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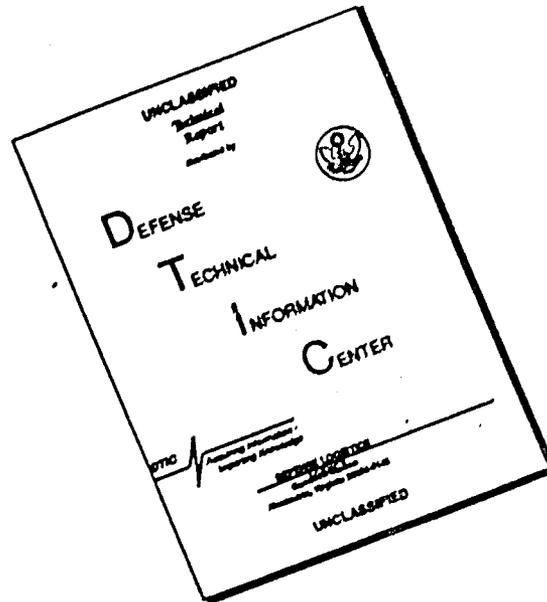
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# TECHNICAL NOTE

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## A SEQUENCE DIAGRAM ANALYSIS OF THE VANGUARD SATELLITE LAUNCHING VEHICLE

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by  
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## SUMMARY

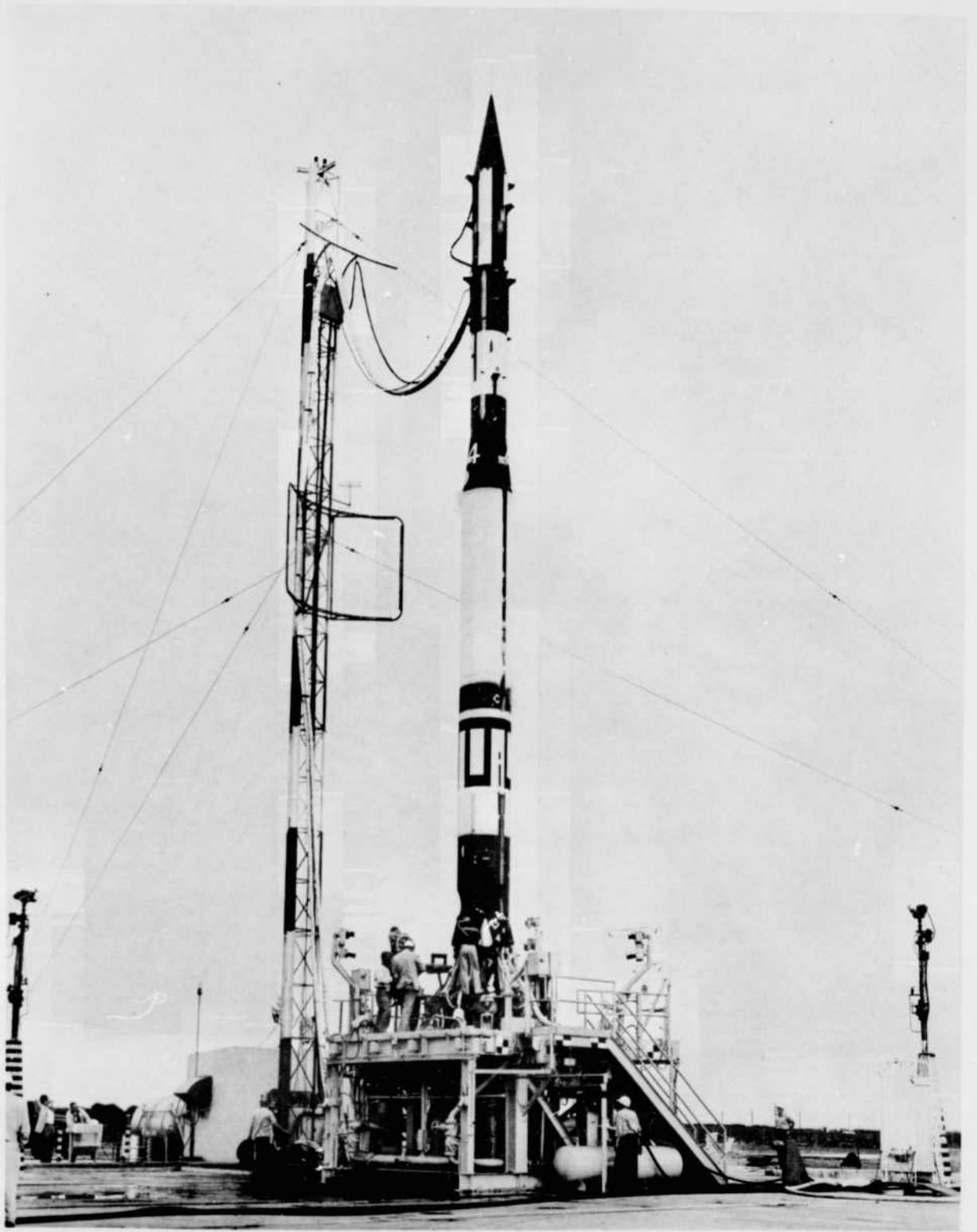
The Vanguard Sequence Diagram method, introduced in an earlier report, is applied herein to depict the operating sequence of the Vanguard Satellite Launching Vehicle. It relates vehicle systems operation during final countdown preparations through lift-off, and includes the entire flight program to satellite separation in orbit. On the basis of information from the diagram, a brief system analysis of the vehicle is performed. The results are presented graphically and include:

- Vehicle state, state-transition breakdown
- Vehicle component makeup
- Launch program events
- Flight profile of cumulative events and vehicle components remaining
- Condensed sequence diagram
- Vehicle in-flight sequencing; flight-test results

A narrative description of the vehicle launch program is included by way of a verbal interpretation of the master sequence diagram.

## CONTENTS

	Page
Summary . . . . .	i
Frontispiece . . . . .	iv
INTRODUCTION . . . . .	1
THE VANGUARD SEQUENCE DIAGRAM METHOD . . . . .	2
Scope of the Diagram and Definition . . . . .	2
Interpretation of the Diagram . . . . .	3
Illustrative Sequence Diagram . . . . .	5
DESCRIPTION OF THE VANGUARD VEHICLE . . . . .	6
THE SLV MASTER SEQUENCE DIAGRAM . . . . .	8
SYSTEM ANALYSIS OF THE SLV . . . . .	9
Vehicle State, Sub-state, and State Transition . . . . .	9
Component Makeup of the Vehicle . . . . .	12
Launch Program Events . . . . .	14
Flight Profile of Cumulative Events and Vehicle Components Remaining . . . . .	16
Condensed Sequence Diagram . . . . .	18
Vehicle In-flight Sequencing; Flight Test Results . . . . .	20
CONCLUDING REMARKS . . . . .	20
ACKNOWLEDGMENTS . . . . .	22
Appendix A - NARRATIVE DESCRIPTION OF THE SLV SEQUENCE OF OPERATIONS . . . . .	23



STATE FIVE: VEHICLE PREPARATION

# A SEQUENCE DIAGRAM ANALYSIS OF THE VANGUARD SATELLITE LAUNCHING VEHICLE

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## INTRODUCTION

The Vanguard Sequence Diagram, as a new method of complex system analysis, was published in 1958. \* In that report, an analysis of the operation of the first Vanguard Test Vehicle (TV-O) was performed to demonstrate the sequence diagram method. The use of that report with the present one will help to familiarize the reader with this graphical method of representing system operation, and will also allow a comparison between the single-stage TV-O and the more complex, three-stage Satellite Launching Vehicle (SLV) considered here.

In the development of a device with as many separate systems and subsystems as the typical multi-stage rocket, the inevitable strong trend toward specialization among personnel often results in a general lack of feeling for *the overall vehicular aggregate*. Personnel closely associated with a particular stage propulsion system, for example, may lose sight of the critical timing imposed on engine starting by a stage-separation requirement. Thus, although individual systems are developed which in themselves show good performance and reliability, the overall vehicle synthesis may not be wholly successful. In many instances, excessive complexity and "induced" component unreliability terminate the planned sequence of operations prematurely, and in-flight failures result. Inadequate vehicle checkout techniques may result from a lack of *general comprehension* of the many interacting sequences in the flight program.

A step toward alleviating these inadequacies would be a specific statement of the combined operation of the entire vehicle. Such a presentation would describe the functioning of all significant systems throughout their operating periods. It would show the cause-effect relationship in component interaction. In brief, it would *define the complexity* of the vehicle in terms of components and sequenced events. The need for such a statement led to the development of the Vanguard Sequence Diagram.

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\*Escher, W.J.D., and Foster, R.W., Project Vanguard Report No. 31, "The Vanguard Sequence Diagram, a Graphical Method of Presenting Complex System Operation," NRL Report 5185, U. S. Naval Research Laboratory, August 15, 1958.

The purpose of this paper, then, is twofold: (1) to present a compact analysis of the Vanguard Satellite Launching Vehicle; and (2) by thus applying it exhaustively to a very complex system to illustrate further the utility of the method and some of the kinds of information which it can yield. To that end, a brief review and explanation of the method are also included here.

It should be pointed out that this report attempts to be definitive only with regard to the vehicle launch sequence program. It does not treat the design or performance of the many vehicle systems and subsystems, nor does it report general flight test results in detail. That information has been published elsewhere.\* The broader utility of the sequence diagram method as proposed in the original paper (i. e., with regard to reliability studies, electrical load profiles, etc.) is not further explored here. Rather, the work presented here is an expansion of information derived from the diagram itself. The resulting analysis may be of interest to investigators in the field of complex system synthesis. In particular, personnel involved in missile and space vehicle development may profit from this exposition.

A complete Master Sequence Diagram of the Vanguard Vehicle will be found inside the rear cover of this report. A detailed narrative interpretation of this diagram is given in Appendix A.

## THE VANGUARD SEQUENCE DIAGRAM METHOD

### Scope of the Diagram and Definition

The sequence diagram portrays the sequential relationships among a system's components as they proceed through a pre-established program of events. The following terms are used with special significance relative to the sequence diagram.

Component - A component may be thought of as any part which constitutes a basic functional entity; it may be equated with the individual "blocks" of a conventional operational block diagram. In general a component may be removed from a system or an assembly but is not subject to further disassembly in a normal service situation. Examples of components are: a relay, a gyro unit, an autopilot amplifier channel. Further breakdown of a component into its fundamental parts is usually possible; however this is not done in the construction of the sequence diagram. In the sequence

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\*"The Vanguard Satellite Launching Vehicle, an Engineering Summary," Engineering Report 11022, The Martin Company, Baltimore Division, April 1960 (CONFIDENTIAL)

diagram each component is assigned a horizontal space with its name and identifying number at the left margin. Components are grouped into major vehicle systems and stages.

Component State - The component state is a particular condition of the component, generally a steady-state condition, characterized by the component's position, operation or non-operation, input, output, etc. Examples of component states are: for a two-position switch, open or closed; for a gas generator, generating or not generating; for a propellant tank, vented, pressurized, or supplying propellant. In the sequence diagram a component state is shown by a bar in the horizontal space assigned to the component. Suitable nomenclature to identify the state and transitions between states is included within the bar.

Event - An event occurs in nearly every instance of component change-of-state. An event's sequential relationship is indicated at each event in which component interaction takes place. Component state changes are identified as to whether they are causes, effects, or necessary conditions. In the sequence diagram an event is shown by a vertical line along which appropriate symbols define the nature of the component interaction. These lines are identified by an event number. An event which is shown on the right of another is understood to occur simultaneously or later. The time scale thus indicated is not normally linear or proportional, owing to the lack of space on the diagram.

## Interpretation Of The Diagram

The sequence diagram is basically a means of identifying the components of a system (left side) and their changing states (horizontal bars) against events (vertical lines) occurring as time progresses (to the right). It is interpreted in the following manner:

### Component and Component State

A component and its state are presented thus:

Valve "A"                      closed                                          open                                          closed

From this the following information is gained: Valve "A" normally has two states, open and closed; it is initially closed, opens for a time and then returns to its closed position.

Transitions in component state are indicated as follows:

Thrust Chamber, II    not-firing  not-firing

From this, the following information is gained: The second-stage thrust chamber, initially not-firing, undergoes a transition to its full-firing state. After a time, shutdown occurs and it returns to its initial state through another transition, of shorter duration than the initial thrust buildup.

Complex operation of a component is shown by multiple transitions:

Main Oxidizer Valve    closed   closed

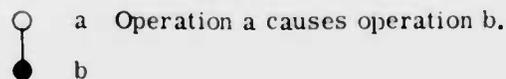
From this, the following information is gained: The main oxidizer valve undergoes a transition from its closed position to a preliminary-open position and thence, after a period of preliminary-open operation, through a considerably longer transition to the full-open position. Finally, the valve closes through a relatively short transition.

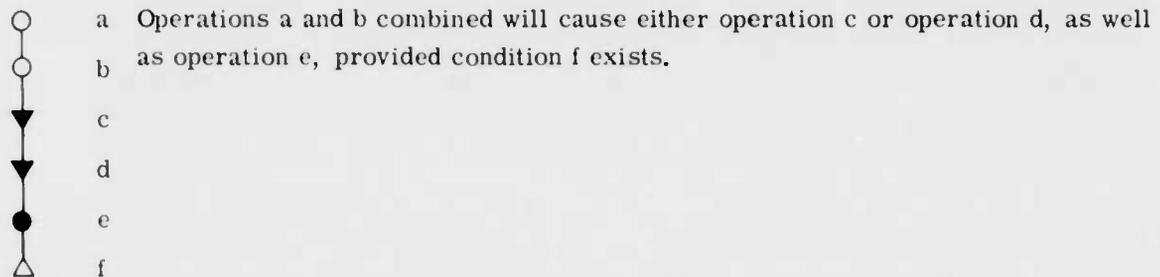
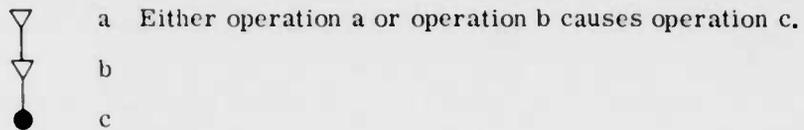
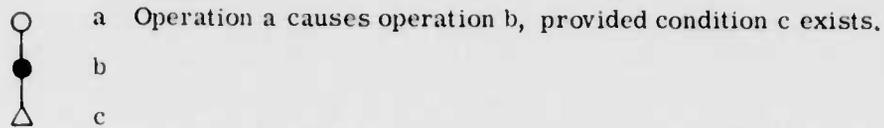
#### Events, Causes, and Effects

The following symbols are used along the vertical event lines:

- Indicates a primary *causing* operation or operations.
- Indicates an operation or operations *effected* (darkened symbol).
- △ Indicates a necessary condition.
- ▽ Indicates an either/or causal relationship.
- Indicates a time-gate requirement met.
- ⊗ Indicates a control-loop closure, or system feedback point.

The symbols associated with a single event are tied together by the vertical event line. Examples are:





#### Time Delay, or Timing Operation

A time delay between events is indicated as follows:



which is interpreted thus: From event 1, a period of  $t$  seconds ensues before event 2 occurs.

### Illustrative Sequence Diagram

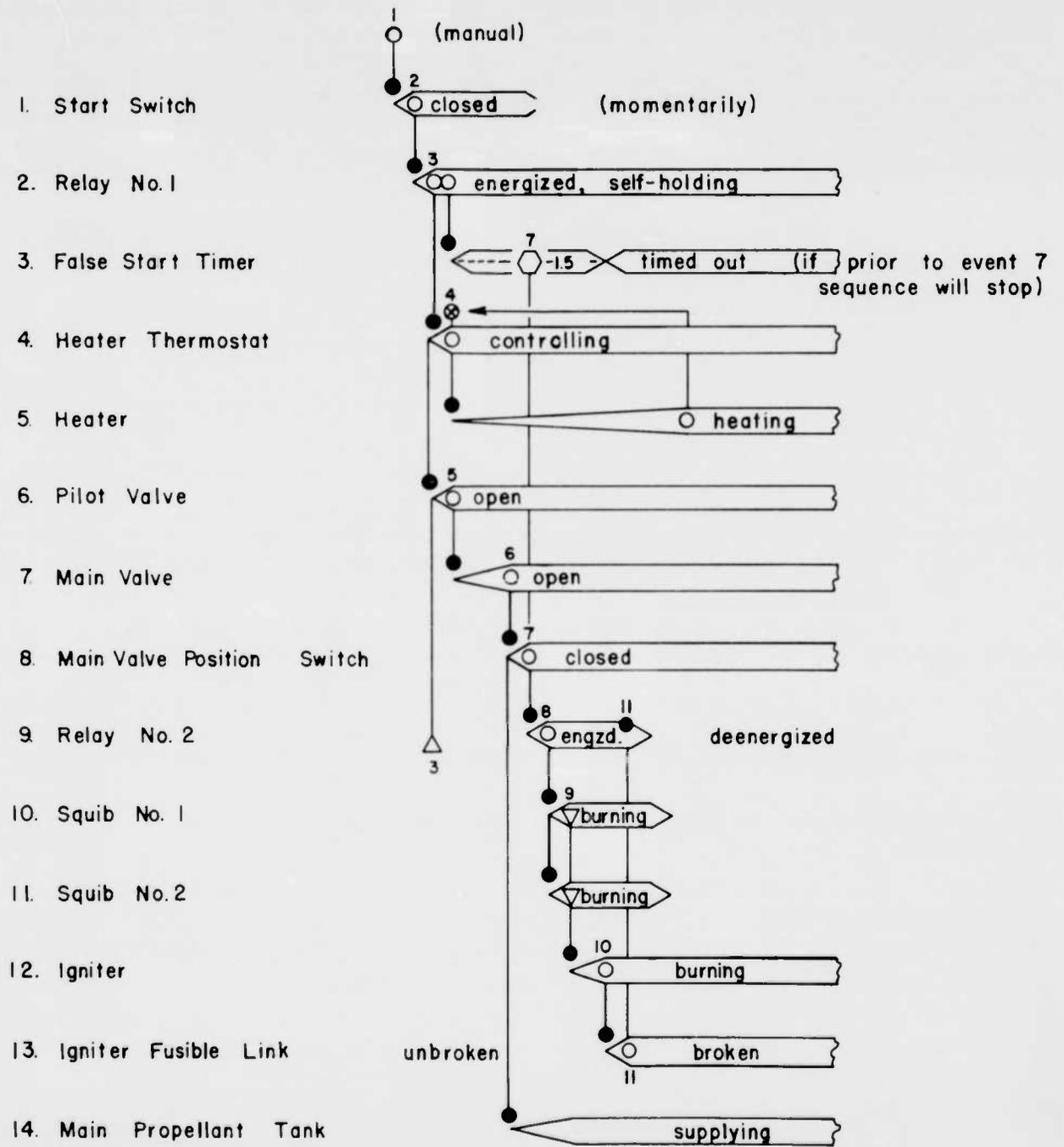
A sample (completely hypothetical) sequence diagram is shown in Figure 1, in which the preceding terms and symbols are employed. Components are listed in the left-hand column and are numbered from top to bottom. Events in time proceed to the right and are numbered sequentially from left to right. In the interpretation that follows, numbers in parentheses refer to component numbers.

The Start Switch (1) is momentarily closed manually, causing Relay No. 1, (2) to become energized and self-holding. Relay No. 1, in becoming energized, starts the False-Start Timer (3). In addition, provided that Relay No. 2 (9) is deenergized, the Heater Thermostat (4) begins controlling the Heater (5) and the Pilot Valve (6) is opened. The open Pilot Valve causes the Main Valve (7) to open in a somewhat longer opening time. The Main Valve, in opening, closes its Position Switch (8) and causes the Main Propellant Tank to begin supplying propellant. The closure of the Position Switch (8) causes Relay No. 2 (9) to become energized, the signal passing through the 1.5-second time gate imposed by the False-Start Timer (3) previously started. (If Relay No. 2 is not energized during this time gate because of some abnormality of the sequence, the sequence will be halted at this point.) Relay No. 2 having been energized, Squibs No. 1 and 2 (10, 11) are activated and begins burning. Either Squib No. 1 or No. 2 is sufficient to start the Igniter (12) burning. After the igniter is burning, its Fusible Link (13) is broken which causes Relay No. 2 (9) to become deenergized, thereby completing the sequence.

## DESCRIPTION OF THE VANGUARD VEHICLE

The Vanguard Satellite Launching Vehicle (SLV) was developed by the Martin Company's Baltimore Division as prime contractor under the technical direction of the Naval Research Laboratory. It was a three-stage vehicle employing a pump-fed oxygen-kerosene rocket engine in the first stage. The second stage was pressure fed, burning nitric acid (WIFNA) and unsymmetrical dimethylhydrazine (UDMH). A solid-propellant rocket motor was employed as a third stage. The overall weight of the SLV at launch was approximately 22,800 pounds; the overall length was 72 feet.

The launching program entailed an initial 10 seconds of vertical ascent, followed by several pre-established vehicle pitchover rates to establish the trajectory for satellite injection. Attitude stabilization in pitch and yaw was effected during first- and second-stage burning by manipulation of individual gimballed thrust chambers. Roll control was accomplished by means of auxiliary gas jet systems aboard each of the two stages. The nose cone was jettisoned during second-stage burning. An extended coasting period followed second-stage cutoff, during which three-axis attitude control was maintained by an "off-on" jet system exhausting residual helium from the propulsion system. Near the apogee of the ascent ellipse a vehicle-borne computer, or an alternate ground-based radar-computer-command aggregate, initiated third-stage firing. The third stage was thereby spun up (to provide flight stability) and it and the payload separated from the second stage by second-stage retro-thrust. Delayed ignition followed, and the payload was rapidly brought up to injection velocity. Then, unless programmed otherwise, the satellite was separated from the third stage.



(14 components, 11 events)

Figure 1 - Illustrative sequence diagram

Following the launching of three limited-objective test vehicles (two were modified Vikings), eleven vehicles with satellite capability were launched in the period from December 6, 1957 through September 18, 1959. Of these, three were fully successful, and established the Vanguard I, II, and III satellites. The payload weights in orbit were 3.25, 22.5, and 50 pounds respectively, exclusive of third-stage case and hardware.

## THE SLV MASTER SEQUENCE DIAGRAM

The SLV Master Sequence Diagram (inside rear cover) depicts the several states of the vehicle as it proceeds through a nominal launching program. Therefore no failures or anomalies in the sequence are considered. It may be noted that vehicle-borne performance and tracking instrumentation (transducers, instrumentation circuits, telemetry transmitters, radar beacon, etc.) are not indicated. This vitally important equipment cannot be said to participate functionally in the launch program. However the radio command transmitter/decoder equipment, although employed primarily for range safety functions (powerplant cutoff, vehicle destruct, and steering commands) can enter into the nominal flight sequence. An alternate method (Back-ups No. 1 and 2) of initiating third stage launch (Transition 2/1) utilizes a ground-based tracking, computation, and radio-command aggregate. Therefore, the vehicle-borne command links are noted on the diagram to the extent required.

Since by its nature the sequence diagram is completely specific with respect to various details which might have been changed from one vehicle to the next, Satellite Launching Vehicle No. One (SLV-1) has been chosen as representative, and the Master Sequence Diagram presented (inside rear cover) here depicts SLV-1. Therefore a brief summary of the SLV-1 flight may be of interest.

This vehicle was launched from the Atlantic Missile Range at 2246:19.5 E.S.T. on May 27, 1958. The flight program was normal through first- and second-stage powered flight. However, at Stage II engine shutdown (Event 296\*) a large pitch attitude disturbance occurred. (It is conjectured that a local materials failure in the thrust chamber occurred during the cutoff transient, causing a large side thrust.) The resulting pitch-up motion thus imparted to the vehicle was quickly reduced to zero by the coasting control jet system, but not before the limited-range ( $\pm 12$  degrees approx.) pitch gyro hit its stop and lost its inertial reference. As a result the vehicle thereafter was attitude-controlled about an erroneous pitch angle reference. The third stage was subsequently spun-up and launched with roughly a 60-degree pitch-up attitude instead of the desired near-horizontal orientation. At the end of third-stage burning the payload had a very large

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\*From SLV Master Sequence Diagram

injection angle error as well as insufficient speed for orbit. At this time the payload was separated from the expended rocket motor, completing the sequence program. Both units traveled upward to an altitude of about 1850 nautical miles and then reentered the atmosphere about 5090 nautical miles down-range. A list of significant event times for the SLV-1 flight is given as Table 1.

Table 1  
SLV-1 Flight Events

Event No.	Event	Time After Lift-Off (sec)
162	Lift-off, 2246:19.5 E. S. T. May 27, 1958	0.00
176	Pitch rate No. 1 initiated	10.02
184	Pitch rate No. 2 initiated	24.04
194	Pitch rate No. 3 initiated	45.03
204	Pitch rate No. 4 initiated	108.03
217	Stage I and II batteries paralleled, Stage I cutoff and II ignition functions armed	120.1
223	Stage I cutoff relay energized	143.5
243	Stage II ignition relay energized	143.9
257	I/II separation relays energized	144.25
265	I/II separation indicated	144.30
280	Stage II heat generator relay energized	152
285	Nose-cone separation initiated	172.02
290	Nose-cone separation indicated	172.10
297	Stage II cutoff relay energized	261.5
323	Pitch rate No. 5 initiated	418
328	Stage III spin-up Relay energized	552.9
339	Stage III separation indicated	554.4
341	Stage III ignition indicated	567.5
344	Stage III burnout indicated	601
354	Satellite separation indicated	628

782

## SYSTEM ANALYSIS OF THE SLV

### Vehicle State, Sub-state, and State Transition

For the purpose of the present system analysis with the sequence diagram, the term "vehicle" is expressly defined in terms of the satellite launching program. The vehicle is that part of the launching system, the sustained functional integrity of which is requisite to

the successful establishment of an operating satellite. By this definition, during the third-stage rocket motor burning period in which the payload is given its final acceleration to orbital velocity, the vehicle consists only of the third-stage rocket, final separation device, and satellite. The separated lower stages are no longer part of the vehicle, since the success of the launching is now independent of their functional integrity.

The Vanguard satellite launching vehicle program is characterized by the several vehicle states listed below. These are represented in Figure 2. Each state is numerically identified in order of increasing component complexity:

- 0 Satellite in orbit
- 1 Stage III powered and coasting flight
- 2 Stage II coasting flight
- 3 Stage II powered flight
- 4 Stage I powered flight
- 5 Vehicle preparation

Each of these states is characterized by a particular mode of propulsion or control which serves to differentiate it from the other states. A vehicle sub-state breakdown is indicated when a given state possesses secondary variations. State 3 can thus be divided into

- 3a Stage II powered flight with nose-cone
- 3b Stage II powered flight without nose-cone

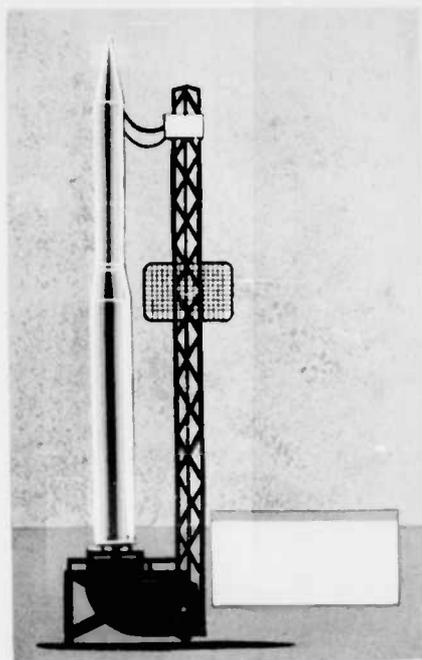
A vehicle state transition is a period in the launching program in which the vehicle changes from one state to another. Each transition is numerically related to the states concerned (Figure 2):

- 1/0 Satellite separation
- 2/1 Stage III launch
- 3/2 Transition to Stage II coasting flight
- 4/3 Stage II launch
- 5/4 Stage I launch

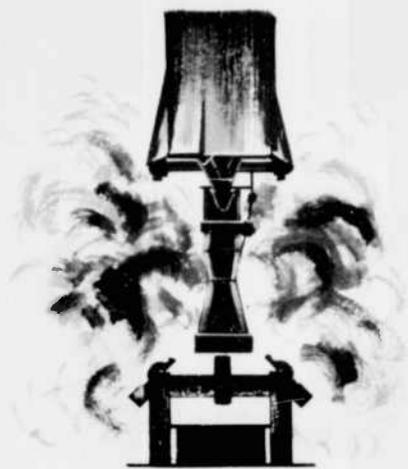
A sub-state transition can be similarly defined:

- 3a/3b Nose-cone jettison

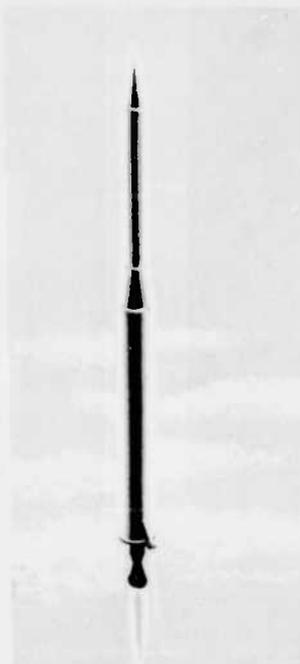
State transitions are considered to be initiated at the first event directly related to the transition, and terminated with the steady-state operation of the vehicle propulsion and/or system in the new state.



