors as letter size, figure-ground contrast, viewing distance, ambient lighting, back lighting and whether all the "audience" can be assumed to have normal vision, a factor which can often be ignored in military display system*.

5.6 SCHEMATIC DISPLAYS

A fundamental problem of analyzing large numbers of measurements is their correlation in order to understand the validity and the meaning of the data. Real-time analysis accentuates the problem. Displays and formats which aid in the correlation of related measurements are

*Color blindness is one factor to consider in non-military displays systems. For example, a number of key NASA personnel are color blind, including at least one Center Director and a Program Manager.

therefore an important consideration so that interpretation can be made by the monitor on the basis of pattern recognition[29].

Correlation of parameter status can be implemented reasonably well for measurements which are normally static or slowly changing. The more dynamic the measurements, the more difficult is the task. Part of this difficulty is the generation of changing predicted data for reference. Another part is the fact that in a real-time situation, you cannot scan ahead to see what happens next -- you must wait to see what happens. Perhaps it is only a second or even milliseconds; nevertheless the question is "After the first cue that something has happened, how long should you wait before correlating?" Because no practical general answer can be given to this question, snap-shot correlations are usually impractical. Emphasis therefore is directed toward displays which provide a running correlation.

One potential aid in assessing the status and validity of the measurements in a given system can be provided by displays which indicate the related measurements which are out of tolerance. In Figure 5-8, three versions are shown. The top diagram illustrates an overall systems status display. The middle diagram illustrates a detailed breakdown of the measurements in levels of interest and significance (corresponding to the data organization in this report). The most effective type is shown in the lower diagram which utilizes a system schematic with the measuring points superimposed. In many ways this is the most desirable method of presentation. A detailed example is given for propulsion in Figure 3-14. A more sophisticated version of this could include the digital values of the measurements as well.

To augment the effectiveness of this type of display, it is useful to provide a snap-shot hard copy print-out (time tagged) of the data in the display on demand of the monitor.

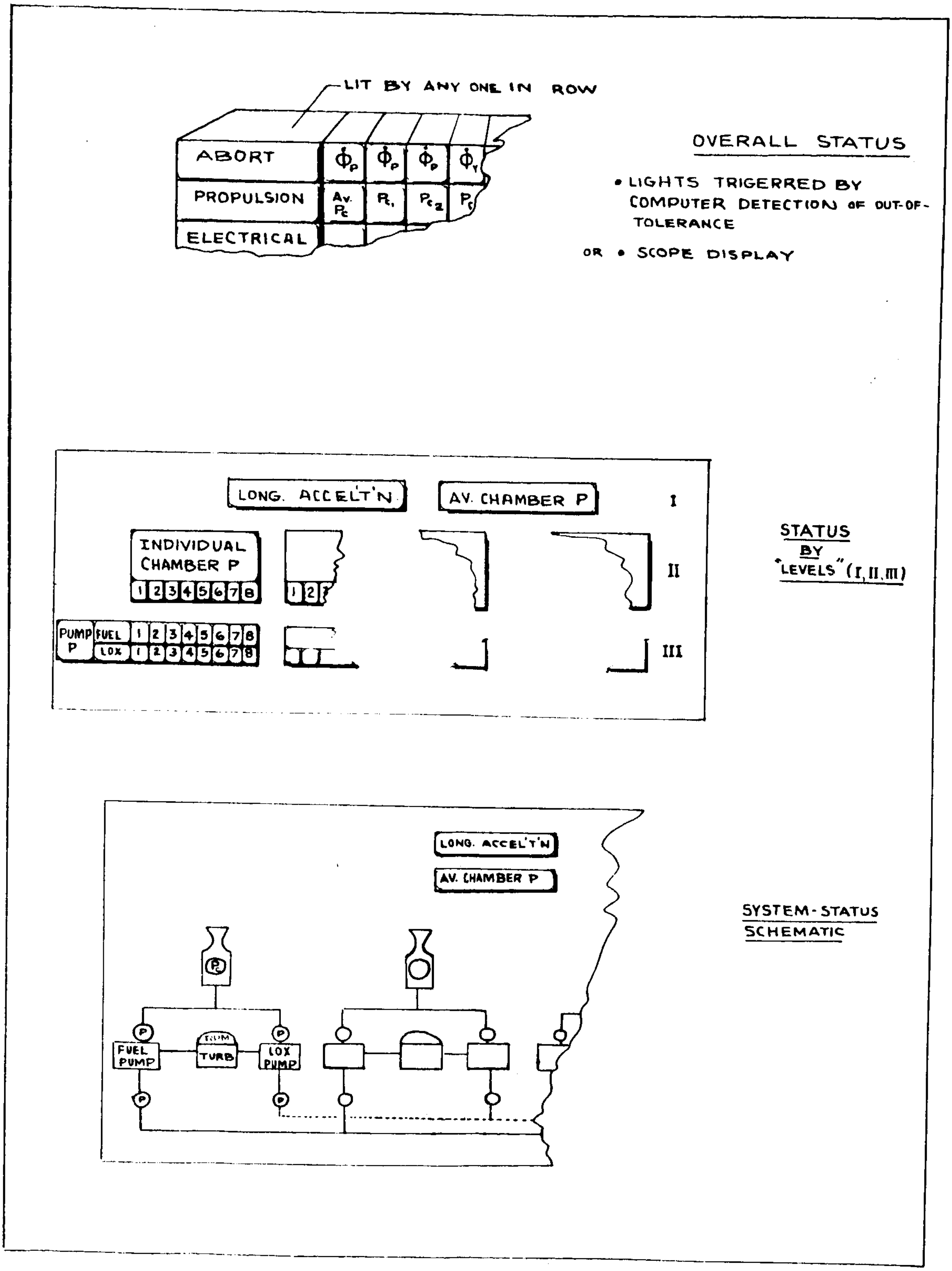


Figure 5-8. Correlation Displays

SECTION 6

OPERATIONAL EXPERIENCE AND CONSIDERATIONS

6.1 SATURN I BLOCK II REAL-TIME EXPERIENCE

The real-time display of flight data in the interim HOSC facilities (Figure 3-2) for Saturn I Block II vehicles provided useful information to the monitoring personnel and general audience, and more important, useful real-time operational experience to the equipment operators as well as to the monitoring personnel. Highlights of these operations are given in Table 6-1.

The problems encountered consisted primarily of:

- ASC-15 telemetry data outputs are not designed for real-time use. As a result, the B5500 must be used to identify and select the data desired. There are also delays in some of the data, and other data of interest drops out at critical periods. Part of the difficulty was due to lack of documentation concerning the detailed nature of the telemetry output signals.
- Problems in data acquisition due to telemetry failures, ground communication failures, display equipment failures and computer susceptibility to overflow.
- Limited display capability.

It is evident from Table 6-1 that difficulties associated with acquiring the data for display have been significant. Whereas, the basic work statement of the present contract is concerned primarily with the questions "What data should be displayed?", and "How should it be displayed?",

Table 6-1. Highlights of Saturn I Block II Real-Time Displays

VEHICLE	DATA SOURCE	DISPLAYS	PROBLEMS
SA-5/SA-6	Green Mountain (essentially S-IV flight only)	• X-Y plotters • Oscillographs on TV monitors	• Computed propulsion data dependent on predicted data, therefore contained no real-time information beyond average Pc.
SA-7	Green Mountain. First use of data from ASC-15 computer.	• X-Y plotters • Oscillographs on TV monitors	• Time generator caused X-Y plot errors.
SA-9	Data Link from KSC. (limited capacity, telemetry only)	TV monitors of X-Y plotters added. Operations room inaugurated.	• PCM data erratic due to a telemetry failure.
SA-8	Data Link (expanded telemetry capacity)	• As for SA-9	• PCM signal failure on vehicle.
SA-10	Data Link (expanded capacity, telemetry and tracking data).	• As for SA-9 • Large X-Y plotter used for (γ) vs. (V/V_r).	• Tracking data input plug at Datakor pulled part way during Ascent because of a communications problem to GSFC. Resultant noise eventually overflowed B5500 and all data was lost.
General			• Commutated data could not be displayed. • ASC-15 telemetry outputs not designed for real-time use.

the factors involved in data acquisition cannot be ignored in the planning and execution of the displays.

On this basis, it is considered appropriate to review the overall requirements and to state a philosophy of real-time operations which supplements the display philosophies which have been developed earlier in this report.

6.2 GENERAL OPERATIONAL CONSIDERATIONS

In Mission Control, a prime concern is the consequence of erroneous or missing data because in Mission Control the most important activities are not those when the vehicle is working properly but when problems appear. In such instances, the displayed data must be both available and correct in order that appropriate mission decisions can be made. Because of eventual MSFC support to mission operations, these factors apply and are examined in more detail in the following paragraphs in order to better understand the context of such support.

Almost invariably, in manned missions, information for decisions is provided both from a primary source and from one or more backup sources. This does not imply that the backup sources are identical with the primary nor that the multiple sources are all interrogated to make the decision; but it does imply that in cases where the primary data is unavailable or of questionable validity, backup information can be referred to. In fact, it is often uneconomical to have complete duplication of equipment to simultaneously process and display both the primary data and the backup data. Instead, the equipment is set up and operated in accordance with Standard Operating Procedures (SOP) and when failures in the primary data sources appear, or upon request by the flight monitors, the backup data is switched in. Note that not only do the SOP's include all the normal operations procedures but the procedures for the abnormal cases as well. On this basis, the elements of an ideal mission control capability are[26, 34, 36, 41]:

- A Flight Director to make mission decisions.
- Mission Rules establishing criteria for the mission decisions.
- A Primary source and Backup source(s) of information for the mission decisions.
- An Equipment Operations Supervisor responsible for operating mode and status of all equipment, and responsible for real-time changes to the mode of operation to ensure that information required by the Flight Director is available at all times.
- Standard Operating Procedures (SOPs) for:
  - Flight Director and Staff
  - Equipment Operations Supervisor and Staff

  These procedures cover both the normal and abnormal situations of both the vehicle and the ground equipment.

Continuing further with this illustration of ideal mission control we can identify five additional factors which have major real-time operational significance.

- Emphasis on Mission Control Data

Data processing and display is limited exclusively to that data required for mission control. Data required for post flight evaluation (PFE) is simply recorded at the receiving station for processing and evaluation at a lager date. Although this appears to be a severe restriction on access to data for PFE, the mission control data inherently contains a significant amount of the data of immediate interest in PFE (in fact, if the set of mission control data can not identify all major problems affecting attainment of mission success, it is incomplete). However, in no case is data processed in real-time solely for PFE, and if, due to ground station malfunctions, a choice must be made between data recording for PFE, and data display for mission control, the data is made available for mission control in all cases. In addition, the data units, rates, nomenclature and formats are governed by the mission control function, not the PFE function.

- Operational Training

The Mission Control decisions are required in real-time and involve the identification and assessment of abnormal conditions. Experience has emphasized the need for concentrated and continuing operational training to:

- Indoctrinate and teach personnel the procedures and the rules, and to provide them with an exact understanding of all data sources and formats, etc.
- Practice the procedures and rules and real time interpretation of displays for normal and abnormal cases, and to practice communicating their prognostications to the required personnel over the correct link and in a clear-cut understandable manner.
- Develop and modify the procedures and rules during the practices to the point where personnel work as an effective team in all conceivable situations.

This practice is required before each flight because of inevitable changes to equipment, voice channel assignments, vehicle, data, data limits, displays, rules, procedures and personnel.

- Multi-Use Equipment

The use of multi-use equipment (i. e., part real-time use, part general use) is avoided in all possible instances. Experience has shown that any equipment not wholly assigned to real-time operations is a potential "trap" because:

- Changes in the equipment are often made without regard or awareness of the effect on the real-time operation.

- Operators, in spite of (or because of) their familiarity with the equipment usually find it difficult to change their procedures to satisfy real-time operational requirements. Or, if they do, they have been known to become confused and to mix their procedures at critical times. They also have difficulty appreciating the fact that if they change their assigned real-time procedures they may affect the functions of some one else.

- The equipment and personnel are often not available for practice because of conflicting schedules and priorities.

- Configurations of equipment for non-real time operations often do not have all the features which could enhance real-time operation reliability, or, even if they do, the special maintenance, set-up and checkout for real time are often compromised by other schedules.

- Planning

The planning required is extensive, and must start far in advance of the mission to provide sufficient time to:

(1) Define decisions to be made.

(2) Define the information required for the decisions.

(3) Define multiple sources of the information.

(4) Assign data channels to accomplish (3).

(5) Specify all data for recording, processing, and display (including channels, units, nomenclature and formats) by means of operational documentation that cannot be changed by ANYONE without "Operations" approval.*

*This is one of the more difficult tasks because it crosses so many "disciplines and jurisdictions", both in and outside of MSFC.

(6) Define procedures (as in (5), changes to procedures must have "Operations" approval).

(7) Train personnel

- indoctrination
- practice
- revision of procedures and rules.

- Personnel

Personnel in the main Operations Room should not be part-time operational personnel. Personnel in support areas may include personnel who are not full-time operational personnel. However, they must be available for sufficient periods of indoctrination and practice to be completely familiar with the equipment and communications and the rules and procedures (both normal and abnormal).

Realization of all elements of the idealized real-time operation, discussed in preceding paragraphs, is required for a maximum capability and reliability.

Deviations from these precepts will introduce degradation of performance of one sort or another. Unfortunately, this degradation will generally be in the ability to handle abnormal situations WHICH IS THE VERY SITUATION WHERE THE CAPABILITY IS REQUIRED.

It is therefore important to identify those areas where current MSFC real time operations deviate from the ideal. To illustrate the end effect that major deviations can have, consider the following. Figure 6-1 is a simplified functional schematic of a hypothetical case of MSFC providing support to IMCC[66], on request, regarding S-IVB performance (deviations) and status and the corresponding effect on subsequent S-IVB powered segments of the mission. There are two important features regarding the functions represented.

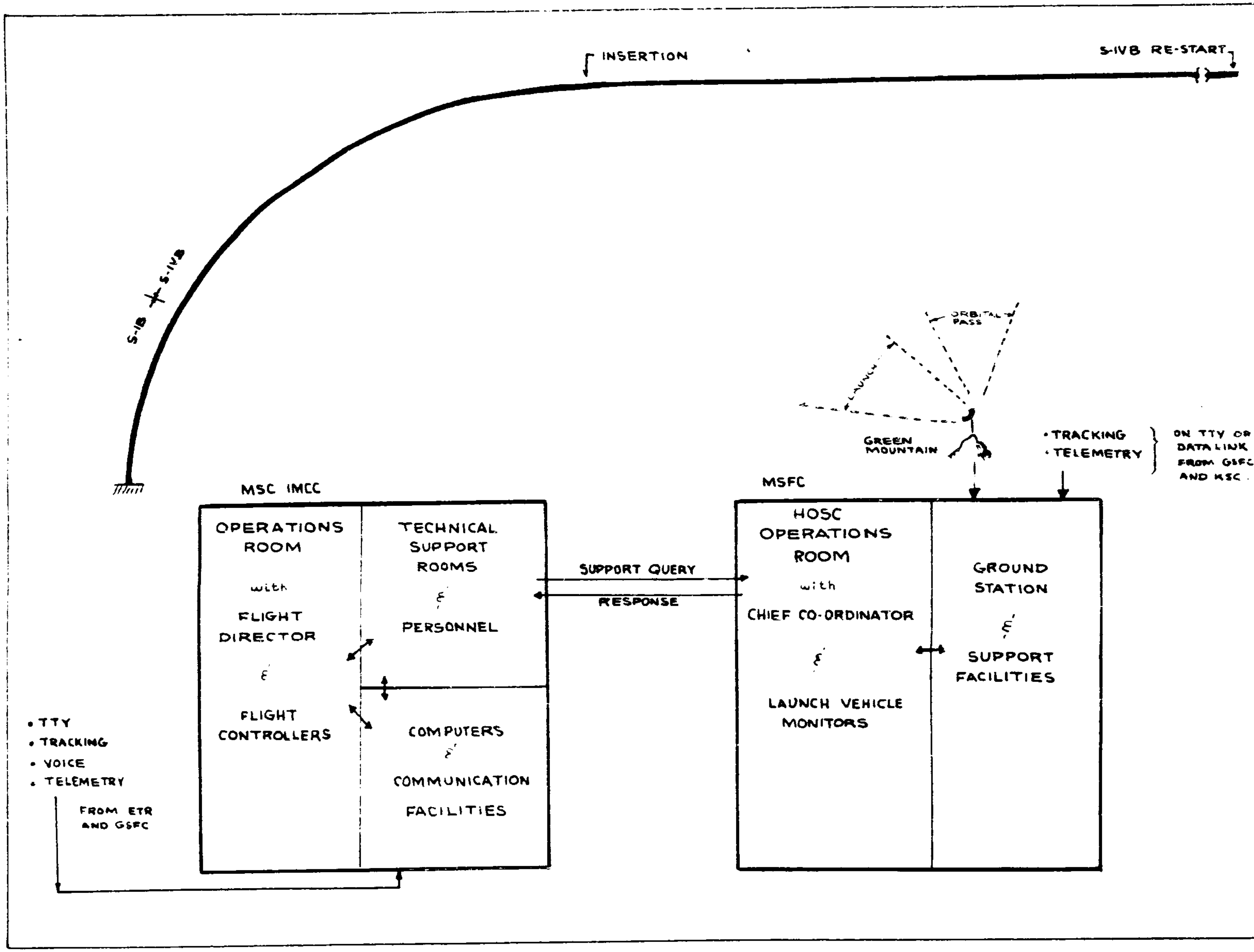


Figure 6-1. Potential MSFC Real-Time Support of Manned Missions

- The IMCC operation conforms essentially to all the factors identified above.
- As illustrated, the IMCC Operations Room is supported directly by selected and trained personnel located in adjacent support rooms. Further technical support from MSFC would generally be on the basis of "on request" and would probably require response in depth (as considerable depth is already provided in both the IMCC Operations Room and the Technical Support Rooms).

It follows that the information available to the mission support personnel at MSFC must be, at the very least, as dependable (in terms of validity) as those at IMCC (the question of depth of information is an additional problem which can only be analyzed relative to the depth of information needed and provided at IMCC). Transients in the operation due to assessments based on incorrect data cannot be tolerated. Further, the general mode of operation is "support on request". If familiarity with personnel, with mission rules, with communication links, with common nomenclature, units and displays, etc., are not generated and kept "alive" by participation in scheduled practices,* experience has shown that the capability and reliability of support functions (such as the MSFC support) cannot be recognized by these who might make the support request so that seldom if ever would a request be received in real time, even if difficulties were encountered at IMCC.

Having established the effect of deviations from the ideal mode of real time operations, the question arises, "What are the present MSFC deviations from the ideal?" To answer this in broad terms, the ideal real time elements identified above are tabulated in Table 6-2 and

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*Simulated missions are practiced by individual spacecraft crews, by individual stations, and by the network as a whole.

Table 6-2. Comparison of MSFC Real Time Operations with "Ideal"

		"IDEAL" Mission Control	MSFC Mission Support and Analysis
BASIC ELEMENTS	1.	Flight Director - for mission decisions	Present position of Chief Co-ordinator provides corresponding focal point for MSFC support to mission decisions.
	2.	Mission Rules (an MSC document)	MSFC mission support personnel must understand them and can be of help to formulate some of them.
	3.	Primary and Backup sources of real time data for decisions	Backup data potentially available in some cases, but largely dependent on common T/M and/or ground communication links.
	4.	Equipment Operations Supervisor	Present operations do not provide for one man with total status information and with communications to Chief Co-ordinator and to each support area.
	5.	Standard Operations Procedures (SOP) • Equipment Operators • Flight Controllers for normal and abnormal equipment and vehicle situations	Written real time procedures* have not been utilized in general. Non-essential personnel have access to working areas. (*for both normal and abnormal operations)
ADDITIONAL FACTORS	a.	Emphasis on Mission Control Data	Present operation includes heavy emphasis on communicating large volumes of data primarily for preliminary PFE quick-look.
	b.	Operational Training (i) Equipment Personnel (ii) Flight Controllers	None conducted to date (for various reasons).
	c.	Multi-Use Equipment	Presently dependent on multi-use equipment.
	d.	Planning	See 2, 3, 5, a, b.
	e.	Personnel	See 2, 4, 5, b.

compared with the MSFC interim operations. This comparison suggests that the interim operations could be expected to be weak in terms of ability to handle abnormal situations, particularly those resulting from data systems problems. This is confirmed by the actual experience to date.

It is not the intent of this report to enumerate detailed recommendations regarding implementation of operational organization and procedures for the new HOSC facilities and future operations, rather it is intended to draw attention to those factors which cannot be ignored in implementing a real-time system. This has been done, with the intent of stimulating further consideration.

One thing is clear, however. If real-time support is to be provided to IMCC, means must be available for obtaining a high degree of confidence in the data and efficiency of the operation. It is better to have no data than incorrect data.

One final remark is appropriate. Experience has shown that personnel familiar with the operations can obtain a significant appreciation of the progress of the flight and the problems encountered, by merely listening to key IMCC intercom loops.* This suggests that provisions should be made for MSFC personnel to monitor appropriate loops. If MSFC data is lost for any reason, this capability would provide useful information to the MSFC monitors.

*i. e., the active loops in the Operations Room and Support Areas, <u>not</u> the public information loop.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 GENERAL

This study was conducted to support interim HOSC data display operations during Saturn I Block II flights, and to provide information useful for the new HOSC operations during Saturn IB and Saturn V missions. Specifically the objective was to determine:

- the data which should be displayed
- corresponding data sources
- appropriate formats for display of the data

These tasks have been accomplished. The interim support was provided through interim reports issued with the contract monthly progress reports (Table A-1 and A-2)[1].

In this final report, the analysis of display data was based on the premise that the general display requirements for a given Saturn system could, and should, be presented in a manner which was common for all stages and vehicles. This generalization has been achieved (Section 3) and is summarized in Figure 7-1. The data is grouped in the levels (I, II, III). Level I is of basic interest and is generally sufficient to indicate adequate performance to detect major problems, and to provide cues to the monitor regarding what data should be monitored in detail. Level II contains this additional detailed information and includes backup information which provides validity checks. Level III contains further detailed breakdown. Level I measurements are therefore the primary displays being scanned continuously. Level II are those monitored or called up as required. Level III are those which can be displayed or called up if display capacity and/or time permits.

The sources of display data include tracking as well as telemetry and these are discussed in general terms in Section 4.

General Display types and formats and considerations for their application are presented in Section 5. Some specific formats were also developed in Section 3 in conjunction with display requirements.

7.2 CONCLUSIONS

On the basis of this study the following conclusions are drawn:

- Display data for various stages and vehicles can be organized in a common manner which minimizes the differences. This facilitates the planning, display implementation, and understanding of the data in real-time.
- Howgozit displays which emphasize the human capability for extrapolation are effective and should be developed and used whenever practical (e.g. Flight Path Angle vs. Velocity Ratio for insertion, (Figure 3-6).
- Digital displays are most useful for measurements which are static or have orderly progression (e.g. orbital elements and time). They should not be used in groups for measurements which vary in either the normal or abnormal case.
- Correlation of the large number of measurements involved, in order to assess validity and enhance understanding of the data, can be achieved effectively by schematic type displays which utilize the computer to trigger out-of-tolerance lights. Digital data can also be included on the display.
- Recall of the S-IVB ascent data for review while the vehicle is parked in orbit prior to the escape maneuver can provide useful information to aid in the decision to continue the mission.

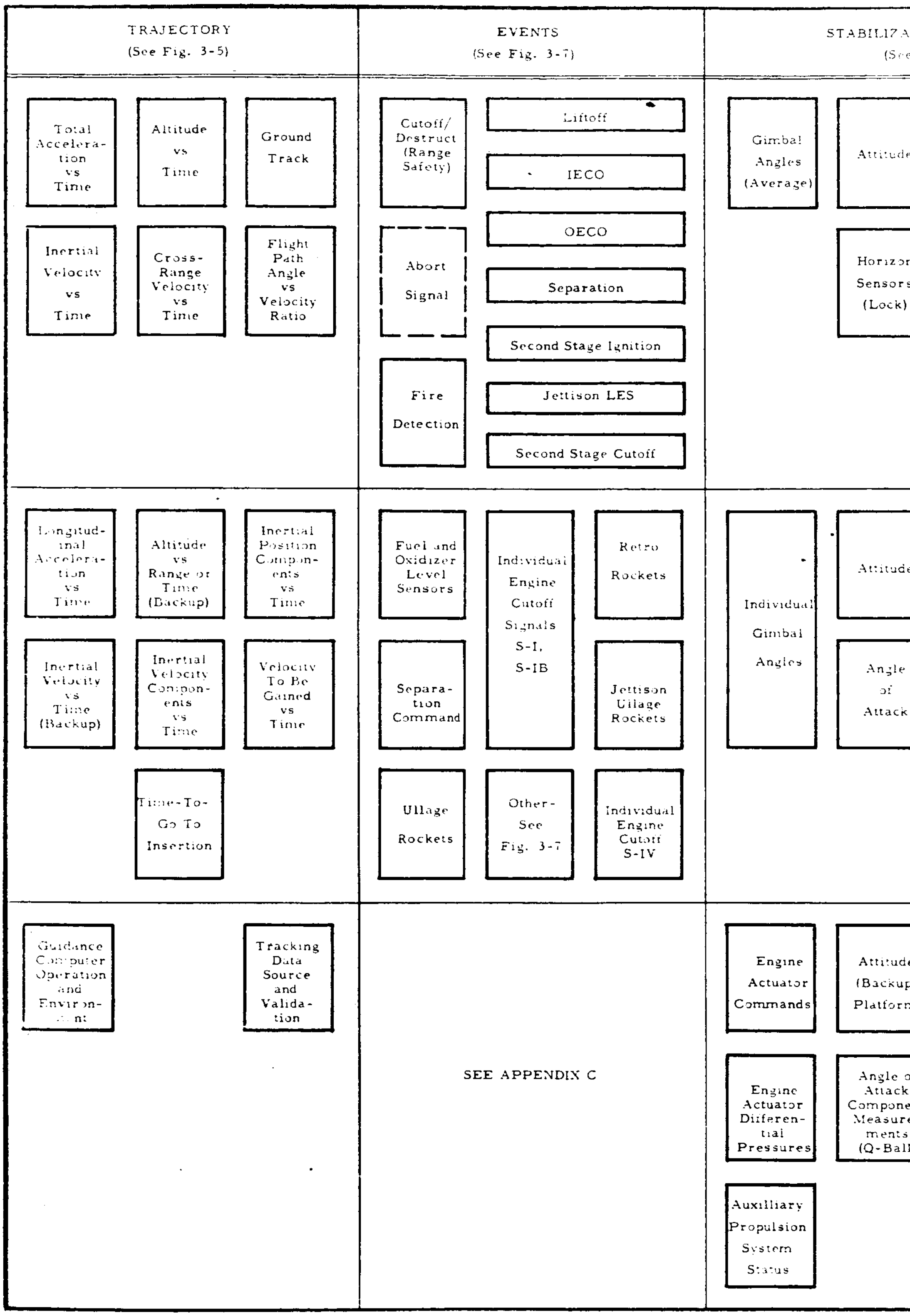

Figure 7-1. General Data f

1 #

TION & CONTROL Fig. 3-9)	PROPULSION (See Fig. 3-12)	ELECTRICAL (See Fig. 3-15)	LEVEL
Angular Velocity (Control); Angular Acceleration (Control); Angular Velocity Switches (EDS)	Average Chamber Pressure vs Time; Acceleration vs Time; Propellant Remaining vs Velocity; Cutoff and Start Commands	Battery and/or Bus Voltages; Inverter Voltages	I
Angular Velocities (EDS); Angular Acceleration; Horizon Sensor Output; Steering Rate Ladder Commands	Individual Chamber Pressures; Individual Pump rpm's; Individual Turbine rpm's; Individual Cutoff/Start Signals	Battery Currents	II
Angular Velocities; Hydraulic Pressures; Platform Air Bearing Pressures Temperature & Supply; Hydraulic Levels	Engine System Measurements; Propellant System Measurements	Measurement Voltage Supply Voltages; Reference Voltage Supply Voltages; Battery Temperatures; Inverter Temperatures	III

r Real-Time Display

2H

This is particularly true with respect to the S-IVB start-stop sequence data and consumables. A summary of S-IVB and IU data which exceeded limits during Ascent would also be useful and could be provided by a simplified real-time version of the Correlation Listing program developed for post-flight evaluation.[50]

- Orbital insertion can be monitored by means of telemetry and/or tracking data. However, for Saturn flights which are launched along the MSFN rather than down the ETR, high speed communications may not be available from the station(s) covering the insertion for either or both telemetry and tracking. In any case tracking data will take precedence. MSFC monitoring of the launch vehicle as it approaches and achieves insertion may therefore be limited to summary type TTY data received from remote station monitors.
- Monitoring key IMCC intercom loops can provide HOSC monitors with useful information, even if they have lost their own display data.
- Alternate means of acquiring and displaying data should be provided to protect against vehicle telemetry and/or ground station failures. This implies planned procedures, and telemetry links and channel allocations tailored to minimize telemetry and communications equipment failure effects.

