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TITLE - Apollo/Saturn V ESE Interlock System

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FILING CASE NO(S) - 330

DATE - November 23, 1966

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ABSTRACT

This memorandum examines the Apollo/Saturn V ESE interlock system with the purpose of comparing it with the published design philosophy and criteria.

It is concluded that, in general, the Apollo/Saturn V interlock system conforms to the current design philosophy and criteria. The interlock system is being actively reviewed in detail by KSC, MSFC and contractors. Many changes to improve the system have already been made and it is expected that many further improvements will come out of the review effort.

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SUBJECT: Apollo/Saturn V
Interlock System - Case 330

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FROM: C. H. Eley III
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[redacted]

TECHNICAL MEMORANDUM

1. INTRODUCTION

The Saturn V ESE interlocks are system elements utilized to provide assurance that each step in the countdown sequence will proceed if, and only if, all essential readiness criteria are met. The Saturn V interlock system, in addition to providing a safeguarding through the interlocks, performs control functions necessary for launch.

Interlocks considered in this paper fall into the following general categories:

a. Interlocks employed from just prior to the start of the Terminal Countdown Sequencer up to issuance of the Ignition Command which will stop the countdown sequence if readiness criteria are not met.

b. Interlocks employed from issuance of the Ignition Command up to Liftoff which will initiate engine shutdown if essential criteria are not met.

Category (a) above includes two major preparatory interlock chains--the first required to start the Terminal Countdown Sequencer (TCS) and the second for issuance of the Ignition Command. Also included in category (a) are a number of parameters which can cause an "immediate" cutoff any time they are lost after start of the TCS. Category (b) above includes one major interlock chain required for issuance of Commit. Almost all interlocks in category (b) are of the "immediate" cutoff type.

The Saturn V Electrical Support Equipment (ESE) schematics, as existing in the fall of 1965, were given by Reference 1. That portion of Reference 1 pertaining to the Saturn V ESE interlocks was extracted and published in schematic form as Reference 2. Saturn V logic diagrams, including the ESE interlock system, are currently available as Reference 3. A further analysis of the Saturn V interlocks was given by Reference 4.

[redacted]

A statement of interlock design philosophy and criteria, dated May 16, 1966, was promulgated by the Apollo Program Director on May 20, 1966. A copy of that statement is included as Appendix A.

The purpose of this paper is to compare the current ESE interlock system with the design philosophy and criteria (Appendix A). To accomplish this comparison, the following steps were undertaken:

a. Prepare a set of Saturn V ESE interlock logic diagrams based on Reference 1 (prior to publication of Reference 3).

b. Compare the diagrams of (a) above to the present interlock configuration to determine the changes that have occurred in the last year.

c. Examine the present interlock system for conformance with the design philosophy and criteria, with particular attention to the system changes.

2. INTERLOCK SYSTEM

The Preparation Complete and Ready for Ignition master interlock chains, which are prerequisites for start of the Terminal Countdown Sequencer (TCS) and Ignition Command (T-187 and T-8.9 seconds respectively), are included as Figure 1 for information. Figure 1 also shows the prerequisites for retraction of the S-IC forward service arm at T-20 seconds.

Nominally, all operations and sequencing from the start of the TCS until launch are automatic and controlled by the TCS. Because of the many recent changes in the TCS outputs, a listing of the current TCS timed outputs is included as Appendix B. Of particular importance is the change of Ignition Command from T-7 to T-8.9 seconds and the addition of S-IC intertank and forward service arm retraction at T-40 and T-20 seconds respectively.

Cutoff parameters during the terminal countdown sequence are of prime importance. Information on these parameters and the times during which they are active has been assembled and a summary is included as Figure 2. The requirements for Commit are included in Figure 2.

3. COMMENTS

a. General

The interlock design criteria referenced in Section 1 (Appendix A) was broken down into criteria for (1) Interlock Selection and (2) Design Implementation. For the purposes of this discussion, criteria under those headings are regrouped as follows:

(1) Group 1

(a) A measured parameter shall be the best available indication of the required condition and its limits substantiated by adequate engineering and test data.

(b) Interlocks after Ignition Command shall be designed as Mission Critical Hardware.

(c) Sensing systems and interlock circuitry shall have a reliability equal to or better than the system being sensed.