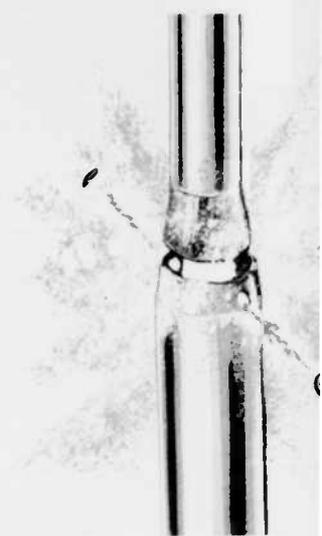
STATE 5  
VEHICLE PREPARATION



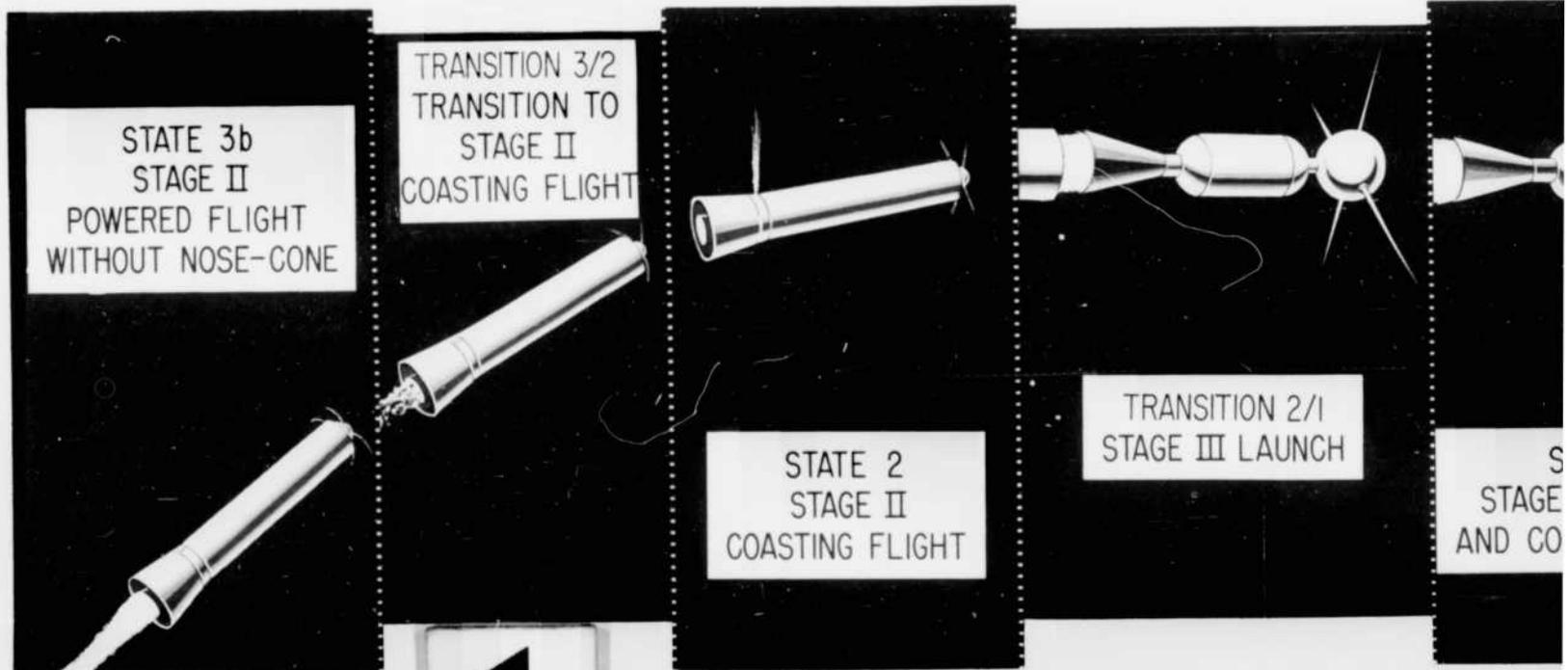
TRANSITION 5/4  
STAGE I LAUNCH



STATE 4  
STAGE I POWERED FLIGHT



TRANSITION 4/3  
STAGE II LAUNCH

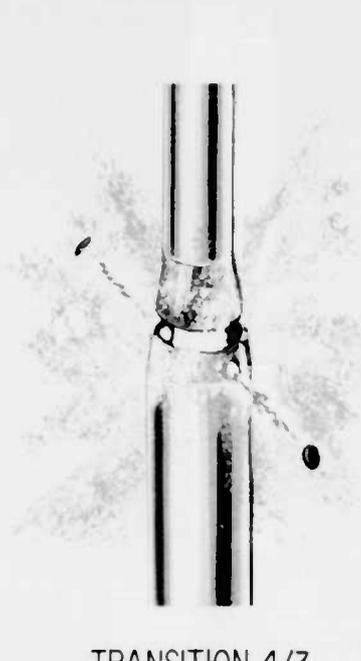


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Figure 2 - Breakdown of vehicle states and state tra



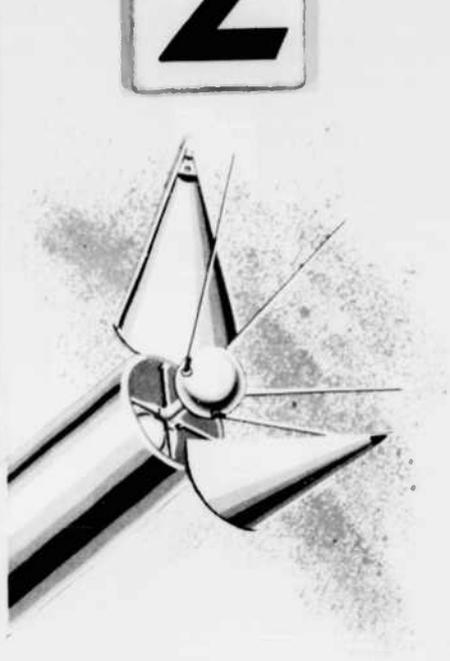
STATE 4  
STAGE I POWERED FLIGHT



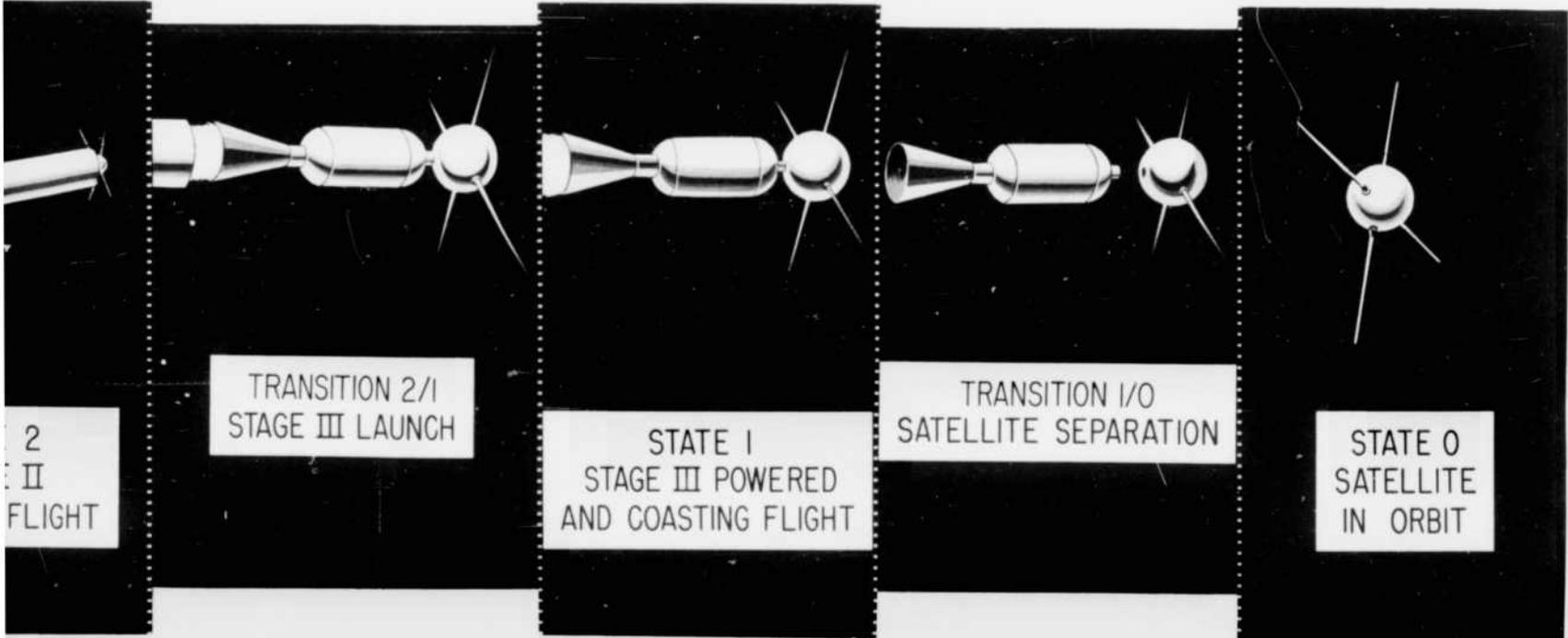
TRANSITION 4/3  
STAGE II LAUNCH



STATE 3a  
STAGE II POWERED FLIGHT  
WITH NOSE-CONE



TRANSITION 3a/3b  
NOSE-CONE JETTISON



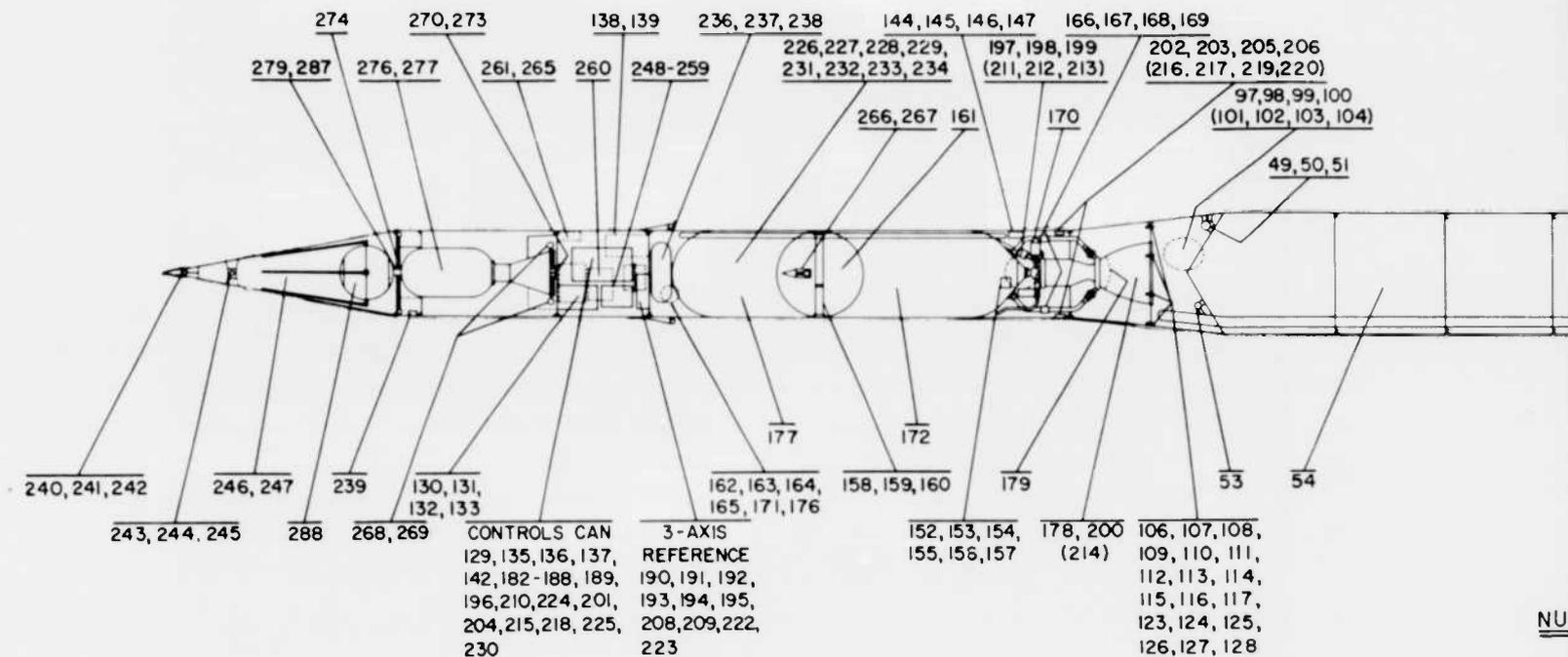
TRANSITION 2/1  
STAGE III LAUNCH

STATE I  
STAGE III POWERED  
AND COASTING FLIGHT

TRANSITION I/0  
SATELLITE SEPARATION

STATE 0  
SATELLITE  
IN ORBIT

Figure 2 - Breakdown of vehicle states and state transitions



NOTE:

VEHICLE STRUCTURE IS BROKEN DOWN  
"COMPONENT-WISE" AS FOLLOWS:

LONGITUDINAL ACCELERATION

STAGE I	25
II	180
III	278

PITCH AXIS

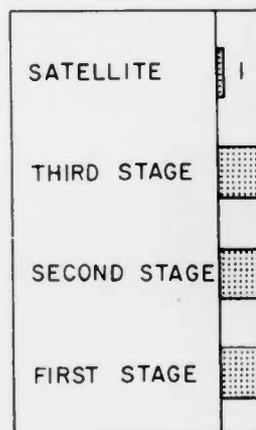
STAGE I	84
II	207

YAW AXIS

STAGE I	89
II	221

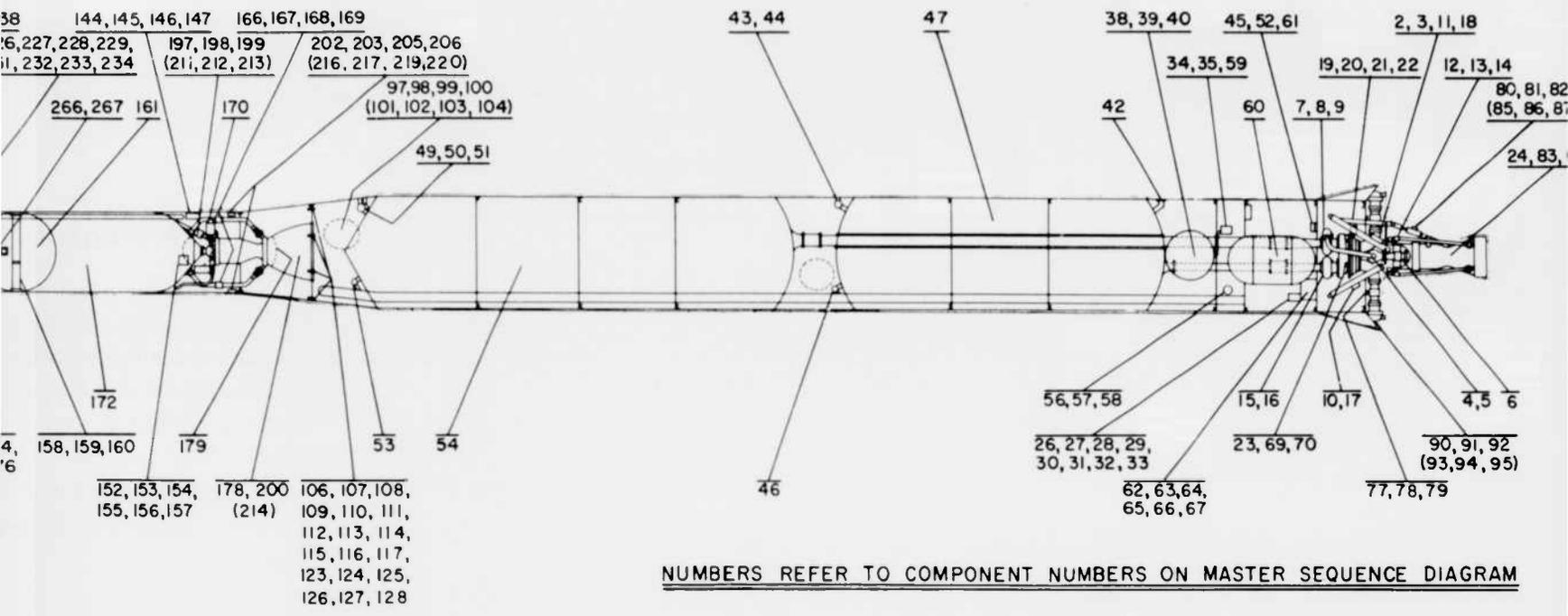
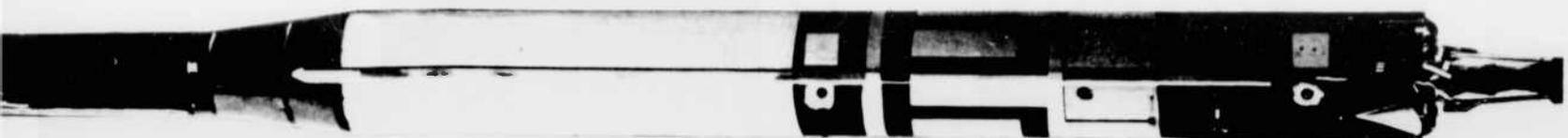
ROLL AXIS

STAGE I	96
II	235

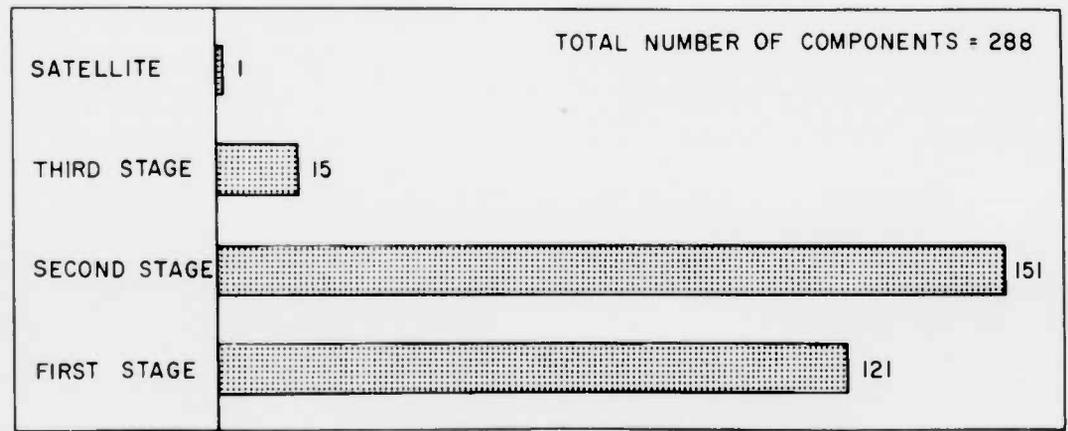


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Figure 3 - Key to vehicle components



2

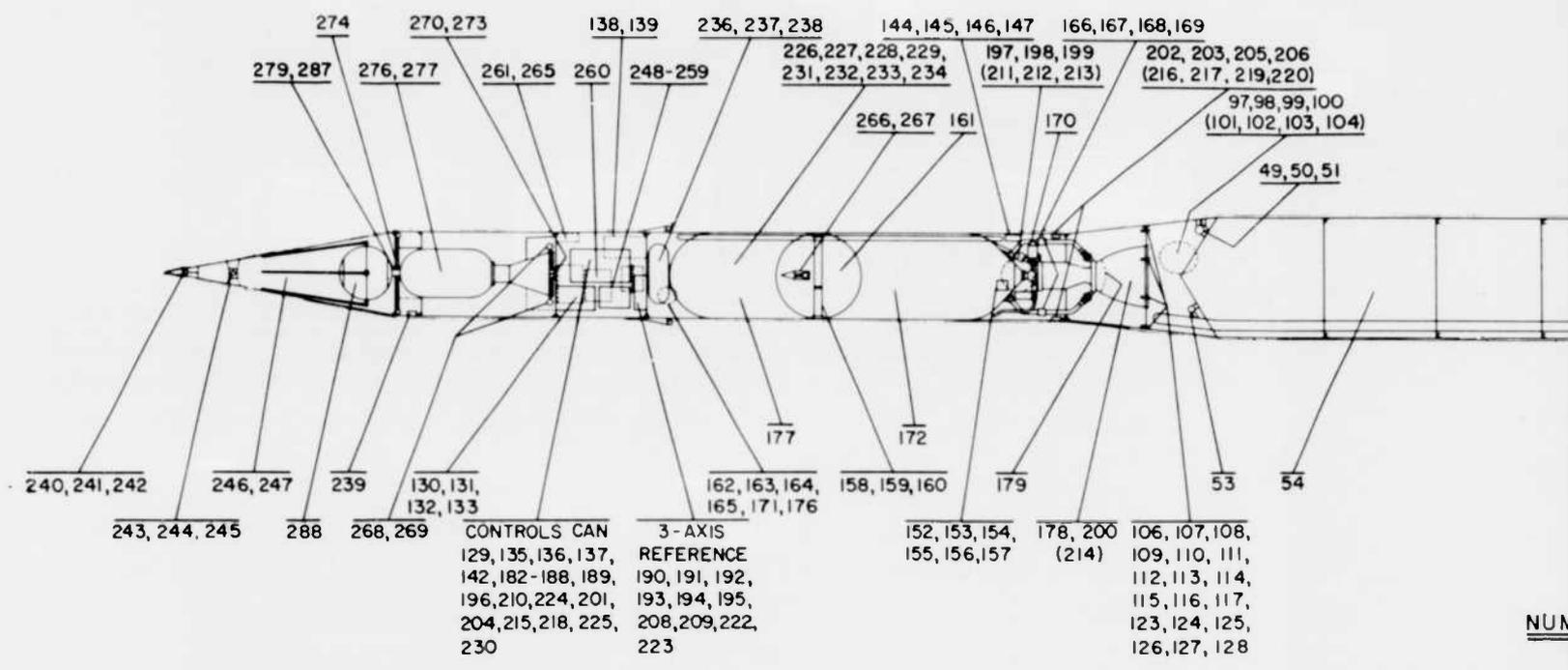


COMPONENT ALLOCATION FOR THE VEHICLE STAGES

Figure 3 - Key to vehicle components

### **Component Makeup of the Vehicle**

The three-stage Vanguard satellite launching vehicle is shown in an exterior view and a cutaway view in Figure 3. The component locations are numerically keyed to the listing on the left side of the Master Sequence Diagram. Component distribution among the vehicle stages is represented graphically in this figure. It will be noted that Stage II is comprised of more components than Stages I or III. In the interest of clarity, where components are too small or too highly concentrated to be distinguishable, omissions have been made.



**NOTE:**

VEHICLE STRUCTURE IS BROKEN DOWN  
"COMPONENT-WISE" AS FOLLOWS:

LONGITUDINAL ACCELERATION

- STAGE I 25
- II 180
- III 278

PITCH AXIS

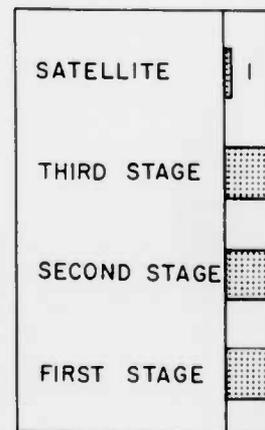
- STAGE I 84
- II 207

YAW AXIS

- STAGE I 89
- II 221

ROLL AXIS

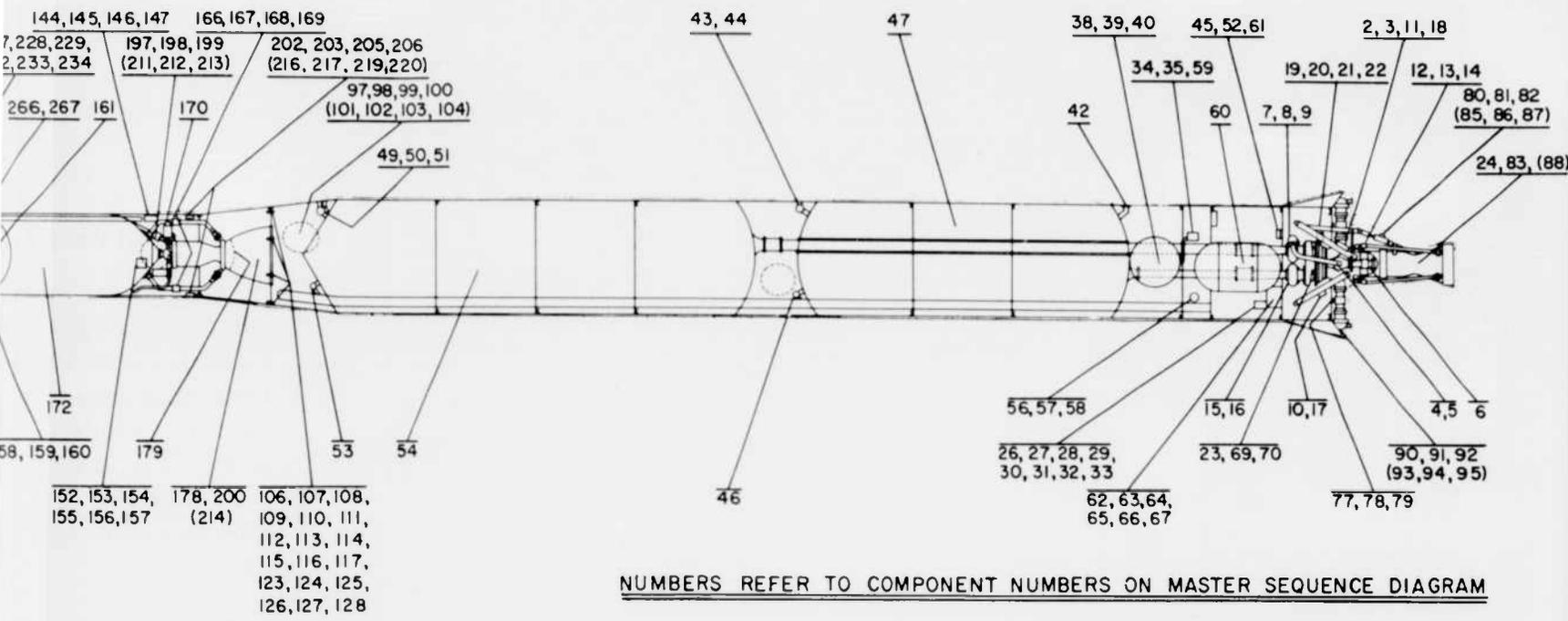
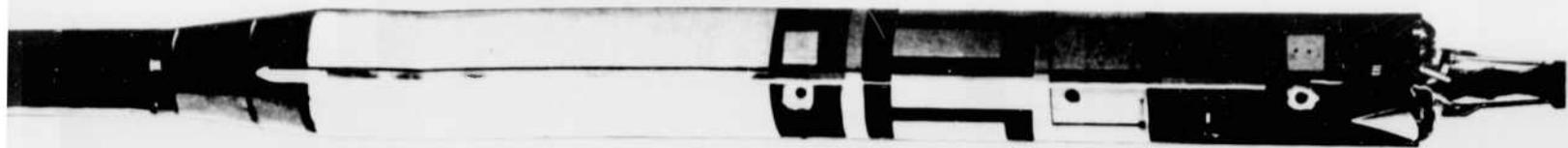
- STAGE I 96
- II 235