7.3 RECOMMENDATIONS

Based on this study, and the HOSC experiences to data, the following recommendations are submitted:

- Planning and implementation of real-time displays require a large amount of detailed information regarding the missions, vehicle, and instrumentation as well as the ground support, communications and display systems. Experience on other projects has shown that reports, manuals and other documentation developed primarily for design and launch purposes are less than adequate for real-time purposes. Available Saturn documentation appears to be no exception. It is therefore recommended that a manual be developed specifically for, and by, the flight monitors. This manual would contain system schematics showing operating modes, characteristics, instrumentation (for real-time use only), and the nominal values and limits expected for each measurement. The data values and patterns corresponding to basic system modes or failures should also be included. It would be revised in detail for each mission to incorporate vehicle and instrumentation design changes, and changes to assigned limits.

- Schematic displays should be developed which closely correspond to the schematics developed for the manual noted above. These displays would primarily be based on warning lights with digital data also used in some cases and as experience dictates.

- Provisions should be made for recalling, during orbital operations, data gathered during S-IVB ascent. A method for summarizing any out-of-tolerances in this data is desirable. This could be accomplished by a simplified real-time version of the correlation listing of Reference 50 developed for post-flight evaluation.

- Consideration should be given to the eventual use of color TV displays (with due consideration of whether any color-blind personnel will be involved).

- Planned efforts are recommended to ensure that key data displays can be maintained in spite of vehicle telemetry problems, communication problems, and ground station problems. This implies review of telemetry channel and link assignments, and development of written procedures for the normal and degraded modes of operation.

- Consideration should be given to providing means of practice to the ground station personnel and the monitors with particular emphasis on abnormal operations (both vehicle and ground equipment). As a minimum the flight monitors should have the opportunity of becoming familiar with the IMCC operation with which they will eventually interface. IMCC simulations which are frequent and extensive provide an ideal opportunity for obtaining a first-hand view of the operations and facilities.

- Where interfaces with IMCC are involved, nomenclature, units of display and limits should be common. It is also desirable that common computational procedures be used.

- The objectives of this study did not include the task of final assignment of specific data to specific display hardware or consoles. The planning of such data organization and assignments should be carried out initially with maximum simplicity and in a manner which will allow orderly evolution to a more sophisticated operation. However, the contents of this report are not restricted to the initial application. The report contains a variety of concepts, some simple, some sophisticated, with the objective of stimulating this evolution and it is not implied that they should all be used initially. The initial emphasis should be on providing reliable, valid, basic information.

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Table A-1. Index of Monthly Contract Reports[1] and Their Major Technical Contents

Report Number		For the	
-	CR 588-137-( )	Month of:	Technical Contents
1	A	July/64	• "Report of First Technical NASA-RCA Meeting" (Enclosure)
2	B	Aug/64	• Basic display requirements • Dual displays

3	C	Sept/64	• SA-7 flight experience
			• "Note on Real Time Display Requirements" (Enclosure)
			  • Requirements
			  • Elements of flight operation
			  • Propulsion
			    • S-IV - current data availability
			    • S-IV - full data availability

4	D	Oct/64	• SI Block 2 measurement review • Measurement charts showing levels of interest • Display methods
5	E	Nov/64	• First NASA-RCA progress review meeting - summary • Go/No-Go and parameter displays • "Note on Real Time Velocity Flight Path Angle Display and Orbit Characteristics Computation" (Enclosure)
6	F	Dec/64	• "Saturn SA-9 Real Time Displays" (Enclosure)
7	G	Jan/65	• Second NASA-RCA progress review meeting - summary

8	H	Feb/65	• Electrical and environmental data for potential display
			• SA-9 flight and display experience
			• "Note on Real-Time Data Operations" (Enclosure)
			  • Real-time display requirements
			  • MSFC real-time operations
			  • Conclusions and recommendations

Table A-1. Index of Monthly Contract Reports[1] and Their Major Technical Contents (Cont.)

	Report Number	For the	
—	CR 588-137 ( )	Month of:	Technical Contents
9	I	March/65	• Third NASA-RCA progress review meeting - summary • "Note on Real Time Displays for Saturn SA-8" (Enclosures) • Switching of displays
10	J	April/65	• (status notes only)
11	K	May/65	• Notes on abort system displays. • Miscellaneous notes on: Events, Correlation, Status, Predictive displays.
12	L	June/65	• "Note on Real-Time Display of Tracking Data" (Enclosures).
13	M	July/65	• Notes on SA-10 flight and displays.
14	N	Aug/65	• (status notes only)
15	O	Sept/65	• (final monthly report with summary status notes.)

Table A-2. Index of Miscellaneous Reports Prepared

	Report	Remarks
1.	Trip Report - Viewing of SA-7 Flight, 18 Sept. 1964	(RCA Internal Report)
2.	Reference Material Presented at Progress Review Meeting, Nov. 5, 1964	
3.	Notes on Progress Review Meeting at RCA, Nov. 5, 1964	
4.	Reference Material Presented at Progress Review Meeting at RCA, March 23, 1965	
5.	Notes on Progress Review Meeting at RCA, March 23, 1965	
6.	Report on First Meeting of NASA-RCA Personnel, July 8, 1964	(Enclosure with Monthly Report No. 1)[1]
7.	Note on Real Time Display Requirements	(Enclosure with Monthly Report No. 3)[1]
8.	Note on Real Time Velocity Ratio Flight Path Angle Display and Orbit Characteristics Computation	(Enclosure with Monthly Report No. 5)[1]
9.	Saturn SA-9 Displays	(Enclosure with Monthly Report No. 6)[1]
10.	Note on Real-Time Operations	(Enclosure with Monthly Report No. 8)[1]
11.	Note on Real-Time Displays for SA-8	(Enclosure with Monthly Report No. 9)[1]
12.	Note on Real-Time Use of Tracking Data	(Enclosure with Monthly Report No. 12)[1]

APPENDIX B

TRAJECTORY

B-1 GENERAL

The basic requirements for real-time display of trajectory parameters are discussed in Section 3.5.3. The application of these basic requirements to any given flight requires further detailed definition of the explicit source of data for the display, its availability in real time, the computations (if any) involved, etc. as illustrated in this Appendix based primarily on the Saturn I Block II (SA-9) vehicle configuration.

In Figure B-1, the Ascent Phase trajectory information is given for SA-9 corresponding essentially to the generalized display requirements of Figure 3-5. The data source indicated in Figure B-1 are further identified in Table B-1. In some cases the use of telemetry or tracking as a data source is optional. The material in this Appendix is primarily based on the use of telemetry data. Figure B-2 shows flow of telemetry data corresponding to Figure B-1.

B-2 FLIGHT PATH ANGLE VS. VELOCITY RATIO[3]

B.2.1 FORMAT

The usefulness and general characteristics of the Flight Path Angle vs. Velocity Ratio plot were discussed in Section 3.5.3 and illustrated in Figure 3-6. For operational use, it is desirable to format the display in at least two parts as was indicated in Figure 3-6. The indicated scale change is required in order to provide the necessary accuracy at insertion. It may even be desirable to split it into three parts to provide better resolution.

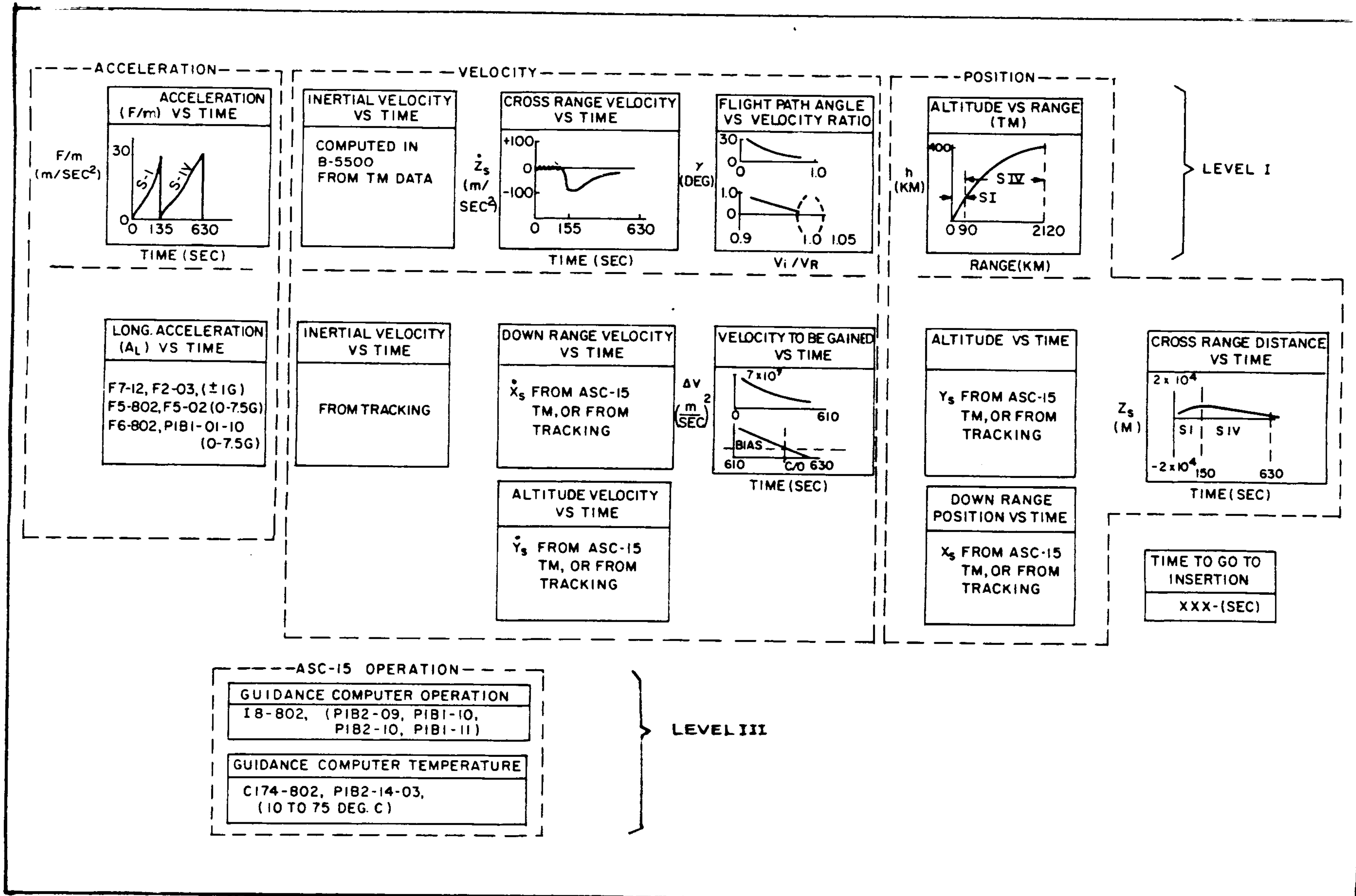

Figure B-1. Trajectory Data - SA-9 Ascent Phase

Table B-1. Trajectory Data Source

Level		Data	Symbol	Data Source	Meas. No.	T/M	Remarks
Level I	1.	Longitudinal Acceleration	F/m	ASC-15	-	P	
	2.	Inertial Velocity Magnitude	V_i	B5500	-	-	Reqs. No. 10
	3.	Altitude	h	B5500	-	-	Reqs. No. 12
	4.	Flight Path Angle	γ	B5500	-	-	Reqs. Nos. 10 & 12
	5.	Cross Range Velocity	$\dot{Z}_s$	ASC-15	-	P	
	6.	Time from Lift-Off	T_{LO}	Clock	-		Initiated by first motion (K_2-802)
Level II	7.	Longitudinal Acceleration	A_L	IU IU	F6-802 F5-802	P F	
	8.	Velocity to be Gained	ΔV	ASC-15		P	(Diff. of squares)
	9.	Inertial Velocity Magnitude	V_i	Tracking ASC-15		P	(Iterative, $V_{s(i-1)}$
	10.	Inertial Velocity Components	$\dot{X}_s$	ASC-15		P	Also from tracking
			$\dot{Y}_s$	ASC-15		P	
			$\dot{Z}_s$	ASC-15		P	
	11.	Altitude	h	Tracking		-	
	12.	Position Components	X_s	ASC-15		P	Also from tracking
			Y_s	ASC-15		P	
			Z_s	ASC-15		P	
	13.	Computer Time from Lift-Off	T_L	ASC-15		P	From ASC-15 L. O. detection
	14.	Time to Go (to insertion)	T_i	ASC-15		P	From ASC-15 L. O. detection
Level III	15.	Guidance Computer Operation	-	IU	I8-802	P	
	16.	Guidance Computer Temp.	-	IU	C174-802	P	

Notes:
- P = PCM
- F = FM/FM
- Based on SA-9 sources

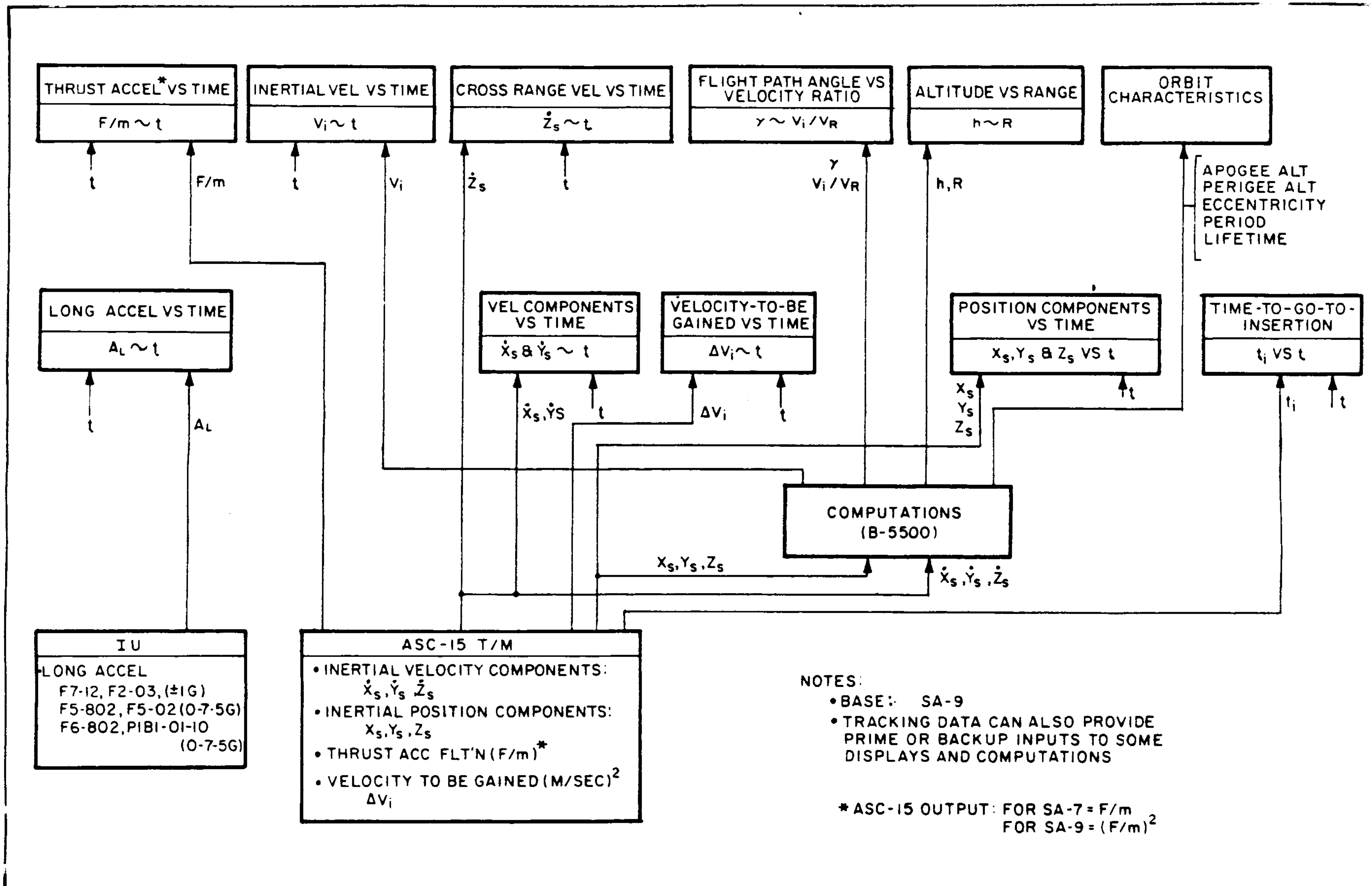

Figure B-2. Trajectory Data Flow (Telemetry - Display Levels I and II)

During the first part of the flight the real-time data is displayed against predict data. During the second part of the flight, i. e., the last few seconds before S-IV cutoff,the real-time data is displayed with predicted data and a go/no-go envelope. The lower bound of this envelope represents the minimum acceptable orbit lifetime* and the upper bound indicates the limit for payload re-entry load and/or heating. The limits are based on the assumption that cutoff occurs at the nominal altitude.

Display of the two (or three) parts of the plot can be implemented effectively either on separate plots or multiple plots.

B. 2. 2 COMPUTATIONS

The Flight Path Angle vs. Velocity Ratio plot can be plotted from telemetry data and/or tracking data. The following is based primarily on telemetry data.

The telemetry inputs needed to compute the $V_i/V_R \sim \gamma$ display are the inertial position and velocity components available from the vehicle guidance computer (ASC-15). These are:

$$X_s, Y_s, Z_s$$

$$\dot{X}_s, \dot{Y}_s, \dot{Z}_s$$

Inertial velocity magnitude V_i is computed as,

$$V_i = \left[\dot{X}_s^2 + \dot{Y}_s^2 + \dot{Z}_s^2 \right]^{\frac{1}{2}}$$

*The nominal criteria for manned payloads is 1-1/2 orbits to ensure the capability of re-entry in a planned recovery area.

The magnitude of velocity required V_R is a preset constant for the particular mission.

Flight path angle to the local horizontal (γ) is computed as,

$$\gamma = \pi/2 - \beta$$

where:

$$\cos \beta = \frac{\bar{V}_i \cdot \bar{r}}{|\bar{V}_i| \; |\bar{r}|} = \frac{\dot{X}_s X_s + \dot{Y}_s (Y_s + Y_{so}) + \dot{Z}_s Z_s}{V_i \; r}$$

and:

$$r = \left[X_s^2 + (Y_s + Y_{so})^2 + Z_s^2 \right]^{\frac{1}{2}}$$

These computations are illustrated in Figure B-3.

To compute the preplot go/no-go envelope it will be assumed that predicted lifetime and re-entry load and heating curves are available for the particular vehicle and payload as functions of radius of perigee (r_π) and eccentricity (e). With r_π and e determined, then velocity at perigee can be computed as:

$$V_\pi = \left[\frac{\mu}{r_\pi} (1 + e) \right]^{\frac{1}{2}}$$

This is also the nominal magnitude of inertial velocity desired (V_R) for cutoff with zero flight path angle at perigee. Then the flight path angle at cutoff (γ_{co}) for a given velocity at cutoff (V_{co}) can be found as:

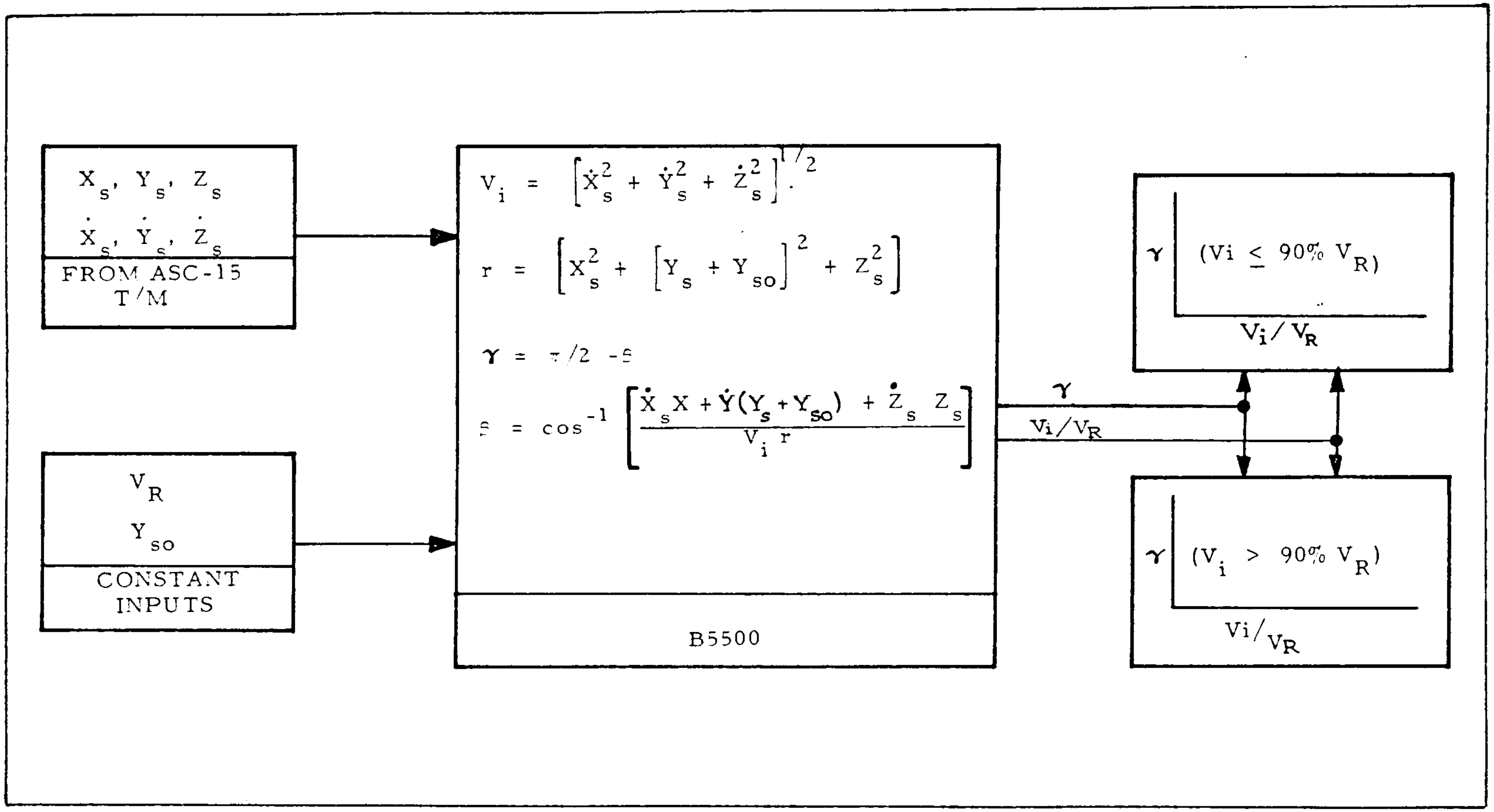

Figure B-3. Flight Path Angle vs. Velocity Ratio Display Generation

$$\cos \gamma_{co} \approx \frac{V_\pi}{V_{co}}$$

when

$$r_{co} \approx r_\pi$$

V_{co}/V_R is then plotted against γ_{co} to provide the go/no-go-envelope.

An example of the γ vs. V_i/V_R plot (predict) is shown in Figures B-4 and B-5 based on the SA-7 trajectory. As noted on Figure B-5, there is approximately a two second loss of required information from the ASC-15 computer immediately prior to engine cut-off command. However, since the T/M signal returns approximately 10 seconds prior to insertion and since during this 10 seconds there is almost no perceptible change (even on the expanded scale) in V_i/V_R or γ, it is expected that the insertion point will be clear despite the earlier 2 second pen excursion.

B. 3 THRUST ACCELERATION VERSUS TIME (F/m vs. t)

This is a continuous single plot of thrust acceleration (F/m from ASC-15) vs. time (t) from lift-off to insertion. A dual time scale would provide greater accuracy but the predicted acceleration histories of the stages are similar and the plots would probably overlap and be difficult to follow. Back-up is provided by accelerometer measurements from the IU.