(2) Group 2

(a) Selected interlocks shall be a prerequisite for proceeding to launch and used only when necessary.

(b) After Ignition Command, cutoff requirements shall be limited to those failures which penalize crew safety, lead to an abort, or prevent accomplishment of primary mission objectives.

(c) After Firing Command, the computer discrete outputs shall be inhibited.

(d) A by-pass capability for the interlock chains shall be provided in the LCC.

(e) All parameters in the interlock system shall be available for independent verification in the LCC.

b. Comments on Group 1

Group 1 criteria (above) are concerned with the details of hardware design. Commenting on such details is beyond the scope of this paper. However, Reference 2 had the following comments on the design details:

"Conclusions - This study was undertaken with the object of reviewing the interlock circuitry in order to determine if the circuitry would function as intended and if changes in the circuitry could be made and substantially improve the reliability. Review of the circuitry has indicated that a few changes could be made in the circuitry and several changes were recommended; however, these changes effect the technique of accomplishing a desired interlock and do not substantially improve the reliability of the interlock circuitry. With primary consideration given to the goal of improving the reliability of the interlock circuitry, two major conclusions were reached:

1. The interlock circuitry as designed will perform the intended functions.

2. The best approach to improving the reliability of the interlock circuitry is not through changing the techniques of accomplishing the desired interlocks, but rather through modifying the interlock requirements and thus eliminating interlock circuitry."

c. Comments on Group 2

With respect to the Group 2 criteria (above), the following comments are made:

(1) Launch Computer Discrete Output Inhibit

The Firing Command (T-186 seconds) inhibits the issuance of discrete outputs by the launch computer. A manual capability exists to inhibit these at any time.

(2) Interlock Parameter Display

An examination of the ESE schematics shows that an indication of the status of each interlock is available in the LCC from at least two of the following sources:

(a) DEE-6 equipment.

(b) Hardwire.

(c) Ground DDAS.

(d) RCA 110A data link (Discrete Input to ML Computer).

Therefore, the requirement for display of interlocks is adequately fulfilled.

(3) By-Pass Capability

The capability has been provided in the LCC to by-pass any of the first level parameters in the S-II and S-IVB Ready (Preparation Complete) and S-II and S-IVB Ready for Launch (Ready for Ignition) interlocks. This is accomplished by installation of jumper plugs on an individual basis to manually send a discrete output to complete the appropriate by-pass.

It is also noted that a similar type by-pass capability is provided in the LCC for seven of the twenty five S-IC stage master interlocks (see Figure 1). The question is then--Should a by-pass capability be provided for the remaining eighteen S-IC master interlocks? An examination of the parameters for those eighteen interlocks shows that they fall into the following categories:

(a) Critical S-IC engine valve positioning for ignition (e.g., Main fuel and prevalves).

(b) Purge (Start of Gas Generator fuel injector and high LOX dome purge between Firing Command and Ignition Command).

(c) Terminal Countdown Sequencer Ready.

(d) Completion of power transfer after T-30 seconds (related to Cutoff).

(e) Range Safety Command Receiver (RSCR) readiness.

(f) Verification that all ignitors are ready for ignition.

(g) Verification that S-IC stage and switch selector logic is set at zero.

The S-II and S-IVB stages are inactive after Ignition Command and once their proper status is verified, by-passing of a malfunctioning interlock can be justified. It is the belief of the authors that because of the critical nature of the S-IC interlocks without by-pass capability, that consideration would not be given to use of a by-pass in an actual launch, even if installed. Thus, it is considered that adequate by-pass capability has been provided.

(4) Interlock Selection

It was found that four S-IC master interlocks have been dropped from the Preparations Complete and Ready for Ignition chains. These were:

(a) Control 750 psi pressure OK.

(b) On board 100 psi purge pressure OK.

(c) Stage Control 3000 psi pressure OK.

(d) Stage 3000 psi purge OK.

One interlock, absence of Propellant Depleted Failure, has been added to the Preparation Complete chain. Inasmuch as Propellant Depleted Failure is used as an "immediate" cutoff parameter (Figure 2) from Firing Command to Commit, its sampling as part of Preparation Complete is justified.

The interlocks selected for the Preparation Complete and Ready for Ignition chains for early Saturn V vehicles are considered to conform with the criteria.