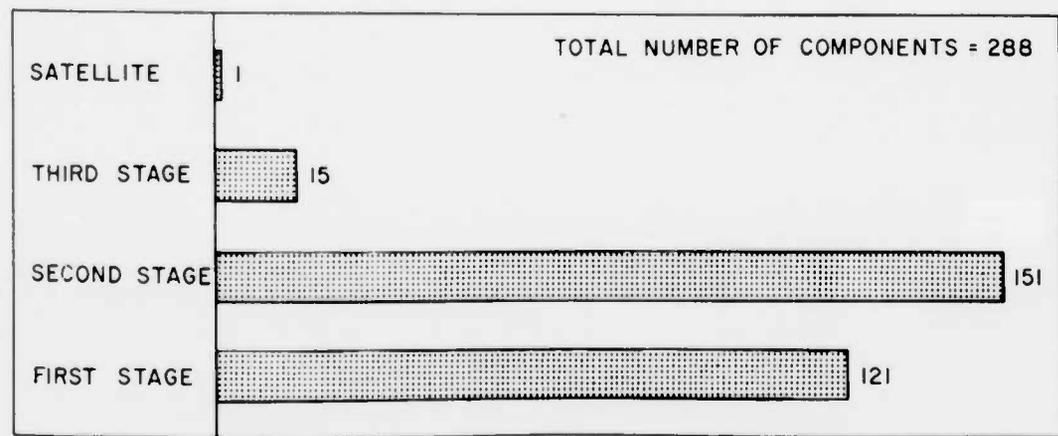
NUM

COM

Figure 3 - Key to vehicle components



2



COMPONENT ALLOCATION FOR THE VEHICLE STAGES

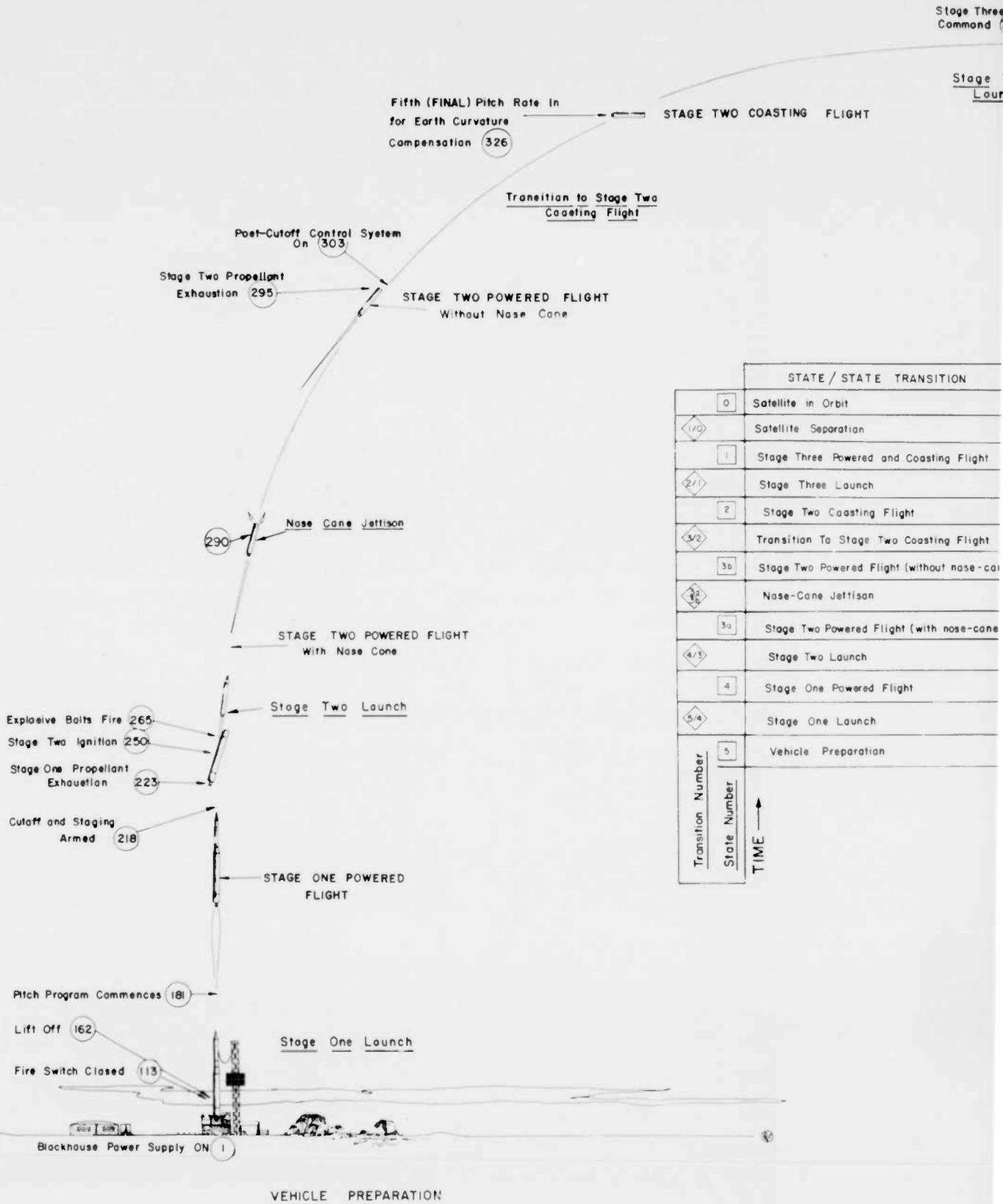
Figure 3 - Key to vehicle components

### **Launch Program Events**

Figure 4 is a schematic representation of the Vanguard nominal launching program. It includes a graphical display of the distribution of flight events among the several states and state-transitions already enumerated. Key events are numbered along the trajectory. For completeness in understanding the sequenced events, the Master Sequence Diagram should be consulted.

It should be noted that this is not a scale trajectory diagram; the actual trajectory would be considerably flatter, with a much longer Stage II powered and coasting flight interval.

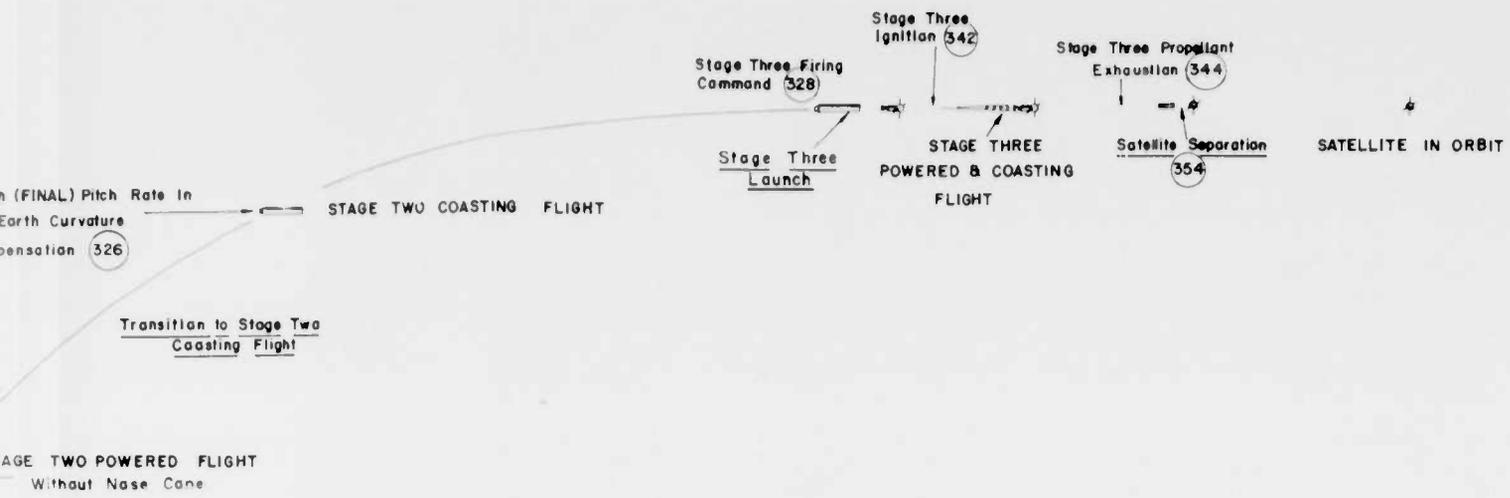
**1**



STATE / STATE TRANSITION	
0	Satellite in Orbit
1/0	Satellite Separation
1	Stage Three Powered and Coasting Flight
2/1	Stage Three Launch
2	Stage Two Coasting Flight
3/2	Transition To Stage Two Coasting Flight
3b	Stage Two Powered Flight (without nose-cone)
3c	Nose-Cone Jettison
3a	Stage Two Powered Flight (with nose-cone)
4/3	Stage Two Launch
4	Stage One Powered Flight
5/4	Stage One Launch
5	Vehicle Preparation

Transition Number  
State Number  
TIME ↑

Figure 4 - Events in the vehicle flight program



	STATE / STATE TRANSITION	EVENTS SEQUENCED	NUMBER OF EVENTS SEQUENCED
0	Satellite in Orbit	354	1
1/0	Satellite Separation	347 - 353	7
1	Stage Three Powered and Coasting Flight	339 - 346	8
2/1	Stage Three Launch	328 - 338	11
2	Stage Two Coasting Flight	319 - 327	9
3/2	Transition To Stage Two Coasting Flight	295 - 318	24
3a	Stage Two Powered Flight (without nose-cone)	290 - 294	5
3b	Nose-Cone Jettison	283 - 289	7
3c	Stage Two Powered Flight (with nose-cone)	277 - 282	6
4/3	Stage Two Launch	222 - 276	55
4	Stage One Powered Flight	166 - 221	56
5/4	Stage One Launch	113 - 165	53
5	Vehicle Preparation	1 - 113	112

Total Number of Events Sequenced: 354

Transition Number  
State Number  
TIME ↑

2

Figure 4 - Events in the vehicle flight program

### **Flight Profile of Cumulative Events and Vehicle Components Remaining**

A typical flight complexity profile can be constructed for any vehicle for which a master sequence diagram exists. This plot summarizes component and event relationships in the vehicle as it progresses through its various states and state-transitions. Figure 5 shows such a flight complexity profile for the Vanguard satellite launching vehicle.

# VEHICLE COMPONENTS FLIGHT SEQUENCE EVENTS

1

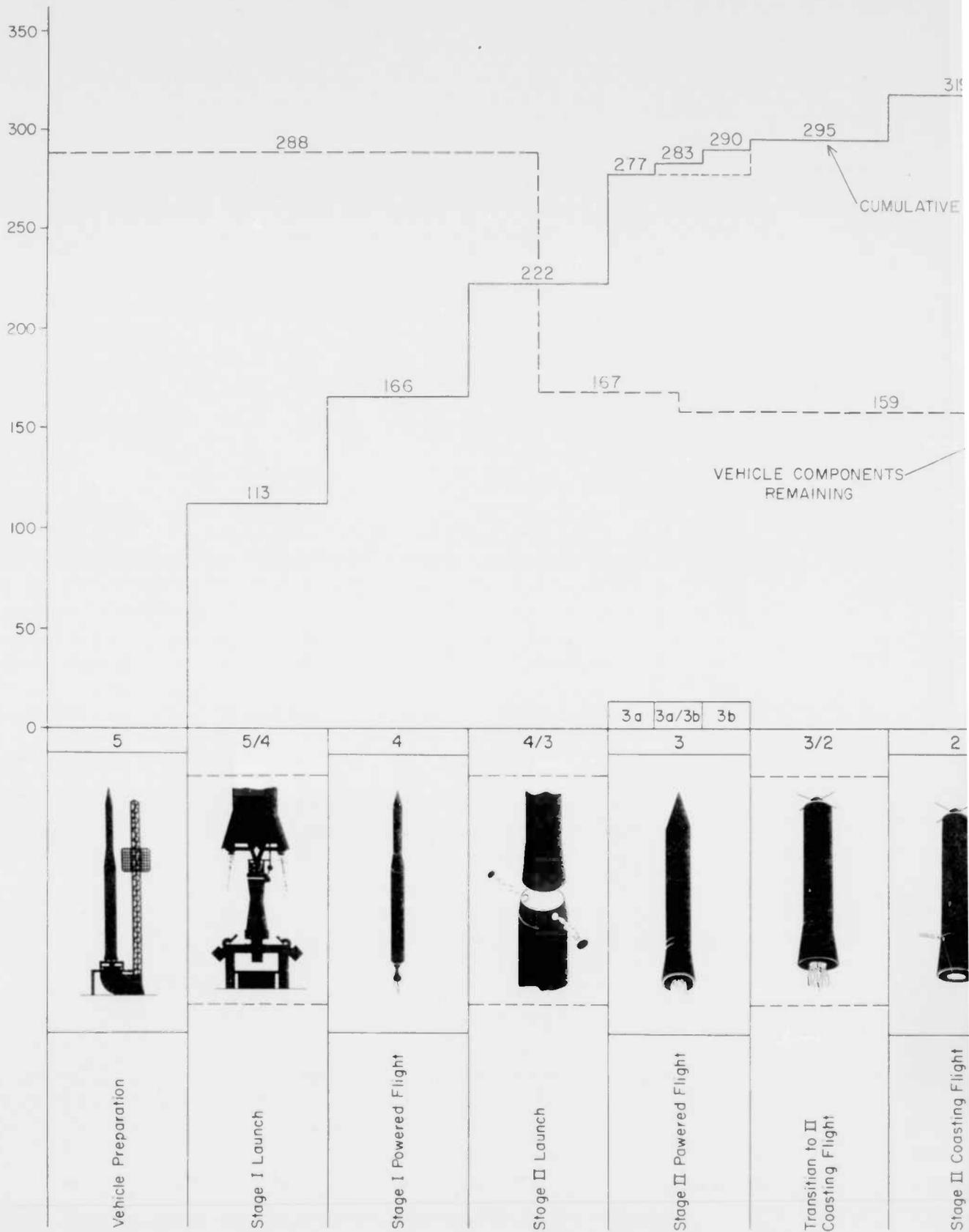


Figure 5 - Profile of components and events over t

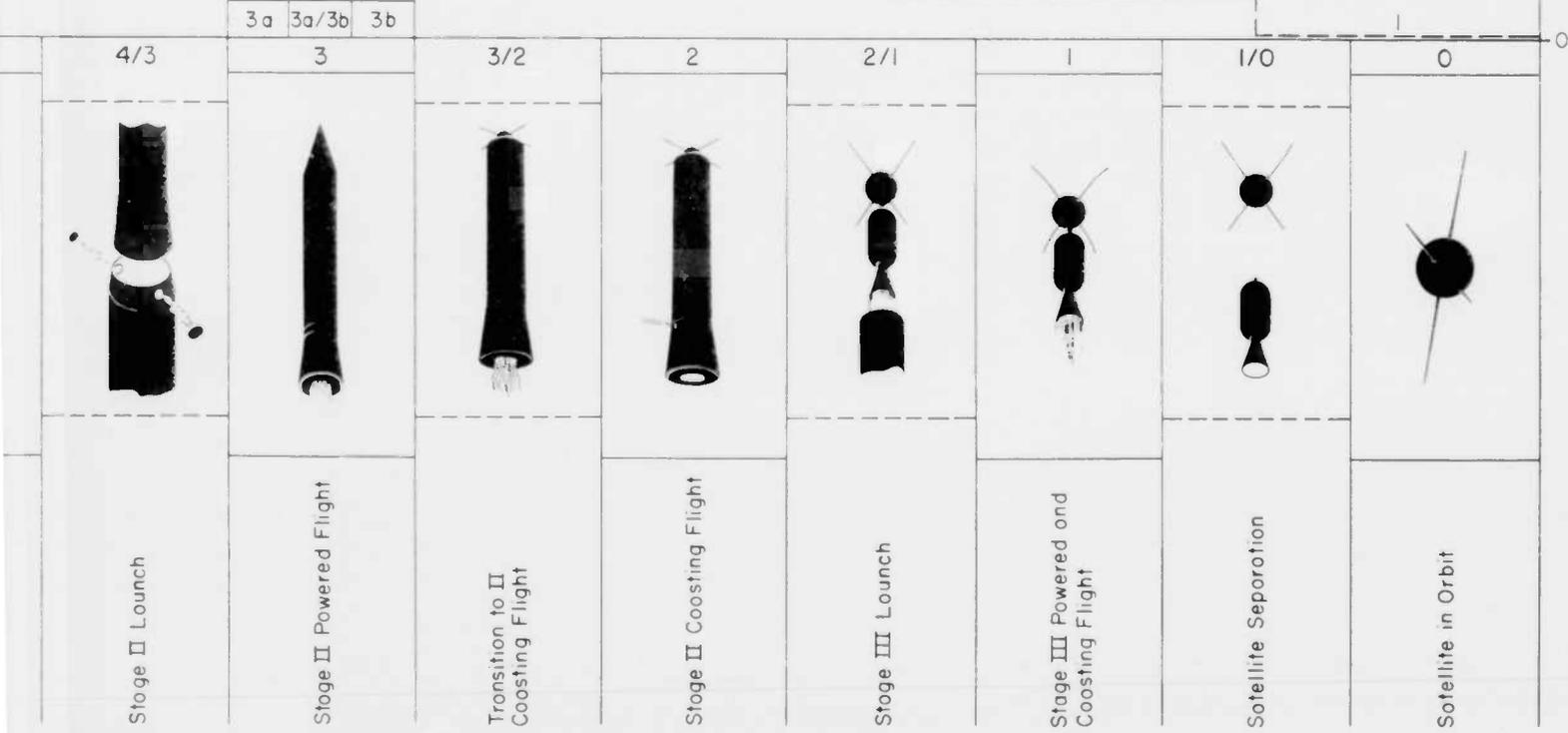
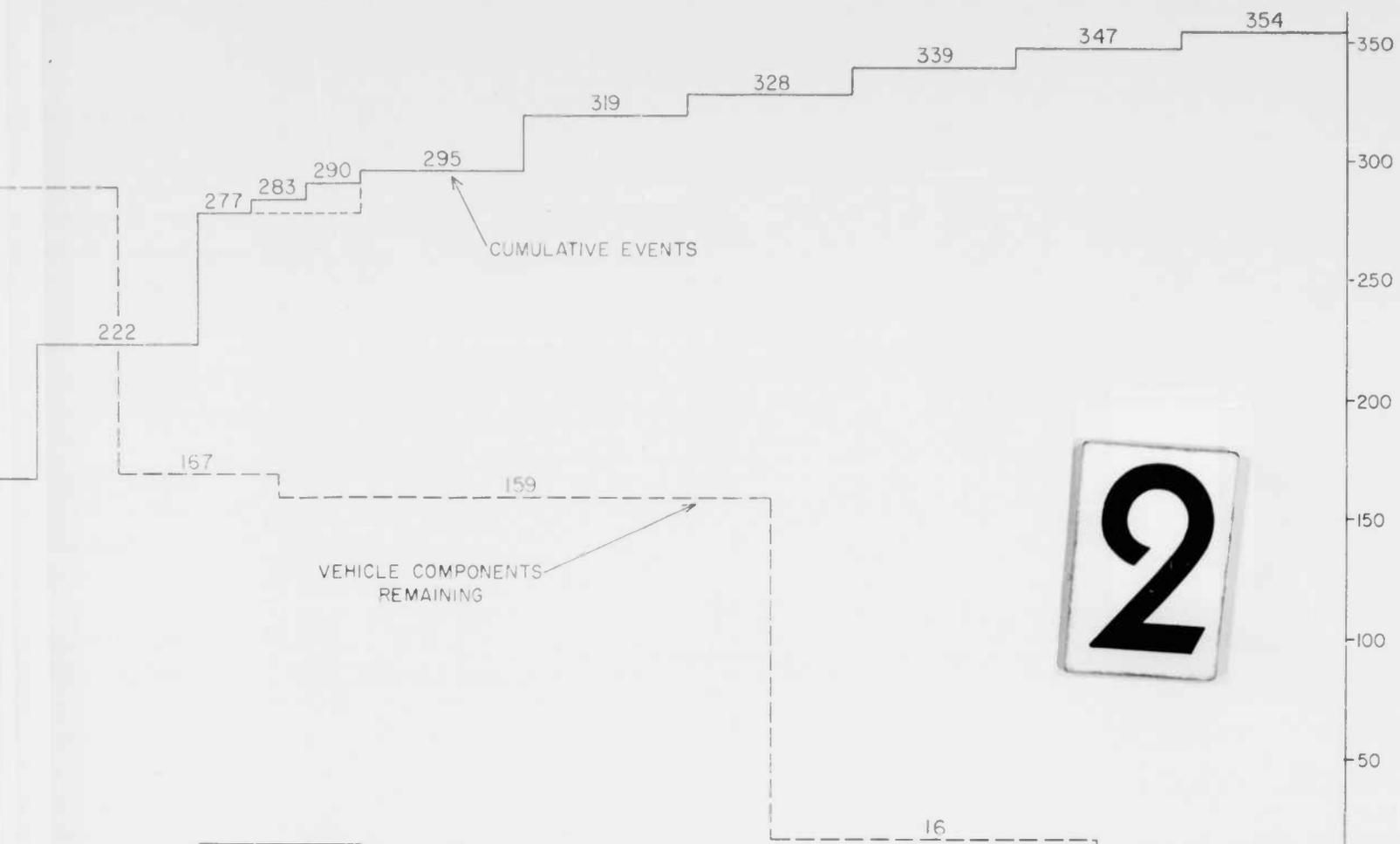


Figure 5 - Profile of components and events over the flight program

## Condensed Sequence Diagram

To provide a brief overall description of the Vanguard launch program, a condensed Sequence Diagram is given in Figure 6. This diagram presents the more basic sequential relationships of the vehicle states and state transitions enumerated earlier, such as the operations initiating launch and staging.

This condensed diagram may help to orient the reader to the more elaborate Master Diagram. As with the larger diagram (see Appendix A), a narrative interpretation of the condensed diagram is provided here:

Vehicle Preparations (State 5) are completed during the launch countdown operations and are considered terminated at closure of the blockhouse "fire" switch, whereupon automatic sequencing of the first-stage rocket engine results in thrust build-up and vehicle lift-off. This comprises Stage I Launch (Transition 5/4).

Stage I Powered Flight (State 4) commences upon lift-off and steady-state operation of all systems and continues to exhaustion of either of the first-stage propellants (nominally 142 seconds), at which time Stage II Launch (Transition 4/3) occurs. The first-stage engine is shut down, the second-stage engine ignited, and the first-stage separated. Stage II Powered Flight (State 3) then takes place until propellant exhaustion (nominal duration 116 seconds). This state is subdivided into powered flight with the nose cone attached (Sub-State 3a), nose-cone jettisoning (Transition 3a/3b), and powered flight with the nose-cone off (Sub-State 3b). A program timer signal at 172 seconds after lift-off causes nose-cone jettisoning.

Upon second-stage propellant exhaustion, the transition to Stage II Coasting Flight occurs (Transition 3/2). This is completed with the post-cutoff attitude control system in operation. Stage II Coasting Flight (State 2) continues for approximately five minutes until the third-stage firing command is received.

This third-stage firing command originates either in the vehicle-borne coasting time computer or by ground radio command which has already (132 seconds previously) started a vehicle-borne fixed-time command timer. Stage III Launch (Transition 2/1) consists of the spinning of the third-stage and energizing of its delayed (15 seconds) igniter, separation from the second stage by retro-rockets, and ignition. Stage III Powered and Coasting Flight (State 1) is thus initiated. During this period the satellite is accelerated to orbital velocity. The satellite separation device, which is armed by third-stage acceleration, causes Satellite Separation (Transition 1/0) at a fixed time after third-stage burnout. This establishes the Satellite in Orbit (State 0).

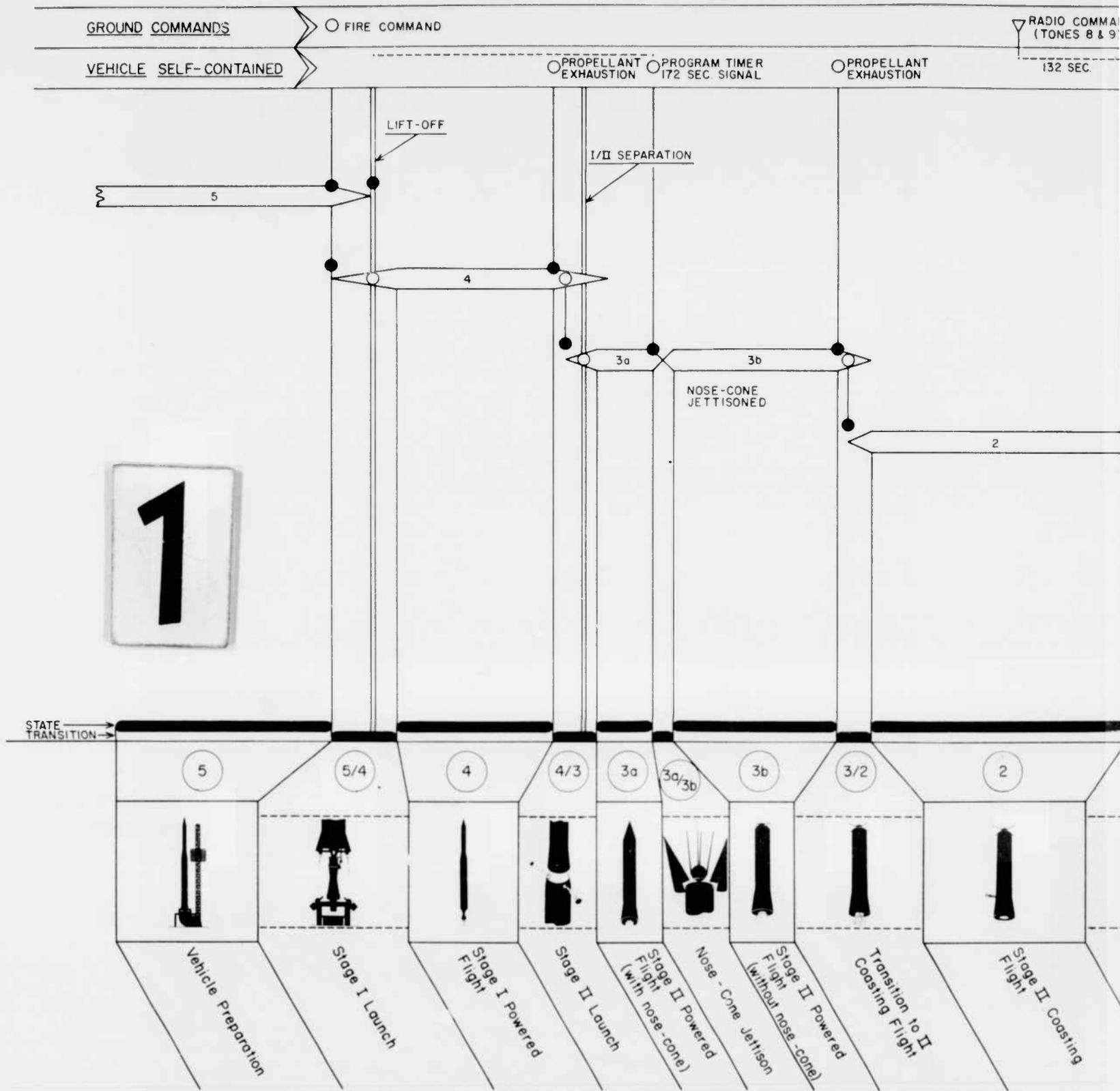
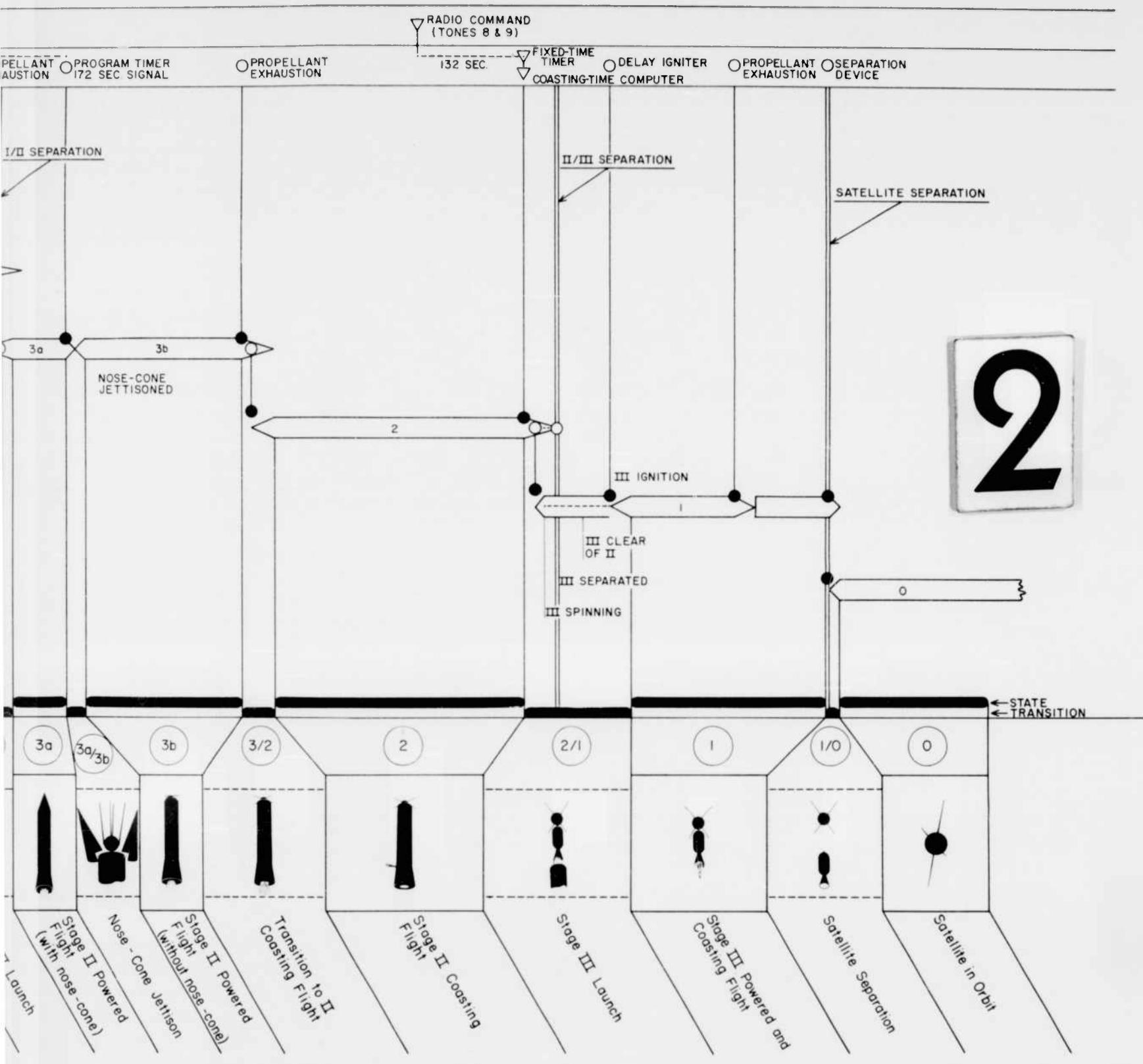


Figure 6 - Condensed sequence diagram of satellite launching vehicle



6 - Condensed sequence diagram of satellite launching vehicle flight program

## Vehicle In-flight Sequencing; Flight Test Results

Figure 7 presents a summary of actual vehicle in-flight sequencing performance for Vanguard vehicles having satellite capability. The progress of each of eleven vehicles is related to both the nominal event sequence and the state, state transition breakdown. Since vehicle lift-off is the point of definite commitment of a vehicle, only in-flight events are considered in assigning a percent success figure to each vehicle.