B. 4 TRAJECTORY ALTITUDE VERSUS DOWN RANGE DISTANCE (h vs. R)

This is shown in Figure B-1 as a continuous single plot of altitude (h) versus range (R). Altitude (h) can be computed in the B5500 from ASC-15 data as follows:

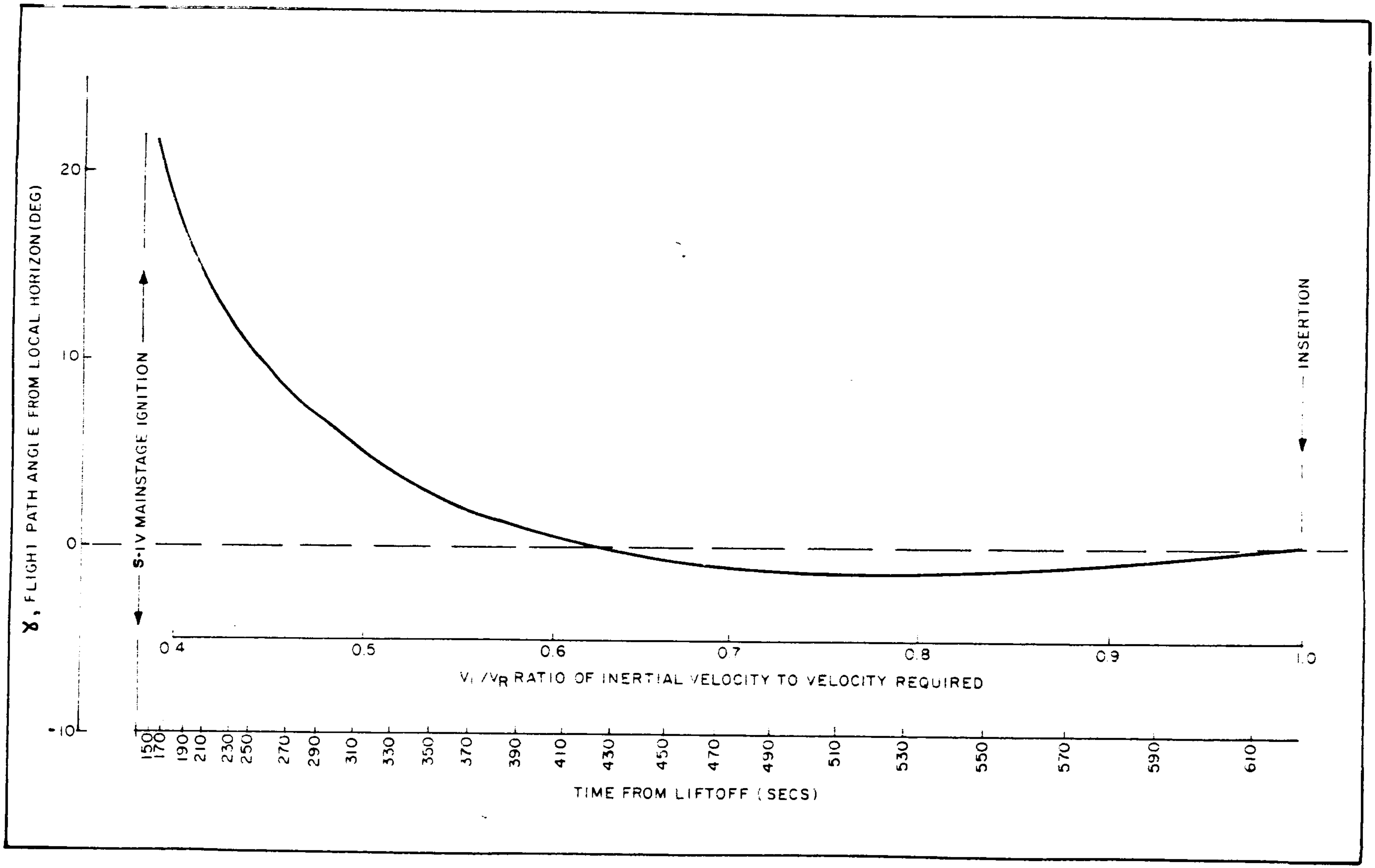

Figure B-4. Flight Path Angle vs. Velocity Ratio, SA-7

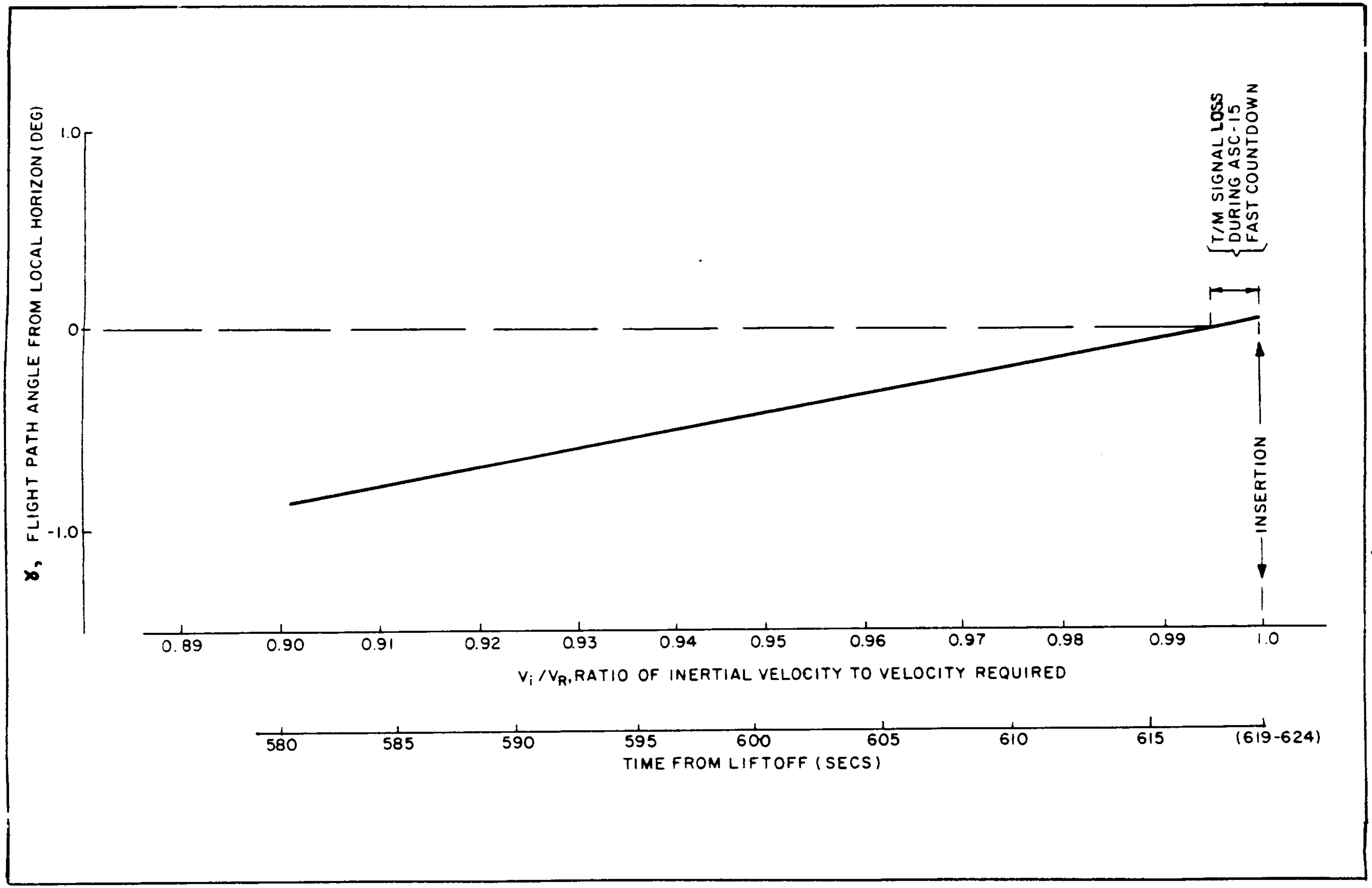

Figure B-5. Flight Path Angle vs. Velocity Ratio, SA-7

$$h = \left[X_s^2 + (Y_s + Y_{so})^2 + Z_s^2 \right]^{\frac{1}{2}} - r_e$$

where:

r_e (earth mean radius) = 6378145.0 meters

Range (R) would be computed as:

$$R = r_e \left[\arc \tan \left(\frac{X_s - X_{so}}{r_e} \right) \right]$$

Dual scales could provide greater accuracy. However, this is probably not warranted unless a more exact computation of h and R is used. Back-up is provided by plotting tracking data vs. R or t.

B.5 VELOCITY TO BE GAINED (ΔV_i vs. t)

This information is available[5] from the ASC-15 computer as "ΔV_i = the difference of squares of biased cut-off velocity and present velocity". It is shown in Figure B-1 as a dual plot with scaling and vertical origin change at 10 seconds before nominal cut-off. The object of this display is to provide a back-up for the computed velocity data of other displays.

The value ΔV_i is generated by the ASC-15 computer with a bias (46 m/sec for SA-9) from the cutoff so that V_i = zero some 2 or 3 seconds before actual cut-off.* Because the objective of this particular display is back-up, it should be kept as independent of other data and computations as possible and therefore it is recommended that rather than bias the value of ΔV_i in the B5500 computer, the scale on the plotter should be

*To allow the computer to enter a special second stage engine cut-off countdown loop.

biased accordingly.

B. 6 ORBIT PARAMETERS

The trajectory orbit parameters (planar) can be determined from V_i, r and γ whose computations have been described in Section B. 2. 2. These parameters can be computed at any point in the orbit but the computation is considerably simplified if the flight path angle is assumed to be zero, in other words at apogee or perigee as assumed herein.

Orbit eccentricity e is found as,

$$e = \frac{r V^2}{\mu} - 1$$

where r is assumed equal to r_π. Then the radius of apogee is,

$$r_\alpha = r \left[\frac{1 + e}{1 - e} \right]$$

and true anomaly $\approx$ 0.

While the flight path angle remains less than 1°* the above short computation can be used with an error in r_π of less than 0. 3% for a perigee altitude of 400 nmi or less than 3. 0% error in altitude of perigee h_π.

Altitudes of perigee h_π and apogee h_α are computed as

$$h_{\pi,\alpha} = r_{\pi,\alpha} - r_e$$

*This is a reasonable assumption for near circular orbit missions.

where r_e is the earth radius for the nominal longitude and latitude of insertion using the same earth as the KSC.

The orbit period is,

$$\mathcal{T} = 2\pi\sqrt{\frac{a^3}{\mu}}, \quad a = \frac{1}{2}(r_\pi + r_\alpha)$$

and the orbit lifetime can be automatically computed or manually determined as a function of r_π and e for a given drag coefficient C_D and atmospheric density ρ.

The orbit parameter computation can be repeated over a number of samples of telemetry data and either an average or the set of discrete values digitally displayed. In taking this average a bound should be put on each parameter, and values beyond these bounds should be excluded from the computation.

The orbit parameter calculations are summarized in Figure B-6.

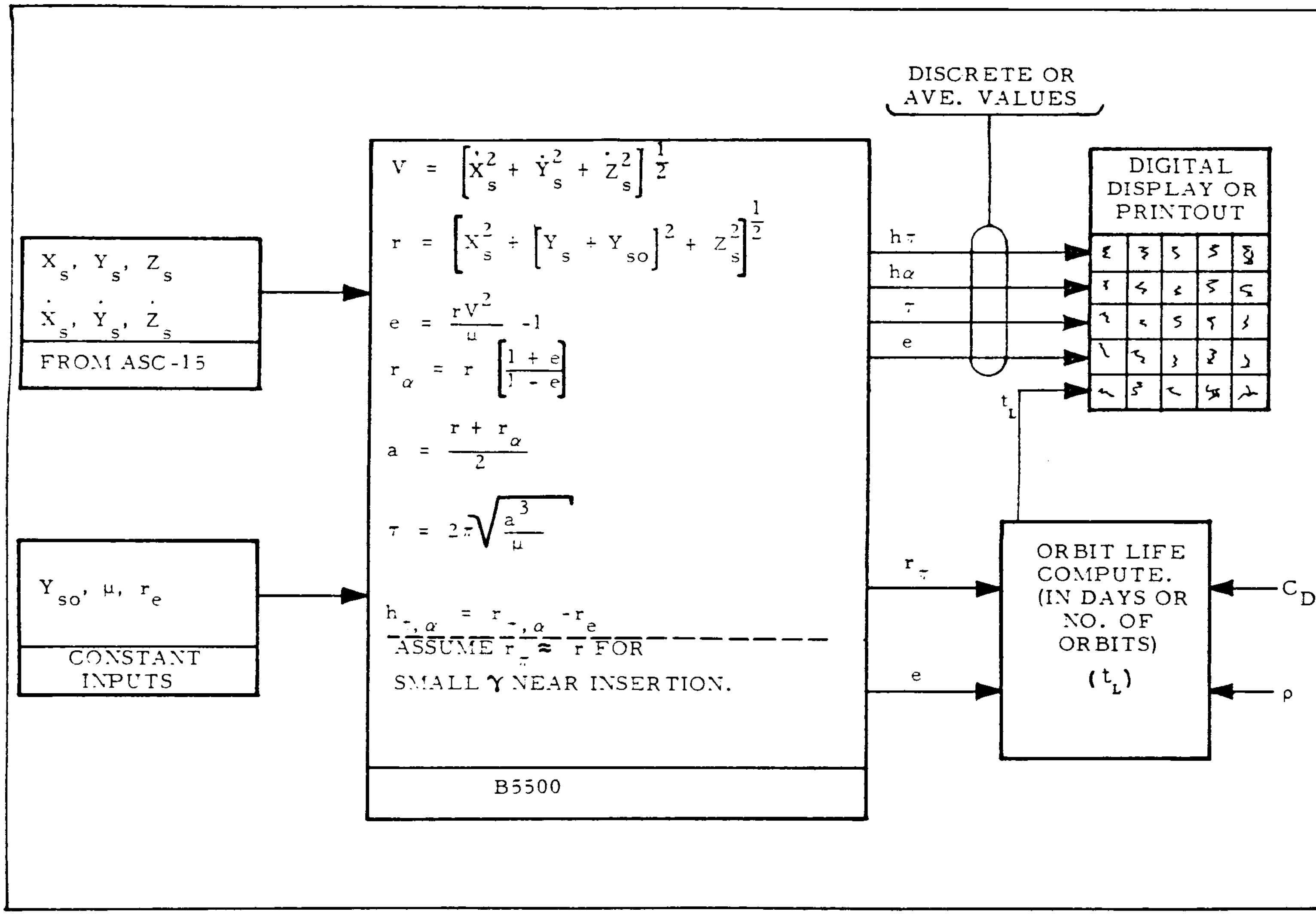

Figure B-6. Orbit Parameter Computation from Telemetry Data

Table B-2. Glossary of Trajectory Parameters

V_i : The magnitude of the vehicle inertial velocity vector.

V_R : The magnitude of the required vehicle velocity at insertion into the desired orbit.

γ : The flight path angle measured from the local horizontal to the inertial velocity vector, positive in a direction opposite to orbit rotation.

Local Horizontal : The plane normal to a line from the earth center to the vehicle present position. This is determined with respect to a spherical earth.

X_s, Y_s, Z_s : Components of vehicle position vector in the inertial guidance reference frame.

$\dot{X}_s$, $\dot{Y}_s$, $\dot{Z}_s$: Components of vehicle velocity vector in the inertial guidance reference frame.

$\bar{r}$: Vehicle position vector from earth center.

$r_{\pi,\alpha}$: Radius of perigee and apogee, respectively.

$h_{\pi,\alpha}$: Altitude of perigee and apogee, respectively.

μ : Gravitation constant

τ : Vehicle orbit period

e : Vehicle orbit eccentricity.

a : Vehicle orbit semi-major axis.

Y_{so} : Distance from earth center to origin of the inertial guidance coordinate system.

r_e : Earth mean radius

V_{co}/V_R and γ_{co} : Precomputed non-optimum cutoff conditions used to generate go/no-go envelope.

ΔV_i : The difference of squares of the biased cut-off velocity and present velocity.

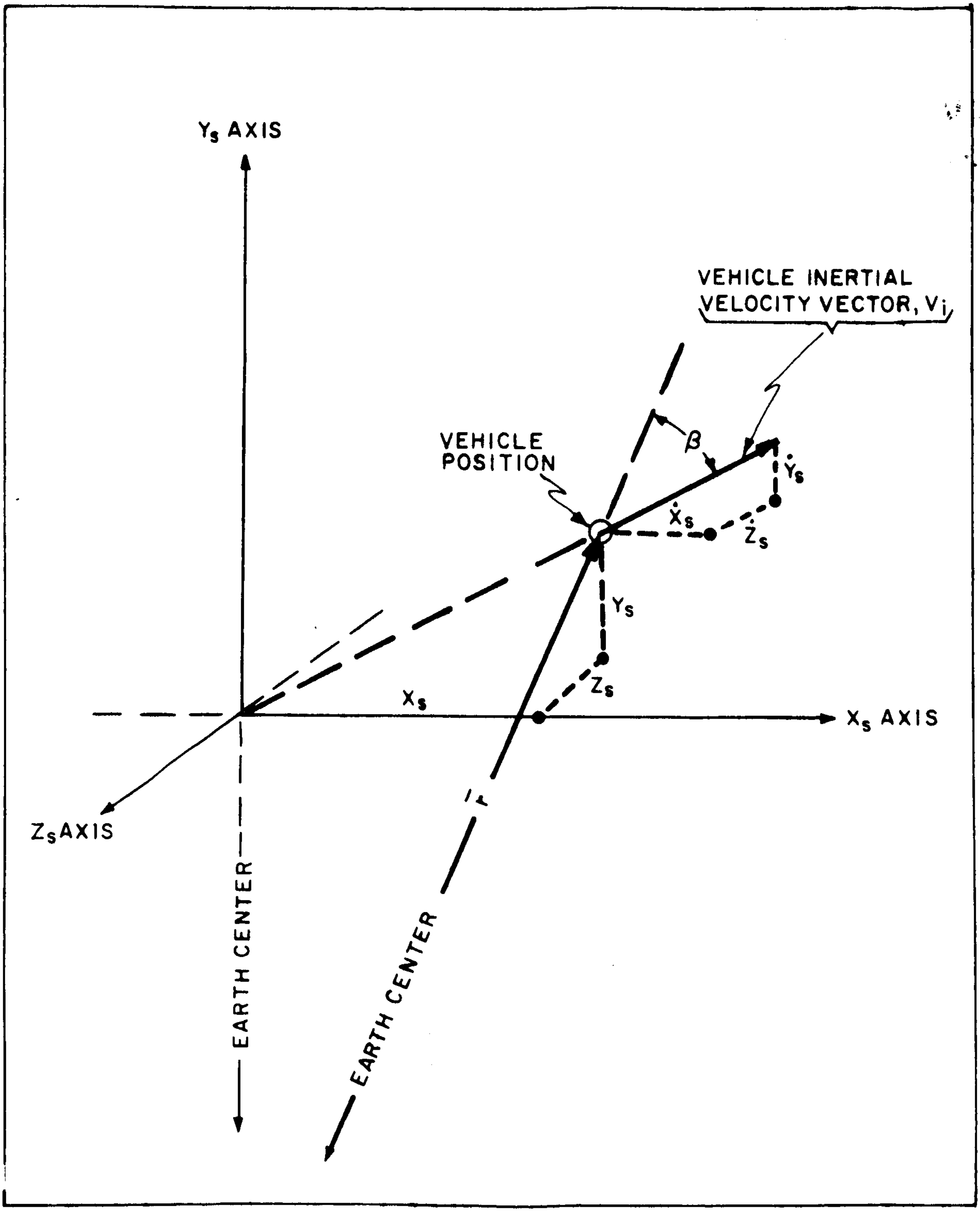

Figure B-7. Orbit Geometry

APPENDIX C

EVENTS

C-1 SATURN I, BLOCK II

Corresponding to the general concepts of Event measurements for display discussed in Section 3. 5. 4, a detailed list of Event signals for SA-9 is given in Table C-1. This list contains Event signals from the S-I, SIV, and ASC-15 and classifies the measurements into three levels (I, II, and III).

C-2 SATURN IB (SA-201)

Event measurements for SA-201 are listed in Table C-2. This list corresponds closely to Table C-1 (SA-9), particularly for the first stage event measurements. Level III measurements are not included as they are not of prime interest in real time except possibly for S-IVB on a playback basis. Telemetered Event signals from the airborne computer are not listed in the table because they were not available at the time the table was prepared.

Table C-2 is based primarily on consideration of the Ascent Phase. Checking of Event status in orbital operations may change the "level" assigned to some measurements and some if not all of the level III measurements may also be of concern. The details will depend on the orbital checkout and restart sequences and the telemetry, ground data handling and communications capability available.

Table C-1. Events - SA-9

EVENT			SOURCE	MEAS. NO.	ASC-15 FLIGHT DISCRETE (FS) NO.
LEVEL I	LEVEL II	LEVEL III			
Liftoff			S-I IU	K2-12 K2-802	
		Decoder Relay No. 1 Decoder Relay No. 2	IU IU	K75-802 K76-802	
		Computer Idle-Load	IU	K80-802	
		Firing Signal MMC Cover Cartridge (6)	IU	K89 Thru K94-900	
		Separation MMC Cover Guiderail (No. 1 + 2)	IU	K95 and K96-900	
		Firing Signal MMC Upper And Lower Detect And Forward Restraint Cartridge (5)	IU	K97 Thru K101-900	
		Separation Signal MMC Forward Restraint And Upper And Lower Detector	IU	K102 Thru K106-900	
	Change From Single Engine Out To Multiple Engine Out Capability		ASC-15		1-2
		Fuel Pressure Valve No. 3 Closed	ASC-15		1-5
		Discrete Malfunction Inhibit	ASC-15		2-2
		Fuel Pressure Valve No. 1 Closed	ASC-15		1-6
		Fuel Pressure Valve No. 2 Closed And LOX/SOX High Press Valves 1 And 2 Open	ASC-15		1-7
		S-IV T/M Calibrate Signal	ASC-15		1-9
	LH_2 Prestart		S-IV ASC-15	XK-601-407	1-10
		LH_2 P/S Press. Sw E1 , E2, . . . , E6	S-IV	XK605-401 Thru 406	
		Control Computer Gain Change	ASC-15		2-5
		Charge Vent Port EBW Firing Units	ASC-15		1-11
		Enable Level Sensors	ASC-15		1-12

Table C-1. Events - SA-9 (Cont)

EVENT			SOURCE	MEAS. NO.	ASC-15 FLIGHT DISCRETE (FS) NO.
LEVEL I	LEVEL II	LEVEL III			
		LOX Emerg. Press. Sw.	S-I	K60-12	
		Destruct EBW Voltage (=1 and =2)	S-I	K63 and K64-11	
		LOX Tank Press. Sw.	S-I	K74-12	
	Open Interstage Ports And Initiate LOX Pre-start		S-IV ASC-15	XK602-407	1-13
		LOX D/S Press. Switch E1, . . . , E6	S-IV	XK606-407 Thru 406	
		He Heater LOX Valve-Open-Closed	S-IV	XK607-407 XK607-408	
		No. 1 LOX Tank Vent Valve Closed	S-IV	XK609-407	
		No. 2 LOX Tank Vent Valve Closed	S-IV	XK610-407	
		He Heater H_2 Valve-Open-Closed	S-IV	XK611-407 XK612-407	
		No. 1 LH_2 Tank Vent Valve Closed	S-IV	XK613-410	
		No. 2 LH_2 Tank Vent Valve Closed	S-IV	XK614-409	
		Open LOX/SOX Purge Valves 2, 3, 5 and 6	ASC-15		1-14
	LOX Level Cutoff		S-I	K15-02 K16-04	
		Position GOX Flow Control Valve	S-I	K72-9	
	Fuel Level Cutoff		S-I	K17-F2 K18-F4	
Cutoff Inboard Engines			S-I ASC-15	K67-12	1-15
		Open LOX/SOX Disposal Valve No. 4	ASC-15		1-16
		Open LOX/SOX Disposal Valves No. 1 and 7	ASC-15		1-17
		Electrically Interconnect Outboard Eng. Thrust-OK Switch and Arm Fuel Depletion Probes	ASC-15		1-18

Table C-1. Events - SA-9 (Cont)

EVENT			SOURCE	MEAS. NO.	ASC-15 FLIGHT DISCRETE (FS) NO.
LEVEL I	LEVEL II	LEVEL III			
	Fuel Depletion Cutoff		S-I	K81-F2 K82-F4	
Cutoff Signal Outboard			S-I ASC-15	K3-12	1-19
	Engine Cutoff Signal (8)		S-I	K4-1 Thru -8	
Cutoff And Destruct Indicator (CDR=1 and =2)			S-I	K65-13 K66-13	
	S-IV Ullage Rocket Fire Command		S-IV ASC-15	XK615-407	2-6
	Initiate S-I/S-IV Separation Explosive Nuts, Fire S-I Retro Rockets, And Actuate S-IV Control Switch		ASC-15		2-7
Separation (EBW Voltage =1 and =2)			S-I	K68-11 K69-11	
	Retro Rocket Ignition Signal (EBW)		S-I	K37-11	
		EBW Voltage =1 Thru 8 (Retro)	S-I	K42 Thru K49-11	
		EBW Voltage =9 And =10 (Vent Ports)	S-I	K50-11 K51-11	
		Ignition Signal Vent Ports (EBW)	S-I	K52-12	
		Separation Prestart Signal (S-I To S-IV)	S-I	K53-12	
		S-IV Hydraulic Accumulators Open	ASC-15		2-8
		Hyd. Accum. Open Command	S-IV	XK632-407	
S-IV Engine Start Command			S-IV ASC-15	XK603-407	2-9
		Start Press. Switch Pickup (E-1 Thru E-6)	S-IV	XK600-401 Thru 406	
		Arm S-IV Engine Cutoff Capability	ASC-15		2-10
		Arm All Eng. Cutoff Command	S-IV	XK618-407	

Table C-1. Events - SA-9 (Cont)

EVENT			SOURCE	MEAS. NO.	ASC-15 FLIGHT DISCRETE (FS) NO.
LEVEL I	LEVEL II	LEVEL III			
		Enable Engine Out Command	S-IV	XK620-407	
		Activate S-IV PU System And Charge Ullage Rocket Jettison EBW	ASC-15		2-12
		PU Valve Command Signal	S-IV	K604-407	
		PU System Activate Command	S-IV	XK617-407	
		Arm Launch Escape Tower (LES) Jettison	ASC-15		2-13
	Jettison S-IV Ullage Rocket And LES		ASC-15		2-14
	U/R Jettison Command		S-IV	XK615-407	
LES Jettison Signal			IU	K109-900	
		S-4 And 10 Tape Recorders Stop-Record Command	ASC-15		2-16
		Cutoff Tape Recorder Playback	ASC-15		1-20
		Control Computer Gain Change	ASC-15		2-17
		Step Pressure Command	S-IV	XK621-407	
		Reservoir Piston Position (Engines 1 Thru 6)			
		LH_2 Tank Non-Propulsive Vent Valves Open T/B	S-IV	XK634-410 XK636-410	
		LOX Tank Non-Propulsive Vent Valve Open T/B	S-IV	XK635-410	
		He Hetr. Sec. Coil Valve Control	S-IV	XK622-407	
		Arm S-IV Depletion Cutoff	ASC-15		2-18
		Arm All Engine Cutoff Command PU	S-IV	K631-407	
S-IV Engine Cutoff Command			S-IV ASC-15	XK624-407	N/A

Table C-1. Events - SA-9 (Cont)

EVENT			SOURCE	MEAS. NO.	ASC-15 FLIGHT DISCRETE (FS) NO.
LEVEL I	LEVEL II	LEVEL III			
		Control To S-IV Command	S-IV	XK625-407	
	Engine Out Signal (Engines -1 Thru -6)		S-IV	XK626-401 Thru 406	
		S-IV T/M Calibrate Command	ASC-15		2-19
		S-IV And IU Tape Recorders Playback Command	ASC-15		2-20
		S-IV And IU Tape Recorders Stop Play-back Command	ASC-15		2-21
		Close S-IV Auxiliary Non-Propulsive Vent Ports	ASC-15		2-22

*ASC-15 issues two sequences of Discretes FS-1, FS-2. It is assumed that all of these appear as output in the PCM telemetry in a form useable in real-time.

- Sequences of Events are not necessarily in the order of listing in this table.
- Flight Sequence Steps K1-12(SI) or K1-802(IV) are not shown in Table.

Table C-2. Events - Saturn IB, SA-201 (Levels I and II)

EVENTS		SOURCE	MEAS. NO.	COMPUTER DISCRETE*
LEVEL I	LEVEL II			
Liftoff		S-IB	K2-12	
	LOX Level Cutoff	S-IB	K15-02 K16-04	
	Fuel Level Cutoff	S-IB	K17-F2 K18-F4	
Cutoff Signal Inboard		S-IB	K67-12	
	Fuel Depletion Cutoff	S-IB	K81-F2 K82-F4	
Cutoff Signal Outboard		S-IB	K3-12	
	Engine Cutoff Signal (8)	S-IB	K4-1 to 8	
Separation		S-IB	K68-11 K69-11	
	Retro Rocket Ignition Signal	S-IB	K37-11	
Cutoff and Destruct Indicator (CDR 1 and 2) **		S-IB	K65-13 K66-13	
	Engine Ready Signal	S-IVB	K012-401	
Ignition Detected		S-IVB	K008-401	
Fire Detection Signal		S-IVB	K009-401	
	Mainstage OK	S-IVB	K014-401	
Cutoff Signal		S-IVB	K013-401	
	Engine Start On Command	S-IVB	K021-404	
	Engine Restart On Command	S-IVB	K022-404	
	Engine Cutoff On Command	S-IVB	K023-404	
	Engine Cutoff Off Command	S-IVB	K024-404	
	Engine Chilldown On Command	S-IVB	K025-404	
	Engine Chilldown Off Command	S-IVB	K026-404	

NOTES:

* Information concerning telemetered computer event signals was not available when this table was compiled. Presumably, signals of the general type given in Table C-1 (SA-9) will be available for use.

** For future manned missions: Range Safety cutoff and destruct commands are usually separated for manned missions to provide time for escape.

- The sequence of events is not necessarily as listed.
- Priorities (as indicated by assignment of an event to a given level) are primarily based on Ascent Phase monitoring. Priorities during orbital operations will be different in some cases.