(5) Preflight Service Arm

The most significant change in the interlock system has been the establishment of the retraction of the S-IC intertank and forward service arms at T-40 and T-20 seconds respectively. Retraction of the S-IC intertank service arm, which can be remotely reconnected, does not impose any serious constraints on a short recycle of the vehicle. However, because of cryogenic, ECS and pneumatic system constraints, retraction of the S-IC forward service arm commits the vehicle to either a launch or scrub. Consequently, retraction of the S-IC forward service arm now denotes a major milestone in the terminal sequence. Previously (Reference 1), loss of any of the Ready for Ignition interlocks would cause Sequence Failure Cutoff only at Time for Ignition. Because of the recycle constraints imposed by retraction of the S-IC forward service arm, that portion of the Ready for Ignition chain which should be completed prior to T-20 seconds is sampled as a prerequisite for retraction of that arm (see Figure 1). Loss of any of those interlocks prior to T-20 seconds will inhibit retraction and cause Cutoff to be issued. This partial sampling of the Ready for Ignition chain at T-20 seconds is primarily considered an operational procedure to avoid knowingly committing the vehicle to a scrub situation because of a failure to complete one of the Ready for Ignition interlocks. No new interlocks in the Ready for Ignition chain are involved. In the strict sense, this T-20 second sampling is not covered by the criteria. However, it is considered a necessary operational procedure.

(6) Cutoff Parameters after Ignition Command

Several significant changes in the Cutoff parameters and circuitry after Ignition Command have been incorporated which simplify the system and are in accordance with the criteria. The system's current cutoff parameters are shown in Figure 2.

(a) EDS

Previously (Reference 1), an EDS Ready interlock (K994) was used in the Preparation Complete and Ready for Ignition chains. A second EDS relay, EDS Ready for Commit (K986) was included in the Commit chain and sampled only at Time for Commit. The circuitry has been simplified in that the EDS Ready for Commit relay has been deleted and the EDS Ready circuit (K994) is also used to provide an EDS Failure Cutoff. One normally closed set of its contacts is now enabled as an "immediate" cutoff by Ignition Command. Thus, loss of EDS Ready any time after Ignition Command will cause an "immediate" cutoff rather than permitting the vehicle to go to Time for Commit.

(b) All Engines Running

The All Engines Running interlock in the Commit chain has been simplified by the deletion of four relays.

(c) Rough Combustion Cutoff

The Rough Combustion cutoff interlock has been removed and the system will be flown open loop on the first few Saturn V's. This has permitted a significant simplification of the engine shutdown circuitry in that the 2-4 Failure shutdown circuit could be removed.

(d) Launch Failure Timer

The Saturn IB Launch Failure Timer is designed to go to a "closed" condition should it fail, representing a single point failure. Therefore, a second timer was added in series in the Saturn IB ESE. The Saturn V ESE uses the TCS to produce a time signal for Launch Failure. Failure of the TCS would merely result in "no time signal," but Manual Cutoff is always available. Thus, addition of a Saturn V Launch Failure timer is not considered necessary.

(e) The following Saturn IB cutoff parameters were deleted in the EDS ESE after ignition for AS-204. They may be considered for eventual deletion from the Saturn V ESE.

EDS Cutoff Enabled Circuit #1 or #2.

Yaw Rates #1, 2 or 3 Excessive.

Roll Rates #1, 2 or 3 Excessive.

Pitch Rates #1, 2 or 3 Excessive.

EDS Enable Logic Zero.

(f) Power Cutoff Parameters

The following electrical power system cutoff parameters were deleted from the Saturn IB ESE for AS-204:

S-IB Network No. 2 voltage OK.

S-IVB Networks No. 4 voltage OK.

S-IVB Forward, Aft No. 1, and Aft No. 2 Buses - indication of transfer to internal power.

Comparable Saturn V power system cutoff parameters should be considered for deletion as vehicle flight development progresses.

(g) Launch Support

A Launch Support Ready for Launch cutoff interlock, effective from Ignition Command to Commit, has been added.