Of eleven vehicles, three progressed through the launch sequence with no critical failures, and thereby established the Vanguard I, II, and III satellites (1958  $\beta$ , 1959  $\alpha$ , and 1959  $\eta$  respectively). Two other vehicles performed the entire sequence but sustained failures that precluded the establishment of a satellite. The remaining six vehicles failed to complete the sequence program. It is interesting to note that, of these six cases of premature sequence termination, five occurred during state transition, and only one during a state operating period. Further, the two vehicles which sustained critical failures and yet continued the sequence program also failed during state transition. Thus seven of the eight unsuccessful vehicles, or 87.5 percent, failed during state transition. A summary follows:

<u>State Transition</u>	<u>Failures</u>
5/4 Stage I Launch	1
4/3 Stage II Launch	4
3/2 Transition to Stage II Coasting Flight	2
<u>State</u>	<u>Failures</u>
4 Stage I Powered Flight	1

By use of Figure 7 an index of success in sequencing can be established for the Vanguard vehicle series. For the eleven vehicles having satellite capability, the average percent success (without critical failure) was 59.7 percent.

## CONCLUDING REMARKS

The sequence diagram has been used in this report to depict the operation of the Vanguard Satellite Launching Vehicle through its flight program. On this basis an abbreviated analysis illuminated several aspects of the vehicle's composition and mode of functioning. Further analysis, such as a reliability study, has been left open at this point. However the information presented should be useful for any such projected study.

1

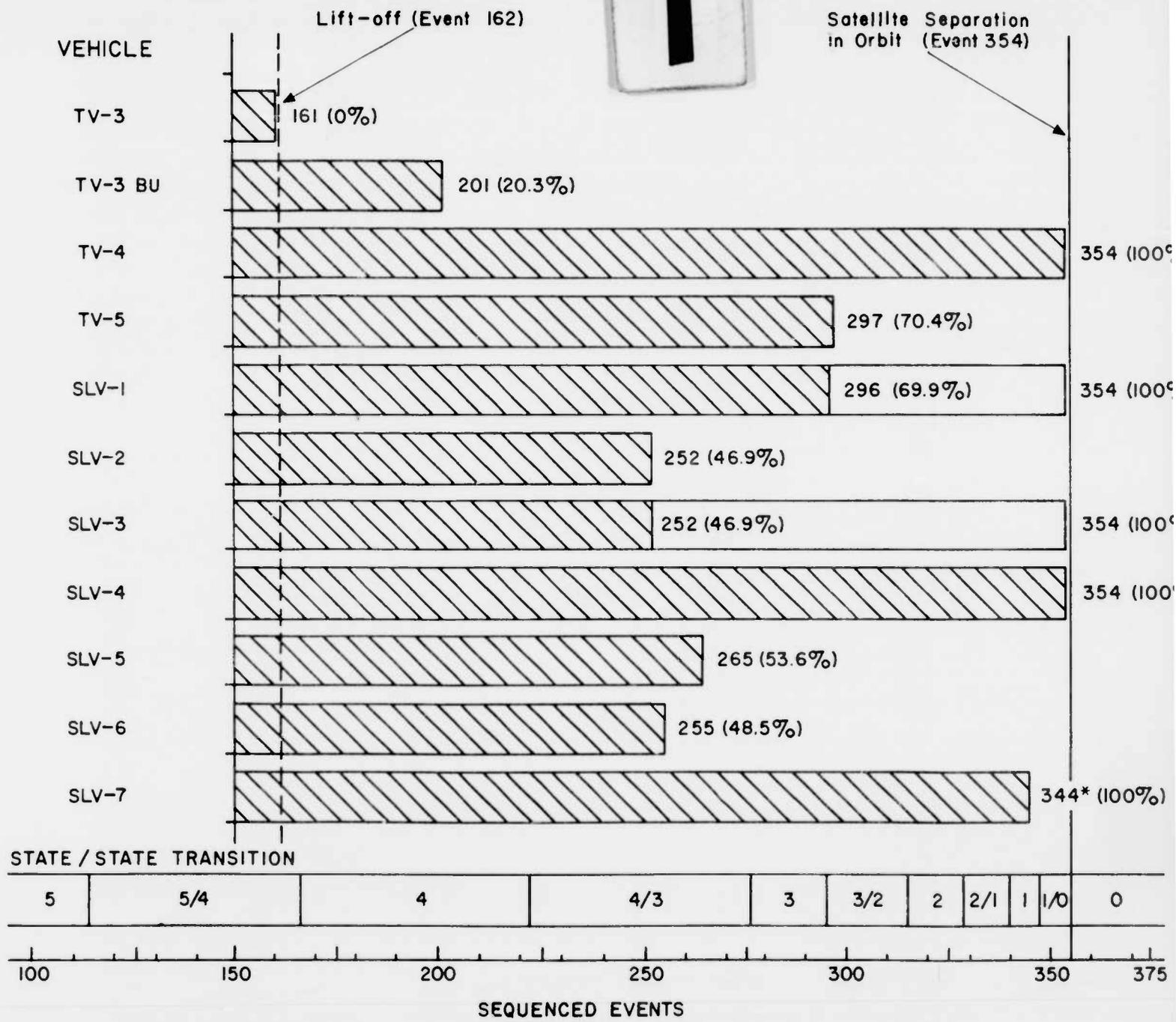


Figure 7 - Summary of vehicle in-flight sequencing for all Vanguard satellite capability

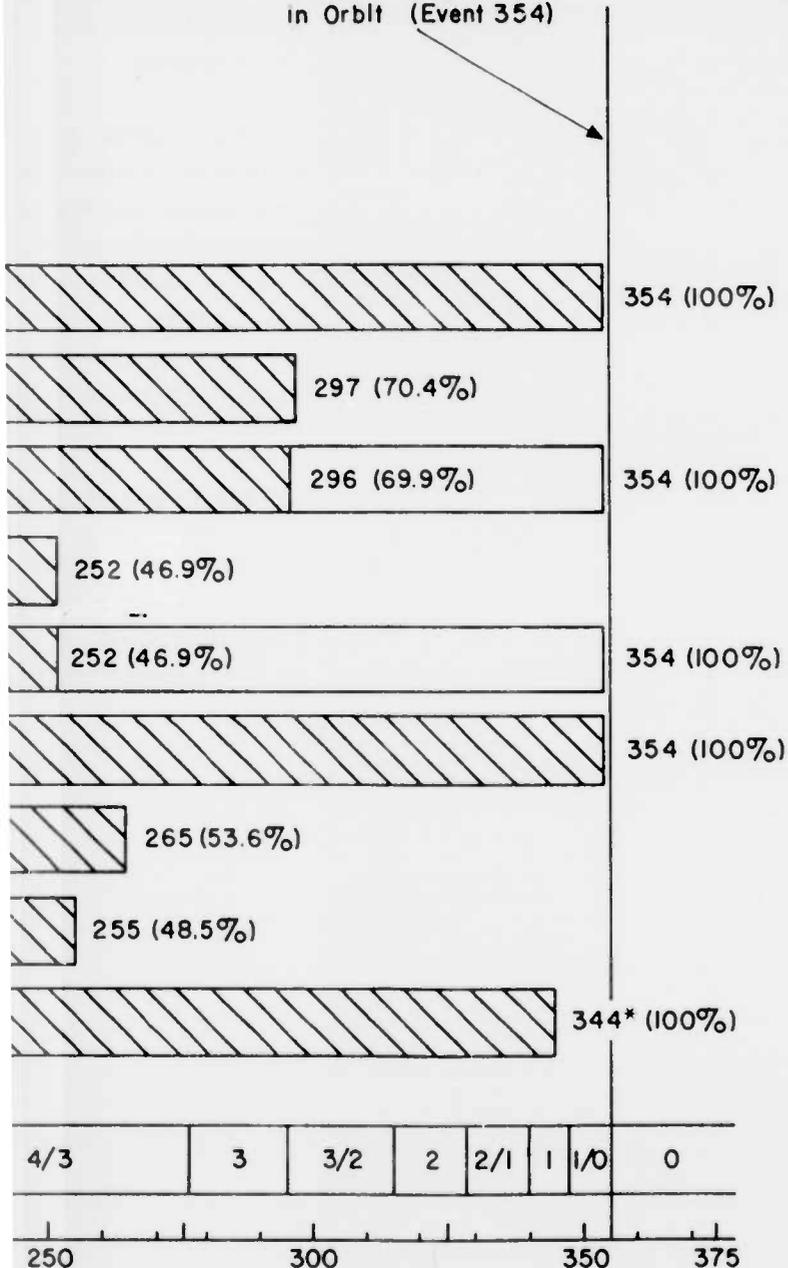
LEGEND

First number: Event Number  
 Second number (in parenthesis): Percent of events from lift-off to satellite separation in orbit successfully sequenced by vehicle.

COMMENTS

- Lost thrust at lift-off
- Spurious gimbal action in 57-60th second of flight caused vehicle break-up
- Established satellite VANGUARD I (1958 $\beta$ )
- Failed to initiate transfer to coasting flight condition; no Stage III firing
- Transient pitch moment at Stage II cut off upset gyro reference; incorrect injection angle for Stage III.
- Stage II oxidizer system partially clogged caused low chamber pressure and cut off
- Stage II fuel injector partially clogged; low injection velocity and altitude
- Established satellite VANGUARD II (1959 $\alpha$ )
- Delay in I/II separation induced Stage II flame separation breaking gimbal actuator
- Stage II helium regulator valve did not operate; rapid thrust decay at start
- Established satellite VANGUARD III (1959 $\gamma$ )

Satellite Separation in Orbit (Event 354)



\*Satellite separation not planned

- Summary of vehicle in-flight sequencing for all Vanguard vehicles having satellite capability

On the basis of the Project Vanguard experience, the construction and up-to-date maintenance of a master sequence diagram is recommended early in the development of a vehicle. This would give a "current picture" of the vehicle, as does the familiar system of current weight statements. A standard drawing version of the diagram such as the one in this report is probably not practical in this instance. The continuous need for revision and modification before the design becomes firm would necessitate many reconstructions of the diagram.

Alternatively a "plotting board" approach for a sequence diagram is feasible. This method would allow new components to be introduced, new cause-effect relationships to be established, and events to be added or removed with a minimum of difficulty. Here event lines might be vertical cords; cause-effect symbols might be color-coded pin heads. The "plotting board" sequence diagram could be reproduced photographically after each modification, or periodically. A file of these photographs would constitute a definitive record of the growth of the vehicle through its development period. Eventually, data-processing machines might well be used to handle sequence diagram information efficiently.

## **ACKNOWLEDGMENTS**

The basic component listing and layout of the SLV Master Sequence Diagram was performed by Mr. H. Kent Frewing while a student summer employee at the Naval Research Laboratory. Acknowledgment is extended to him, and to Mr. Frank H. Ferguson who originally envisioned the potential value of a single definitive statement about the launch vehicle.

## APPENDIX A

**NARRATIVE DESCRIPTION\* OF THE SLV  
SEQUENCE OF OPERATIONS****State 5: Vehicle Preparation**

The following operations were performed as dictated by the countdown procedure: Prior to the commencement of activity, the main blockhouse power supply (G1) was energized to supply 28-volt dc power for the duration of the test. The equipment house dc power supply was also turned on (G26). Prior to the start of the countdown, the gyro monitoring panel power switch (G5) was placed in the "On" position. The power-control-bus relay (G2), which had been previously energized when the main blockhouse power supply was turned on, provided power to the firing panel master power switch (G3) which was subsequently turned on.

At T-100 minutes the rotary power-transfer selector switch (G4) was placed in the "ground power" position to switch the vehicle electrical power system to external 28-volt power. This occurred when the power transfer contactor (G27) became energized and the Stage I and Stage II main busses (V68 and V134) were activated. At that time the majority of the vehicle electrical operating systems became energized and commenced operation.

In becoming activated, the program timer time-reference generator (V182) energized the program timer power amplifier (V183). Provided that the program timer Relay A was deenergized, motor drive assembly (V184) of the program timer began operating with its clutch released. The coasting-time-computer reference frequency amplifier also caused the coasting-time-computer power amplifier and the timing motor and gear train (V254, 255 and 256) to commence operation.

The oxidizer pump and battery heaters switch (G6) was turned on, energizing the heater contactor (G28). This energized the oxidizer pump neck heater (V7), and the Stage I battery heater (V66). The battery heater was controlled by a thermostat (V67) in an "Off-On" mode to regulate the battery temperature. Switch (G7) was turned on to energize

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\*For use with Vanguard Master Sequence Diagram

the propane heater contactor (G29) which energized the propane tank heater in the second stage. This heater was not thermostatically controlled but rather was monitored by a panel operator on the basis of readings of the propane tank pressure indicator.

At T-80 minutes the umbilical-bus arming switch (G30) was operated into the "Flight" position. This caused the helium-umbilical fire-sequencing relay (G31), the cooling-air-umbilical fire-sequencing relay (G32), and the electrical-umbilical fire-sequencing relay (G33) all to become energized.

By T-20 minutes the gyro rotor switch (G9) was turned on. The gyro rotor relay (V129) was thereby deenergized, causing the pitch, yaw, and roll gyro rotors (V194, 208, and 222) and the coasting-time-computer pendulous gyro rotor (V251) to begin to build up to operating speed. The coasting-time-computer turntable servo (V252) went into a controlling mode with spin-up of the pendulous gyro. By T-17 minutes the gyro caging amplifier switch (G10) was turned on to electrically cage the pitch, yaw, and roll gyros once they had attained operating speed.

At T-15 minutes, the Stage I helium pressurizing switch (G8) was operated as required to pressurize the Stage I spheres. This energized the Stage I helium pressurizing relay (G35), which opened the helium pressurizing valve (G36) provided the ground supply source (G25) was supplying helium as required. The helium check valve (V37) was opened by the gas flow and the two helium spheres, (V38 and V39) were loaded to rated pressure (the spheres were pressurized to a lower level earlier for system check-out purposes), provided the helium burst disc assembly (V40) remained intact (safety function).

At T-9 minutes the Stage I ground hydraulic power switch (G11) was turned on, causing the ground hydraulic power supply (G37) to supply Stage I hydraulic power. At that time the Stage I pitch and yaw transfer valves (V80 and V85) and hydraulic actuators (V81 and V86) combined to begin positioning the gimballed thrust chamber in pitch and yaw (V83 and V88).

At T-6 minutes the Stage II hydraulic-pump motor switch (G12) was actuated to the "On" position and, provided the hydraulic-pump ground power cutoff and oxidizer pressurizing relay (G39) was deenergized, the hydraulic pump ground contactor (G38) was energized. This caused the Stage II hydraulic-pump motor and pump (V145 and 146) to begin operating, thereby energizing the Stage II hydraulic system (V147 through 151). The Stage II pitch and yaw transfer valves (V197 and V211) and hydraulic actuators (V198 and V212) then operated to position the Stage II gimballed thrust chamber in pitch and yaw (V200 and V214).

At T-6 minutes the Stage II pressurizing switch (G13) was operated as required to commence Stage II propulsion system pressurization. The switch activated the Stage II pressurizing relay (G40) to open the Stage II pressurizing valve (G41). Then, provided that the helium pressure source (G25) was supplying helium as required and that the helium-umbilical disconnect and line (G51) was connected, the Stage II helium sphere

(V161) began its pressurization cycle, the oxidizer pressurizing check valve (V171) was opened and—provided the bypass helium shutoff valve (V164) was open—the oxidizer tank (V172) was pressurized. Provided that the bypass helium shutoff valve (V164) was open, the fuel tank pressurizing check valve (V176) was also opened and fuel tank pressurizing commenced (V177). The pressure in the oxidizer and fuel tank, once pressurized, were controlled in an "Off-On" mode through interaction of helium sphere pressure switch No. 2 (V163) and the bypass helium shutoff valve (V164). This mode of pressure regulation was continued until the startup of the Stage II propulsion system in flight.

At T-5 minutes the rotary power-transfer selector switch (G4) was turned to the "Flight power" position. This energized the Stage I fire bus relay (G14) and in turn de-energized the power transfer contactor (G27). The battery-contactor control relay (V62) was switched from the "latched" to the "unlatched" position\*, energizing the battery contactor (V63). The Stage I battery (V64) then supplied vehicle 28-volt power in lieu of the ground power supply. The energizing of the fire bus relay (G14) caused the remote Stage I fire bus contactor (G42) to become energized.

At T-165 seconds, if a "Range clear" condition existed, the range safety "Hold fire" switch (G15) was closed to the "Proceed" position, energizing the range safety relay (G16).

At T-120 seconds the Stage I pressurizing switch (G17) was operated to: (A) energize the hydraulic-pump ground power cutoff and oxidizer pressurizing relay (G39), which in turn deenergized the hydraulic-pump ground power contactor (G38), and (B) provided that Lift-Off Switch No. 1 (V77) was in the "On stand" position, to energize the pressurizing relay (V26). Provided that the radio and ground cutoff relay (V28) remained deenergized, V26 was electrically latched after the switch was released. This effected several functions, as follows: (A) The dynamotor control relay (V136) was energized causing the dynamotor (V138) to switch from vehicle bus power to the Stage II battery (for purposes of B-plus voltage isolation). (B) The rocket cutoff relay in the Stage I engine sequencer (G71) was energized. (C) The helium regulator assembly (V34) was turned on and began regulating pressure in the Stage I propulsion system. Upon being activated, the helium regulator assembly (V34) allowed the helium spheres (V38, 39) to supply helium to the propulsion system tankage as required. (D) The Hydraulic-pump motor relay (V144) was energized causing the Stage II hydraulic-pump motor to operate on the Stage II battery power (switched from vehicle bus power). (E) The fuel-tank vent-valve pilot valve (V43) opened to close the fuel-tank vent-relief valve (V44). (F) The fuel pump inlet switch (V45) was energized, causing the fuel-tank pressurizing valve (V46) to open as required to pressurize and maintain the pressure in the fuel tank (V47) provided that the fuel tank pressurizing test switch (V30) was in the "Flight" position. The control mode was "Off-On." (G) The peroxide tank vent valve (V56) was opened causing the peroxide tank vent relief valve to become closed (V57). Provided the peroxide fill disconnect (V55) was closed, the peroxide tank

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\*These two positions were functionally identical insofar as the relay was concerned.

vent-relief valve (V57) was closed, the peroxide tank burst disc assembly was sealed and intact, and the peroxide tank pressurizing hand-valve (V59) had been previously opened, the peroxide tank was now pressurized to the rated regulated pressure. (H) The helium regulator assembly (V34) also supplied pneumatic operating pressure to the Stage I roll-jet solenoid valves (V90 and V93), to permit pneumatic actuator assemblies No. 1 and 2 (V91 and V94) to actuate their respective swivel nozzles (V92 and V95) as required for Off-On roll control in flight.

At T-45 seconds the kerosene tank was raised to starting pressure by momentary operation of the fuel tank pressure override switch (G18); this upset the previously established Off-On regulating cycle opening the fuel tank pressurizing valve (V46) to permit further increase in kerosene tank pressure for the start condition only. When rated starting pressure was established, the override switch (G18) was turned off to reestablish the fuel tank Off-On regulating cycle for flight; however, tank pressure remained at the maximum point until fuel flow began.

At completion of the Stage II pressurization and topping procedure, the Stage II pressurizing switch (G13) was turned off, deenergizing the Stage II pressurizing relay (G40) and thus closing the Stage II pressurizing valve (G41); no further topping of the Stage II helium sphere occurred.

At T-45 seconds the helium-umbilical disconnect switch (G19) was operated to the "Disconnect" position, thus energizing the helium-umbilical disconnect relay (G43) provided that the umbilical-bus arming switch (G30) was in the "Flight" position and the Stage I remote firing-bus contactor (G42) was energized. The helium-umbilical pneumatic actuator (G50) was then actuated, releasing the helium-umbilical disconnect and line (G51) from the vehicle. This caused the helium-umbilical fire sequencing relay (G31) to return to its deenergized position.

At T-30 seconds the cooling-air-umbilical disconnect switch (G20) was operated to the "Disconnect" position, energizing the cooling-air-umbilical disconnect relay (G44) provided that the umbilical-bus arming switch was in the "Flight" position and the remote firing-bus contactor (G42) was in the energized position. The cooling-air-umbilical pneumatic actuator (G42) was actuated, releasing the cooling-air-umbilical disconnect and line from the vehicle. This in turn mechanically withdrew the satellite cooling air line (G54) and caused the cooling-air-umbilical fire-sequencing relay (G32) to return to its deenergized position.

At T-30 seconds the Stage I oxidizer tank vent switch (G21) was actuated to the "Vents Closed" position and, provided that the radio and ground cutoff relay (V28) was in the deenergized position, the oxidizer-tank vent-valve pilot valve (V49) was energized via the oxidizer tank pressurizing relay (V27). This caused the oxidizer-tank vent-relief valves No. 1 and No. 2 (V50 and 51) to close, relieving overpressure from boil-off as required.

At T-20 seconds the oxidizer tank pressure override switch (G22) was operated momentarily, actuating the oxidizer tank pressurizing valve (V53) to pressurize the oxidizer tank (V54) to starting pressure, provided that the hydraulic-pump ground power cutoff and oxidizer pressurizing relay (G39) was energized, that the oxidizer tank pressurizing relay (V27) was deenergized, and that the oxidizer tank pressurizing test switch (V31) was in the "Flight" position. The oxidizer tank could be pressurized only if the oxidizer-tank fill disconnect (V48) was closed (lox topping terminated) and the oxidizer-tank vent-relief valves No. 1 and No. 2 (V50 and V51) were also closed. The oxidizer pump inlet pressure switch (V52) was opened but remained electrically inactive until the "Fire" command.

With final Stage I helium sphere pressure topping terminated, the Stage I helium pressurizing switch (G8) was turned off, the helium pressurizing relay (G35) became deenergized, and the helium pressurizing valve (G36) remained closed.

At T-5 seconds the Stage I engine purge switch (G23) was turned to the "Purge" position, energizing the purge relay (G45) provided that the fuel valve open relay (G-79) in the engine sequencer was deenergized. The energizing of the purge relay (G45) opened the purge solenoid valve (G57) and, provided that the purge disconnect (G64) was connected, the purge check valve (V1) opened to admit low-pressure nitrogen into the thrust chamber assembly (V24) cooling passage. This nitrogen passed out of the fuel injector orifices, carrying with it a quantity of kerosene vapor and spray from the fuel-primed thrust chamber jacket.

At T-0 the fire/cutoff switch (G24) was operated to the "Fire" position, and Transition 5/4: Stage I Launch, ensued.

### Transition 5/4: Stage I Launch

With closure of the fire/cutoff switch (G24) to the "Fire" position, the Stage I firing relay (G46) was energized. Provided that the umbilical-bus arming switch (G30) was in the "Flight" position, the electrical-umbilical solenoid (G55) was actuated to release the electrical-umbilical disconnect and line (G56), causing the electrical-umbilical fire-sequencing relay (G33) to return to its deenergized position.

The pitch, yaw, and roll gyros (V194, 208, and 222), were all uncaged as a consequence of disconnecting the caging amplifier through the umbilical plug connections.

The energizing of the Stage I firing relay (G46) also energized the oxidizer tank pressurizing relay (V27), which (A) held the oxidizer vent-valve pilot valve (V49) open, and (B) enabled the oxidizer pump inlet pressure switch (V52) and oxidizer tank

pressurizing valve (V53) to operate together in an Off-On mode to regulate the oxidizer tank (V54) pressure. However, the previously set higher starting pressure was maintained until oxidizer flow began.

Provided that the helium-umbilical fire-sequencing relay (G31), the cooling-air-umbilical fire-sequencing relay (G32), the electrical-umbilical fire-sequencing relay (G33), the Stage III umbilical fire sequencing relay (G34) (not used), and the engine cutoff relay (G47) were all deenergized, and that the purge relay (G45), the oxidizer tank pressurizing relay (V27), and the Stage I pressurizing relay (V26) were energized, then the ground sequencing power relay (G48) became energized. This caused the following: (A) The heater contactor (G28) became deenergized, deenergizing the oxidizer pump neck heater (V7) and the Stage I battery heater (V66); (B) the cutoff delay relay (G49) began its 1/10-second delay cycle prior to becoming energized; and (C) the following relays in the Stage I engine sequencer were energized: The ignition indication relay (G72), the combustion indication relay (G73), the peroxide valve closed relay (G74), the ignition to oxidizer gate (G82), and the peroxide to lift-off gate (G84).

At this point components in the Stage I engine sequencer, the ignition control unit, and the Stage I rocket engine assembly proceeded through the engine start sequence as follows: The energizing of the peroxide valve close relay (G74) energized the oxidizer valve relay (G75), which in turn caused the oxidizer to fuel timer (G81) to become energized (but not timing). The energizing of the ignition indication relay (G72) energized the ignition indication to peroxide gate (G83). This in turn energized the cutoff relay (G76), provided that the rocket cutoff relay (G71) had been energized previously. If the cutoff delay relay (G49) proceeded through its timing cycle before the cutoff relay (G76) became energized, the engine went into its cutoff sequence. For the cutoff relay (G76) to become energized, it was also necessary that the following relays had been energized previously: combustion indication relay (G73), ignition to oxidizer gate (G82), and peroxide to lift-off gate (G84). The energizing of the cutoff relay (G76) energized the ignition relay (G77), causing the ignition to oxidizer gate (G82) to begin its timing mode for time-gate imposition, the ignition contactor (G85) to become energized, and the oxidizer valve closing valve, (V2), to close, thereby releasing the holding pressure on the oxidizer main valve (V4).

The energizing of the ignition contactor (G85) activated the igniter assembly (G86), which began burning within the thrust chamber. In the initial burning the ignition indicator link (G87) was broken, deenergizing the ignition indication relay (G72), and thus satisfying the time-gate imposed by the ignition to oxidizer gate (G82). The energizing of the ignition indication relay (G72), provided that the ignition relay (G77) had been previously energized, opened the oxidizer valve opening valve (V3). Provided that the oxidizer valve closing valve (V2) had been previously closed, the oxidizer main valve (V4) was actuated open to the preliminary open position, thus opening the oxidizer valve closed switch (V5). This in turn deenergized the oxidizer valve closed relay (G75), causing the oxidizer to fuel timer (G81) to start its timing mode.

The oxidizer main valve (V4), in moving to the preliminary open position, allowed oxidizer pressure to open the oxidizer check valve (V6), thus permitting the oxidizer tank and suction line (V54) to start supplying oxygen. Provided that the igniter (G86) was burning and the oxidizer check valve (V6) had opened, low-order combustion began in the thrust chamber assembly (V24) with the igniter, the fuel prime, and gaseous oxygen participating. When the oxidizer to fuel timer (G81) had completed its timing cycle, provided that the oxidizer valve closed relay (G75) was deenergized and the cutoff relay (G76) remained energized, the fuel start relay (G78) started its delay cycle, subsequently becoming energized. In addition, the fuel opening relay (V10) became energized and, provided that the combustion indication relay (G73) was energized, the fuel valve opening valve (V11) opened. This opened the fuel main valve (V12) to its full open position, thus causing the fuel valve closed switch (V13) to open and the fuel valve open switch (V14) to close. This in turn caused the fuel valve open relay (G79) to become energized. The fuel tank and suction line (V47) then supplied kerosene through the fuel main valve to the thrust chamber at low pressure. Provided the igniter (G86) was still burning and the ignition flame had been sustained in the thrust chamber, fuel-rich combustion began in the thrust chamber assembly (V24). When sufficient combustion pressure had been developed at the nozzle exit, the combustion indicator (G88) was expelled from the thrust chamber causing the combustion indicator switch (G89) to open, thereby deenergizing the combustion indication relay (G73). This, provided that the peroxide valve closed relay (G74) and the fuel start relay (G78) were energized, caused the peroxide opening relay (V17) to become energized, opening the peroxide valve pilot valve (V18) and in turn the main peroxide valve (V19). This opened the peroxide valve closed switch (V20), deenergizing the peroxide valve closed relay (G74). The peroxide tank (V60) supplied high-pressure peroxide flow through the open peroxide valve (V19) into the peroxide decomposer (V22). The decomposer began generating heated gas which passed into the inlet of the turbine (V23). Meanwhile, the closure of the peroxide valve open switch (V21) energized the peroxide valve open relay (G80), provided the fuel valve open relay (G79) had been previously energized. This causes the peroxide to lift-off gate (G84) to begin its timing cycle, and simultaneously the time gate of the ignition indication to peroxide gate (G83) was satisfied. (The peroxide to lift-off time gate was locked out for launch.)