APPENDIX D

STABILIZATION AND CONTROL

D. 1 SATURN I BLOCK II (SA-9)

The general philosophy of Stabilization and Control data and displays was discussed in Section 3. 5. 5. In this Appendix the corresponding data for SA-9 is detailed in Figures D-1 to D-5 and in Table D-1.

D. 2 SATURN IB (SA-201)

SA-201 data corresponding to the SA-9 information, noted above, is given in Table D-2, and in Figures D-6 and D-7.

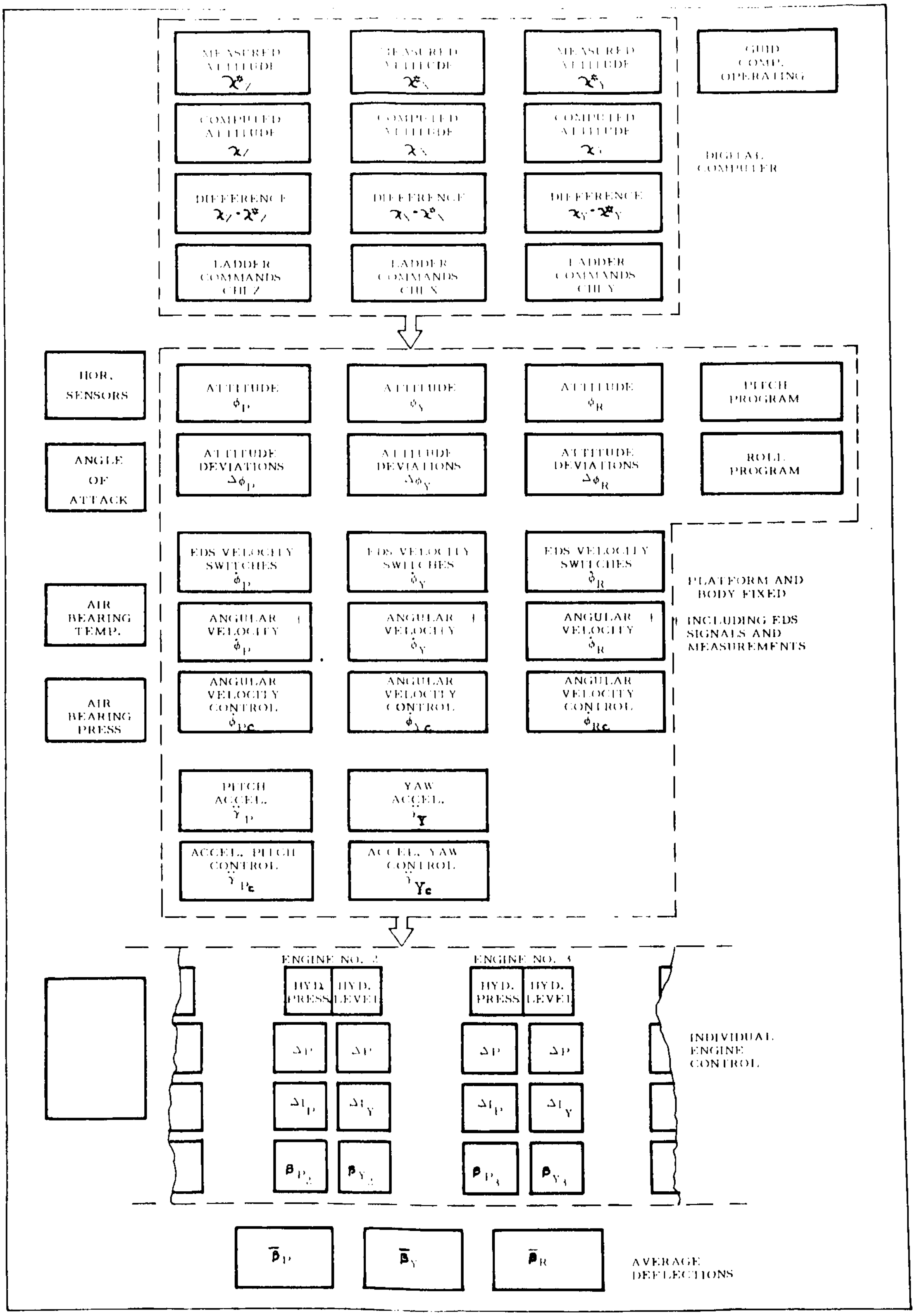

Figure D-1. Stabilization and Control Data-General

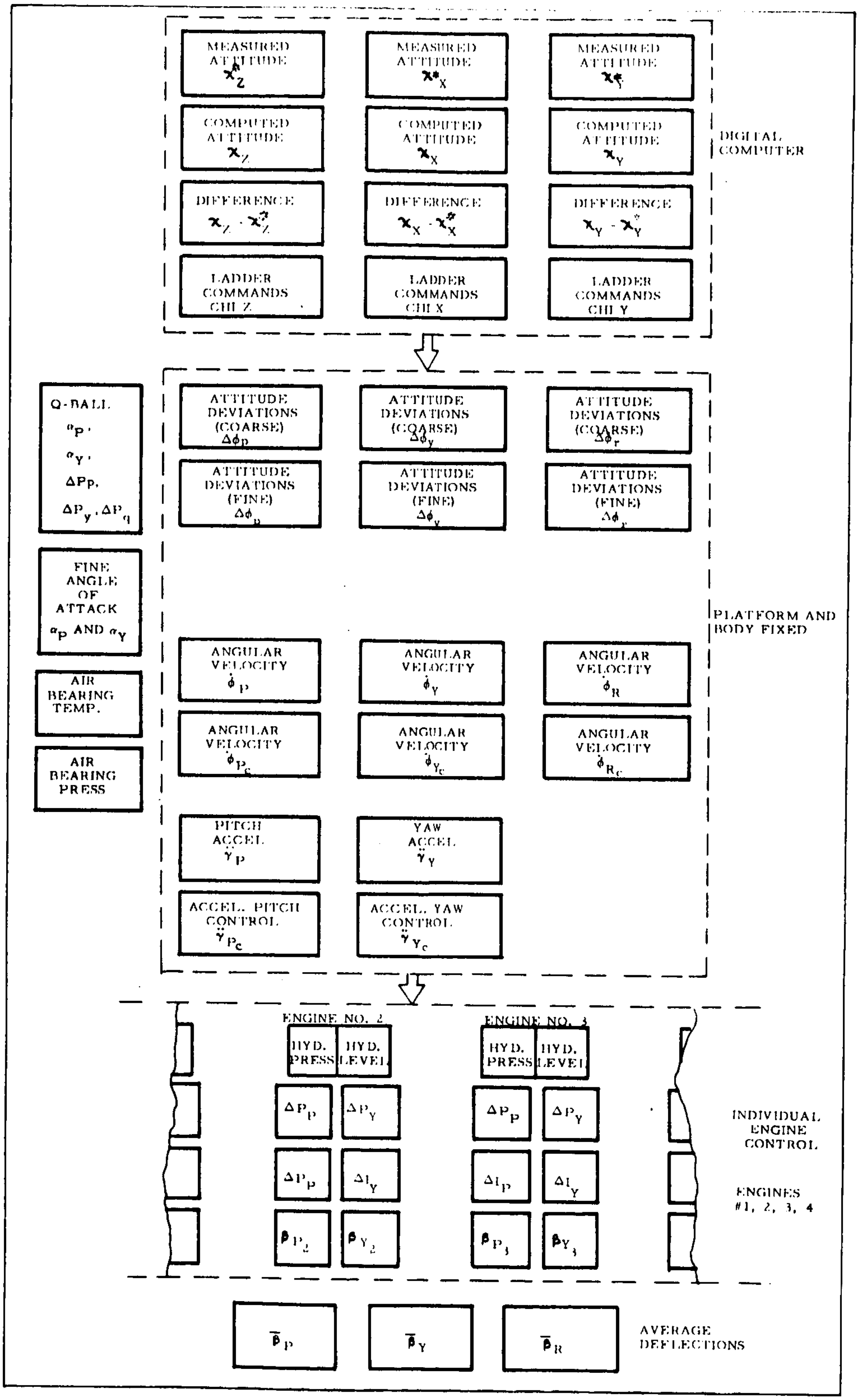

Figure D-2. Stabilization and Control Data - S-I

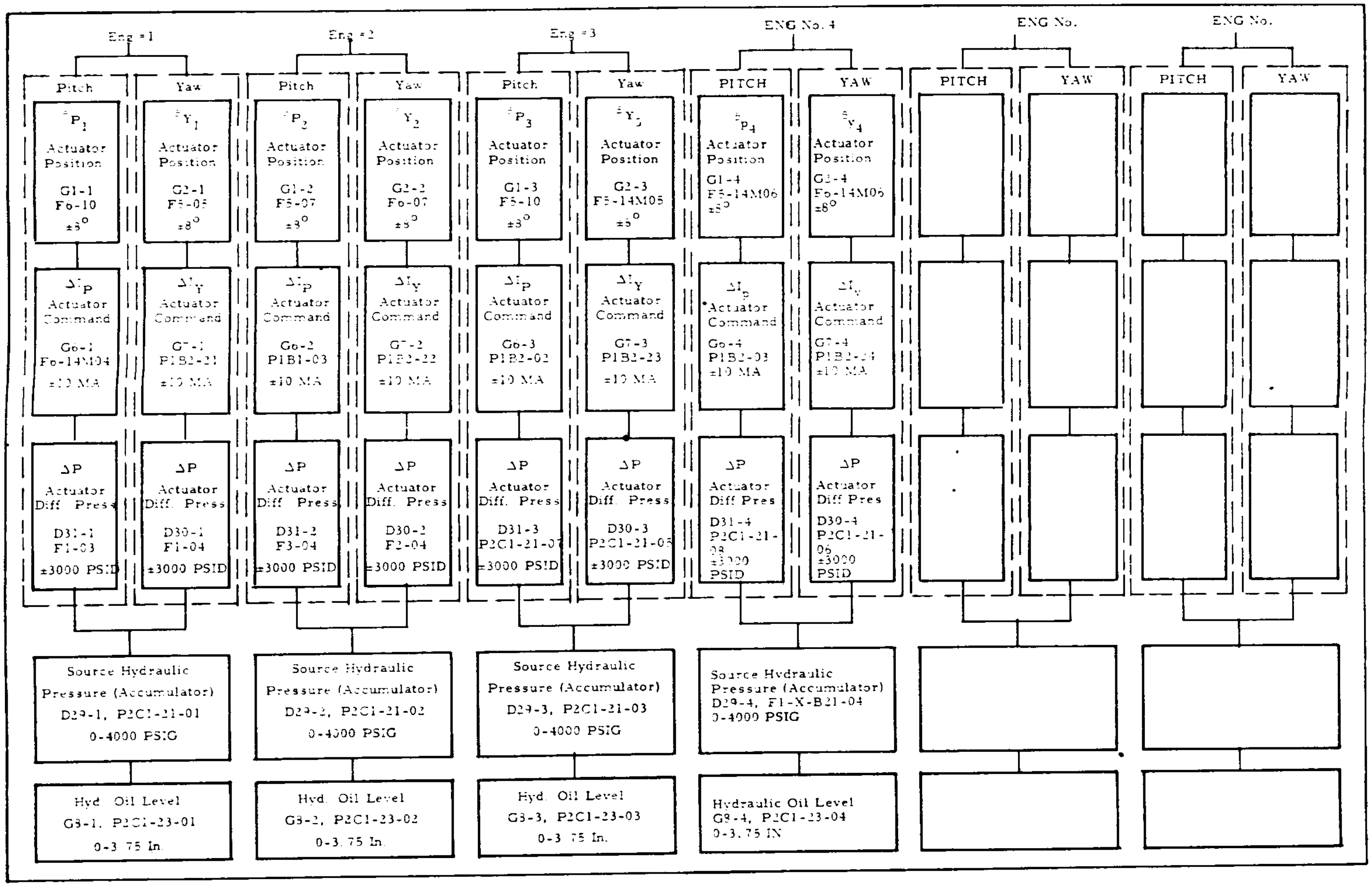

Figure D-3. Stabilization and Control Data - S-I Engines (SA-9)

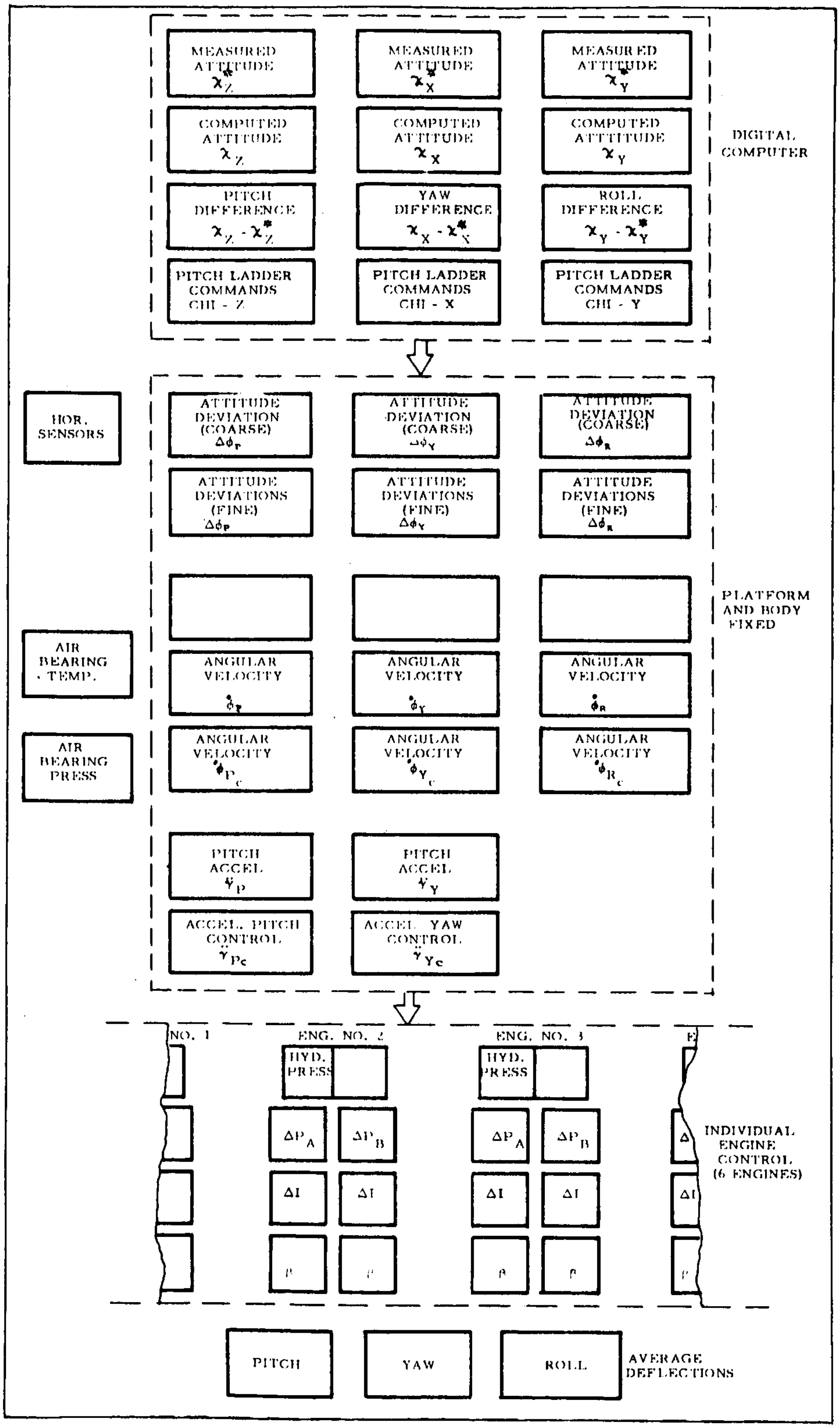

Figure D-4. Stabilization and Control Data - S-IV

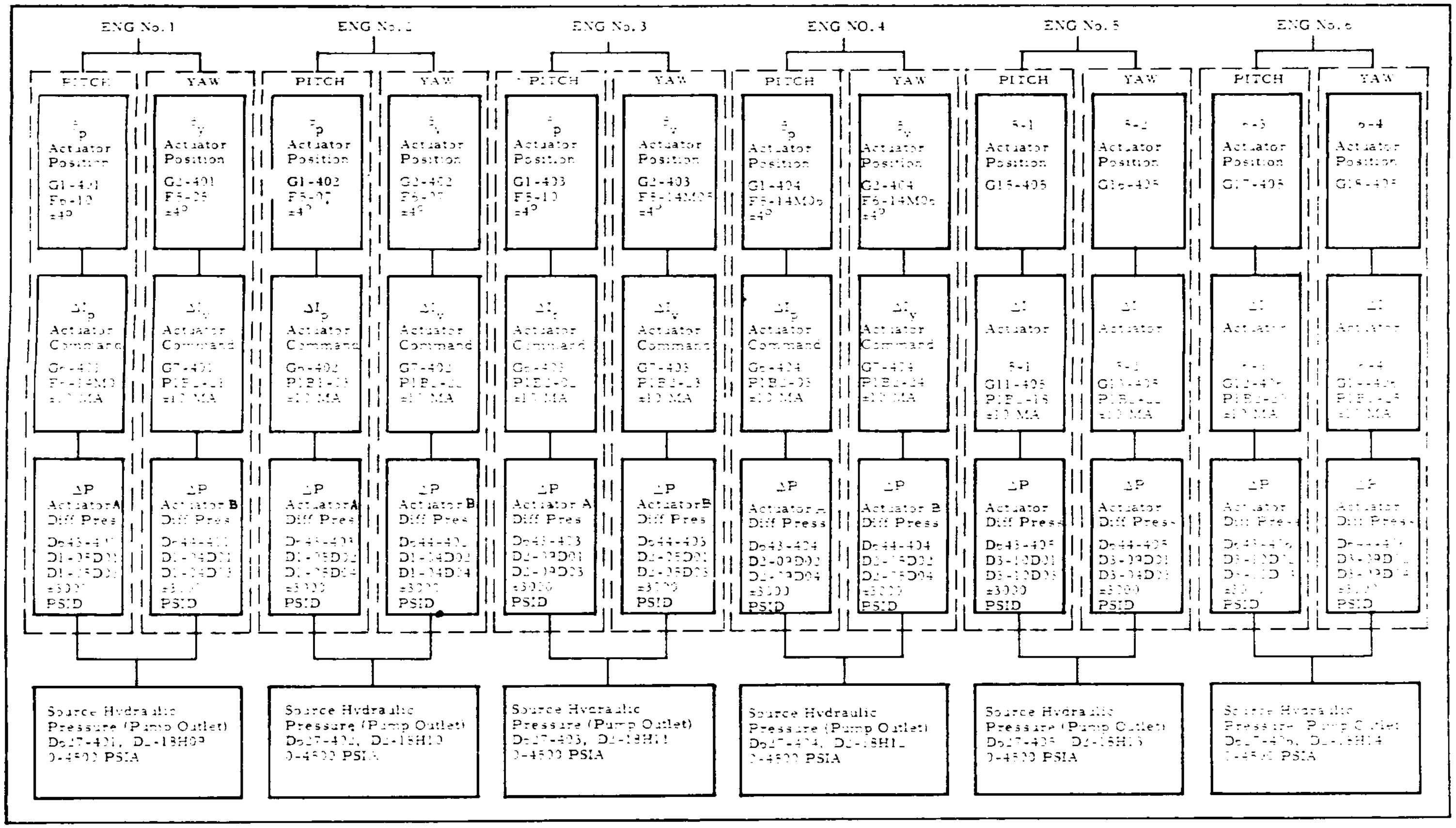

Figure D-5. Stabilization and Control Data - S-IV, Engines (SA-9)

Table D-1. Stabilization and Control Data & Sources-SA-9

Level	No.	Data		Sym	Source	Meas. No.	Remarks
LEVEL I	1.	Actuator Deflections - Average	Pitch	$\bar{\beta}_p$	B5500	--	S-I and S-IV
			Yaw	$\bar{\beta}_y$	B5500	--	
			Roll	$\bar{\beta}_r$	B5500	--	
	2.	Attitudes (Deviations - Platform)	Pitch	$\Delta\phi_p$	IU	H26-802	
			Yaw	$\Delta\phi_y$	IU	H25-802	
			Roll	$\Delta\phi_z$	IU	H24-802	
	3.	Angular Velocity (Control)	Pitch	$\dot{\gamma}_{pc}$	IU	F42-802	
			Yaw	$\dot{\gamma}_{yc}$	IU	F43-802	
			Roll	$\dot{\gamma}_{rc}$	IU	F44-802	
	4.	Angular Velocity Switches		--			Not Applicable
	5.	Angular Acceleration (Control)	Pitch	$\ddot{\gamma}_{pc}$	IU	F40-802	
			Yaw	$\ddot{\gamma}_{yc}$	IU	F41-802	
LEVEL II	6.	Fin Vane Angle of Attack		α_p	S-I	F45-16	
				α_y	S-I	F46-16	
	7.	Actuator Deflections	Pitch (1)	β_{p_1}	S-I	G1-1	
			(2)	β_{p_2}	S-I	G1-2	
			(3)	β_{p_3}	S-I	G1-3	
			(4)	β_{p_4}	S-I	G1-4	
			Yaw (1)	β_{y_1}	S-I	G2-1	
			(2)	β_{y_2}	S-I	G2-2	
			(3)	β_{y_3}	S-I	G2-3	
			(4)	β_{y_4}	S-I	G2-4	
			Pitch (1)	β_{p_1}	S-4	G1-401	
			(2)	β_{p_2}	S-4	G1-402	
			(3)	β_{p_3}	S-4	G1-403	
			(4)	β_{p_4}	S-4	G1-404	
			Yaw (1)	β_{y_1}	S-4	G2-401	
			(2)	β_{y_2}	S-4	G2-402	
			(3)	β_{y_3}	S-4	G2-403	
			(4)	β_{y_4}	S-4	G2-404	
			Actuator 5-1	--	S-4	G15-405	
			5-2	--	S-4	G16-405	
			6-3	--	S-4	G17-405	
			6-4	--	S-4	G18-405	

Table D-1. Stabilization and Control Data & Sources-SA-9 (Cont)

	No.	Data	Sym	Source	Meas. No.	Remarks
LEVEL II	8.	Attitude Actual Actual Actual	χ^*z χ^*x χ^*y	ASC-15 ASC-15 ASC-15	-- -- --	$(\chi - \chi^*)$ = Error
		Computed	χ_z χ_x χ_y	ASC-15 ASC-15 ASC-15	-- -- --	
	9	Steering Rate Ladder Commands	CHI-x CHI-y CHI-z	ASC-15 ASC-15 ASC-15	--	
	10	Accelerations Pitch Yaw	$\ddot{\gamma}_p$ $\ddot{\gamma}_y$	IU IU	F31-802 F32-802	
	11	Angular Velocities (ED)		--	--	Not Applicable
LEVEL III	12	Q-Ball Angle of Attack Pitch & Press Components Yaw Pitch Δp Yaw Δp Dyn. Press	αp α_y Δp_p Δp_y Δp_q	B5500 B5500 IU IU IU	-- -- D133-400 D135-400 D137-400	
	13	Engine Actuator Commands Pitch Yaw	ΔI_p ΔI_y ΔI_y ΔI_y ΔI_y	S-1 S-1 S-1 S-1 S-1	G6-1 to G6-4 G7-1 G7-2 G7-3 G7-4	4 Measurements
		Pitch	ΔI_p ΔI_p ΔI_p ΔI_p	S-4 S-4 S-4 S-4	G6-401 G6-402 G6-403 G6-404	
		Yaw	ΔI_y ΔI_y ΔI_y ΔI_y	S-4 S-4 S-4 S-4	G7-401 G7-402 G7-403 G7-404	
		Actuator 5-1 5-2 6-3 6-4	-- -- -- --	S-4 S-4 S-4 S-4	G11-405 G13-405 G12-405 G14-405	
	14	Engine Actuator Differential Press Pitch	ΔP_p ΔP_p ΔP_p ΔP_p	S-1 S-1 S-1 S-1	D31-1 D31-2 D31-3 D31-4	

Table D-1. Stabilization and Control Data & Sources-SA-9 (Cont)

	No.	Data		Sym	Source	Meas. No.	Remarks
LEVEL III			Yaw	ΔP_y	S-1	D30-1	
				ΔP_y	S-1	D30-2	
				ΔP_y	S-1	D30-3	
				ΔP_y	S-1	D30-4	
			Actuators A	ΔP_A	S-4	D643-401	
				ΔP_A	S-4	D643-402	
				ΔP_A	S-4	D643-403	
				ΔP_A	S-4	D643-404	
				ΔP_A	S-4	D643-405 & 406	
			Actuators B	ΔP_B	S-4	D644-401	
				ΔP_B	S-4	D644-402	
				ΔP_B	S-4	D644-403	
				ΔP_B	S-4	D644-404	
				ΔP_B	S-4	D644-705 & 706	
	15	Source Hydraulic Press.	Eng. 1	--	S-1	D29-1	
			Eng. 2	--	S-1	D29-2	
			Eng. 3	--	S-1	D29-3	
			Eng. 4	--	S-1	D29-4	
			Eng. 1	--	S-4	D627-401	
			Eng. 2	--	S-4	D627-402	
			Eng. 3	--	S-4	D627-403	
			Eng. 4	--	S-4	D627-404	
			Eng. 5	--	S-4	D627-405	
			Eng. 6	--	S-4	D627-406	
	16	Hydraulic Oil Level	Eng. 1	--	S-1	G8-1	
			Eng. 2	--	S-1	G8-2	
			Eng. 3	--	S-1	G8-3	
			Eng. 4	--	S-1	G8-4	
	17	Angular Velocity	Pitch	$\dot{\phi}_p$	IU	F34-802	
			Yaw	$\dot{\phi}_y$	IU	F35-802	
			Roll	$\dot{\phi}_R$	IU	F36-802	
	18	Platform Air Bearings Press. Supply & Press., Ambient T, Etc.		--	Misc.	--	

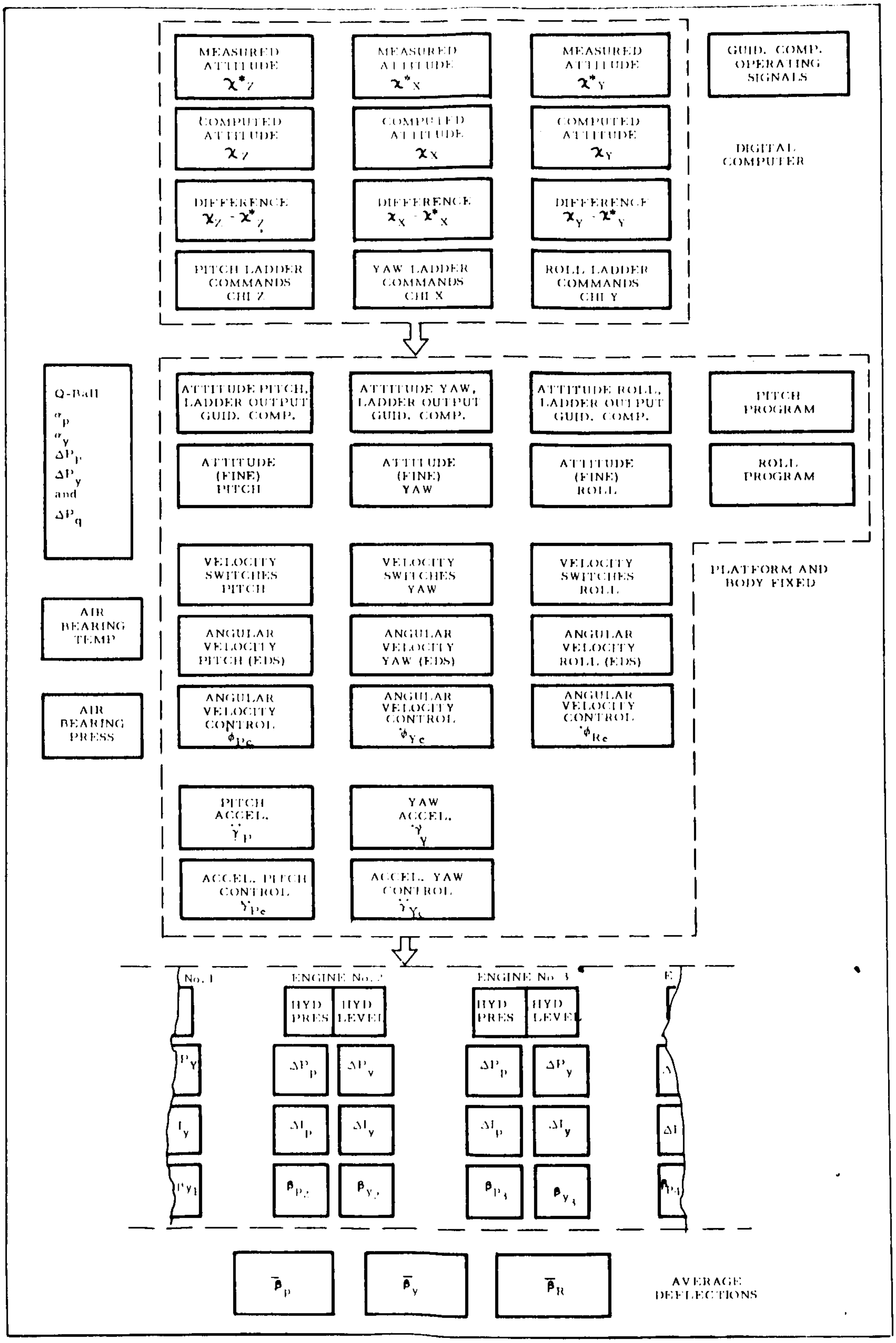

Figure D-6. Stabilization and Control Data - S-IB (SA-201)