(h) Commit-Cutoff Separation

With respect to the first prospective manned Saturn IB (AS-204), the question was raised as to whether a positive time separation existed between a possible Cutoff and Commit. Because of the very remote possibility of a relay race between Cutoff and Commit, a set of normally closed contacts from the Time for Commit relay was added in the Cutoff chain to inhibit Cutoff a finite time before Commit and preclude such a possibility. One of the recent changes to the Saturn V ESE has also included the addition of a set of normally closed contacts from the Time for Commit relay in the Cutoff circuitry, thus also providing Saturn V with a positive separation of Commit-Cutoff.

The cutoff parameters used after Ignition Command for early Saturn V vehicles are considered to conform with the criteria for interlock selection.

4. CONCLUSIONS

The Saturn V interlock system is being actively reviewed by KSC, MSFC, and contractors with a view towards ensuring proper operation and improving reliability. Many changes to improve the system already have been made and it is expected that many further improvements will come out of that effort. Subject to the comments in Section 3, it appears that the Saturn V launch interlock system conforms with the design criteria, Appendix A.

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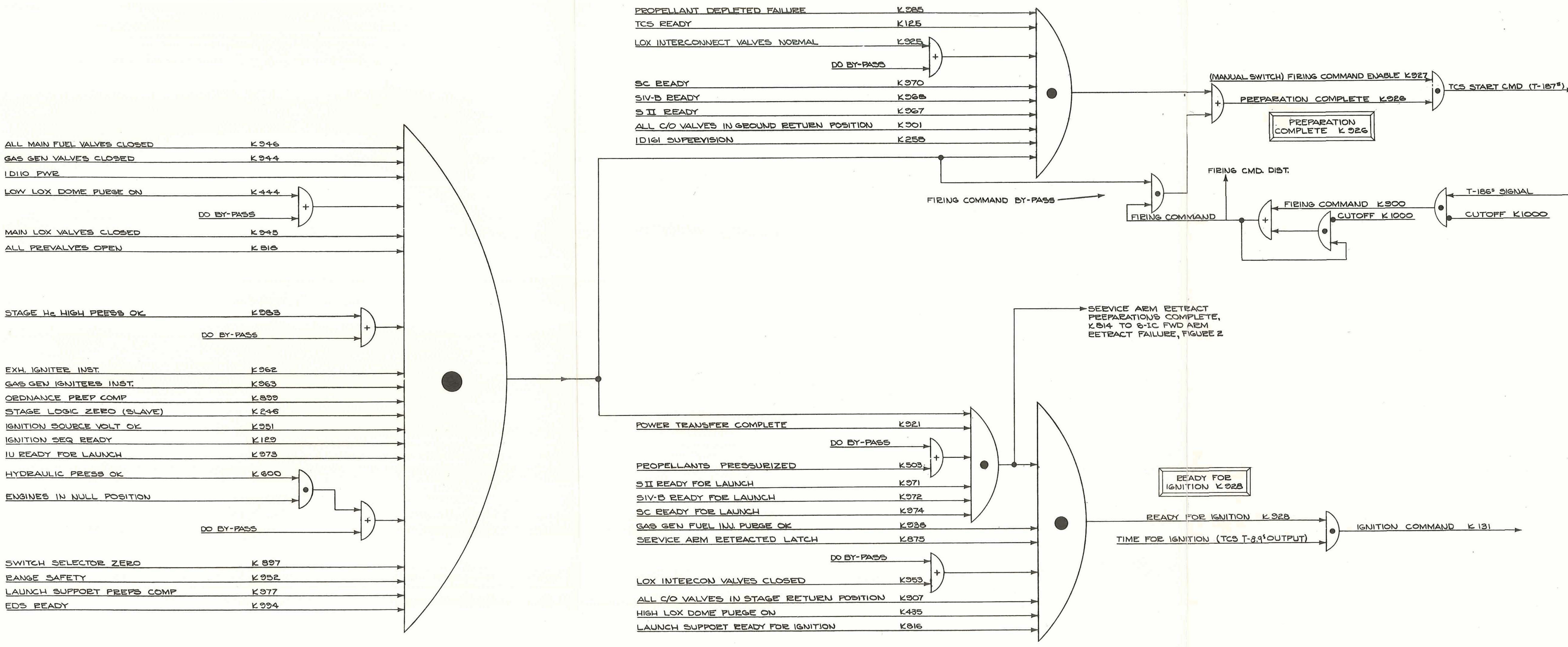
Attachments
References
Appendix A & B