With high-pressure heated gas being supplied to it, the turbine (V23) began driving the oxidizer pump (V8), and the fuel pump (V15), into a pumping condition. At turbopump activation, the gear-driven Stage I hydraulic pump (V69) was operated to supply hydraulic system pressure (V70 through V74). Provided that the purge check valve (V1) was closed by the preliminary fuel flow, combustion continued in the thrust chamber assembly (V24), and the supply of kerosene and oxygen continued from the fuel and oxidizer tanks (V47, 48), then high-pressure combustion was initiated by the propellant pumps and the thrust chamber assembly (V24) developed increasing thrust. Increasing oxidizer pump-out pressure forced the spring-loaded oxidizer main valve (V14) to move to its full-open position. Both oxidizer and fuel flow rates ascended to rated values. Increasing combustion chamber

pressure activated the Stage I thrust chamber pressure switch (V61). When developed thrust exceeded the vehicle weight plus disconnect forces, the vehicle structure (longitudinal acceleration) (V25) lifted from the launch stand, disconnecting the electrical disconnects (G58 through G61), the oxidizer fill and topping disconnect (G62), the helium high-pressure disconnect (G63), the purge disconnect (G64), and the hydraulic disconnects (G65 and G66). As the vehicle rose, the launch stand swing-away supports, I through IV, (G67 through G70), rotated to the "Clear" position. The helium disconnect and check valve (V36) was closed. In order to maintain pressure in the helium spheres (V38 and V39) either the helium disconnect (V-36) or the helium check valve (V-37), or both, had to be closed. With lift-off and disconnect, the vehicle hydraulic disconnect units (V75 and V76) were closed to seal the Stage I hydraulic system.

At lift-off ( $T + 0$ ), lift-off switches Nos. 1, 2, and 3 (V77, V78 and V79) moved into the "In-flight" position. Lift-off switch No. 2 (V78) in going into the "In-flight" position, provided that the controls switch (V135) was in the "Flight" position, caused the coasting-time-computer clutch (V258) to be engaged, which in turn caused the time indication arm of the coasting-time computer (V259) to begin rotating at a rate proportional to the vehicle's total longitudinal acceleration. Lift-off switch No. 3 (V79), going into the "In-flight" position, caused the clutch in the program-timer motor drive assembly (V184) to be energized and to commence driving the gear train and transport mechanism (V185), starting the programming tape of the program timer (V186) into motion.

When the vehicle was clear of the launch stand, the vehicle structure about the pitch axis (V84) and the yaw axis (V89) was controlled in attitude by the gimbaled thrust chamber control loop. The vehicle structure about the roll axis (V96) was controlled by the two swivel nozzles of the Off-On roll control system, using the turbine exhaust products as the reaction medium. The attitude control loops in pitch, yaw and roll were closed back to the gyro reference system via the vehicle airframe.

When all systems had reached a steady-state operating status, Stage I Launch (Transition 5/4) was terminated and State 4, Stage I Powered Flight, began. At lift-off all ground components (G1 through G89) were eliminated from the scope of interest.

## **State 4: Stage I Powered Flight**

The initial 10 seconds of powered flight occurred normally with a constant attitude reference in the vehicle pitch, yaw and roll control axes. Thereafter, a pitch-over program

was begun by the program timer, with a total of five constant pitching rates being introduced via the pitch gyro over the remainder of the trajectory.\*

At ten seconds<sup>†</sup> the program timer programming tape (V186) caused momentary activation of microswitch and actuator C (V187c) which, provided that relay A (V188a) was deenergized, caused relay B (V188b) to become energized, in turn energizing relay C (V188c). This caused the program resistor unit (V189) to provide a gyro torquing current corresponding to the first pitch rate via the frequency-compensated dc converter (V192) to the pitch gyro torquer, which caused the pitch gyro (V194) to be precessed at the first pitch rate. As the pitch attitude reference changed, the gimballed thrust chamber system caused the vehicle structure (about the pitch axis) (V84) to execute the first pitch-over rate.

Prior to 24 seconds the programming tape (V186) caused the microswitch and actuator B (V187b) to be activated, energizing relay A (V188a). At 24 seconds the programming tape (V186) activated microswitch and actuator C (V187c) momentarily which, provided that relay A (V188a) was energized, caused relay B (V188b) to become deenergized and, in turn, relay C (V188c) to become deenergized. At the same time, microswitch and actuator D (V187d) was activated and, provided that relay A (V188a) was energized, relay D (V188d) and in turn relay E (V188e) were energized. Provided that relay C (V188c) was deenergized, the closure of relay E (V188e) caused the program resistor unit (V189) to yield a current corresponding to the second pitch rate which, via the frequency-compensated dc converter (V192) caused the pitch gyro to precess at the second pitch rate. The vehicle structure (in the pitch axis) (V84) accordingly changed from the first to the second pitch rate.

Prior to 44 seconds, the programming tape (V186) deactivated microswitch and actuator B (V187b), thereby deenergizing relay A (V188a). At 44 seconds, the programming tape (V186) momentarily activated microswitch and actuator B (V187b); and provided that relay A (V188a) was deenergized, relay D (V188d) and then relay E (V188e) became energized.

At the same time, the programming tape activated microswitch E (V187e); and provided that relay A (V188a) was deenergized, relay F (V188f) and then relay G (V188g) became energized. Provided that relay E (V188e) was deenergized, relay G (V188g), in closing, caused the program resistor unit (V189) to yield a current corresponding to the third pitch rate via the frequency-compensated dc converter (V192), which produced the third pitch rate precession of the pitch gyro (V194). Thereupon the vehicle structure (in the pitch axis) (V84) transferred to the third pitch-over rate.

Prior to 108 seconds, the programming tape (V186) activated microswitch and actuator B (V187b) energizing relay A (V188a). At 108 seconds, the programming tape (V186)

\*In the SLV-6 vehicle, a roll program was also employed.

<sup>†</sup>All times based on a lift-off zero unless otherwise noted.

momentarily activated microswitch and actuator E (V187e), deenergizing relay F (V188f), provided that relay A (V188a) was energized. At the same time the programming tape momentarily activated microswitch and actuator F (V187f), energizing relay H (V188h) provided that relay (V188a) was energized.

Relay H (V188h), in becoming energized, energized relay I (V188i), which in turn caused the program resistor unit (V189) to yield a current corresponding to the fourth pitch rate via the frequency-compensated dc converter (V192) to the pitch gyro (V194). Accordingly, the vehicle transferred to the fourth pitch rate. Relay I (V188i) was effective only if relay G (V188g) had become deenergized. After 108 seconds, the programming tape (V186) deactivated microswitch and actuator B (V187b), which in turn deenergized relay A (V199a).

At 120 seconds the programming tape (V186) activated microswitch and actuator G (V187g); and provided that relay A (V188a) was deenergized, relay J (V188j) and in turn relay K (V188k) became energized. Relay K (V188k), in becoming energized, caused the Stage II battery contactor control relay (V130) to transfer from the "latched" to the "unlatched" position, and energized arming relays No. 1 and No. 2 (V140 and V141). Arming relay No. 1 (V140), in becoming energized, electrically armed the oxidizer pump outlet pressure switch (V9) and the fuel pump outlet pressure switch (V16), enabling them to signal propellant exhaustion for shutdown initiation. The Stage II battery contactor control relay (V130), in switching to the "unlatched" position, energized the Stage II battery contactor (V131), connecting the battery (V132) to the main vehicle bus. Thereby the Stage I and Stage II batteries were paralleled in supplying electrical power to the vehicle.

The vehicle continued in State 4: Stage I Powered Flight, until the exhaustion of either the kerosene or the oxygen (at a nominal time of 142 seconds) whereupon Transition 4/3: Stage II Launch was initiated.

### **Transition 4/3: Stage II Launch**

When either the Stage I kerosene supply or oxygen supply was depleted, the fuel pump outlet pressure switch (V16) or the oxidizer pump outlet pressure switch (V9) detected exhaustion and closed. Provided they had been electrically armed previously (at 120 seconds), either one energized the cutoff relay (V29), provided that the radio and ground cutoff relay (V28) remained deenergized. The energizing of the cutoff relay (V29) effected several operations:

- (A) The fuel opening relay (V10) and the peroxide opening relay (V17) were deenergized.

(B) The oxidizer valve closing valve (V2) was deenergized open, and the oxidizer valve opening valve (V3) was deenergized closed; these two functions act together to close the oxidizer main valve (V4) quickly. The fuel valve opening valve (V11) was deenergized closed. The closure of the fuel main valve (V12) was delayed pneumatically for 2 to 3 seconds to minimize hydraulic hammer in the fuel system. The peroxide valve opening valve (V18) was deenergized closed, causing the peroxide valve to be closed (V19). This in turn closed the peroxide valve closed switch (V20) and opened the peroxide valve open switch (V21).

(C) The closure of the cutoff relay also permitted the pressurizing relay (V26) and the oxidizer tank pressurizing relay (V27) to remain in the energized condition, provided lift-off switch No. 1 (V77) was in the "In-flight" position.

(D) Provided that the radio and ground cutoff relay (V28) remains deenergized, then the ignition backup timer (V33) started its 1-second timing cycle, and the roll jet helium augmentation valve (V41) opened.

(E) Opened the interstage pressure-relief doors (discussed later).

The rapid closure of the main oxidizer valve (V4) produced a sharp termination of oxidizer flow into the thrust chamber, thereby reducing thrust rapidly. The closure of the peroxide valve (V19) cut off the flow of hydrogen peroxide to the gas generator (V22), thereby shutting off the flow of heated gas to the turbine. A rapid deceleration of the turbo-pump followed. Hydraulic system pressure was sustained for a short interval by virtue of the hydraulic accumulator (V72), despite the non-operative hydraulic pump (V69). The opening of the roll-jet helium augmentation valve (V41) permitted the flow of helium gas through the roll-jet swivel nozzles (V92 and V95), thus permitting roll control action to be maintained despite the cessation of turbine exhaust gases. With the closure of the propellant valves, the Stage I propellant tanks stopped supplying propellants. The gimballed thrust chamber control in pitch and yaw was eliminated at thrust termination.

As has been noted, the cutoff relay (V29) in being energized, fired pressure-relief-door latch squibs Nos. 1a and 1b, and 2a and 2b (V97, 98 and V101, 102). The firing of either latch squib 1a or 1b unlatched pressure relief door latch No. 1 (V99). The firing of either latch squib 2a or 2b unlatched pressure relief door latch No. 2 (V103). The unlatching of pressure relief door latch No. 1 (V99) caused pressure relief doors No. 1 (V100) to be opened and jettisoned by spring action. Pressure relief door latch No. 2 (V103) caused pressure relief door No. 2 also to be opened and jettisoned. The inter-stage compartment was thereby vented for the ensuing firing of the Stage II thrust chamber.

When combustion chamber pressure in the thrust chamber assembly (V24) dropped to 10 percent of nominal pressure, the Stage I thrust chamber pressure switch (V61) was deactuated. Either the Stage I thrust chamber pressure switch, in being deactuated, or as a backup, the ignition backup timer (V33) having timed through its 1-second cycle,

caused the ignition relay (V152) in the Stage II Aerojet sequencer to become energized, provided: (A) that either the fuel pump outlet pressure switch (V16) or the oxidizer pump outlet pressure switch (V9) had closed, (B) that the radio and ground cutoff relay remained deenergized, (C) that arming relay No. 2 (V141) had been energized and (D) that the lift-off switch (V79) was in the "In-flight" position.

Upon being energized, the Stage II ignition relay (V152) produced several results: (A) Provided that the cutoff relay (V156) was deenergized, the oxidizer thrust-chamber valve pilot valve (V166) was opened. (B) Provided that the thrust indication relay (V153) and the cutoff relay (V156) were both deenergized the heat generator relay (V154) was energized. The heat generator relay (V154), in becoming energized, caused the heat generator relay delay relay (V155) to become energized. (C) Contacts of the roll clockwise and counterclockwise slave relays (V225 and V230) were electrically armed to enable the Stage II roll control jet system to function after separation of Stage I.

The oxidizer thrust-chamber valve pilot valve (V166), in opening, opened the oxidizer thrust-chamber valve (V167). This permitted the oxidizer at tank pressure to break through the oxidizer burst disc (V170) which breaks at approximately 1/3 tank pressure, and the oxidizer tank (V172) began supplying the nitric acid oxidizer to the thrust chamber injector (V178) via the thrust chamber cooling jacket. The opening of the oxidizer thrust-chamber valve (V167) caused oxidizer valve position switches Nos. 1 and 2 (V168, 169) to be opened in sequence at 27 percent and 78 percent of the full-travel position respectively. The actuation of oxidizer valve position switch No. 1 (V168) opened the fuel thrust-chamber valve pilot valve (V174), which in turn opened the fuel thrust-chamber valve (V175). This permitted the fuel tank (V177) to commence supplying the unsymmetrical dimethyl hydrazine fuel to the thrust chamber injector.

The actuation of oxidizer valve position switch No. 1 (V168), provided that the thrust indication relay (V153) was deenergized, tripped the electrical solenoid of the helium regulator valve (V165) causing it to turn on and regulate helium from the helium sphere (V161).

With the oxidizer tank (V172) and the fuel tank (V177) supplying propellants to the thrust chamber, and provided that the thrust chamber nozzle closure (V179) was intact (sealing the thrust chamber), hypergolic ignition and chamber pressure build-up occurred and the thrust chamber (V178) developed increasing thrust. The thrust chamber closure (V179) was expelled and the Stage II thrust chamber pressure switch (V181) was activated by the chamber pressure buildup at 68 percent of nominal chamber pressure. The activation of this switch, provided the ignition relay (V152) was energized, energized the thrust indication relay (V153). Upon being energized, this relay (V153) deactivated the Off-On helium pressurizing system consisting of the helium pressure switch No. 2 (V163) and the bypass helium shutoff valve (V164), which became closed. Thereafter the tank pressure regulation was performed solely by the helium regulator valve (V165).

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\*Subsequently demonstrated not to be a necessary condition for ignition.

Either the thrust indication relay (V153), upon becoming energized, or as a backup the closure of oxidizer valve position switch No. 2 (V169), energized the Stage I separation relay (V105) and the Stage II separation relay (V122). Upon being energized the Stage I separation relay (V105), provided that arming relay No. 1 (V140) was energized, fired the six explosive-bolt detonators (V106, 107, 108, 109, 110 and 111) in the Stage I end of the explosive bolt assembly, whereas the Stage II separation relay (V122), in becoming energized (provided that arming relay No. 1 (V140) was energized) fired the six explosive-bolt detonators in the Stage II end (V123, 124, 125, 126, 127 and 128). The firing of either detonator in each of the six explosive bolts severed the bolts (V112, 113, 114, 115, 116 and 117) effecting physical separation of Stage I from Stage II.

With the thrust chamber developing full thrust, the Stage II vehicle structure (V180) continued to be accelerated along the flight path. Upon separation, the electrical connections (V118, 119, 120 and 121) between the stages were disconnected. This effected the following functions: (A) The Stage I cutoff relay (V29) was deenergized, closing the roll-jet helium augmentation valve (V41), thus stopping the flow of helium to the roll jet swivel nozzles (V92 and V95) and thereby terminating roll control of Stage I while eliminating any forward acceleration due to roll jet thrust. (B) The vehicle electrical power was now supplied solely by the Stage II battery (V132). The hydraulic pump motor (V145) continued to operate on power from the vehicle electrical bus in lieu of the circuit through the Stage I pressurizing relay (V26) provided that arming relay No. 2 (V141) was energized. (C) The clutch brake (V253) of the coasting-time computer remained engaged in lieu of the circuit through the lift-off switch of Stage I, provided that arming relay No.2 (V141) was energized.

Operating under thrust, the Stage II gimballed thrust chamber provided pitch and yaw control moments (V200) and (V124) to reinstate the attitude control loops. Pitch (V196, 197, 198 and 199) continued with the fourth pitch rate in effect; yaw (V210, 211, 212 and 213) continued in constant-reference attitude control. In the roll axis, the slave relay contacts (V225 and V230) having been activated, the two "clockwise" solenoid valves (V226 and 228) operated with the two "counterclockwise" solenoid valves (V231 and 233) to provide Off-On control by the gas jets (V227, 229, 232, and 234). The propane tank and regulator assembly (V237) supplied propane gas to the roll control system during Stage II burning provided the helium/propane three-way valve (V238) was in the "propane" position.

With the attainment of steady-state conditions in the propulsion and control systems of Stage II, and the physical separation of Stage I, Transition 4/3: Stage II Launch was completed. Vehicle components V1 through V121 were thereby divorced from the vehicle.

### State 3: Stage II Powered Flight

State 3 was subdivided as follows: State 3a, Stage II Powered Flight With Nose-cone. Transition 3a/3b: Nose-cone Jettison, and State 3b: Stage II Powered Flight Without Nose-cone.

#### *State 3a: Stage II Powered Flight with Nose-Cone*

When the supply pressure in the helium sphere (V161) had dropped to approximately 1400 psi (initially 1700 psi) as it was used to expel propellants, helium pressure switch No. 1 (V162) was deactuated deenergizing the heat generator relay (V154), which in turn deenergized the heat generator delay relay (V155) through a time delay. During this time delay, when heat generator relay (V154) was deenergized and the contacts of the heat generator delay relay (V155) were still closed, current flowed to heat generator squibs Nos. 1 and 2 (V158 and V159) caused them to fire. Either heat generator squib No. 1 or 2, in firing, caused the solid-propellant heat generator (V160) to commence burning within the helium sphere, augmenting the specific volume of the remaining gas. Heated helium was thereby supplied from the helium sphere (V161).

#### *Transition 3a/3b, Nose-Cone Jettison*

At 172 seconds the programming tape (V186) in the program timer activated micro-switch and actuator I (V187i) which, provided relay (V188a) was deenergized, caused relay M (V188m) to become energized. This, in turn, energized the nose-cone separation relay (V239); and provided power arming relay No. 2 (V141) was energized, power was supplied to fire nose-cone latch squib Nos. 1 and 2 (V240 and 241). Either squib, in firing, would unlatch the nose-cone latch (V242) at the tip of the nose-cone. Closure of the nose-cone separation relay (V239) also fired the nose-cone explosive bolt detonators Nos. 1 and 2 (V243 and V244). When either of these detonators fired, the nose-cone bolt was separated and, provided that the nose-cone latch (V242) was unlatched, the separating spring assembly caused the two nose-cone halves (V246 and 247) to separate and be jettisoned from the stage. When the two nose-cone halves were clear of the vehicle, transition 3a/3b was terminated, and vehicle state 3b commenced.

#### *State 3b: Stage II Powered Flight Without Nose-cone*

The propulsion and control system operation continued as before. The program timer programming tape (V186) caused momentarily activated microswitch and actuator K (V187k) which, if program timer relay A (V188a) was deenergized, caused relay O (V188o) to become energized. At exhaustion of either the fuel or the oxidizer, propulsion system shutdown was initiated and State 3 was terminated.

### Transition 3/2: Transition to Stage II Coasting Flight

At exhaustion of either the fuel or the oxidizer in the fuel tank and feed lines (V177) or oxidizer tank and feed lines (V172), rapid thrust decay in the Stage II thrust chamber (V178) resulted in a fall-off in acceleration of the vehicle structure along its longitudinal axis (V180), and in deactivation of the Stage II thrust chamber pressure switch (V181). The later energized the cutoff relay (V156), provided that the thrust indication relay (V153) was energized and the heat generator relay (V154) was deenergized. This caused the following: (A) The coasting time computer, Stage II cutoff received relay (V249) was energized. (B) Closure of the cutoff relay (V156) closed the oxidizer thrust-chamber valve pilot valve (V166) and the fuel thrust-chamber valve pilot valve (V174). This resulted in the rapid closure of the oxidizer thrust-chamber valve (V167) and the fuel thrust-chamber valve (V175), stopping all propellant flow and sealing the pressurized tanks. (C) Closure of the cutoff relay (V156) also energized the hydraulic pump motor cutoff relay (V142) (which has no function at this point) and (D) the pitch/yaw power relay (V143).

The energizing of the pitch/yaw power relay (V143) caused several operations: (A) The contacts of the left (V215) and right (V218) yaw slave relays were armed with 28 volt dc power. The up (V201) and down (V204) pitch slave relays were similarly armed. (B) The helium/propane three-way valve (V238) was energized from the "propane" position to the "helium" position, thereby terminating the flow of propane gas from the propane tank into the roll system (V237). The roll jet system was thereafter supplied with residual helium from the pressurized fuel tank (V177), provided the fuel thrust-chamber valve (V175) was closed. Arming of the pitch slave relays brought into operation the two pitch solenoids and gas jets (V202, V203 and V205, V206) to provide attitude control of the vehicle structure about the pitch axis (V207). Similarly, arming of the yaw slave relay contacts brought into operation the two yaw solenoid valve and gas jet assemblies (V216, V217 and V219, V220) which operated to provide attitude control of the vehicle structure about the yaw axis (V221). Provided the Oxidizer Thrust Chamber valve was closed helium gas was provided from the pressurized oxidizer tank (V172).

With loss of thrust, the gimballed thrust chamber controller in pitch and yaw lost effectiveness. This function was taken over by the pitch/yaw control jets. Control about the roll axis (V235) continued with the Off-On control-jet-and-solenoid-valve assemblies (V226, 227 and 228, 229 in the clockwise direction and V231, 232 and 233, 234 in the counterclockwise direction), operating now on residual helium after changeover from propane gas employed during powered flight.

Closure of the Stage II cutoff received relay (V248) in the coasting-time computer energized the auxiliary relay (V249) provided that the speed indication arm (V254) had rotated away from initial position at takeoff. The closure of the auxiliary relay (V249) disengaged the pendulous gyro (V251) and the clutch brake (V253) and engaged the clutch

(V259) which, provided that the timing motor and gear train (V257) was operating, caused the time indication arm (V259) to start rotating, initiating the timing mode of the computer. At the same time, the disengagement of the clutch brake (V253) caused the speed indication arm (V254) to be stopped in a position indicating the speed at Stage II cutoff. Its contacts subsequently were engaged by the time indication arm (V259) to initiate the Stage III firing operation. With propulsion system cutoff complete, and all systems approaching steady-state operation, Transition 3/2 was completed.

## State 2: Stage II Coasting Flight

During coasting flight, the program timer programming tape (V186) momentarily activated microswitch and actuator F (V187f). This, providing that relay (V188a) was deenergized, caused relay (V188h) and, in turn, relay (V188i) to be deenergized (no direct function).

During the coasting phase of the flight, two basic systems were compared for the "time-to-apogee" prediction in order to effect an optimum Stage III firing time. One was the coasting-time computer which was already in its timing mode and which, if no interruption was imposed, proceeded to fire Stage III at the computed point in the trajectory. The alternate system was a ground computational system, based on radar tracking data, which predicted the optimum Stage III firing time. The predicted results of these two systems were compared and a decision was made between the alternatives of allowing the vehicle-borne or the ground-based system to effect Stage III firing.

If the ground-based system was selected, then at a fixed time prior to the designated Stage III firing time a radio command was transmitted to the vehicle simultaneously on decoder channels eight and nine. Reception of both of these radio tones by the command receiver/decoder unit (V260) started the ground command delay timer (V261) in its timing mode, at the same time opening contacts in the coasting-time-computer command circuit. This ground command link was assigned the backup No. 1 function (subordinate to the coasting-time computer) with regards to the Stage III firing command.

Backup No. 2 was a fixed-time firing command from the program timer. Backup No. 3 was a radio command which instantaneously effected the Stage III firing command; the link was radio command tones four and six, which had to be received simultaneously to effect the firing command. Thus, a primary and three backup channels were capable of initiating the Stage III firing command in the vehicle. When any one of these initiated the Stage III firing command, State 2 was terminated, and Transition 2/1: Stage III Launch, ensued.

## Transition 2/1: Stage III Launch

At initiation of the Stage III firing command in the vehicle, provided the Stage II radio cutoff relay (V262) remained deenergized, the Stage III spin-up and ignition relay (V263) was energized. The closure of this relay caused the following: (A) The separation delay timer (V264) began its 1.5-second timing cycle for subsequent firing of the retro rockets. At the same time, (B) the two spin rockets Nos. 1 and 2 (V268 and V269), were ignited and rotational torque was thus to the spin table (V271) upon which the Stage III solid-propellant rocket motor was applied. This torque released the spin table rotational restraint (V270), and the table was spun up to operating speed (approximately 150 rpm). (C) The rocket igniter delay squib (V275) within the Stage III rocket motor was energized to begin its timing phase of 15 seconds. (D) Closure of the spin and ignition relay (V263) also deactivated the pitch and yaw attitude control jet systems to minimize the possibility of impact due to control action during the separation maneuver.

Immediately thereafter, the rotation of the spin table (V271) caused the igniter wire cutter (V272) to cut the ignition wire to the Stage III rocket motor. After one and one-half revolutions, the rocket motor longitudinal restraint (V273) was mechanically released to free the spinning rocket motor in the longitudinal direction.

Upon completion of its 1.5-second timing cycle, the separation delay timer (V264) energized the Stage III separation relay (V265), which (A) deactivated the roll control jet system, and (B) ignited the retro rockets Nos. 1 and 2 (V266, 267). These produced thrust which decelerated the Stage II vehicle structure in the longitudinal direction (V180), thereby backing it away from the Stage III rocket motor and satellite, provided the longitudinal restraint (V273) had been unlocked. In "moving forward" with respect to the Stage II structure, the upper bearing support assembly (V274) shed its four spider arms by spring action. The separation and clearance of the spinning Stage III rocket motor and satellite completed Transition 2 1, and State 1 was inaugurated.

## State 1: Stage III Powered and Coasting Flight

Approximately 15 seconds after its initiation, the Stage III rocket igniter delay squib (V275) activated the rocket igniter (V276) which started the main propellant grain burning in the rocket motor. In burning, the Stage III rocket motor developed sufficient impulse to accelerate the satellite to orbital speed prior to propellant exhaustion. The acceleration of the stage caused the inertia arm (V279) in the satellite separation device to become armed during the burning period. At propellant exhaustion, the satellite and empty

rocket case were in a free-fall orbiting path, and Transition 1/0: Satellite Separation ensued.

### **Transition 1/0: Satellite Separation**

The accelerating period having ended at Stage III burnout, the satellite separation device inertia arm (V279), which was previously armed during the thrusting period, was actuated to start the separation timer (V280) on its timing mode. After the preset time interval, the timer (V280) operated a switch (V281) which activated batteries No. 1 (V282) and No. 2 (V284) in the satellite separation device. The operation of these two batteries caused "caterpillar" squib devices Nos. 1 and 2 (V283 and 285) to expand. The activation of either caterpillar squib actuated the unlocking device (V286) which permitted the compression spring (V287) to separate the satellite from the Stage III rocket case with a differential velocity of several feet per second. Satellite separation and clearance from the Stage III case thus terminated the Transition 1/0.

### **State 0: Satellite in Orbit**

Following separation and clearance from the Stage III rocket case, the final state of the Vanguard Satellite Launching Vehicle was attained: Satellite in Orbit. The expended Stage III case, having itself achieved orbital speed in accelerating the satellite, also remained in an orbit with characteristics differing slightly from those of the satellite orbit.