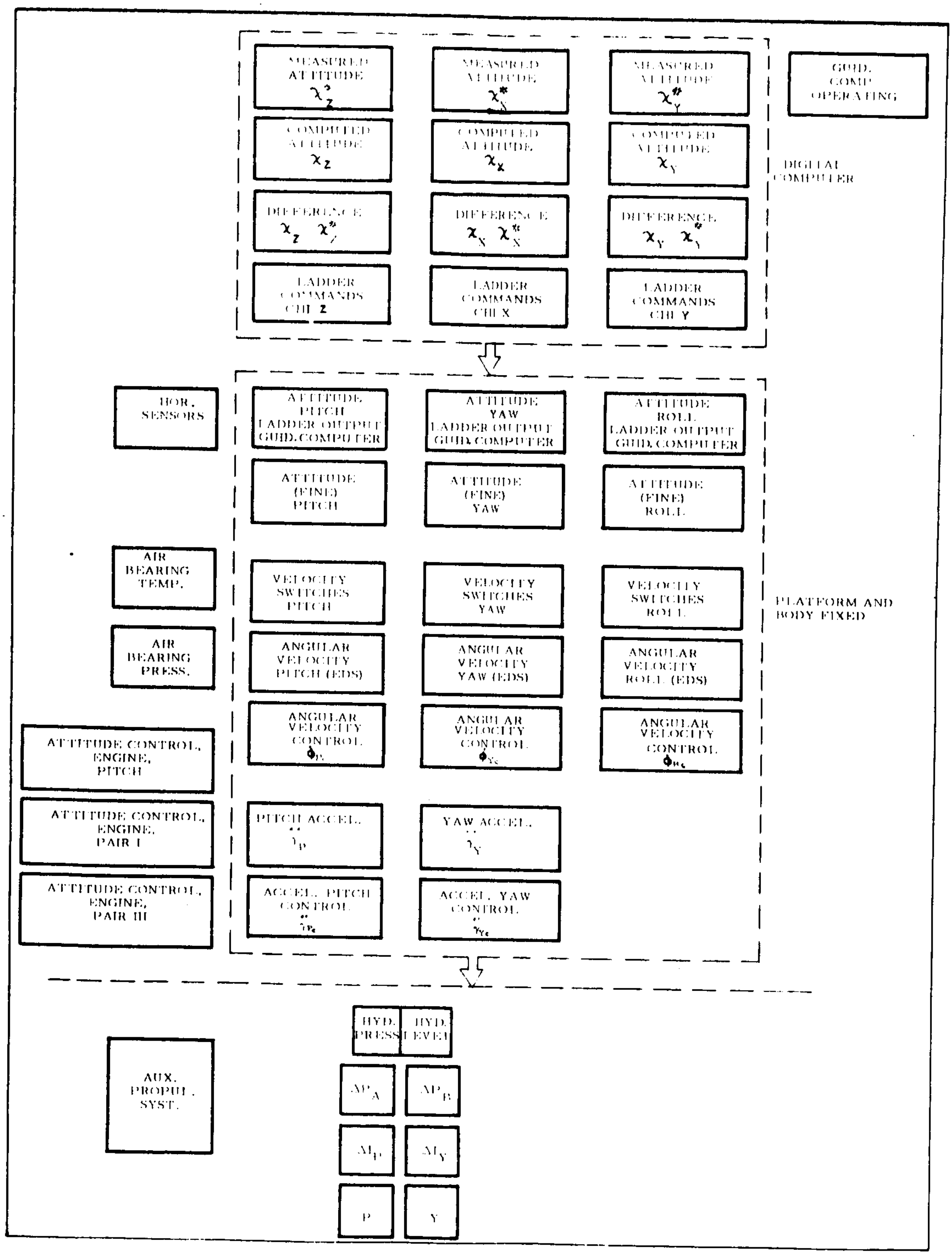

Figure D-7. Stabilization and Control Data - S-IVB (SA-201)

Table D-2. Stabilization and Control Data Sources - SA-201

	No.	Data		Source	Meas. No.	Remarks
LEVEL I	1.	Actuator Deflections	Pitch Yaw Roll		--- ---	Average for S-IB. No roll for S-IVB.
LEVEL I	2.	Attitudes-Ladder Output, Guidance Computer	Pitch Yaw Roll	IU-201 IU-201 IU-201	H54-603 H55-603 H56-603	
LEVEL I	3.	Angular Velocity (Control)	Pitch Yaw Roll Pitch Yaw	IU-201 IU-201 IU-201 S-IB S-IB	R4-602 R5-602 R6-602 R12-12 R13-12	
LEVEL I	4.	Angular Velocity Switches		IU-201	R16-602 to R24-602	Rate Switches from EDS. (9 Measurements)
LEVEL I	5.	Angular Acceleration (Control)	Pitch Yaw Pitch Yaw	IU-201 IU-201 S-IB S-IB	A4-601 A5-601 A10-11 A11-11	
LEVEL II	6.	Fin Vane Angle of Attack		---	---	Not Avail.
LEVEL II	7.	Actuator Deflections	Pitch (1) Pitch (2) Pitch (3) Pitch (4) S-IVB Pitch Yaw (1) (2) (3) (4) S-IVB Yaw	IU-201 IU-201 IU-201 IU-201 IU-201 IU-201 IU-201 IU-201 IU-201 IU-201	G1-1 G1-2 G1-3 G1-4 G1-401 G2-1 G2-2 G2-3 G2-4 G2-401	S-IB (Pitch 1–4) S-IVB S-IB (Yaw 1–4) S-IVB
LEVEL II	8.	Attitude Actual: and Computed:	Pitch Yaw Roll Pitch Yaw Roll			χ^* and χ signals from guidance computer.
LEVEL II	9.	Attitude, (Fine)	Pitch Yaw Roll	IU-201 IU-201 IU-201	XH48-603 XH50-603 XH52-603	
LEVEL II	10.	Angular Acceleration	Pitch Yaw Pitch Fwd. Pitch Aft. Yaw Fwd. Yaw Aft.	S-IB S-IB S-IVB S-IVB S-IVB S-IVB	A53-11 A54-11 A001-411 A002-404 A003-411 A004-404	
LEVEL II	11.	Angular Velocities (EDS)	Pitch Yaw Roll	IU-201 IU-201 IU-201	R7-602 to R15-602	EDS (9 Measurements)
LEVEL III	12.	Q-Ball:	Pitch Coarse Pitch Fine Yaw Coarse Yaw Fine Dynamic Press. Coarse Dynamic Press. Fine	IU-201 IU-201 IU-201 IU-201 IU-201 IU-201	D1-900 D2-900 D3-900 D4-900 D5-900 D6-900	

Table D-2. Stabilization and Control Data and Sources - SA-201 (Continued)

LEVEL III

No.	Data	Source	Meas. No.	Remarks
13.	Engine Actuator, Commands: ΔI Pitch (1) Pitch (2) Pitch (3) Pitch (4)	IU-201 IU-201 IU-201 IU-201	H1-1 H1-2 H1-3 H1-4	S-IB
	(S-IVB). ΔI Pitch	IU-201	H1-401	S-IVB.
	ΔI Yaw (1) (2) (3) (4)	IU-201 IU-201 IU-201 IU-201	H2-1 H2-2 H2-3 H2-4	S-IB
	(S-IVB) ΔI Yaw	IU-201	H2-401	S-IVB
14.	Engine Actuator Diff. Press. ΔP Yaw (1) ΔP Yaw (2) ΔP Yaw (3) ΔP Yaw (4) ΔP Pitch (1) ΔP Pitch (2) ΔP Pitch (3) ΔP Pitch (4)	S-IB S-IB S-IB S-IB S-IB S-IB S-IB S-IB	D30-1 D30-2 D30-3 D30-4 D31-1 D31-2 D31-3 D31-4	S-IB
	Pressure Diff. - Actuator "A" Pressure Diff. - Actuator "B"	S-IVB S-IVB	D044-401 D045-401	S-IVB
15.	Source - Hyd. Pressure	S-IV S-IB	D041-403 D29-1 to 4	
16.	Level - Reservoir Oil	S-IB S-IVB	J007-403 H8-1 to 4	
17.	Angular Velocities Pitch Yaw	S-IB S-IB	R3-9 R4-9	
18.	Temp. Air Bearing Inlet Temp Air Bearing Exit Temp. ST-124M Inertial Bearing Temp. - Guidance Computer Pressure ST-124M Air Bearing Inlet	IU-201 IU-201 IU-201 IU-201 IU-201	C31-603 C32-603 XC34-603 XC53-603 D11-603	

In addition to the above, SA-201 has the following:

No.	Data	Source	Meas. No.	Remarks
19.	Pitch Program - ST-124M Roll Program - ST-124M	IU-201 IU-201	H29-603 H30-603	Level II
20.	Guidance Computer Operation	IU-201	H60-603	Level III
21.	Attitude Control, Engine, Pitch Attitude Control, Engine, Pair I Attitude Control, Engine, Pair III	IU-201 IU-201 IU-201	H3-400 H4-400 H5-400	Level III

APPENDIX E

PROPULSION

E-1 SATURN I, BLOCK II (SA-9)

In Section 3. 5. 6, the general philosophy of Propulsion data and displays were discussed. In this Appendix, these general concepts are applied to the SA-9 vehicle and are illustrative of the displays and data sources for ascent monitoring. Figures E-1 to E-5 show the S-I and S-IV stages. Tables E-1 and E-2 list the corresponding data sources.

E-2 SATURN IB (SA-201)

Corresponding to the S-1 and S-IV data of SA-9 given in Figures E-2 and E-4, the S-IB and S-IVB data of SA-201 are given in Figures E-6 and E-7 and Tables E-3 and E-4.

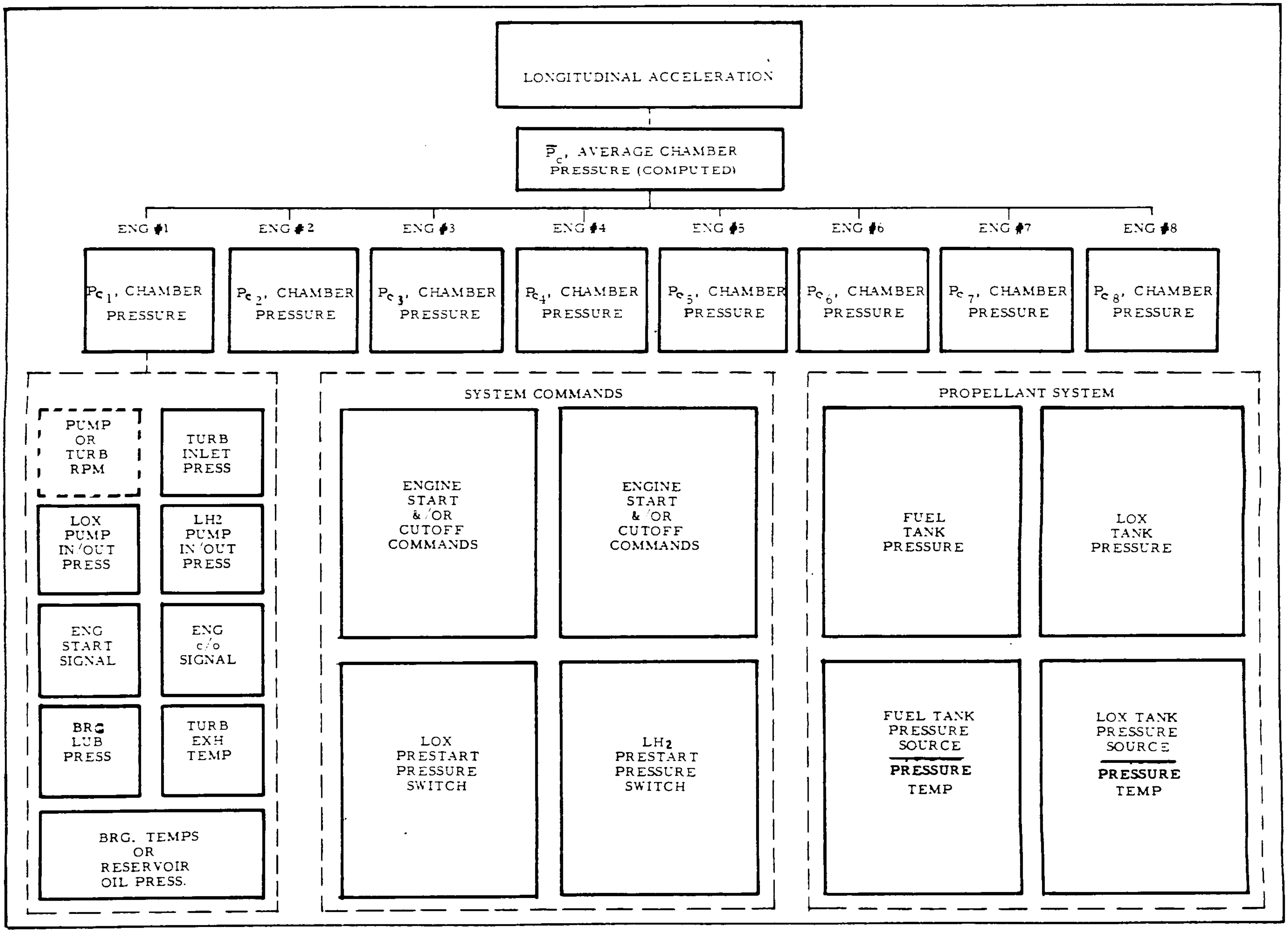

Figure E-1. Propulsion Measurements - Saturn I Block II, SA-9, General

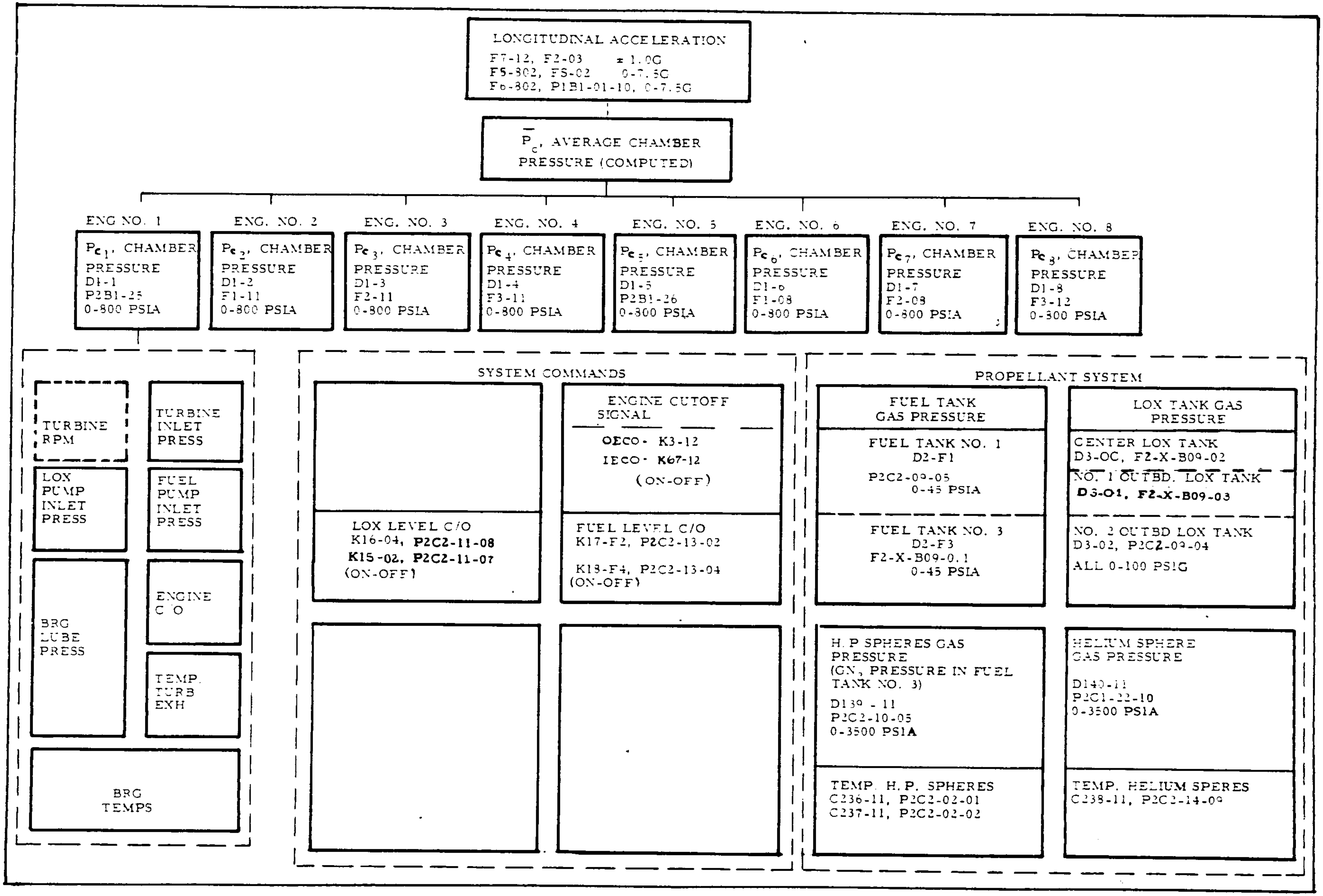

Figure E-2. Propulsion Measurements - SA-9, S-I Stage

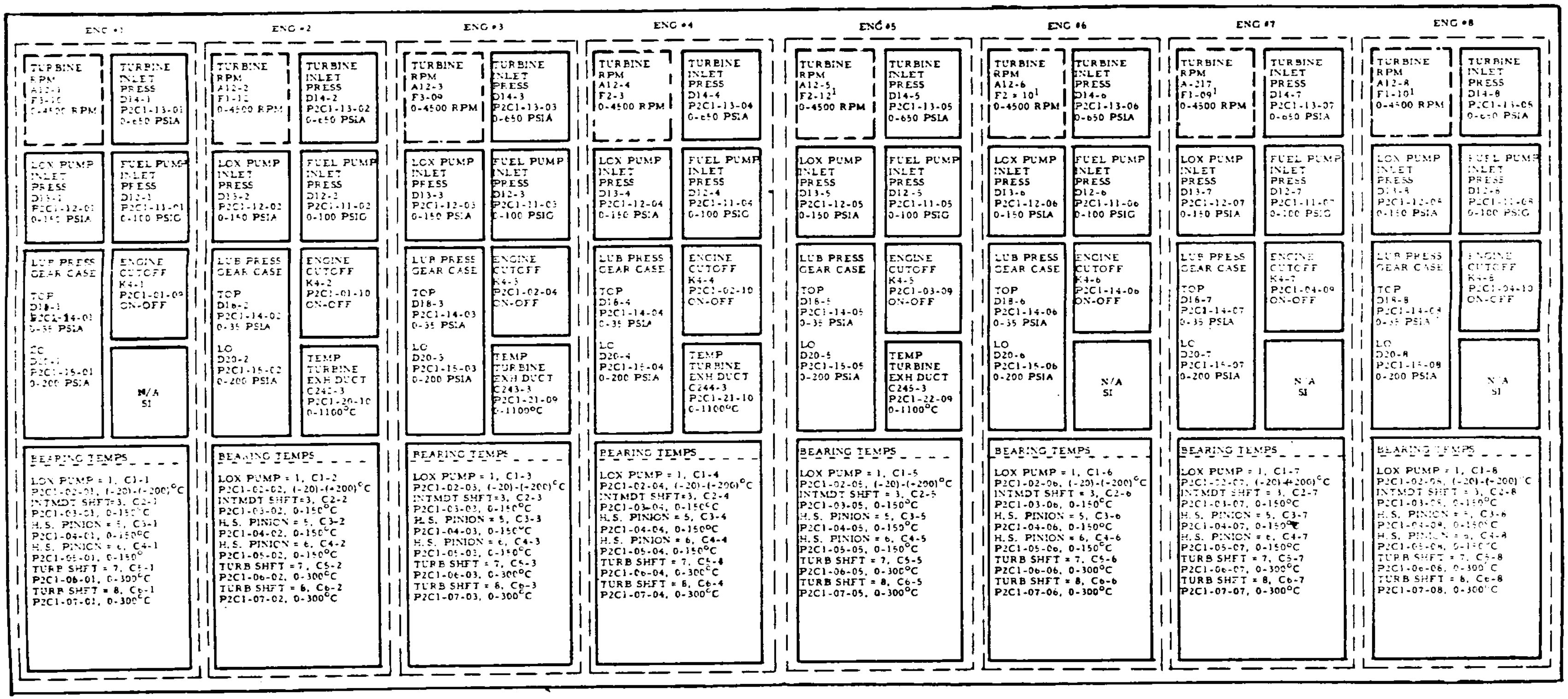

Figure E-3. Propulsion Measurements - SA-9, S-I Stage, Engine Details

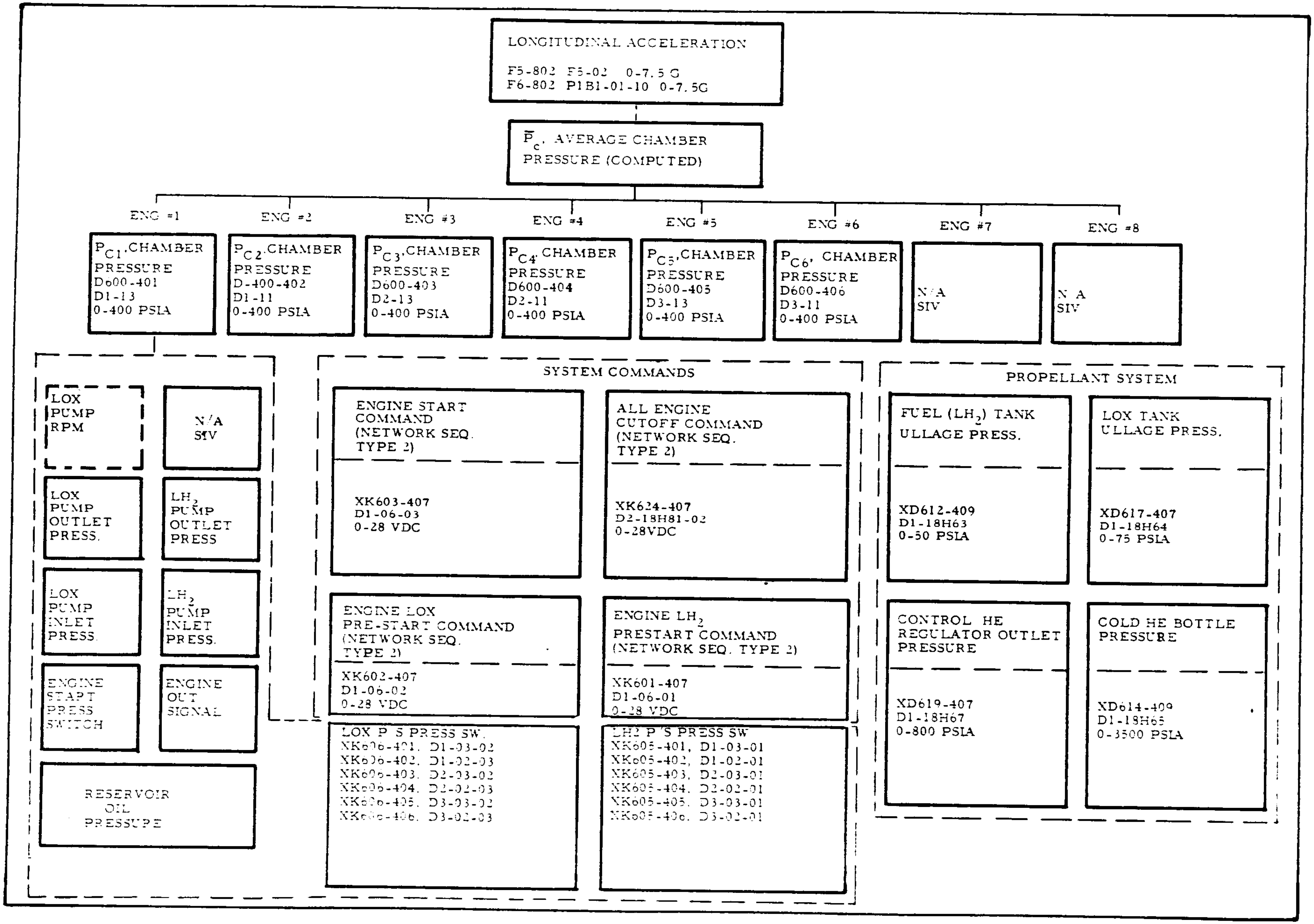

Figure E-4. Propulsion Measurements - SA-9, S-IV Stage

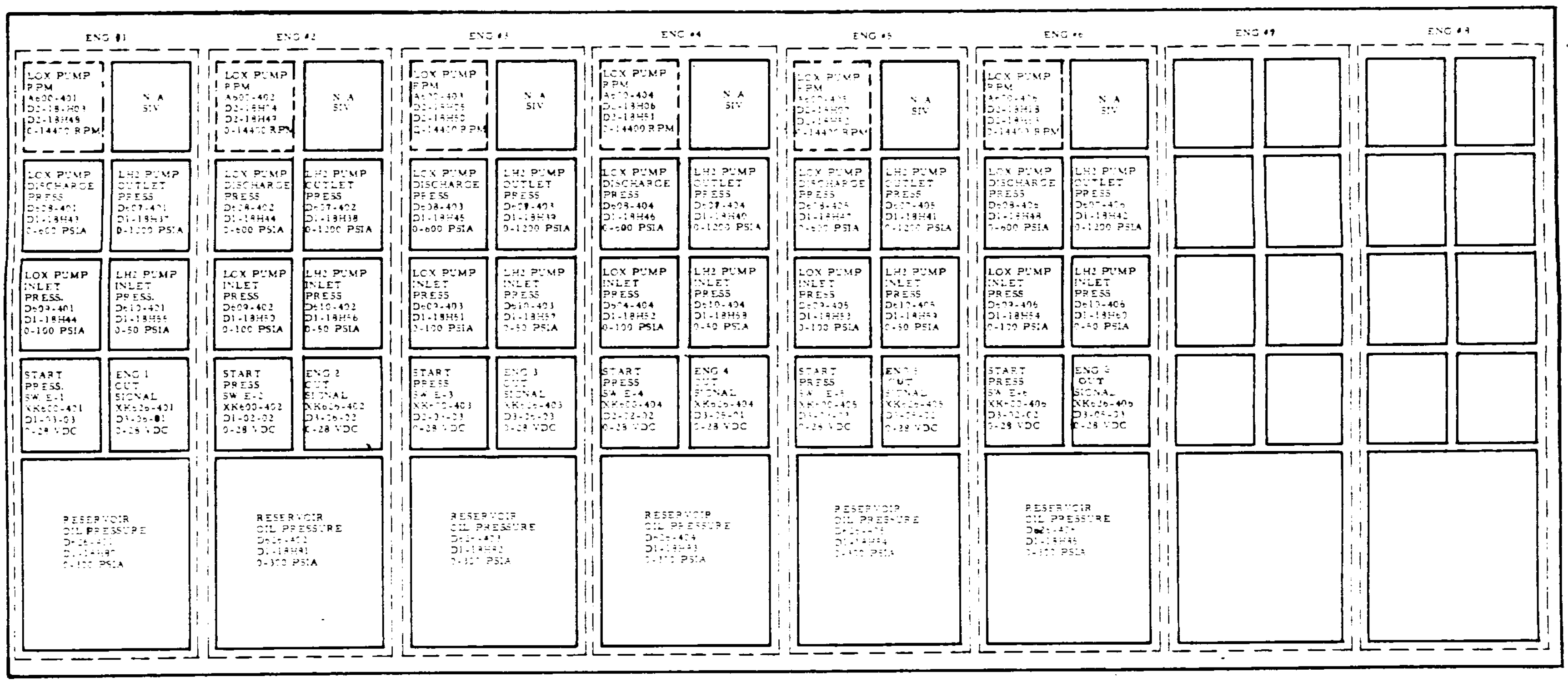

Figure E-5. Propulsion Measurements - SA-9, S-IV Stage, Engine Details

Table E-1. Propulsion Data List S-I

DATA	MEAS. NO.	*T/M CHANNEL
Individual Engine Chamber Pressures:	D1-1	P
	D1-2	F
	D1-3	F
	D1-4	F
	D1-5	P
	D1-6	F
	D1-7	F
	D1-8	F
Turbine RPM's.	A12-1	F
	A12-2	F
(Signals not suitable for real-time use.)	A12-3	F
	A12-4	F
	A12-5	F
	A12-6	F
	A12-7	F
	A12-8	F
Outboard Engine C/O Inboard Engine C/O	K3-12 K67-12	F F
Engine C/O Signals:	K4-1 Thru -8	P
LOX Pump Inlet Press:	D13-1 Thru -8	P
Turbine Inlet Press:	D14-1 Thru -8	P