"PREPARATION COMPLETE"
AND
"READY FOR IGNITION"
MASTER INTERLOCK CHAINS
APOLLO / SATURN V

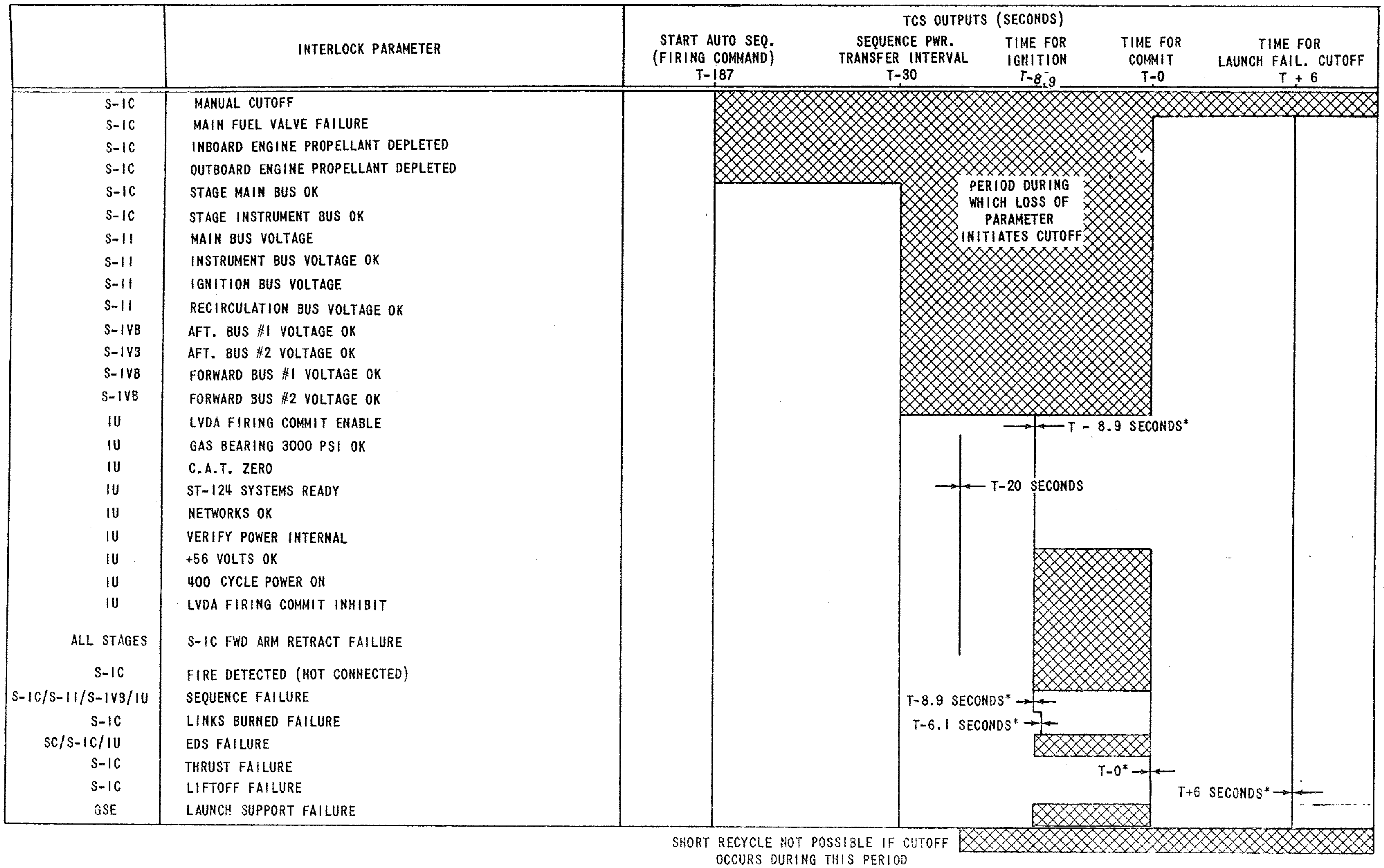
FIGURE 1

9/27/66

1

2

3



*NOTE: THESE PARAMETERS CAN ONLY INITIATE CUTOFF AT THE SPECIFIC TIME INDICATED

FIGURE 2 - SATURN V ESE CUTOFF PARAMETERS

REFERENCES

1. The following MSFC Advanced Electrical System Schematics (updated):

   "S-IC ESE, Saturn V" drawing No. 40M10616, dated October 18, 1965.