<p>NASA TN D-782 National Aeronautics and Space Administration. A SEQUENCE DIAGRAM ANALYSIS OF THE VANGUARD SATELLITE LAUNCHING VEHICLE. William J. D. Escher and Richard W. Foster. May 1961. 40p., charts in pocket. OTS price, \$1.00. (NASA TECHNICAL NOTE D-782)</p> <p>The Vanguard Sequence Diagram method, introduced in an earlier report, is applied herein to depict the operating sequence of the Vanguard Satellite Launching Vehicle. It relates vehicle systems operation during final countdown preparations through lift-off, and includes the entire flight program to satellite separa- tion in orbit. On the basis of information from the diagram, a brief system analysis of the vehicle is performed. The results are presented graphically and include: Vehicle state, state-transition breakdown Vehicle component makeup Launch program events</p> <p>Copies obtainable from NASA, Washington (over)</p>	<p>I. Escher, William J. D. II. Foster, Richard W. III. NASA TN D-782</p> <p>(Initial NASA distribution: 19, Electronics; 23, Launching facilities and operations; 28, Missiles and satellite carriers; 39, Propulsion systems, liquid-fuel rockets; 48, Space vehicles; 49, Simulators and computers.)</p>	<p>NASA TN D-782 National Aeronautics and Space Administration. A SEQUENCE DIAGRAM ANALYSIS OF THE VANGUARD SATELLITE LAUNCHING VEHICLE. William J. D. Escher and Richard W. Foster. May 1961. 40p., charts in pocket. OTS price, \$1.00. (NASA TECHNICAL NOTE D-782)</p> <p>The Vanguard Sequence Diagram method, introduced in an earlier report, is applied herein to depict the operating sequence of the Vanguard Satellite Launching Vehicle. It relates vehicle systems operation during final countdown preparations through lift-off, and includes the entire flight program to satellite separa- tion in orbit. On the basis of information from the diagram, a brief system analysis of the vehicle is performed. The results are presented graphically and include: Vehicle state, state-transition breakdown Vehicle component makeup Launch program events</p> <p>Copies obtainable from NASA, Washington (over)</p>	<p>I. Escher, William J. D. II. Foster, Richard W. III. NASA TN D-782</p> <p>(Initial NASA distribution: 19, Electronics; 23, Launching facilities and operations; 28, Missiles and satellite carriers; 39, Propulsion systems, liquid-fuel rockets; 48, Space vehicles; 49, Simulators and computers.)</p>
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NASA TN D-782

Flight profile of cumulative events and vehicle components remaining  
Condensed sequence diagram  
Vehicle in-flight sequencing; flight-test results  
A narrative description of the vehicle launch program is included by way of a verbal interpretation of the master sequence diagram.

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# BLOCKHOUSE MANUAL OPERATIONS

(PERFORMED AS DIRECTED BY COUNT-DOWN)



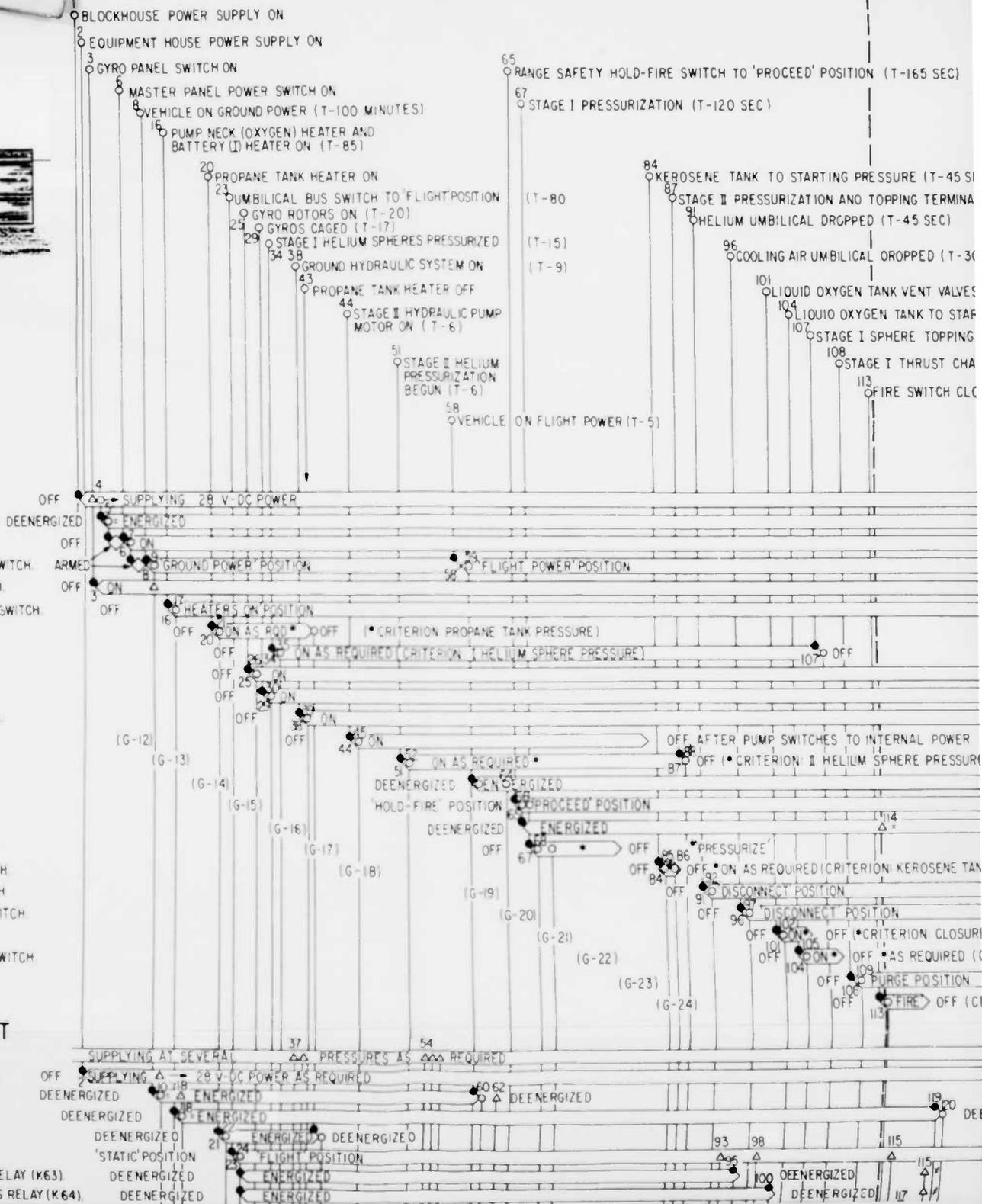
5 VEHICLE PREPARATIONS

## GROUND COMPONENTS BLOCKHOUSE EQUIPMENT

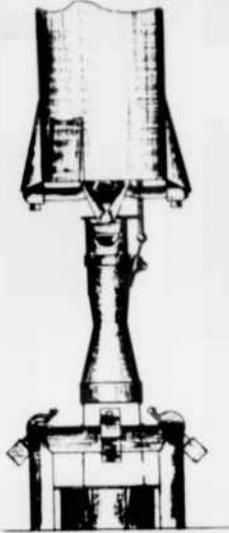
- G-1 MAIN BLOCKHOUSE POWER SUPPLY
- G-2 POWER CONTROL BUS RELAY
- G-3 MASTER POWER SWITCH
- G-4 ROTARY POWER TRANSFER SELECTOR SWITCH
- G-5 GYRO MONITORING PANEL POWER SWITCH
- G-6 OXIDIZER PUMP AND BATTERY HEATERS SWITCH
- G-7 PROPANE HEATER SWITCH
- G-8 (I) HELIUM PRESSURIZING SWITCH
- G-9 GYRO ROTOR SWITCH
- G-10 GYRO CAGING AMPLIFIER SWITCH
- G-11 (I) GROUND HYDRAULIC POWER SWITCH
- G-12 (II) HYDRAULIC PUMP MOTOR SWITCH
- G-13 (II) PRESSURIZING SWITCH
- G-14 (I) FIRE BUS RELAY
- G-15 RANGE SAFETY HOLD FIRE SWITCH
- G-16 RANGE SAFETY RELAY
- G-17 (I) PRESSURIZING SWITCH
- G-18 FUEL TANK PRESSURE OVERRIDE SWITCH
- G-19 HELIUM UMBILICAL DISCONNECT SWITCH
- G-20 COOLING AIR UMBILICAL DISCONNECT SWITCH
- G-21 OXIDIZER TANK VENT SWITCH
- G-22 OXIDIZER TANK PRESSURE OVERRIDE SWITCH
- G-23 (I) ENGINE PURGE SWITCH
- G-24 FIRE CUT-OFF SWITCH

## EQUIPMENT HOUSE EQUIPMENT

- G-25 HELIUM PRESSURE SOURCE
- G-26 MAIN EQUIPMENT HOUSE POWER SUPPLY
- G-27 POWER TRANSFER CONTACTOR (K68)
- G-28 HEATER CONTACTOR (K48)
- G-29 PROPANE HEATER CONTACTOR (K5704)
- G-30 UMBILICAL BUS ARMING SWITCH
- G-31 HELIUM UMBILICAL FIRE SEQUENCING RELAY (K63)
- G-32 COOLING AIR UMBILICAL FIRE SEQUENCING RELAY (K64)



PROCEED' POSITION (T-165 SEC)



5/4 STAGE I LAUNCH

TO STARTING PRESSURE (T-45 SEC)  
URIZATION AND TOPPING TERMINATED  
BILICAL DROPPED (T-45 SEC)

NG AIR UMBILICAL DROPPED (T-30 SEC)

LIQUID OXYGEN TANK VENT VALVES CLOSED (T-30 SEC)

104 LIQUID OXYGEN TANK TO STARTING PRESSURE (T-20 SEC)

107 STAGE I SPHERE TOPPING TERMINATED (T-10 SEC)

108 STAGE I THRUST CHAMBER PURGE ON (T-5 SEC)

113 FIRE SWITCH CLOSED (T-0)

LIFT OFF (T+0)

162



107 OFF

SWITCHES TO INTERNAL POWER  
RION: II HELIUM SPHERE PRESSURE)

REQUIRED (CRITERION: KEROSENE TANK PRESSURE)

CT POSITION

DISCONNECT POSITION

102 OFF (CRITERION: CLOSURE OF OXYGEN TANK VENT VALVES (2))

103 OFF (AS REQUIRED (CRITERION: OXYGEN TANK PRESSURE))

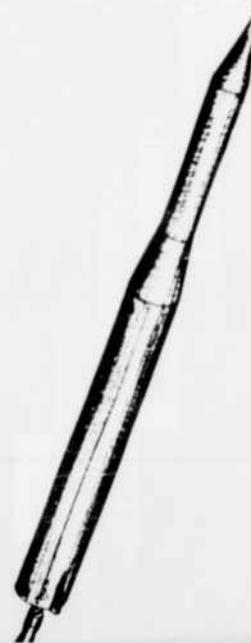
104 OFF PURGE POSITION

108 OFF FIRE OFF (CRITERION INDICATED START OF ENGINE)

119 DEENERGIZED

DEENERGIZED

DEENERGIZED



PROG

INITIAL  
EVENT

16  
17  
18  
19  
20  
21

28  
32

(R

LEGEND

I, II, III	FIRST, SECOND, & THIRD STAGES, RESPECTIVELY	
○	OPERATION CAUSING (OPEN SYMBOL)	} CONNECTED BY VERTICAL EVENT LINE
●	OPERATION EFFECTED (DARKENED SYMBOL)	
△	NECESSARY CONDITION	
▽	EITHER/OR RELATIONSHIP	
○	TIME GATE REQUIREMENT MET	
●	CONTROL LOOP CLOSURE POINT	
---	TIME FUNCTION	
□	COMPONENT STATE	
□	TRANSIENT IN COMPONENT STATE	
I	VEHICLE SEPARATION	
⊢ (#)	NORMALLY OPEN (CLOSED) ELECTRICAL CONTACTS	
BU	BACK-UP	
I	STATE / TRANSITION BOUNDARY	

PROGRAM TIMER INITIATED EVENTS

<u>INITIATION EVENT NO</u>	<u>TIME AFTER LIFT-OFF</u>	<u>FUNCTION</u>
162	0-SEC	LIFT-OFF
175	0	PROGRAM TAPE STARTED
176	10	PITCH RATE #1 INITIATED
184	24	" " #2
194	45	" " #3
204	108	" " #4
214	120	STAGE I & II BATTERIES PARALLELED, STAGE I CUT-OFF, SEPARATION, STAGE II IGNITION FUNCTIONS ARMED
283	172	NOSE-CONE JETTISON
323	418	PITCH RATE #5 INITIATED
---	591	STAGE III FIRING CIRCUIT ARMED STAGE III FIXED TIME FIRING COMMAND (BACK-UP NO 3)

(REFERENCE IS MADE TO COMPONENTS V-1B2 / 1B9)



- G-26 MAIN EQUIPMENT HOUSE POWER SUPPLY.
- G-27 POWER TRANSFER CONTACTOR (K68).
- G-28 HEATER CONTACTOR (K48).
- G-29 PROPANE HEATER CONTACTOR (K5704).
- G-30 UMBILICAL BUS ARMING SWITCH
- G-31 HELIUM UMBILICAL FIRE SEQUENCING RELAY (K63).
- G-32 COOLING AIR UMBILICAL FIRE SEQUENCING RELAY (K64).
- G-33 ELECTRICAL UMBILICAL FIRE SEQUENCING RELAY (K61).
- G-34 (III) STAGE UMBILICAL FIRE SEQUENCING RELAY.
- G-35 (I) HELIUM PRESSURIZING RELAY
- G-36 (I) HELIUM PRESSURIZING VALVE.
- G-37 (I) GROUND HYDRAULIC POWER SUPPLY
- G-38 HYDRAULIC PUMP GROUND POWER CONTACTOR (K47).
- G-39 HYDRAULIC PUMP GROUND POWER CUT-OFF AND OXIDIZER PRESSURIZING RELAY (K-46).
- G-40 (II) PRESSURIZING RELAY
- G-41 (II) PRESSURIZING VALVE
- G-42 (I) REMOTE FIRING BUS CONTACTOR
- G-43 HELIUM UMBILICAL DISCONNECT RELAY (K66)
- G-44 COOLING AIR UMBILICAL DISCONNECT RELAY (K67).
- G-45 PURGE RELAY (K59).
- G-46 (I) FIRING RELAY (K60)
- G-47 (I) ENGINE CUT-OFF RELAY (K58)
- G-48 GROUND SEQUENCING POWER RELAY (K50).
- G-49 CUT-OFF DELAY RELAY (K55).

**LAUNCH STAND EQUIPMENT**

- G-50 HELIUM UMBILICAL PNEUMATIC ACTUATOR.
- G-51 HELIUM UMBILICAL DISCONNECT AND LINE
- G-52 COOLING AIR UMBILICAL PNEUMATIC ACTUATOR
- G-53 COOLING AIR UMBILICAL DISCONNECT AND LINE
- G-54 SATELLITE COOLING AIR LINE
- G-55 ELECTRICAL UMBILICAL SOLENOID
- G-56 ELECTRICAL UMBILICAL DISCONNECT AND LINE
- G-57 PURGE SOLENOID VALVE
- G-58 ELECTRICAL DISCONNECT ENGINE START AND CONTROLS (J2602)
- G-59 ELECTRICAL DISCONNECT POWER (J2601)
- G-60 ELECTRICAL DISCONNECT INSTRUMENTATION #1
- G-61 ELECTRICAL DISCONNECT INSTRUMENTATION #2
- G-62 OXIDIZER FILL AND AND TOPPING DISCONNECT.
- G-63 HELIUM HIGH-PRESSURE DISCONNECT.
- G-64 PURGE DISCONNECT.
- G-65 GROUND HYDRAULICS DISCONNECT HIGH PRESSURE
- G-66 GROUND HYDRAULICS DISCONNECT LOW PRESSURE
- G-67 SWING-AWAY SUPPORT PAD I
- G-68 SWING-AWAY SUPPORT PAD II
- G-69 SWING-AWAY SUPPORT PAD III
- G-70 SWING-AWAY SUPPORT PAD IV

**STAGE I ENGINE SEQUENCER  
(LOCATED IN EQUIPMENT HOUSE)**

- G-71 ROCKET CUT-OFF RELAY (RCO).
- G-72 IGNITION INDICATION RELAY (II).
- G-73 COMBUSTION INDICATION RELAY (CI)
- G-74 PEROXIDE VALVE CLOSED RELAY (PVC).
- G-75 OXIDIZER VALVE CLOSED RELAY (OVC).
- G-76 CUT-OFF RELAY (CO)
- G-77 IGNITION RELAY (I)
- G-78 FUEL START RELAY (FS).
- G-79 FUEL VALVE OPEN RELAY (FVO).
- G-80 PEROXIDE VALVE OPEN RELAY (PVO).
- G-81 OXIDIZER-TO-FUEL TIMER (O/F).
- G-82 IGNITION-TO- OXIDIZER GATE (I/O)
- G-83 IGNITION INDICATION-TO-PEROXIDE GATE (I I/P).
- G-84 PEROXIDE-TO-LIFT-OFF GATE (P/LO)



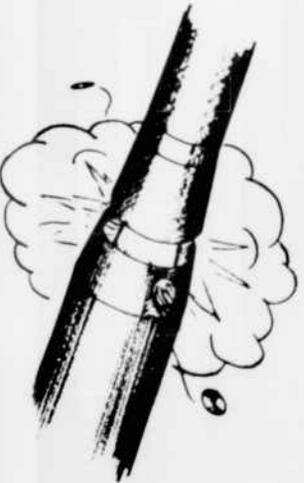
**IGNITION CONTROL UNIT (LOCATED  
ON LAUNCH STAND)**

- G-85 IGNITION CONTACTOR (IC).
- G-86 IGNITER (I).
- G-87 IGNITION INDICATOR LINK (IL).
- G-88 COMBUSTION INDICATOR (CI)
- G-89 COMBUSTION INDICATOR SWITCH.



STATE OF TRANSITION





4/3 STAGE II LAUNCH



4/3

3a

3a/3b

3b

3/2

2

2/1

1

1/0

0

**IGNITION CONTROL UNIT (LOCATED ON LAUNCH STAND)**

G-85 IGNITION CONTACTOR (IC)

(G-85)

DEENERGIZED

G-86 IGNITER (I)

(G-86)

INACTIVE

G-87 IGNITION INDICATOR LINK (IL)

G-88 COMBUSTION INDICATOR (CI)

G-89 COMBUSTION INDICATOR SWITCH

**STATE OR TRANSITION**

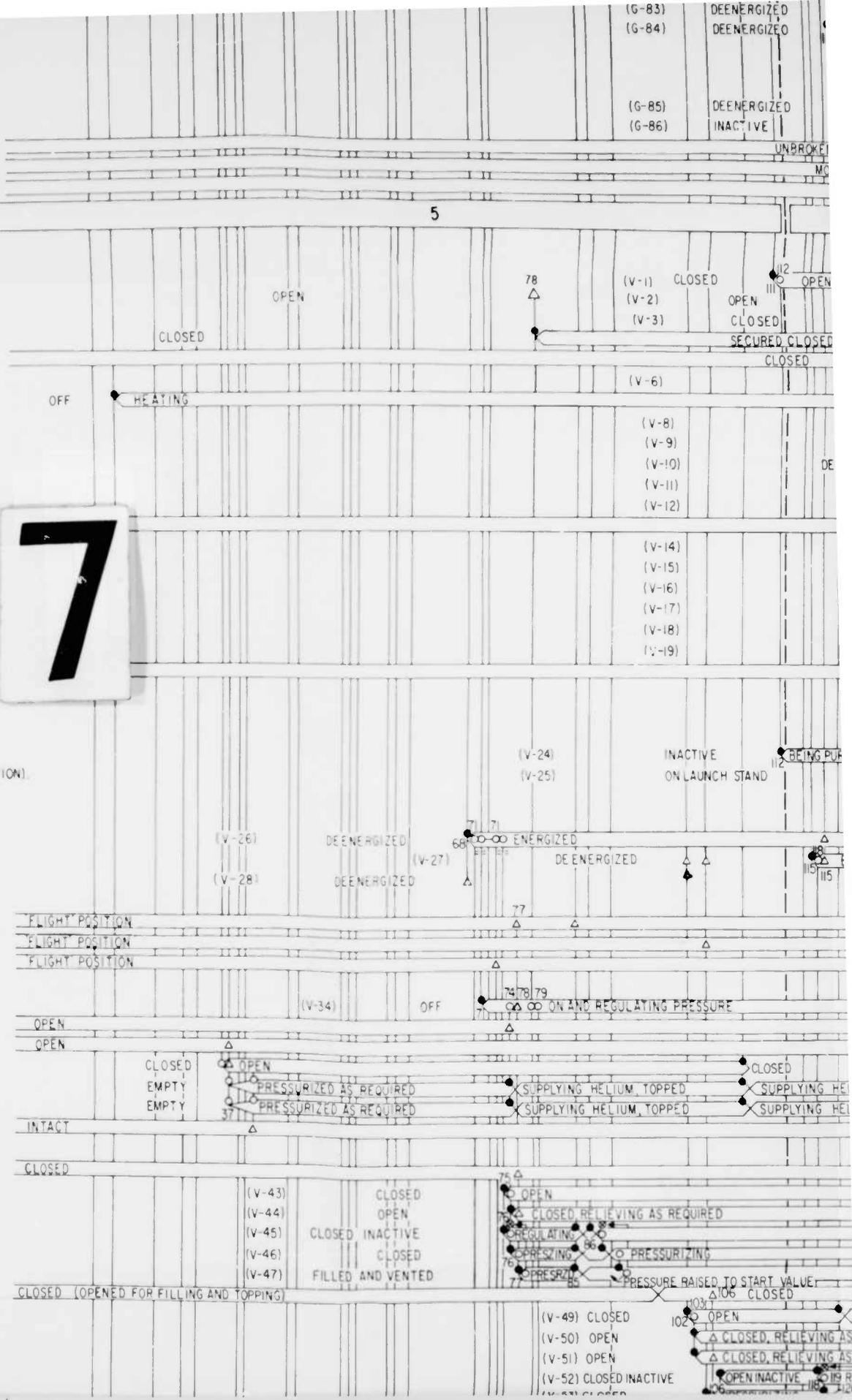
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**STAGE I****ROCKET ENGINE ASSEMBLY**

- V-1 PURGE CHECK VALVE
- V-2 OXIDIZER VALVE CLOSING VALVE
- V-3 OXIDIZER VALVE OPENING VALVE
- V-4 OXIDIZER MAIN VALVE
- V-5 OXIDIZER CLOSED SWITCH (OVCS)
- V-6 OXIDIZER CHECK VALVE
- V-7 OXIDIZER PUMP NECK HEATER
- V-8 OXIDIZER PUMP
- V-9 OXIDIZER PUMP OUTLET PRESSURE SWITCH
- V-10 FUEL OPENING RELAY (FO)
- V-11 FUEL VALVE OPENING VALVE
- V-12 FUEL MAIN VALVE
- V-13 FUEL VALVE CLOSED SWITCH (FVCS)
- V-14 FUEL VALVE OPEN SWITCH (FVOS)
- V-15 FUEL PUMP
- V-16 FUEL PUMP OUTLET PRESSURE SWITCH
- V-17 PEROXIDE OPENING RELAY (PO)
- V-18 PEROXIDE VALVE OPENING VALVE
- V-19 PEROXIDE VALVE
- V-20 PEROXIDE VALVE CLOSED SWITCH (PVCS)
- V-21 PEROXIDE VALVE OPEN SWITCH (PVOS)
- V-22 PEROXIDE DECOMPOSER
- V-23 TURBINE
- V-24 THRUST CHAMBER ASSEMBLY
- V-25 VEHICLE STRUCTURE (LONGITUDINAL ACCELERATION)

**PROPULSION SYSTEM (OTHER THAN ROCKET ENGINE)**

- V-26 PRESSURIZING RELAY (K 2801)
- V-27 OXIDIZER TANK PRESSURIZING RELAY (K 2804)
- V-28 RADIO AND GROUND CUT-OFF RELAY
- V-29 CUT-OFF RELAY
- V-30 FUEL TANK PRESSURIZING TEST SWITCH
- V-31 OXIDIZER TANK PRESSURIZING TEST SWITCH
- V-32 HYDRAULIC PUMP MOTOR TEST SWITCH
- V-33 IGNITION BACK-UP TIMER
- V-34 HELIUM REGULATOR ASSEMBLY
- V-35 HELIUM HIGH PRESSURE HAND VALVE
- V-36 HELIUM DISCONNECT AND CHECK VALVE
- V-37 HELIUM CHECK VALVE
- V-38 HELIUM SPHERE #1
- V-39 HELIUM SPHERE #2
- V-40 HELIUM BURST DISK ASSEMBLY
- V-41 ROLL JET HELIUM AUGMENTATION VALVE
- V-42 FUEL TANK FILL CONNECTION
- V-43 FUEL TANK VENT VALVE PILOT VALVE
- V-44 FUEL TANK VENT-RELIEF VALVE
- V-45 FUEL PUMP INLET PRESSURE SWITCH
- V-46 FUEL TANK PRESSURIZING VALVE
- V-47 FUEL TANK (AND SUCTION LINE)
- V-48 OXIDIZER TANK FILL DISCONNECT
- V-49 OXIDIZER TANK VENT VALVE PILOT VALVE
- V-50 OXIDIZER TANK VENT-RELIEF VALVE #1
- V-51 OXIDIZER TANK VENT-RELIEF VALVE #2
- V-52 OXIDIZER PUMP INLET PRESSURE SWITCH
- V-53 OXIDIZER TANK PRESSURIZING VALVE

**7**



4/3

3a

3a/3b

3b

3/2

2

2/1

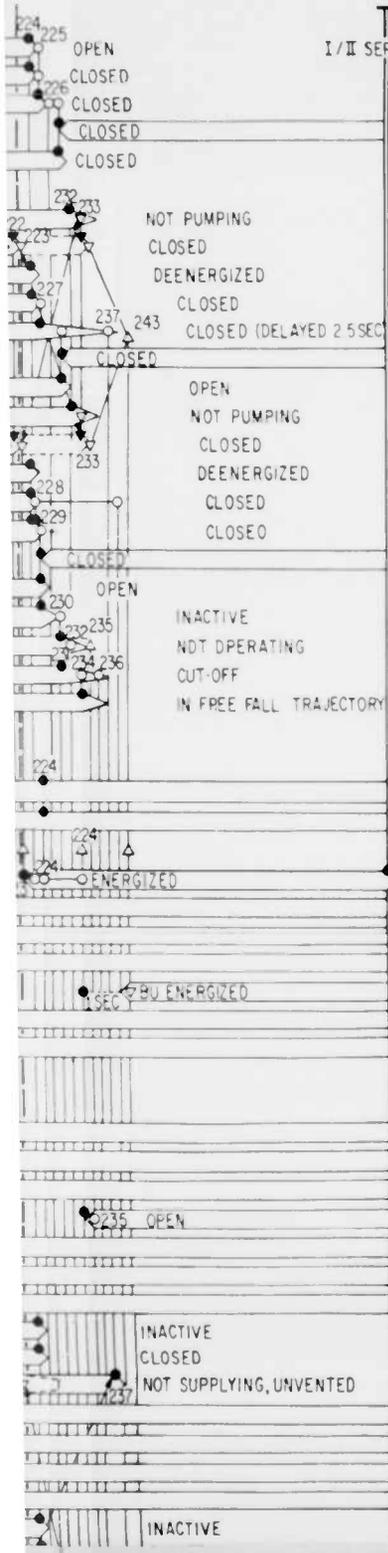
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265

I/II SEPARATION

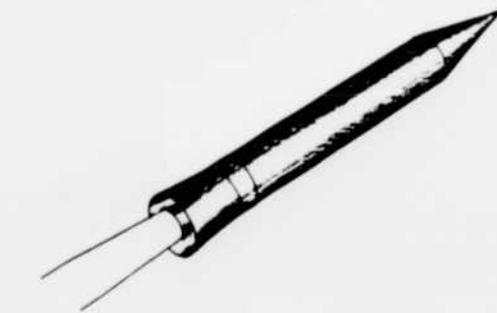


→ TO IMPACT

DEENERGIZED

267  
CLOSED

9



3a STAGE II POWERED FLIGHT (WITH NOSE CONE)



- V-37 HELIUM CHECK VALVE
- V-38 HELIUM SPHERE #1
- V-39 HELIUM SPHERE #2
- V-40 HELIUM BURST DISK ASSEMBLY
- V-41 ROLL JET HELIUM AUGMENTATION VALVE
- V-42 FUEL TANK FILL CONNECTION
- V-43 FUEL TANK VENT VALVE PILOT VALVE
- V-44 FUEL TANK VENT-RELIEF VALVE
- V-45 FUEL PUMP INLET PRESSURE SWITCH
- V-46 FUEL TANK PRESSURIZING VALVE
- V-47 FUEL TANK (AND SUCTION LINE)
- V-48 OXIDIZER TANK FILL DISCONNECT
- V-49 OXIDIZER TANK VENT VALVE PILOT VALVE
- V-50 OXIDIZER TANK VENT-RELIEF VALVE #1
- V-51 OXIDIZER TANK VENT-RELIEF VALVE #2
- V-52 OXIDIZER PUMP INLET PRESSURE SWITCH
- V-53 OXIDIZER TANK PRESSURIZING VALVE
- V-54 OXIDIZER TANK (AND SUCTION LINE)
- V-55 PEROXIDE FILL-DISCONNECT
- V-56 PEROXIDE TANK VENT VALVE PILOT VALVE
- V-57 PEROXIDE TANK VENT RELIEF VALVE
- V-58 PEROXIDE TANK BURST DISK ASSEMBLY
- V-59 PEROXIDE TANK PRESSURIZING HAND VALVE
- V-60 PEROXIDE TANK
- V-61 STAGE I THRUST CHAMBER PRESSURE SWITCH