(* Note: P = PCM, F = FM/FM)

Table E-1. Propulsion Data List S-I (Cont)

DATA		MEAS. NO.	*T/M CHANNEL
Fuel Pump Inlet Press:		D12-1 Thru-8	P
Bearing Gear Case Lub. Press:	Top:	D18-1 Thru-8	P
	Lower:	D20-1 Thru-8	
Turbine Exhaust Temp.: (Engines 2, 3, 4, and 5 only).		C242-3 Thru C245-3	P
Bearing Temperatures:	LOX Pump:	C1-1 Thru-8	P
	Intmdt. Shaft:	C2-1 Thru-8	P
	High Speed Pinion:	C3-1 Thru-8	P
		C4-1 Thru-8	P
	Turbine Shaft:	C5-1 Thru-8	P
		C6-1 Thru-8	P
LOX Level C/O	(On/Off)	K16-04, K15-02	P
Fuel Level C/O	(On/Off)	K17-F2, K18-F4	P
LOX Tank Pressure:	Center	D3-OC	F
	No. 1 Outboard	D3-01	F
	No. 2 Outboard	D3-02	P
Fuel Tank Pressure:	Tank No. 1	D2-F1	P
	Tank No. 2	D2-F3	F
Sphere Pressure	GN_2 In Fuel Tank No. 3	D139-11	P
	He Sphere Press.	D140-11	P
Temp. H.P. Spheres (GN_2)		C236-11, C237-11	P
Temp. Helium Spheres		C238-11,	P

Table E-2. Propulsion Data List S-IV

DATA	MEAS. NO.	*T/M CHANNEL
Individual Engine	D1-13	D
Chamber Pressures:	D1-11	D
	D2-13	D
	D2-11	D
	D3-13	D
	D3-11	D
LOX Pump RPM	A600-401	D
	A600-402	D
(Signals not suitable for real-time use.)	A600-403	D
	A600-404	D
	A600-405	D
	A600-406	D
Engine Start Command	XK603-407	D
Engine Out Signals Engines 1 Thru 6:	XK626-401 Thru-406	D
LOX Pump Inlet Press:	D609-401 Thru-406	D
LOX Pump Exit Press:	D608-401 Thru-406	D
LH_2 Pump Inlet Press:	D610-401 Thru-406	D
LH_2 Pump Outlet Press:	D607-401 Thru-406	D
Reservoir Oil Press:	D626-401 Thru-406	D

*Note: D = Digital Links

Table E-2. Propulsion Data List S-IV (Cont)

DATA		MEAS. NO.	*T/M CHANNEL
LOX Prestart Press. Switches:		XK606-401 Thru-406	D
LH_2 Prestart Press. Switches:		XK605-401 Thru-406	D
LOX Prestart Command		XK602-407	D
LH_2 Prestart Command		XK601-407	D
LOX Tank Press. Ullage		XD617-407	D
Fuel Press. LH_2 Ullage		XD612-409	D
Press. Sources:	He Regul. Outlet	XD619-407	D
	He Bottle Press.	XD614-409	D
Engine Start Press. Switches		XK600-401 Thru -406	D

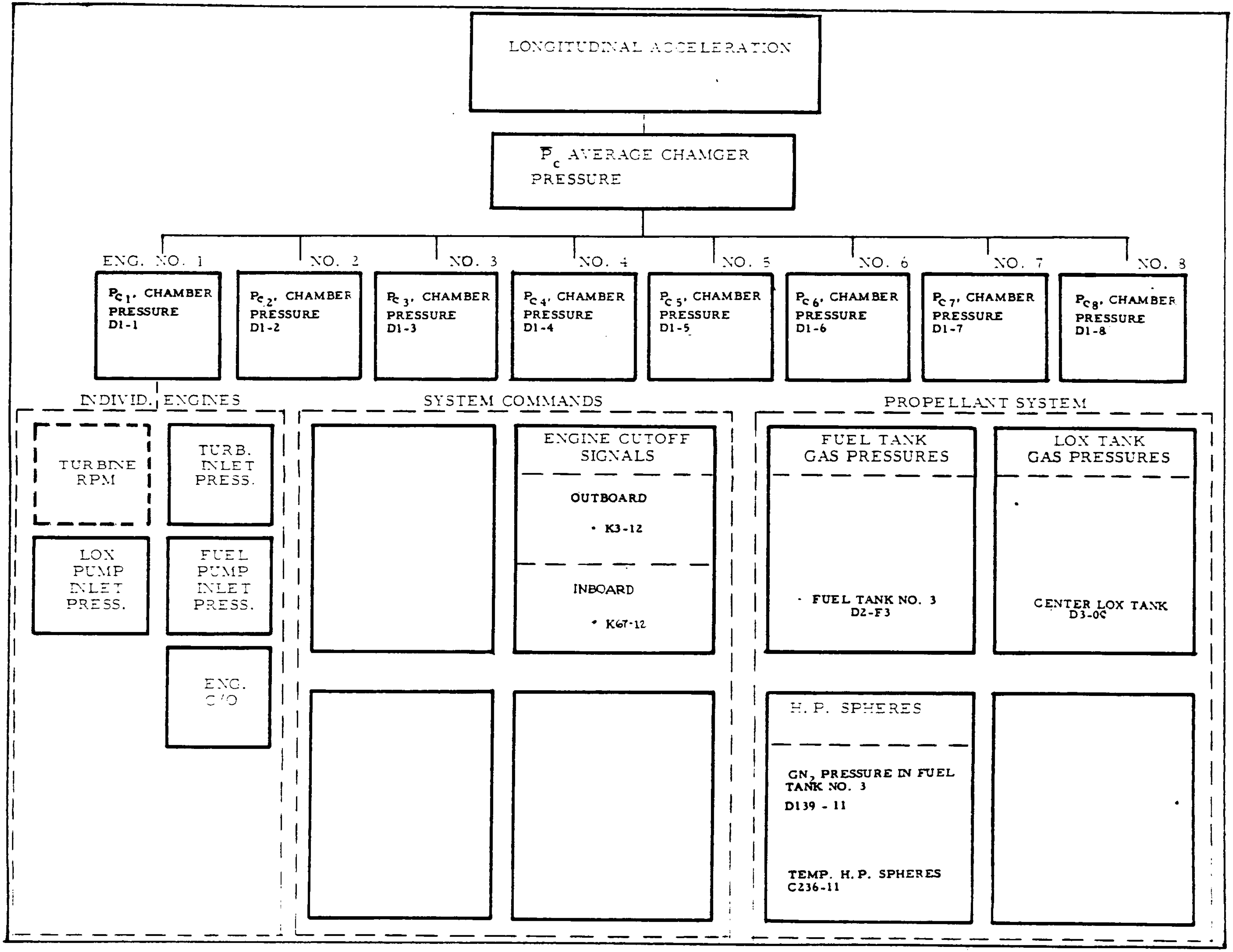

Figure E-6. Propulsion Measurements - Saturn IB, Stage S-IB

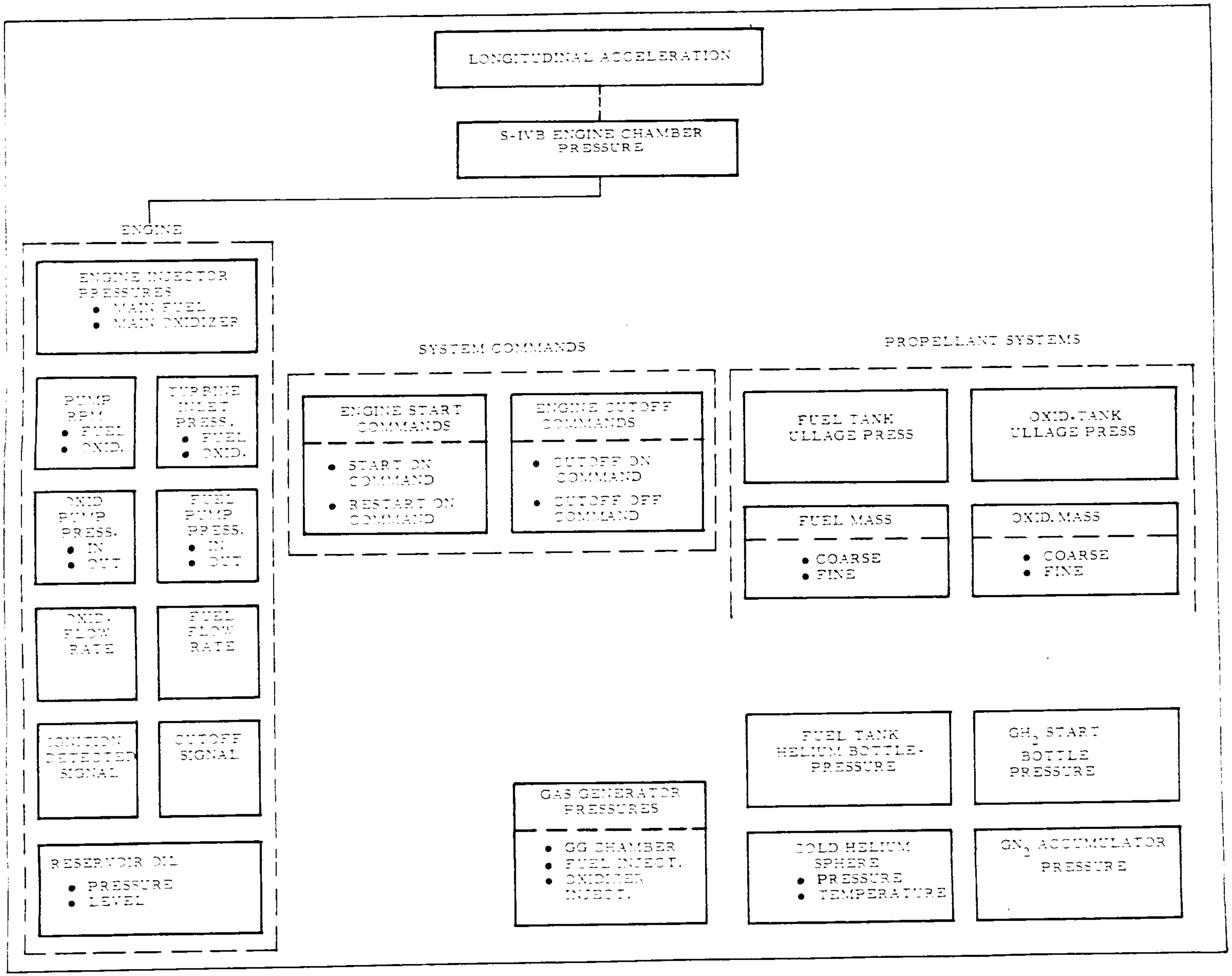

Figure E-7. Propulsion Measurements - Saturn IB, Stage S-IVB

Table E-3. Propulsion Data List S-IB

Data	T/M *Channel	Measurement No.	Remarks
Engine Chamber Pressures	P	D1-1 thru D1-8	
Turbine RPM	F	T12-1 thru T12-8	Signals not suitable for real.-time use.
IECO OECO	F F	K67-12 K3-12	
Engine Cutoff's	F	K4-1 thru K4-8	
Fuel Pump Inlet Pressure	F	D12-1 thru D12-4	4 only
Oxidizer Pump Inlet Pressure	F	D13-1 thru D13-4	4 only
Turbine Inlet Pressure	F	D14-1 thru D14-8	
Fuel Tank Gas Pressure	F	D2-F3	
LOX Tank Gas Pressure	F	D3-OC	
Gas Pressure H.P. Spheres	F	D139-11	
Temperatures LOX Pump Bearings	P	C1-1 thru C1-8	
Temp. H.P. Spheres	F	C236-11	
LOX Level C/O	F	K15-02, K16-04	On/Off
Fuel Level C/O	F	K17-F2, K18-F4	On/Off

* Note: P=PCM, F=FM/FM)

Table E-4. Propulsion Data List S-IVB

Data	Channel	Measurement No.	Remarks
Pressure-Thrust Chamber	PAM/FM	D001-401	401 = Engine, J2
Pressure-Fuel Pump Inlet	PAM/FM	D002-401	
Pressure-Fuel Pump Discharge	PAM/FM SUBCOM	D008-401	
Pressure-Oxidizer Pump Inlet	PAM/FM	D003-401	
Pressure-Oxidizer Pump Discharge	PAM/FM SUBCOM	D009-401	
Pressure-Fuel, Turbine Inlet	PAM/FM	D006-401	
Pressure-Oxidizer, Turbine Inlet	PAM/FM	D007-401	
Pressure-Main Fuel Inject	PAM/FM	D004-401	
Pressure-Main Oxidizer Inject	PAM/FM	D005-401	
Pressure-GG Chamber	PAM/FM	D010-401	
Pressure-GG Fuel Inject	PAM/FM	D011-401	
Pressure-GG Oxidizer Inject	PAM/FM	D012-401	
Pressure-Cold He Sphere	PAM/FM SUBCOM	D016-408	
Pressure-GH_2 Start Bottle	PAM/FM SUBCOM	D017-408	
Pressure-Fuel Tank He Bottle	PAM/FM SUBCOM	D020-403	
Temp. Cold He Sphere	PAM/FM SUBCOM	C005-408	

Table E-4. Propulsion Data List S-IVB (Cont)

Data	Channel	Measurement No.	Remarks
Pressure-GN_2 Accumulator	PAM/FM SUBCOM	D043-403	
Flow Rate-Fuel Flow Rate-Oxidizer	PAM/FM SUBCOM	F002-401 F001-401	
Event-Ignition Detected	PAM/FM	K008-401	
Event-Cutoff Signal	PAM/FM	K013-401	
Event-Engine Start ON Command	PAM/FM	K021-404	
Event-Engine Restart ON Command	PAM/FM	K022-404	
Event-Engine Cutoff ON Command	PAM/FM	K023-404	
Event-Engine Cutoff OFF Command	PAM/FM SUBCOM	K024-404	
Speed-Oxidizer Pump (RPM)	PAM/FM	T001-401	
Speed-Fuel Pump (RPM)	PAM/FM	T002-402	
LH_2 Coarse Mass LH_2 Fine Mass LO_2 Coarse Mass LO_2 Fine Mass	PAM/FM PAM/FM PAM/FM PAM/FM	N001-411 N002-411 N003-411 N004-411	
Reservoir Oil Pressure	PAM/FM SUBCOM	D042-403	
Reservoir Oil Temp.	PAM/FM SUBCOM	C051-403	
Fuel Tank Ullage Pressure	PAM/FM SUBCOM	D021-410	
Oxidizer Tank Ullage Pressure	PAM/FM SUBCOM	D022-406	

APPENDIX F

Electrical Systems

Following the concepts outlined in Section 3. 5. 7, this section contains detailed measurements, schematics and lists of telemetered parameters for Saturn I (SA-9) and Saturn IB (SA-201).

Figure F-1 is a schematic presentation of the Electrical Systems of the S-I and S-IV stages showing the type and location of measurements that correspond to Figure 3-15. Similarly, Figure F-2 is the schematic presentation of the IU Electrical System. The general configuration of all three schematic diagrams are basically the same, with the major differences being

- the number of items (e. g. batteries), and
- the distribution trees of power supplies.

Table F-1 lists the SA-9 Electrical Systems measurements which correspond to Figure F-1. Table F-2 is the equivalent list for the Saturn IB, SA-201 vehicle.

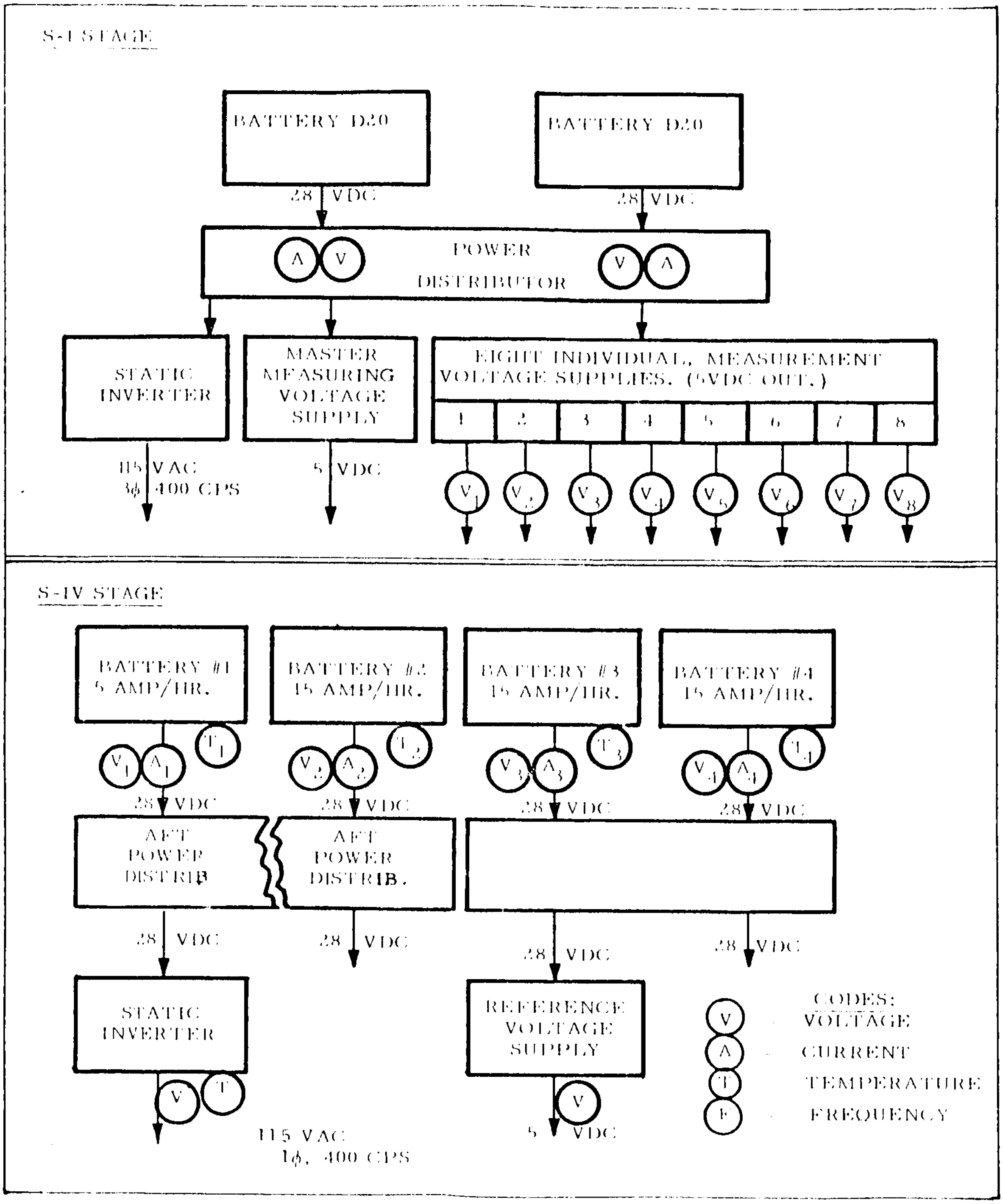

Figure F-1. Saturn I Electrical Systems, Simplified Measurement Schematics. S-I Stage and S-IV Stage

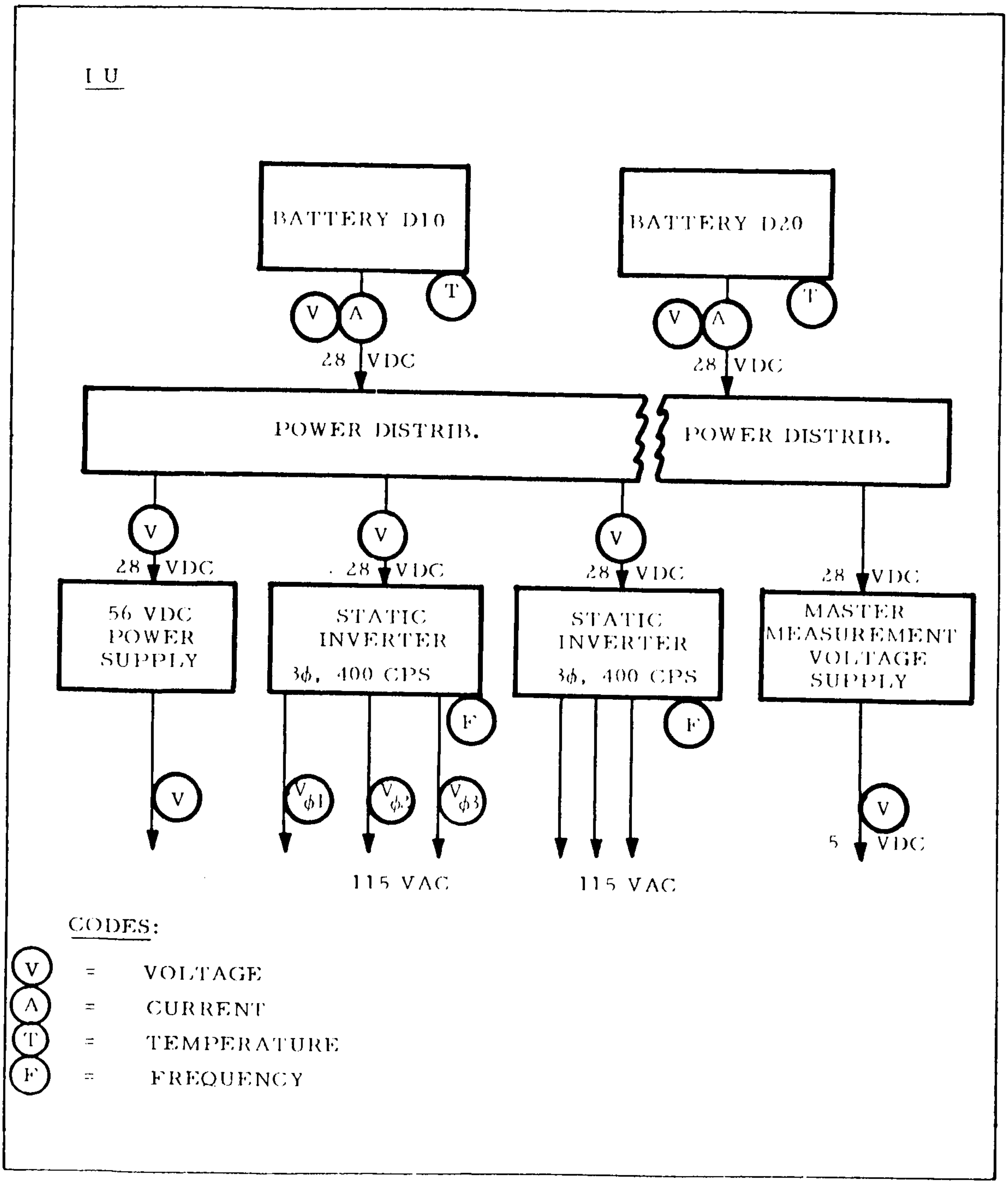

Figure F-2. Saturn I Electrical Systems, Simplified Measurement Schematic - IU

Table F-1. Saturn I - Vehicle SA-9
Electrical Data

NO.	DATA	MEAS. NO.	REMARKS
1.	D21 Bus Voltage	M16-12	S-I STAGE
2.	D11 Bus Voltage	M17-12	
3-10	Measuring Voltages	M1-9 thru M8-9.	
11.	D10, Battery Current	M18-12	
12	D20, Battery Current	M19-12	
1.	#1 Battery Voltage	XM608-407	S-IV STAGE
2.	#2 Battery Voltage	XM609-407	
3.	TM Battery Voltage	XM627-407	
4.	TM Battery Voltage	XM628-407	
5.	TM Battery Voltage	XM629-407	
6.	Battery Current 0-7 amps	M631-407	
7.	Battery Current 0-27 amps	M632-407	
8.	Battery Current 0-110 amps	M633-407	
9.	Battery Current 0-27 amps	M638-407	
10.	Inverter Voltage	XM610-407	
11. to 17	Reference Voltages, (Hi, Low, Absolute, etc.)	M600-410 thru M606-410	
18. thru 22.	Reference Voltages	M622-410 thru M626-410	
23.	Battery #1 Temp.	C655-407	
24.	Battery #2 Temp.	C656-407	
25.	Battery, Inst. #1 Temp.	C685-407	
26.	Battery, Inst. #2 Temp.	C708-407	
27.	Inverter Temp.	C657-407	
1-3	Bus Voltages	M14-802 M16-802 M17-802	IU
4&5	Battery Currents	M18-802 M19-802	
6, 7&8	Inverter Volts, 3 Phases	M46-802 thru M48-802	
9&10	Inverter Frequencies	M9-802& M35-802	
11	Measuring Voltage	M36-802	
12	Battery #1 Temp.	C315-802	
13	Battery #2 Temp.	C316-802	
14	56 VDC Supply	M61-802	

Table F-2. Saturn IB - Vehicle 201
Electrical Data

NO.	DATA	MEAS. NO.	REMARKS
1	D10 Battery Voltage	M501-12	S-IB STAGE
2	D20 Battery Voltage	M500-12	
3	D11 Bus Voltage	M17-12	
4	D21 Bus Voltage	M16-12	
5	D10 Battery Current	M18-12	
6	D20 Battery Current	M19-12	
7	Measuring Voltage #1	M1-9	
8	Measuring Voltage #2	M2-9	
1	Main Bus Battery Voltage	M002-411	S-IVB STAGE
2	Peaking Bus Bat. Voltage	M003-404	
3	Static Inverter/Converter	M001-411	
4	Static Inverter/Converter 5 VDC	M004-404	
5	Main Bus Battery Current	M008-411	
6	Peaking Bus Battery Current	M009-404	
1	6D11 Bus Voltage	M12-601	S-IU-201
2	6D21 Bus Voltage	M13-601	
3	6D31 Bus Voltage	M14-601	
4	6D41 Bus Voltage	M19-601	
5	250 VA Inverter Voltage Phase AB	M6-603	
6	250 VA Inverter Voltage Phase BC	M7-603	
7	250 VA Inverter Voltage Phase CA	M8-603	
8	6D10 Battery Current	M16-601	
9	6D20 Battery Current	M17-601	
10	6D30 Battery Current	M18-601	
11	6D40 Battery Current	M20-601	
12	Measuring Voltage, 5VDC	M1-602	
13	56 VDC Supply Voltage	M3-601	

APPENDIX G

DISPLAYS

In Section 5.2, the use of double plotting on X-Y recorders is discussed. Examples of this type of plot were generated by MSFC to investigate their applicability. These examples, shown in Figures G-1 to G-14 are plotted using predicted and/or actual SA-7 data (primarily S-IV data). Types of plots shown are:

- Two measured parameters alternating, vs time.
  - 1 second alternation.
  - 10 second alternation.
- Measured parameter alternating with its predicted value, vs time.
  - 1 second alternation.