   "S-II ESE, Saturn V" drawing No. 40M10590, dated October 29, 1965.

   "S-IVB ESE, Saturn V" drawing No. 40M3870, dated September 22, 1965.

   "IU ESE, Saturn V" drawing No. 40M14490, dated December 23, 1965.

   "EDS ESE, Saturn V" drawing No. 40M13162, dated August 23, 1965.

   "Systems Integration ESE, Saturn V" drawing No. 40M13780, dated November 19, 1965.

2. "Saturn V ESE Interlock Study" dated June, 1966, by the General Electric Company, Apollo Support Department, Huntsville, Alabama.

3. "Saturn V Logic Diagrams," MSFC Drawing No. 40M37700, dated October 1, 1966.

4. Saturn V Interlock Review, Vehicle SA-501, P&VE MSFC.

APPENDIX A

1. SUBJECT: Apollo/Saturn Launch Interlocks

2. PURPOSE: This document sets forth the objective, design philosophy and criteria for design of launch interlocks in the Apollo/Saturn program.

3. OBJECTIVES:

As limited and rigid launch opportunities will be available for the Saturn/Apollo missions, it is important that the checkout and launch system be designed to give maximum assurance that:

(1) a launch will be achieved if the space vehicle and essential GSE are in proper operating condition, and conversely,

(2) a safe and orderly hold or shutdown action will be taken if essential readiness criteria are not met at any point in the countdown.

Accordingly, means shall be provided to ascertain the readiness of all essential space vehicle and GSE systems, and to provide for appropriate manual or automated reaction in the event of discrepancies.

4. SCOPE:

Interlocks are system elements utilized to provide assurance that each step in the countdown sequence will proceed if, and only if, all essential readiness criteria are met. Interlocks fall into three general categories with respect to time:

(1) Interlocks employed prior to start of the Automatic Launch Sequencer which provide the bases for hold or workaround decisions, or protect hardware and personnel.

(2) Interlocks employed from start of the Automatic Launch Sequencer to issuance of Ignition Command, which will stop the countdown process if readiness criteria are not met.

(3) Interlocks employed between issuance of Ignition Command and Launch Commit, which initiate shutdown if criteria essential for liftoff are not met.

5. CRITERIA FOR INTERLOCK SELECTION

At each step in the countdown the interlock system shall include, and be limited to, those functions and conditions which are prerequisite to proceeding to a safe launch which will accomplish primary mission objectives. Selection of each interlock will be based on demonstration that:

(1) The function or condition is a prerequisite for proceeding to launch.

(2) It is interlocked while and only while it is a prerequisite for progression.

(3) The measured parameter is the best available indicator of the required condition.

(4) All parameter limit values are substantiated by adequate engineering and test data. The limits shall be as wide as possible, consistent with crew safety and mission success.

6. CRITERIA FOR DESIGN AND IMPLEMENTATION

The design and implementation of each interlock function shall provide high assurance that the countdown will proceed if, and only if, the function is satisfactory.

(1) Interlocks shall be accomplished directly and automatically by hardware when reliability and response time considerations demonstrate this to be the preferred method of meeting basic objectives of crew safety and mission readiness.

(2) For equipment design, the Ignition Command shall be regarded as the beginning of the mission, and all GSE and interlock circuitry that could initiate cutoff after Ignition Command shall be designed and qualified as Mission Critical hardware.

(3) After Ignition Command, cutoff parameters shall include, and shall be limited to those failures which penalize crew safety, lead to an abort, or prevent accomplishment of primary mission objectives.

(4) The sensing system and interlock circuitry shall be designed to have reliability better than the system being sensed.

(6) After initiation of Firing Command, the computer discrete output shall be inhibited and any discretes required to be issued during this period come from the Automatic Launch Sequencer/Ignition Sequencer.

(7) The capability to bypass interlocks chains in the event of an interlock malfunction shall be provided in the LCC. The bypass implementation which will be used only in the event of substantiated interlock malfunction, shall provide access to the lowest reasonable level of interlock functions.