### POWER SUPPLY SYSTEMS

- V-62 BATTERY CONTACTOR CONTROL RELAY (#2602)
- V-63 BATTERY CONTACTOR (#2601)
- V-64 BATTERY
- V-65 BATTERY SAFETY DISCONNECT
- V-66 BATTERY HEATER
- V-67 BATTERY HEATER THERMOSTAT
- V-68 MAIN BUS
- V-69 HYDRAULIC PUMP
- V-70 STAGE I HYDRAULIC PUMP CHECK VALVE
- V-71 HYDRAULIC HIGH PRESSURE RELIEF VALVE
- V-72 HYDRAULIC ACCUMULATOR
- V-73 HYDRAULIC RESERVOIR
- V-74 HYDRAULIC LOW PRESSURE RELIEF VALVE
- V-75 VEHICLE HYDRAULIC DISCONNECT HIGH PRESSURE
- V-76 VEHICLE HYDRAULIC DISCONNECT LOW PRESSURE
- V-77 LIFT OFF SWITCH #2601
- V-78 LIFT OFF SWITCH #2602
- V-79 LIFT OFF SWITCH #2603

### CONTROLS SYSTEM

#### PITCH

- V-80 TRANSFER VALVE
- V-81 HYDRAULIC ACTUATOR
- V-82 FOLLOW-UP POTENTIOMETER
- V-83 GIMBALED THRUST CHAMBER
- V-84 (I) VEHICLE STRUCTURE (PITCH AXIS)

#### YAW

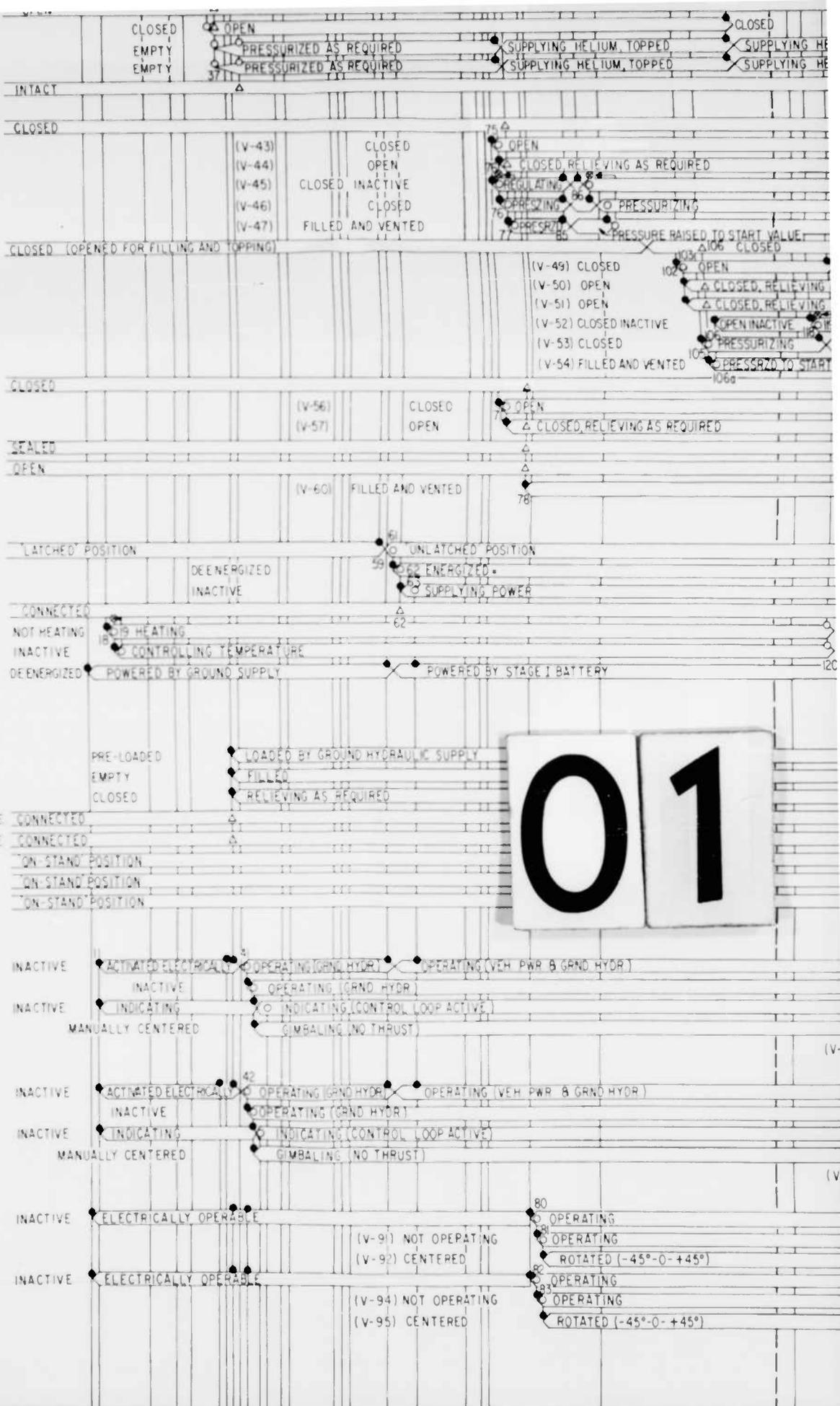
- V-85 TRANSFER VALVE
- V-86 HYDRAULIC ACTUATOR
- V-87 FOLLOW-UP POTENTIOMETER
- V-88 GIMBALED THRUST CHAMBER
- V-89 (I) VEHICLE STRUCTURE (YAW AXIS)

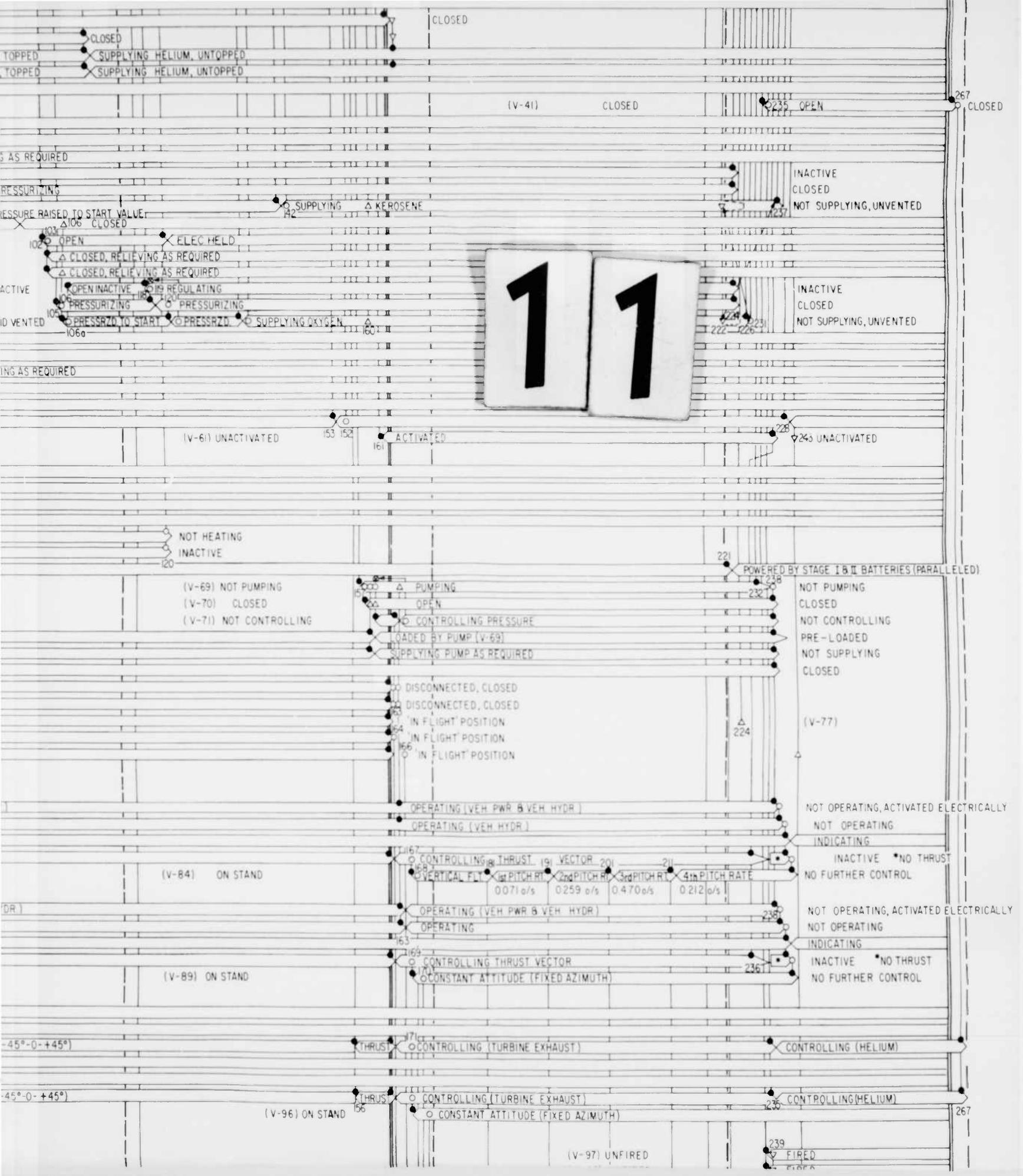
#### ROLL

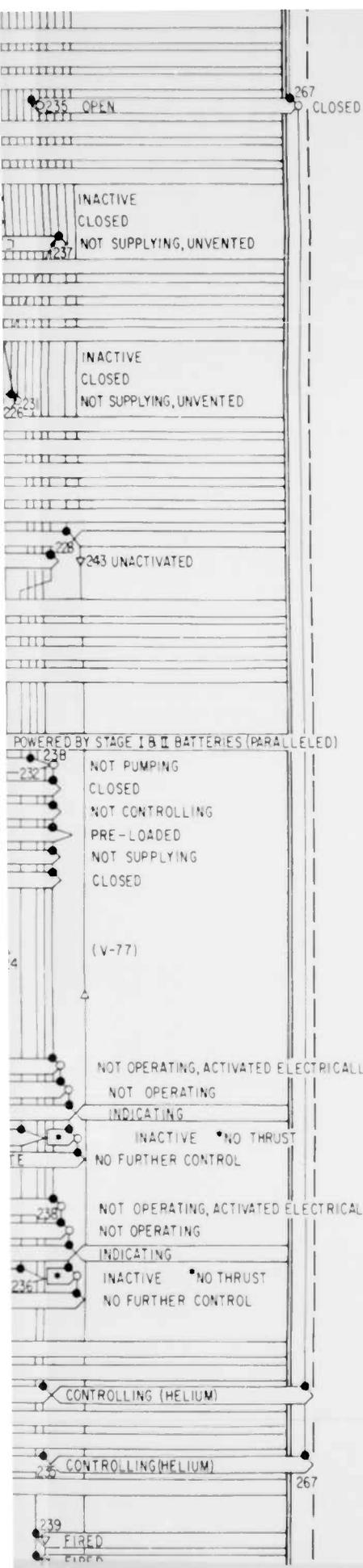
- V-90 SOLENOID VALVE (3-WAY) #1
- V-91 PNEUMATIC ACTUATOR ASSEMBLY #1
- V-92 SWIVEL NOZZLE #1
- V-93 SOLENOID VALVE (3-WAY) #2
- V-94 PNEUMATIC ACTUATOR ASSEMBLY #2
- V-95 SWIVEL NOZZLE #2
- V-96 (I) VEHICLE STRUCTURE (ROLL AXIS)

### SEPARATION SYSTEM (I/II)

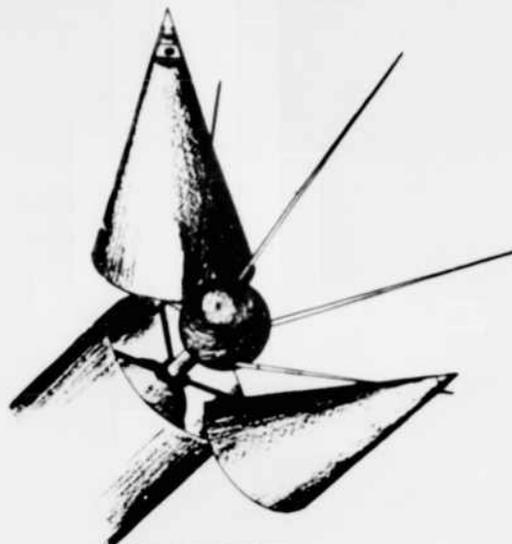
- V-97 PRESSURE RELIEF DOOR LATCH SQUIB #1a
- V-98 PRESSURE RELIEF DOOR LATCH SQUIB #1b







3a STAGE II POWERED FLIGHT (WITH NOSE CONE)



NOSE CONE JETTISON

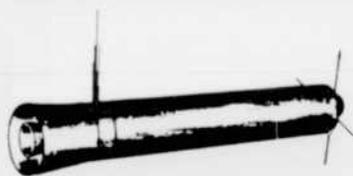
3a/3b



3b STAGE II POWERED FLIGHT (WITHOUT NOSE CONE)



3/2 TRANSITION TO STAGE II COASTING FLIGHT



2 STAGE II COASTING FLIGHT

1 2

- V-93 SOLENOID VALVE (3-WAY) #2
- V-94 PNEUMATIC ACTUATOR ASSEMBLY #2
- V-95 SWIVEL NOZZLE #2
- V-96 (1) VEHICLE STRUCTURE (ROLL AXIS)

INACTIVE

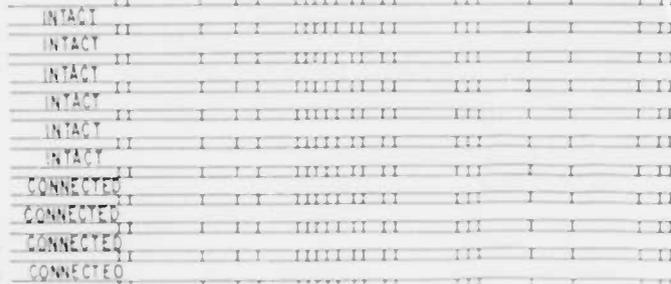
ELECTRICALLY OPERABLE

(V-94) NOT OPERATING  
(V-95) CENTERED

OPERATING  
OPERATING  
ROTATED (-45°-0- +45°)

**SEPARATION SYSTEM (I/II)**

- V-97 PRESSURE RELIEF DOOR LATCH SQUIB #1a
- V-98 PRESSURE RELIEF DOOR LATCH SQUIB #1b
- V-99 PRESSURE RELIEF DOOR LATCH #1
- V-100 PRESSURE RELIEF DOOR #1
- V-101 PRESSURE RELIEF DOOR LATCH SQUIB #2a
- V-102 PRESSURE RELIEF DOOR LATCH SQUIB #2b
- V-103 PRESSURE RELIEF DOOR LATCH #2
- V-104 PRESSURE RELIEF DOOR #2
- V-105 SEPARATION RELAY (K2605)
- V-106 EXPLOSIVE BOLT DETONATOR #1a
- V-107 EXPLOSIVE BOLT DETONATOR #2a
- V-108 EXPLOSIVE BOLT DETONATOR #3a
- V-109 EXPLOSIVE BOLT DETONATOR #4a
- V-110 EXPLOSIVE BOLT DETONATOR #5a
- V-111 EXPLOSIVE BOLT DETONATOR #6a
- V-112 EXPLOSIVE BOLT #1
- V-113 EXPLOSIVE BOLT #2
- V-114 EXPLOSIVE BOLT #3
- V-115 EXPLOSIVE BOLT #4
- V-116 EXPLOSIVE BOLT #5
- V-117 EXPLOSIVE BOLT #6
- V-118 ELECTRICAL DISCONNECT-POWER AND SEQUENCING
- V-119 ELECTRICAL DISCONNECT-CONTROLS
- V-120 ELECTRICAL DISCONNECT-INSTRUMENTATION #1
- V-121 ELECTRICAL DISCONNECT-INSTRUMENTATION #2



**STATE OR TRANSITION**

5

**STAGE II  
SEPARATION (I/II)**

- V-122 SEPARATION RELAY (K2838)
- V-123 EXPLOSIVE BOLT DETONATOR #1b
- V-124 EXPLOSIVE BOLT DETONATOR #2b
- V-125 EXPLOSIVE BOLT DETONATOR #3b
- V-126 EXPLOSIVE BOLT DETONATOR #4b
- V-127 EXPLOSIVE BOLT DETONATOR #5b
- V-128 EXPLOSIVE BOLT DETONATOR #6b



**POWER SUPPLY SYSTEMS**

- V-129 GYRO ROTOR RELAY
- V-130 BATTERY CONTACTOR CONTROL RELAY (K2827)
- V-131 BATTERY CONTACTOR (K2806)
- V-132 BATTERY
- V-133 BATTERY SAFETY DISCONNECT
- V-134 MAIN BUS
- V-135 CONTROLS SWITCH (S2608)
- V-136 DYNAMOTOR CONTROL RELAY (K2612)
- V-137 DYNAMOTOR ELECTRONIC FILTER
- V-138 DYNAMOTOR
- V-139 INVERTER AND REGULATOR
- V-140 ARMING RELAY #1 (K2836)
- V-141 ARMING RELAY #2 (K2837)
- V-142 HYDRAULIC PUMP MOTOR CUT OFF RELAY
- V-143 PITCH YAW POWER RELAY (K3607)
- V-144 HYDRAULIC PUMP MOTOR RELAY (K2606)
- V-145 HYDRAULIC PUMP MOTOR
- V-146 HYDRAULIC PUMP
- V-147 STAGE II HYDRAULIC PUMP CHECK VALVE
- V-148 HYDRAULIC HIGH PRESSURE RELIEF VALVE
- V-149 HYDRAULIC ACCUMULATOR
- V-150 HYDRAULIC RESERVOIR
- V-151 HYDRAULIC LOW PRESSURE RELIEF VALVE
- AEROJET SEQUENCER**
- V-152 IGNITION RELAY (K-5)
- V-153 THRUST INDICATION RELAY (K-1)
- V-154 HEAT GENERATOR RELAY (K-3)
- V-155 HEAT GENERATOR RELAY (K-4)





(V-96) ON STAND

THRUST  
 CONTROLLING (TURBINE EXHAUST)  
 CONSTANT ATTITUDE (FIXED AZIMUTH)

CONTROLLING (HELIUM)

(V-97) UNFIRED  
 (V-98) UNFIRED  
 (V-99) LATCHED  
 (V-100) CLOSED  
 (V-101) UNFIRED  
 (V-102) UNFIRED  
 (V-103) LATCHED  
 (V-104) CLOSED

239 FIRED  
 240 FIRED  
 241 UNLATCHED  
 241 OPENED AND JETTISONED  
 241 FIRED  
 224 242 FIRED  
 242 UNLATCHED  
 242 OPENED AND JETTISONED  
 (V-105) DEENERGIZED  
 (V-106) UNFIRED  
 (V-107) UNFIRED  
 (V-108) UNFIRED  
 (V-109) UNFIRED  
 (V-110) UNFIRED  
 (V-111) UNFIRED

LIFT-OFF

SEVERED  
 SEVERED  
 SEVERED  
 SEVERED  
 SEVERED  
 SEVERED  
 DISCONNECTE  
 DISCONNECTE  
 DISCONNECTE  
 DISCONNECTE

5/4  
**14**

4

4/3

3a

3a/3b

(V-122) DEENERGIZED  
 (V-123) UNFIRED  
 (V-124) UNFIRED  
 (V-125) UNFIRED  
 (V-126) UNFIRED  
 (V-127) UNFIRED  
 (V-128) UNFIRED

I/I SEPARATION  
 DEENERGIZED  
 258 UNLATCHED  
 259 FIRED  
 260 FIRED  
 261 FIRED  
 262 FIRED  
 263 FIRED  
 264 FIRED

(V-130) LATCHED POSITION  
 (V-131) DEENERGIZED

217 219 UNLATCHED POSITION  
 220 ENERGIZED  
 221 SUPPLYING POWER (FULL LOAD)

222 POWERED BY STAGE I & II BATT (PARALLELED) POWERED BY STAGE I & II BATT (PARALLELED)

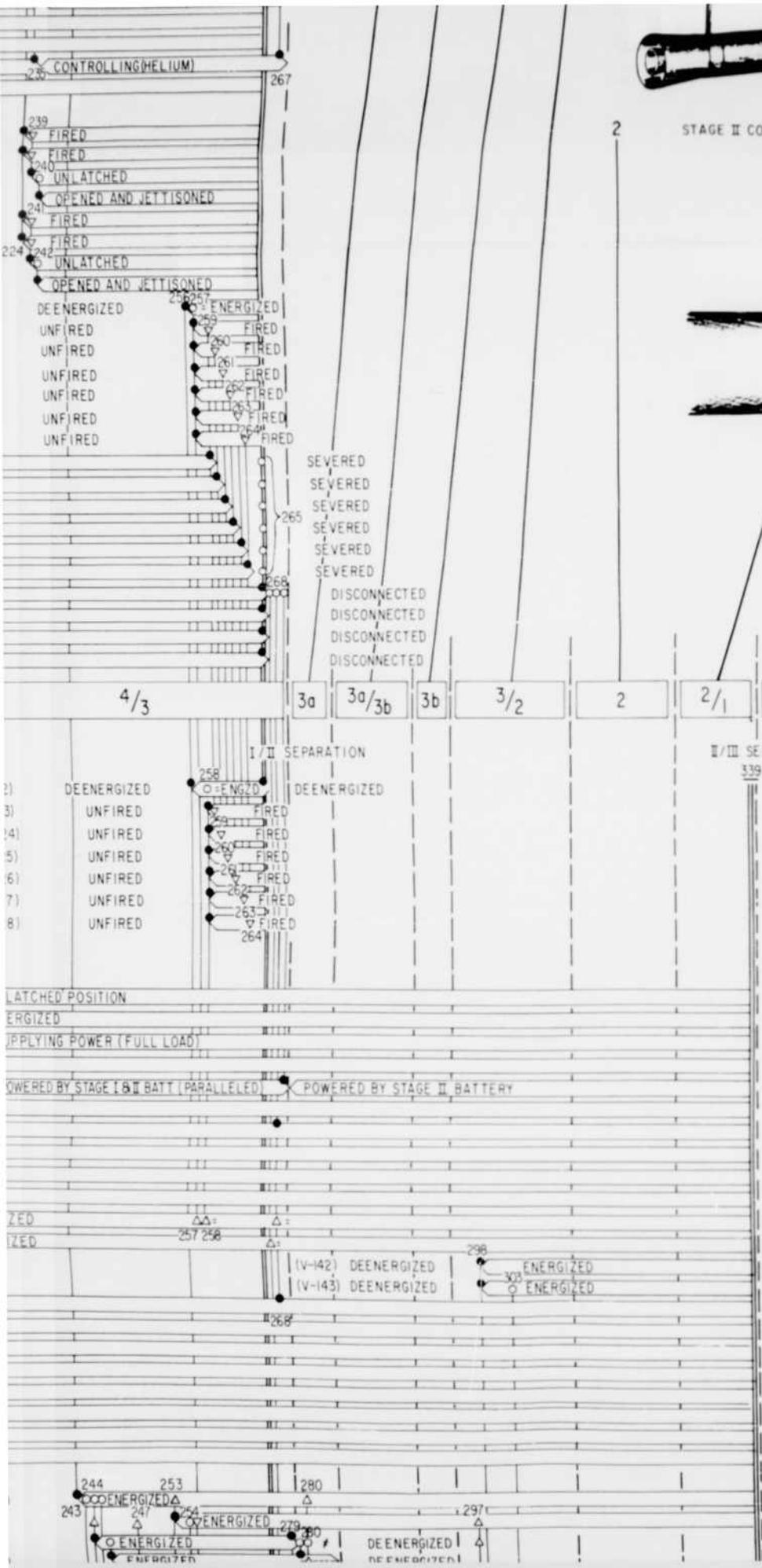
(V-140) DEENERGIZED  
 (V-141) DEENERGIZED

218 ENERGIZED  
 219 ENERGIZED

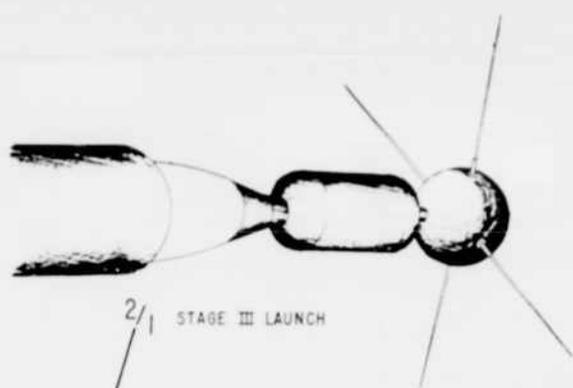
(V-142) DEENERGIZED  
 (V-143) DEENERGIZED

(V-152) DEENERGIZED  
 (V-153) DEENERGIZED  
 (V-154) DEENERGIZED  
 (V-155) DEENERGIZED

243 DEENERGIZED  
 244 DEENERGIZED  
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 278 DEENERGIZED  
 279 DEENERGIZED  
 280 DEENERGIZED



STAGE II COASTING FLIGHT



2/1 STAGE III LAUNCH

15

V-156 CUT-OFF RELAY (K-2)

V-157 OXIDIZER PROBE RELAY (K-7)

### PROPULSION SYSTEM

V-158 HEAT GENERATOR SQUIB #1

V-159 HEAT GENERATOR SQUIB #2

V-160 HEAT GENERATOR

V-161 HELIUM SPHERE

V-162 HELIUM SPHERE PRESSURE SWITCH #1 (HPS<sub>1</sub>)

V-163 HELIUM SPHERE PRESSURE SWITCH #2 (HPS<sub>2</sub>)

V-164 BY PASS HELIUM SHUT-OFF VALVE (BHSV)

V-165 HELIUM REGULATOR VALVE (RV)

V-166 OXIDIZER THRUST CHAMBER VALVE PILOT VALVE (OTCPV)

V-167 OXIDIZER THRUST CHAMBER VALVE (OTCV)

V-168 OXIDIZER VALVE POSITION SWITCH #1 (TVS<sub>1</sub>)

V-169 OXIDIZER VALVE POSITION SWITCH #2 (TVS<sub>2</sub>)

V-170 OXIDIZER BURST DISK

V-171 OXIDIZER PRESSURIZING CHECK VALVE

V-172 OXIDIZER TANK (AND FEED LINES)

V-173 OXIDIZER PROBE (OP)

V-174 FUEL THRUST CHAMBER VALVE PILOT VALVE (FTCPV)

V-175 FUEL THRUST CHAMBER VALVE (FTCV)

V-176 FUEL TANK PRESSURIZING CHECK VALVE

V-177 FUEL TANK (AND FEED LINES)

V-178 THRUST CHAMBER

V-179 THRUST CHAMBER NOZZLE CLOSURE

V-180 VEHICLE STRUCTURE (LONGITUDINAL ACCELERATION)

V-181 STAGE II THRUST CHAMBER PRESSURE SWITCH

### PROGRAM TIMER

V-182 TIME REFERENCE GENERATOR

V-183 POWER AMPLIFIER

V-184 MOTOR DRIVE ASSEMBLY

V-185 GEAR DRIVE AND TRANSPORT MECHANISM

V-186 PROGRAMMING TAPE

V-187 MICROSWITCHES AND ACTUATORS (II)

TYPICAL REPRESENTATION



V-188 RELAYS (15)

TYPICAL REPRESENTATION



V-189 PROGRAM RESISTOR UNIT (II RESISTORS)