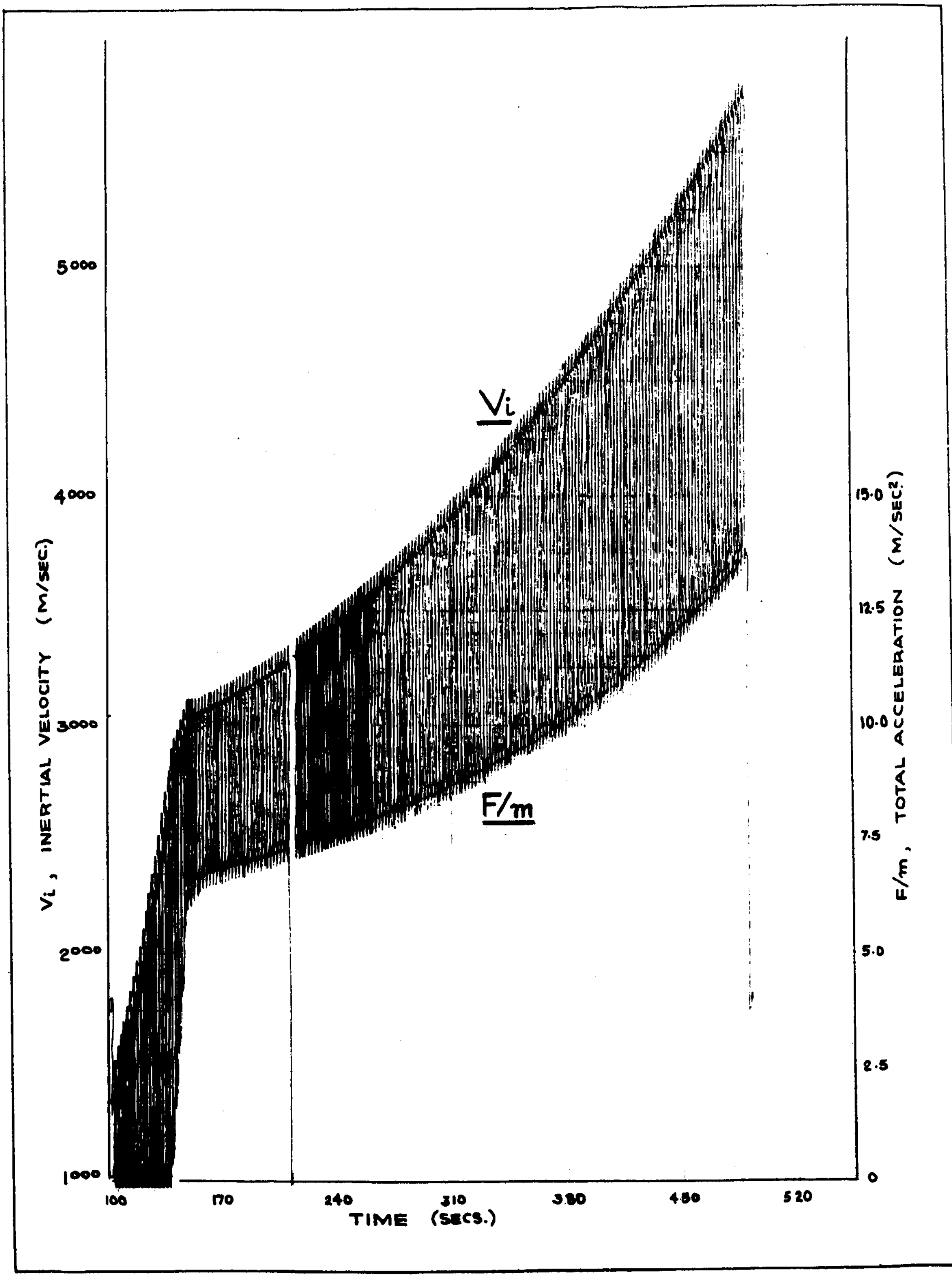

Figure G-1. V_i and F/m Alternating (Δt = 1.0 secs. SA-7 Data)

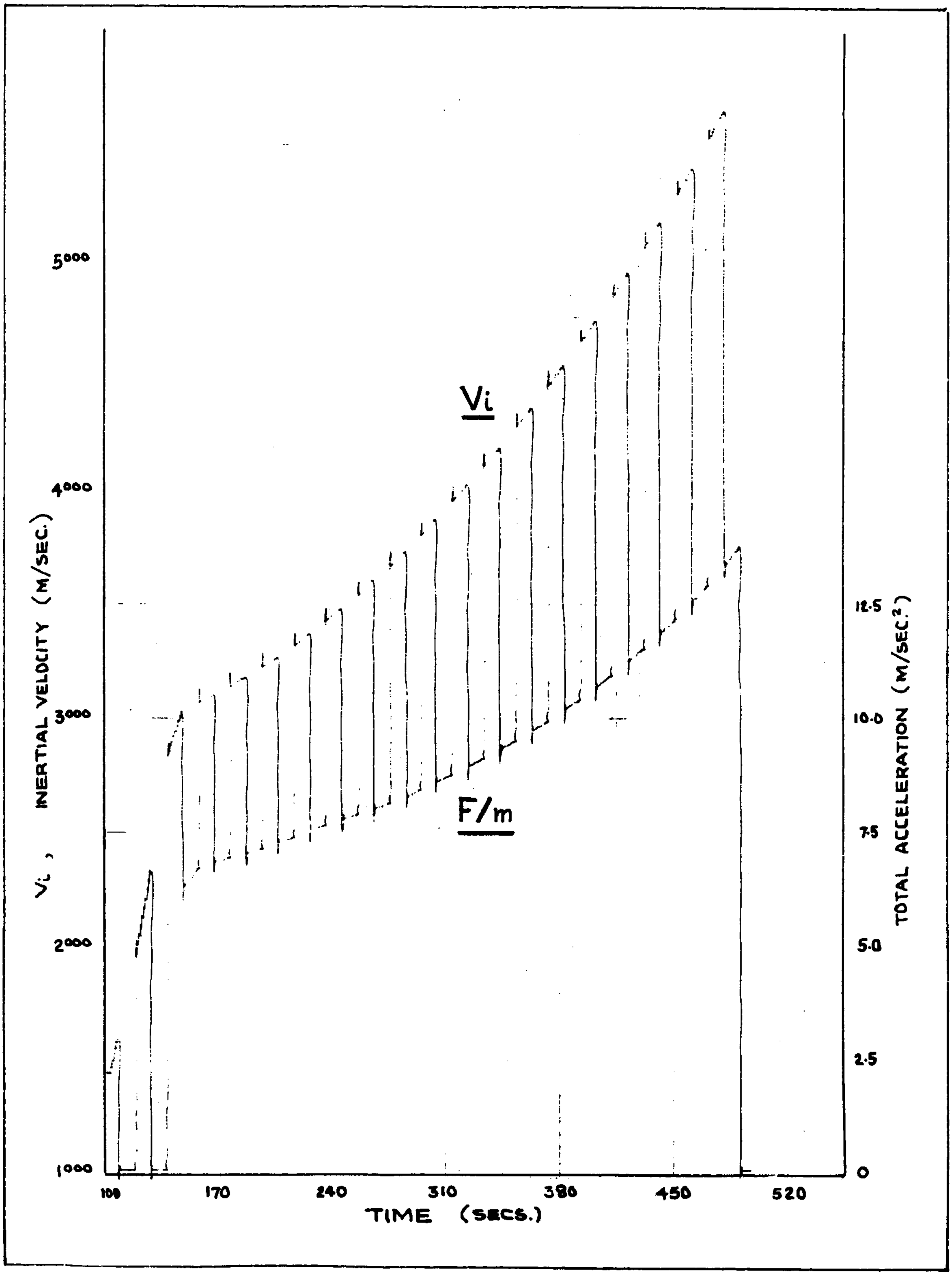

Figure G-2. V_i and F/m Alternating (Δt = 10 secs. SA-7 Data)

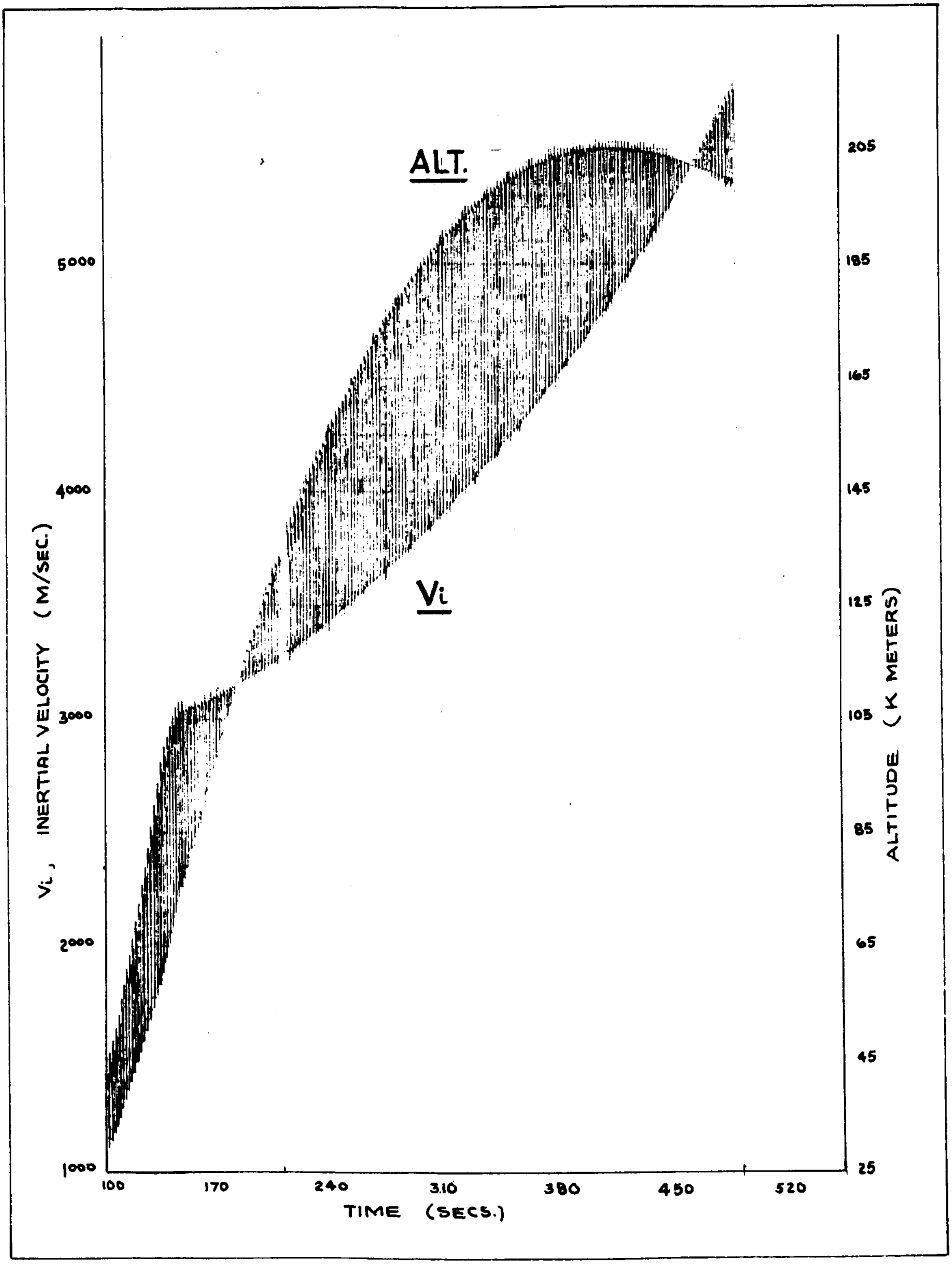

Figure G-3. Altitude and V_i Alternating (Δt = 1.0 secs. SA-7 Data)

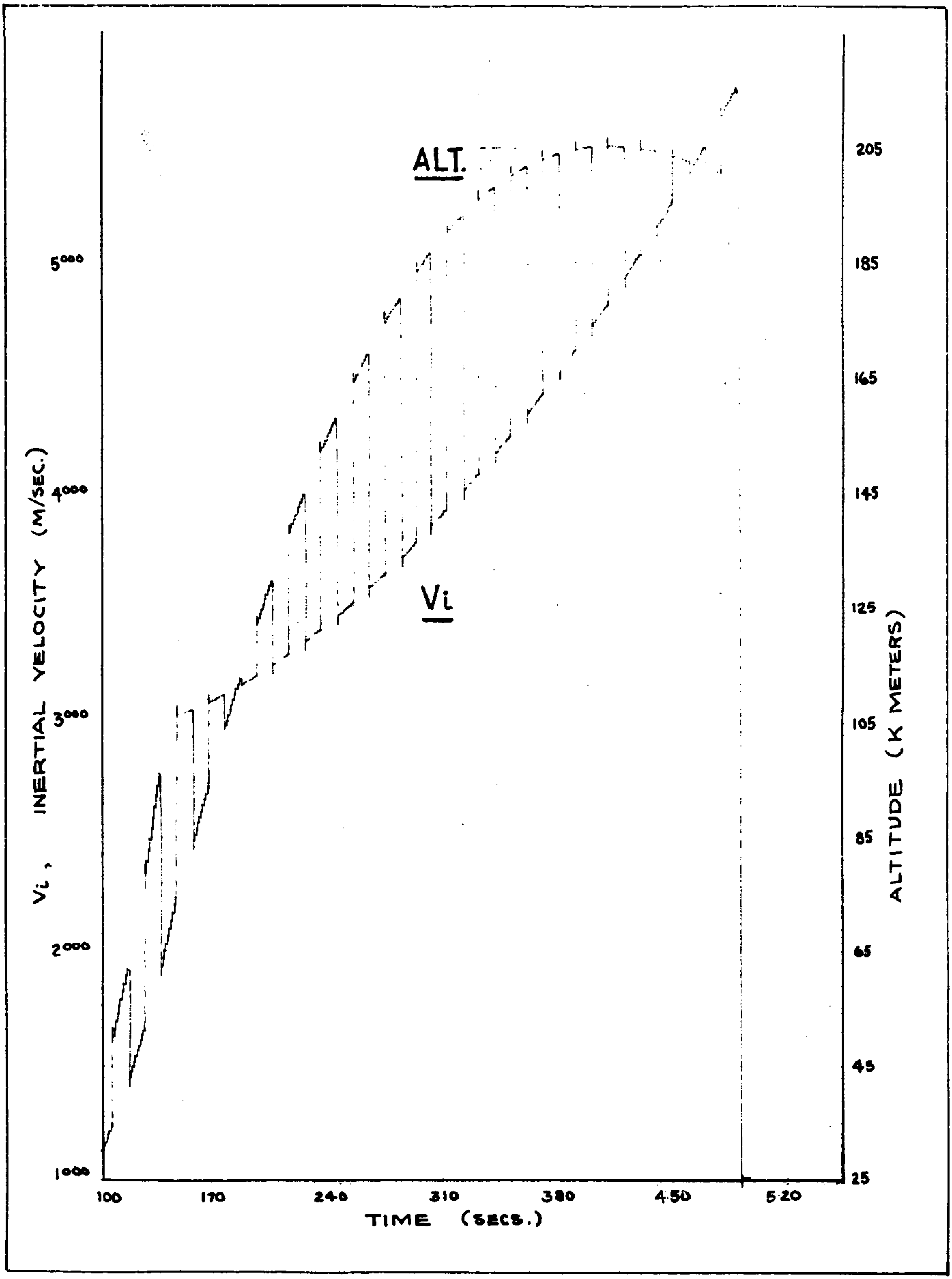

Figure G-4. Altitude and V_i Alternating (Δt = 10 secs. SA-7 Data)

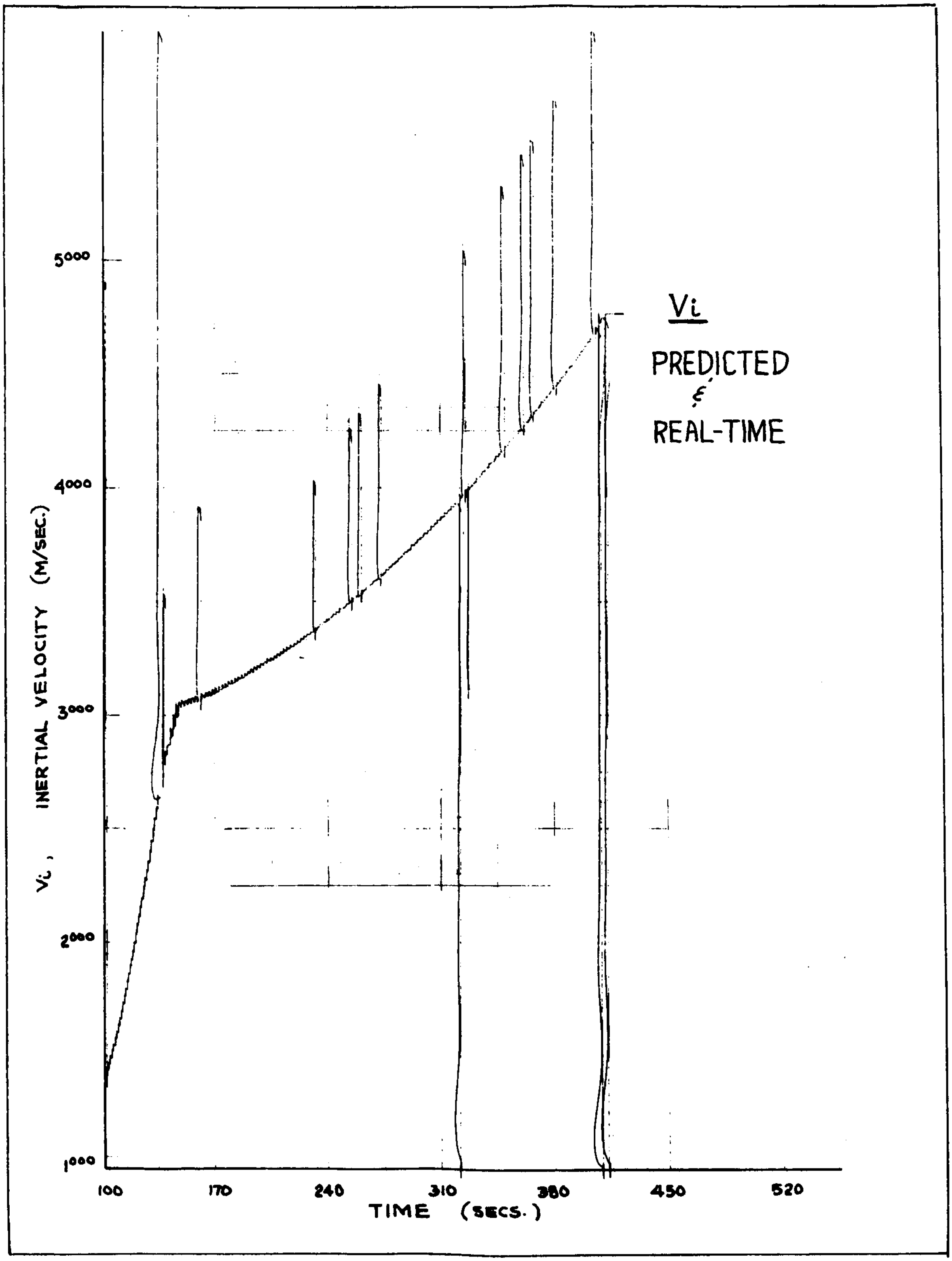

Figure G-5. V_i : Actual Alternating with Predict (SA-7 Data)

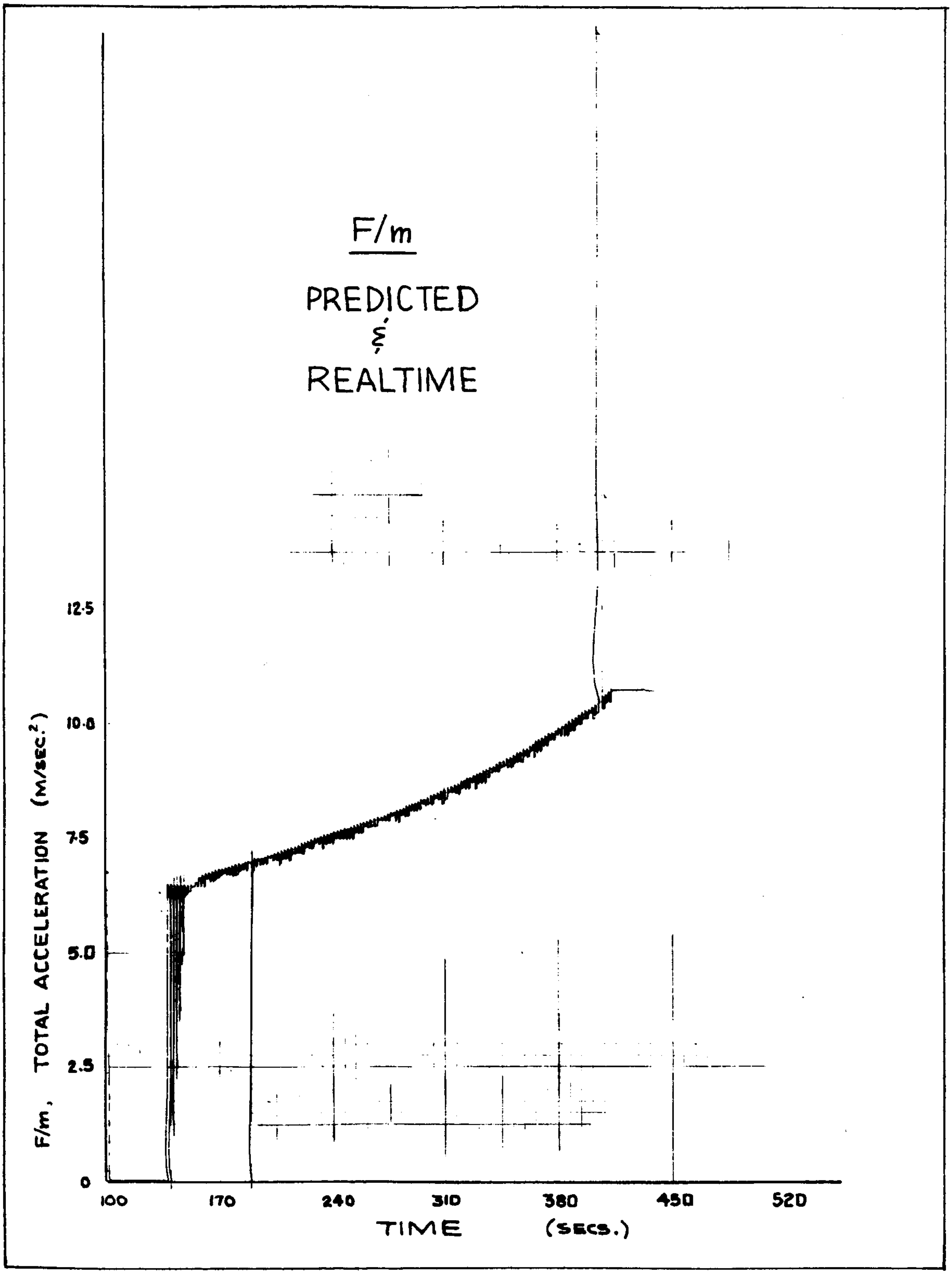

Figure G-6. F/m: Actual Alternating with Predict (SA-7 Data)

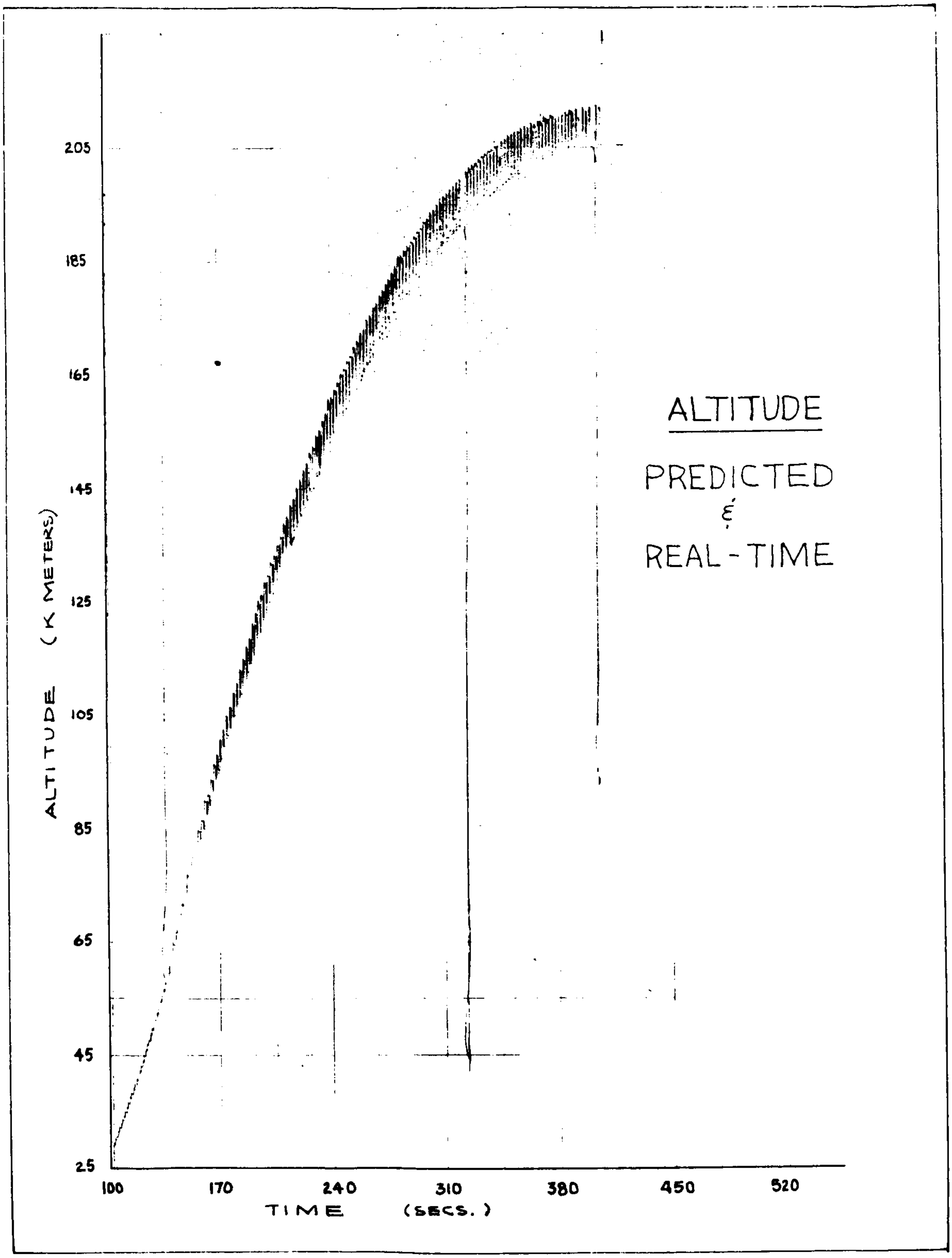

Figure G-7. Altitude: Actual Alternating with Predicted (SA-7 Data)