(8) All parameters incorporated in the interlock system shall be available for independent verification in the LCC. Failures which will lead to a hold or a cutoff shall be positively indicated and displayed in a manner which will assure earliest possible recognition for analysis and action.

APPENDIX B

TERMINAL COUNTDOWN SEQUENCER OUTPUTS - SATURN V

T-TIME SECONDS	CHANNEL	FUNCTION
-186	1	FIRING COMMAND
-176	2	NOT USED
-167	3	S-IVB LOX PRESSURIZATION, S-II-TIME FOR LOX TANK PRESSURIZATION PLUS 15 SECONDS
-160	4	NOT USED
-152	5	TIME FOR S-IVB LOX PRESSURIZATION PLUS 15 SECONDS
-142	6	NOT USED
-132	7	NOT USED
-122	8	NOT USED
-112	9	NOT USED
-102	10	
-102	11	S-IC SEQUENCER HYDRAULIC COMMIT
-97	12	S-IVB AND S-II LH_2 PRESSURIZATION
-96	13	S-IC FUEL PREPRESSURIZATION
-87	14	NOT USED
-82	15	TIME FOR S-IVB AND S-II LH_2 PRESSURIZATION PLUS 15 SECONDS
-72	17	S-IC LOX PRESSURIZATION
-65	21	ARM COMMAND FACILITY CAMERA CONTROL
-60	19	APOLLO ACCESS ARM UNLOCK & RETRACT; UNLATCH INTERTANK SERVICE ARM
-52	20	S-IC ENGINE CALORIMETER PURGE ON
-40	24	RETRACT S-IC INTERTANK SERVICE ARM; S-II LOX PRESSURIZE OVERRIDE CONTROL

APPENDIX B (Cont'd)

TERMINAL COUNTDOWN SEQUENCER OUTPUTS - SATURN V

T-TIME SECONDS	CHANNEL	FUNCTION
-40	25	S-IC DISABLE LOX FILL AND DRAIN VALVES
-30	18	S-IC STAGE RETURN
-30	22	TIME FOR POWER TRANSFER; SERVICE ARMS UNLOCK; START CAMERA SYSTEM
-27	23	S-II START TANK VENT CONTROL PRESSURE; S-IVB DIRECTIONAL VENT TO FLIGHT POSITION
-20	26	RETRACT S-IC FORWARD SERVICE ARM
-15	16	ARM COMMAND-FACILITY CAMERA CONTROL: GUIDANCE RELEASE ALERT
-12	27	S-IC LOX INTERCONNECT VALVE CLOSE COMMAND
-11	28	S-IC LOX DOME & GG FUEL INJECTOR PURGE ON
-10	29	GUIDANCE RELEASE; PAD WATER SUPPLY ON; S-IC HEATER POWER DISABLE
-8.9	30	TIME FOR IGNITION
-8.8	31	POWERS IGNITOR AC POWER CONTROL SECONDARY FOR #1 GAS GEN & EXHAUST IGNITORS
-8.7	32	POWERS IGNITOR AC POWER CONTROL SECONDARY FOR #2 GAS GEN. & EXHAUST IGNITORS
-6.85	33	NOT USED
-6.8	34	NOT USED
-6.1	35	TIME FOR LINKS BURNED
-6.04	36	START ENGINE #105
-5.66	37	START ENGINE #103
-5.51	38	START ENGINE #101
-5.35	39	START ENGINE #104
-5.21	40	START ENGINE #102
-5	41	CAMERA CONTROL; ENGINE START SOLENOIDS OFF
-3.54	48	S-IC FUEL AUXILIARY PREPRESSURIZE

APPENDIX B (Cont'd)

TERMINAL COUNTDOWN SEQUENCER OUTPUTS - SATURN V

T-TIME SECONDS	CHANNEL	FUNCTION
0	42	TIME FOR COMMIT
COMMIT +6	43	CUTOFF (LIFTOFF FAILURE)
+10	44	TAIL SERVICE MAST SHUTOFF
+20	45	CAMERA CONTROL; RESET SUPPLY RETURN VALVES
CUTOFF +0.1	46	ENGINE SHUTDOWN SEQUENCING
CUTOFF +1.1	47	CLOSE ENGINE PREVALVE BACKUP
+60	49	NOT USED
+240	40	NOT USED