### CONTROLS SYSTEMS

#### REFERENCE SYSTEM

V-190 POWER SUPPLY

V-191 TEMPERATURE CONTROLLER

V-192 FREQUENCY COMPENSATED d.c. CONVERTER

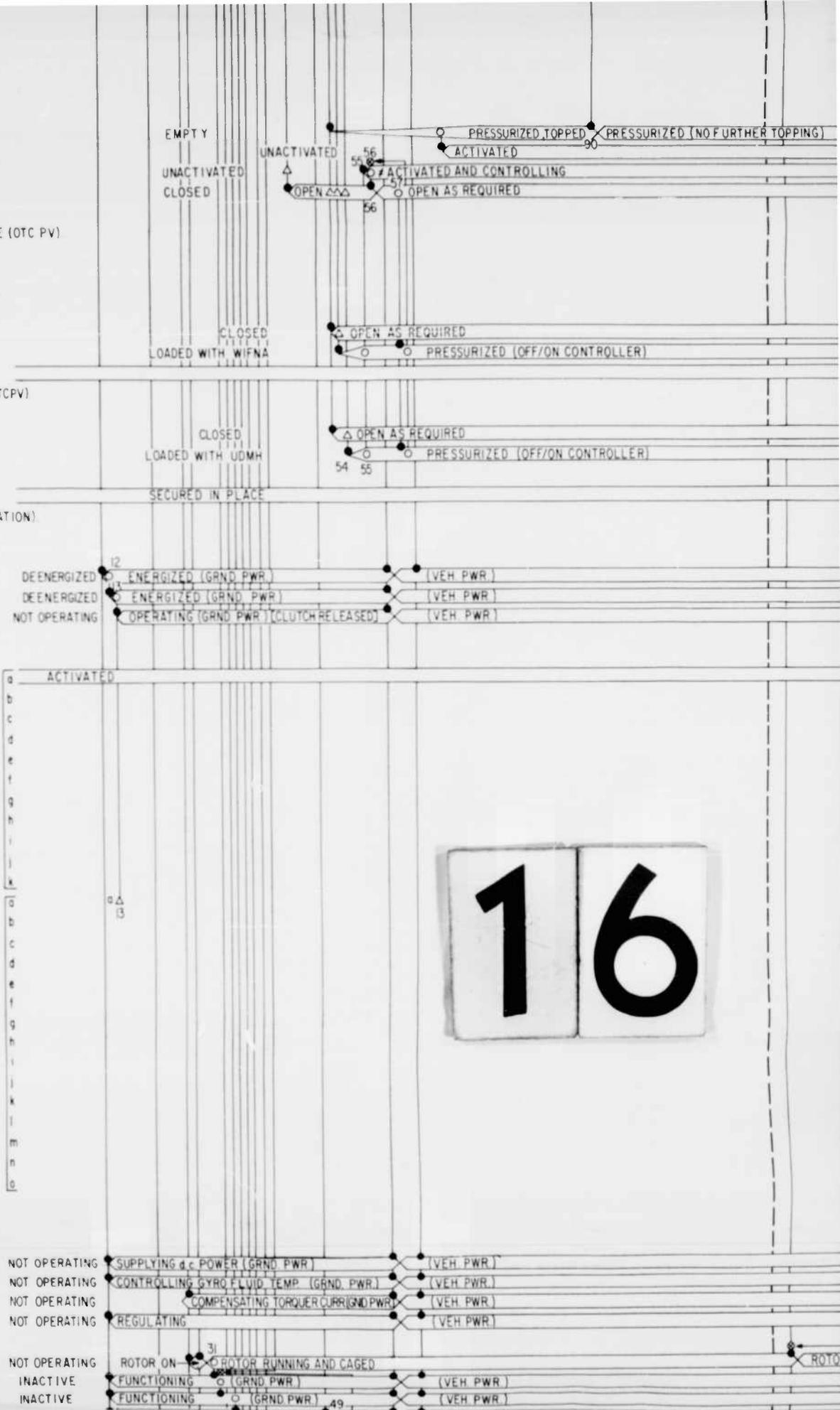
V-193 DRIFT TRIM REGULATOR

#### PITCH

V-194 PITCH GYRO

V-195 PITCH ISOLATION AMPLIFIER

V-196 AUTOPILOT AMPLIFIER (PITCH CHANNEL)



PRESSURIZED (NO FURTHER TOPPING)

(V-155) DEENERGIZED

ENERGIZED

(V-158) UNFIRED  
(V-159) UNFIRED  
(V-160) UNEXPENDED  
SUPPLYING HELIUM

(V-165) INACTIVE  
(V-166) CLOSED  
(V-167) CLOSED  
(V-168) UNACTIVATED  
(V-169) UNACTIVATED  
(V-170) SEALED

ACTIVATED BUT NOT  
CLOSED  
ON  
REGULATING TANK  
ACTIVATED  
ACTIVATED  
BROKEN

ROLLER)

245 SUPPLYING SUPPLYING, PRESSURIZED

(V-174) CLOSED  
(V-175) CLOSED

248 OPEN  
249 OPEN

ROLLER)

(V-178) INACTIVE

SUPPLYING SUPPLYING, PRESSURIZED  
DEVELOPING THRUST  
EXPULSED  
ACCELERATED ALONG TRAJEC

(V-180) ON STAND

ACCELERATED ALONG TRAJECTORY BY STAGE I

(V-181) UNACTIVATED

ACTIVATED

(V-185) NOT OPERATING  
(V-186) STATIONARY

DRIVING GEAR TRAIN [CLUTCH ENERGIZED]

OPERATING  
MOVING  
10 SEC 24 SEC 45 SEC 108 SEC 120 SEC

17

LIFT-OFF

(V-189) PRE PROGRAM CONDITION (ZERO RATE)

1st PITCH RT 0.071 o/s  
2nd PITCH RT 0.259 o/s  
3rd PITCH RT 0.470 o/s  
4th PITCH RATE 0.212 o/s

ROTOR UNCAGED

GYRO PRECESSION STARTED

1st PITCH RT 2nd PITCH RT 3rd PITCH RT 4th PITCH RATE



18

SEPARATION

V-193 DRIFT TRIM REGULATOR

**PITCH**

- V-194 PITCH GYRO
- V-195 PITCH ISOLATION AMPLIFIER
- V-196 AUTOPILOT AMPLIFIER (PITCH CHANNEL)
- V-197 TRANSFER VALVE
- V-198 HYDRAULIC ACTUATOR
- V-199 FOLLOW-UP POTENTIOMETER
- V-200 GIMBALED THRUST CHAMBER
- V-201 SLAVE RELAY: UP (K3602)
- V-202 SOLENOID VALVE UP
- V-203 GAS JET: UP
- V-204 SLAVE RELAY: DOWN (K3603)
- V-205 SOLENOID VALVE: DOWN
- V-206 GAS JET: DOWN
- V-207 VEHICLE STRUCTURE-PITCH AXIS

**YAW**

- V-208 YAW GYRO
- V-209 YAW ISOLATION AMPLIFIER
- V-210 AUTOPILOT AMPLIFIER (YAW CHANNEL)
- V-211 TRANSFER VALVE
- V-212 HYDRAULIC ACTUATOR
- V-213 FOLLOW-UP POTENTIOMETER
- V-214 GIMBALED THRUST CHAMBER
- V-215 SLAVE RELAY: LEFT (K3605)
- V-216 SOLENOID VALVE: LEFT
- V-217 GAS JET: LEFT
- V-218 SLAVE RELAY: RIGHT (K3604)
- V-219 SOLENOID VALVE RIGHT
- V-220 GAS JET: RIGHT
- V-221 VEHICLE STRUCTURE-YAW AXIS

**ROLL**

- V-222 ROLL GYRO
- V-223 ROLL ISOLATION AMPLIFIER
- V-224 AUTOPILOT AMPLIFIER (ROLL CHANNEL)
- V-225 SLAVE RELAY: CW (K3600)
- V-226 SOLENOID VALVE: CW #1
- V-227 GAS JET: CW #1
- V-228 SOLENOID VALVE: CW #2
- V-229 GAS JET: CW #2
- V-230 SLAVE RELAY: CCW #1 (K3601)
- V-231 SOLENOID VALVE: CCW #1
- V-232 GAS JET: CCW #1
- V-233 SOLENOID VALVE: CCW #2
- V-234 GAS JET: CCW #2
- V-235 VEHICLE STRUCTURE----ROLL AXIS

**PROPANE SYSTEM**

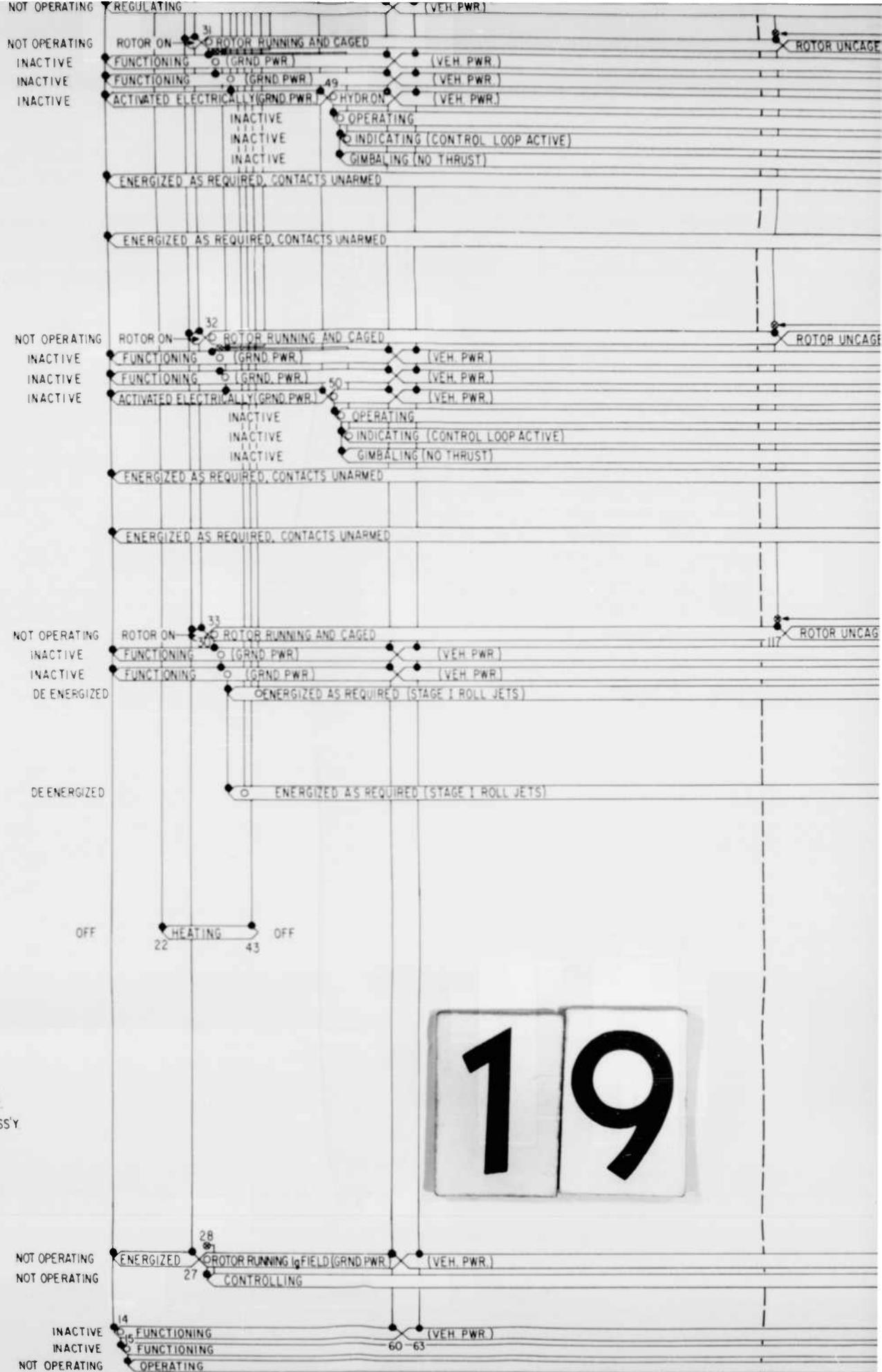
- V-236 PROPANE TANK HEATER
- V-237 PROPANE TANK B REGULATOR ASS'Y
- V-238 HELIUM/PROPANE 3-WAY VALVE

**NOSE CONE SEPARATION SYSTEM**

- V-239 NOSE CONE SEPARATION RELAY (K2604)
- V-240 NOSE CONE LATCH SQUIB #1
- V-241 NOSE CONE LATCH SQUIB #2
- V-242 NOSE CONE LATCH
- V-243 NOSE CONE EXPLOSIVE BOLT DETONATOR #1
- V-244 NOSE CONE EXPLOSIVE BOLT DETONATOR #2
- V-245 NOSE CONE BOLT AND SEPARATING SPRING ASS'Y
- V-246 NOSE CONE HALF (W/TIP)
- V-247 NOSE CONE HALF (W/O TIP)

**COASTING TIME COMPUTER**

- V-248 STAGE II CUT OFF RECEIVED RELAY (K100)
- V-249 AUXILLIARY RELAY (K101)
- V-250 END COASTING TIME RELAY (K102)
- V-251 PENDULOUS GYRO
- V-252 TURN-TABLE SERVO
- V-253 CLUTCH-BRAKE (E100)
- V-254 SPEED INDICATION ARM
- V-255 REFERENCE FREQUENCY AMPLIFIER
- V-256 POWER AMPLIFIER
- V-257 TIMING MOTOR AND GEAR TRAIN



ROTOR UNCAGED

GYRO PRECESSION STARTED

PITCH RATE 1st PITCH RATE 2nd PITCH RATE 3rd PITCH RATE 4th PITCH RATE

269 CONTROLLING THRUST VECTOR

I/II SEPARATION (V-202) NOT OPERATING (V-203) NOT OPERATING

(V-207) CONTROLLED BY STAGE I

(V-205) NOT OPERATING (V-206) NOT OPERATING STAGE II GIMBAL CONTROL 269 0.212 o/s

ROTOR UNCAGED

270 CONTROLLING THRUST VECTOR

(V-216) NOT OPERATING (V-217) NOT OPERATING

(V-221) CONTROLLED BY STAGE I

(V-219) NOT OPERATING (V-220) NOT OPERATING STAGE II GIMBAL CONTROL 270

ROTOR UNCAGED

STAGE II CONTROL JETS

(V-226) NOT OPERATING (V-227) NOT OPERATING (V-228) NOT OPERATING (V-229) NOT OPERATING

STAGE II CONTROL JETS

244 (V-231) NOT OPERATING (V-232) NOT OPERATING (V-233) NOT OPERATING (V-234) NOT OPERATING

(V-235) CONTROLLED BY STAGE I

271 CONTROLLING OPEN AS REQUIRED 273 THRUSTING AS REQ'D (ON PROP) 274 OPEN AS REQUIRED 275 THRUSTING AS REQ'D (ON PROP) 272 CONTROLLING OPEN AS REQUIRED 275 THRUSTING AS REQ'D (ON PROP) 276 OPEN AS REQUIRED 277 THRUSTING AS REQ'D (ON PROP) 278 CONTROLLED BY CONTROL J

(V-237) LOADED WITH PROPANE, SELF-PRESSURIZED

279 SUPPLYING PROPANE GAS (V-238) PROPANE POSITION 286 NOSE CONE JETTISON ENG'D DEENERGIZED 287 FIRED 288 FIRED 289 LATCHED 289 FIRED 289 RELEASED 286 JETTISONED 286 JETTISONED 290 (V-248) DEENERGIZED (V-249) DEENERGIZED

20

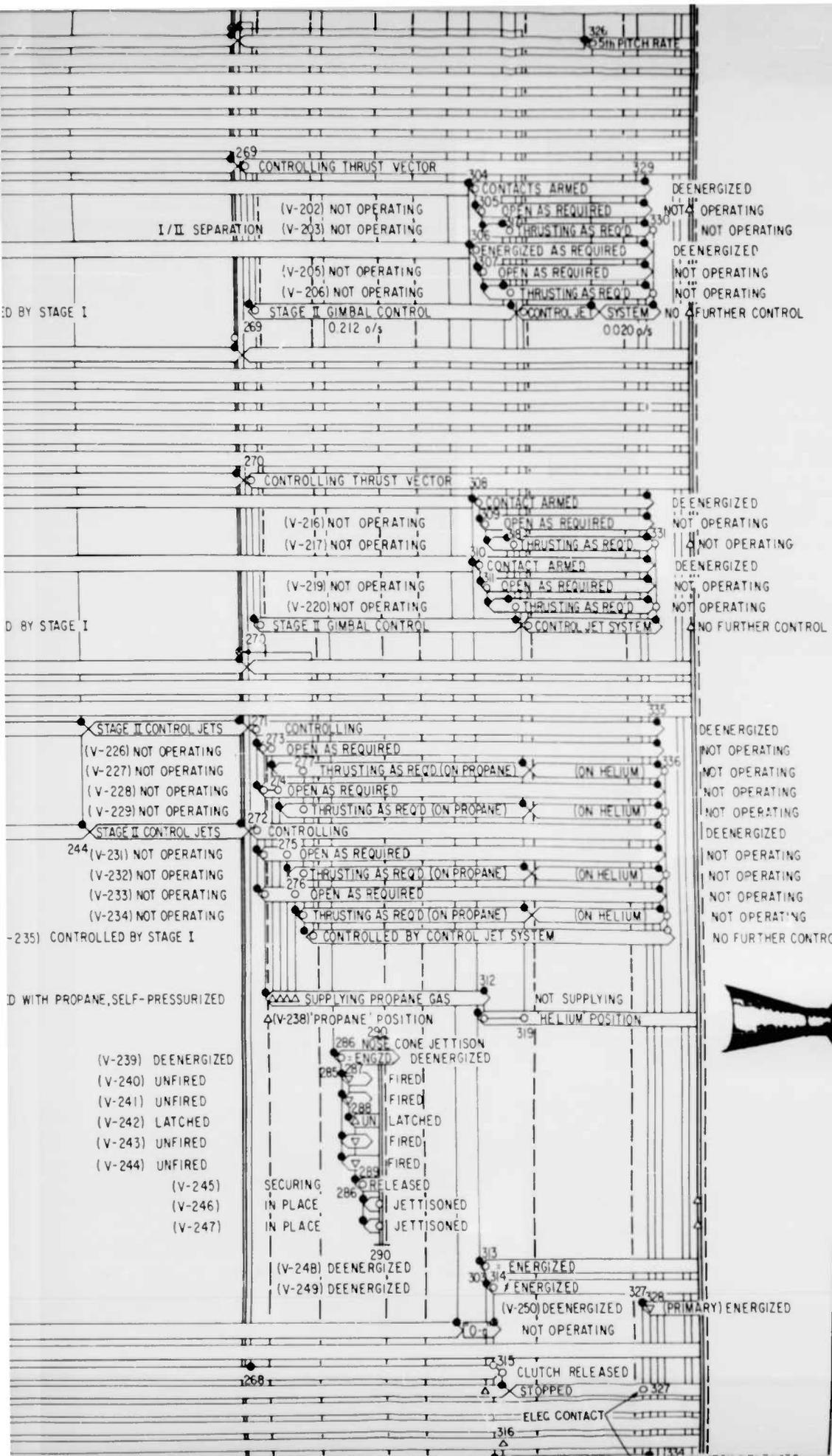
(V-239) DEENERGIZED (V-240) UNFIRED (V-241) UNFIRED (V-242) LATCHED (V-243) UNFIRED (V-244) UNFIRED (V-245) (V-246) (V-247)

165 GYRO SENSING FLIGHT ACCELERATION

164 CLUTCH ENGAGED

ROTATING ( $\omega = K \times \text{ACCEL}$ )

268



21



STAGE III POWERED AND COASTING FLIGHT



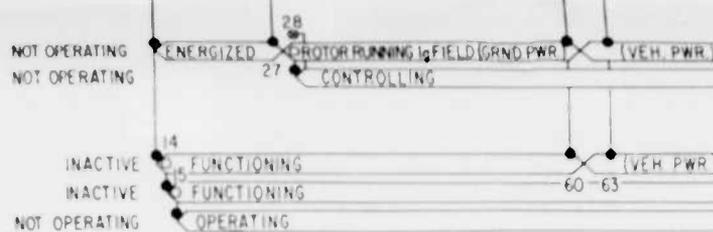
- V-243 NOSE CONE EXPLOSIVE BOLT DETONATOR #1
- V-244 NOSE CONE EXPLOSIVE BOLT DETONATOR #2
- V-245 NOSE CONE BOLT AND SEPARATING SPRING ASS'Y
- V-246 NOSE CONE HALF (W/TIP)
- V-247 NOSE CONE HALF (W/O TIP)

### COASTING TIME COMPUTER

- V-248 STAGE II CUT OFF RECEIVED RELAY (K100)
- V-249 AUXILIARY RELAY (K101)
- V-250 END COASTING TIME RELAY (K102)
- V-251 PENDULOUS GYRO
- V-252 TURN-TABLE SERVO
- V-253 CLUTCH-BRAKE (E100)
- V-254 SPEED INDICATION ARM
- V-255 REFERENCE FREQUENCY AMPLIFIER
- V-256 POWER AMPLIFIER
- V-257 TIMING MOTOR AND GEAR TRAIN
- V-258 CLUTCH (E101)
- V-259 TIME INDICATION ARM

### SEPARATION SYSTEM (II / III)

- V-260 COMMAND RECEIVER/DECODER
- V-261 GROUND COMMAND DELAY TIMER (B2601)
- V-262 (II) RADIO CUT-OFF RELAY (K2527)
- V-263 (III) SPIN AND IGNITION RELAY (K2526)
- V-264 (III) SEPARATION DELAY TIMER (B 2526)
- V-265 (III) SEPARATION RELAY (K2528)
- V-266 RETRO-ROCKET #1
- V-267 RETRO-ROCKET #2
- V-268 SPIN-ROCKET #1
- V-269 SPIN-ROCKET #2
- V-270 SPIN-TABLE ROTATIONAL RESTRAINT
- V-271 SPIN-TABLE
- V-272 IGNITER WIRE CUTTER



(V-260)

## STATE OR TRANSITION

5

### STAGE III

#### PROPULSION AND SUPPORT SYSTEM

- V-273 ROCKET MOTOR LONGITUDINAL RESTRAINT
- V-274 UPPER BEARING SUPPORT ASSEMBLY
- V-275 ROCKET IGNITER DELAY SQUIB
- V-276 ROCKET IGNITER
- V-277 ROCKET MOTOR
- V-278 VEHICLE STRUCTURE (LONGITUDINAL ACCELERATION)

#### SATELLITE AND SEPARATION DEVICE

- V-279 INERTIA ARM
- V-280 TIMER
- V-281 SWITCH
- V-282 BATTERY #1
- V-283 CATERPILLAR SQUIB #1
- V-284 BATTERY #2
- V-285 CATERPILLAR SQUIB #2
- V-286 UNLOCKING DEVICE
- V-287 COMPRESSION SPRING
- V-288 SATELLITE

### LEGEND

- I, II, III FIRST, SECOND, & THIRD STAGES, RESPECTIVELY
- OPERATION CAUSING (OPEN SYMBOL)
- OPERATION EFFECTED (DARKENED SYMBOL)
- △ NECESSARY CONDITION
- ▽ EITHER / OR RELATIONSHIP
- TIME GATE REQUIREMENT MET
- CONTROL LOOP CLOSURE POINT
- TIME FUNCTION
- ▭ COMPONENT STATE
- ▭ TRANSIENT IN COMPONENT STATE
- ┃ VEHICLE SEPARATION
- (N) NORMALLY OPEN (CLOSED) ELECTRICAL CONTACTS
- BU BACK-UP
- ┃ STATE / TRANSITION BOUNDARY

21

(V-243) UNFIRED  
 (V-244) UNFIRED  
 (V-245)  
 (V-246)  
 (V-247)

SECURING IN PLACE  
 IN PLACE  
 (V-248) DEENERGIZED  
 (V-249) DEENERGIZED

165 GYRO SENSING FLIGHT ACCELERATION  
 164 CLUTCH ENGAGED  
 ROTATING (ω = K x ACCEL)

(V-258) CLUTCH RELEASED  
 (V-259) ZERO POSITION

(V-260) OPERATING AND RECEIVING COMMAND CARRIER

162  
 LIFT-OFF

(V-261) NOT OPERATING (SPRING W

5/4

4

4/3

3a

3a/3b

3b

22

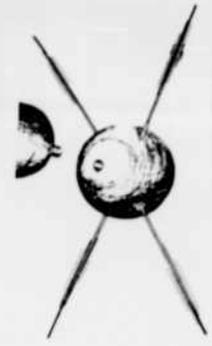
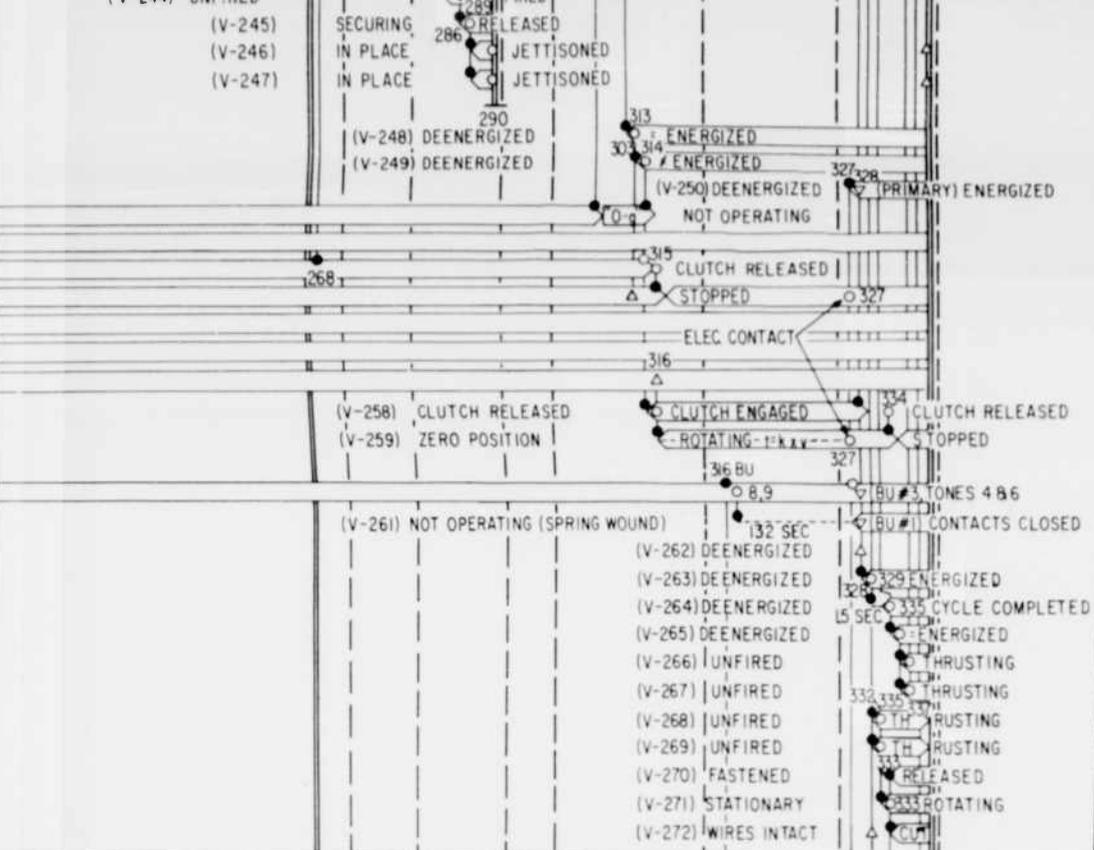
I/II SEPARATION  
 265

MASTER SEQUENCE DIAGRAM  
 VANGUARD  
 SATELLITE LAUNCHING VEHICLE  
 (SLV-1, REPRESENTATIVE)

NAVAL RESEARCH LABORATORY	DRAWN H.K. FREWING	9-5-58
PROJECT VANGUARD, CODE 4120	W.J.D. ESCHER	2-16-59
	TRACED G. BERRYHILL	7-2-59

(V-244) UNFIRED  
 (V-245) UNFIRED  
 (V-246) UNFIRED  
 (V-247) UNFIRED

SECURING IN PLACE  
 RELEASED  
 JETTISONED  
 JETTISONED  
 (V-248) DEENERGIZED  
 (V-249) DEENERGIZED



SATELLITE SEPARATION  
 1/0

4/3    3a    3a/3b    3b    3/2    2    2/1    1    1/0    0

(V-273) FASTENED  
 (V-274) SUPPORTING  
 (V-275) UNFIRED  
 (V-276) UNFIRED  
 (V-277) UNFIRED  
 (V-278) UNFIRED

▽ TONE 8  
 ▽ TONE 9

RADIO TRANSMISSION FROM  
 PRE-APPOINTED GROUND STATIONS

▽ TONE 4  
 ▽ TONE 6

RELEASED (AFTER 1/2 TURNS)  
 339 RELEASED, SPIDER ARMS JETTISONED  
 5 SEC  
 FIRED  
 FIRED  
 SPINNING (150 RPM)  
 333  
 BURNING  
 344  
 345  
 PROPELLANT EXHAUSTED  
 FREE FALL (ORBITING)  
 (V-279) UNARMED  
 ARMED  
 346  
 ACTIVE  
 347  
 CYCLE COMPLETED  
 30 SEC  
 348  
 ACTIVATED  
 349  
 SUPPLYING  
 350  
 EXPANDED  
 351  
 SUPPLYING  
 352  
 EXPANDED  
 353  
 UNLOCKED  
 354  
 EXPANDED  
 (V-280) UNACTIVATED  
 (V-281) UNACTIVATED  
 (V-282) INACTIVE  
 (V-283) UNACTIVATED  
 (V-284) INACTIVE  
 (V-285) UNACTIVATED  
 (V-286) LOCKED  
 (V-287) COMPRESSED  
 (V-288) ATTACHED TO ROCKET (III)

SATELLITE SEPARATION  
 354

I/II SEPARATION  
 265

II/III SEPARATION  
 339

SATELLITE SEPARATION  
 354



SATELLITE  
 IN ORBIT

23