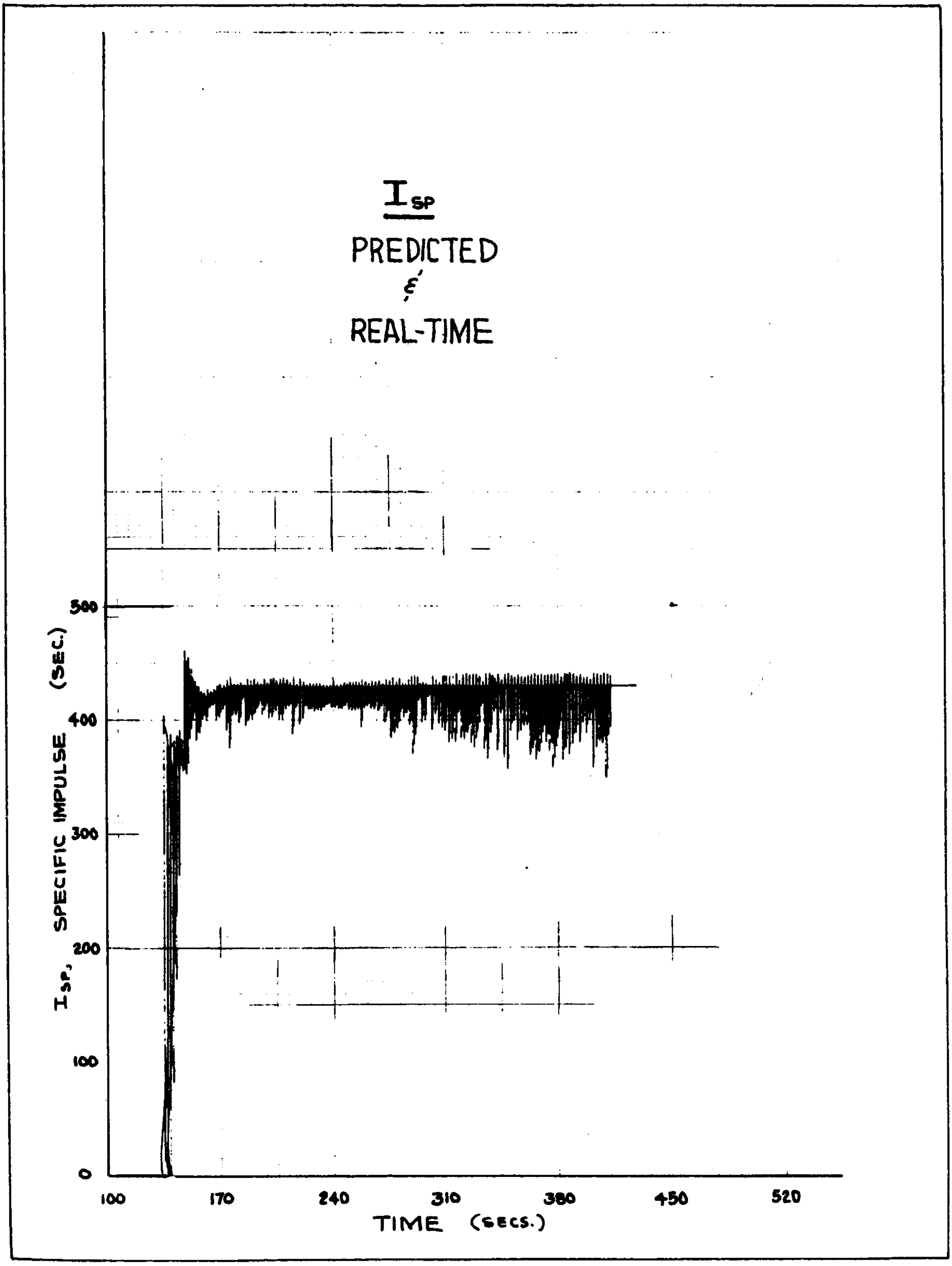

Figure G-8. I_{sp}: Actual Alternating with Predict (SA-7 Data)

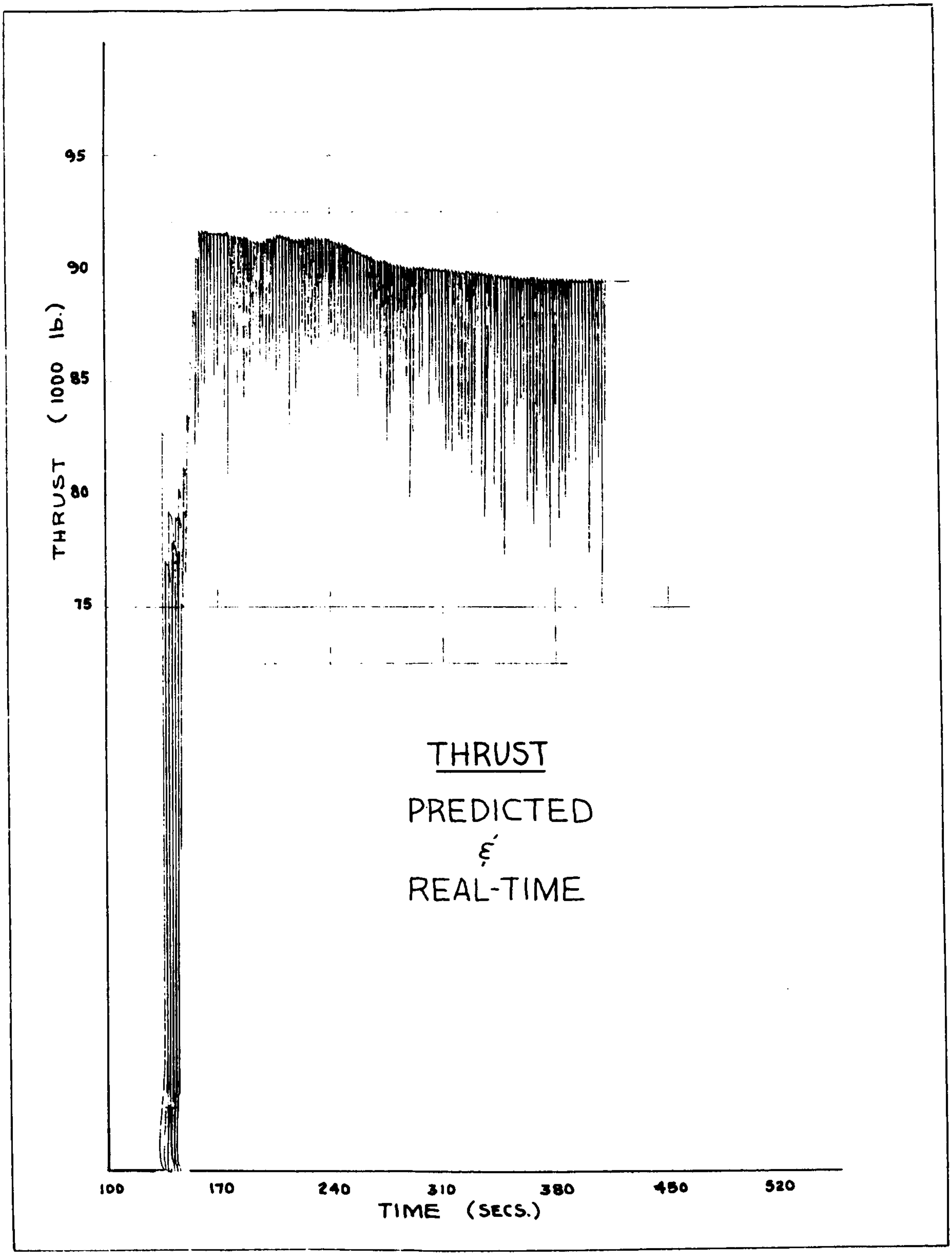

Figure G-9. Thrust: Actual Alternating with Predict (SA-7 Data)

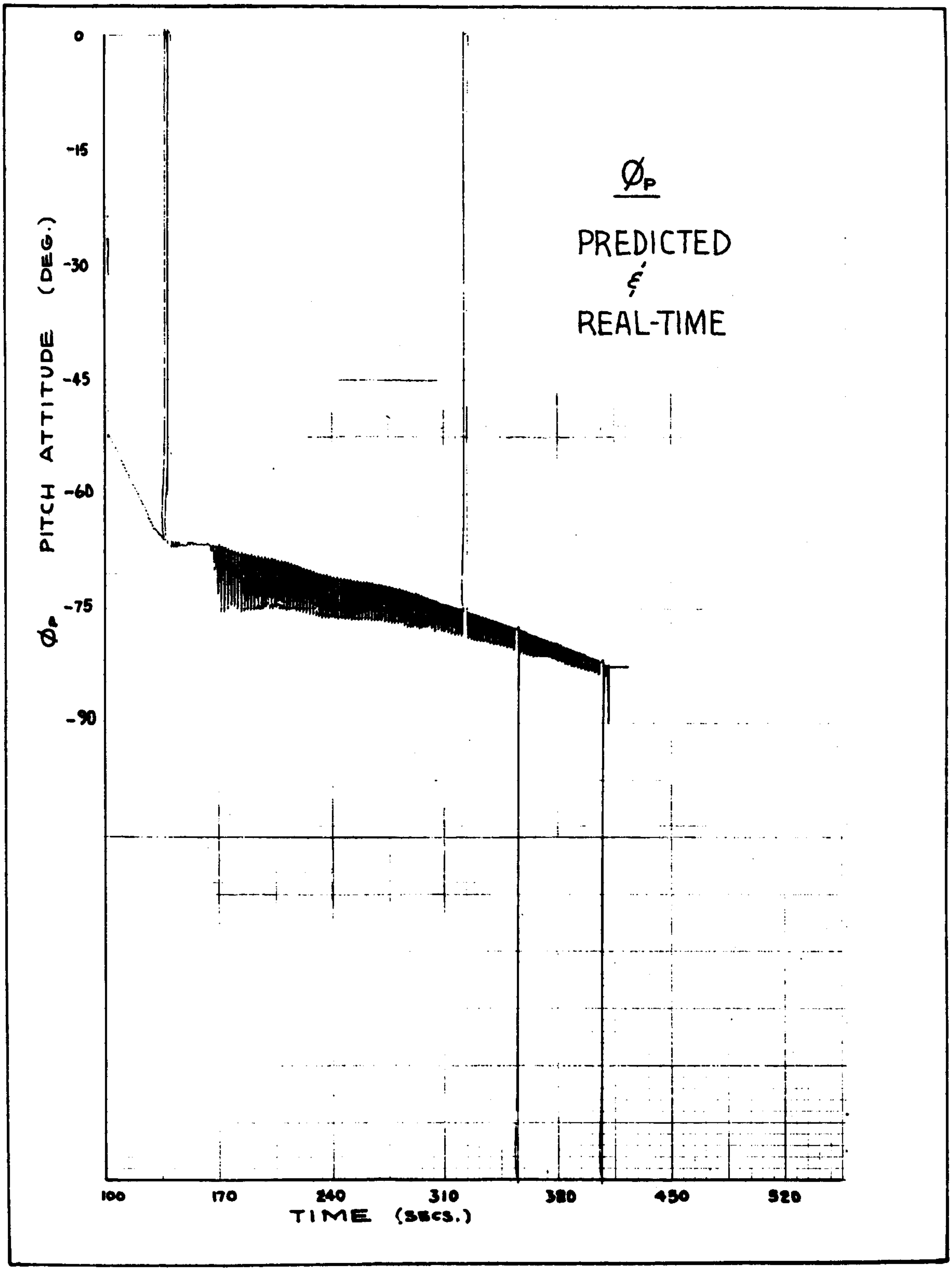

Figure G-10. ϕ_p: Actual Alternating with Predict (SA-7 Data)

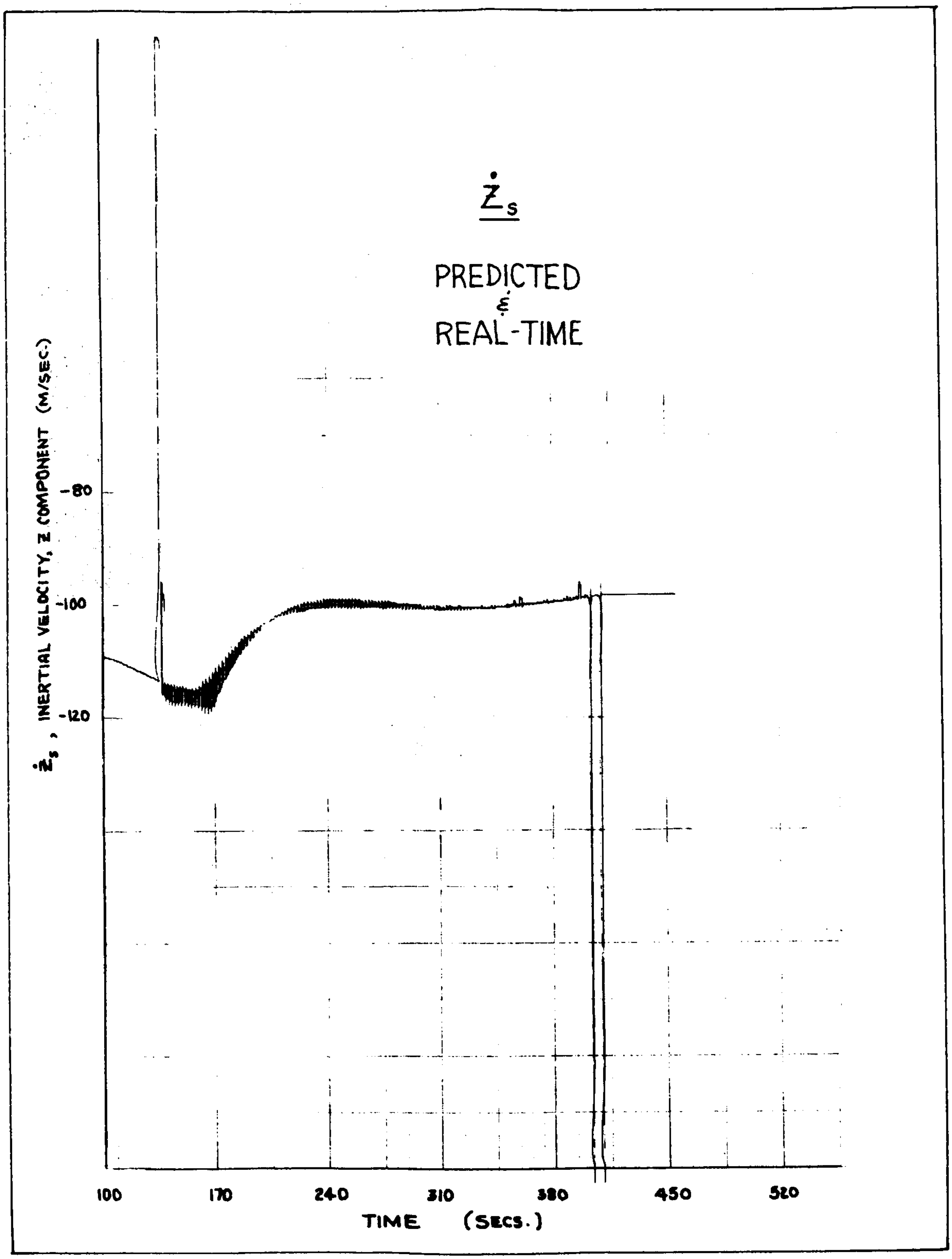

Figure G-11. $\dot{Z}_s$: Actual Alternating with Predict (SA-7 Data)

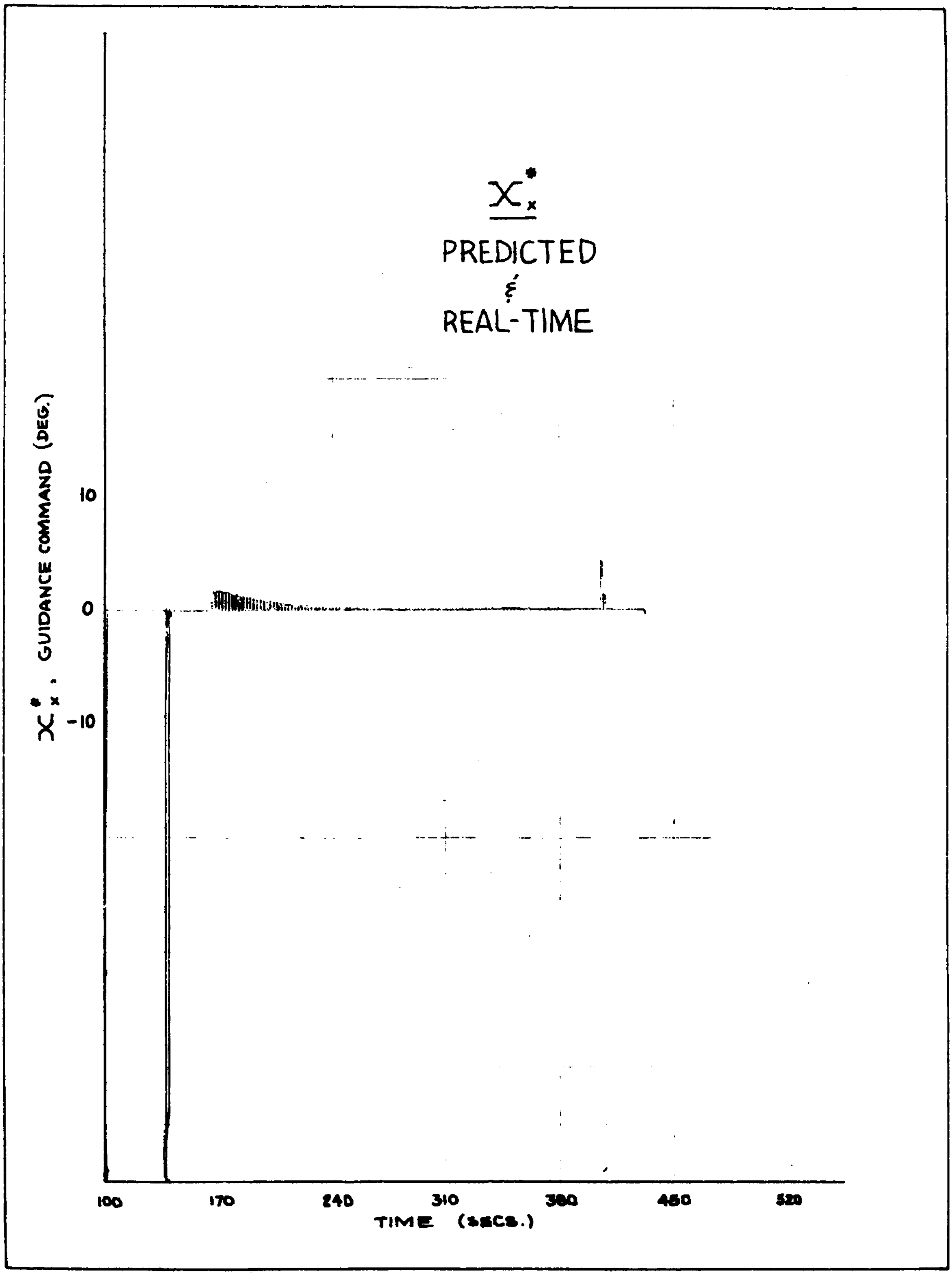

Figure G-12. χ_x^*: Actual Alternating with Predict (SA-7 Data)

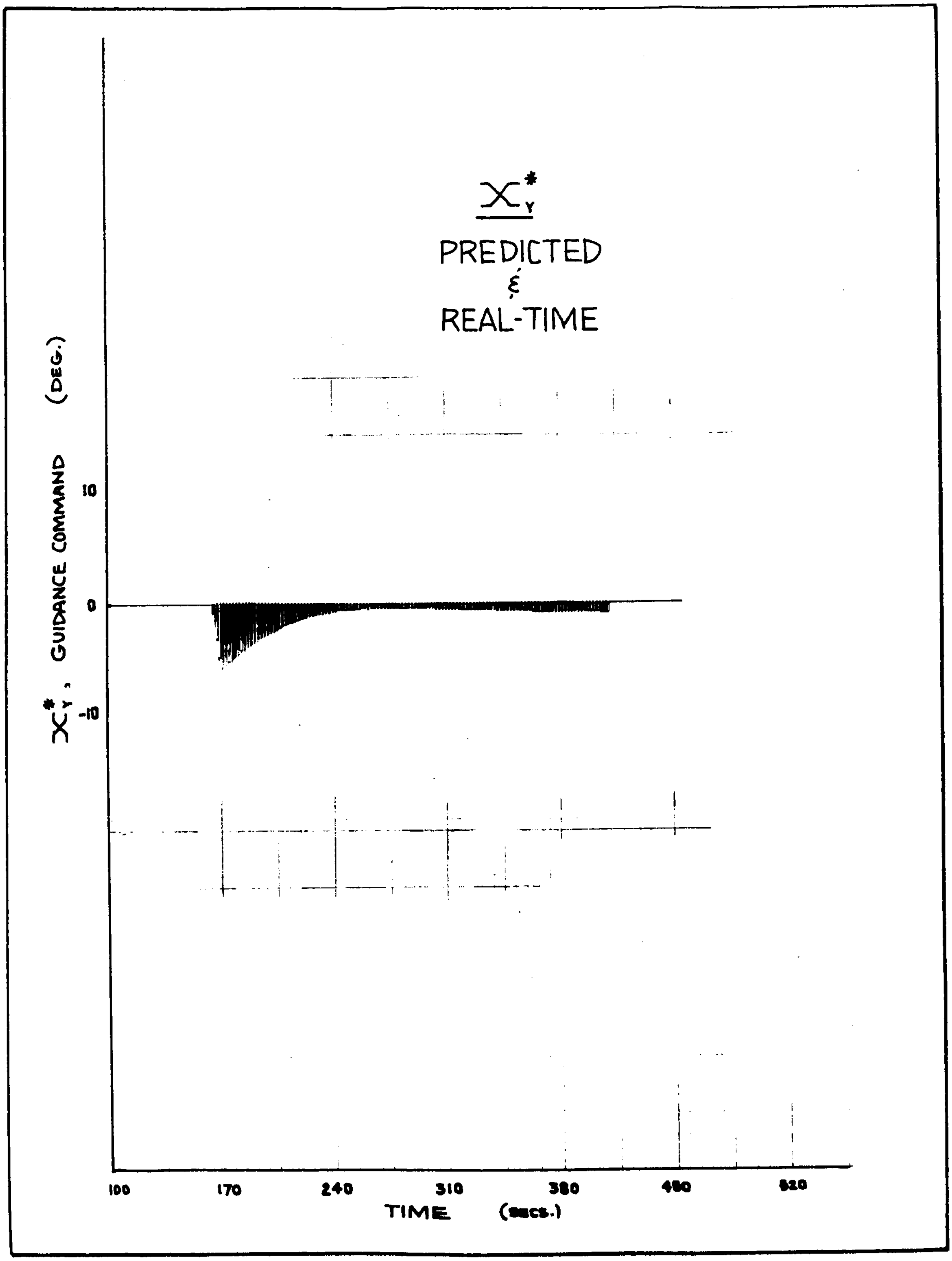

Figure G-13. χ_y^* : Actual Alternating with Predict (SA-7 Data)

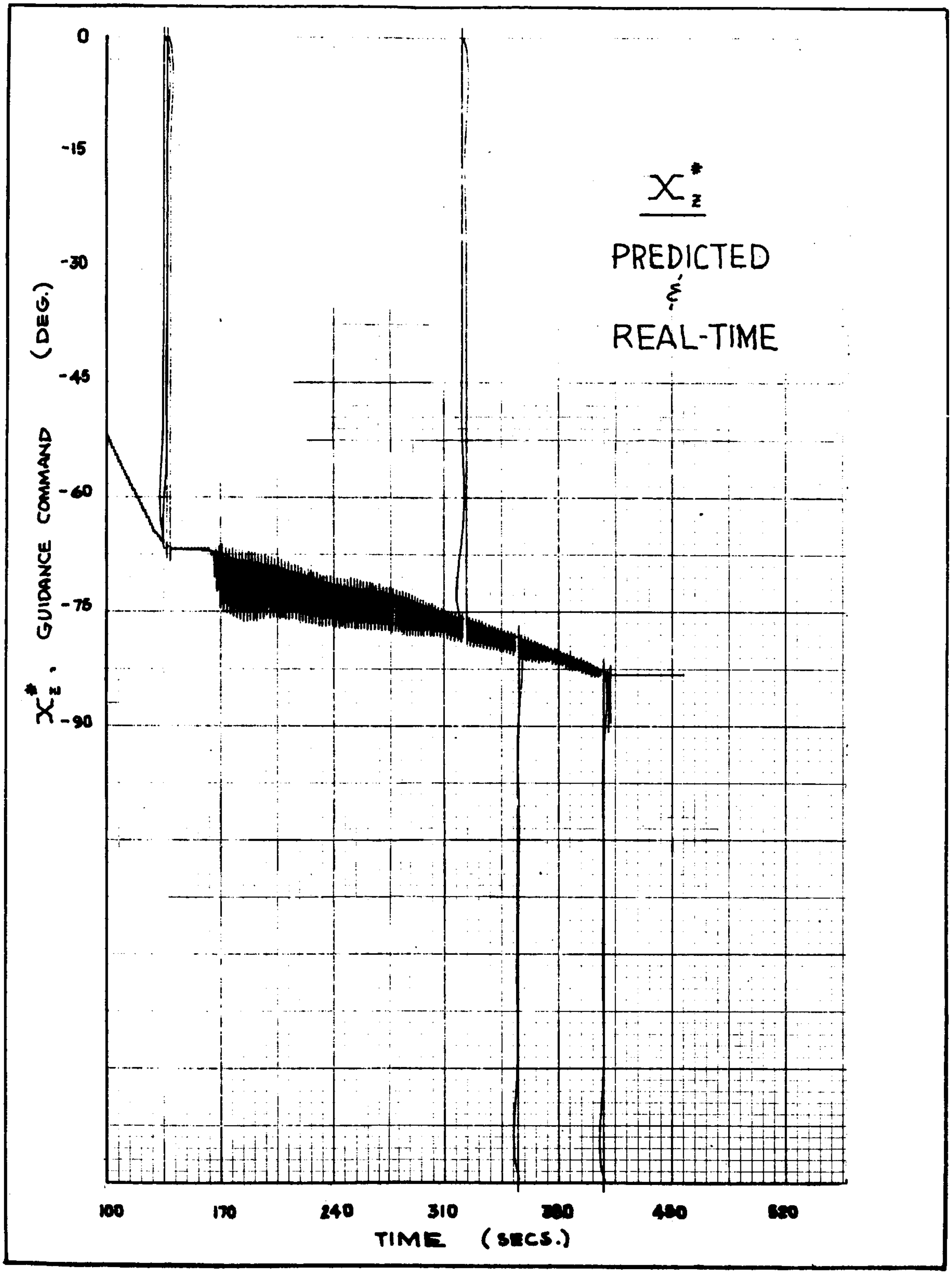

Figure G-14. χ_z^* : Actual Alternating with Predict (SA-7 Data)